BUSTED! EVOLUTION'S BIGGEST MYTHS

HOW IT WORKS

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LIFE ON MARS
HOW WE WILL SURVIVE ON THE RED PLANET

+

LIFE-SAVING NANOBOTS
CASINO TECH EXPLAINED
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MEDIEVAL KNIGHTS
WIRELESS HEADPHONES

FASTEST STRONGEST DEADLIEST

BIG CAT ATTACK

HOW EARTH'S MOST FEARSOME FELINES CATCH THEIR PREY

NUCLEAR REACTORS

Find out how we can generate electricity by splitting atoms

+ LEARN ABOUT
- OSIRIS-REX
- WHITE HOLES
- ROCK CYCLE
- WINGSUITS
- OCEAN LINERS
- BLOOD-BRAIN BARRIER
- HONEYCOMB EELS
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ISSUE 092

Sega Toys Planetarium Homestar Original

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

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

Buy online £99

www.segatoys.space

ISSUE 92

WELCOME

The magazine that feeds minds!

"The big question about Mars is whether life could have existed there, or if it still does..."

Life on Mars, page 28

Meet the team...

Dave
Editor-in-Chief
If good things come in small packages then nanotech must be incredible. Find out how these microscopic marvels are set to start saving lives on page 50.

Katy
Research Editor
Evolution is one of the most well-known yet misunderstood areas of science! Swing over to page 40 to see why you're not descended from a monkey.

Jack
Senior Staff Writer
Being a bit of a petrolhead, it was fascinating to catch a glimpse into the future of driving, and what cool tech the cars of tomorrow will have.

James
Staff Writer
In the science section, our nuclear reactor feature is radiating some seriously good vibes. Discover why these power stations have us hot and bothered over on page 48.

Duncan
Senior Art Editor
It's amazing to think that in just a few short years we could be living on Mars! Learn how we'll get there, build our homes and more on page 28.

Laurie
Assistant Designer
You certainly wouldn't want to cross paths with a hungry pride of lions nor a stealthy jaguar. Feast your eyes on page 14 to learn more about the big cats.

FOLLOW US... How It Works magazine @HowItWorksmag

Big cats are among the animal kingdom's best predators, but what makes them so well-adapted to life at the top of the food chain? Find out exactly why these fascinating felines are such skilled hunters in this month's environment feature.

Back in October you may have heard the exciting news that billionaire entrepreneur Elon Musk announced his plan to have humans on Mars as soon as 2022. This timescale is far more ambitious than NASA's, which aims to launch its first manned mission to the Red Planet in the 2030s. No matter which way or how soon we get there, establishing a base on Mars will be the first step in making humans an interplanetary species. Exciting times are ahead!

Also this issue, we bust some common misconceptions surrounding Charles Darwin's famous theory of evolution, and reveal the intriguing history of espionage.

Enjoy the issue!

Jackie **Jackie Snowden**
Deputy Editor

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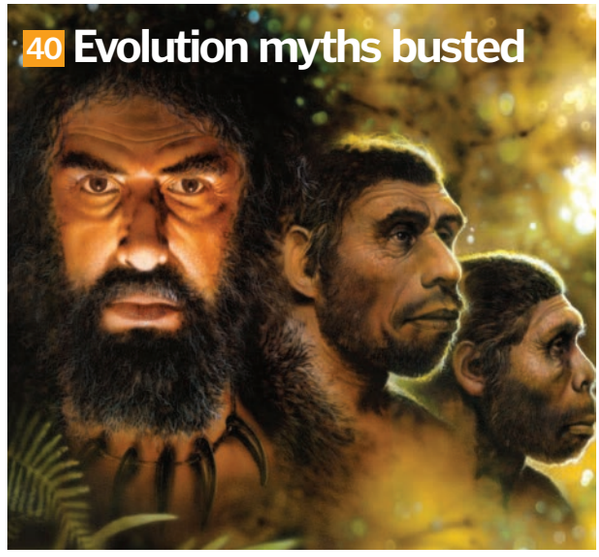

Meet the experts...

Jonathan O'Callaghan
Join Jonny in this issue's journey to Mars as he explains how the planet may have been habitable billions of years ago, and how humans will get to the Red Planet in the not-so-distant future.

Laura Mears
This month Laura busts some common myths about Charles Darwin's famous, but often misunderstood, theory. She also explains the workings of our brain's security system.

Jo Stass
This issue, Jo tackles all manner of topics! She explains how Apple's new wireless AirPods work, unravels the mysteries of white holes, and takes a tour of the ancient library of Alexandria.

Ella Carter
Ella reveals why big cats are such superb hunters in this issue's environment feature. Find out why lions hunt in prides while other species choose to go solo, and what makes tigers the kings of the jungle.

Stephen Ashby
Steve reviews some of the latest book releases in science and tech, including an extremely detailed user's guide to the legendary Saturn V rocket!

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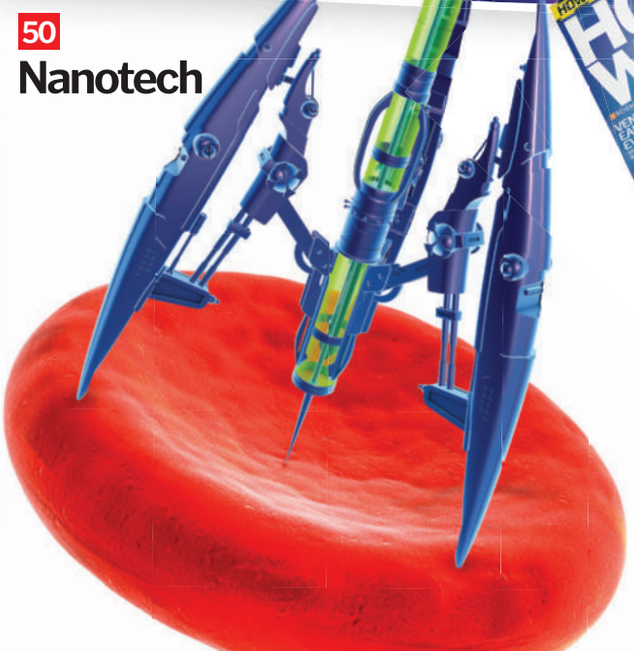


REGULARS

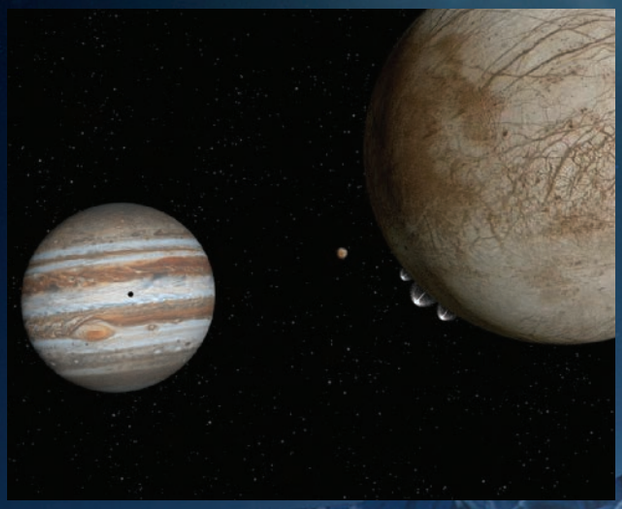
Water jets found on Jupiter's moon

The Hubble Space Telescope has detected evidence of a hidden ocean under the surface of Europa

Earth is the only place in our Solar System that is known to have liquid water – which is thought to be an essential ingredient for life. However, scientists have long suspected that it could also exist elsewhere, and new data collected by the Hubble telescope has provided further evidence that our watery world is not alone. Astronomers have captured ultraviolet images of Europa, one of Jupiter's icy moons, and identified what appear to be huge plumes of water vapour erupting from its surface. This is the latest information to indicate that an ocean of liquid water lies somewhere within Europa.

Another team had previously suggested the presence of plume-like structures in 2012, using a technique where they measured the magnetic fields between the moon and Jupiter. And, now that a completely different method has been used to arrive at a similar conclusion, the scientific community is starting to get excited.

The plumes seem to be sporadic, as the eruptions were observed at random times – the researchers only saw the water vapour on three out of ten images – but further missions to confirm what is now strongly suspected are already being planned. The James Webb Space Telescope, expected to launch in 2018, may provide further insight by imaging Europa in infrared light, while future flybys will be tasked with taking a closer look at the moon and its spouting water.



The plumes of water vapour shooting from Europa are thought to come from a subsurface ocean

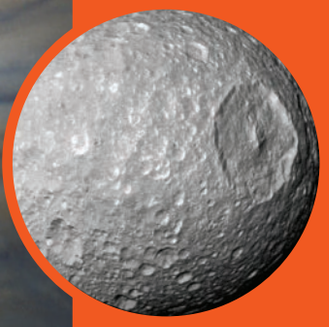
It's believed that the plumes rise over 150km above the surface before falling back to Europa

"Astronomers captured ultraviolet images of Europa and identified what appear to be huge plumes of water vapour erupting from its surface"

Where else could we find water in the Solar System?

Pluto

The distant dwarf planet orbiting our star is in the midst of an Antarctic winter, and the Sun will not shine on its south pole for 80 years! But some astronomers are optimistic that liquid water may be buried underneath Pluto's frozen surface.



Mimas

Although it may look like the dreaded Death Star, this moon could be one of the best places to discover new life, as research suggests that a sub-surface ocean may be responsible for its irregular rotation and orbit around parent planet, Saturn.

Ceres

NASA has discovered that this dwarf planet is formed of distinct layers. This means water and other light materials could have partially separated from the dense rock at the centre, and moved closer to the outer surface early in the planet's existence.

Callisto

Another of Jupiter's moons, Callisto's surface is covered in craters that sit on top of an incredibly thick layer of ice. Beneath it, scientists believe there could be an ocean that is at least 10km deep.

TALKING POINT

IS IT TIME TO REGULATE AI?

Artificial intelligence is progressing much faster than many scientists believed it would

The key players developing artificial intelligence are meeting to discuss the field's future

Artificial intelligence (AI) has the potential to have a huge impact on humanity, and the teams developing these systems are fully aware of it. Now, representatives from Amazon, Facebook, Google's DeepMind, IBM and Microsoft have decided to come together to decide the future of the technology, which has so far been developed with little or no oversight.

For today's machine-learning technologies, little regulation is needed. But the huge success of Google DeepMind's AlphaGo earlier this year was seen as a significant step forward, and showed how quickly AI is developing. The system defeated a world champion of Go – arguably the most complex board game in the world – using an 'intuitive' neural network experts didn't expect us to build for another decade.

"Most games are… slightly constrained in some way, but that makes them the perfect challenge for us [to use] as a stepping stone towards building a general intelligence," explains DeepMind founder Demis Hassabis, who envisions AI systems that are able to think much more broadly in the coming years.

Already the scientists from DeepMind have begun implementing AI technologies into many other projects, including healthcare collaborations. But many are sceptical about how we will regulate a technology that will undoubtedly become and integral part of modern lives. "We've seen a very fast development in AI over a very short period of time," comments Professor Yoshua Bengio from the University of Montreal, who agrees that joining forces is the best way to ensure AI systems "serve the common good."

The next decade could be a turning point in AI evolution, and by considering transparency, privacy and trust in the new machines, the companies are confident that they can steer the technology towards the benefit rather than the harm of mankind.

Are we in control?

Plenty of films and books have imagined the destructive forces of independent, intelligent machines, but until the last few years, most have dismissed them as just fun pieces of fiction. Today, we're much closer (but notably still a long way off) to accidentally building humanity-ending technologies, and widely respected technology entrepreneur Elon Musk has warned that AI could pose even more of a threat to our current existence than nuclear weapons.

Scientist Stephen Hawking has suggested that this leap in intelligence could come from our efforts to build a fully self-aware AI system. Once active, this conscious machine would be able to improve itself, and as it would be free from the biological form of evolution that we humans are limited to, it would be able to achieve this aim in the blink of an eye, evolving into a super intelligence beyond our comprehension. And what would this intelligence's intentions be for the human race? Hopefully, we won't need to find out.

Notable scientists, including Elon Musk (right), have warned that AI may pose a threat to humanity

Dinosaurs may have had similar hair colours to humans

Dinosaurs were brunettes, redheads and blondes

Pigments from descendant species reveal dinosaur feathers shared colours with human hair

Despite the number of films suggesting otherwise, we still don't know exactly what dinosaurs looked like. One of the greatest mysteries is the colour of their feathers, which now may have finally been revealed by scientists from the University of Manchester, UK. The research team analysed the pigments in fossils of their bird descendants to determine which colours their feathers reflected. They found a pigment called eumelanin, which creates darker shades, as well as pheomelanin, which produces red and yellow hues.

Pangolins have been reduced to critically low numbers in Asia

Wildlife summit vows to protect at-risk species

Over 180 nations have met to tackle animal trade and trafficking

Environmentalists around the globe rejoice, as a host of animals currently facing the risk of extinction have been granted protection from poachers and traffickers by new bans on international trade. Many species will benefit from the new laws, including barbary macaques, which are illegally captured to pose in tourist photos, and pangolins, which are poached for their meat and scales.

NEWS BY NUMBERS

£728k

The prize money awarded to Yoshinori Ohsumi for the 2016 Nobel Prize in Physiology or Medicine

7.97bn km

The total distance travelled by the Rosetta space probe throughout its 12-year mission studying Comet 67P

1,800

The number of great apes illegally traded in the last decade

25°

The maximum 'bend' of Panasonic's new flexible battery

Scientists achieve quantum teleportation

The scientists teleported the photon's properties across Calgary, Canada, using a fibre optic network

Physicists exchanged information across a city without physically moving anything

Scientists have been successfully exploiting our knowledge of quantum physics to send information 8.2 kilometres across the Canadian city of Calgary, without moving any matter.

This is possible because of a phenomenon called quantum entanglement, in which actions on one particle can affect another, even if they are far apart. Photons and other elementary particles have a property called spin, which can exist in different states.

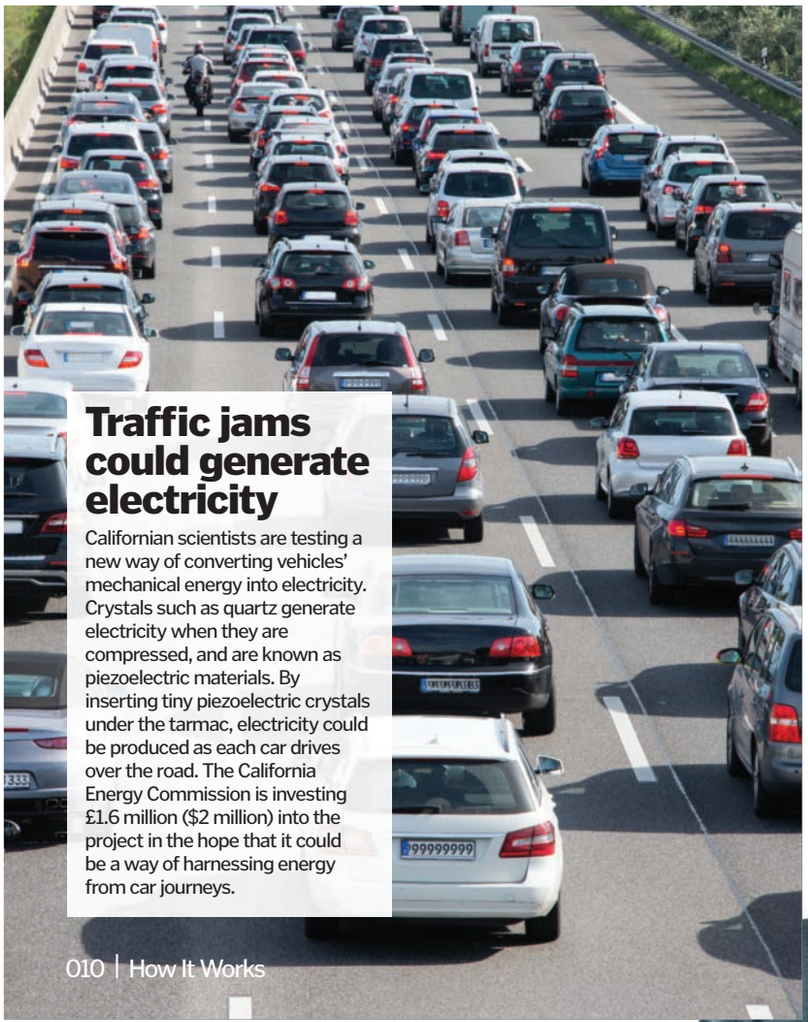
By measuring the spin state of one entangled particle, the spin state of the other is immediately affected. In this way, entangled photons can remain connected no matter the distance, allowing signals to be sent by defining the spin of a quantum particle.

GLOBAL EYE

10 COOL THINGS WE LEARNED THIS MONTH

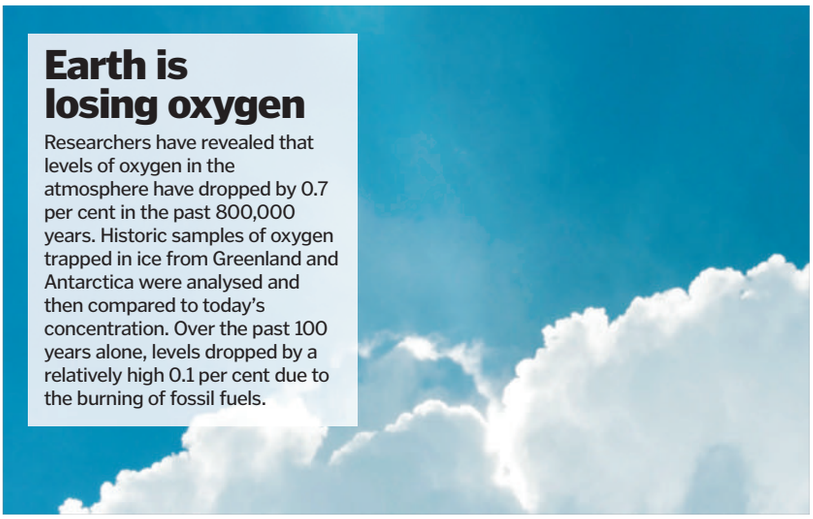
A new species of prehistoric shark has been discovered

Based on the discovery of several 4.5-centimetre fossilised teeth, a new species of extinct shark has been described. Known as the 'paradoxodon', it swam in the oceans 20 million years ago and was roughly the size of a great white shark. It belongs to the same family of sharks as the massive megalodon, which could reach lengths of over ten metres.



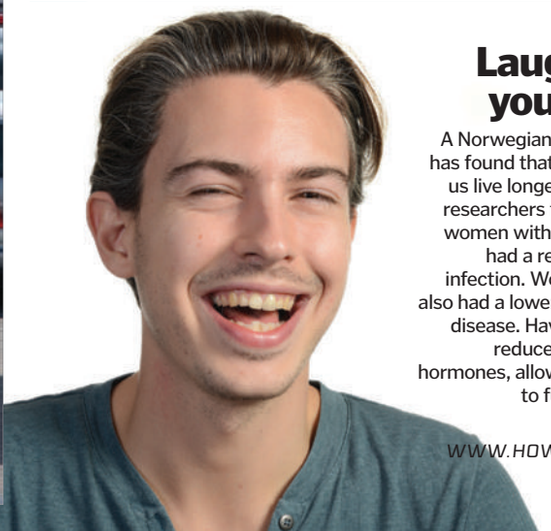
Traffic jams could generate electricity

Californian scientists are testing a new way of converting vehicles' mechanical energy into electricity. Crystals such as quartz generate electricity when they are compressed, and are known as piezoelectric materials. By inserting tiny piezoelectric crystals under the tarmac, electricity could be produced as each car drives over the road. The California Energy Commission is investing £1.6 million ($2 million) into the project in the hope that it could be a way of harnessing energy from car journeys.



Earth is losing oxygen

Researchers have revealed that levels of oxygen in the atmosphere have dropped by 0.7 per cent in the past 800,000 years. Historic samples of oxygen trapped in ice from Greenland and Antarctica were analysed and then compared to today's concentration. Over the past 100 years alone, levels dropped by a relatively high 0.1 per cent due to the burning of fossil fuels.



Laughing helps you live longer

A Norwegian study spanning 15 years has found that laughing regularly helps us live longer and healthier lives. The researchers found that both men and women with a good sense of humour had a reduced risk of dying from infection. Women who laughed more also had a lower risk of dying from heart disease. Having a regular giggle may reduce the production of stress hormones, allowing the immune system to function more effectively.

The ‘five-second rule’ is wrong

We’ve all heard the rule: if you drop food on the floor, you have five seconds to pick it up before bacteria can infect it. However, new research has found that most foods will be contaminated almost immediately. The amount of bacteria depends on the type of food and texture of the surface. Wet foods pick up more microbes, and carpets transfer fewer germs than smooth surfaces.

Passwords can be sent through your body

Passwords sent over Wi-Fi are susceptible to hacking, even if they’re encrypted. To prevent this, ‘on-body’ transmissions have been designed that create a link between you and your devices. When you touch a fingerprint scanner on your smartphone and put your hand on the doorknob, it will unlock, with no need for an airborne password.

We can 3D-print synthetic bone

If you break a bone, a 3D printer could soon come to the rescue. A team from Northwestern University in the US have developed hyperelastic ‘bone’ grafts that can be printed in a matter of hours, or even minutes. The biomaterial is strong enough to bear weight when used as a femur graft, while also flexible enough to be squeezed through a small incision for minimally invasive surgery.

Mars’ crust contributed to its atmosphere

NASA’s Curiosity rover has found new evidence that Mars’ surface chemistry affects the makeup of the planet’s atmosphere. Xenon and krypton isotopes in the Martian regolith can escape into the atmosphere when the surface is disturbed by events such as asteroid impacts.

Humans reached South America earlier than we thought

An excavation at an archaeological site in eastern Argentina has revealed stone tools used by hunter-gatherers and various animal bones that are at least 14,000 years old. Previously, it was believed that the Clovis people – hunter-gatherers who crossed from Asia during the last ice age – were the first to migrate to South America 13,000 years ago. However, in the last decade, evidence has been found that disputes this idea. Carbon dating confirms that these newly-discovered Argentinean tools predate the Clovis settlers by 1,000 years or more.

Some deserts are more than 30 million years old

The deserts of central Asia like the Gobi are believed to be the world’s oldest. In a recent study, high levels of carbon-13, which indicate a lack of rainfall, were found in samples from the central Asian deserts. The reason for their longevity is believed to be mountain ranges to the north and south blocking winds that carry precipitation.

An aircraft carrier engineer

An inside look at the huge Queen Elizabeth Class aircraft carrier project

Nick Fox is an assistant chief engineer for BAE Systems Maritime Naval Ships division, working on the Royal Navy's next generation of aircraft carriers at the Rosyth Dockyard in Fife, Scotland. HMS Queen Elizabeth and HMS Prince of Wales will be the largest warships the Royal Navy has ever produced when they're completed in 2017 and 2020 respectively. Taller than Niagara Falls and longer than the Houses of Parliament, each carrier will accommodate up to 1,600 personnel when they enter service.

We find out how Nick and his team spend the day designing and building the systems that will soon power and navigate the two mighty vessels.

Nick is the assistant chief engineer on the Queen Elizabeth Class aircraft carrier project

MORNING BRIEFING
8am

8am is the cornerstone of the day. We have a daily senior management meeting to find out what we're going to do that day. We also discuss any issues, and whether there are any particular tasks we're relying on people getting done.

THE DAY AHEAD
9am

After 9am my days become pretty varied. I could be involved with designing things, testing equipment, working with our suppliers to ensure we're meeting what the customer wants and working with the client to see if they are happy with the progress. I am very much involved in the design and documentation side of things; managing the engineering activity on the ship.

PRECAUTIONARY MEASURES
10am

I go on the ship about once every two days. Before doing so, we always fill out a safety assessment so we understand the hazards we'll be exposed to. We also need to ensure we're wearing the

Both HMS Queen Elizabeth and HMS Prince of Wales will be able to carry up to 40 aircraft

"I'm very much part of a team. My job is to make sure that what we're doing as a collective delivers"

When complete, the carriers will be the largest warships ever built in the UK

correct protective clothing: overalls, safety boots, safety hats and eye protection. Safety first and the rest will follow.

TESTING THE SYSTEMS
11am

At the moment we're testing everything, from air conditioning to shower systems to guiding systems to radars. My job is to monitor all of this and make sure we are going to deliver what the customer wants. We have specialist teams that look after each system and how it's performing. They will look at what testing you want to do today and if everyone understands what their role is going to be.

SUPERVISING THE RADAR TESTS
2pm

There's a commissioning team of radar specialists. The first stage of testing is to see if everything is powering up as you expect it to. These systems aren't just one computer, but a whole series of computers that have to work together as an integrated system. Individual computers are then tested to make sure they perform as expected, before building up to multiple systems.

TEAMWORK
3pm

I'm very much part of a team. My job is to oversee the teams of specialists to make sure that what we're doing as a collective delivers. The teams report to me on the systems and testing. Sometimes we can have a really good day and leave at 3pm. It all depends on what's happening each day.

DEBRIEF
5pm

If we've done testing, we'll have a debrief at the end of the day to talk through the results – whether they were as expected and if we'll do anything differently tomorrow. Each system has a controlled shutdown process to put it in a state where we're happy to leave it unmanned.

END OF THE DAY
5:30pm

Once the systems are shut down, we can then lock the compartments and everyone goes home. Most days I leave between 5pm and 5:30pm. The best thing about my job is feeling like I'm making a difference to something that has such a huge capability for the Royal Navy. That's what I take home at the end of the day.

BIG CAT ATTACK

Find out what makes these cats such effective killing machines in a formidable show of muscle, fur and teeth

The world's big cats are majestic powerhouses of muscle and strength, with acute senses and killer instincts. The true big cats are the four largest species of the genus 'Panthera': lions, tigers, jaguars and leopards. However, there are also many other large cat species that have incredible hunting abilities, one of which is the mighty cheetah.

Mostly found in sub-Saharan Africa, cheetahs are super-streamlined and built for killing on the fly. They have specialised muscle fibres to power their long limbs, black 'tear lines' to help counteract glare from the African sun and a spotted coat to keep them camouflaged in the long grasses.

Although their spots may look similar at first glance, a closer look reveals that leopards (which often share the cheetah's habitat) have very different markings. Leopard spots are more detailed, featuring clusters of black and brown rosettes rather than the cheetah's simple black ovals. These markings mimic the shifting shadows of trees and leaves, allowing the cheetah to blend into the background. If one's stalking you, you won't know about it until it's too late! Leopards have a wider range, and can be found in forests, deserts, mountains and grasslands throughout Africa and Asia.

> *"Lions can even take down the largest animals on land: elephants"*

Back on the savannah, it's the lions that have the edge. When they're feeling really plucky, these cats can even take down the largest animals on land: elephants. They can do this because they have evolved to work together. Hunting as a group allows lions to take on much larger animals, surrounding and overwhelming them. It's thought that this ability to hunt cooperatively is due to a highly developed frontal cortex – the part of the brain that deals with problem solving and social behaviour. This is particularly evident in lionesses, the pride members that do the majority of the hunting. These amazing creatures stake a claim to be the most intelligent of the big cats. Competition is vast, though.

As the largest of the big cats, tigers are supreme predators. Found in swamps, grasslands and rainforests throughout Southeast Asia, China and the mountains of far-east Russia, these striped heavyweights hunt alone, relying on their camouflage and stealth to track down prey and catch it with the element of surprise.

Read on to get under the skin of all of these fierce felines, and find out more about the physiology of a big cat attack.

What's on the menu?

Each giant feline has a taste for something different

Lion

The 'king of the jungle' can essentially eat anything it can catch, but given that lions are found on the plains of sub-Saharan Africa, they commonly eat the animals nearby. Like all big cats, lions need a high-protein, all-meat diet.

WILDEBEESTS
ZEBRAS
CAPE BUFFALOS
ANTELOPES
GIRAFFES

Leopard

Hunting alone, leopards search out mostly smaller, hoofed animals although they will occasionally prey on monkeys and other smaller creatures if the pickings are slim. In general these smaller prey are easier to catch single-handed and drag into the treetops for eating.

IMPALAS
GOATS
MONKEYS
RODENTS

Tiger

The largest of the big cats, tigers need their fill of meat. Their favourite prey depends on their habitat, but they primarily eat larger mammals as they have more fat and protein to sustain the tigers' needs. However, when times are tight, tigers will tuck into anything, from fish to rodents.

WILD BOARS
DEER
ANTELOPES
WATER BUFFALOS

Jaguar

Not shy of a challenge, jaguars have a very varied diet. Their amazing hunting ability allow them to take down large forest-dwelling mammals and their willingness to take to water provides a whole other selection of prey items.

PECCARIES
CAPYBARAS
TAPIRS
CAIMANS
TURTLES

Cheetahs

While not officially a big cat species of the Panthera genus, cheetahs are formidable felines. They use speed and strength to catch their main prey, ungulates, but can also supplement their diets with smaller creatures such as hares and even birds.

GAZELLES
IMPALAS
HARES
WARTHOGS

The need for speed

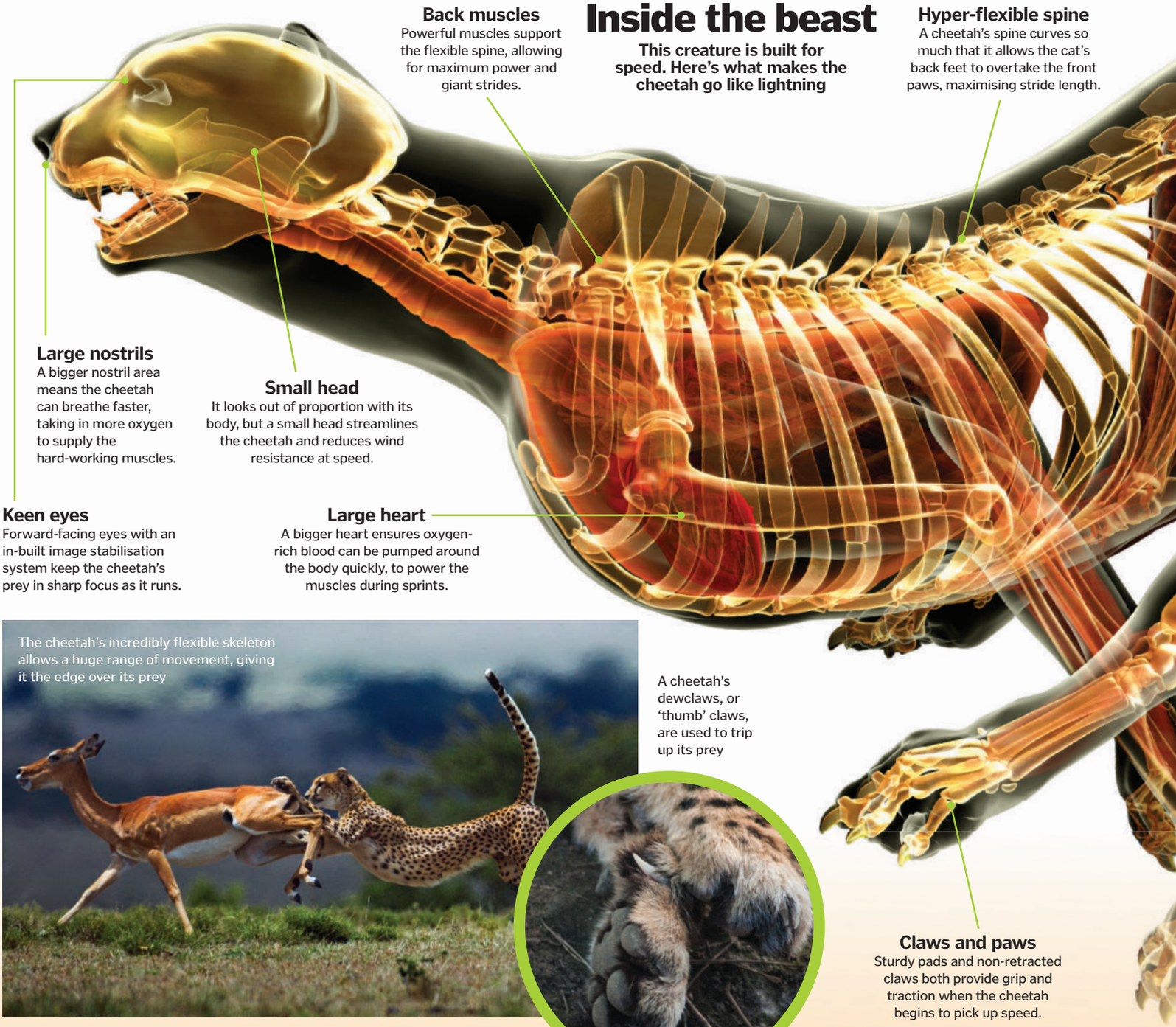
For some big cats, speed is the name of the game

Have you ever looked at a picture of the African savannah, and seen lions walking among a group of impalas and wondered why the impalas are just grazing away, instead of running for their lives? This is because the impalas know that a single lion in the open isn't fast enough and they can easily outrun them. The lions know this too, and won't waste their energy trying. For other big cats though, speed is everything. Leopards use speed for a quick-fire burst, usually after they have expertly stalked their prey and got within striking distance. Similarly, tigers use a swift leap or lunge to grab their prey once it's within reach. The element of surprise is key!

Cheetahs are the real athletes of the big cats, though. They can sprint for long distances and accelerate quickly, with some records clocking up a sustained distance of around four kilometres and an acceleration of 0 to 75 kilometres per hour in two seconds. However, they can only stay at their top speed for around 400 to 800 metres, so they must plan their attack carefully. They will approach downwind from the prey so that their scent doesn't give them away, and then launch an ambush at lightning speed. If they time this well, they will successfully outpace their prey and go in for the kill.

Inside the beast

This creature is built for speed. Here's what makes the cheetah go like lightning



Back muscles
Powerful muscles support the flexible spine, allowing for maximum power and giant strides.

Hyper-flexible spine
A cheetah's spine curves so much that it allows the cat's back feet to overtake the front paws, maximising stride length.

Large nostrils
A bigger nostril area means the cheetah can breathe faster, taking in more oxygen to supply the hard-working muscles.

Small head
It looks out of proportion with its body, but a small head streamlines the cheetah and reduces wind resistance at speed.

Keen eyes
Forward-facing eyes with an in-built image stabilisation system keep the cheetah's prey in sharp focus as it runs.

Large heart
A bigger heart ensures oxygen-rich blood can be pumped around the body quickly, to power the muscles during sprints.

The cheetah's incredibly flexible skeleton allows a huge range of movement, giving it the edge over its prey

A cheetah's dewclaws, or 'thumb' claws, are used to trip up its prey

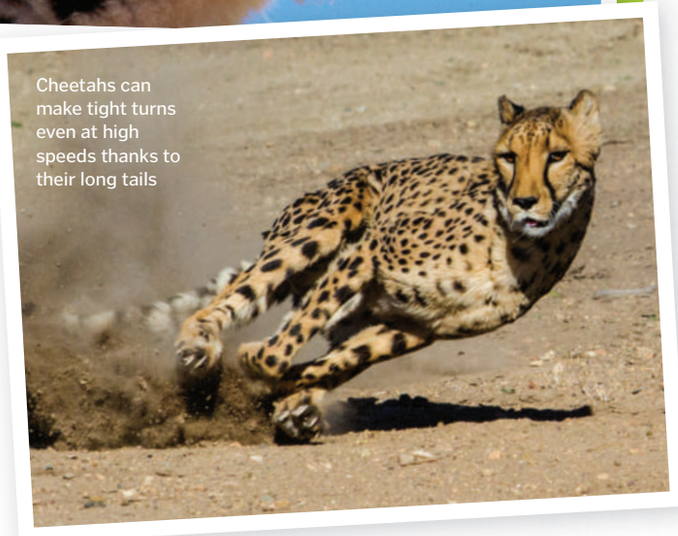
Claws and paws
Sturdy pads and non-retracted claws both provide grip and traction when the cheetah begins to pick up speed.

Why cheetahs don't roar

Only the 'true' big cats, those in the genus Panthera (lions, tigers, leopards and jaguars) can let out a deep, guttural roar. This is because the part of their voice box known as the hyoid bone is flexible. Coupled with a stretchable ligament it makes a sound-producing passage and the more the ligament stretches, the deeper the pitch.

Cheetahs, along with other 'smaller' big cats like pumas, instead have a similar voice-box anatomy to house cats. The hyoid bone is completely hardened, meaning roars are impossible to generate. The voice box is a fixed structure, but this allows them to purr – something that the Panthera cats cannot do. Interestingly, the exception to the rule is the snow leopard; although it is a member of the Panthera genus and has a flexible hyoid, this cat can neither roar nor purr! Instead, it makes a 'chuffing' sound.

Cheetahs communicate with other vocalisations instead, like high-pitched chirps and low chuffs



Cheetahs can make tight turns even at high speeds thanks to their long tails

Fast-twitch fibres
These muscle fibres are able to contract very quickly to provide a burst of power, although they tire quickly.

Lightweight skeleton
A light body means the cheetah's weight can be carried further and faster.

"Only 'true' big cats let out a deep, guttural roar"

Long tail
This acts as a counterbalance and a rudder, helping the cat make tight turns at high speed.

Big cats by numbers

How the other fierce felines measure up in the top-speed stakes

56km/h
TIGER THE LARGEST BIG CAT CAN MOVE RAPIDLY IN SHORT BURSTS

59km/h
LION FAST ENOUGH TO CATCH A RUNNING WILDEBEEST, PROVIDING OTHERS ARE NEARBY

60km/h
LEOPARD LONG, STRONG LEGS FOR CLIMBING TREES HELP THE LEOPARD ACCELERATE

80km/h
JAGUAR STILL BEHIND THE MIGHTY CHEETAH, BUT THE FASTEST OF THE REST

94km/h
CHEETAH FASTEST ANIMAL ON LAND

Strategy of the hunt

Each predator plays to its strengths, executing different tactics to hunt and catch their prey

Lions use their sheer size, brute strength and power in numbers to go after large prey items, such as buffalos, zebras and giraffes. They both stalk prey and attack en masse, coming at prey from different angles to startle and confuse. Lions will also scavenge, stealing kills off other predators such as hyenas and cheetahs.

All the other big cat species are solitary hunters, and need to employ a very different and more fine-tuned approach. Cheetahs use their highly specialised bodies to generate massive thrust, using propulsion and attuned senses to home in on their quarry. They then use their dewclaw to trip the prey, causing it to stumble and fall.

Tigers will use their keen senses and superb camouflage to stay hidden in the undergrowth. They stalk prey until close enough to strike – lunging at it from around six metres away. With razor sharp claws outstretched, any animal in this cat's sights may struggle to get away! These cats can even launch attacks from water. The tiger will then use its bulk to grapple with its prey.

Snow leopards are ambush predators and will use their rocky, mountainous home to their advantage. They will often creep up on prey near cliff ledges and drop onto them from above.

Leopards and jaguars have similar strategies. To locate prey in the dark, leopards have excellent night vision, around seven times better than ours. They rely on their hypersensitive paws to feel the terrain, ensuring that no twig-snaps or leaf rustles give away their position. A quick lunge and a powerful bite are enough to seal the deal. However, due to their climbing preferences, these cats will employ the 'drop from above' tactic too. Leopards and jaguars aren't afraid of swimming and will happily get wet to secure a meal, or sometimes they won't bother hunting at all, and will keenly scavenge a meal.

Life in the pride

Each member of the pride has its own role, to ensure all the lions benefit from family life

Lionesses do the majority of the hunting for the pride

Young males
When they reach maturity, young males are often ousted and leave the pride to form bachelor groups before they join their own pride.

Lionesses
There are around 12 lionesses in a pride unit, and they are usually all related.

Time to leave
If a male or female is injured or too old and can't perform their role, they are pushed out of the pride.

Safety in numbers
Lions live in open grasslands, where a kill draws easy attention. The pride works together to defend food from scavengers.

Mealtime hierarchy
After a kill, the males always eat first. Then the females will eat their fill and the cubs follow.

"Big cats' finely tuned senses make them hyper-aware of their surroundings"

Hunting school

Lesson number one: eat, or be eaten! How young cubs learn to be predators

Lion
Play fighting is a big part of learning. Lions in the pride will encourage cubs to pounce and stalk one another before being introduced to live prey.

Tiger
By the time they reach 18 months, tiger cubs will be skilled hunters. They learn through watching their mother and finishing off her contests.

Leopard
The essential skills that leopard mothers teach their young include how to pin down animals, and the best place to clamp down on a throat.

Teamwork is key; lions can bring down much larger prey because they work together

Cooperative hunting
Females work together to bring down a kill, making hunting both efficient and effective.

Dominant male
The male guards the territory, chasing away intruders and would-be adversaries to protect his lionesses.

Male challengers
The dominant lion may be challenged for his females and territory, so a strong male benefits the pride.

Cubs
All cubs are offspring of the dominant male. They don't help with the hunting until they're around one year old.

Cub rearing
Females share the burden of looking after cubs, taking it in turns to either hunt or babysit.

"A group of lions will come at prey from different angles to startle and confuse"

Staying stealthy

For most big cats, their most powerful weapon is stealth. But how does a two-metre-long, 250-kilogram Bengal tiger manage to stay hidden long enough to get within striking distance of its prey? The answer lies in the tiger's amazing agility, striped camouflage, and staying downwind of the prey. Orange and black stripes may seem garish to us, but these markings break up the tiger's outline in both grassland and jungle.

The same is true for the other big cats – leopards, jaguars and even lions all have subtle markings that blend them into the background. The big cats' finely tuned senses are also essential, making them hyper-aware of their surroundings. This, coupled with their strong and flexible bodies, allow the big cats to hide, waiting for the moment to strike.

A striped coat helps tigers blend into the undergrowth

Jaguar
Young jaguars stay with their mothers for two years or more. They watch her every move and learn to hunt by her example.

Cheetah
A mother cheetah will teach her cubs to hunt by bringing young or weak prey back to their lair. The cubs can then practise chasing and catching.

In for the kill

After the take-down comes the dispatch, a grizzly yet necessary part of the hunt

Tigers use their strong front legs to tackle and immobilise their prey, before biting down on the neck

When big cats get a hold on their prey and they have paws on the prize, the next step is crucial: the kill. Almost all of the big cats use the method of asphyxiation to kill their prey. This is the quickest method to make sure that the prey does not get away, and that all of the energy these animals have expended on stalking and chasing doesn't go to waste. Big cats have incredibly strong jaws, powered by efficient musculature in their head and neck. To complement a strong jaw are sets of super-sharp teeth, perfect for piercing flesh and holding prey down.

For lions, the kill is usually a team effort. Because they often hunt in groups, one lion will frequently assume the role of clamping its colossal jaws around a prey animal's snout, attempting to suffocate it while the rest of the hunting team hang on its flanks to bring it to the ground. This is sometimes called the 'lion kiss of death', and they can bring down very large prey in this way.

It's very often thought that big cats automatically 'go for the jugular' to dispatch their prey, but this isn't the case. When their teeth aim for the neck, it's the animal's windpipe that the cat is aiming for, rather than the veins. Their vice-like jaws clamp onto the windpipe and crush it, suffocating the prey for a quick kill.

