BBC

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SCIENCE AND TECHNOLOGY

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THE STORY OF GRAVITY

Theories of falling, from Aristotle to Einstein

HOW BACTERIA CHANGE YOUR MOOD

The link between microbes and the mind

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Orion will take us to asteroids and Mars

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- Is there a bet you can't lose?
- Why does looking down seem further than looking up?

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Fuel consumption figures mpg (litres/100km) and CO_2 emissions (g/km), Audi A3 Sportback e-tron: Urban: N/A, Extra Urban: N/A, Combined/
test results: one when the battery is fully charged and the other when the battery is discharged. The two test results are a weighted average,
petrol engine generating electricity. Standard EU Laboratory Test figures are for comparative purposes between vehicles and may not reflect

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The new Audi A3 Sportback e-tron.

WHAT CAR?
Car of the Year 2015
Best electric car

weighted: 176.6 mpg (1.6 litre/100km). CO_2 emissions: 37g/km. The 'Combined/weighted' fuel consumption CO_2 figures calculated from two taking into account mileage range on battery power only, providing a figure in a variety of charge conditions. Extended range achieved by 1.4 TFSI real driving results. Images for illustration purposes.

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WELCOME

YOU'LL KNOW ALL about 'friendly bacteria' if you eat yoghurt. Increasingly, though, scientists are finding that bacteria have more influence on us than was previously believed. Research has revealed how microbes are pulling our strings, and affecting our personality and behaviour. Nicola Davis reveals how they do it on p40.

Speaking of decisions: do you ever wonder which roads are safest? Is it better to drive on a motorway or a B-road? One way of deciding is by using micromorts, a unit of measurement defined by statisticians as a one in a million chance of death. So that's what we did. On p64 we reveal the UK's safest – and most dangerous – roads according to the science of risk.

Talking of risk, NASA is starting to plan manned missions that go beyond Earth's orbit. But before putting astronauts in harm's way, its new space vehicle, Orion, is undergoing unmanned tests. Turn to p50 to see pictures of Orion under construction and find out how it fared on its first flight.

Elsewhere, we offer dating tips from animals in honour of Valentine's Day (p48); investigate shock claims about the British royal family resulting from Richard III's DNA (p61); and ask a leading neuroscientist how to beat information overload (p58). Enjoy the issue!

Graham

Graham Southorn, Editor

PS Don't miss our April issue, on sale 5 March 2015

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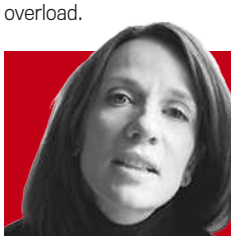
THIS MONTH WE...

...checked out the latest technology at the CES 2015 show in Las Vegas. Read about some of the gadgets we investigated in this month's Just Landed and On The Horizon pages.

...asked neuroscientist Prof Daniel Levitin for advice on how to cope with one of the biggest challenges we face in the modern world, at home and at work: information overload.



...talked to documentary maker Polly Morland about her book *Risk Wise*, in which she explores the ways that individuals react to risk depending on their lifestyles.

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APPEARING IN THIS ISSUE...

Neil Ashton

As a research engineer at the University of Manchester, Neil has a keen interest in aerospace. On p50, he shines a light on NASA's Orion space vehicle and its upcoming missions.

Nicola Davis

Nicola is commissioning editor for *Observer Tech Monthly* and holds degrees in organic chemistry. On p40, she investigates the ways in which microbes affect our personalities.

David Shukman

David is Science Editor for BBC News and writes a column every month in our Discoveries section. In this issue he reports on a high-energy light source in an unlikely location.

Jennifer Verdolin

Jennifer is author of *Wild Connections: What Animal Courtship And Mating Tell Us About Human Relationships*. On p48, she reveals romantic tips from nature.