Tigers use this method for larger prey. By biting the neck and using the animal's strength against itself in order to drag it to the ground, they can bring down very large animals single-handedly. For smaller critters they may bite the nape of the neck in order to sever the spinal column. Leopards also use this super-effective technique.

Jaguars, on the other hand, do things a little differently; these animals are the only big cats to prey on reptiles, and it's thought that their killing style has evolved to take down dangerous and armoured prey. The jaguar, instead of going for the throat, directly bites its prey in the back of the neck or head, severing the spinal cord and puncturing the braincase. By using this technique, the jaguar can get past the thick hides of caiman and pierce the strong shells of turtles.

Killer blow

How a leopard secures its prey in one huge burst of power

Strong bite
The leopard holds its prey at the neck, where it delivers the killer blow.

Muscular legs
Strong legs provide bursts of energy for jumps and lunges.

Eye on the prize
Leopards' eyes have a specialised membrane that allows them to focus even in low light.

Sharp claws
Claws help immobilise prey and climb to safety.

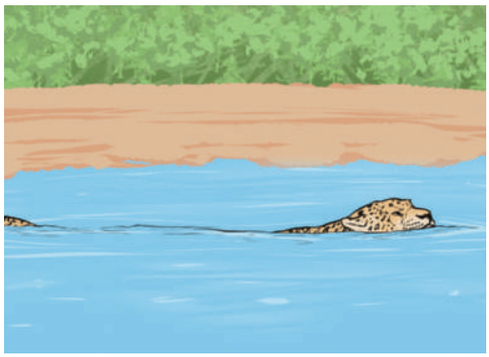
"Their vice-like jaws clamp onto the windpipe and crush it, suffocating the prey for a quick kill"

Big cats aren't just restricted to land in order in hunt down some dinner

Working together means the pride can tackle much larger animals, with more meat to go around

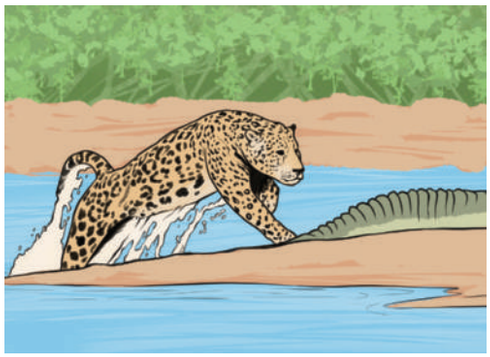
Jaguar vs caiman

These cats aren't scared of water, nor the scaly, snappy reptiles that live within



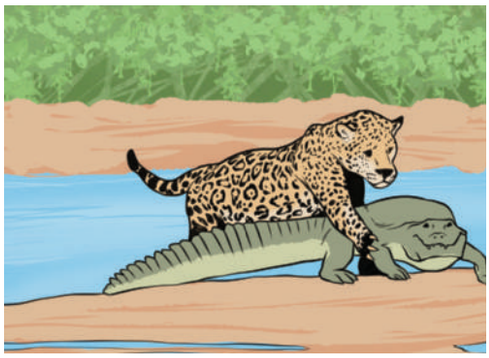
1 The swim

Jaguars are great swimmers. With prey in his sights, this jaguar chooses a water approach, making sure to swim stealthily with no splashes or sudden moves.



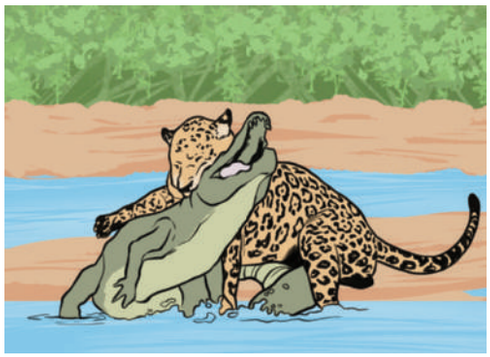
2 The stalk

Exiting the water, the jaguar has the element of surprise on the unsuspecting caiman. He stalks for one second more to get closer.



3 The attack

The caiman has little time to run before the jaguar takes a leap onto him. The jaguar again has the element of surprise and immobilises the caiman.



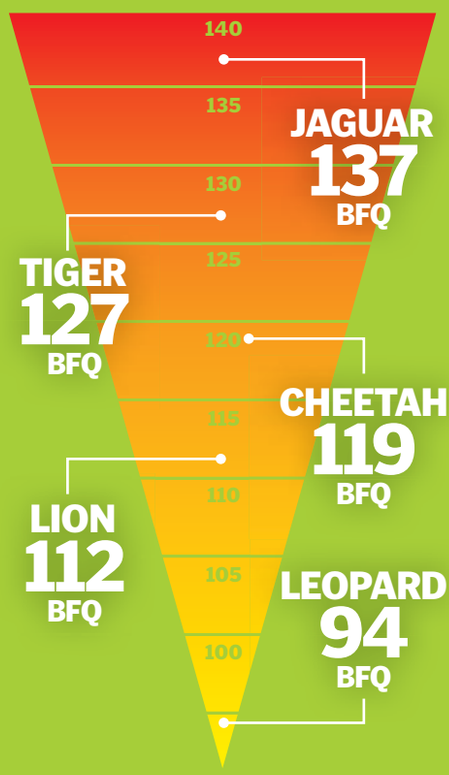
4 The death blow

A sharp bite into the braincase at the back of the caiman's head instantly immobilises the reptile. A successful hunt for the jaguar!

Big cat bite force

Check out the sheer power of these formidable predators

Bite force quotient (BFQ) is a measure of an animal's bite force relative to its body size. For comparison, a domestic cat's BFQ is 58.



How do leaves decompose?

The hard-working organisms that recycle dead plants into the ingredients for new life

1. Falling leaves
In autumn, deciduous trees shed their leaves and on the forest floor they become food for detritivores, or decomposers. These are the invertebrates (mainly insects such as worms, beetles and maggots), fungi and bacteria that break down plant matter.

2. Recycling waste
As they eat, the detritivores use the nutrients inside the leaves to produce energy for themselves. What they don't use is either returned to the atmosphere as carbon dioxide, or digested and excreted to be deposited into the soil.

3. New growth
The nutrients in the soil are used by seeds, and later roots, to help grow new plants, which then use the carbon dioxide in the air for photosynthesis. Therefore, nothing goes to waste and the life cycle can begin all over again.

What are conkers?

Discover the toxic truth behind the popular playground game

Commonly found swinging from pieces of string, as children use them to do battle with their friends, conkers are actually the seeds of the horse chestnut tree. After the flowers of the tree have been pollinated, they develop into these glossy, dark brown seeds, which are encased within a spiky, green shell. The shell protects the seeds as they are developing, stopping birds and other animals from eating them.

When autumn arrives, the spiky shells fall to the ground and crack open to reveal the shiny conkers inside. Here, they have a further defence mechanism, as the seeds contain toxic chemicals called glycosides and saponins, which are poisonous to many animals, as well as humans. If eaten raw, the seeds can cause sickness, although some animals, such as deer and wild boar, are able to break these compounds down and digest conkers safely. Once on the ground, the seeds are carried away and buried by animals who store them for food during the winter. If they aren't eaten, they will start to grow, continuing the plant's life cycle.

"The seeds contain toxic chemicals"

RED ARROWS HAWK T1

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LIMITED EDITION OF 9,999 individually numbered – first orders receive lower edition numbers

Shown larger than actual size. Bezel measures 1.8 inches (4.65 cm) in diameter. Strap (inc. buckle) measures 8.3 inches (21 cm) in length.

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Applications are now open and this offer is likely to attract great interest, and not just from watch collectors, so please apply promptly.

KEY DETAILS

EVENT: Red Arrows Eastern Hawk Tour, with performances scheduled for China (for the first time), India, Malaysia and Singapore.

LIMITED RELEASE: Only 9,999 of these watches are available. Each is individually numbered on the reverse with a unique edition number. Earliest orders will receive lowest watch numbers.

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YOURS FOR £149.95 (plus £9.99 S&H)*, payable in five interest-free instalments of £29.99 each. Pay nothing now.

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Reverse will feature an etched Red Arrows Hawk T1 jet formation in addition to 'Red Arrows' and the words associated with this elite aviation display team.

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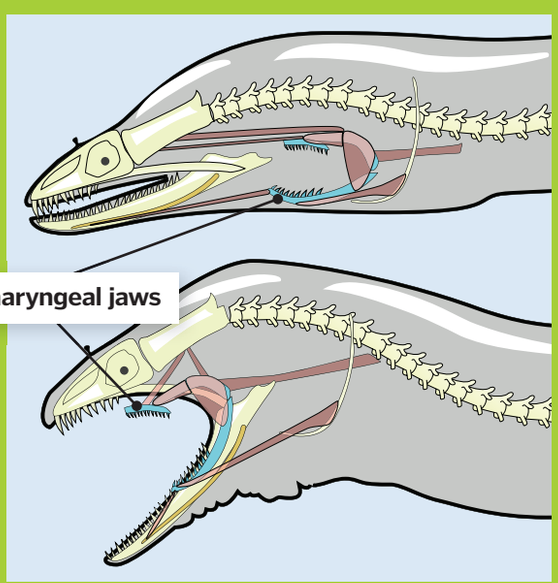
The honeycomb eel

With muscular bodies and formidable bites, these coral reef residents aren't to be messed with

Honeycomb eels are a species of moray eel, a family of muscular, powerful eels that live in nooks and crannies of brackish water and coral reefs across the world. Honeycomb eels reach lengths of around 1.5 metres and are found in the tropical waters of the Indo-Pacific. They may look like snakes, but eels are actually fish with no scales – instead, their bodies are covered with a layer of slimy, protective mucus. Their honeycomb pattern is as functional as it is beautiful, corresponding to its vibrant coral reef neighbourhood and blending the predator into the background.

These marine beasts have long, tapering bodies made of strong muscle, enabling the eel to swim surprisingly fast using an efficient, serpentine movement. All moray eels are intensely territorial and will defend their patch ferociously; mid-water scraps between these aggressive fish are not unheard of.

As ambush predators, scent is their key sense. Eels will conceal themselves in their hidey-hole homes until something tasty swims by, before quickly snatching it out of the water in a burst of energy and a flash of sharp teeth. These eels aren't fussy eaters; a range of species, from squid to fish to crabs, are on the menu. Yet morays won't eat everything that comes near and they are often found cohabiting with cleaner wrasse, small fish that feed on their bodily parasites.



Twice the bite

One feature that helps the ferocious honeycomb eel stay at the top of the food chain is its amazing set of double jaws. When the eel strikes out to grab a fish, sharp teeth in the main set of jaws skewer the prey to immobilise it. Then, from deep within the eel's throat, the pharyngeal jaws with hooked teeth come into play. In what has to be the creepiest eating habit ever, these extra jaws reach up from inside the gullet and grab the food, dragging it down towards the stomach.

Extra jaws drag prey to the eel's stomach, while other fish use suction to do the job

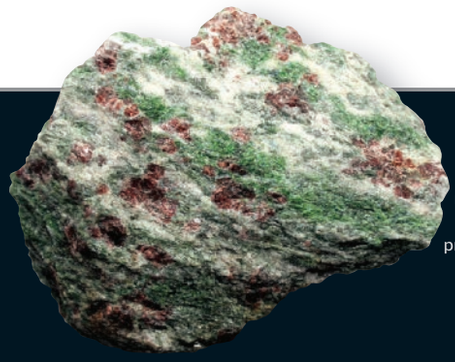
Eels constantly move their impressive jaws up and down – this isn't aggression, they're just moving their gills!

Cleaner wrasse eat the parasites that live on the eel's body

"All moray eels are intensely territorial and will defend their patch ferociously"

Recycling rock

How the rocks on our planet are weathered, worn and transformed countless times



Eclogite is a metamorphic rock forged by the high pressures of Earth's upper mantle

Our planet is covered with different types of rock, from great mountains to molten magma to grains of sand – and all of these forms are connected by the rock cycle. This model shows how the three main classifications of rock – igneous, sedimentary and metamorphic – are able to morph into one another as different forces act upon them.

Wind, rain, snow and ice gradually erode mountains and cliffs to provide the material that will eventually be compacted to become sedimentary rock. The internal structure of our planet itself also plays an important role. The mantle – a 2,900-kilometre-thick, semi-molten region found beneath the Earth's crust – provides extreme heat and pressure that compact rock into a metamorphic form. The planet's core generates intense heat that melts the lower mantle into magma. This magma becomes igneous rock as it cools, either at the Earth's crust or above the surface when it is ejected in volcanic eruptions.

The rock cycle is a story of rebirth and recycling, where the old provides materials for the new. The cycle takes thousands if not millions of years, but we can see snapshots of the process: waves crashing against rocks, shifting glaciers and dramatic volcanic eruptions all provide glimpses of the processes that govern Earth's ever-changing geology.

The rock cycle

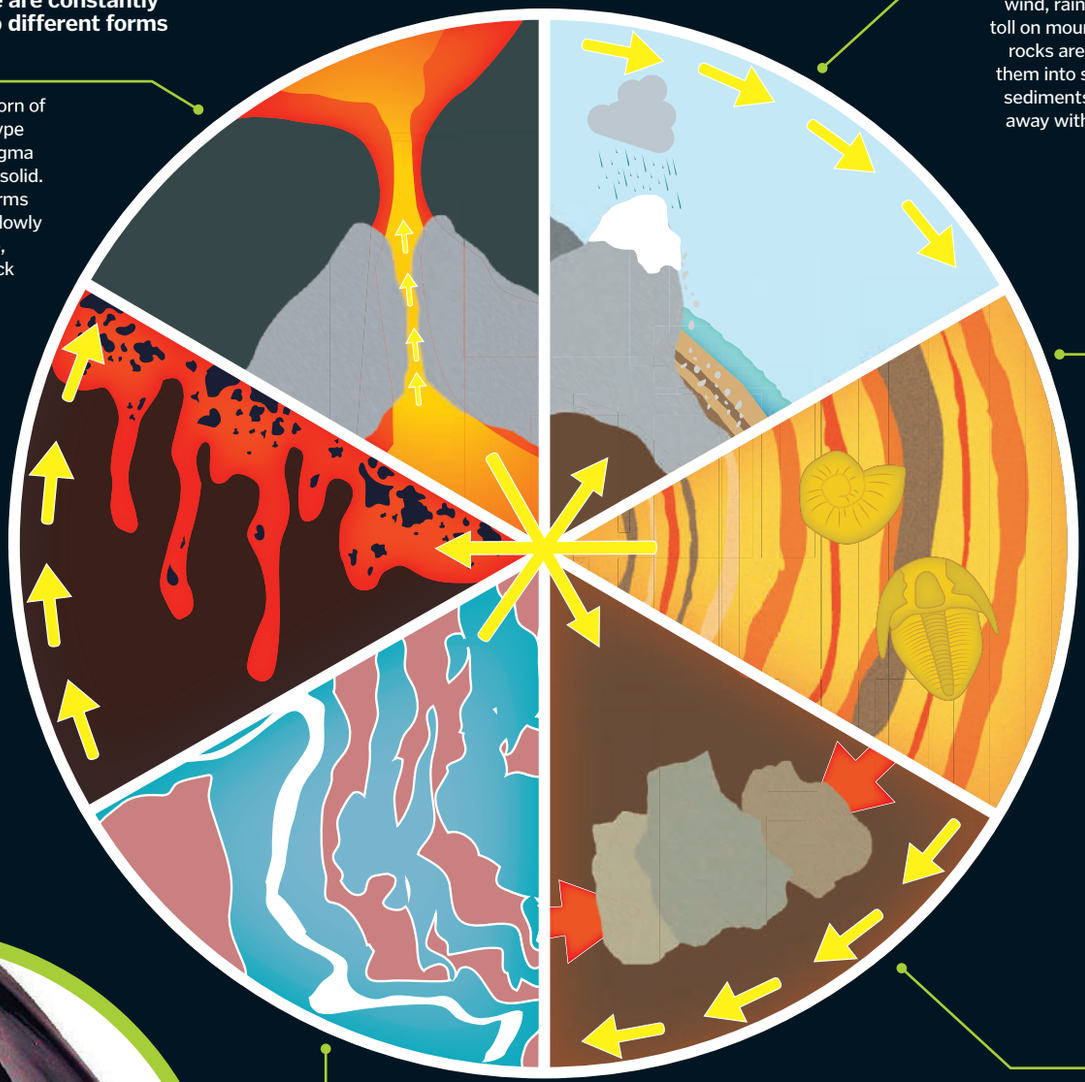
The forces of nature are constantly morphing rocks into different forms

Igneous rock

Igneous, which means 'born of fire or heat', is the rock type formed when molten magma cools enough to become solid. Intrusive igneous rock forms when the magma cools slowly under the Earth's surface, and extrusive igneous rock forms when the magma cools rapidly on the surface, such as after a volcanic eruption.

Weathering and erosion

Weather conditions such as heat, wind, rain, snow and ice take their toll on mountains and cliffs, and the rocks are slowly eroded, breaking them into smaller fragments called sediments. These are then carried away within bodies of water, such as streams and rivers.



Sedimentary rock

When sediments eventually settle, they are deposited in layers that accumulate over millions of years. The weight of the layers compresses the sediments at the bottom, squeezing out water and enabling crystals to form. These crystals act a bit like cement, gluing the pieces of rock together.

Rising heat

The intense heat found below the surface – sometimes stemming from the planet's superheated core – can generate temperatures up to 1,300 degrees Celsius, causing rock to melt into a molten form called magma, which rises towards the cooler surface via convection.

The igneous rock obsidian forms when lava cools so rapidly that atoms are unable to form crystals

Metamorphic rock

The combination of intense pressure and high temperatures (between 300 and 700 degrees Celsius) doesn't melt rocks, but changes their chemical structure. They are transformed into dense metamorphic rock.

Plate tectonics

Our planet's crust is formed of tectonic plates, which are always moving very slowly. When these plates collide, mountains are formed and earthquakes are generated, and the friction also results in huge amounts of heat and pressure below the surface.

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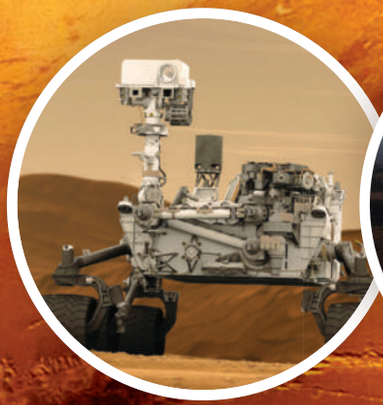
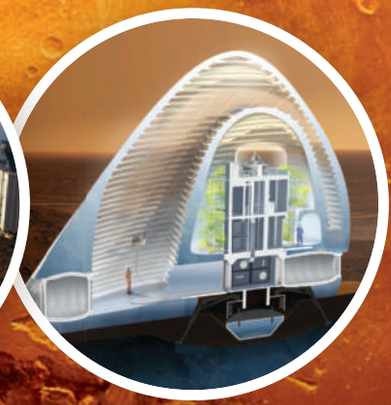
LIFE ON MARS

HOW WE'VE EXPLORED THE RED PLANET – AND WHAT'S COMING NEXT





A brief history of Mars

How this world turned from habitable to deadly

4.5 BILLION YEARS AGO

Formation

The planet Mars forms, along with the other rocky planets in the Solar System.

4.5 TO 4.1 BN YEARS AGO

Pre-Noachian

A little-known period of Martian history when the planet was likely pounded by asteroids.

4.1 TO 3.7 BN YEARS AGO

Noachian

Volcanic activity thickened the atmosphere, causing rain, forming valleys and lakes we see remnants of today.

In September 2016, SpaceX founder Elon Musk announced a bold plan to colonise Mars with humans. It made headline news around the world, and while there are understandably some critics, it has once again raised the prospect of exploring Mars.

Today, Mars is a barren and inhospitable world. With an atmosphere that's 95 per cent carbon dioxide, temperatures as low as -153 degrees Celsius and no magnetic field, it's not exactly a habitable location. But several billion years ago, we're pretty sure Mars had vast amounts of water. We can see evidence for this in what appear to be valleys carved by rivers, empty lakebeds and even coastlines.

The big question remaining about Mars is whether life could have existed there, or still does. It is unclear how long the planet had surface water for, and it may not have been long enough for life to thrive. But it's possible that primitive, microbial life might have taken hold.

Two upcoming missions, the European ExoMars 2020 rover and the American Mars 2020 rover, will be endeavouring to answer this question. These two rovers are an exciting precursor to what looks set to be the era of Mars exploration.

At the moment, NASA is hard at work on a new spacecraft and rocket that will take people to Mars in the 2030s. Their goal is to further the exploration of the human species and, perhaps, create a permanent base on Mars.

Then Musk came along in September 2016 and threw a spanner in the works. He said he was working on a giant rocket that, beginning in the 2020s, would start launching people 100 at a time to Mars, with the goal of a million people settled there by the turn of the century.

Mars is back on the agenda, and even if there has never been life there before, there soon will be: humans are homing in on the Red Planet.

"We're pretty sure Mars once had vast amounts of water"

The Mars 2020 rover will search for signs of microbial life on the Red Planet

Mars then and now

How has the Red Planet changed over the past 4 billion years?

Water
A thick atmosphere and magnetic field may once have allowed water to exist on the surface.

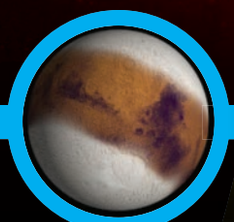
No magnetic field
Without a magnetic field, the surface of Mars is subjected to intense solar and cosmic radiation.

Thin atmosphere
Today, Mars has a relatively thin atmosphere, making the pressure too low on the surface for liquid water.

Coast
Scientists have recently observed what appear to be ancient coastlines on Mars.

Martian seas
Recent evidence suggests the northern hemisphere of Mars once had more water than Earth's Arctic Ocean.

No surface water
Any water that was once on the surface has long since boiled away, but some may remain underground.



3.7 TO 2.9 BN YEARS AGO

Hesperian
Much of Mars' surface water turned to ice as temperatures dropped during this period.

2.9 BN YEARS AGO TO PRESENT

Amazonian
Over the past few billion years, a thinning atmosphere left much of the planet smooth, dry and devoid of geologic activity.

TODAY

Present day
Mars is now a cold and barren world, with only hints of its ancient water remaining.

Robots on Mars

How we're using robotic explorers to uncover the Red Planet

In July 1965, NASA's Mariner 4 spacecraft conducted a flyby of the Red Planet, returning the first ever images of the Martian surface. Since then, we have learned a huge amount from our robotic missions – and perhaps it won't be too long until humans are there, too.

When we first started sending missions to Mars, scientists were unsure what they'd find. But over time, we have been able to paint a picture of what this world once looked like. The goals of our missions have changed too, from those of initial discovery, to more refined searches for life and water.

NASA's Viking landers arrived in 1976 and were the first dedicated probes to search for life. Results were inconclusive, but a fire was stoked in Martian exploration by returning the first images from the surface itself. However, following several failed attempts, it would be another two decades until the next successful Mars mission. NASA's Mars Global Surveyor launched in 1996, and between 1998 and 2006 it extensively mapped the surface and provided much of the data needed for later missions. Excitingly, it also provided evidence for water ice on Mars.

Our first rover arrived in 1997. Sojourner analysed rocks on Mars and found similar features to Earth. In 2004, the wildly successful Spirit and Opportunity rovers also arrived, with the latter still active on the surface today.

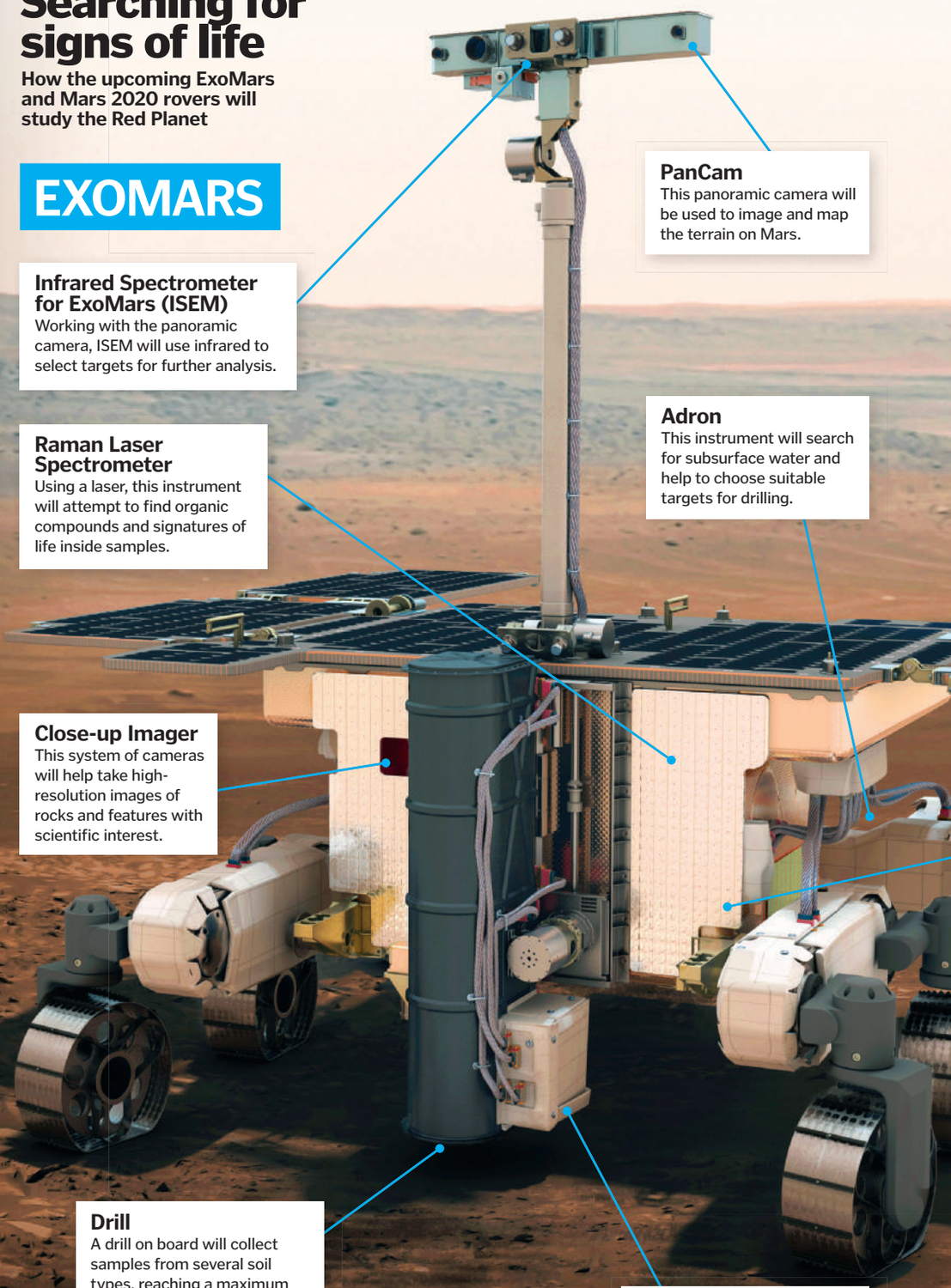
In 2012 we said hello to the Curiosity rover, which landed in Gale Crater, and has since discovered this location likely contained an ancient lake. 2014's MAVEN mission, meanwhile, has helped us discover how solar winds destroyed the Martian atmosphere.

But there's still much more to learn – and that's where ESA and NASA's amazing next generation of Martian rovers comes in.

Searching for signs of life

How the upcoming ExoMars and Mars 2020 rovers will study the Red Planet

EXOMARS



PanCam
This panoramic camera will be used to image and map the terrain on Mars.

Infrared Spectrometer for ExoMars (ISEM)
Working with the panoramic camera, ISEM will use infrared to select targets for further analysis.

Raman Laser Spectrometer
Using a laser, this instrument will attempt to find organic compounds and signatures of life inside samples.

Adron
This instrument will search for subsurface water and help to choose suitable targets for drilling.

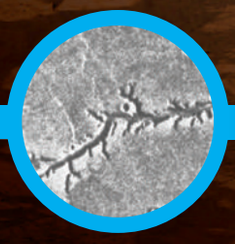
Close-up Imager
This system of cameras will help take high-resolution images of rocks and features with scientific interest.

Drill
A drill on board will collect samples from several soil types, reaching a maximum depth of two metres.

Mars Multispectral Imager for Subsurface Studies
This instrument will help study the mineralogy of rocks encountered by the drill.

A history of water on Mars

How we've painted a picture of a once habitable world



CANYONS – 1971

Mariner 9
NASA's Mariner 9 spacecraft found a vast canyon on Mars and beamed back images of the planet's south pole.

RIVERS – 1976

Viking 1 and 2
The Viking landers found evidence that rivers of water had spread far across the surface.

SALTY – 1997

Pathfinder
Pathfinder found that temperatures on Mars were high enough to support salty liquid water.

Methane on Mars

In 2014, NASA's Curiosity rover had discovered a temporary increase of methane in its location on Mars. This hinted at – but does not prove – the presence of biological processes.

An instrument on board the rover called Sample Analysis at Mars (SAM) 'sniffed' the atmosphere over the course of 20 months. In two of those months, there were spikes of methane that were ten times larger than the average in other months.

This suggests there was a localised methane source. There are several possible causes, including the interaction of rock and water underground. But there could be a biological reason, perhaps subsurface microbes releasing methane. It raises the possibility that some basic life may still exist on Mars today.

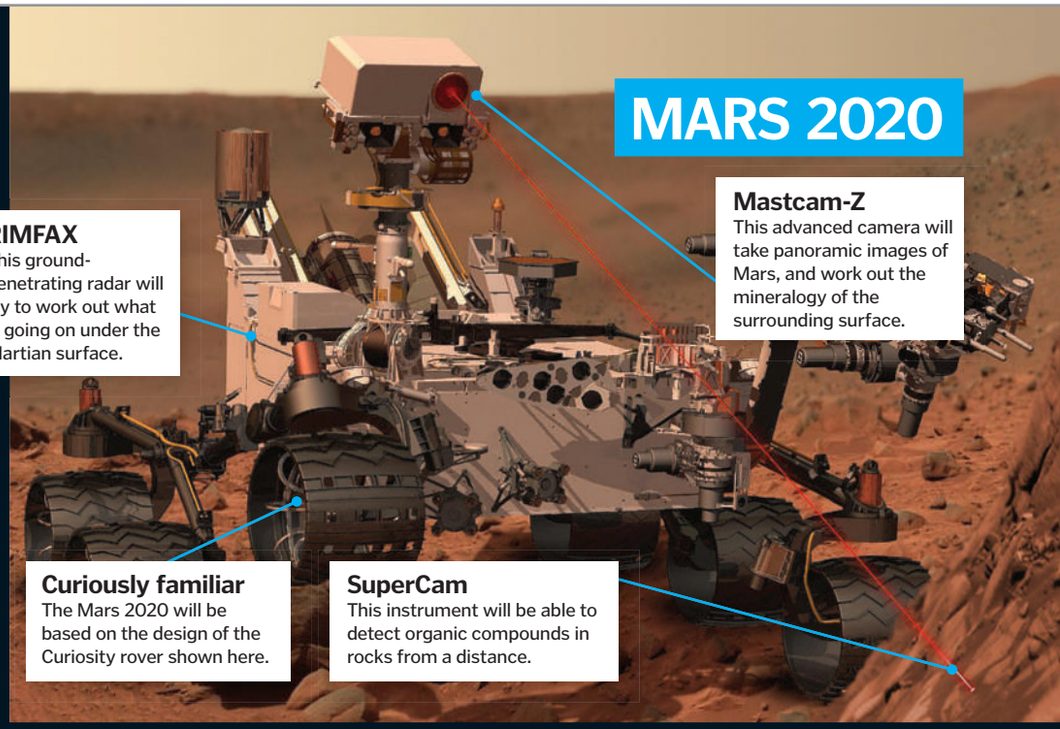
Curiosity found spikes in methane levels on Mars

Mars Organic Molecule Analyser
The biggest instrument on ExoMars, MOMA will directly try to find biomarkers in samples collected by the drill.

"NASA's Viking landers were the first probes to search for life"

MAVEN is NASA's most recent spacecraft to be sent to Mars

MARS 2020

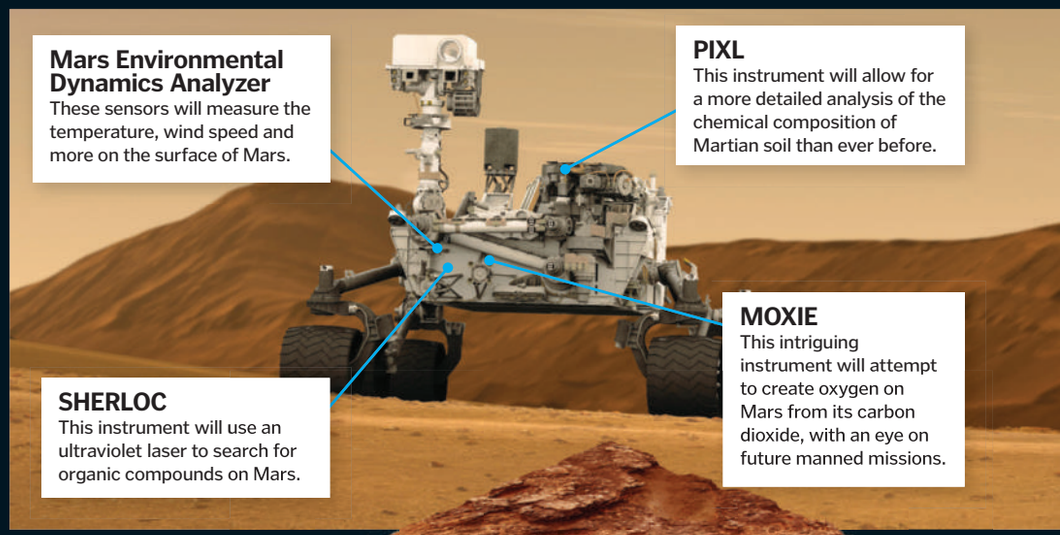


RIMFAX
This ground-penetrating radar will try to work out what is going on under the Martian surface.

Mastcam-Z
This advanced camera will take panoramic images of Mars, and work out the mineralogy of the surrounding surface.

Curiously familiar
The Mars 2020 will be based on the design of the Curiosity rover shown here.

SuperCam
This instrument will be able to detect organic compounds in rocks from a distance.



Mars Environmental Dynamics Analyzer
These sensors will measure the temperature, wind speed and more on the surface of Mars.

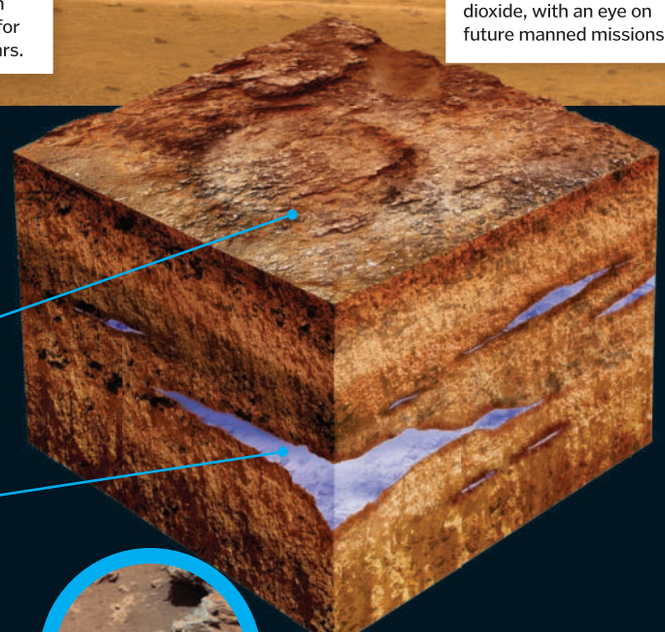
PIXL
This instrument will allow for a more detailed analysis of the chemical composition of Martian soil than ever before.

MOXIE
This intriguing instrument will attempt to create oxygen on Mars from its carbon dioxide, with an eye on future manned missions.

SHERLOC
This instrument will use an ultraviolet laser to search for organic compounds on Mars.

Hidden water

There could be ice or even liquid water trapped under the Martian surface



Clues
Geological features on the surface suggest Mars once had rivers, lakes and seas.

Reservoirs
Mars' surface is barren, but remnants of ice could be trapped underground.

LIQUID – 1999
Mars Global Surveyor
Images from the Mars Global Surveyor between 1999 and 2001 suggested liquid water may still be flowing on Mars.

ICE – 2001
Mars Odyssey
This probe found that there could be huge deposits of ice and water below the surface of Mars.

STREAM – 2012
Curiosity
Curiosity has found that its landing site within the Gale Crater may have been an ancient stream bed.

Getting to Mars

How we're preparing for manned missions to the Red Planet

"Elon Musk has revealed his bold plan to get to Mars"

The rockets

To get beyond Earth's orbit, you need a very big rocket. For the Apollo missions to the Moon, we had the Saturn V, which remains the most powerful rocket ever built. But for missions to Mars, things are going to need to get bigger – and better.

First up is NASA's Space Launch System (SLS). Measuring 117 metres in height, this heavy-lift rocket will launch astronauts and cargo to Mars. Its first test flight is not scheduled until 2018, though, and questions remain over how it will be used.

More recently, SpaceX founder Elon Musk revealed his bold plan to get to Mars with his Interplanetary Transport System (ITS). At a height of 122 metres, Musk wants to use this to colonise Mars with a million people by the turn of the century.

It is likely that Russia and China will also reveal rockets bound for Mars over the coming decades.

Will SpaceX's Interplanetary Transport System deliver on its promises?

Practising on the ISS

Long-duration stays aboard the International Space Station (ISS) are helping prepare crews for Mars. These stays normally last six months, but in 2015, an American astronaut and Russian cosmonaut spent an entire year on the station, providing crucial data on how humans will cope with the longer spaceflights needed for Mars missions.

SLS Rocket

NASA's Space Launch System will enable humans to explore destinations beyond the Moon.

NASA's crew capsule

The Orion spacecraft is NASA's answer to launching astronauts from Earth and returning them from Mars. It will house up to six astronauts, taking them into Earth's orbit where they will likely dock with another larger habitat, which they will use for the journey to Mars, although this has yet to be finalised.

Journey to Mars

How NASA plans to send humans to Mars by 2040

PRESENT-2024

International Space Station

Missions to the ISS will continue until 2024, monitoring how humans cope with spaceflight.

2018

Exploration Mission-1

SLS and an unmanned Orion capsule will launch together for the first time in 2018.

2023

Asteroid Redirect Mission

By 2023, NASA plans to send humans to a captured asteroid in lunar orbit.

Simulating a Mars mission

On 28 August 2016, six people emerged from a two-story dome in Hawaii, having spent a whole year in isolation. Why? They were simulating what it might be like to live on Mars under similar conditions in the future.

The mission, called HI-SEAS (Hawaii Space Exploration Analog and Simulation), was part-run by NASA to prepare for its planned manned missions in the 2030s. During the experiment, the team spent their entire time inside the dome, having to don 'spacesuits' to venture outside, just as explorers will have to on future Mars missions. Their communications to Earth were also delayed by 20 minutes – the same lag Martian explorers will experience.

Although there's no substitute for actually being on Mars, the goal of this programme was to see how humans would cope with isolation. NASA's missions to Mars may last three years in total, including 500 days on the surface – a long time away from Earth and other human contact.

HI-SEAS uses a dome in Hawaii to simulate Mars missions

Deep space habitats

Getting to Mars will take up to nine months, so astronauts will need something larger than a small shuttle to live in. This is likely to be a multi-roomed spacecraft similar to the ISS, and will require shielding to protect astronauts from cosmic radiation.

Ion engines

The spacecraft that takes humans to Mars will likely use some form of solar electric propulsion, or ion engines, to gradually accelerate and decelerate the spacecraft. This will help save on fuel, leaving more room for cargo and reducing the mass needed at lift-off from Earth.

Robotic helpers

Images from orbiters and data from rovers at Mars will be used to pick a landing site for the manned missions, with a number of candidates already being discussed. Once humans reach Mars, probes can also be used as relay satellites to communicate with Earth.

Snagging an asteroid

NASA is planning a robotic mission to collect a chunk of an asteroid and redirect it into lunar orbit. Astronauts would then be sent to explore it and practise technologies and techniques they would need on Mars missions. However, some deem the mission unnecessary, and it is currently being reviewed.

2030

The Moon

By 2030, NASA wants to be conducting regular missions to lunar space.

2033

Phobos

NASA may launch a crewed mission to the Martian moon Phobos in around 2033.

2039

Mars

By the end of the 2030s, NASA plans to send humans to the surface of Mars.

Humans on Mars

What will we actually do when we get to the Red Planet?

Of all the aspects of sending people to Mars, what life will actually be like there is the most speculative of the lot. That's not to say people haven't thought about it, but no one yet knows for sure how humans will survive there.

What seems likely, though, is that the first missions to Mars will involve telerobotics. This will see humans orbit Mars, perhaps living on the Martian moon Phobos, and operate rovers on the surface. Without the communications delay that Earth-controlled rovers suffer, this could allow for much more rapid exploration of the surface.

Eventually, though, humans will set foot there. If Elon Musk is to be believed, these humans will be self-sustaining, living off the land and using clever equipment to create oxygen, water, and even make the planet Earth-like. It remains to be seen if his plan to have a million people living there by the turn of the century comes to fruition, though.

For NASA, the plans are likely to be simpler and more realistic. Think along the lines of the Apollo missions, with small crews venturing to the surface, staying on Mars for a few weeks or a few years, before returning home.

To create a habitat on Mars, it may be necessary to partially submerge a structure in the Martian soil. This will provide a barrier against cosmic and solar radiation, keeping the crews healthy.

We know there is a lot of water ice locked at the poles and under the surface of Mars, so making use of this will be important. Depending on how successful the Mars 2020 and ExoMars rovers are, it may be that there is enough water underground to support a small Martian colony. This water could be purified into drinking water, or broken down into its constituent elements to make fuel.

With humans on Mars, we will be able to explore the surface like never before. Gone will be the days of tentative robotic footsteps; we will be able to study and analyse vast swathes of the Red Planet, and perhaps definitively answer if there is life on Mars.

"People have long dreamed of turning Mars into an Earth-like world"

Mars Ice House

This proposal won NASA's 3D-Printed Habitat Challenge in 2015

The dome
Before a crew arrives, robots turn the water into ice, and create a layered dome that can house people.

Sunlight
When completed, humans would be able to live inside the dome, growing plants in sunlight.

Ice, ice, maybe
As its name suggests, this structure would be made entirely out of ice.

Exploration
Astronauts could enter and exit the structure with ease, allowing them to explore the Martian surface.

Water
Subsurface water would continuously be mined to re-supply the astronauts and keep them alive.

Terraforming Mars

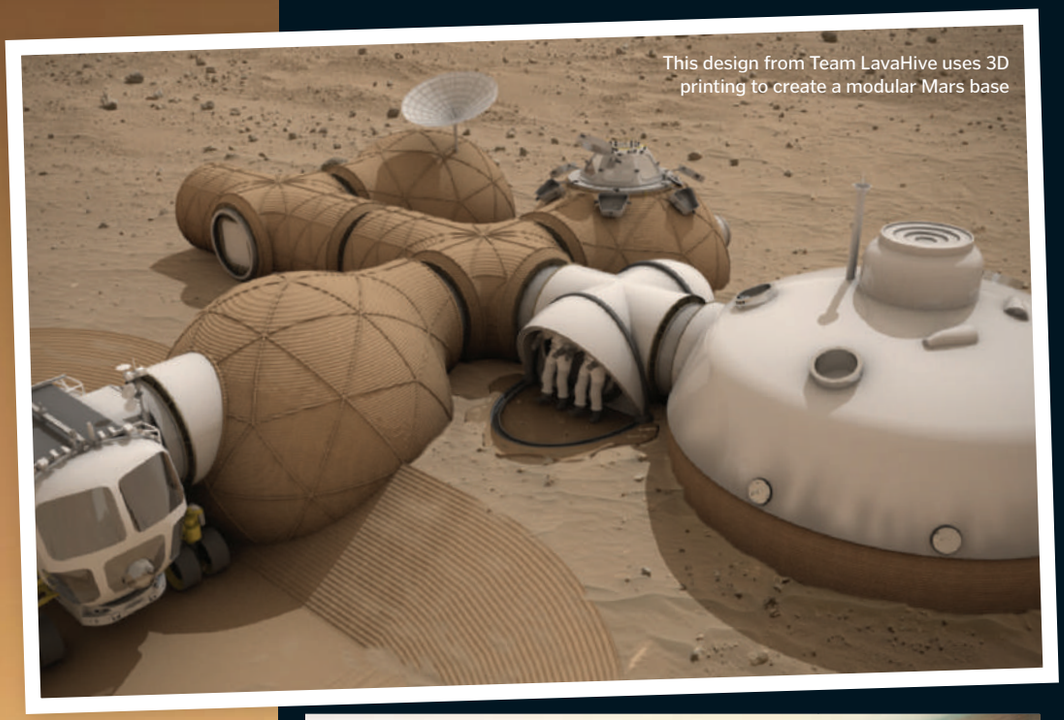
The steps we'd need to take to make Mars habitable

50 YEARS
Preparation
Send humans to Mars, and install the machinery necessary to terraform the planet.

100 YEARS
Colonisation
If Elon Musk is right, we could have a million people living on Mars in 100 years.

100 YEARS
Melting
By heating the poles we would release vapour and CO_2 into the atmosphere, heating the planet.

150 YEARS
Plants
By this point, oxygen levels may be suitable for plant life on the surface.



This design from Team LavaHive uses 3D printing to create a modular Mars base

Can we make Mars habitable?

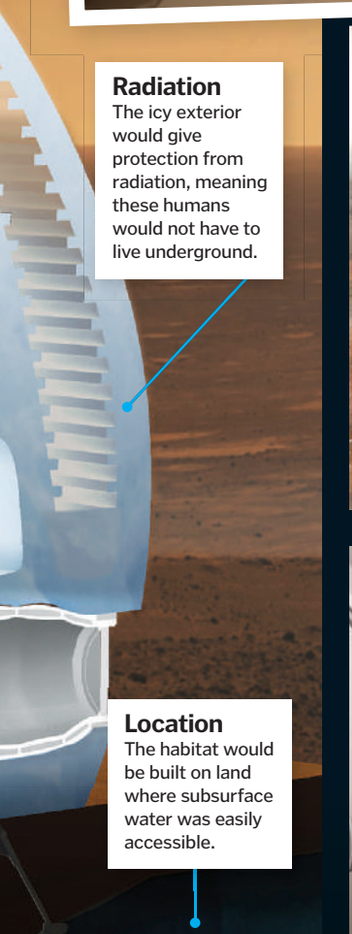
People have long dreamed of turning Mars into an Earth-like world. And it might be possible, although perhaps not just yet.

One way to do it would be to heat the vast amount of ice at the Martian poles, maybe with large mirrors in orbit. This would release carbon dioxide into the atmosphere, thickening it, and potentially heating up the planet.

Another method would be to use factories on the surface to manufacture chlorofluorocarbons (CFCs) from the air and soil. CFCs are responsible for Earth's ozone, which traps heat from the Sun, and perhaps we could create a similar effect on Mars.

We'd also need to find a way to turn the atmosphere from predominantly carbon dioxide into oxygen and nitrogen, like on Earth.

One complication, though, is that without a magnetic field, the Martian atmosphere is continuously blown away by the Sun. Who knows, though – perhaps there's a solution in the future.

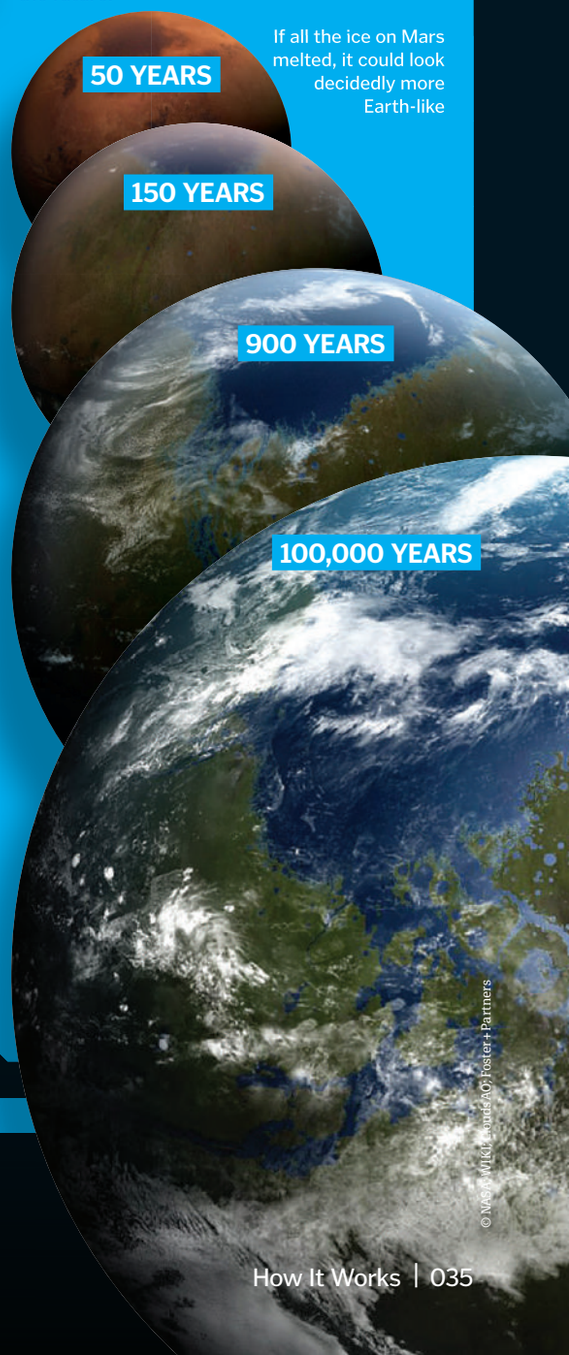


Radiation
The icy exterior would give protection from radiation, meaning these humans would not have to live underground.

Location
The habitat would be built on land where subsurface water was easily accessible.

This concept from Team Gamma uses semi-autonomous robots to construct a habitat from the Martian soil

Habitat modules would have both private and communal spaces



If all the ice on Mars melted, it could look decidedly more Earth-like

900 YEARS

Humans
In an optimistic scenario, Mars could then be suitable for everyday human life in 900 years.

100,000 YEARS

The future
However, other estimates suggest it may take 10,000 to 100,000 years to terraform the planet. Stay tuned!

Thorne-Zytkow stars

What happens when one star eats another?

In 1975, physicist Kip Thorne and astronomer Anna Zytkow first proposed the idea of a bizarre stellar hybrid that forms when an enormous dying star devours a smaller dead star. Labelled a Thorne-Zytkow Object (TZO), it remained a theory for decades, but in 2014 scientists detected the most likely candidate to date. HV 2112 is a red supergiant located in a dwarf galaxy about 199,000 light years away, and contains excessive levels of the elements thought to be characteristic of a TZO. Further study of the star is now underway to confirm whether or not it is such a cosmic rarity.

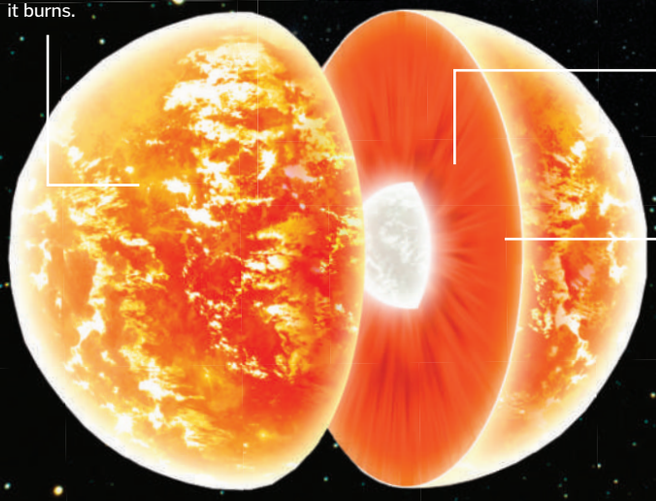
A hybrid star

How do these rare stellar giants form?

Stellar merger
When a red supergiant engulfs an orbiting neutron star, a TZO is then formed.

Red supergiant
The second ingredient is an enormous dying star, which is up to 2,000 times wider than the Sun.

Inner shell
A shell of burning material surrounds the TZO's neutron core, generating new elements as it burns.

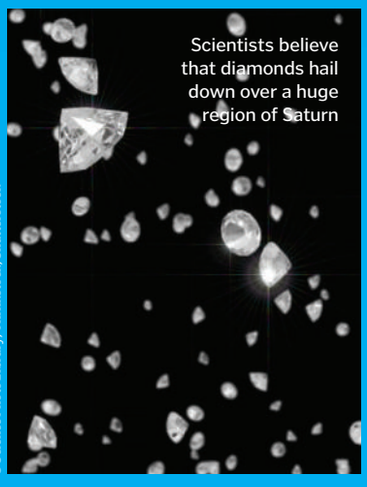


Convection
The circulation of hot gas inside the star consequently carries the unusual elements to the surface.

New elements
Unusually large amounts of these elements, which include rubidium, molybdenum and lithium, set TZOs apart from normal red supergiants.

Neutron star
The first ingredient of a TZO is a neutron star, which is the extremely dense, collapsed core of a large, dead star.

"In 2014 scientists detected the most likely Thorne-Zytkow candidate to date"



Scientists believe that diamonds hail down over a huge region of Saturn

Diamond rain

You may need to pack a seriously strong umbrella for a trip to Saturn

While we experience some pretty weird and extreme weather here on Earth, our blizzards and hailstorms have got nothing on the bizarre precipitation elsewhere in the Solar System. US scientists believe that on Jupiter and Saturn it rains diamonds, with some of the gems up to a centimetre in diameter. They came to this conclusion by studying the chemistry of the planets' atmospheres, and estimate that 1,000 tons of diamonds are created on Saturn each year.

The formation of these crystals is thought to begin in the gas giants' upper atmospheres, where lightning storms turn methane into tiny soot particles. As it falls through the atmosphere, the pressure increases, turning soot into graphite, and as it falls further it hardens into diamond. These diamonds are not forever, though: once they reach the extreme pressure and heat of the planets' hot cores, these precious hailstones eventually melt into a sea of liquid carbon.

White holes

Is there such a thing as a black hole in reverse?

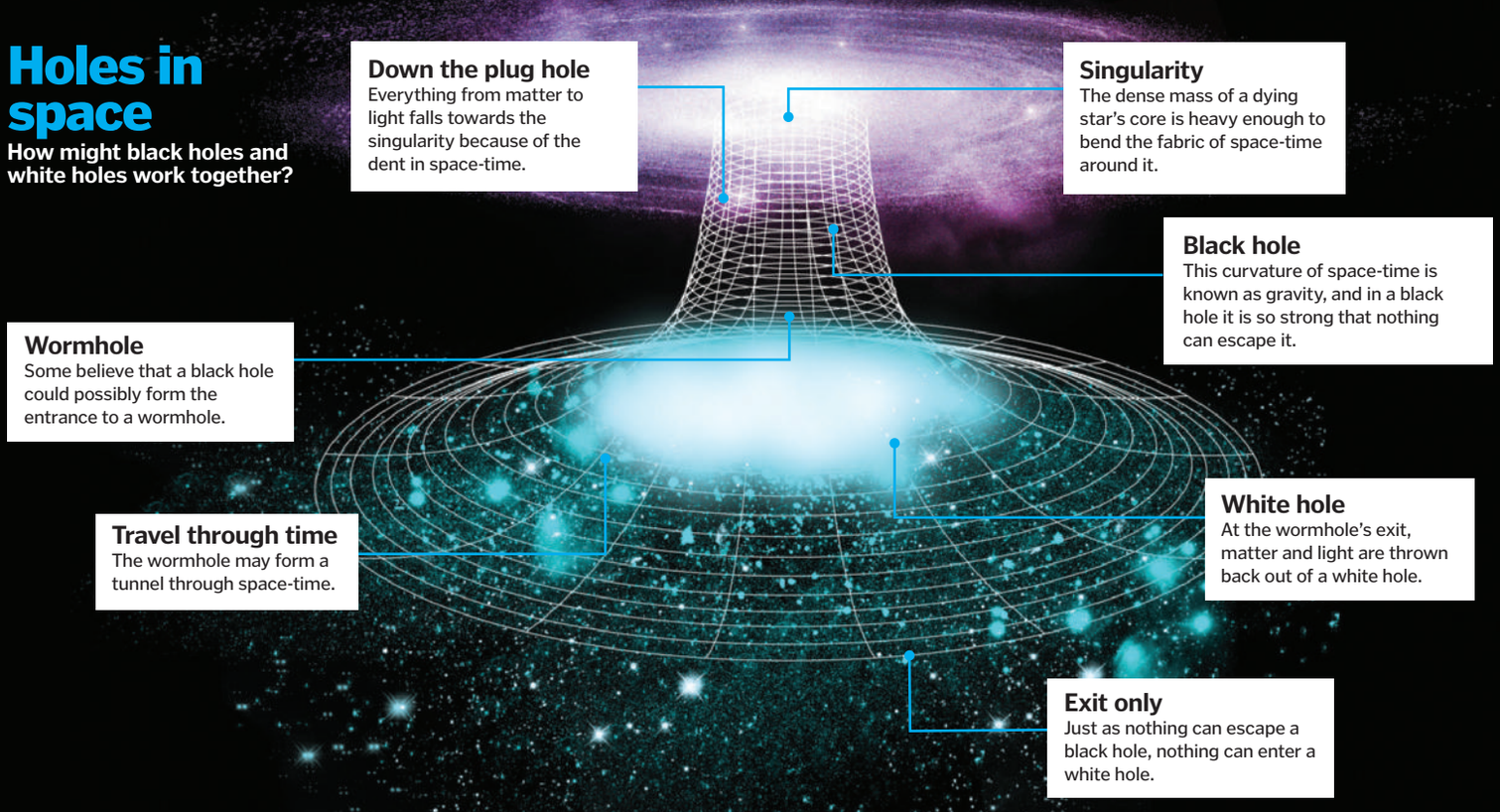
The universe is full of holes – black holes to be precise. These cosmic objects form when a massive star, much bigger than our Sun, collapses in on itself and dies in a spectacular supernova. The remains of this star are concentrated into a very small but dense area, known as a singularity, with a very strong gravitational pull. In fact, it's so strong that everything around it, even light, gets sucked in and cannot escape, making black holes difficult, but not impossible, to detect. What astronomers haven't yet been able to detect though, are white holes. Currently just a theoretical mathematical concept, these space objects are essentially the opposite of black holes, expelling matter and light into the universe instead of sucking it in.

One theory about the formation of white holes is that they begin as their darker counterparts. Once a black hole has engulfed as much matter as it can, it may go into reverse, expelling it all back out again to become a white hole. Alternatively, some believe that white holes may be the exit of another type of space hole, the wormhole, while others have suggested that the Big Bang began as a white hole, expelling all the elements of the universe.

The fact remains though that, as yet, we have no proof of their existence. Although white holes have the potential to exist according to the theory of general relativity, it's thought that they would simply be too unstable to last for very long.

Holes in space

How might black holes and white holes work together?



Down the plug hole
Everything from matter to light falls towards the singularity because of the dent in space-time.

Singularity
The dense mass of a dying star's core is heavy enough to bend the fabric of space-time around it.

Black hole
This curvature of space-time is known as gravity, and in a black hole it is so strong that nothing can escape it.

Wormhole
Some believe that a black hole could possibly form the entrance to a wormhole.

Travel through time
The wormhole may form a tunnel through space-time.

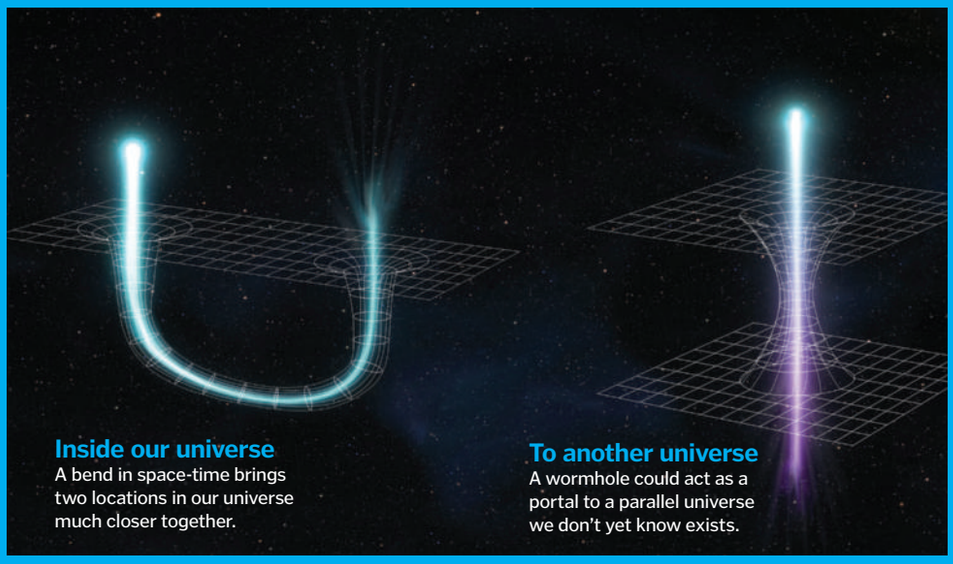
White hole
At the wormhole's exit, matter and light are thrown back out of a white hole.

Exit only
Just as nothing can escape a black hole, nothing can enter a white hole.

What are wormholes?

Also known as an Einstein-Rosen bridge, a wormhole is a tunnel that punches through the fabric of space-time, acting as a shortcut to transport matter across the universe. If you imagine the universe as a sheet of paper, bending it in half would bring the two ends closer together. Punching a hole through the paper would then provide a much quicker route from end to end than simply drawing a line across the flattened sheet.

Although only predicted by the theory of general relativity, it is thought that a wormhole would have a black hole at its mouth, sucking in matter to then transport it through the tunnel and into the past. A white hole then, could be the tunnel's exit, throwing the matter back out into the same universe, or indeed another one we don't yet know about. Theoretically, wormholes could make time travel possible, but in reality they are likely to be far too small and unstable to transport humans.



Inside our universe
A bend in space-time brings two locations in our universe much closer together.

To another universe
A wormhole could act as a portal to a parallel universe we don't yet know exists.

OSIRIS-REx

How this mission will return a chunk of asteroid to Earth

Since the final Luna mission to the Moon in 1976, we have returned less than a gram of material from another celestial body to Earth. That's quite a shocking statistic if you think about it, but in 2023, it's all set to change.

NASA's OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) will return the largest extraterrestrial sample to Earth since the Apollo missions, from an asteroid located beyond the orbit of Mars. Launched on 8 September 2016 from Cape Canaveral in Florida, OSIRIS-REx has begun its two-year journey to the asteroid Bennu, 7.2 billion kilometres from Earth.

The craft, measuring 2.4 by 2.4 metres, will arrive at Bennu in August 2018. Less than two years later, it will use a robotic arm to grab a chunk of the asteroid, anywhere from 60 grams to two kilograms in size. It will then leave the asteroid in March 2021, and return the space rock sample to Earth in September 2023.

It's a highly ambitious mission, with a huge number of unknowns. For example, this is only the second mission to try to return a sample from an asteroid. The first, Japan's Hayabusa spacecraft, ran into a number of complications following its launch in 2003, including the process of actually collecting the sample, and only just managed to limp home with a tiny selection of rocky grains on board in 2010.

Scientists will be hoping for a better turn of events this time around, with the aim of furthering our understanding of asteroids – and also perhaps preventing a deadly impact with Earth in the future.

Mission goals

The main goal of the OSIRIS-REx mission is to return a sizeable sample to Earth for study, letting us see what asteroids like Bennu are made of, where they came from, and what role they had in the early Solar System. It's possible that asteroids like Bennu brought water to Earth, and possibly the ingredients for life, too.

Bennu also has a very small chance of hitting Earth in the late 22nd century, rated at one in 2,500. Scientists will study the effect of the Sun on the asteroid, known as the Yarkovsky effect, to see if this might push it more into our path in the future and raise the chance of it hitting us.

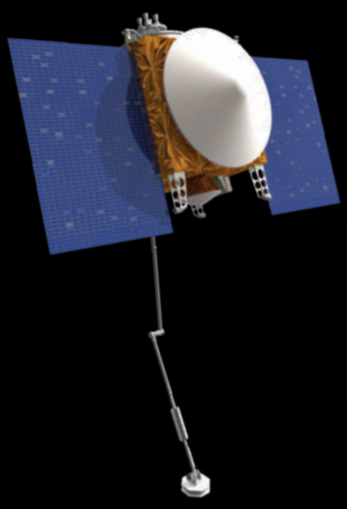
No one is quite sure what Bennu looks like yet

On board OSIRIS-REx

What instruments will the spacecraft use to study Bennu?

GN&C LIDAR
This system, standing for Guidance, Navigation and Control, will help measure the range to Bennu during sample acquisition.

TAGCAMS
Additional cameras, known as the Touch-And-Go Camera System (TAGCAMS), are able to snap extra images of the sample capture event.

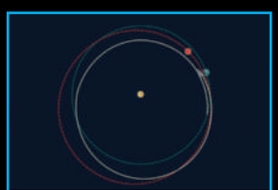


Mission timeline

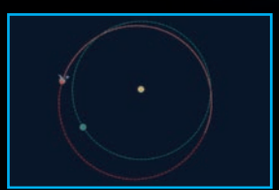
How OSIRIS-REx will travel to Bennu and return to Earth

"OSIRIS-REx will return the largest extraterrestrial sample to Earth since the Apollo missions"

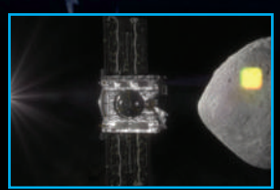
1. Launch
8 SEPTEMBER 2016
OSIRIS-REx successfully launched atop an Atlas V rocket from Cape Canaveral in Florida, and started its two-year journey to Bennu.



2. Gravity assist
23 SEPTEMBER 2017
OSIRIS-REx will swing back past Earth after a year orbiting the Sun, giving it a boost from Earth's gravitational field towards Bennu.



3. Approach
AUGUST 2018
The spacecraft will officially begin its approach to Bennu when it is 2 million kilometres away, by matching the asteroid's speed.



4. Survey
OCTOBER 2018
OSIRIS-REx will start a one-year survey of the asteroid, selecting a suitable site to collect a sample from.

SRC
The Sample Return Capsule (SRC) will use a heat shield and parachutes to safely return the sample to Earth.

OTES
The OSIRIS-REx Thermal Emission Spectrometer (OTES) will use infrared data to determine the minerals and temperature on Bennu.

Solar panels
The spacecraft's two solar panels generate between 1,226 and 3,000 watts, depending on the distance from the Sun.

OCAMS
The three cameras that are in the OSIRIS-REx Camera Suite (OCAMS) will be used to image and map Bennu, as well as record the sampling event.

REXIS
The Regolith X-ray Imaging Spectrometer (REXIS) will work out what elements are present on Bennu.

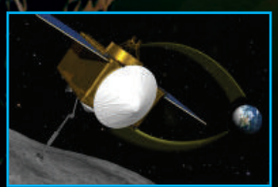
OLA
The OSIRIS-REx Laser Altimeter (OLA) will produce a 3D map of the asteroid and help pick a sample site.

OSIRIS-REx launched on 8 September 2016 from Cape Canaveral in Florida

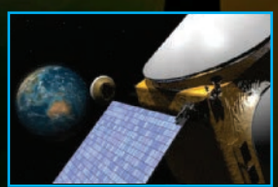
High gain antenna
This large dish is used to communicate with Earth throughout the duration of the mission.

TAGSAM
The Touch-And-Go Sample Acquisition Mechanism (TAGSAM) will be responsible for collecting the sample from Bennu's surface.

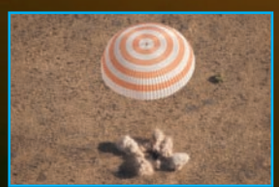
5. Sample collection
3 MARCH 2021
OSIRIS-REx will hover a few metres away from Bennu, extend a robotic arm, and fire three bursts of nitrogen gas to collect a sample.



6. Return
OCTOBER 2018
With the sample safely stowed in a capsule, OSIRIS-REx will begin its return journey back to Earth.

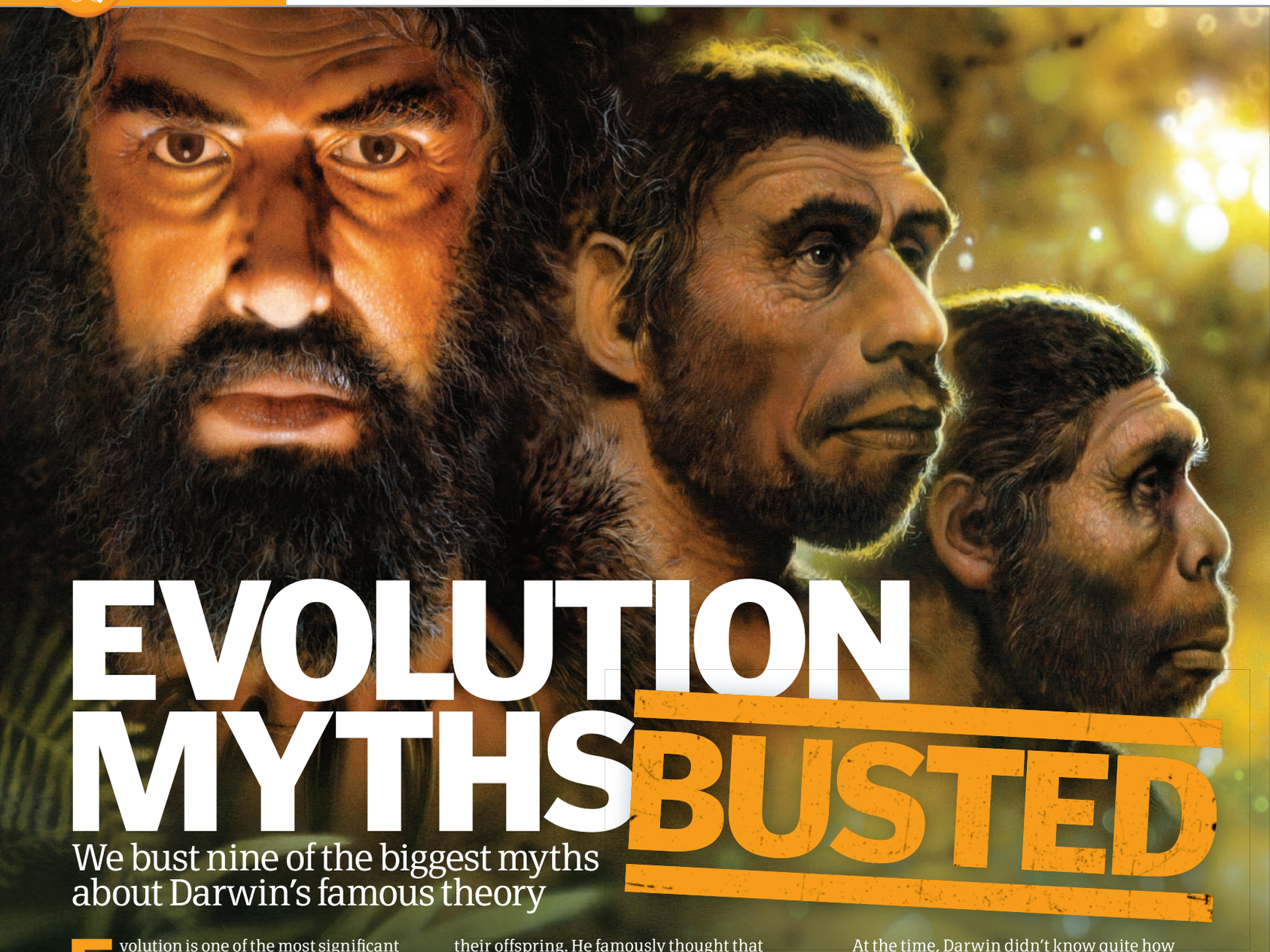


7. Ejection
24 SEPTEMBER 2023
Four hours before re-entry, OSIRIS-REx will jettison its return capsule to journey alone. The spacecraft will be manoeuvred to orbit the Sun.



8. Landing
24 SEPTEMBER 2023
The capsule will free-fall before deploying a parachute at an altitude of 3,000m, bringing it to a soft landing in the Utah desert.

9. Research
BEYOND SEPTEMBER 2023
Scientists will open the capsule, and study samples for organic compounds and clues to our own beginnings.



EVOLUTION MYTHS BUSTED

We bust nine of the biggest myths about Darwin's famous theory

Evolution is one of the most significant scientific ideas of all time. It describes how species change over time, or diverge to create more than one descendant species. It explains how humans became so brainy, why giraffes are so tall, and how bacteria can develop antibiotic resistance in just days.

The race to explain the web of life started in earnest in the 1800s. For decades, naturalists had been fascinated by the similarities between different animals, and during the 19th century, more and more ancient fossils were pulled from the ground. Earth scientists were beginning to reveal that the planet was much older than previously thought. It became clear that humans hadn't been around for all that long, and that huge animals had once lived, but were now extinct.

A naturalist called Jean-Baptiste Lamarck recognised that different species appeared to suit their environments. He proposed that they did this by adapting slowly throughout their lifetimes and then passing on these changes to their offspring. He famously thought that giraffes acquired their long necks by constantly stretching to reach the tallest trees for food, and those that stretched more would have longer-necked offspring.

Although Lamarck's theory was flawed – it did not explain how the changes happened – he made two important observations: species could gradually change to better suit their environment, and these changes were passed on to future generations.

Building on these observations and his extensive studies of plants and animals, Charles Darwin published what is now known as the theory of evolution by natural selection in 1859. He proposed that, rather than adapt during their lifetimes, organisms naturally vary slightly from their relatives, and that some have traits that help them to survive longer, and have more offspring. Those that were best adapted would be more likely to pass their traits to the next generation, and over a long time, the species would change.

At the time, Darwin didn't know quite how traits could be passed on from parent to offspring, and the theory caused a lot of controversy. However, in the decades that followed, we discovered that genes were the vehicles that passed information from one generation to the next, and that tiny changes in the genetic code provide the small variations that drive evolution. We have traced genetic trees, uncovered countless fossils, and watched evolution happening in real time both in the wild and in the lab.

Today, the theory of evolution has been expanded and developed to become one of the key pillars of biology. Yet it still causes controversy, because it remains one of the most misunderstood areas of science. How do we know it happened if there are gaps in the fossil record? Why is it called a 'theory' if scientists know it is true? And why haven't all monkeys evolved into humans? Join us as we bust the most common myths surrounding Darwin's game-changing theory.

MYTH

WE ARE DESCENDED FROM MONKEYS

So why haven't all monkeys evolved into humans?

This is perhaps one of the biggest misconceptions about evolution – that humans are descended, step-by-step, from modern monkeys or apes. It may be that the well-known 'evolution of man' image, showing a series of apes that become ever-more upright and human-like, has helped to spread this myth.

First, we should be absolutely clear that monkeys and apes are not the same thing. Modern monkeys are divided into New World and Old World monkeys, both of which are separate groups of species to apes. The apes are then divided again into lesser apes (gibbons) and great apes – which include humans. So we certainly aren't descended from monkeys, but what about apes?

We share many traits with the other great apes – chimpanzees, orangutans, bonobos and gorillas – and they are our closest living relatives. But they're not our ancestors either. Each of the great apes, including humans, evolved independently from a 'common ancestor'.

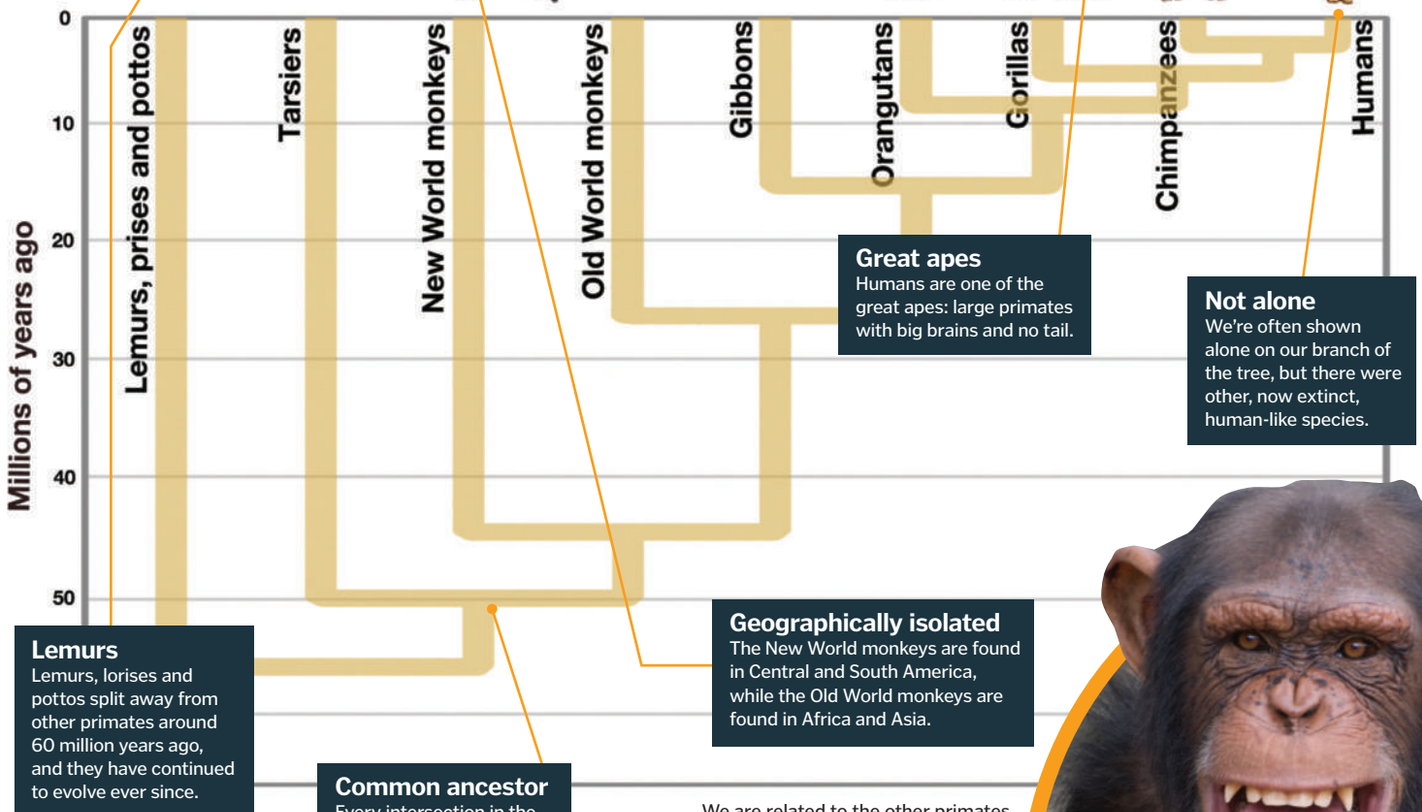
If you trace human fossils back, they gradually become more and more ape-like, with bigger teeth, smaller brains, and stockier limbs. And if you trace chimpanzees back, they become more like that common ancestor too. If you go back millions of years, the evolutionary history of humans and chimpanzees eventually converges, and you find that we share a relative that was a different species entirely – our common ancestor.

Every intersection in an evolutionary tree, like the one below, represents a common ancestor. If you trace back even further, you will eventually find a common ancestor between apes and monkeys, between all primates, between all animals and so on. Each of the branches of the evolutionary tree continues to evolve, producing new species of all sizes, shapes and colours.

"Each of the great apes, including humans, evolved independently from a common ancestor"

Primate family tree

We are not descended from chimps or modern monkeys, but they are our closest living relatives



Extinctions
There used to be tarsiers across the world, but now there are only ten species left, all in Asia.

Closest relatives
We are most closely related to chimpanzees and bonobos.

Great apes
Humans are one of the great apes: large primates with big brains and no tail.

Not alone
We're often shown alone on our branch of the tree, but there were other, now extinct, human-like species.

Lemurs
Lemurs, lorises and pottos split away from other primates around 60 million years ago, and they have continued to evolve ever since.

Geographically isolated
The New World monkeys are found in Central and South America, while the Old World monkeys are found in Africa and Asia.

Common ancestor
Every intersection in the tree represents a common ancestor – a species that diverged to form two or more new species.

We are related to the other primates, but not descended from them

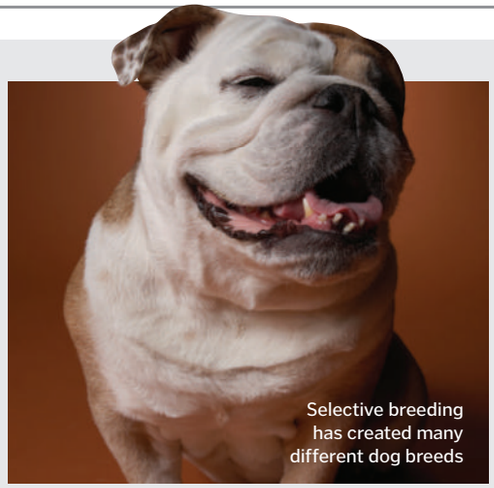
MYTH YOU CAN'T TEST EVOLUTION

It happens so slowly that it's impossible to prove

Evolution usually happens over millions of years, and even in several human lifetimes we can't hope to see anything as dramatic as dinosaurs evolving into birds. The trouble with tracking evolution is that genetic changes have to be passed on for many generations before the effects become obvious. If animals live a long time, it's hard to watch them evolve before our eyes. But that doesn't mean that we can't see evolution happening in real time.

During the Industrial Revolution, Britain went through a rapid period of environmental change. Factories churned out soot, and it coated the trees. Peppered moths had previously used birch trees for camouflage, and it was an advantage to be pale, because dark moths stood out against the bark and were quickly spotted and eaten by birds. But, once the soot came, being darker became an advantage. Quickly, the number of darker moths in the population grew as they survived and passed on their useful genetic trait.

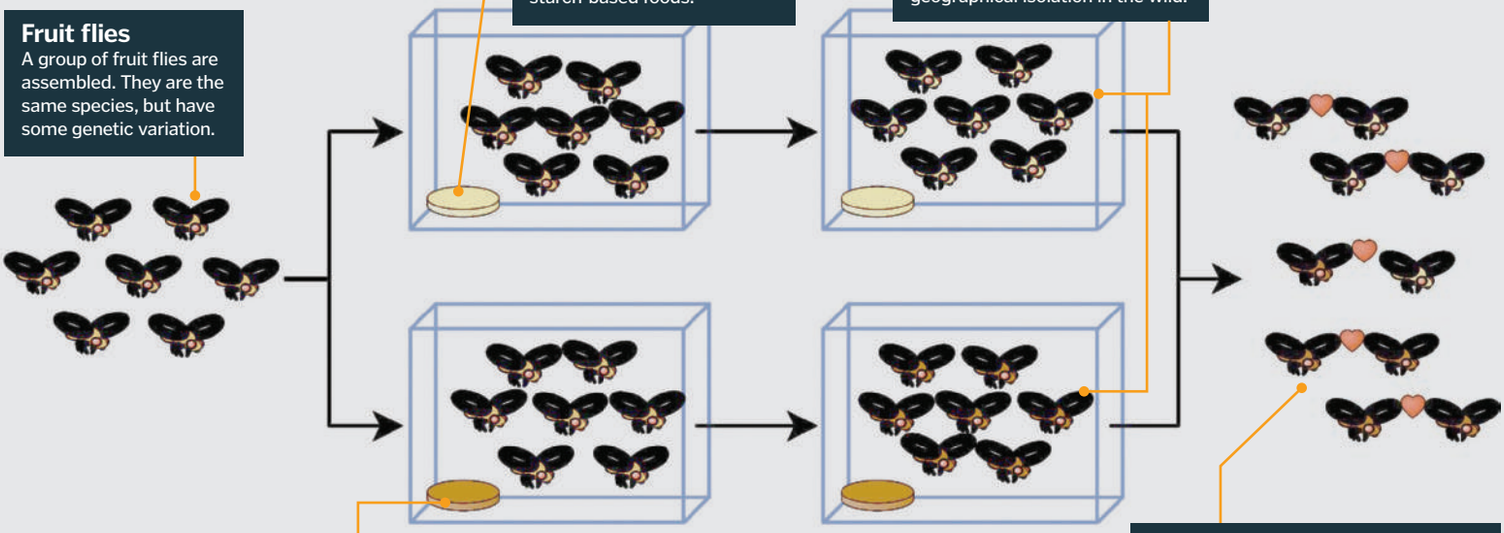
And if you want an example in your own back garden; we have been simulating evolution with dogs for centuries. We choose which traits we like, and only breed the dogs that have them: hounds have been selected for scent and sight, herding dogs were bred for double coats that shield them from the weather, and bulldogs were favoured for their flattened faces. This man-made doggy evolution is still happening today, and you only have to look at the emerging health problems with pure breeds to see the effects in action.



Selective breeding has created many different dog breeds

Evolution in action

Insects and microbes reproduce so fast that it's easy to see them evolving in the lab



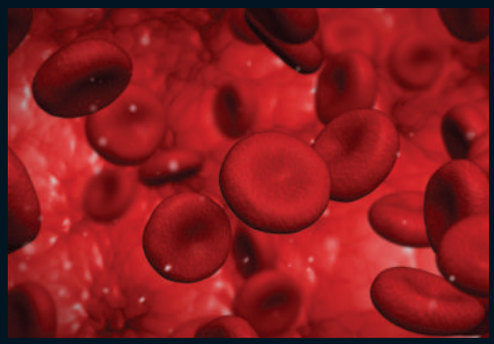
> "Evolution has no goal at all, and the results are far from perfect"

MYTH EVERYTHING IS AN ADAPTATION

All traits have an evolutionary purpose

It's tempting to imagine that there is a story behind every trait, but not everything is an adaptation. Much of what you see today happened by chance or as a side effect of something else that turned out to be useful. Others are just remnants of traits that used to be useful, but are not really needed any more. Evolution often involves trade-offs and compromises, and it is constrained by the adaptations that an organism already has.