WANT TO SUBSCRIBE? Turn to p36 to save **40%** on the shop price of *BBC Focus*

SUBSCRIBER BONUS On p36, **Prof Elaine Fox** and **Dr Kevin Dutton** explain the difference between emotions and feelings

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COVER: MAGIC TORCH

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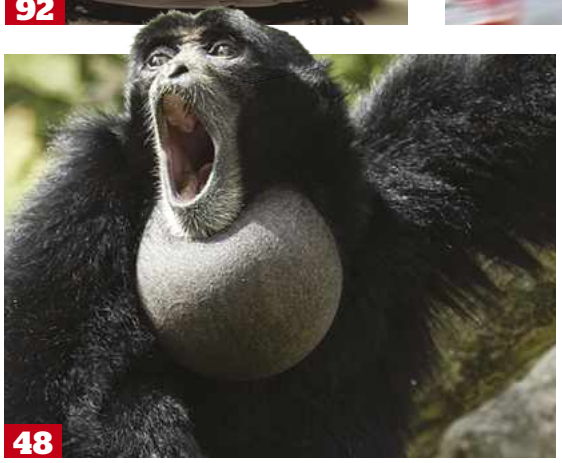

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insiders

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Awe-inspiring images from the world of science

MegaPixel

Model engineering

RESEMBLING THE WORLD'S most advanced model kit, the 3,500 components that make up the Bloodhound SSC supersonic car are laid out in the team's headquarters. Perched in the driving seat is Wing Commander Andy Green, the man who'll be behind the wheel when the vehicle attempts to break the land speed record in the Kalahari Desert later this year.

The team aims to reach a top speed of 1,600km/h (1,000mph), almost 400km/h per hour faster than the current land speed record set by Green in ThrustSSC in 1997. Before then, however, it has to be put back together.

"The thousands of components all fit together like a 3D jigsaw," explains Bloodhound's Jules Tipler. "After being manufactured, the components are trial-assembled and, where appropriate, bonded and riveted together, which is what's happening here. Eight aerospace and motorsport technicians, supported by four technicians from the Royal Electrical and Mechanical Engineers, will take six weeks to do the final assembly."

PHOTO: STEFAN MARJORAM/BLOODHOUND

MegaPixel

Bearded bloom

IF YOU WERE planning to buy your loved one roses for Valentine's Day, you might want to turn the page now. This scanning electron micrograph shows that the seemingly smooth undersurface of a red rose petal is in fact covered with scruffy bristles. Why this is so, however, is not known.

"Hairs are an enigmatic piece of plant structure and their roles are not always clear," says Timothy Walker, a lecturer in plant sciences at the University of Oxford. "Stinging hairs have an obvious function, but why there should be hairs on the petals of a rose is a mystery. They are, however, very useful when identifying plants, with there being more than 15 different types of hair."

The hairs are only present on the lower surface of the petal. But even the velvet shimmer seen on the upper surface of the petal has a faintly unpleasant origin: it's caused by light reflecting off thousands of finely corrugated warts.

PHOTO: MARTIN OEGGERLI/MICRONAUT/ SCHOOL OF LIFE SCIENCES/FHNW

MegaPixel

Bug brothers

THIS INTIMATE SCENE shows two mosquito pupae apparently staring into one another's eyes. It was taken using an optical microscope set at 10x magnification and was created by stacking two separate images together.

Pupa is one stage of four in a mosquito's life cycle. "Like many insects, mosquitoes undergo complete metamorphosis," explains BBC presenter and entomologist Adam Hart. "They have a larval stage that is aquatic and very different from the adult, just as a caterpillar is very different from a butterfly. The larval stage is about gathering resources quickly. Once it's large enough, the larva develops into the pupa, the stage where the transformation from aquatic larva to flying adult occurs."

Pupae can often be seen lurking just below the surface of the water in which they live. "Mosquito pupae can swim, though not especially well. They are comma-shaped and they swim by kicking out the 'tail' of the comma – their abdomen," explains Hart.