Chance mutations
Many traits don't have an obvious reason or advantage, and aren't an adaptation. For example, around 25 per cent of the population are 'supertasters', with far more taste buds than others.



Side effects
Some traits are side effects of others. The colour of our blood isn't an adaptation; instead, it is a side effect of the molecule that transports oxygen – haemoglobin just happens to be red.

MYTH EVOLUTION EXPLAINS THE ORIGINS OF LIFE

If evolution explains how life has changed, surely it should explain how it all began

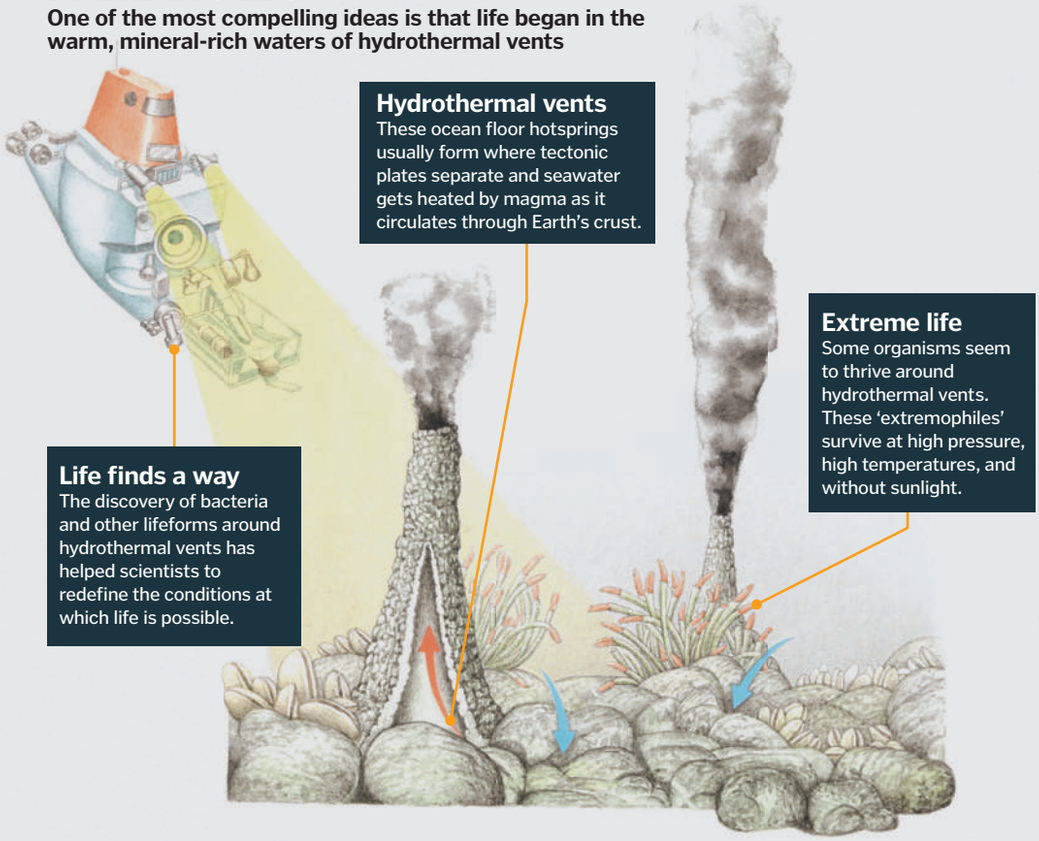
Evolution can tell us a lot about why life is the way it is, and how life changes and adapts over time, but it doesn't claim to explain how it started.

Evolution has already taken us back as far as LUCA: the Last Universal Common Ancestor. This is the organism from which all life on Earth evolved. Using gene tracking, and comparing the genes of organisms in the two most ancient branches of the tree of life (archaea and bacteria), it is estimated that LUCA lived around 3.8 billion years ago, and had at least 100 genes.

The science of evolution can give us clues about what would have been needed for life to begin, but this puzzle has not yet been solved, and is currently being tackled by a range of scientists working across biology, chemistry and the Earth sciences. But, however life began, evolution explains what happened next.

Primitive life

One of the most compelling ideas is that life began in the warm, mineral-rich waters of hydrothermal vents



Hydrothermal vents
These ocean floor hotsprings usually form where tectonic plates separate and seawater gets heated by magma as it circulates through Earth's crust.

Extreme life
Some organisms seem to thrive around hydrothermal vents. These 'extremophiles' survive at high pressure, high temperatures, and without sunlight.

Life finds a way
The discovery of bacteria and other lifeforms around hydrothermal vents has helped scientists to redefine the conditions at which life is possible.

Multipurpose genes
Many genes have more than one function (known as pleiotropy). For example, these curly-feathered chickens have one gene change that affects their digestion, body temperature and egg laying, as well as their feathers.

Vestigial traits
Some traits are left over from our ancestors, and are no longer useful. Take our wisdom teeth; they were useful when our jaws were bigger and diets tougher, but now they're often just a nuisance.

MYTH EVERYTHING HAPPENS FOR A REASON

Evolution has an ultimate goal and is trying to solve a problem

The way we talk about evolution can make it seem as though organisms are trying to evolve to be better, faster or stronger than the rest. In truth, evolution has no goal at all, and the results are far from perfect.

Evolution is ultimately driven by genetic mutations, which happen fairly randomly. Some of these variations help organisms to survive a little bit longer or have more offspring, and these useful genes are passed on to the next generation. Others make life a little harder.

The environment and conditions that organisms find themselves in dictate which of these random mutations will be useful and which won't. This could be down to the climate, predators, food availability or attractiveness to a mate, but however the traits are selected, they make gradual changes over time with no end-goal in sight.

Evolution works by trial and error, and the end results aren't always as polished as they could be. For example, the human eye has a serious flaw. The blood vessels and nerves actually run in front of the light-detecting cells, and have to travel through the back of the eye to get to the brain. This creates a blind spot. It is a step-by-step process that has led to our eyes evolving, but it certainly isn't the 'best' way things could have been arranged.

Organisms don't want, try or need to evolve, they just do – and the results are both amazing and unpredictable.

MYTH THE EYE IS TOO COMPLEX TO HAVE EVOLVED

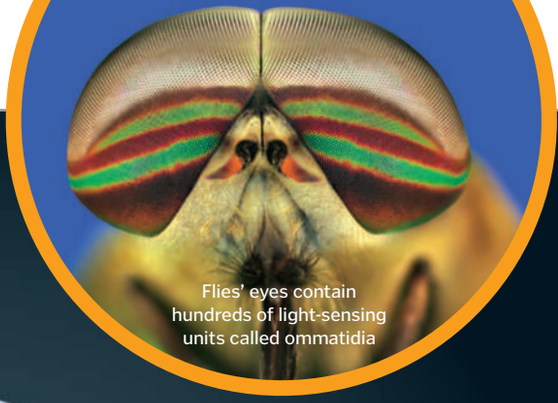
Half an eye is no use, so how could these intricate visual machines have developed?

Even Darwin had trouble imagining that eyes were the product of evolution, but if you take it step by step, it starts to make sense.

At the simplest level, eyes are spots or patches of pigments that respond to sunlight. If these pigments are on a flat surface, they just sense light and dark, but if they become dipped down into pits, they can be used to tell which direction the light is coming from.

Then, if these pits become a little deeper, and the opening starts to close over, it forms the equivalent of a pinhole camera, restricting the light coming in and producing actual images. If that pinhole then becomes covered by a layer of transparent cells, the pit can fill with fluid, allowing a lens to start to form from crystals inside. This lens helps with focusing, making the images even sharper.

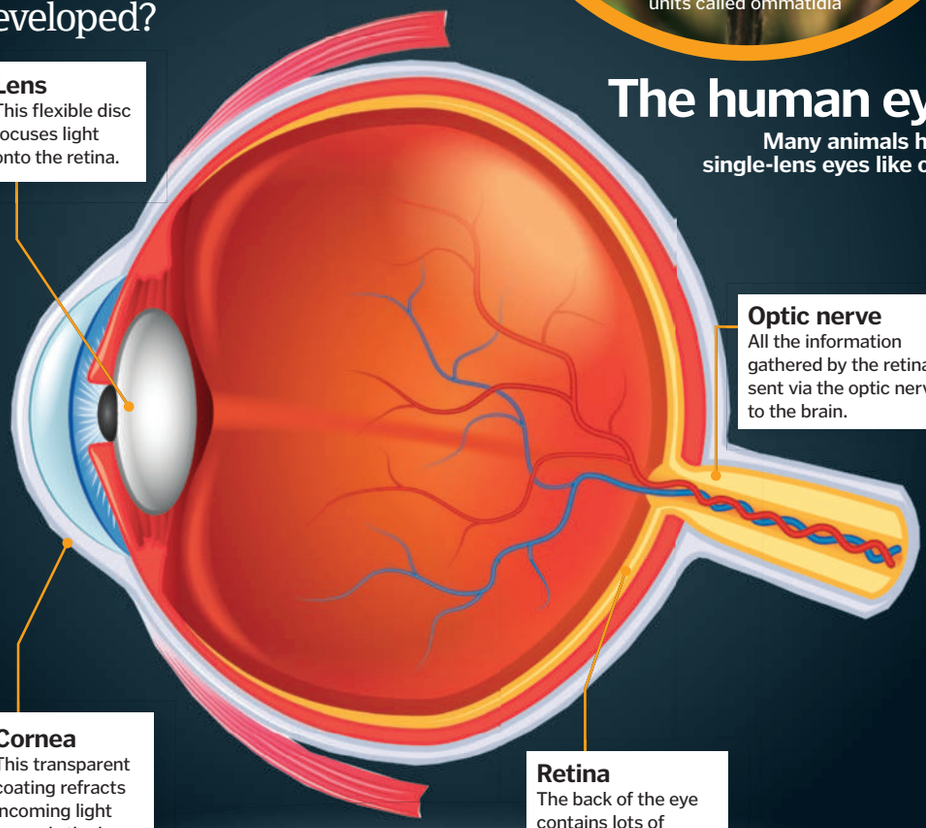
Each of these small adaptations may give an organism a slight advantage in its environment, such as being able to hunt more effectively or spot predators from further away. Over many generations, the adaptation is selected for, and the eye shape of the species gradually changes.



Flies' eyes contain hundreds of light-sensing units called ommatidia

The human eye

Many animals have single-lens eyes like ours



Lens
This flexible disc focuses light onto the retina.

Optic nerve
All the information gathered by the retina is sent via the optic nerve to the brain.

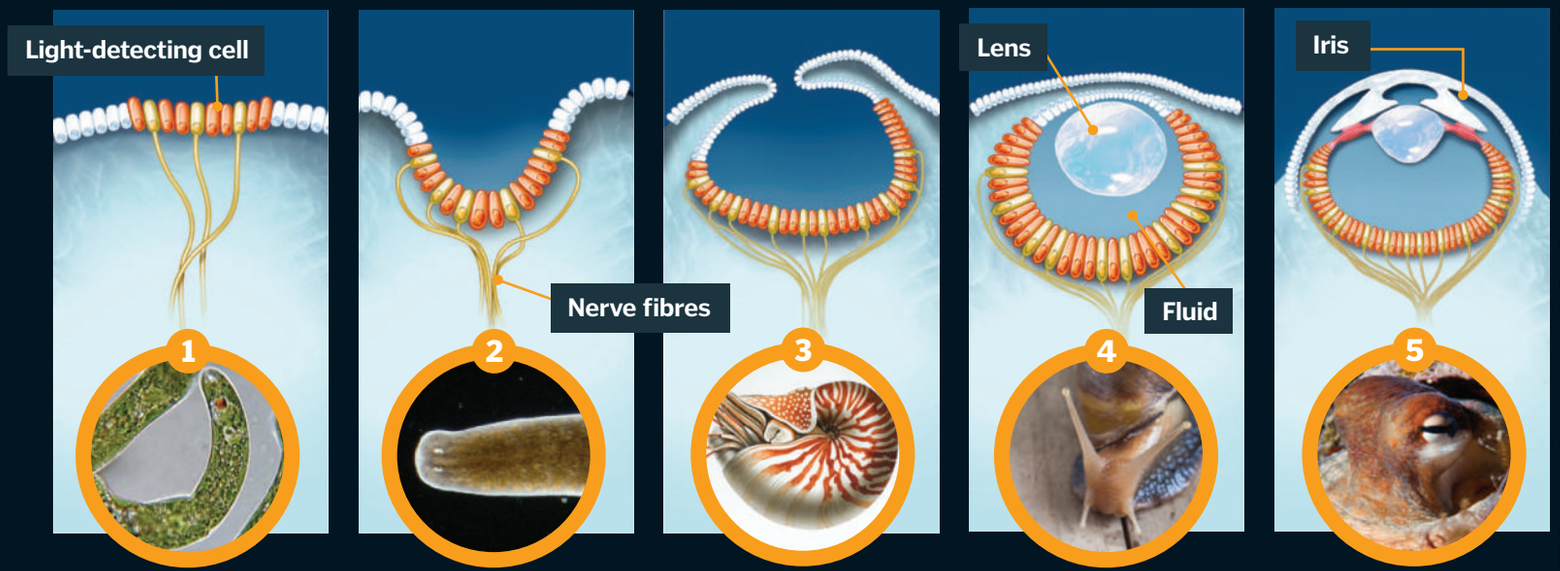
Cornea
This transparent coating refracts incoming light towards the lens.

Retina
The back of the eye contains lots of light-sensitive cells.

Increasing complexity

If you look closely, simple versions of the human eye exist in the natural world

"Those with the most useful adaptations are more likely to survive and breed"



1 Spot
Single-celled organisms called Euglena have 'eyespots' containing light-sensitive pigments, which help them to detect light and dark.

2 Cup
Flatworms have spots of pigment that are buried inside cups, helping them to determine which direction the light is coming from.

3 Pinhole camera
Deeper cups with a slightly closed opening form the equivalent of a pinhole camera, allowing animals like the nautilus to see images.

4 Lens
Transparent cells cover the opening at the front of the eye, and a simple lens structure forms inside. Snails have eyes like this.

5 Complex camera
Over time, tiny improvements gradually add up to the complex camera eyes that organisms such as octopuses and humans have today.

MYTH

AREN'T THERE GAPS IN THE FOSSIL RECORD?

Missing links in fossils must disprove evolution

It would be nice if we could see neat historical lines that traced the evolution of modern species step by step, but fossils are very rare. Of all of the mammal species that are currently in danger of extinction, we only know of fossils for nine per cent of them. In the future, if we were to look back, it would be like the rest never existed at all.

Fossils don't form very often. Even for those animals with the right body type, fossil formation is very dependent on how, and where, they die. In jungles, for example, other organisms quickly devour the dead, removing all traces of their bodies. Because of this, gaps in the fossil record are inevitable.

However, new fossils are being found all the time, and many 'transitional' species have been identified that do provide support for evolutionary theory. Take the horse, for instance. Today's horses have one toe, but they evolved from dog-sized ancestors with multi-toed feet. The fossil record shows several intermediate steps, showing how toes were lost, shortened and combined to form the familiar hoof that we see today.

Archaeopteryx shows the link between dinosaurs and birds, with key features of both

MYTH

NATURAL SELECTION DRIVES ALL EVOLUTION

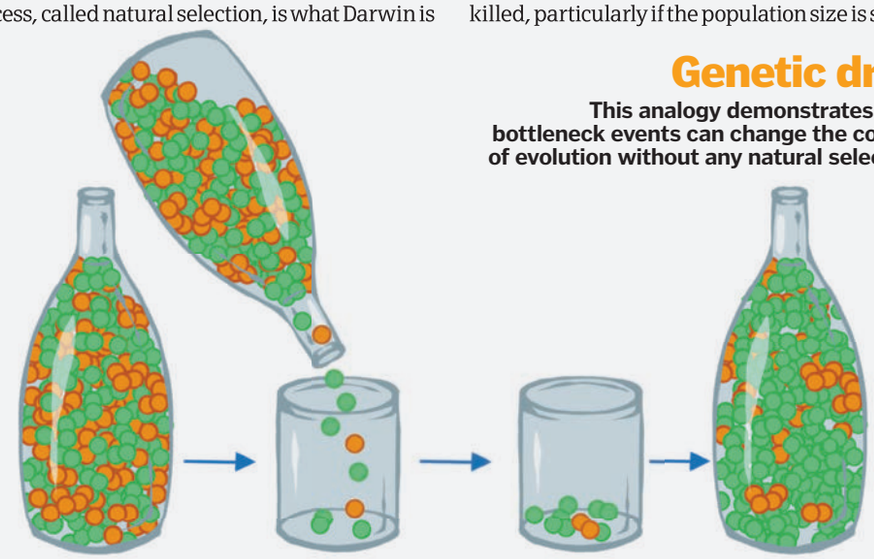
Is survival of the fittest the only way that evolution happens?

Random mutations of genes can make some individuals slightly different to others, creating genetic variation. Predators, competition and other environmental factors can put pressure on organisms, and those with the most useful adaptations are more likely to survive and breed, passing on their genes to their offspring. This process, called natural selection, is what Darwin is famous for describing, but it isn't the only way that evolution can occur.

Another important mechanism is called genetic drift. Here, rather than traits being selected for, they are lost or become more common due to a random event. This can happen if populations become separated, or if some individuals are killed, particularly if the population size is small.

Genetic drift

This analogy demonstrates how bottleneck events can change the course of evolution without any natural selection



1. Original population
To start with, this population is mixed, with orange and green individuals in roughly equal proportions.

2. Bottleneck
A random event happens, such as a natural disaster, causing the population size to decrease dramatically.

3. Remaining population
Now, there are more green individuals than orange; the gene pool has changed by chance.

4. New population
As the remaining population breeds, the genes are passed on, creating a new population where green is much more common. In time, orange could be lost altogether.

MYTH

EVOLUTION IS 'JUST' A THEORY

We don't know for certain that evolution occurs

This one is hard to argue with, given that the word 'theory' is right there in its title, but the real problem is the word 'just'. In science, there's no such thing as 'just' a theory.

In general conversation, the word 'theory' is used interchangeably with words like 'hunch', 'speculation' and 'belief'. It's a fuzzy way to indicate that you think something might be true, but you don't have all of the evidence to back it up. This is not the case in science.

A scientific theory is based on a vast body of evidence. There are many well-established principles of science, including evolution, that are centred around theories – for instance, that Earth orbits the Sun (heliocentric theory) and that living things are made of cells (cell theory). They provide a comprehensive explanation of what we see, and can be used to predict what might happen in the future.

The evidence for evolution is compelling, and the theory has been confirmed repeatedly in different ways. The fossil record, though incomplete, demonstrates the progression of organisms over time. This is supported by the physical, chemical and genetic similarities between living things. And there are plenty of real-life examples out there of organisms visibly changing over several generations.

Evidence of evolution is written all over our DNA

The more evidence scientists find, the more they reinforce Darwin's ideas. Evolution is not 'just' a theory, because in science, a theory is one of the strongest and most compelling arguments that can be made.

Decongestants can be found in nasal sprays as well as cold and flu relief tablets

Sinus-pressure relief
Decongestants can also be used to relieve symptoms of sinus infections.

Direct delivery
Many decongestants are available as nasal sprays to provide faster relief at the source of stuffiness.

Breathing easy
Chemicals in the decongestant help to reduce swelling in your nasal passages.

How decongestant medicines work

The chemicals that combat the common cold by clearing a blocked nose

We've all had the unpleasant experience of suffering from a blocked nose that remains uncomfortably stuffy. This is one of the biggest frustrations of the common cold, but contrary to popular belief, a blocked nose is not the result of mucus. Instead, it is due to the swelling of tissues and blood vessels found in the nasal lining and sinuses, which expand and obstruct our airways.

Fortunately, decongestants can come to the rescue by providing relief from these symptoms. They contain chemicals that bind to receptors found in the nose and sinuses and cause vasoconstriction – a process where the muscles in the walls of the blood vessels contract. This reduces the size of blood vessels and so counteracts the cause of the blockage by reducing swelling.

As well as causing the contraction of blood vessels, a decongestant called pseudoephedrine is also capable of relaxing smooth muscle tissue in the airways, so you can breathe even easier.

The blood-brain barrier

This biological wall keeps your brain safe and secure

Your brain is arguably your most important organ, and it is vital that it isn't affected by wayward chemicals or aggressive infections. To keep your nerve cells safe, your body builds a biological wall called the blood-brain barrier.

Blood vessels are the highway of the human body, carrying nutrients and oxygen to tissues, and taking away waste products, but unfortunately, they can also transport harmful chemicals and infections. In most parts of the body, chemicals are able to freely cross through the walls of the blood vessels, leaking between the cells and out into the tissues, but thankfully this does not occur in the brain.

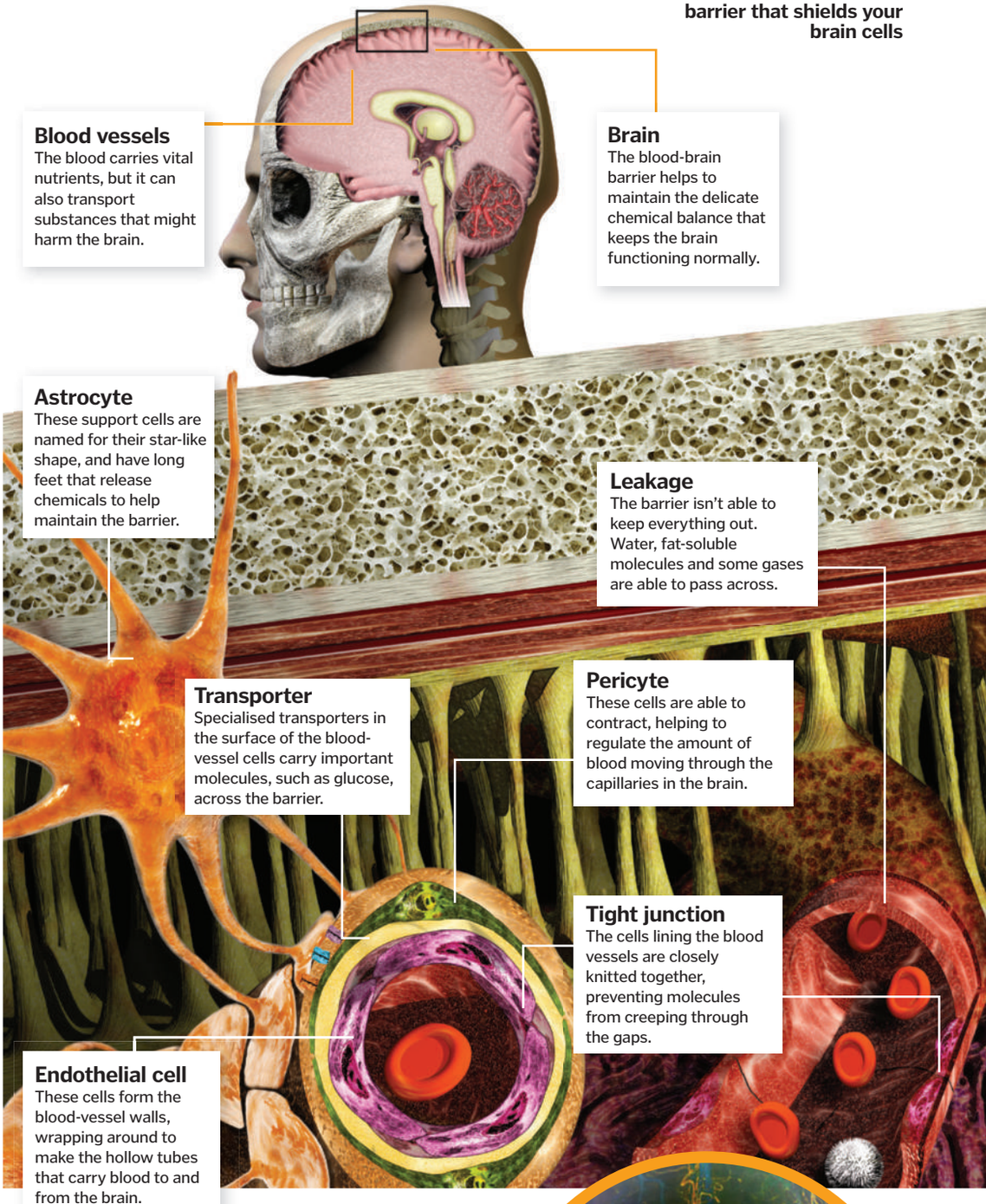
To prevent unwanted contaminants from entering, the cells lining the blood vessels are closely knitted together by structures called 'tight junctions'. Web-like strands pin the membrane of one cell to the membrane of the next, forming a seal that prevents any leakage through the cracks.

Wrapped around these cells are pericytes, which are cells that have the ability to contract like muscle, controlling the amount of blood that passes through the vessels. Just outside the pericytes, a third cell type, the astrocytes, send out long feet that produce chemicals to help maintain the barrier.

Some large molecules, like hormones, do need to get in and out of the brain, and there are areas where the barrier is weaker to allow these to pass through. One such region, called the 'area postrema', is particularly important for sensing toxins. It is also known as the 'vomiting centre', and you can probably guess what happens when that is activated!

Protecting the brain

Take a closer look at the barrier that shields your brain cells



Blood vessels
The blood carries vital nutrients, but it can also transport substances that might harm the brain.

Brain
The blood-brain barrier helps to maintain the delicate chemical balance that keeps the brain functioning normally.

Astrocyte
These support cells are named for their star-like shape, and have long feet that release chemicals to help maintain the barrier.

Leakage
The barrier isn't able to keep everything out. Water, fat-soluble molecules and some gases are able to pass across.

Transporter
Specialised transporters in the surface of the blood-vessel cells carry important molecules, such as glucose, across the barrier.

Pericyte
These cells are able to contract, helping to regulate the amount of blood moving through the capillaries in the brain.

Tight junction
The cells lining the blood vessels are closely knitted together, preventing molecules from creeping through the gaps.

Endothelial cell
These cells form the blood-vessel walls, wrapping around to make the hollow tubes that carry blood to and from the brain.

Crossing the barrier

If nothing could cross the blood-brain barrier, your brain cells would quickly die. In fact, water and some gases pass through easily, and the cells are able to take up important molecules, such as sugars, and pass them across. Molecules that dissolve in fat can also slip through, allowing chemicals like nicotine and alcohol to easily pass into the brain. There is a problem, though. Most medicines are too big or too highly charged to cross over, and if a patient has a neurological condition like depression or dementia, treating the brain directly is a real challenge. Researchers are working on ways to breach the barrier, including delivering treatments directly into the fluid around the brain, disrupting the barrier by making the blood vessels leaky, and even designing Trojan horse molecules to sneak treatments across.


Sizewell B is the only nuclear power plant in the UK to use a pressurised water reactor

Inside a nuclear reactor

How do we generate electricity by splitting atoms?

The power of nuclear fission was first fully realised during World War Two with the invention of the devastating atomic bomb. It was only after the war, when the world had witnessed this incredible release of energy, that attentions were turned to harnessing nuclear reactions as a power source.

Today, nuclear energy is used to power all manner of things from submarines to space probes. Even our homes are partly nuclear-powered, as roughly 20 per cent of electricity in the UK and the US is provided by nuclear stations.

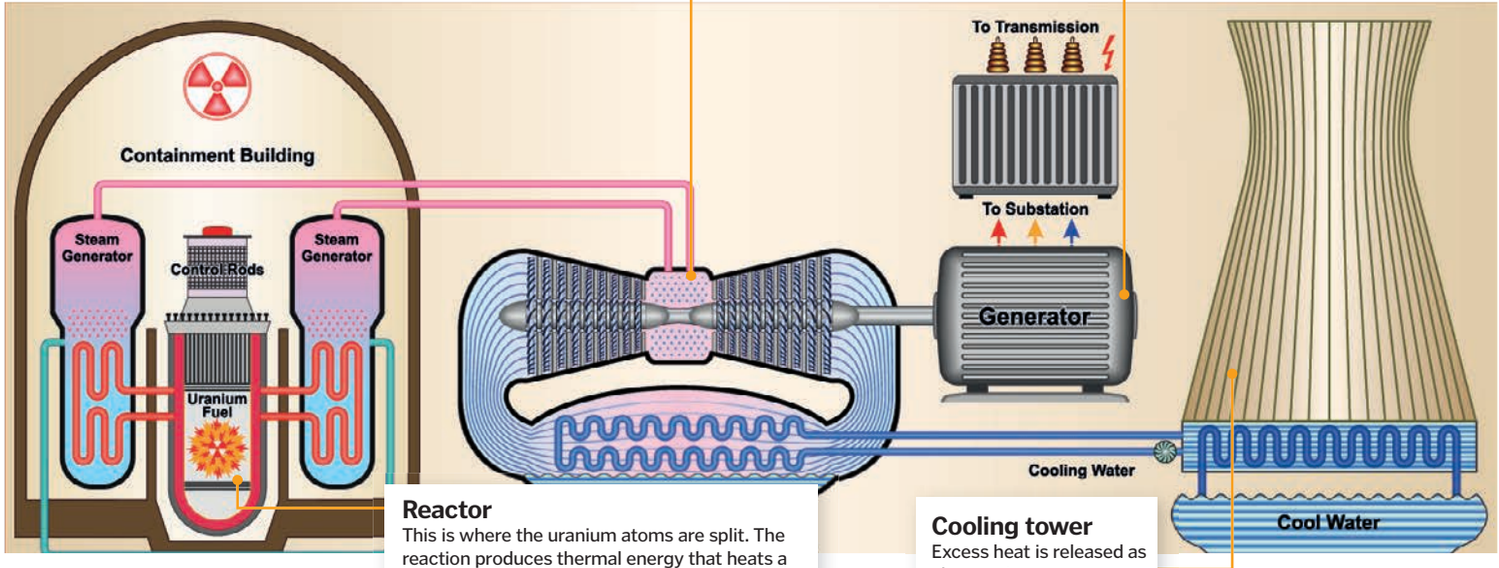
Like most other means of generating electricity, nuclear power plants use heat energy to produce steam that spins turbines. This is a very similar process to burning fossil fuels, currently our main method of producing electricity, but it generates only a fraction of the greenhouse gas emissions.

The fuel used in nuclear power plants is an unstable form of uranium, which releases heat energy when the atom is split in two. In a controlled environment like those found in power plants, this heat can be harvested for efficient energy production. Many people still have concerns about nuclear power due to the radioactive waste that is produced and the potential for devastating accidents – such as the disasters at Chernobyl in 1986 and Fukushima in 2011.

Modern designs of these plants, however, have safety measures in place that limit exposure of radioactive particles to external materials. New techniques to recycle the radioactive waste are also being developed, which is leading some top scientists to now consider nuclear fission as one of the greenest methods of generating electricity.

How a nuclear power plant works

How do we turn nuclear energy into electricity?



Turbine
The steam produced by the heat of the reaction spins a turbine.

Electricity
Generators transform the kinetic energy of the spinning turbines into electricity.

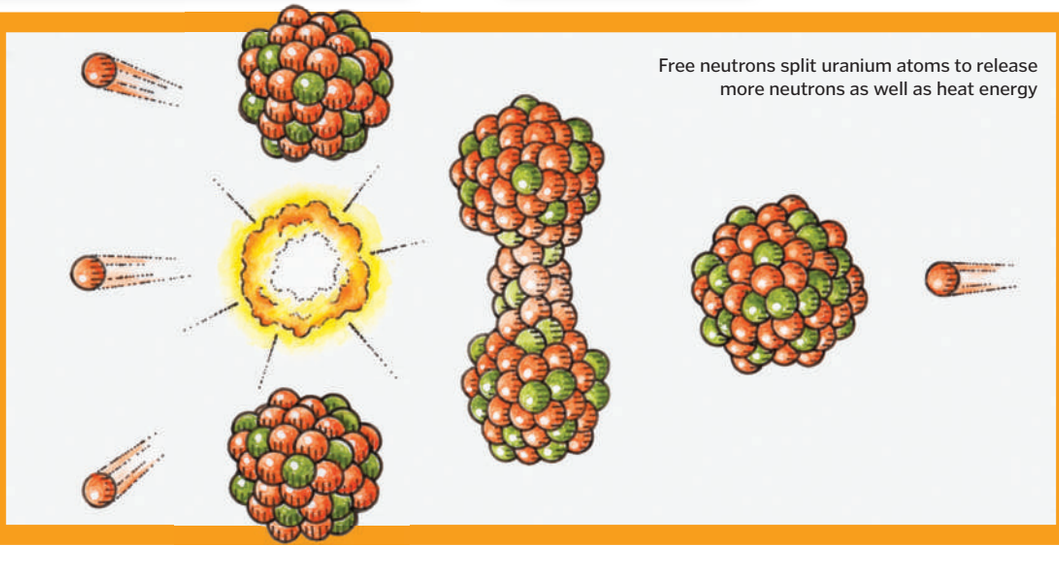
Reactor
This is where the uranium atoms are split. The reaction produces thermal energy that heats a coolant (typically water) in the steam generator.

Cooling tower
Excess heat is released as clean water vapour.

Fission explained

An atom is comprised of a nucleus, formed of neutrons and protons, with electrons orbiting around it. When atoms are split into two or more pieces, we refer to it as fission.

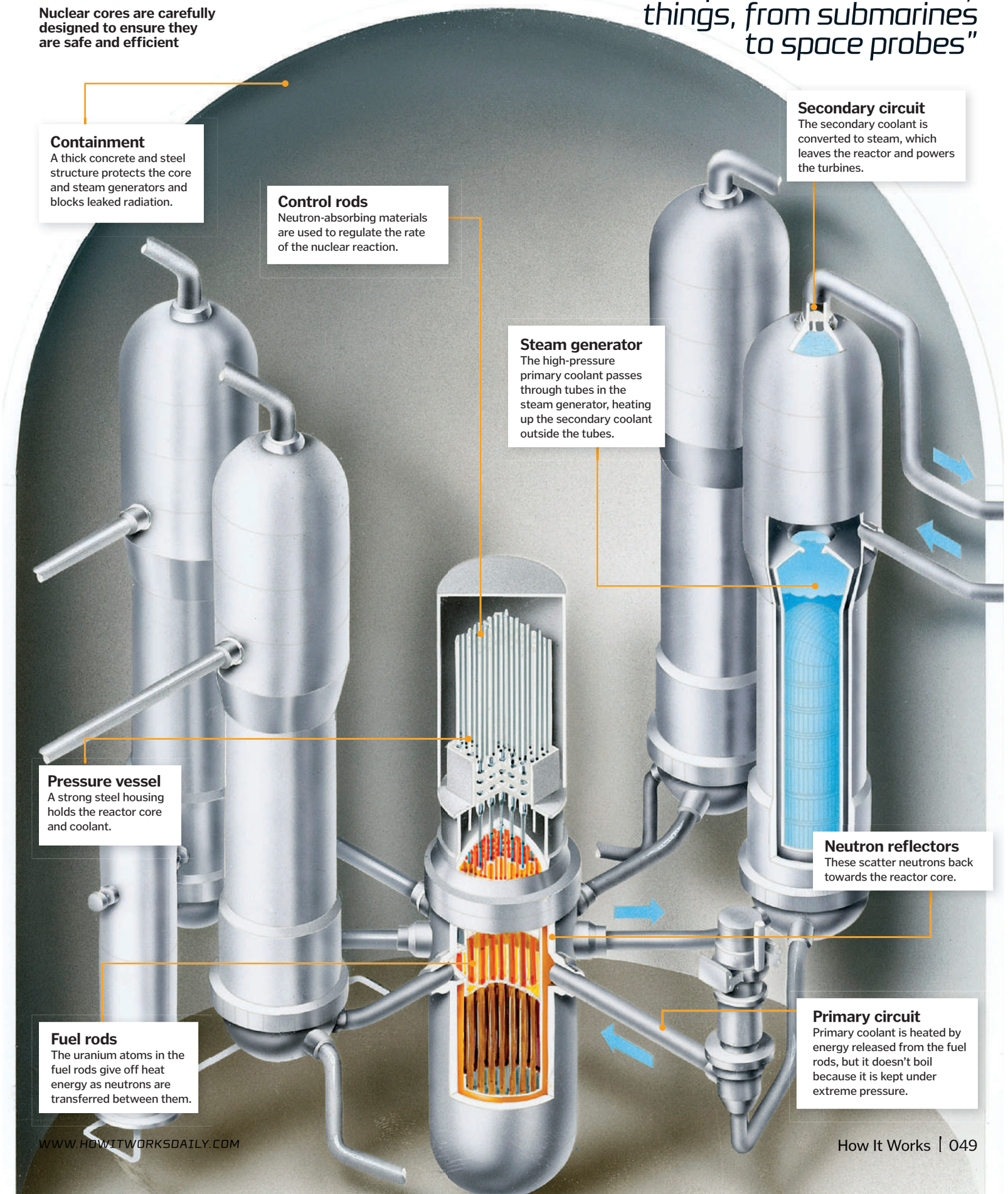
In nuclear fission, the nuclei of uranium atoms are split when they collide with a free neutron. This causes the nucleus to divide and form two separate atoms, releasing energy and more neutrons in the process. These neutrons then collide with other uranium atoms and the result is a chain reaction – neutrons and energy are continuously released until the fuel source is exhausted.


Free neutrons split uranium atoms to release more neutrons as well as heat energy

How the reactor works

Nuclear cores are carefully designed to ensure they are safe and efficient

"Nuclear energy is used to power all manner of things, from submarines to space probes"



Containment
A thick concrete and steel structure protects the core and steam generators and blocks leaked radiation.

Control rods
Neutron-absorbing materials are used to regulate the rate of the nuclear reaction.

Secondary circuit
The secondary coolant is converted to steam, which leaves the reactor and powers the turbines.

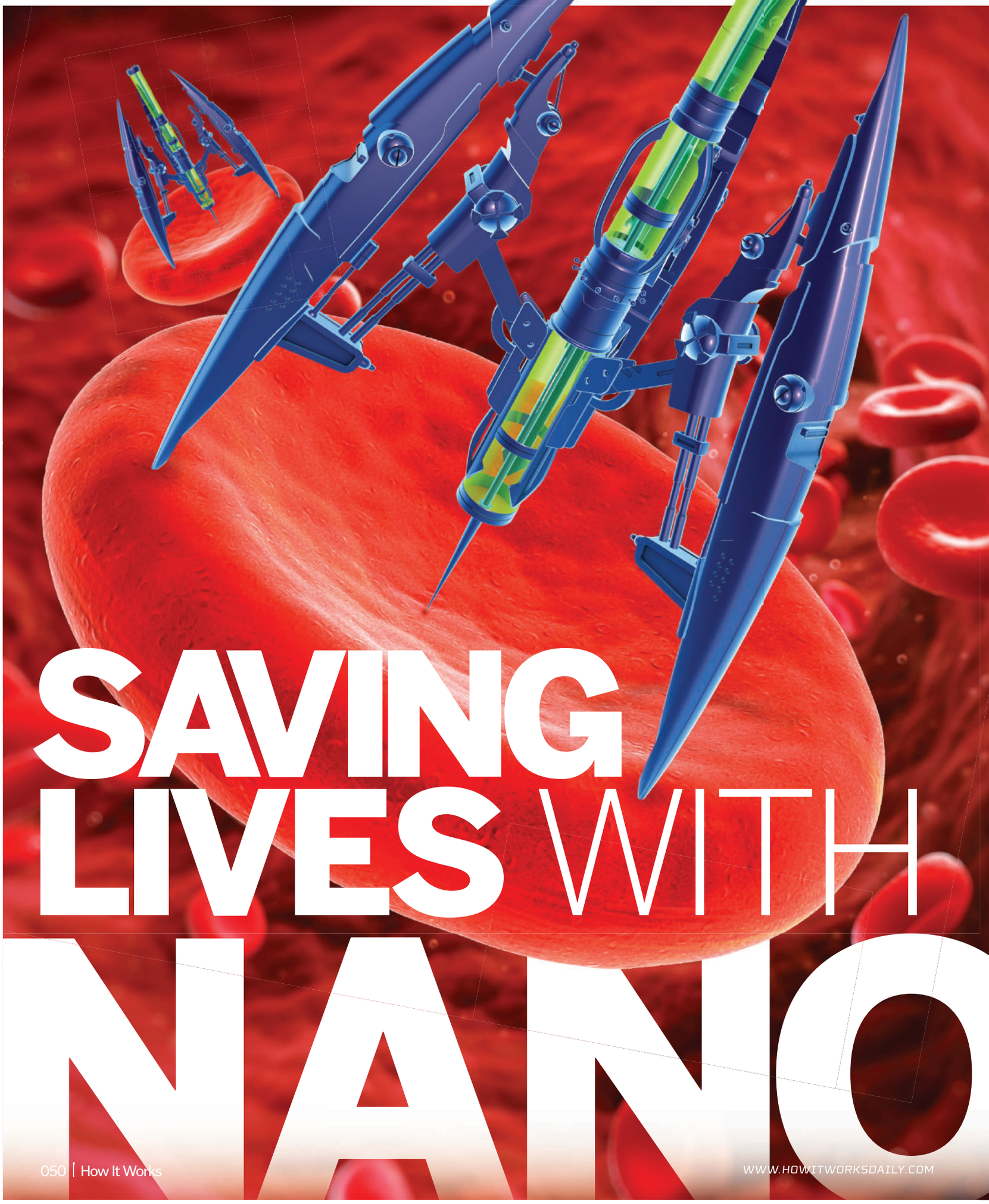
Steam generator
The high-pressure primary coolant passes through tubes in the steam generator, heating up the secondary coolant outside the tubes.

Pressure vessel
A strong steel housing holds the reactor core and coolant.

Neutron reflectors
These scatter neutrons back towards the reactor core.

Fuel rods
The uranium atoms in the fuel rods give off heat energy as neutrons are transferred between them.

Primary circuit
Primary coolant is heated by energy released from the fuel rods, but it doesn't boil because it is kept under extreme pressure.



SAVING LIVES WITH NANO

MEET THE MINUSCULE MEDICS THAT COULD CONQUER INCURABLE DISEASE

What if we could control entire systems on the molecular level? What if inside your cells you had millions of helpers; tiny guardians tasked with clearing toxins from your body and keeping you in tip-top condition, removing pathogens before they have a chance to cause harm? This is one of the main goals of nanotechnology – an advanced field championed by scientists, engineers and mathematicians who are busy developing machines that would fit inside the eye of a needle.

It may seem truly exceptional and perhaps impossible, but all living organisms rely on machines such as these. Some species of bacteria, for example, propel themselves along using a spinning tail called a flagellum, which is powered by a rotating motor built from a ring of proteins. This operates in much the same way as the mechanical variants we use in industry, but just on a much smaller scale. Our own cells are also filled with dedicated machinery known as organelles that are responsible for certain jobs including the assembly, packaging and transport of materials inside and outside of the cell. The ribosome is one such example of a complex machine that fits nicely inside a cell, where it efficiently assembles proteins from genetic code. So our bodies are already packed with natural nanotech, but now the goal is to manufacture the artificial kind.

Synthetic structures are identified as pieces of nanotechnology when they range in size from one to 100 nanometres, so even at their largest they're 5,000 times smaller than this full stop. They're incredibly small pieces of tech! Nanotechnology has a wide range of potential applications, particularly in medicine, where nanomachines

What could nanomedicine do for us?

A dedicated task force of tiny structures could repair and improve our bodies

Youthful appearance
Wrinkles could be prevented by nanoparticles that penetrate deep into the skin, transporting compounds to make skin smoother and plumper.

Enhanced dental implants
Titanium dioxide nanotubes loaded with silver nanoparticles could surround implant material to improve adhesion to the bone and protect against infection.

Connected
Nanobots swimming in the capillaries of our brains could allow our thoughts and emotions to be uploaded to cloud servers.

Glaucoma treatment
Contact lenses containing nanoparticles could periodically release beneficial drugs when placed onto the eye, helping to manage symptoms.

Heart repair
Nanoparticles coated with sticky proteins could escort therapeutic drugs to damaged arteries, repairing the elastic walls.

Improved oxygen supply
Mechanical red blood cells known as respirocytes could carry additional oxygen around the body to improve physical performance.

Bone regeneration
Nanostructures could act as scaffolds to support bone repair after injury.

Antiviral
Viral infections could be kept at bay by nanoparticles that bind to viruses and stop them from spreading.

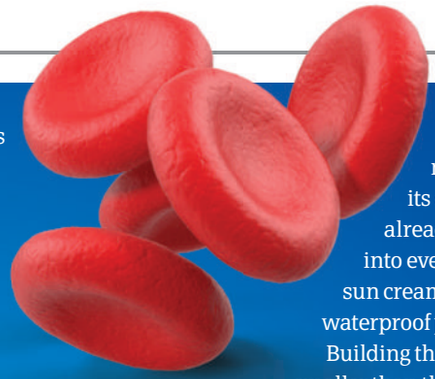
Cancer targeting
Cancer-fighting drugs could be guided to tumours by nanoparticles capable of recognising the cancerous cells.

Biocapsules
Carbon nanotubes packed with insulin-producing cells could be inserted under the skin, and the contents would be released when blood sugar levels were high.

could move freely through our vessels to support and repair our cells and tissues. While the idea of these mini-medics is theoretical for now, drugs involving nanoparticles are currently being used to treat certain diseases.

Nanomedicine could also join the fight against cancer. Already in labs across the world, scientists have started to develop pieces of nanotech capable of identifying cancer in its early stages, just by testing a small amount of blood or saliva. Once perfected, this could be a huge milestone in diagnosing a disease that is currently very difficult to notice before tumours have grown. Even if these reporters are not used in time then nanoparticles could come to save the day, having also been used as homing missiles to deliver chemotherapy drugs directly to cancer cells.

New methods of fighting disease are an exciting prospect, but nanotechnology promises even more. Currently incurable disorders like degenerated and severed neurons that lead to paralysis could be healed with nanostructures in the future, and researchers plan to use nanomachines to patrol the cells and systems of our bodies to prevent diseases before they have the chance to cause damage. These envisioned nanobots could be remote-controlled externally or left to roam the body freely. We will even be able to equip them with minuscule arms for clearing unwanted molecules and power them with motors much like the ones found in bacteria.



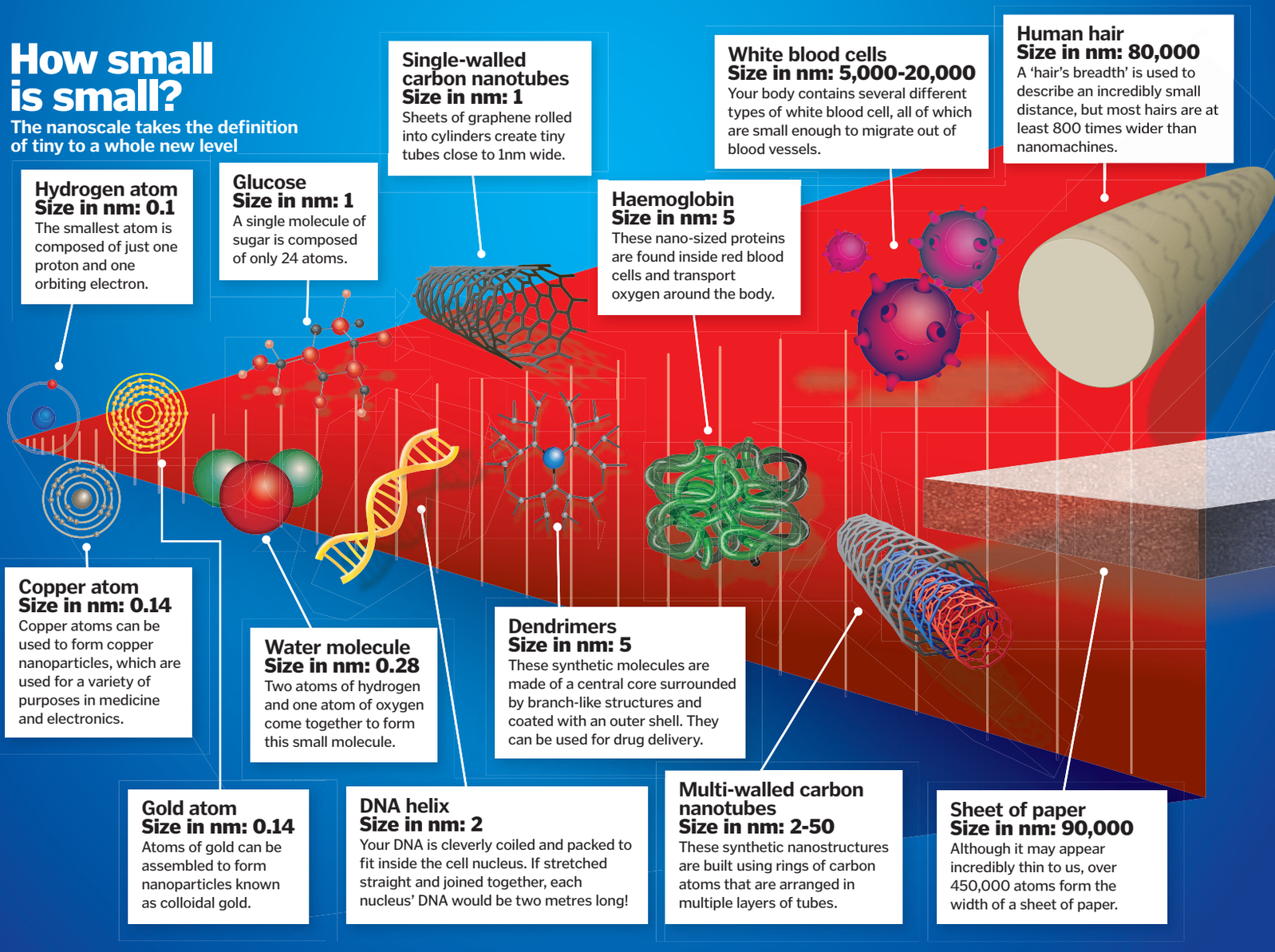
And we needn't stop at keeping ourselves healthy, as nanotechnology could also be used to enhance our bodies beyond their natural capabilities. Our stamina and endurance could be massively improved by using nanoparticles to carry extra molecules of oxygen in the bloodstream to support the work of red blood cells. This could grant us the ability to hold our breath for several hours underwater – in theory, nanotechnology could be the tool that creates the very first superhumans.

Right now, nanotechnology is still in its early stages, but it is already being incorporated into everyday items, including sun creams, clothing and waterproof phone coatings.

Building things hundreds of times smaller than the text you're reading is very tricky, and particles don't always play by the same rules as we do. At the atomic level, the laws of physics as we experience them no longer wholly apply, and we enter the realm of quantum mechanics. Despite these obstacles, advances in technology allow us to peer into this invisible world, and to see and interact with structures at an atomic scale. As we learn more about the properties of certain atoms and molecules, we will be able to manipulate matter at the nanoscale to develop new and improved materials and structures. From engineering to medicine, the building blocks of tomorrow's tech are set to be very small indeed.

How small is small?

The nanoscale takes the definition of tiny to a whole new level



Hydrogen atom
Size in nm: 0.1
The smallest atom is composed of just one proton and one orbiting electron.

Glucose
Size in nm: 1
A single molecule of sugar is composed of only 24 atoms.

Single-walled carbon nanotubes
Size in nm: 1
Sheets of graphene rolled into cylinders create tiny tubes close to 1nm wide.

Haemoglobin
Size in nm: 5
These nano-sized proteins are found inside red blood cells and transport oxygen around the body.

White blood cells
Size in nm: 5,000-20,000
Your body contains several different types of white blood cell, all of which are small enough to migrate out of blood vessels.

Human hair
Size in nm: 80,000
A 'hair's breadth' is used to describe an incredibly small distance, but most hairs are at least 800 times wider than nanomachines.

Copper atom
Size in nm: 0.14
Copper atoms can be used to form copper nanoparticles, which are used for a variety of purposes in medicine and electronics.

Water molecule
Size in nm: 0.28
Two atoms of hydrogen and one atom of oxygen come together to form this small molecule.

Dendrimers
Size in nm: 5
These synthetic molecules are made of a central core surrounded by branch-like structures and coated with an outer shell. They can be used for drug delivery.

Gold atom
Size in nm: 0.14
Atoms of gold can be assembled to form nanoparticles known as colloidal gold.

DNA helix
Size in nm: 2
Your DNA is cleverly coiled and packed to fit inside the cell nucleus. If stretched straight and joined together, each nucleus' DNA would be two metres long!

Multi-walled carbon nanotubes
Size in nm: 2-50
These synthetic nanostructures are built using rings of carbon atoms that are arranged in multiple layers of tubes.

Sheet of paper
Size in nm: 90,000
Although it may appear incredibly thin to us, over 450,000 atoms form the width of a sheet of paper.

TYPES OF NANOTECHNOLOGY

What objects can we create by manipulating molecules and atoms?

Much like natural nano-sized structures and molecules, synthetic pieces of nanotechnology are a diverse group. By using our knowledge of how atoms are arranged into structures, we can design and model different shapes with a wide range of properties. Nanotechnology can vary from relatively simple to immensely complex structures: some are used solely as protective housings with the responsibility of transporting drugs, and others have intricate mechanical actions such as mimicking a wheel spinning on an axle.

Microscopic motors

While not strictly nanotechnology, microscopic motors can serve as a stepping stone in order to develop even smaller structures. Once we can build small enough motors, they could theoretically power medical nanobots.

Nanotubes

These cylindrical structures can be just a nanometre wide, but reach lengths of 20 centimetres – that means they are 200 million times longer than they are wide! They are built using carbon that's arranged in rings.

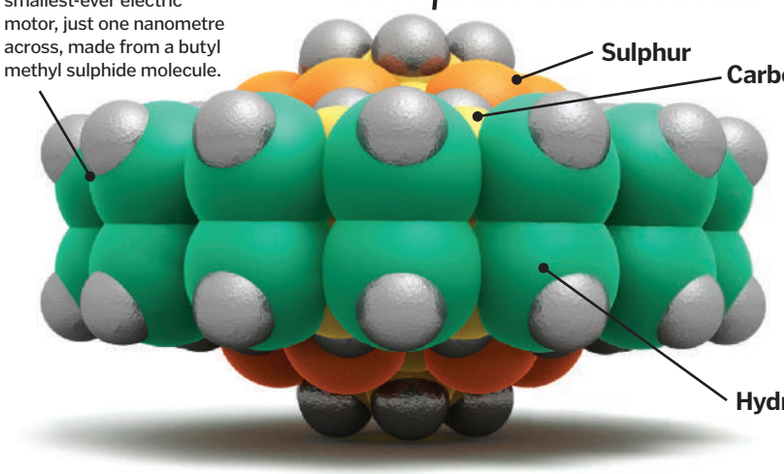
Elemental form

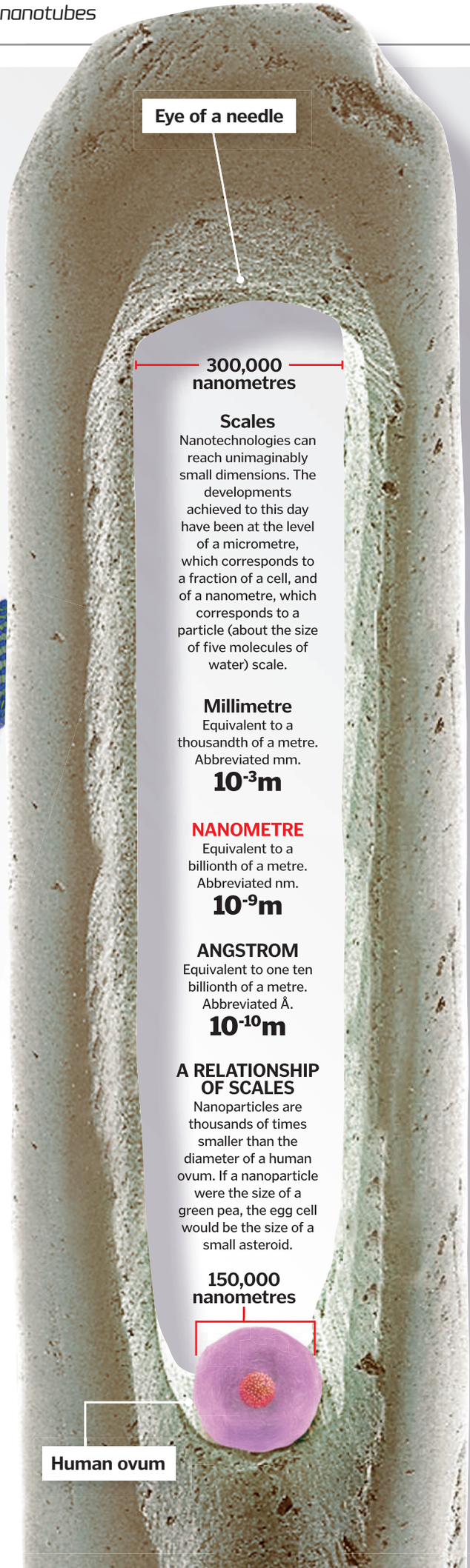
Like graphite and diamond, nanotubes are a basic form of carbon. They are used in heavy industry.

Engineered nanomolecules

Molecules can be modified and manipulated to build custom nanomachines. In 2011, a team of researchers created the smallest-ever electric motor, just one nanometre across, made from a butyl methyl sulphide molecule.

"Nanotechnology can vary from relatively simple to immensely complex structures"





USES OF NANOMEDICINE

How can nanotechnology be applied to help fight disease and save lives?

In medicine, artificially created molecules the size of proteins, which are able to slip in and out of the blood stream and individual cells, could be an incredibly useful tool for delivering drugs throughout the body. Nanomotors could be used to direct helpful molecules to organs where they're needed. The choice of materials used to build these machines and structures also helps them to effectively achieve their function. Rings of carbon atoms – that assemble as long, thin nanotubes – provide strength and could be used as scaffolds to help repair bone, while nanoparticles filled with gold or silver can be used to destroy cancer cells or unwanted bacteria.

Bacteria
Silver nanoparticles can destroy certain species of bacteria by interacting with their outer membranes, causing structural changes that make this protective layer degrade.

Cell death
Without their outer membrane, many bacteria (including E. coli, which can cause food poisoning) are unable to survive.

Fighting infection with nanoparticles

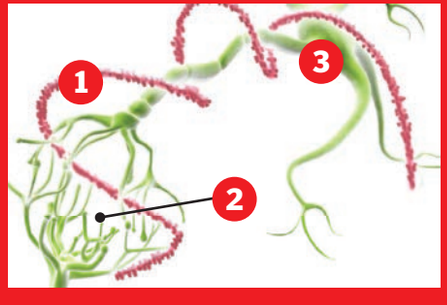
Silver ions are effective tools for killing bacteria

Silver ion
Silver has antimicrobial properties, and the element is often incorporated into medical dressings and equipment to help prevent and fight infections.

Repairing nerve cells

Our central nervous systems are filled with neurons, which are organised in an expansive network to send information and instructions efficiently all around the body. The ability of neurons to be able to carry information is dependent on the electrical signals that are sent along and between them. If the neurons are damaged, the circuit is broken – and this is often irreparable.

Scientists are looking to carbon nanotubes for a way to repair this damage. By placing nanotubes in close contact with the neurons, they are able to act as a scaffold, consequently allowing the neurons to grow and reform connections. In the future, this could be used to develop treatments for neurological disorders such as Parkinson's.



1 Nanotube mesh
Nanotubes occupy space around the neurons. This provides a scaffold for the neurons and helps to guide their growth.

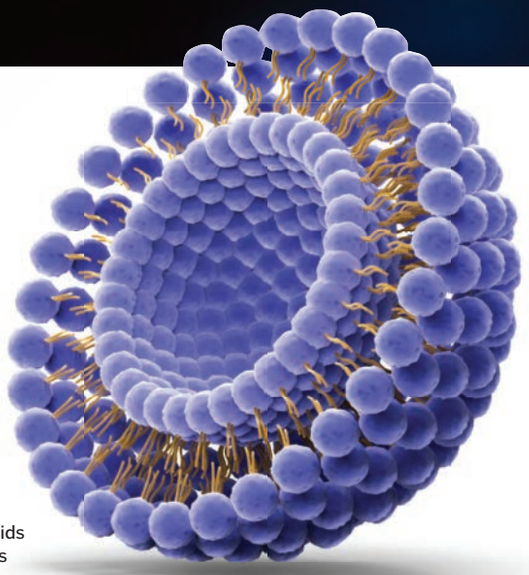
2 Neuron connection
Neurons have to be close to one another to communicate. They can send chemical signals to each other across small gaps called synapses.

3 Regrowth
In the presence of the nanotubes, neurons can grow and re-establish contact with their neighbours.

Drug delivery

Ensuring that therapeutic drugs reach their cell targets is no easy task when you're dealing with a complex organism like a human. Drugs may not arrive at the right destination, and those that do may not be able to enter the cells. The use of nanoparticles called liposomes – which are able to carry drugs into cells – may be a way to overcome this obstacle.

Liposomes surround the drug particles and help guide them to their destination. Once a liposome makes contact with a cell, it is slowly engulfed in a process called endocytosis. The liposome usually breaks down slowly inside the cell, but X-rays can be used to rupture the fatty layers more rapidly, so that they release their tiny parcels of drugs.

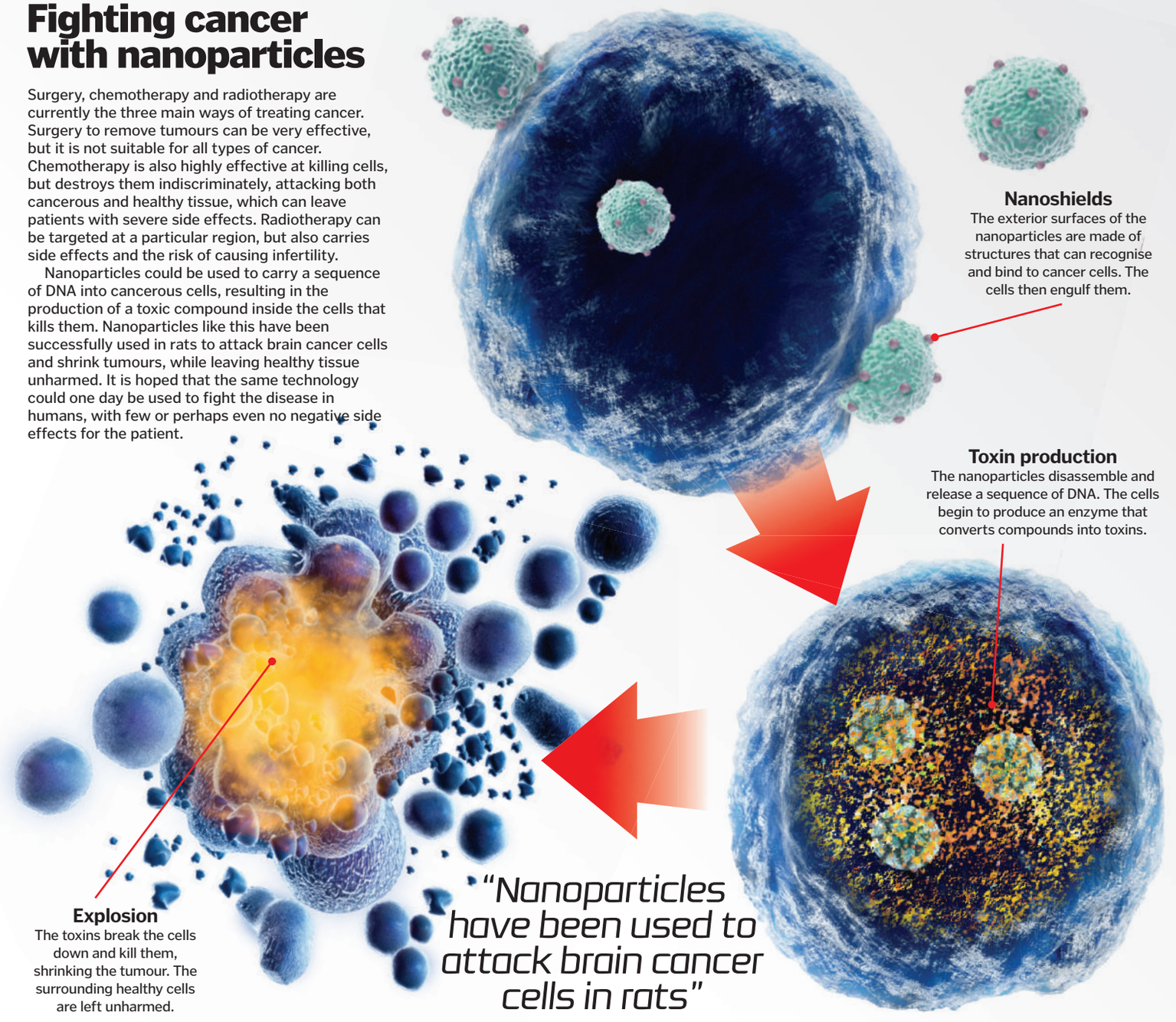


Liposomes are nanoscale 'bubbles' made of phospholipids – the same molecules that make up our cell membranes

Fighting cancer with nanoparticles

Surgery, chemotherapy and radiotherapy are currently the three main ways of treating cancer. Surgery to remove tumours can be very effective, but it is not suitable for all types of cancer. Chemotherapy is also highly effective at killing cells, but destroys them indiscriminately, attacking both cancerous and healthy tissue, which can leave patients with severe side effects. Radiotherapy can be targeted at a particular region, but also carries side effects and the risk of causing infertility.

Nanoparticles could be used to carry a sequence of DNA into cancerous cells, resulting in the production of a toxic compound inside the cells that kills them. Nanoparticles like this have been successfully used in rats to attack brain cancer cells and shrink tumours, while leaving healthy tissue unharmed. It is hoped that the same technology could one day be used to fight the disease in humans, with few or perhaps even no negative side effects for the patient.



Nanoshields
The exterior surfaces of the nanoparticles are made of structures that can recognise and bind to cancer cells. The cells then engulf them.

Toxin production
The nanoparticles disassemble and release a sequence of DNA. The cells begin to produce an enzyme that converts compounds into toxins.

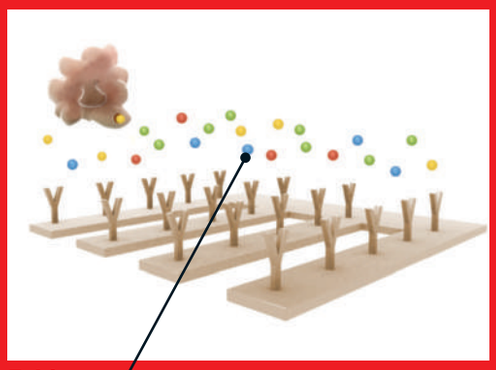
Explosion
The toxins break the cells down and kill them, shrinking the tumour. The surrounding healthy cells are left unharmed.

"Nanoparticles have been used to attack brain cancer cells in rats"

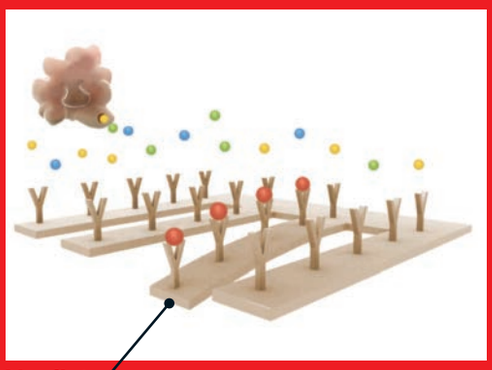
Detecting disease with nanocantilevers

Assembling structures on the molecular level can be very challenging, but one advantage is that small changes can have a large and detectable impact. In other words, adding single atoms or molecules can heavily influence their physical structure.

This idea has been used by scientists to create nanocantilevers. These nano-sized beams are covered in antibodies – small, Y-shaped proteins that recognise specific molecules. Cancer cells secrete molecules that bind to corresponding antibodies, forcing the beams to change shape. This concept could be used to quickly identify cancer in medical tests.



Evidence
Cancerous cells act very differently from healthy cells and produce certain proteins in much larger amounts. This leads to an abundance of certain molecules being released from the cell.



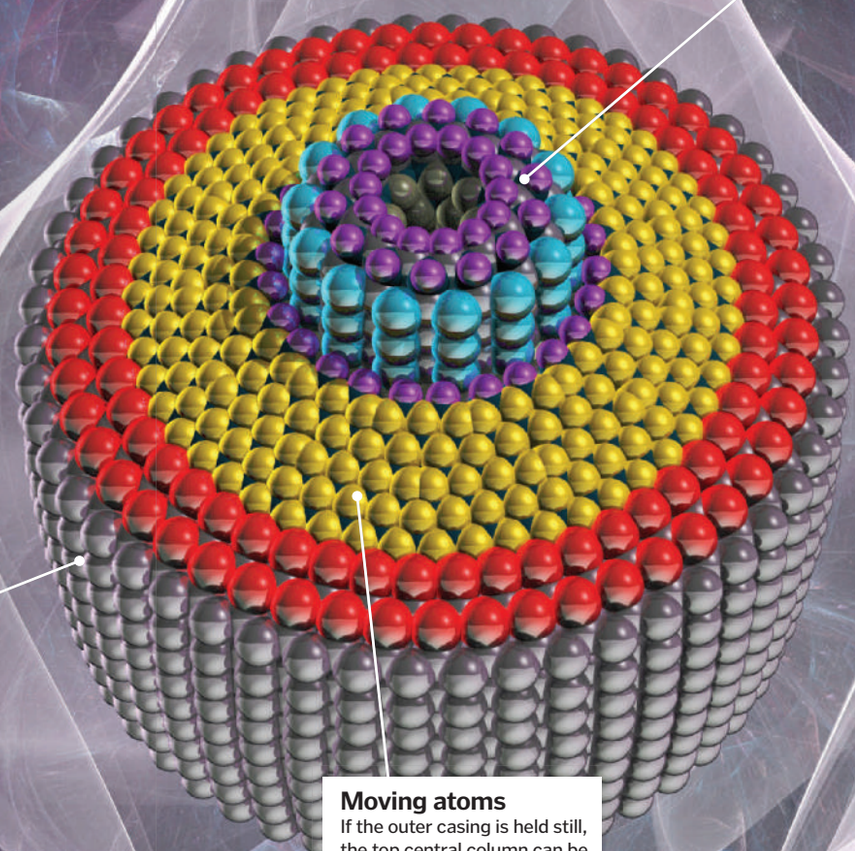
Verdict
The nanocantilever is coated with antibodies that attach to the molecules secreted by cancerous cells. The bound molecules then distort the shape of the nano-sized beams, which informs doctors that cancer is present.

HOW TO BUILD A NANOBOT

Two methods are used to make things at the nanoscale: top-down or bottom-up

Assembling mini machines is no simple task, especially when we're talking about gears that only contain a few thousand atoms! Currently there are two quite different proposed methods of nanoconstruction: top-down and bottom-up. The top-down approach involves starting with a bulk of atoms and shaving away the parts you don't want, much like how a sculptor would carve away at a stone block until it assumed the form they wanted. Starting with a large amount of material makes this the more straightforward option, but every chunk that is cut away represents a considerable amount of waste, and the tools used for the task are so much larger than the final product that they are difficult to use accurately.

The alternative is the bottom-up approach, which is mostly still in the theoretical stage. This method involves building the nanobot atom by atom, or combining atoms in a way that lets them interact and self-assemble into the shape we want, which is of course quite complex! But when you're constructing controllable mechanical actions on the nanoscale, precision is everything, so the bottom-up approach will most likely take over in the future.



Bottom-up construction
Complex structures, such as this molecular gear, would only be able to achieve specific rotations if all the atomic parts were arranged very precisely, so bottom-up assembly would be required.

Assembly
A central column of atoms acts as an axle and is surrounded by other atoms that spin much like a wheel. The outer casing is formed of larger elements to reduce the number of atoms needed.

Moving atoms
If the outer casing is held still, the top central column can be rotated and used to spin the atoms between the shaft and external elements.

Everyday nanotech

It may seem futuristic, but nanotechnology is already here

Sunscreen
Zinc oxide and titanium dioxide are common ingredients in popular sun-protection products. Many modern lotions now use zinc oxide nanoparticles that are less visible on the skin than their larger counterparts.

Self-cleaning glass
A film of titanium dioxide just a few nanometres thick can be applied to sheets of glass, allowing the material to clean itself. The coating breaks down and loosens dirt, which is then washed away by rainwater.

Clothing
Antibacterial silver nanoparticles can be incorporated into certain fabrics that are used to make socks and sports clothing. These nanoparticles help to kill the bacteria that are responsible for sweaty smells.

How nanobots can be used to fight disease

The movie *Fantastic Voyage* told the story of a submarine holding a small crew that had been shrunk down so small they could be inserted into the bloodstream. Their mission: to clear a blood clot that was lurking inside their human host. The story seemed impossible at the time, but today we are busily working toward our own mini-medics to help heal us from the inside.

Medical nanobots are one of the most ambitious areas of nanotechnology. The aim is to create tiny, controllable robots that can navigate through the bloodstream to reach places we currently find hard to reach, and repair damage without the need for invasive surgery. They could break down hard plaques found on arterial walls or clear blood clots in the brain.

Nanobots could perform surgery on individual cells, minimising the damage to healthy tissue

The future of nanomedicine

Nanobots could soon be roaming through our bloodstream and fixing unseen dangers

Plaque removal
The nanobot reduces the size of the plaque using flexible arms that bind to the individual components and separate them from the bulk.

Blood flow
Red blood cells transport oxygen to tissues through the bloodstream. The force provided by the beating heart pushes the cells through arteries at high pressure, which increases when blood vessels are blocked by plaques.

Cholesterol build-up
When an arterial wall is damaged, calcium, cholesterol and other components begin to build up and form hard plaques. If left unchecked, plaques can suddenly rupture with fatal consequences.

Injection
Nanomachines could be injected to wherever they're needed in the body via a hypodermic needle.

Swarm
Many nanobots could be administered at the same time to clear debris from multiple arteries simultaneously, or clear large plaques even faster.

Housekeepers
Once large plaques have been cleared, the nanobots could be used as routine cleaners to break down any existing fat deposits before they have a chance to cause heart disease.

Wireless control
Medics are able to control the nanobots in real time using magnetism, with each individual robot having personalised magnetic markers for identification.

"The top-down approach is similar to how a sculptor would carve a stone block until it assumed the form they wanted"

Wireless headphones allow you to move around freely, instead of being tethered to your device

Wireless headphones

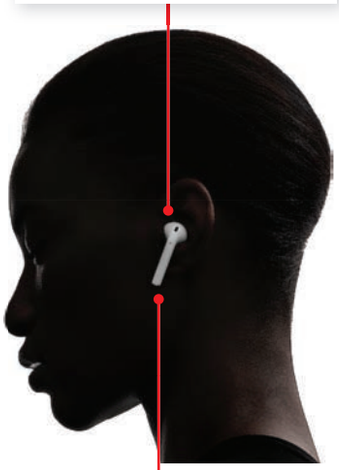
You never have to face the dreaded tangle of headphone wires again

When Apple announced the launch of the new iPhone 7, the big news was the removal of the headphone jack. It meant that users would have to use headphones that plug in to the charging port, or get themselves a pair of wireless headphones that don't need to be plugged in at all.

Wireless headphones have been around for a while, and can connect to your phone, computer or TV in one of two ways. Some use infrared, an invisible beam of light that transmits sounds from a device to the headphones, but this will only work if the headphones are in the device's line of sight. Therefore, most models, including Apple's new wireless AirPod headphones, use Bluetooth. Sound is transmitted via a low-powered radio signal from the device to a receiver chip in the headphones. It only has a range of about ten metres, but will work even if the headphones and device are in different rooms. As they are not plugged in, wireless headphones are powered by standard disposable batteries or their own inbuilt, rechargeable batteries.

How Airpods work

How do Apple's new earphones stream music without wires?



Bluetooth
The AirPods connect to your device via Bluetooth, which wirelessly streams your music to sensors in the earphones.

Apple W1 chip
The AirPods contain a microchip specifically designed to provide a more efficient wireless connection.

Charging case
The AirPods' batteries can last for up to five hours, and an accompanying portable charging case lets you recharge on the go.

Accelerometers
Sensors in each AirPod can detect when you take the earphones out, automatically pausing your music so you don't miss a beat.

Hedge trimmers

Discover how motorised machines make light work of shaping your garden foliage

Hedge trimmers are handy tools for keeping your garden shrubs neat and tidy. They may look similar to chainsaws, but instead of a rotating chain, they have a pair of toothed blades stacked one on top of the other. The top blade moves back and forth while the bottom blade remains stationary, helping to cut branches as the moving blade shifts past it.

When the hedge trimmer is switched on, the motor inside the handle section starts to spin. The motor is attached to a disc, which is connected to the top blade by a crank. The crank converts the spinning motion of the motor into the back-and-forth motion of the blade. The lower blade is not attached to the crank, and therefore does not move. As the top blade shifts past the stationary blade, any foliage in between is sliced.

Hedge trimmer motors can be powered by gas or electricity. Gas-powered trimmers are generally more powerful but tend to be heavier. Electric trimmers can be powered by rechargeable batteries or by the mains via a cable. These models are lighter and quieter, but may struggle to cut through tough branches.

Hedge trimmers can be gas-powered or battery-powered, or plugged in to an electricity supply

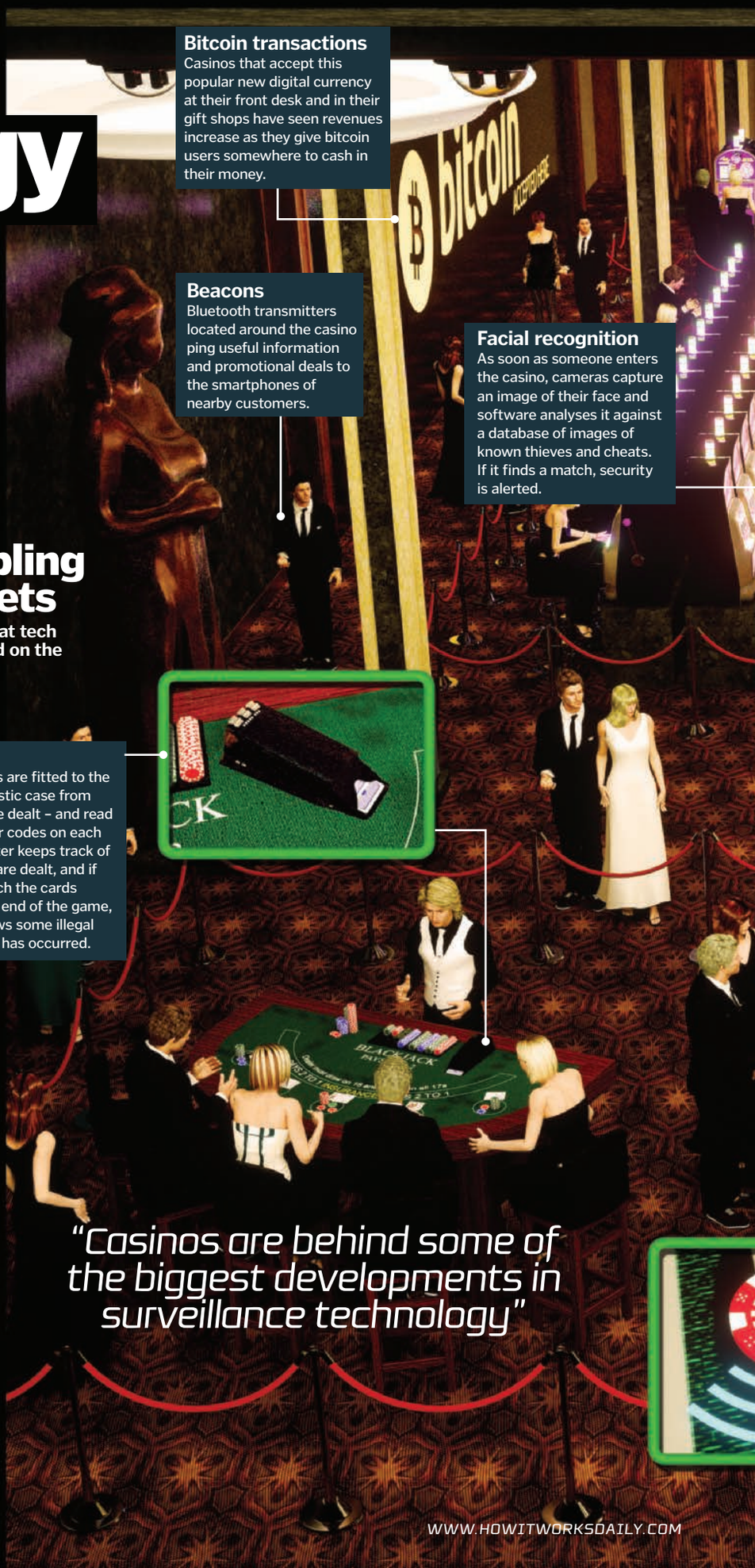
Casino technology

The ingenious innovations casinos use to catch criminals and boost profits

With their sprawling floors of gambling tables and row upon row of slot machines, casinos can cash in millions of pounds every day. However, with so much money at stake, they also find themselves vulnerable to the dark side of the gambling world – the professional crooks out to cheat their way to the jackpot. With such a vested interest and an enormous budget to play with, it's no wonder then that casinos are behind some of the biggest developments in surveillance technology. They have the funds to employ some of the best security experts in the business, and the tech they've developed has gone on to be used by many other sectors, including government agencies.

Of course, all this new technology is not just there to prevent big money scams. It can also help increase the casino's profits, and even benefit the customers too. Gamblers are willing to sacrifice a great deal of personal information when they register to play at casinos, which the establishment can use to encourage them to spend more money. In return, the customers are rewarded for their big bets with deals and perks that keep them coming back for more.

RFID chips help casinos keep track of profits and catch cheats



Bitcoin transactions
Casinos that accept this popular new digital currency at their front desk and in their gift shops have seen revenues increase as they give bitcoin users somewhere to cash in their money.

Beacons
Bluetooth transmitters located around the casino ping useful information and promotional deals to the smartphones of nearby customers.

Facial recognition
As soon as someone enters the casino, cameras capture an image of their face and software analyses it against a database of images of known thieves and cheats. If it finds a match, security is alerted.

Gambling gadgets

Discover what tech can be found on the casino floor

Angel Eye
These scanners are fitted to the 'shoe' – the plastic case from which cards are dealt – and read the invisible bar codes on each card. A computer keeps track of the cards that are dealt, and if they don't match the cards revealed at the end of the game, the dealer knows some illegal card-switching has occurred.

"Casinos are behind some of the biggest developments in surveillance technology"

Computerised slot machines

Learn how your luck is in the hands of computers and maths

CCTV
Cameras provide surveillance teams with a comprehensive view of the casino floor, so they can spot and record any suspicious or incriminating behaviour. Cameras above the gambling tables can also help to reveal cheating.

TableEye21
Overhead video cameras, video analysis software and smart chips are used to track all sorts of stats about the games being played and overlay them onto a live video feed. This information can then be used to profile players, identify cheaters and work out which gamblers are bad for the casino's profits.

1. Pull the lever
To play the game, the player simply pulls on a lever or presses a button.

2. Random numbers
The computer records the three numbers given by a random number generator.

3. Calculations
The computer then divides each number by a set value to work out the remainder.

4. Virtual reel
The remainder corresponds to a point on a virtual reel.

5. Matching up
Each point on the virtual reel corresponds to a point on the actual reel.

6. Actual reel
The computer works out how far to move the actual reel so it lands on this point.

Smart chips
To prevent chip theft, or the use of counterfeit chips, casinos fit theirs with tiny radio frequency identification (RFID) tags. These send unique radio signals to receivers in the cash-in booth, so the casino can keep track of authentic chips.

Non-Obvious Relationship Awareness (NORA)
Casinos gather vast amounts of information about their customers. NORA software can analyse this data to spot if two or more gamblers have a personal connection to each other or a dealer, which may indicate cheating.

THE FUTURE OF DRIVING

Discover what cutting-edge tech will transform the cars of tomorrow

Virtual reality

Why VR tech is heading onto the factory floor and into the showroom

Tomorrow's driving experience starts in the dealership. Showrooms themselves will look different, as rows of cars parked side by side are replaced with empty stages for customers to explore the latest models through virtual reality (VR). Clients will be given high-resolution VR headsets, such as an Oculus Rift or HTC Vive, to provide an immersive 3D and 360-degree view of their prospective new car. While this might sound futuristic, British tech company ZeroLight is already developing this system in partnership with Audi to provide a virtual showroom that offers customers the chance to explore cars as if they were actually there in the room. Both the interior and exterior design can be changed, so clients can see which configurations they prefer and what optional extras might look like. They can even delve under the bonnet and see the inner workings of the engine.

VR will also give companies the chance to demonstrate vehicles that are yet to be released, so customers can explore upcoming models in greater detail than simply browsing a website.

Before cars hit the virtual showroom, manufacturers can use VR to design better and

Automotive manufacturer Audi and tech company ZeroLight are pioneering virtual showrooms

Drivers can give commands with intuitive gestures in Mercedes-Benz's F 015 concept

Advanced interface

Innovative input methods and 'infotainment' systems are changing the in-car experience

Simply getting from A to B is no longer enough in the automotive industry. In an effort to make arduous long journeys and stressful morning commutes more bearable, cars will become media hubs. Audi's next-gen virtual dashboard is one such concept that will transform the driving experience. This system displays important information, such as 3D maps, traffic information and hazard alerts, in the driver's field of view on an ultra-thin, high-resolution OLED display. This multifunctional display is supplemented by two touchscreen displays on the centre console, which control features such as the media systems and air conditioning. One aim of this system is that it will be able to learn the driver's habits and use this information to improve their journeys. For example, if traffic starts to build up on your usual route to work, the system will alert you via a companion smartphone app and advise you to set off early.

In Mercedes-Benz's F 015 concept, the classic dashboard is entirely replaced with a smart screen that constantly monitors where your eyes are looking and tracks your hand gestures. In this system, you will just have to look at the setting you want to adjust, such as the radio volume or air conditioning temperature, then move your hand to change it.

Volvo is partnering with Ericsson to take in-car entertainment to the next level. Future Volvo models will come complete with both autonomous technology and high-bandwidth streaming capabilities, meaning the driver will be able to relax with their favourite films or TV shows as the car handles the driving. It will even be smart enough to take a slightly longer route to your destination if the episode you're watching hasn't quite finished.

Elements of Audi's next-gen dashboard will be incorporated in some of its 2017 models

Volvo's concept allows drivers to sit back and relax with their favourite shows while the car drives itself

safer vehicles. At Ford's Immersion Lab in Michigan, US, VR plays an integral role in the production process. By developing highly detailed virtual models, Ford can evaluate different configurations and designs early on, without having to build physical prototypes. This saves money and allows engineers more creative freedom to explore new design options.

Some manufacturers are also using VR to improve safety. Before BMW even build the first example of a new model, it will already have been crash tested at least 100 times in all kinds of virtual situations.

Intelligent autos

From data gathering to self-driving, how will cars of the future use information?

Inspired by swarm behaviour seen in birds, fish and insects, Audi is developing swarm intelligence systems to improve its autonomous technologies. In nature, groups of animals can appear to move as one, and that's precisely the principle that Audi wants to transfer to cars on the road to help reduce traffic. By using mobile networks, Audi cars will be able to stay interconnected, gathering and sharing traffic information with the help of a SIM card (e-SIM) that is permanently embedded in the car. The e-SIM connects the vehicle to a cloud database, which provides information about what lies on the road ahead. Using this information, the car can advise the driver on alternative routes that will successfully avoid congestion or hazards on the road. Swarm intelligence systems are still a work in progress, but Audi has successfully demonstrated the principle with small-scale demonstration models.

While many companies are developing self-driving cars, this technology must be thoroughly tested before drivers will be willing to let go of the steering wheel. Volvo's Drive Me project, due to start next year in Gothenburg, Sweden, will be the world's first large-scale, long-term autonomous car trial. A fleet of 100 Volvo XC90s will put the company's most advanced autopilot technologies to the test in the real world.

Augmented head-up displays will also be used in cars to alert drivers to potential hazards

Future tech on the roads

In the coming years, inner-city driving will become a whole new experience

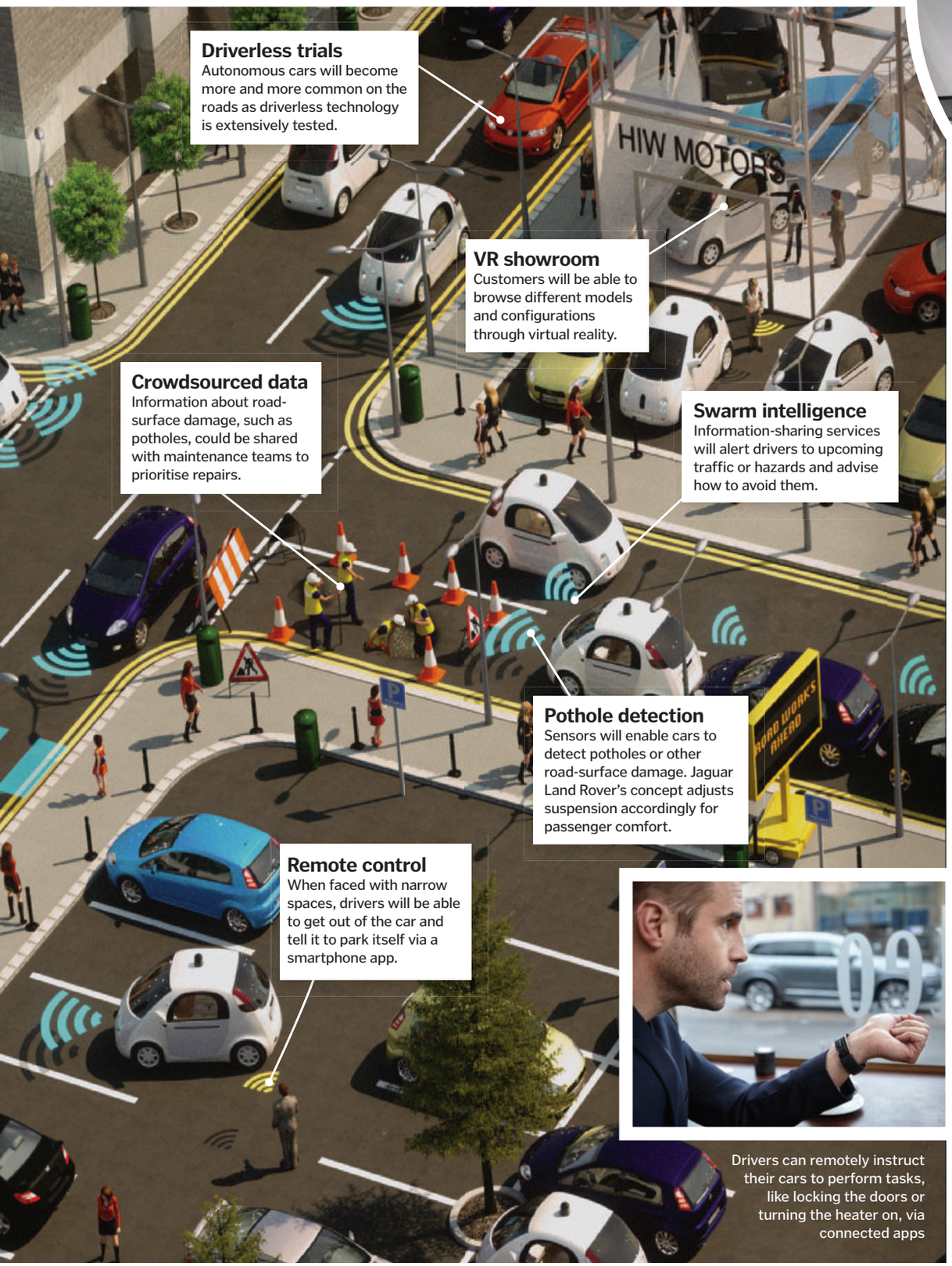
Enhanced awareness
Improved radar and camera systems will make driving safer by alerting drivers to objects in their blind spots, and helping them see around corners at blind junctions.

Augmented reality
Mechanics and technicians will don augmented-reality glasses to make repairs and fix engine issues more effectively.

Pedestrian crossing
Laser projection systems can shine a zebra crossing onto the road to let pedestrians cross safely.

Mercedes-Benz's F 015 concept has laser projectors and LED screens for other road users and pedestrians

Audi's 1:8 scale models demonstrate the swarm intelligence system in action



Driverless trials
Autonomous cars will become more and more common on the roads as driverless technology is extensively tested.

VR showroom
Customers will be able to browse different models and configurations through virtual reality.

Crowdsourced data
Information about road-surface damage, such as potholes, could be shared with maintenance teams to prioritise repairs.

Swarm intelligence
Information-sharing services will alert drivers to upcoming traffic or hazards and advise how to avoid them.

Pothole detection
Sensors will enable cars to detect potholes or other road-surface damage. Jaguar Land Rover's concept adjusts suspension accordingly for passenger comfort.

Remote control
When faced with narrow spaces, drivers will be able to get out of the car and tell it to park itself via a smartphone app.

Drivers can remotely instruct their cars to perform tasks, like locking the doors or turning the heater on, via connected apps

Future showrooms will allow customers to experience different vehicles in the virtual world

DRIVING BY NUMBERS

2050
The date by which all new cars will be fully driverless, according to some predictions

10 million
Lives saved every 10 years if driverless cars were used worldwide

2.4mn km
The distance Google's testing fleet of cars have self-driven so far

453 DAYS
The total time the average British commuter spends stuck in traffic during their working life

2.6
The number of crashes per million km driven by humans

2
The number of crashes per million km driven by autonomous cars

£8mn
How much Jaguar Land Rover saved between 2008-2010 by using VR systems in car development

The levels of autonomous driving

What technology needs to be tested before we trust our cars to take full control?

Level 0
No autonomy: The driver is fully in control of the car at all times.

Level 1
Semi-autonomous: the car has stability control and cruise control.

Level 2
Unlinked assistance systems are used, such as pilot assist and braking cooperation.

Level 3
At this level the car can take full control for a period of time.

Level 4
The car can make some of its own decisions, such as changing routes to avoid traffic.

Level 5
Full autonomy: no steering wheel or controls and no need for human input.

The Flyer

The lightweight military vehicle that can be used for both transport and combat

The US military are picky customers. For use in the modern battlefield, land vehicles are required to fit into transport aircraft and, once delivered, they're expected to scout the landscape, transport troops, support allies and engage the enemy. This list of demands can be a headache for defence companies trying to provide vehicles for the military. But rather than constructing a machine dedicated to just transport or combat, General Dynamics opted for the 'one-size-fits-all' approach and designed the Flyer – a vehicle that can be altered and configured to perform many different roles on the battlefield.

Depending on the needs of the army, the Flyer can be locked and loaded with guns to create a highly mobile combat vehicle, or mostly cleared out to provide space for a team of soldiers and their cargo. Its narrow width means that it can be transported onto the battlefield by military aircraft and its sophisticated design allows it to be ready for action less than a minute after being deployed.

Two variants of the Flyer have been used in warzones. The Flyer-60 is 60 inches (152 centimetres) wide and is highly mobile and easy to transport. The Flyer-72 is its big brother, 12 inches (30 centimetres) wider and able to carry more soldiers, pack more firepower or wear more armour. It has become one of the most advanced lightweight military vehicles ever produced.

Crossing rough terrain and travelling off-road are routine tasks for the Flyer

Multiple configurations
The vehicle's weaponry can be adapted to suit different tactical purposes.

Mobile
The Flyer-72 can traverse rough terrain, withstand harsh weather and reach a top speed of 160km/h.

Ready for anything

The Flyer-72 has been expertly designed to be adaptable, mobile and deadly

Narrow
At 72in (183cm) wide, the vehicle can be transported inside military aircraft.

The Flyer-60 can pack a whole load of firepower inside its narrow shell

"The Flyer can be locked and loaded with guns or cleared out to make space for soldiers and cargo"

Crew
Up to nine soldiers or escorted civilians can be transported.

Armoured
Increased protection can be provided if anticipating heavy enemy fire by attaching fitted armour plates to the outer shell.

Heavy payload
With a payload capacity of over two tons, crew and cargo can be transported efficiently.

Long distance
When travelling on flat ground at a steady 64km/h, the lightweight vehicle can travel over 1,000km on one tank of fuel.

The competition

The needs of modern warfare have spawned many light military vehicles

L-ATV
Labelled as "the future of light combat vehicles" by its creators Oshkosh Defense, this all-terrain machine can be fitted with a hybrid diesel-electric drive train for improved functionality, efficiency and fuel economy.

Desert Patrol Vehicle
This souped-up dune buggy can seat up to six and excels at crossing desert terrain swiftly and easily. The more modern strike vehicle variant also has mounted weaponry.

Otokar COBRA
This armoured vehicle can be adapted to fill a range of roles, from combat vehicle to ambulance. It can also be equipped with an amphibious feature.

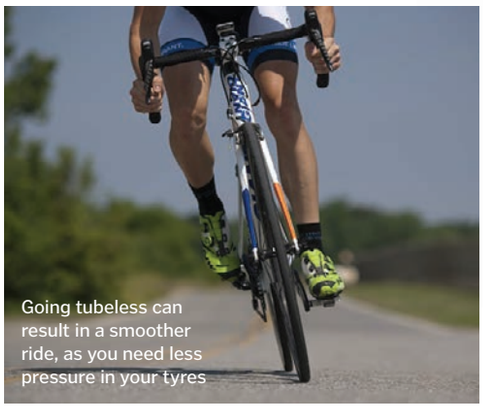
Foxhound patrol vehicle
Although heavier than other alternatives, the increased protection against roadside bombs that's provided by the armoured housing provides a highly desirable protection to weight ratio, allowing the vehicle to exceed 120km/h.

Tubeless tyres don't deflate as fast as conventional tyres when punctured

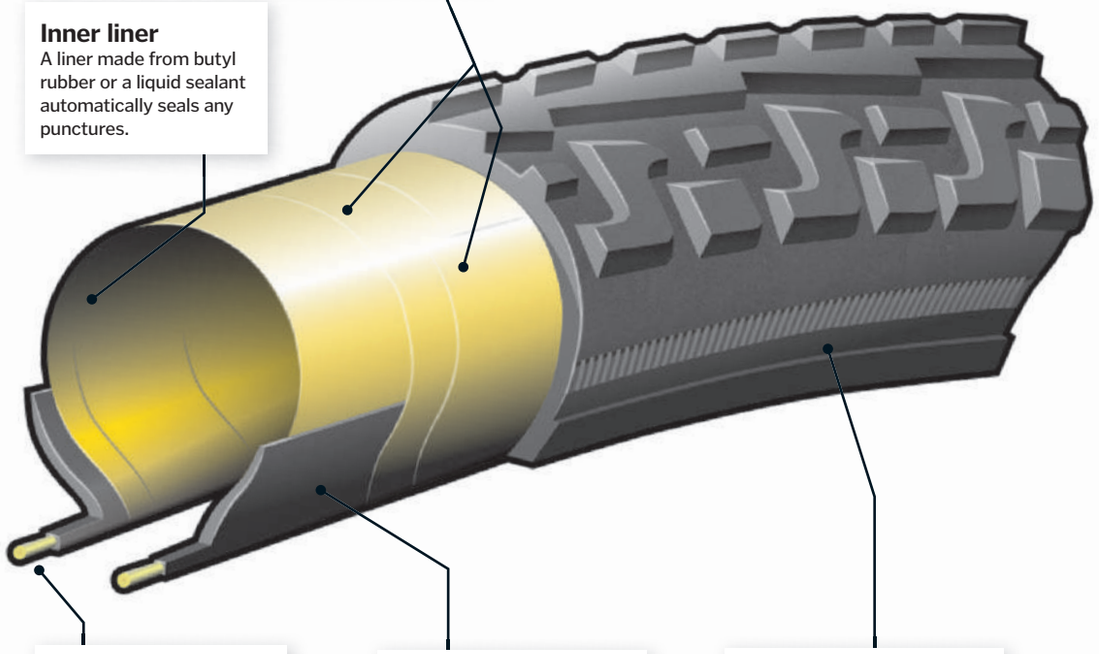
Tubeless bike tyres

Say goodbye to punctures with tyres that fix themselves

Standard bike tyres contain an inner tube filled with air that sits inside the rubber casing. If this type of tyre gets a puncture, air leaks out of the inner tube quickly, leaving the rider stranded, unable to continue their journey. This common problem is why many cyclists are now opting for tubeless tyres. These contain an airtight inner lining that, if punctured, lets the air escape more slowly, giving the rider time to get home before the tyre deflates completely.



Going tubeless can result in a smoother ride, as you need less pressure in your tyres



Casing plies
Layers of nylon or Kevlar are held together by the bead wires to create the main shape of the tyre.

Inner liner
A liner made from butyl rubber or a liquid sealant automatically seals any punctures.

Bead wires
The tyre is mounted onto loops of wire around the wheel rim, creating an airtight seal.

Chafer
This strip reinforces the tyre wall to protect against damage caused by friction with the wheel rim.

Wall rubber
A layer of rubber around the tyre further protects the inner casing and provides the rider with traction.

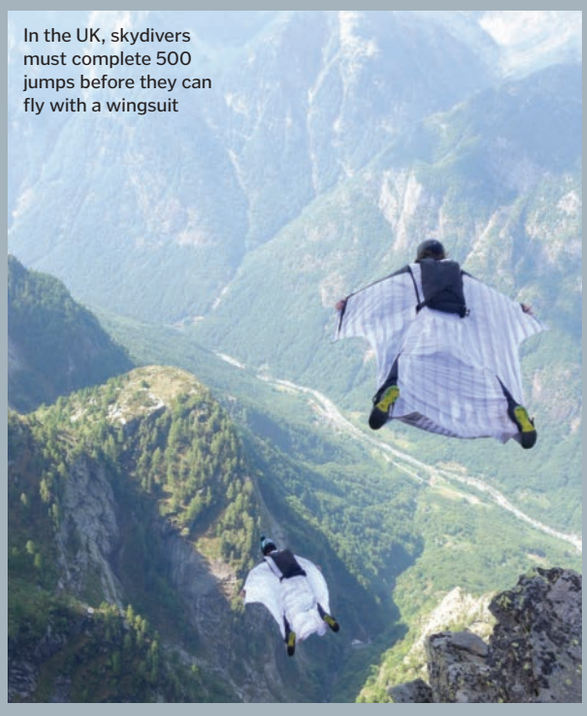
Wingsuit physics

Fly like a bird with a soaring suit and a little bit of science

After leaping out of a plane, skydivers fall to the ground at almost 200 kilometres per hour, making their entire descent a bit of a blur. However, by putting on some clever parachute-like clothing, they can slow down their dive and regain some control, enabling them to soar horizontally as well as vertically and perform some impressive aerial acrobatics.

By wearing a wingsuit, a skydiver transforms themselves into a giant wing, with their body acting as the rigid framework, and the fabric between the legs and beneath the arms creating a large horizontal surface, or airfoil. After leaving the plane, the jumper's weight pulls them down, but as they spread their arms and legs, air resistance created by the airfoil generates lift, slowing down their rate of descent. To glide horizontally, they must then bring their arms in a little and keep their head low to reduce drag, the force that opposes forward momentum.

While the suit is able to slow their descent to less than 100 kilometres per hour, this isn't slow enough for a safe landing, and so a parachute must be deployed to reduce speed before they reach the ground.



In the UK, skydivers must complete 500 jumps before they can fly with a wingsuit

Patrolling the sea

What tech powers the Sea Hunter and keeps it afloat?

Ocean giant
The Sea Hunter is 40 metres long and weighs 140 tons, much larger than most unmanned ships.

Fuel range
Powered by two diesel engines, the ship can remain at sea for up to three months before running out of fuel.

Composite hull
The hull features a foam core with a lightweight, fibreglass skin to aid buoyancy.

Trimaran design
The ship features a main hull with two smaller floats on either side to keep it balanced.

ACTUV was christened Sea Hunter in April 2016 before beginning a two-year trial

Sea Hunter

Meet the US Navy's new drone ship: a submarine tracker that doesn't need a single person on board

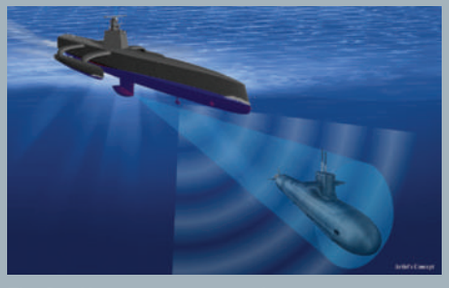
Submarines are one of the main threats to the world's navies. Hidden beneath the ocean surface, they are able to fire missiles and torpedoes that can cause catastrophic damage. To combat this problem, US defence company Leidos has built a new type of ship capable of tracking down even the stealthiest of submarines. It has been developed for Defense Advanced Research Projects Agency (DARPA) as part of its ACTUV program and will eventually be handed over to the US Navy.

ACTUV stands for Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel, as the program is set to feature a fleet of autonomous ships that can navigate the seas without a crew on board. The first to be built is the Sea Hunter, a 140-ton vessel with a range only limited by the amount of fuel it can carry. The ship is steered by computers using radar navigation – the method of sending and receiving radio signals to detect the proximity of nearby objects – but is also constantly monitored by a human on land, who can take control remotely if necessary.

At the moment, the Sea Hunter can only track submarines, as it is illegal for an unmanned vessel to carry weapons. However, it was designed to be versatile, and its operations could be extended to detecting underwater mines in the future. It is currently undergoing two years of testing in San Diego, California, before being unleashed on the open ocean alone.

Detecting subs

To identify submarines lurking beneath the ocean surface, the Sea Hunter uses sonar mounted on its hull. This system emits pulses of sound waves that travel through the water, and when they hit an object, such as a submarine, they bounce back towards the ship. By measuring the time it takes for the sound waves to return to the ship, the distance between the ship and the sub can be calculated. The Sea Hunter's sonar system has been developed by defence contractor Raytheon, and can be configured to detect underwater mines as well as submarines.



The Sea Hunter uses sonar to locate enemy submarines on the ocean floor

Experimental vessels

The strange ships pushing the boundaries of maritime design

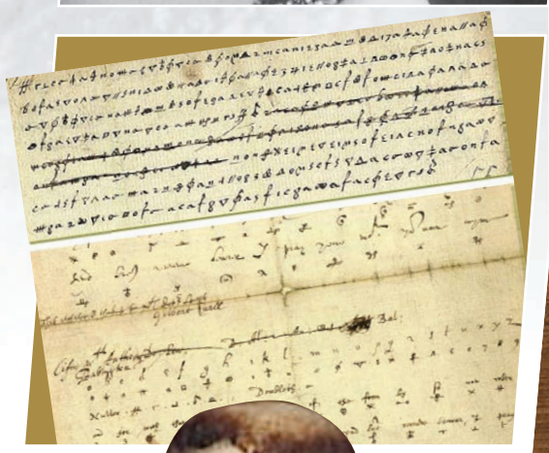
Sea Shadow
An unusual shape and special hull coating made this Lockheed Martin vessel almost undetectable by sonar and radar, but it was never launched beyond testing.

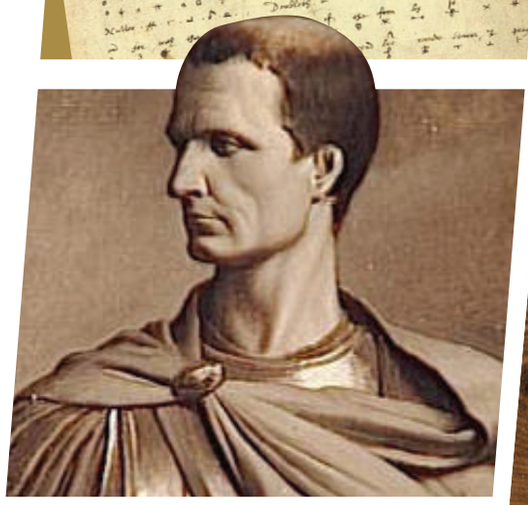
Sea Fighter
The US Navy's aluminium catamaran was designed to test a variety of technologies, including a multi-purpose ramp for launching and recovering vehicles.

Sea Slice
Designed to sail close to the shore, this combat ship's four small hulls sit below the surface to avoid causing waves that could slow it down or knock it off course.

SPIES THROUGH HISTORY

The secrets of espionage through the ages





The principle of gathering confidential information, from secret documents to military tactics, has proved invaluable for rulers, empires and governments throughout history. Covertly collecting information about enemies, and even allies, provided nations with the opportunity for military, political or economic gain.

Espionage is the gathering of secret information, and the methods used changed dramatically as technology developed. In Ancient Rome, letters could be intercepted en route to their intended recipient. In an attempt to prevent this, Julius Caesar invented one of the earliest-known ciphers – a code used to disguise messages – to stop enemy spies reading his secret military communications.

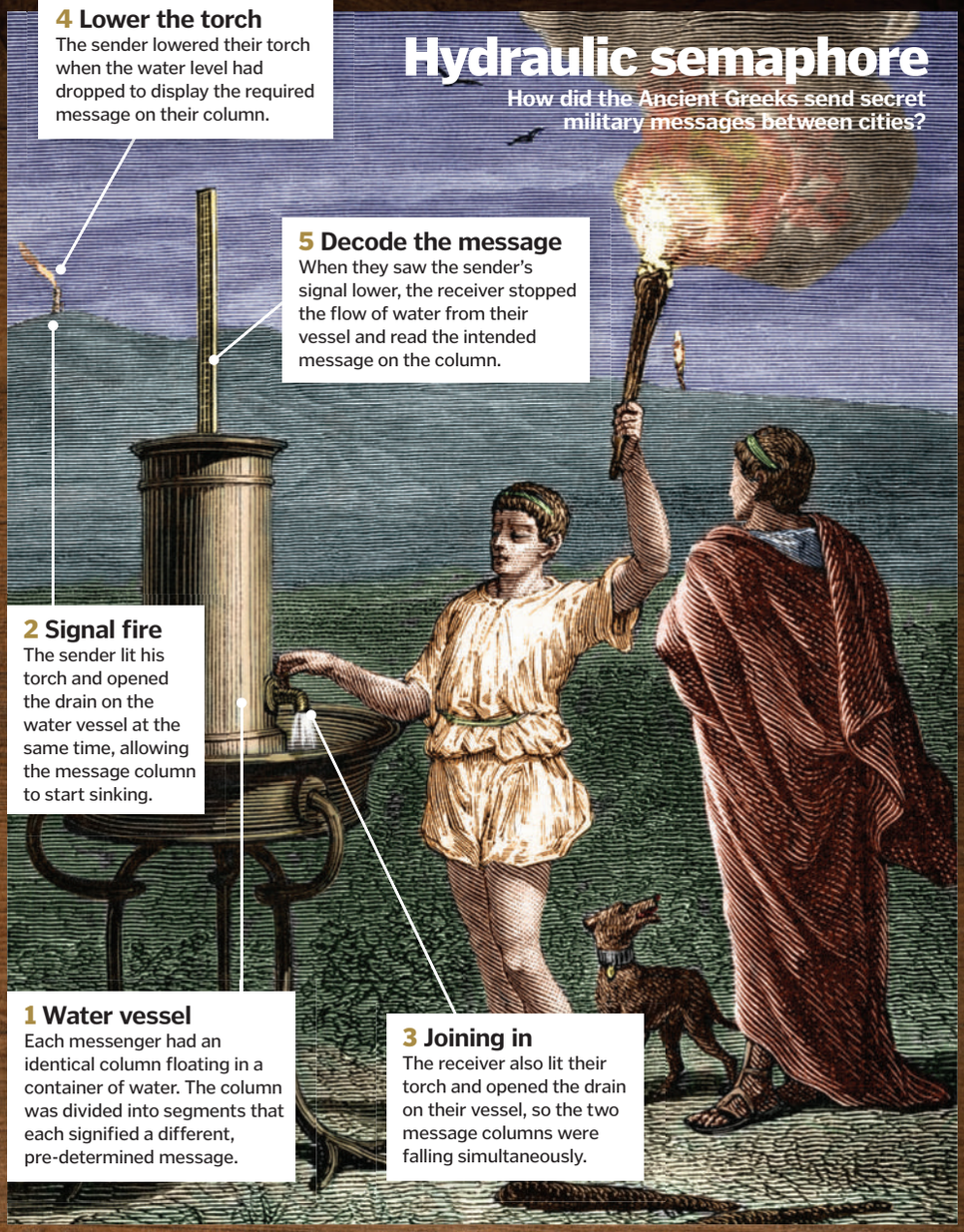
In the 20th century, espionage was particularly important during the two world wars, as nations established huge intelligence networks in an effort to stay one step ahead of the enemy. Some estimate that deciphering the Nazi's 'uncrackable' Enigma machines (used to encode messages) helped shorten World War Two by several years, saving countless lives.

During the Cold War, with the threat of nuclear war between the US and Soviet Union looming, strategic intelligence was vital and influenced tactics on both sides. Spies disguised gadgets as everyday objects to help gather information, from coat button cameras to microphones hidden in shoe heels.

Counterintelligence operations continue to be incredibly important to this day. Security services across the world work to protect their citizens against threats to national interests, conducting counter-terrorism operations and tackling cyber crime.

Hydraulic semaphore

How did the Ancient Greeks send secret military messages between cities?



4 Lower the torch
The sender lowered their torch when the water level had dropped to display the required message on their column.

5 Decode the message
When they saw the sender's signal lower, the receiver stopped the flow of water from their vessel and read the intended message on the column.

2 Signal fire
The sender lit his torch and opened the drain on the water vessel at the same time, allowing the message column to start sinking.

1 Water vessel
Each messenger had an identical column floating in a container of water. The column was divided into segments that each signified a different, pre-determined message.

3 Joining in
The receiver also lit their torch and opened the drain on their vessel, so the two message columns were falling simultaneously.

"Eavesdropping, intercepting messages and scouting enemy movements were the key methods used to gather intelligence"

Ancient espionage

How intelligence was gathered by ancient civilisations

In the first cities of Ancient Mesopotamia and Ancient Egypt, spying was an effective way for kings and pharaohs to monitor the population, as well as to discover enemy weaknesses. The Ancient Egyptians used court spies to root out disloyal subjects, and they were also among the first to develop poisons for sabotage or assassinations.

With no spy gadgets at their disposal, eavesdropping on conversations, intercepting communications and scouting enemy movements were the key methods used to gather useful intelligence. Resourceful techniques were developed to ensure written messages remained secret, including codes and trick inks.

The Ancient Greeks excelled at espionage and subterfuge. The legendary tale of the Trojan horse became a symbol of their cunning and deceptive military tactics. They developed efficient methods of communicating important messages between cities, including a fire signal system known as hydraulic semaphore.

Another tactic used by the Greeks to prevent communications being intercepted was carving important messages into wood and then covering it in wax. The wooden board would then be sent to an ally who would melt the wax to read the message. A more gruesome method was writing on the outside of an inflated animal bladder, before deflating it and packing it into a flask. The document could then be transported anywhere unnoticed until it was opened, inflated and read.

Julius Caesar's speculatores

The Roman Republic was a fragmented, unruly place and keeping hold of power was never easy. Many rulers hired bodyguards for protection, but Julius Caesar saw the value of secret surveillance and used spies called 'speculatores' to gather intelligence of potential revolts. This reconnaissance network helped Caesar keep abreast of goings on both domestically and internationally. Some sources suggest that Caesar was aware of the Roman Senate-led plot to assassinate him.

Not even Caesar's speculatores could prevent his assassination

The Mongol spy network

United under leader Genghis Khan, the Mongols were one of the most feared military forces of the 12th and 13th centuries as they rampaged across Asia. However, this mighty army would not have been as successful had it not been for an extensive intelligence network. Genghis Khan gathered information from trade merchants, who had an in-depth knowledge of the areas he wished to conquer. This intelligence allowed the Mongols to pinpoint weaknesses in enemy territories.

Spies' information gave the Mongols an advantage when conquering new lands

Elizabethan espionage

The final Tudor monarch created a secret service network that helped keep her on the throne

As a Protestant queen with no heirs, Elizabeth I's reign was threatened by those who would have preferred the Catholic Mary Queen of Scots. With the threat of assassination, the Queen set up a network of spies to protect her against dissidents and uncover foreign plots. Head of Elizabeth's secret service was Sir Francis Walsingham, a Protestant lawyer. Those hired as spies were among the greatest minds in the land; scholars, scientists and linguists were all tasked with protecting the vulnerable monarchy.

Technological advancements also aided the intelligence network. Invisible ink made from milk or lemon juice was first utilised in this period, allowing secret messages to be revealed by warming the paper over a candle. Cryptography became more advanced, and the spy network needed to be able to both write and decipher different codes.

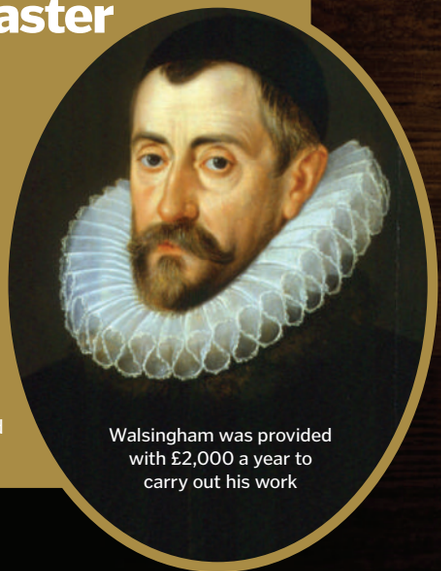
A series of plots to overthrow or assassinate the Queen were uncovered during her reign. The intelligence gathered by Elizabeth's secret service most likely saved her life on more than one occasion. For example, after her imprisonment, Mary Queen of Scots maintained contact with the outside world by sending coded messages to her allies hidden in barrels of beer. Little did she know that the barrels were being smuggled by a double agent acting on behalf of Walsingham, who deciphered her messages and proved that Mary was involved in a plot to kill Elizabeth. Those involved, Mary included, were quickly caught, tried and executed for treason.

Agents in Elizabeth's spy network gathered information about the Spanish Armada's preparations

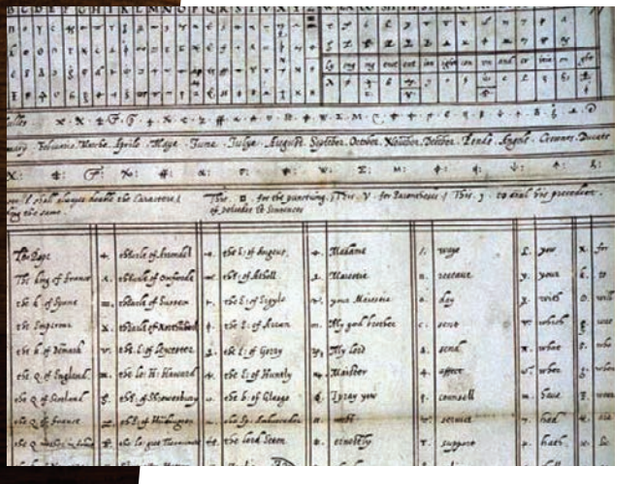
Elizabeth's spymaster

At the head of the Elizabethan spy network was the secretary of state, Sir Francis Walsingham. With threats coming from Catholic Spain, devout Protestant Walsingham built up a network of spies all over Europe – including prison informants and double agents – with the aim of gathering intelligence about the activities of Catholics, as well as political and economic information.

To ensure his agents were as effective as possible, Walsingham established a spy school to train new recruits. His network proved invaluable to national security after foiling several plots against the Queen, as well as providing intelligence about the Spanish Armada leading up to the attempted invasion in 1588.



Walsingham was provided with £2,000 a year to carry out his work



Mary sent secret messages to her allies using these cipher symbols, but Walsingam's spies decoded them

World War spies

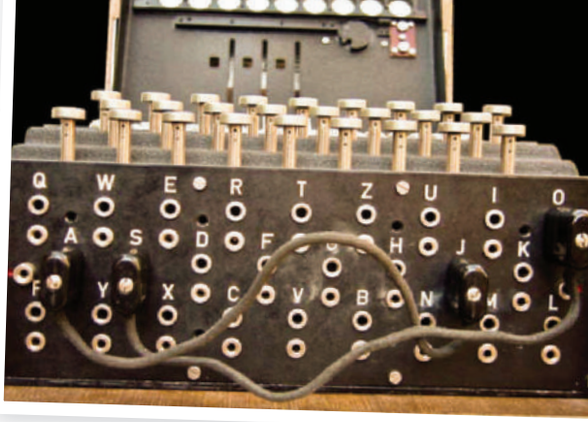
How inventive spying strategies were used to try and win both global conflicts

World War One may be remembered primarily for trench warfare, but behind the lines, spies were performing a vital role. One of the most successful spy networks during the war was codenamed 'La Dame Blanche'. With over 1,000 members, the organisation worked for the British, conducting valuable reconnaissance missions in German-occupied Belgium, spying on trains, roads and airfields.

The development of aircraft in the early 20th century meant that aerial reconnaissance was also a large part of the war. Both German and French planes took photos from above to examine troop movements. German intelligence greatly helped its divisions push forward on the Eastern Front. By acquiring secret documents and intercepting radio messages, they knew what moves the Russians would make.

When World War Two began, espionage was still an instrumental part of warfare. Germany's military intelligence organisation, the Abwehr, was particularly effective during the occupation of the Netherlands. The group captured 52 Allied agents and 350 resistance fighters, some as soon as they parachuted in. Still under the illusion that they were supplying their Dutch allies, the British unwittingly provided the Germans with 570 boxes of weapons and ammunition.

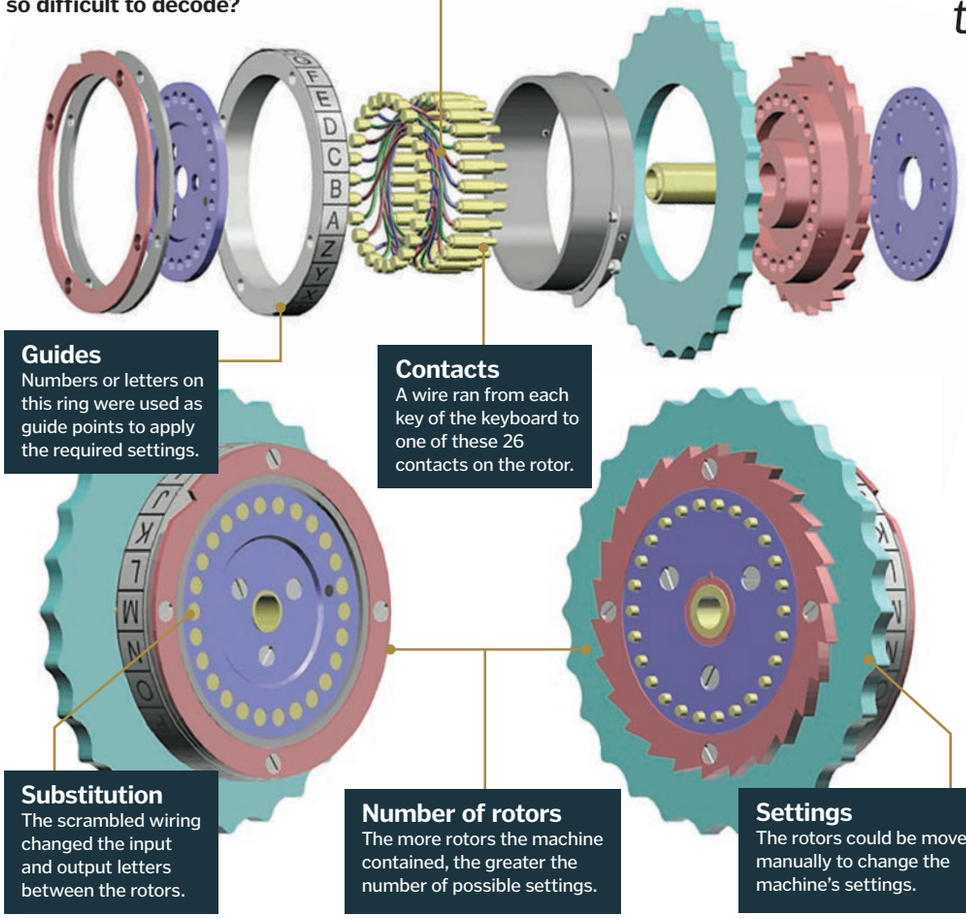
Most famously, the Nazi's Enigma machines were used to ensure their army's messages remained secure. To send a signal, an operator typed in their message and then scrambled it using a series of rotors, which would reproduce the message as a jumble of different letters. The receiver would need to know the exact settings used by the sender in order to decode the original message on their own machine. The settings were frequently changed, and a typical army-issue Enigma machine could have over 150 million trillion different settings, so cracking the code was considered impossible. The British eventually managed to decipher Enigma after teams of mathematicians and code-breakers at Bletchley Park developed computers known as bombes that could work out the machine's settings based on an intercepted coded message. Some historians estimate that the intelligence the Allies gathered by breaking the Enigma code helped shorten the war by two years.



On the front face of the Enigma machine was an electronic plugboard that could be used to swap pairs of letters, for an extra level of encryption

The Enigma machine

What made the messages sent by the Nazi's encryption device so difficult to decode?



"A typical army-issue Enigma machine could have over 150 million trillion different settings"

World War spies

The shady double agents that provided intelligence to the opposition

Howard Burnham
Burnham was an intelligence officer for the French government in World War One and often hid his spying equipment in his wooden leg.

Mata Hari
A Dutch dancer, Hari spied for the Germans before being caught by the French and sent to the firing squad in 1917.

Virginia Hall
Hall was a US spy during World War Two who provided support, information and training for resistance fighters and the Allies in occupied France.

Takeo Yoshikawa
Living in Hawaii during World War Two, Japanese spy Yoshikawa provided intelligence to his country ahead of the surprise attack on Pearl Harbour.

Cold War eSpionage

After the Second World War, a new era of spying emerged during a bitter rivalry

A decades-long power struggle between the US and the USSR began after the collapse of the Third Reich. The nations held opposing ideologies – capitalism versus communism – and had a mutual distrust of one another's intentions. Tensions rose as both powers entered into an arms race and the threat of a devastating nuclear war grew. Espionage was one of the primary methods used to try and break the deadlock. Each of the two superpowers was determined to gain the upper hand, so spies were sent all over the world to gather intelligence about the enemy.

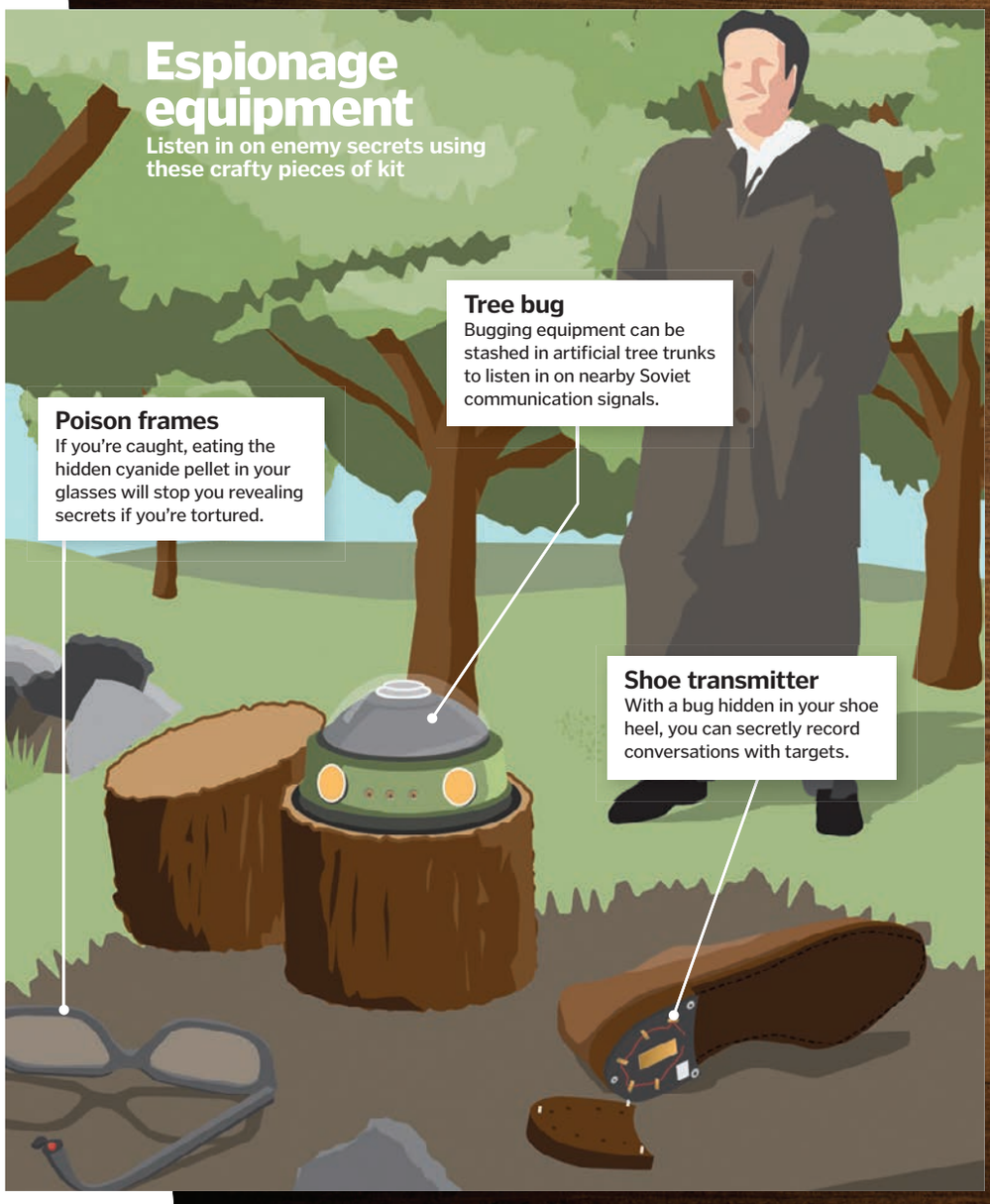
One of the most infamous spy networks behind the Iron Curtain was the Ministry for State Security, commonly known as the Stasi. Operating in East Berlin, the organisation used brutal methods to monitor the activities of the East German capital's citizens. Stasi soldiers would shoot citizens who strayed out of line or tried to make a break for the West.

"The Blackbird could travel at more than three times the speed of sound"

After World War Two, the US set up Project Shamrock and Project Minaret, espionage exercises to monitor all telegraph information entering and leaving the country. Despite this, there were a number of spies operating in the US for the Soviets, gathering information on nuclear weapons, military movements and new technologies.

Aerial reconnaissance continued to play a huge part in intelligence operations. The CIA located Soviet ballistic missiles using spy satellites under the Corona Program. After a CIA pilot was shot down while flying over the USSR in a U-2 spy plane in 1960, the US realised that continuing to use these aircraft was too risky. In response, the record-breaking SR-71 Blackbird was constructed. The Blackbird could travel at more than three times the speed of sound, and reach altitudes high enough to avoid radar detection. The reconnaissance jet even had special radar-absorbing black paint.

The SR-71 Blackbird spy plane could accelerate to supersonic speeds to outfly an incoming missile



HOW TO BE A COLD WAR SPY

Have you got what it takes to go undercover in search of Soviet secrets?

1 CIA training

Only the most successful recruits are selected to be agents. An intensive course including both physical and mental tasks will show who's capable of being a spy.

2 The life of a spy

To avoid arousing suspicion, you must create a believable persona and back-story. The finest agents appear to live completely ordinary lives.

3 Data collection

Your main objective is to determine the Soviets' intentions towards the US. The intelligence you gather could give your country a huge advantage.

4 Decryption skills

The best spies have a talent for code-breaking. Soviet intelligence agents encrypt their messages so you will have to decipher them to reveal any secret plans.

5 Break morale

With your spy persona, you have the ability to spread rumours behind enemy lines. Create fake news stories to cause unrest among citizens or the leadership.

6 Avoid capture at all costs

If you're caught, it's all over. Espionage is a serious offence during the Cold War, carrying the penalty of a long prison sentence or execution.

The 'Illegals Program'

In 2010, ten Russian agents were arrested in the US. Upon interrogation by the FBI, it was revealed that they had been active in the US for years as sleeper agents, spies who weren't always active but resided in the US if ever needed for duty. Known as 'Illegals', some of the spies posed as American citizens with fake names and backgrounds, and had normal jobs. They had been instructed to make contact with academics to obtain secret intelligence that they could report back to Russia. All ten of the spies were charged with conspiracy to act as an agent of a foreign government, and were released into Russian custody as part of a prisoner exchange.

Anna Chapman was arrested after an FBI operation exposed her as a sleeper agent

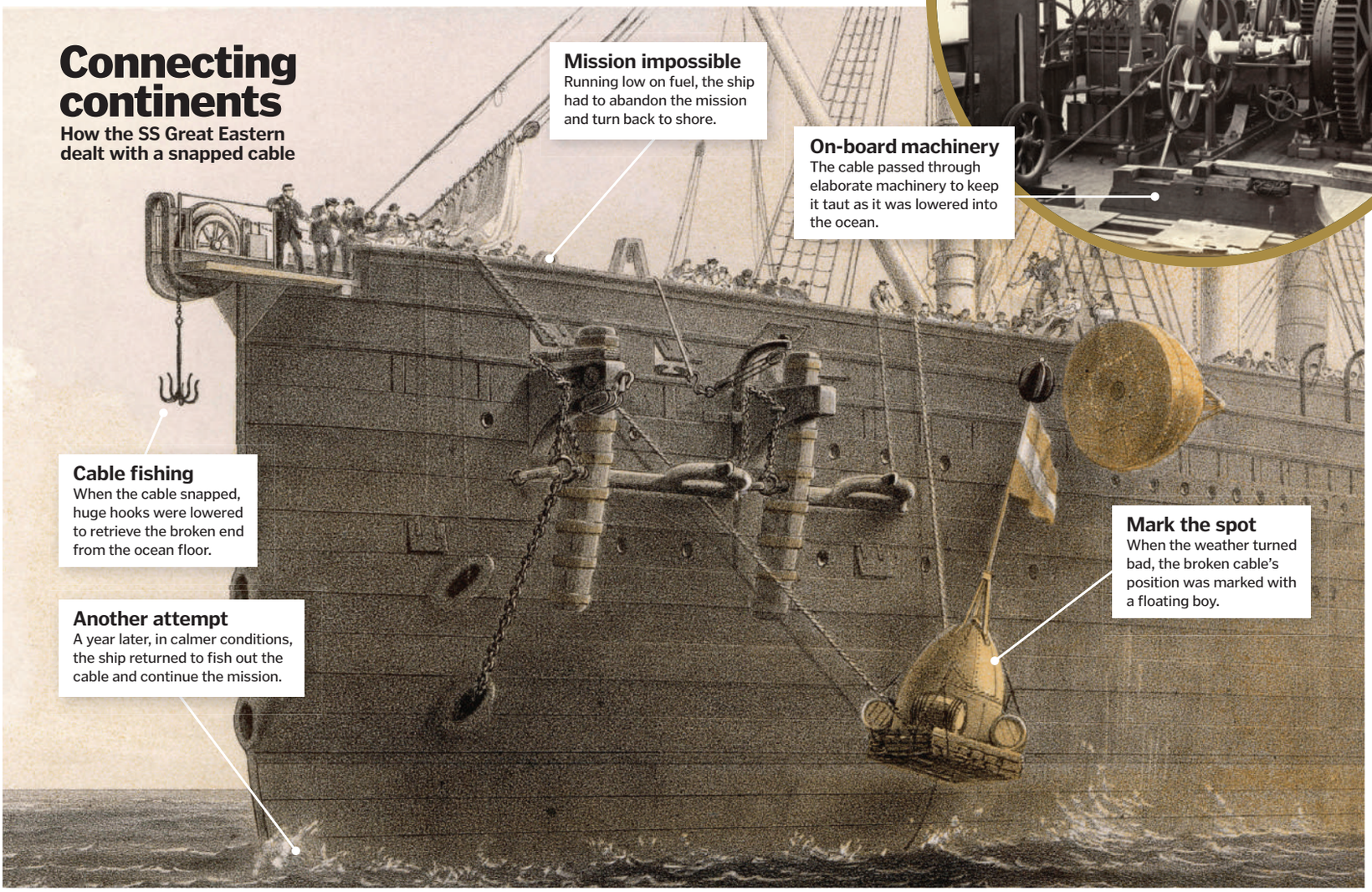
Spies wanted

How intelligence agencies operate in the internet age

Most of us share our lives with friends and family on social media, but this data creates problems if you want to be a spy. Intelligence agencies are struggling to operate effectively in a time where false identities and backstories are hard to create. Most people will leave traces of their real lives online, and facial recognition software can potentially use these traces to link an undercover agent to their true identity.

To try and combat this, the UK's Secret Intelligence Service (SIS, or MI6) are planning to hire nearly 1,000 new staff by 2020. In a statement, SIS chief Alex Younger explained: "The information revolution fundamentally changes our operating environment. In five years' time there will be two sorts of intelligence services – those that understand this fact and have prospered, and those that don't and haven't."

Vauxhall Cross in London has been the SIS's headquarters since 1994



The first transatlantic telegraph cables

The mission that connected Britain and North America

These days, it takes less than a second to send a message between Britain and North America, but in 1850, you would have had to wait ten days for your letter to arrive by ship. At the time, networks of overland cables already connected cities and countries, sending electrical signals in Morse code that were received almost instantly at the other end. However, it wasn't until 1851 that these cables were first laid underwater, soon prompting the next big challenge: a transatlantic connection. This would involve the seemingly impossible challenge of laying over 2,500 kilometres of cable beneath the Atlantic Ocean.

The first few attempts to lay the cable failed, but in 1858, the west coast of Ireland and Newfoundland on the Canadian east coast were successfully connected. Messages were exchanged at a rate of a few words per minute for about a month, but in an attempt to increase the transmission speed, the cable's voltage was boosted, causing it to fail.

Six years later, another attempt was made, this time using the SS Great Eastern, the world's largest ship at the time. Its first mission was plagued with disasters and ended with the cable snapping in the middle of the ocean. A year later in 1866, the second attempt succeeded in laying a new cable and even repairing the old one, which served as a back-up for this revolutionary new communication system.

Learn more

Visit London's Guildhall Art Gallery to celebrate the 150th anniversary of the first transatlantic cables, with their *Victorians Decoded: Art and Telegraphy* exhibition. Entry is free and the exhibition will run until 22 January 2017. Visit the website for more info: **www.cityoflondon.gov.uk/victoriansdecoded**

Then and now

You might assume that we've come a long way since the days of communicating via underwater wires, but the truth is, not much has changed. In fact, 99 per cent of all transoceanic digital communication, including phone calls and email, is made possible by networks of cables lying under the oceans.

While the cables used in 1866 were made of copper insulated with layers of hemp, iron and a type of tree resin called gutta-percha, nowadays we use fibre-optic cables instead. They are still laid by ships but can transmit 84 billion words per second, which is a vast improvement on a few words per minute.

Companies carefully plot where to lay cables, avoiding reefs, shipwrecks and ocean trenches

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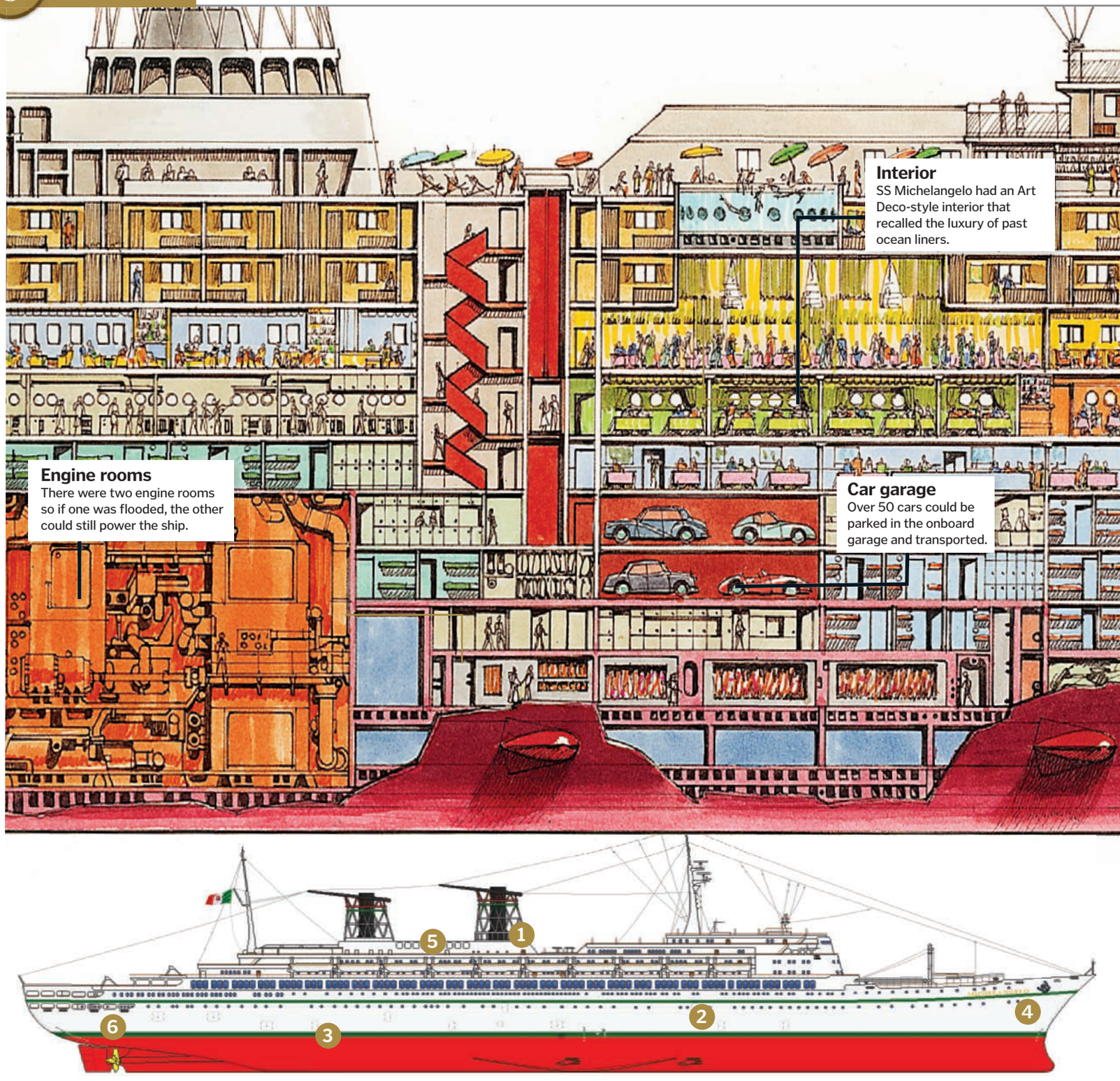


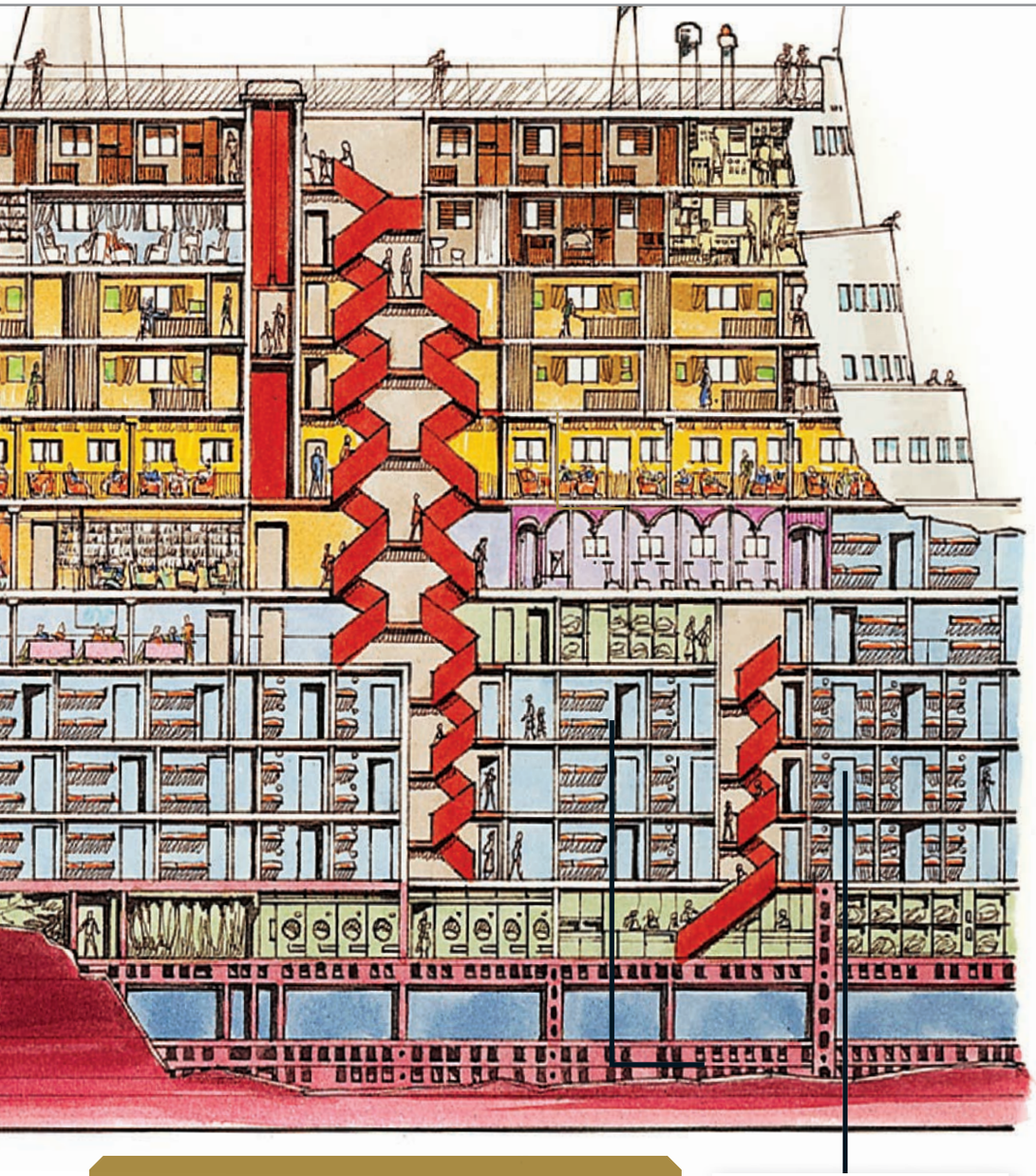
SS Michelangelo

A luxurious liner that was one of the last ships to be built solely for transatlantic travel

In the 1960s, developments in aviation were threatening the once hugely popular liner industry. A vessel that tried to buck the trend was SS Michelangelo, named after the famous Renaissance artist. Along with its sister ship, SS Raffaello, they were the two longest Italian ocean liners ever built.

SS Michelangelo was redesigned numerous times during its construction. An early problem was excessive vibration in the ship's stern when travelling at speed. This was first detected during the liner's sea trials and was later fixed by modifications to the ship's propellers. The changes also gave Michelangelo a higher top speed of nearly 60 kilometres per hour. The funnels had a lattice-shaped structure, a feature that is now included on modern cruise ships to make them more streamlined.

SS Michelangelo took five years to complete and made its maiden voyage to New York on 12 May 1965, carrying 1,495 passengers. As it was nowhere



Inside the Michelangelo

Explore the inner workings of this luxurious ocean liner

1. Funnels
The unconventional funnels were designed to disperse fumes away from the passengers on deck.

2. Colour scheme
Most of the exterior was painted in white rather than the traditional black, to suit the Mediterranean climate.

3. Stabliser system
The ship used an anti-rolling system to prevent passengers from feeling seasick during the voyage.

4. Dimensions
The vessel was 276.2m in length, 0.7m longer than its sister ship, the SS Raffaello.

5. Onboard pets
Kennels between the two funnels allowed passengers to bring their pets on board.

6. Power
Huge steam turbines powered twin propellers, making Michelangelo the fifth fastest ocean liner at the time.

Cabins
The ship could carry a total of 1,775 passengers, with a choice of first-class, second-class and tourist cabins.

Life on board

The liners operated a three-class system: first class, second class and tourist class. The only difference on board the Michelangelo was that second class was officially named 'cabin class', as these guests didn't want to be labelled as 'second class'. Every passenger could experience and appreciate the ship's grandeur and the array of modern technology on board.

The ship had 30 lounges, three nightclubs and even a cinema. The social areas had televisions for entertainment and when the ship was too far from the coast to receive a signal, a closed circuit TV system showed areas of the ship on the screens. The ship's swimming pools had infrared lamps to keep the water warm, while air conditioning systems were used throughout the ship for climate control.

The end of the line

The defection of tourists from the seas to the skies prevented SS Michelangelo from ever being profitable. A rapid decrease in passengers in its final years meant the crew often outnumbered the guests. On its final Atlantic crossing in June 1975, the library and laundry were closed and supplies of alcohol and cigarettes, which hadn't been stocked up, soon began to dwindle.

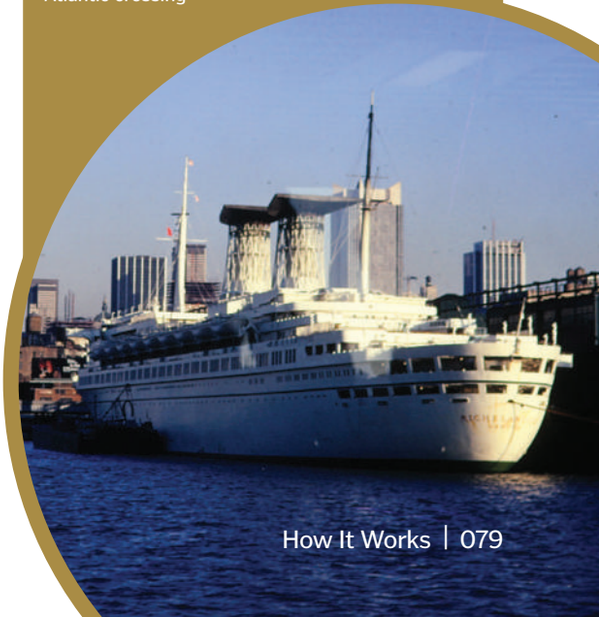
Upon its final return to Italy, Michelangelo was greeted in Italy by thousands of people. It was retired to the dockyard but temporarily saved from the scrapyard by the Shah of Iran, who turned it into a moored military barrack. It was eventually scrapped in 1991.

1,202 passengers were on board for the ocean liner's final voyage, which was its 121st Atlantic crossing

"The ship was intended to be the most luxurious way to cross the Atlantic"

near a match for the speed of air travel, the ship was intended to be the most luxurious way to cross the Atlantic. In 1966, a voyage during a storm led to the deaths of two passengers and one crewmember, and left over 50 people injured. This prompted the designers to replace the aluminium plating of the exterior with steel.

Despite this setback, the ship was popular with the Italian public, who gave it the nickname 'Mic'. Inevitably though, the introduction of more powerful and spacious airplanes, like the Boeing 747, was too much for the ship to compete with. Air travel became cheaper and more efficient and by the late-1970s, cross-Atlantic liners were obsolete.



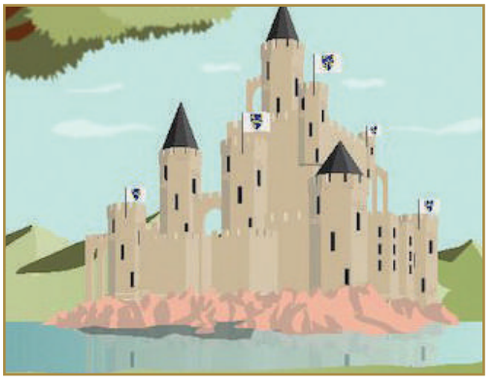
How to become a knight

The intensive training required to achieve knighthood in the Middle Ages

Knights were mounted armoured warriors of the Medieval era. Their place in society was below lords and above peasants and they would earn a living by protecting the realm from attack. In return, the nobility would grant land to the knights but the wealthy barons would only hire those who were skilled in combat. A boy's education could take over ten years as they progressed from page to squire to mounted warrior. The apprenticeship may have begun on a wooden horse in a manor house, but it many cases it finished on a stallion in the heat of battle.

The road to knighthood

From page to knight, training was an arduous yet rewarding journey



1 Starting out

Although it was technically possible for any boy to become a knight, those born into nobility had a distinct advantage. Training was expensive, and they would also need to be kitted out with weapons and a horse. Because of this, in most cases only the very rich could afford to become knights.

2 A young page

The journey to knighthood began as a page. At the age of seven, a boy was sent away to a noble household to serve a knight. Here, he would be taught chivalry – the qualities expected from a knight, including courage and honour – and other skills such as archery and swordsmanship.

3 Horsemanship

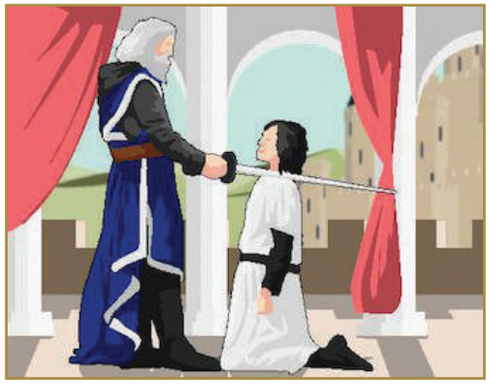
One of the most important skills a trainee knight needed to master was riding a horse. Pages practised on wooden horses until they became squires at the age of 14. As well as riding, the squires would also help take care of the horses and clean the knight's armour.

4 First taste of battle

There's no better training than experiencing battle first-hand. A military force in the Middle Ages needed every man it could muster and knights that graced the battlefield often had squires. All the techniques and skills learnt in training led to this.

5 The making of a knight

Further battles would provide more opportunities for squires to strengthen their fighting skills. Now a relative veteran, they could gain experience in different situations such as mounted attacks, siege warfare and close-quarters combat.



6 Arise, Sir Knight!

If a squire had proven himself to be skilled and brave on the battlefield, he would be given his knighthood at the age of 21. During the 'dubbing' ceremony, he would kneel before another knight, a king or a lord, and be tapped on the shoulder with a sword.

Spinning wheels

Discover how a simple wheel makes spinning yarn easy

Start spinning
As the drive wheel spins, it turns the flyer, twisting the wool into yarn and winding it around the bobbin.

Bobbin and flyer
An existing piece of yarn is wound around the bobbin, which is slotted onto the U-shaped flyer.

Orifice
The yarn is pulled through an opening at one end of the flyer called the orifice.

Attaching the wool
Here, wool fibres are attached to the end of the yarn and held in place by the spinner's dexterous fingers.

Drive wheel
The footman spins the drive wheel, which is attached to the flyer with a drive band.

Treadle and footman
The spinner presses their foot on and off the treadle, which moves a wooden pole – called the footman – up and down.

The wheel turns both the flyer and the bobbin, so the yarn is wound up neatly as it is spun

The Library of Alexandria

What happened to the largest and most significant library of the ancient world?

The remains of the library could be lying underneath the modern city of Alexandria in Egypt

Before the 3rd century BCE, libraries were only used to store and conserve texts about local heritage and traditions. But in 295 BCE, the King of Macedonia, Ptolemy I Soter, tasked his royal adviser Demetrius of Phaleron with setting up a library filled with a copy of every text in the world. It was built in the empire's capital Alexandria, in the grounds of the 'Musaeum', a place of study for some the world's greatest thinkers. It is thought that at its peak it held some half a million scrolls, prompting a second 'daughter' library to be later established in the temple of Serapis, just south of the city. The only evidence we have for the libraries' existence is accounts in ancient texts, and exactly what happened to them is the subject of much debate. Some say they were accidentally destroyed by Julius Caesar in 48 BCE when he set fire to ships in the city's harbour and the flames spread. Others claim Emperor Theodosius destroyed them in an attempt to wipe out paganism in 391 CE.

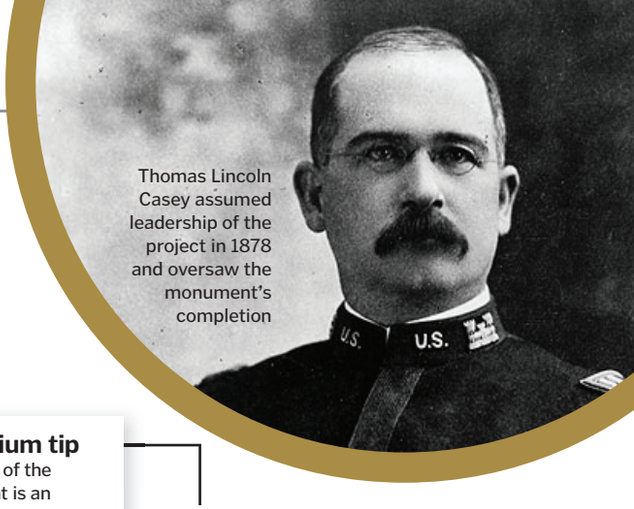
The Washington Monument

Inside the US capital's iconic marble obelisk that commemorates the achievements of the nation's first president

Standing tall above the US capital city, the Washington Monument is a constant reminder of the legacy of founding father George Washington. As the first president of the United States, he is one of the most important figures in the nation's history.

The 169-metre-high monument was designed by Robert Mills in the shape of an Ancient Egyptian obelisk. It started out as a private project that was financed by the Washington National Monument Society, with Mills contributing the chosen design. A crowd of around 20,000 Americans gathered to watch as the first cornerstone was laid on 4 July 1848.

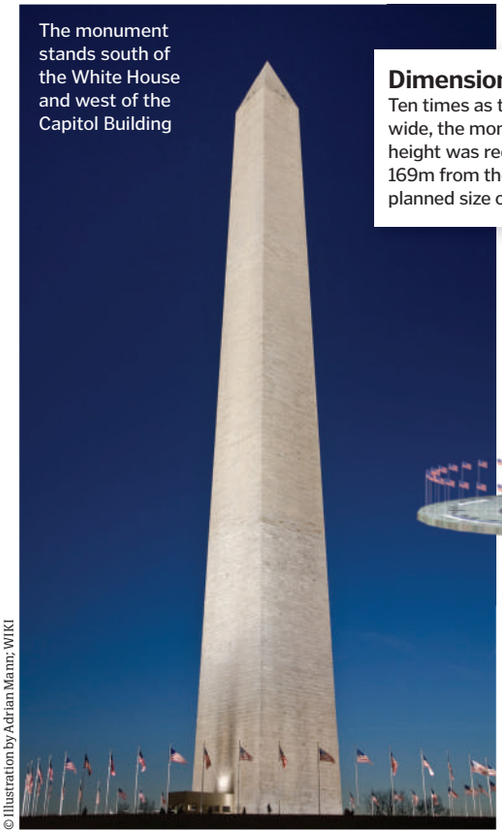
However, the project soon ran into issues. In 1854, the society was declared bankrupt, and a year later Mills died. Construction was halted throughout the US Civil War and was only restarted in 1876. The US Congress took control over construction and things ran much more smoothly. The monument was finally completed in 1884 and eventually opened to the public four years later.



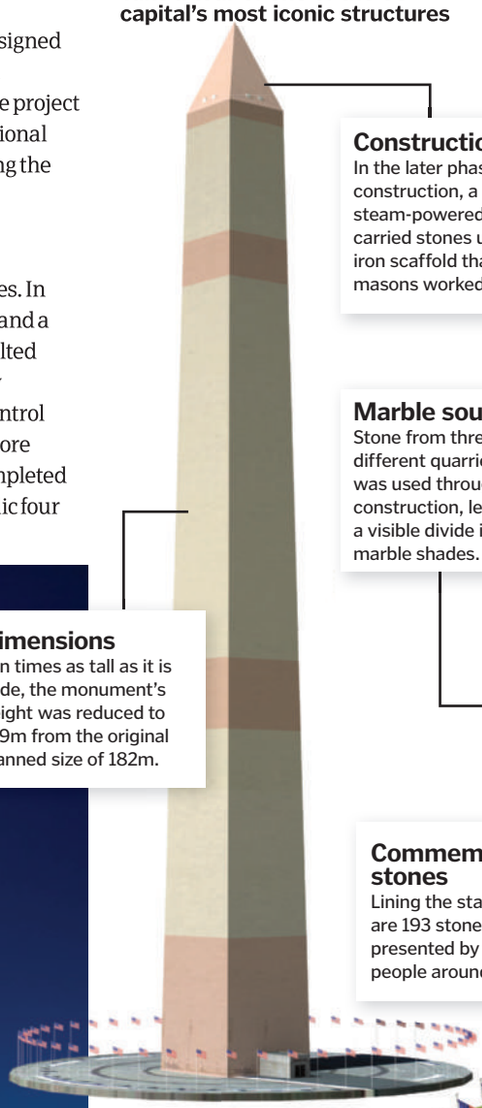
Thomas Lincoln Casey assumed leadership of the project in 1878 and oversaw the monument's completion

Inside the Washington Monument

Take a tour of one of the US capital's most iconic structures



The monument stands south of the White House and west of the Capitol Building



Aluminium tip
At the top of the monument is an aluminium cap, originally intended to serve as a lightning rod.

Steam-powered lift
In 1888, a steam-powered lift was installed that could take visitors to the observation deck in 12 minutes. The first electric lift was added in 1901, and has been updated several times since.

Construction
In the later phases of construction, a steam-powered lift carried stones up the iron scaffold that the masons worked from.

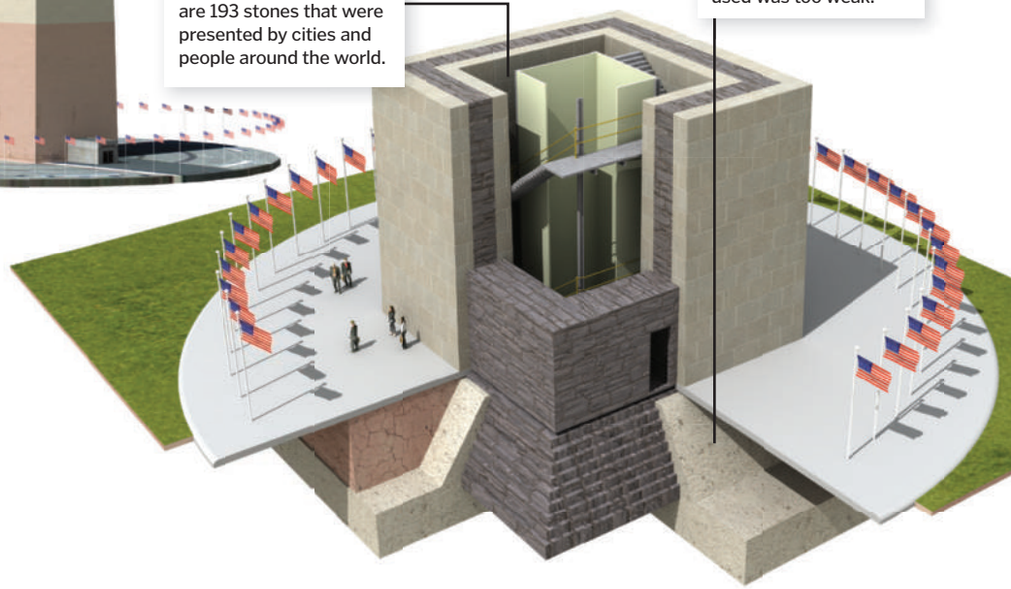
Iron staircase
Inside the tower is an 897-step, 50-flight spiral staircase that takes about 20 minutes to ascend.

Marble sources
Stone from three different quarries was used throughout construction, leaving a visible divide in the marble shades.

Dimensions
Ten times as tall as it is wide, the monument's height was reduced to 169m from the original planned size of 182m.

Foundations
Concrete was added to the monument's foundations part way through construction, as the original material used was too weak.

Commemorative stones
Lining the stairwell, there are 193 stones that were presented by cities and people around the world.



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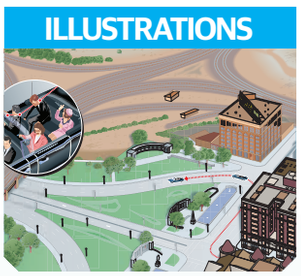

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MEET THE EXPERTS

Who's answering your questions this month?

Laura Mears

Laura studied biomedical science at King's College London and has a master's from Cambridge. She escaped the lab to pursue a career in science communication and also develops educational video games.

Alexandra Cheung

Having earned degrees from the University of Nottingham and Imperial College London, Alex has worked at many prestigious institutions, including CERN, London's Science Museum and the Institute of Physics.

Tom Lean

Tom is a historian of science at the British Library where he works on oral history projects. He recently published his first book, *Electronic Dreams: How 1980s Britain Learned To Love The Home Computer*.

Shanna Freeman

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

Joanna Stass

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

Concorde travelled at twice the speed of sound, reaching 2,170km/h

Why did Concorde stop flying?

Izzy Rowland

With increased oil prices and reduced demand for flights following the 9/11 attacks, the gas-guzzling Concorde became unprofitable to run and was retired in 2003. Concorde was the world's first commercial supersonic jet, and had been in service since 1976. With only 14 aircraft in service, upkeep of Concorde was expensive. It also consumed over twice as much fuel per kilometre as a standard aircraft. Although the supersonic aircraft cut the journey time of a London to New York flight down from seven or eight to 3.5 hours, tickets were prohibitively expensive. A fatal Concorde crash in 2000 also caused a slump in demand. **AC**

Is there such a thing as a 'male' or 'female' brain?

Denise Albert

In 2015, a study led by Daphna Joel at Tel Aviv University in Israel looked at MRI scans of more than 1,400 different brains belonging to both men and women. Researchers looked at the various anatomical traits, such as size, weight and tissue thickness, of the different parts of each brain and found 29 brain regions that are generally different sizes in males and females. However, looking at each individual brain scan, they found that less than eight per cent had all of the brain features that typically belong to one particular gender, as the majority had a mixture of both 'male' and 'female' traits. **JS**

A recent study has debunked the idea that there are two distinct brain genders

The coldest natural temperature recorded on Earth was 183 Kelvin (-90 degrees Celsius) in Antarctica

Why can't we cool anything down to absolute zero?

Seamus Richards

The colder a substance gets, the more energy it takes to remove heat from it, making it theoretically impossible to cool something to absolute zero (0 degrees Kelvin or -273 degrees Celsius). The coldest known temperature in our universe is 2.73 Kelvin, experienced in the outer reaches of the universe, but in the lab, scientists have achieved 0.45 nanokelvins, a mere half-a-billionth of a degree above absolute zero. At this temperature, researchers held atoms in place with a combined magnetic and gravitational field, since no container can be made that cold. **AC**

NASA's Juno mission may uncover some of Jupiter's secrets

What is at a gas giant's centre?

Ella Wright

The cores of gas giants are believed to be either solid rock or a molten ball of metal and liquid compounds. Gas giants are huge planets composed almost entirely of gases such as hydrogen and helium. Under the exceedingly high pressure and temperature conditions at a gas giant's core, hydrogen becomes a liquid or even a metal. What we know about Jupiter's core is mostly deduced from the properties of its gravitational field. These studies suggest that between three and 15 per cent of its mass is concentrated in a dense region at its core, although its exact composition is unknown. **AC**

How much air do we breathe in a lifetime?

William Barker

The tidal volume, the amount of air breathed in and out with each breath during normal breathing, is around 0.5 litres in an adult. With an average of 14 breaths per minute, that makes seven litres of air per minute, 420 litres per hour, and 10,080 litres per day. Following this logic, you will breathe more than 3.6 million litres of air in a year, and with an average life expectancy in the UK of 81 years, you can expect to breathe almost 300 million litres in the course of your lifetime. That's enough to fill nearly 120 Olympic swimming pools! **LM**

Every minute, you breathe around seven litres of air

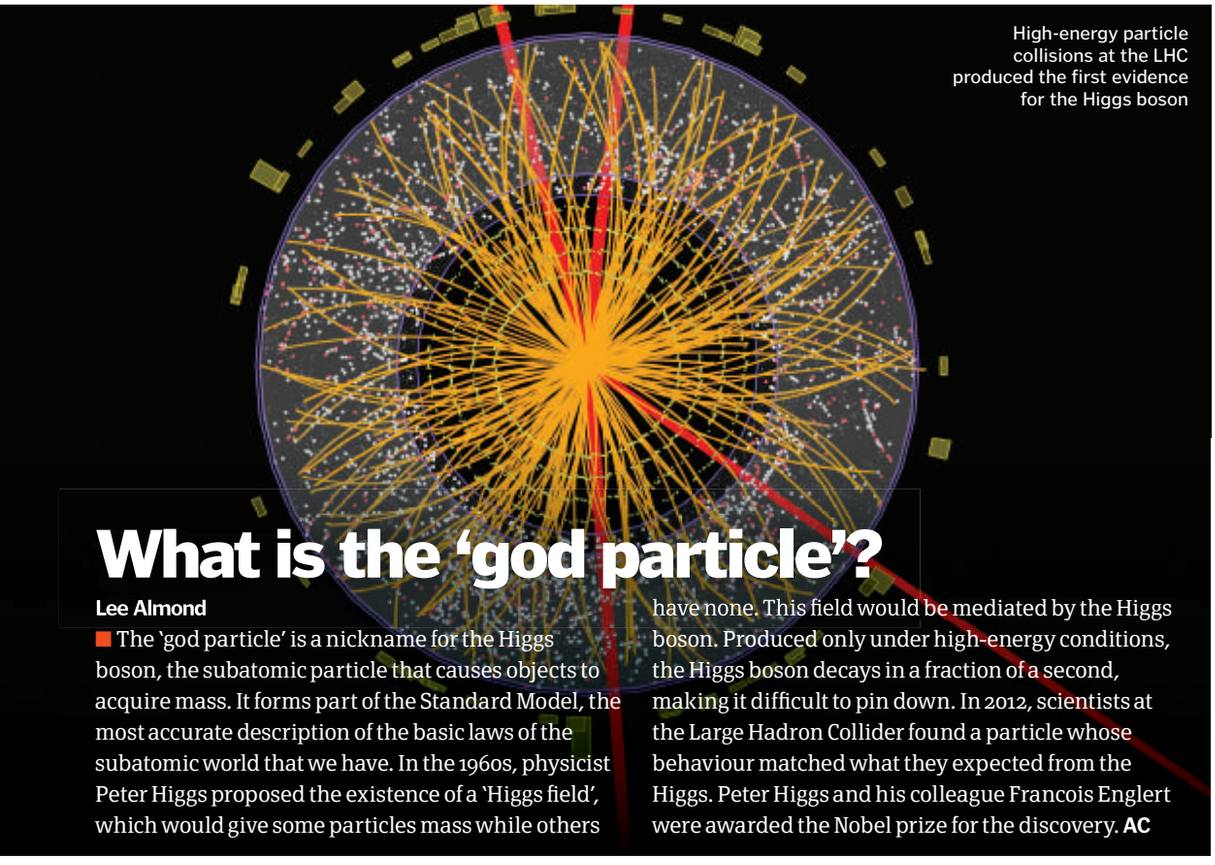
BRAIN DUMP

Antivirus software has to deal with constantly evolving threats from new viruses

How does antivirus software work?

Kayleigh Tees

Antivirus software basically does two jobs. First it identifies a virus threat, then it does something about it. The major technique for identifying viruses is to compare what's happening on your computer with a 'dictionary' of viruses, and react if a match is detected. As there are always new viruses, the dictionary needs to be regularly updated. However, antivirus software also looks out for programs behaving suspiciously, doing the sort of things viruses do, so it can alert you to things that might be viruses but aren't in its dictionary. Antivirus software runs constantly, checking on your computer's activities as they happen, but can also scan all your computer's files. Depending on how a virus is detected, the antivirus software might warn you not to use an infected program or webpage before the virus actually strikes, or if your files are infected, it will quarantine them or delete the virus code. **TL**


High-energy particle collisions at the LHC produced the first evidence for the Higgs boson

What is the 'god particle'?

Lee Almond

The 'god particle' is a nickname for the Higgs boson, the subatomic particle that causes objects to acquire mass. It forms part of the Standard Model, the most accurate description of the basic laws of the subatomic world that we have. In the 1960s, physicist Peter Higgs proposed the existence of a 'Higgs field', which would give some particles mass while others have none. This field would be mediated by the Higgs boson. Produced only under high-energy conditions, the Higgs boson decays in a fraction of a second, making it difficult to pin down. In 2012, scientists at the Large Hadron Collider found a particle whose behaviour matched what they expected from the Higgs. Peter Higgs and his colleague Francois Englert were awarded the Nobel prize for the discovery. **AC**

FASCINATING FACTS

What is the difference between perfume and eau de toilette?

It is to do with the concentration of aromatic oils. Perfume is long-lasting and expensive, made up of up to 40 per cent aromatic oils. Eau de toilette has up to 15 per cent and is cheaper, but fades away faster. **SF**


How long a fragrance lasts depends on its concentration of essences

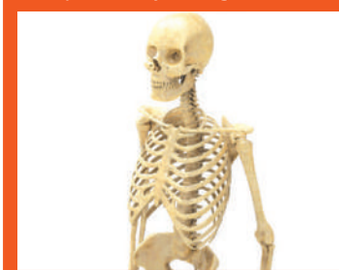
Would headphones tangle in space?

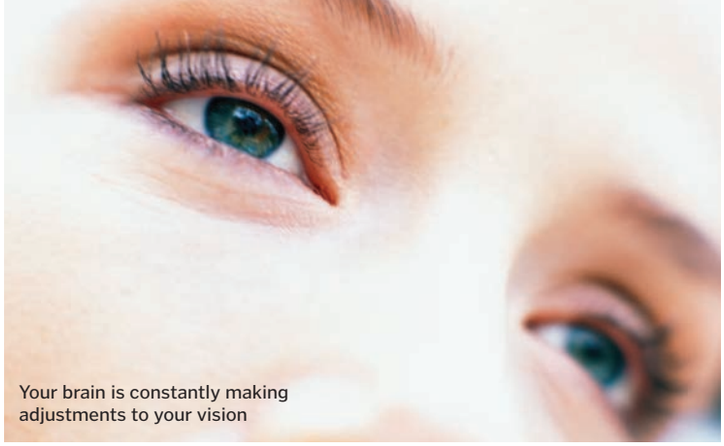
As movement and wire length are most important in causing headphone tangles, they are just as likely to get tangled in space – maybe even more tangled, as they are freer to move without gravity. **TL**


Headphone tangles are just as likely a problem in space as on Earth

How heavy are your bones?

Your skeleton accounts for around 15 per cent of your body weight. For a 70-kilogram adult, that's around 10.5 kilograms – a similar weight to an airplane carry-on bag. **LM**


Your skeleton makes up just over a seventh of your weight



Your brain is constantly making adjustments to your vision

Why do your eyes appear to flicker when you look out the window of a moving train?

Chris Thorne

Your eyes are constantly adjusting to keep track of your surroundings. For example, if you are following a runner as they move around a track, you can trace their position by slowly panning your eyes across the landscape using a motion known as 'smooth pursuit'. But on a moving train, you can only track each passing object for a short time before it goes out of view. At that point, your eyes flick back to a new target, in a motion known as a 'saccade'. Quickly repeating these two movements makes your eyes look as if they're flickering. **LM**

Can you drink rainwater?

Sara Cesare

Rainwater can become contaminated as it falls through the air by sulphur dioxide and nitrogen oxide (forming acid rain). These gases enter the atmosphere from manufacturing, vehicle emissions, and power plants that burn fossil fuels. The rain may also contain dust or soot. If you have a home rainwater collection tank and the water runs off your roof, it may contain contaminants from roofing, dirt, insects or bird faeces. It must also be properly stored to keep it free of bacteria. You must treat rainwater before drinking it, by boiling, filtering, and/or adding chlorine or iodine. **SF**

Rainwater collected in harvesting tanks can be used for other purposes, such as irrigation

Is it dangerous to stare into the microwave?

Hannah Brockheimer

Microwaves, the short radio waves microwave ovens produce to cook food, carry a huge amount of energy that can be harmful to humans. However, there is no reason this should stop you from watching your dinner spinning around in there. The microwaves are safely sealed within the metal contraption, which turns off as soon as the door is opened, and the metal mesh on the inside of the glass has holes that are too small for them to pass through. Even if your microwave was somehow 'leaking', only very small amounts of electromagnetic radiation would travel outside the cooking compartment, not enough to cause you any harm. **JS**

Even a 'leaky' microwave would produce less electromagnetic radiation than a mobile phone

It's possible the proverb was mistranslated, and its original meaning was that feeding a cold 'staves off' a fever

Is there any truth in the phrase 'feed a cold, starve a fever'?

Theo Case-Browning

This proverb is thought to date back to the 14th century, but there is not enough scientific evidence to support it. A study conducted in 2002 found that patients who ate a meal had higher levels of molecules that trigger the immune response to viral infections (like the common cold), while patients who fasted had higher levels of substances that promote the immune response to bacterial infections (that can cause fever). However, this study only involved six volunteers, so there is not enough data to provide conclusive evidence. The best advice is to follow your appetite, and ensure you're still drinking lots of water to stay hydrated. **JS**

What would happen if you could open a window on a plane in mid-air?

Lily Morrissey

The atmosphere in an airplane is at a higher pressure than the atmosphere the plane is flying through. If you could open a window, the cabin would decompress. This is because air pressure always tries to balance, so high-pressure air will flow towards lower-pressure areas. Loose objects would be sucked out the window, and it would quickly become hard to breathe. That's why plane windows don't open! **TL**

Opening a plane window in flight would be very dangerous

BRAIN DUMP

This 3D bioprinter lays down living cells instead of ink

How do 3D printers print human tissue?

Gillian Sinclare

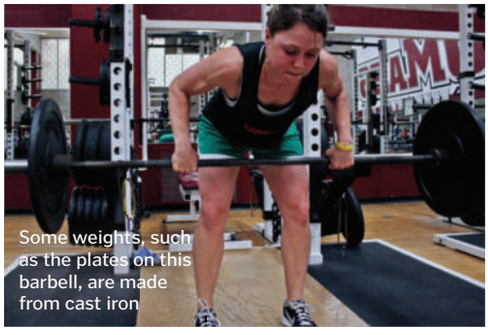
At the heart of it, bioprinters are very similar to normal printers. In fact, the very earliest versions simply used the nozzles from regular inkjet printers, because they just happened to make droplets the right size to print human cells. Cells like to grow together in sheets, but to be printed they have to first be separated. They are then combined with dissolvable gels to help them stay in the right configuration while they grow. The cells are carefully laid down in layers with the gel, and over time, they multiply to fill the gaps. So far, there has been real success in printing simpler tissues like skin, cartilage, and muscle, but organs are much more complicated. They have lots of different types of cells, arranged in complex 3D structures, so it's going to take a long time before we crack the designs needed to print them. **LM**

What is the difference between 'hard' and 'soft' water?

Lucy Mills

Depending on where you live, the water that flows out of your household taps could be classed as hard or soft. While rainwater is considered 'soft' (because it is naturally weakly acidic), if it flows over or passes through certain types of rock before it reaches your home, it can become more alkaline and therefore 'hard'. This is because mineral compounds, such as calcium or magnesium ions, dissolve into the water from rocks such as chalk and limestone. Most people think hard water tastes better than soft water and it contains minerals that are good for your bones and teeth, but it also has some drawbacks. When washing with hard water and soap, it is more difficult to form a decent lather, and mineral compounds in the water react with the soap to form scum. Also, if hard water is heated it can form limescale, which coats the heating elements found in kettles and washing machines, reducing their overall efficiency. **JS**

Some water treatment plants soften water by adding lime, so it causes less damage to your appliances



Some weights, such as the plates on this barbell, are made from cast iron

What material are weights made from?

Laurence York

Gym weights – including barbells, dumbbells, and those used on weight-lifting equipment – can be made from various materials. The weights are called plates, and on barbells and dumbbells, the centre piece is the bar. The least expensive plates are made from plastic or plastic filled with cement, but they can also be made of steel or cast iron. Metal plates are the most durable, and can be coated in plastic to prevent rusting and protect flooring. **SF**

Why do TVs and computers get dusty?

New flatscreen televisions attract far less dust than old boxy television sets

Catherine Green

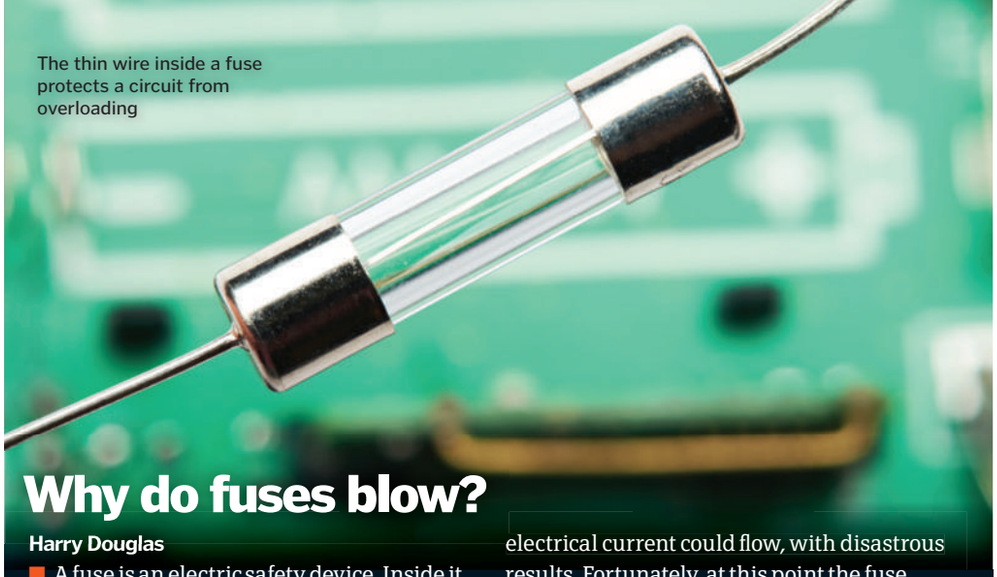
Electrical devices attract dust because they generate static electricity. Older, boxy televisions get very dusty because quite a strong positive charge builds up on the screen and attracts dust particles that have a negative charge. Modern, flatscreen televisions actually attract far less dust because they work at much lower voltages that don't result in a build-up of static, but dust shows up clearly on their shiny black surfaces, making them look more dusty. Computers get dusty because, just like a vacuum cleaner, their cooling fans suck dust towards them and it settles on and around the equipment. **TL**

FASCINATING FACTS

Who invented milk cartons?

George Stonegate

The first paper milk carton was invented in 1915 in Ohio, US, by John Van Wormer. Its design remains largely unchanged, although the inside is now coated with polyethylene to make it waterproof. **AC**



The thin wire inside a fuse protects a circuit from overloading

Why do fuses blow?

Harry Douglas

A fuse is an electric safety device. Inside it is a thin section of wire designed to melt if too much electric current flows through it. If the circuit the fuse is on gets overloaded, if there's a short circuit, or if an appliance malfunctions, then a larger than intended electrical current could flow, with disastrous results. Fortunately, at this point the fuse wire should melt, breaking the electric circuit and preventing further damage or even fire if the current were to continue to flow. So a blown fuse shows that it has done its job properly. **TL**

How do we know what the dinosaurs ate?

Jack Wheeler

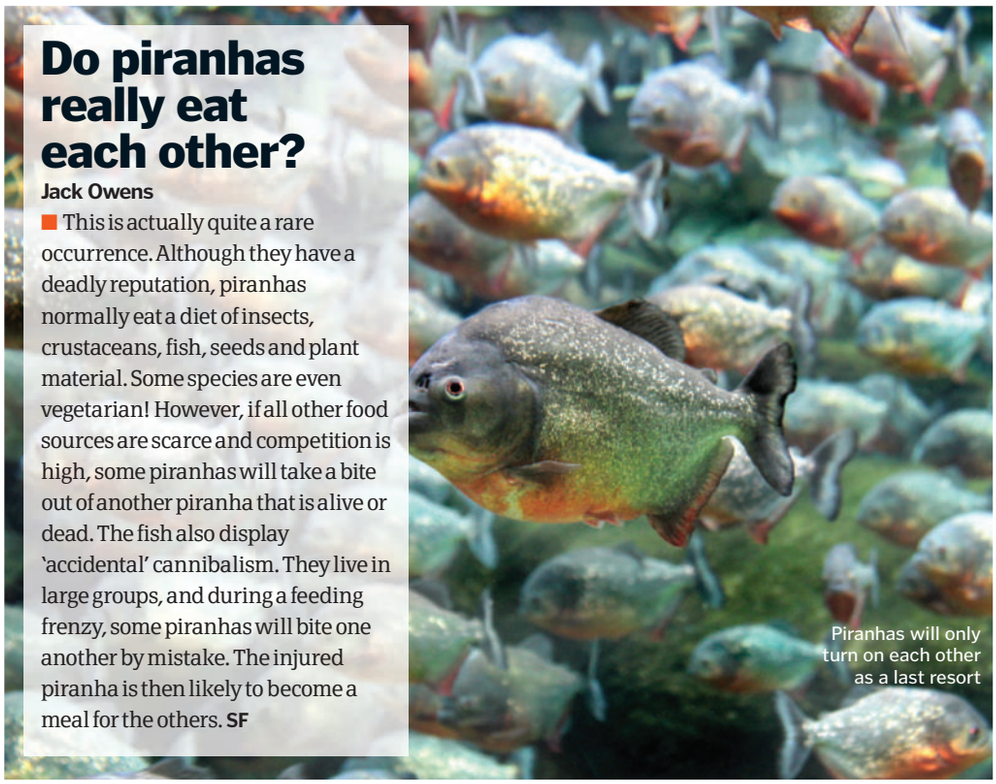
The size and shape of dinosaur fossils can give us clues about their diet. Dinosaurs that hunted prey tend to have body shapes similar to today's carnivores, such as big cats. Plant-eaters had larger, denser body types, similar to modern-day elephants. If the fossil has intact teeth, we get even more information. Dinosaurs with serrated and pointed teeth were likely carnivores, while those with big, flat teeth were more likely to be herbivores. We think there were some omnivores because some fossils have varied teeth. If the fossils have items in the area of their abdominal cavity, we can try to interpret their stomach contents. Pine needles, pine cones, or shards of bone point to one type of diet or the other. We have also found coprolite – fossilised dinosaur excrement – containing ground-up bone fragments. Finally, examining other fossils found around the dinosaur may also help determine what it ate. **SF**

Camarasaurus was a herbivorous dinosaur with flat, wide teeth

Do piranhas really eat each other?

Jack Owens

This is actually quite a rare occurrence. Although they have a deadly reputation, piranhas normally eat a diet of insects, crustaceans, fish, seeds and plant material. Some species are even vegetarian! However, if all other food sources are scarce and competition is high, some piranhas will take a bite out of another piranha that is alive or dead. The fish also display 'accidental' cannibalism. They live in large groups, and during a feeding frenzy, some piranhas will bite one another by mistake. The injured piranha is then likely to become a meal for the others. **SF**



Piranhas will only turn on each other as a last resort

How efficient is solar power?

Kevin George

With current technology, it's surprisingly inefficient. The Sun strikes Earth with more energy in a day than we would need to power the world for a year, but capturing that energy isn't easy. Solar panels are made up of photovoltaic cells, which convert light energy into electrical current. These cells are often made from silicon, which is only able to absorb a small range of light wavelengths. This results in an efficiency of around 16 to 18 per cent. Using a material called telluride may give up to 30 per cent efficiency, but it is very expensive. **LM**

It's not possible to catch all of the Sun's energy, but we're gradually finding ways to harness more of it

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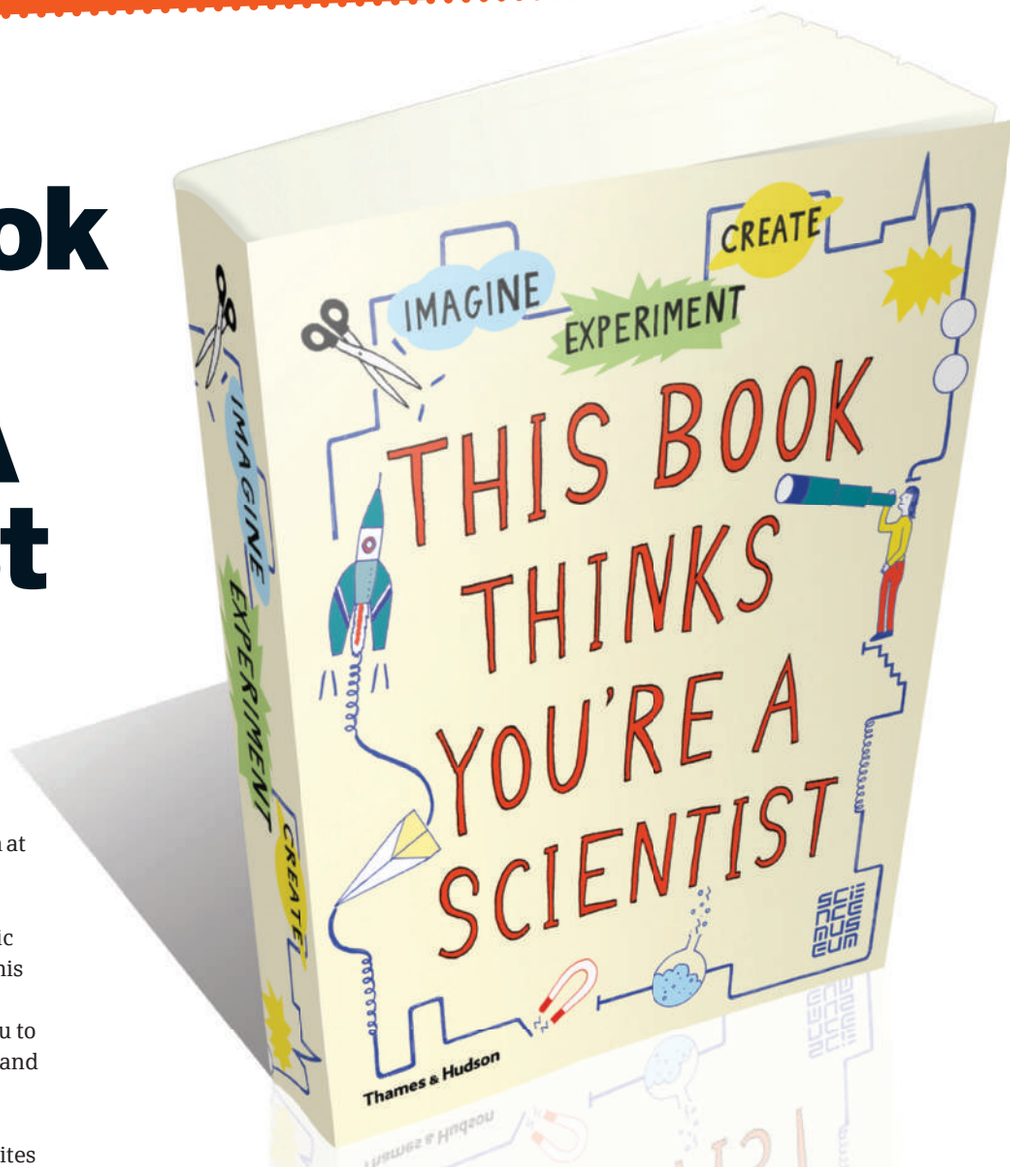
BOOK REVIEWS

The latest releases for curious minds

This Book Thinks You're A Scientist

Try out some silly science in your own lab

- Author: **Science Museum**
- Publisher: **Thames & Hudson**
- Price: **£8.95 / $14.95**
- Release date: **Out now**



Science isn't just something you learn at school, it's something you can see in action all around you, from the way gravity causes objects to fall to the way static electricity makes your hair stand on end. This book, developed in association with the Science Museum in London, encourages you to do just that, with pages full of fun activities and experiments that highlight the everyday science happening before your very eyes. Aimed at children aged seven and up, it invites young readers to ask questions about the world around them, and then discover the answers for themselves by testing out their ideas. With lots of wonderful illustrations and step-by-step instructions that are easy to follow, it's easy to get stuck in and start learning right away.

From the very first page, kids are encouraged to get creative and use their imaginations, as they are tasked with drawing themselves as super scientists, complete with a cape and an array of science gadgets. From there the fun and silliness continues, with experiments about forces and motion, mathematics, Earth and space, light, matter, sound, electricity and magnetism. Each activity is accompanied by a 'How It Works' box, explaining the science behind the experiment in simple terms, and the pages are also peppered with humour to keep little ones laughing as well as learning.

As this is an activity book, which requires kids to draw on and cut out the pages, you will really only get one use out of it. However, that one use is likely to keep the kids entertained for hours, which will prove useful for a rainy day or a long school holiday.

All of the experiments use items you should already have at home (thankfully without creating too much mess) and many can be done outdoors, encouraging your children to get active too. With its enchanting, hand-drawn, informal style and ability to make science fun, this book is perfect for kids with inquisitive minds, and for parents who want to learn a thing or two as well.

★★★★★

YOU MAY ALSO LIKE...

How It Works Book Of Junior Science

Author: **Imagine Publishing**
Publisher: **Imagine Publishing**
Price: **£9.99 (approx. $13)**
Release date: **Out now**

Packed full of fascinating facts, fun trivia and easy-to-follow diagrams, this guide will feed young minds with all the information they need about the amazing world we live in.

My Crazy Inventions Sketchbook

Author: **Andrew Rae & Lisa Regan**
Publisher: **Laurence King**
Price: **£9.95 / $15.95**
Release date: **Out now**

Ready to inspire the next generation of engineers, this book features stunning drawings of weird inventions and encourages kids to draw their own.

See Inside How Things Work

Author: **Conrad Mason**
Publisher: **Usborne**
Price: **£9.99 (approx. $13)**
Release date: **Out now**

Lift the flaps to take a look inside some of the world's most amazing machines, from car engines and submarines to toilets and microwaves, and discover how they work.

What's Really Happening To Our Planet?

Simplifying the facts of climate change

- Author: **Tony Juniper**
- Publisher: **Dorling Kindersley**
- Price: **£12.99 / $19.95**
- Release date: **Out now**

This brilliantly illustrated work is not only extremely well-researched and written in an easy-to-understand way, it's also incredibly important. With so many conflicting reports on what is happening to our planet, Juniper lays out the facts of the current situation. While you might suspect this is all about climate change, there is much more to discuss – a rising population, greater demand for fresh water, and the increase in social integration thanks to the internet. Of course, the fundamental point is that, without a change, the planet will ultimately be uninhabitable. However, the genius of this book is that this point is made slowly, and backed up by so much evidence that you'll likely start changing your lifestyle in hours.

★★★★★

The Middle Ages Unlocked

Look back into a less-documented time period

- Author: **Gillian Polack & Katrin Kania**
- Publisher: **Amberley**
- Price: **£9.99 / $17.95**
- Release date: **Out now**

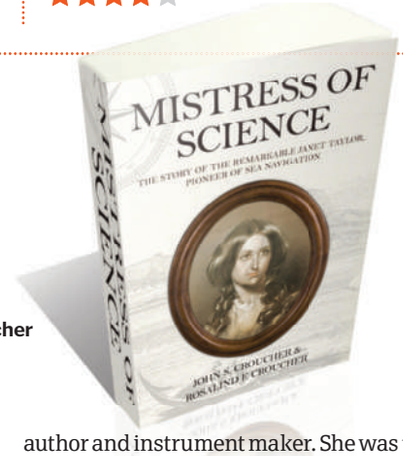
Digging into this period of history can be a little hit-and-miss, due to limited historical documents and various inconsistencies in reporting. However, Polack and Kania pull together threads of what we know about the lifestyle in the Middle Ages, and tie them together neatly and informatively. It is undoubtedly a book that benefits from time – we would recommend dipping in and out, rather than reading through in one sitting. However, it's well-researched and fairly accessible, with no complex terms going unexplained. It really is a strong starting point for those that want to learn more about this fascinating part of history – and one that is rarely documented so completely.

★★★★☆

Mistress Of Science

The story of one woman's extraordinary success in navigation

- Author: **John S Croucher & Rosalind F Croucher**
- Publisher: **Amberley**
- Price: **£20 / £34.95**
- Release date: **Out now**



The early 19th century wasn't the easiest time to be a young woman in science, but Janet Taylor defied convention to become one of the greatest figures in the male-dominated field of sea navigation.

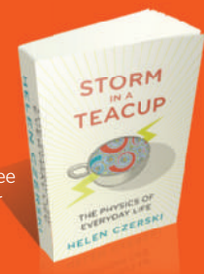
This intriguing book describes how Taylor went from humble beginnings in County Durham, England, to become a talented mathematician, astronomer, author and instrument maker. She was the first woman in 200 years to patent a nautical instrument, and reached the top of her field while also raising a family of eight children and three step-children. The book itself is easy to get into, and it's great to see an overlooked historical figure gaining some well-deserved recognition.

★★★★☆

Storm In A Teacup

Forget string theory – this is the physics of the everyday

- Author: **Helen Czerski**
- Publisher: **Bantam Press**
- Price: **£18.99 / $26.95**
- Release date: **Out now**



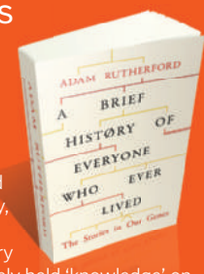
Pick this up and you won't put it down. As you jump from topic to topic, you'll soon see the clever links between them and wonder at how the book ever came together. Czerski is skilled at taking seemingly unrelated topics (whales diving to capture giant squid and a bakery class, for example) and exploring them in a way that not only makes sense, but expands your understanding. The use of everyday topics to explain complex physics in an easily understandable way is only helped by the brilliant narrative style, which is a pleasure to read. You'll be fascinating your friends with everyday science facts for weeks afterwards!

★★★★★

A Brief History Of Everyone Who Ever Lived

A closer look at the plethora of information in your genes

- Author: **Adam Rutherford**
- Publisher: **Orion Publishing**
- Price: **£20 (approx. $26)**
- Release date: **Out now**



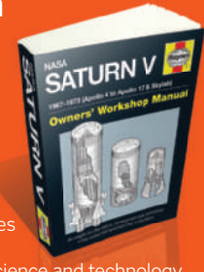
Have you ever thought about where you come from? In his *Brief History*, Rutherford not only makes you consider your ancestry, but he also helps you understand more about genetics. Some of its more revelatory parts show just how out of date most widely held 'knowledge' on the subject really is, but it does a great job of bringing you up to date, and explaining how fluid the world of genetics is. The writing is a little heavier than many popular science books but it's still accessible – we suspect that laymen and experts alike will find something to enjoy.

★★★★☆

NASA Saturn V Owners' Workshop Manual

The incredible feat of engineering that took us to the Moon

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



Until NASA's Space Launch System or SpaceX's Falcon Heavy take off, Saturn V remains the most powerful rocket ever made. This latest Haynes Manual celebrates the iconic rocket in all its glory. Of course, the 'manual' is just an exploration of the science and technology behind the rocket, rather than an instruction book. As with all Haynes manuals though, the book gets technical quickly, meaning you'll need to take everything in if you want to keep up. This title will appeal most to fans of space travel, but even those with a passing interest in science or technology will be inspired.

★★★★☆

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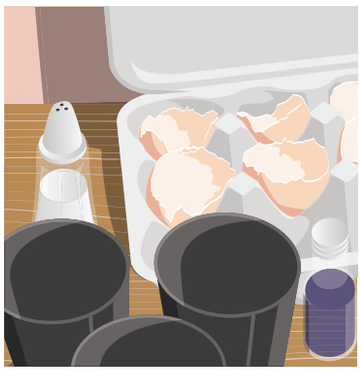
Make your own geode crystals

Learn how to make your own coloured crystals just like those inside rocks



1 Gather your tools

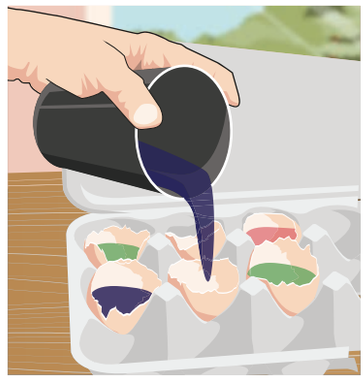
You'll need some eggshells (cracked as close to the narrow end as possible), egg cartons, water, heat-resistant coffee cups, spoons and food colouring. You'll also need to find a collection of soluble solids, which means things that can be dissolved in water. These include salt, sugar and baking soda. You should be able to find some of these at home.

2 Prepare your eggshells

The first thing you need to do is to clean the eggshells with hot water. This will cook the skin on the inside of the shell, known as the egg membrane, which you can peel off using your fingers once you've poured away the water. Make sure all of the skin is removed before continuing to the next step, otherwise mould could grow and ruin your crystals.

3 Make a salty solution

Put your clean eggshells in an egg carton, and then boil some water. Once the water is bubbling nicely, pour some into an empty cup until it is half full – you'll need one half-full cup of water for every eggshell you've prepared. While the water is still hot, add your soluble solid in spoonfuls to each cup and keep adding and stirring until the solid no longer dissolves.



4 Choose your colours

Now it's time to choose what colours we'd like our crystals to be. For every cup you've made choose a colour of food colouring and add it to the salty solution, and then we're ready to pour! Add your coloured solution to the eggshell, filling the empty space as much as you can but being careful not to tip the egg or let the solution overflow.

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

5 Form your crystals

Once you've finished pouring, you need to wait patiently for the water in your solution to evaporate. Find a safe place for your eggshells and leave them overnight. You will return to find the inside of your shells coated in coloured crystals! These have formed like geodes found in nature, as the solids dissolved in the water have had a chance to slowly come together and form crystal structures.

In summary...

Geodes look like any other rocks from the outside, but when we break them open we can see that inside they're hollow and lined with crystal structures. By using an eggshell as the exterior round rock and filling it with water saturated with dissolved solids that form crystal structures, we can simulate this amazing natural process.

NEXT ISSUE
- Colour-changing flowers
- Build a hologram projector

Make water walk

See how water travels via absorption and combine colours to make entirely new ones

1 Pour the water

For this experiment you'll need at least three empty glasses, water, food colouring and paper towels. Leave the middle glass empty and fill the two either side full of water. Next, use food colouring to change the glasses filled with water to different colours. Now's the time to bet your friends that you can combine the colours without pouring any of the liquid…

2 Add paper towels

Take two paper towels and fold them in half lengthwise two times. Then fold them once width-wise and place one end of the towel in a glass filled with coloured water, and the other end in the empty glass next to it. You'll soon be able to see the coloured water 'walking' up the towels and towards the empty glass all on its own. This happens because the paper towels are made of molecules that attract water.

3 Watch the colours combine

After a few hours you'll see that the coloured water has walked its way into the middle glass and is filling it with a different colour of water – which is a mixture of the two colours you started with. To see how other colours combine you can repeat this experiment with different shades of food colouring, or you can set up a longer chain with lots of different colours in a row with empty glasses and see if you can make an entire rainbow of coloured water.

In summary…

Paper towels are absorbent because water is attracted to the sugar molecules that they are made from. When the two come into contact the water is absorbed into the paper so that the two molecules can bond. This attraction is even strong enough to overcome gravity, so we can see the water walk up and along the towel into the empty glass.

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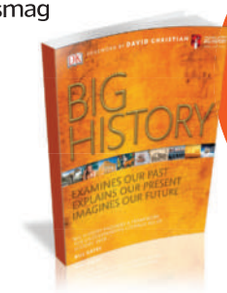

WIN!
AMAZING PRIZE FOR LETTER OF THE MONTH!
BIG HISTORY
Discover our place in the story of our planet with DK's epic tome. It's full of amazing illustrations and infographics that really bring history to life!

Letter of the Month

3,2,1, jump!

Dear **HIW,**

I subscribe to your magazine and think it is a fantastic way to learn, along with your YouTube channel, which I love watching. A question came to mind the other day: what would happen if you stood the world's population as close together as possible and all jumped at the same instant?
Oliver Russell (aged 14)

Thanks for the interesting question, Oliver! There are now more people on Earth than ever before – more than 7 billion of us currently call this planet 'home'. So it seems obvious to think that if we were able to put all of our masses together and jump at the same time, we could make quite an impact on the Earth.

Surprisingly, if everyone were stood shoulder to shoulder for this event, we'd only take up the space of a large city. If we all then jumped 30 centimetres in the air and brought our weight down on the planet (the collective mass of the human race has been estimated at 363 billion kilograms!) then we would move the Earth – but only very, very slightly. In fact, it would move even less than the width of a hydrogen atom. That's because our planet weighs a whole lot more than all of us, and heavy things are difficult to move!


If every human on Earth jumped at the same time the planet would very slightly recoil

What's happening on... Twitter?

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Such an interesting article from @HowItWorksmag on Croatia's Waterfall Paradise: the Plitvice Lakes. A very good read!

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@twinveep
@HowItWorksmag Fab! My son has a physics Masters + planetary & space science – I might surprise him by knowing what he's talking about! :D

@CityWestminster
It's Recycle Week read on @HowItWorksmag how you can get involved and help create a #greenercity

Feeling the heat

Dear **HIW,**

I am a voracious reader and have loved your magazine ever since I got my first issue. The question I would like to ask you is: why do some people sweat when they eat chillies?
Anish Mariathasan (aged 12)

Sweating when eating spicy chillies can really spoil a great meal, and a chemical found in the chilli peppers called capsaicin is to blame.

This chemical activates heat-sensitive receptors in our mouths that tell the brain we're overheating, so the brain starts acting as if we are in an uncomfortably hot room. This results in signals being sent to the sweat glands, and we begin to perspire to try and cool ourselves down.


Chilli peppers contain a chemical known as capsaicin, which is what triggers the sweat response

Titanium in medicine

Dear **HIW,**

What is it about titanium that allows it to bond to animal tissue? Is it unique, or are there other materials that can be used for bodily repair?
Mr R Hickman

When bones are damaged, proteins and growth factors are released that initiate bone repair. If a titanium implant is fitted, the bone will grow and weave around the implant to incorporate the material. Like other biomaterials, titanium and its alloys are good agents for this process, as they are neither toxic nor able to trigger an immune response. Titanium is also thought to be an optimal choice due to an oxide layer that forms when the metal is exposed to oxygen, which protects the material from corrosion and may play a role in the exchange of molecules between the bone and the implant.


Titanium screws are used to support bone repair

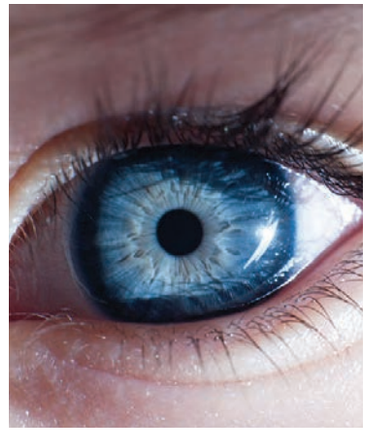
Inside the eye

Dear **HIW,**

I love your magazine and have a subscription so that I can always read the latest copy of my favourite magazine. I was thinking, why do our eyes have colour and why can't we see this colour when we look around?
Ollie Carroll (aged 11)

That's a great question, Ollie. The coloured part of our eye is called the iris, and we can't see the colour from this area because we only absorb light from the pupil, which is the black part in the centre of our eye.

The iris is designed to stop light travelling through it, and for most people, a pigment known as melanin helps with this job. Melanin is also what causes our eyes to differ in colour. People with lots of melanin have brown eyes, people with no melanin have blue eyes, and people with some melanin have green or hazel eyes.


Eye colour depends on the amount of melanin at the front of the iris

HOW IT WORKS

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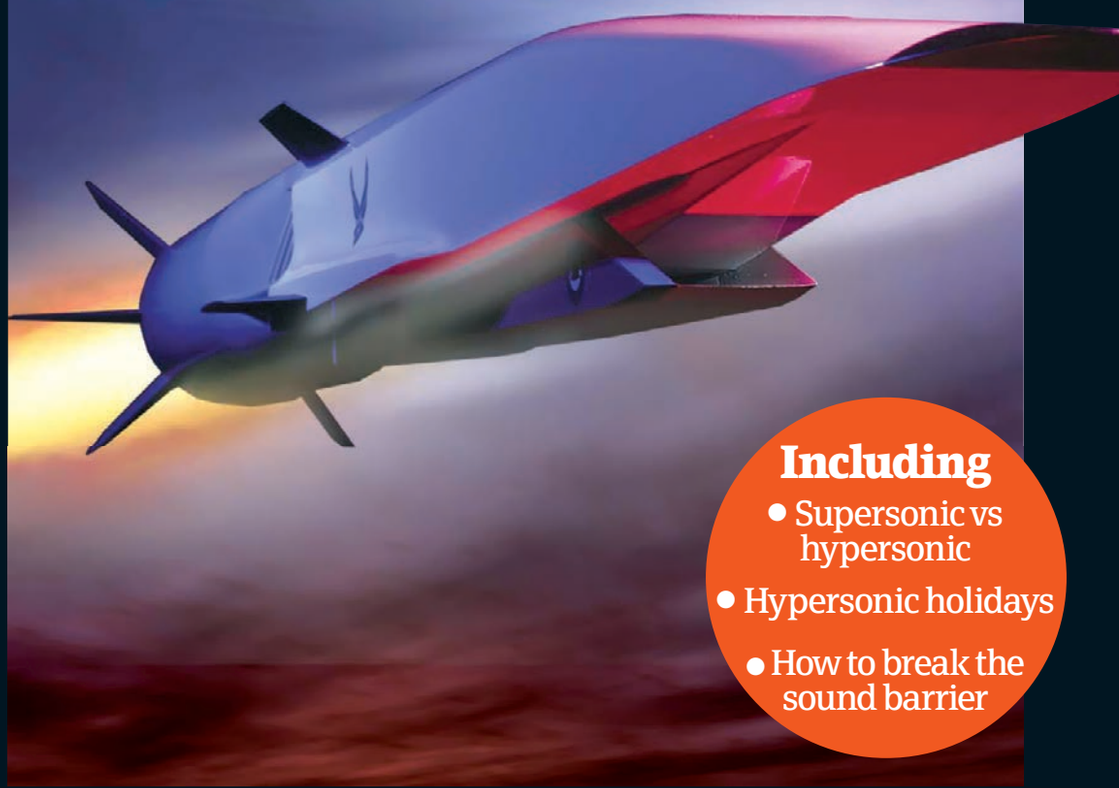

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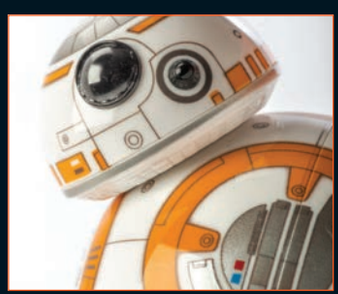

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Amazing trivia to blow your mind

3.7 BILLION YEARS
The age of the earliest fossils ever found

3,890
THE ESTIMATED NUMBER OF TIGERS LEFT IN THE WILD

159 MILLION TRILLION
THE NUMBER OF POSSIBLE SETTINGS ON THE NAZI'S ENIGMA MACHINES

$200,000
THE COST OF A TICKET TO MARS WITH SPACEX UNDER ELON MUSK'S AMBITIOUS NEW PLAN

The game of conkers was originally played with snail shells

ONE SHEET OF NEWSPAPER IS 100,000 NANOMETRES THICK

16-20 HOURS
HOW MUCH OF A LION'S DAY IS SPENT RESTING AND SLEEPING

3
THE NUMBER OF ATTEMPTS OSIRIS-REX WILL HAVE TO COLLECT ASTEROID SAMPLES

THE 2016 NOBEL PRIZE IN CHEMISTRY HAS BEEN AWARDED FOR THE SYNTHESIS OF MOLECULAR MOTORS THAT ARE 1,000 TIMES THINNER THAN A STRAND OF HAIR

115 YEARS
THE MAXIMUM LIFESPAN OF HUMANS, ACCORDING TO A NEW STUDY

14.45KM
How far the Curiosity rover has driven since landing on Mars

A SINGLE 2.5CM-LONG URANIUM-235 PELLET CONTAINS MORE ENERGY THAN A TON OF COAL

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OF THE HUMAN POPULATION HAVE GREEN EYES

36,000
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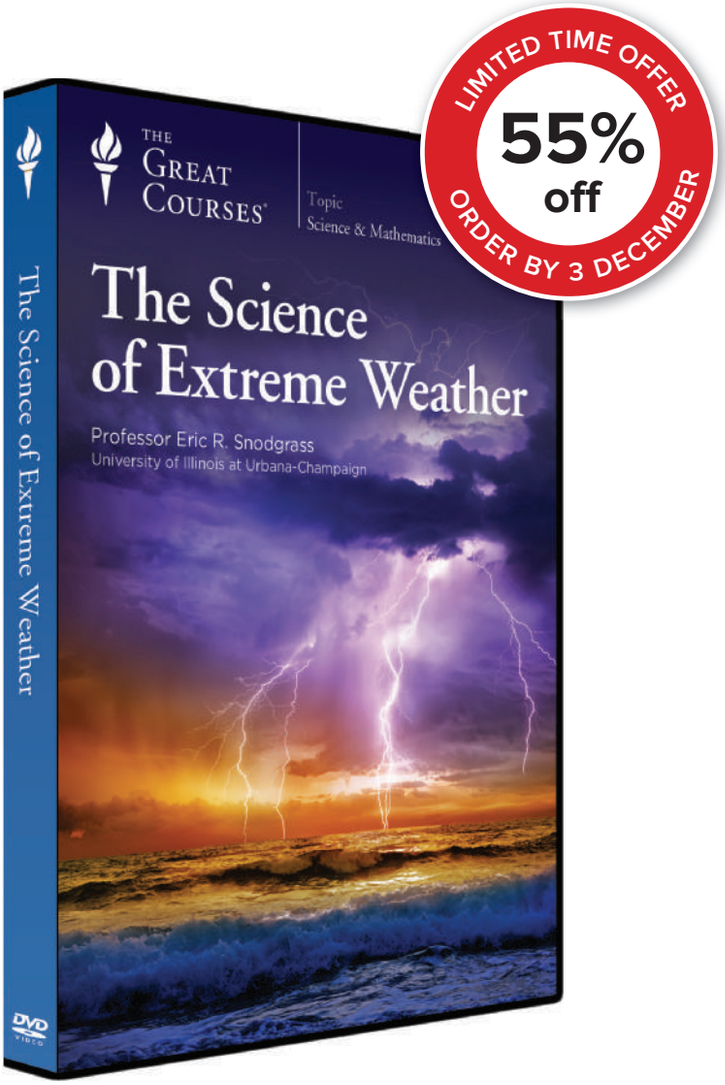

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