PHOTO: J ROJKOWSKI/OLYMPUS

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MESSAGE OF THE MONTH

Rendering of a city, as imagined by The Venus Project

Jacque Fresco: futurist extraordinaire

The climate change article in the January issue (p56) was interesting. But I read with astonishment that Prof Dickson Despommier of Columbia University is a pioneer of vertical farming. Have your staff and contributors ever heard of Jacque Fresco, the renowned (and 98-year-old) futurist and creator of The Venus Project? He is a social engineer who believes in a different way of life using science and tech to make people's lives better. He has been an inventor and pioneer of many futuristic concepts, including the design of a circular automated city fed by locally grown food from vertical aeroponic farms. He devised these ideas over a period stretching from the late 1920s until the present day. I have often thought that *BBC Focus* should do an article about the man and his vision of a resource-based economy based on science and technology. To find out more, visit www.thevenusproject.com or you can watch films about his ideas and designs on YouTube. See *Future By Design* (http://bit.ly/1BF9m5D) and *A New World System: Paradise Or Oblivion* (http://bit.ly/1yvAO86).

Will Hatton

Write in and win!

The winner of next issue's Message of the Month wins a pair of Lindy Cromo NCX-100 Noise Cancelling Headphones, worth £99.98. Ideal for trains, planes or noisy rooms, they provide hi-fi sound and remove 95 per cent of ambient noise. **lindy-headphones.co.uk**

New year, new diets

Your diet article is probably very apt, but you missed out the most important factor in regards to the paleo diet: namely the 10 miles or so of fast running, either after your prey or away from it!

Pat McDonnell

I was disappointed on reading the article on diets (January, p51) to find that the writer seems to be confused about the difference between calorie and kilocalorie. Both are used indiscriminately, leading to possible misunderstanding. There are other aspects of this article open to criticism. It is essential that articles on food, particularly in a science magazine, should be written by scientists and not journalists.

Roger Collison, Meltham

In scientific terms, calories and kilocalories are not interchangeable. However, calorie is often a shorthand for kilocalorie. The NHS website, for instance, says the daily recommended intake for men is around 2,500 calories, when of course they mean 2,500kcal. We used the colloquial 'calories' in the body of the feature, but in the 'Focus diet' section we used kcal, in line with what you might find on food packaging. We should have made this clearer. – ***Ed***

John Harrison saw these ash cones in Iceland

Strange cones

The fairy circles picture in '10 strangest phenomena in nature' (January, p40) reminded me of something I saw in Iceland over 20 years ago – tiny ash cones on top of snow (pictured above). I have consulted several meteorologists about a

PHOTO: THE VENUS PROJECT, NEWSPRESS

possible explanation but no one was able to produce a definitive answer. If any of your experts have a better explanation I would be delighted to hear it.
John Harrison

Who do we know?

I found the article on the nature of light (December, p116) as intriguing as I had expected. However, I was shocked at the startling omission of Louis de Broglie. If any single mind changed our picture of light's behaviour, it is he. His developments in wave-particle duality formed the solution to the problems facing the great minds at the time (which the article outlines clearly). It baffles me that an article asking 'How do we know?' fails to tell us what we know today, or who is responsible – a rare oversight.
Andrew Derrett, Brighton

Phone from India

On p84 of the September 2014 edition, you mentioned one of the cheapest smartphones on the market, the Karbonn A50S. It is produced and sold in India for the equivalent of £26. Inspired by *Focus*, I arranged for an acquaintance to purchase the phone on a trip to India. I inserted my BT sim card, which kept my list of contacts. Voice calls and text messaging work like a dream. I am also able to access all the usual emails, video and data services, but only when I am connected to a Wi-Fi hotspot. If this drawback doesn't bother you, I would still recommend this phone.
David Shaffer, Westcliff-on-Sea

David Shaffer is thrilled with his new Karbonn phone

Driving green

Your article on p61 of the January issue suggested we need a smart grid to plug in an electric vehicle, but to delay charging until the middle of night is somewhat behind the times. For the past 18 months my wife has been the proud owner of a Nissan Leaf electric car, which has a built-in timer to do just that. After plugging in, it waits until we're on the night tariff to charge itself in our garage. We live in very rural Somerset, but with its range of 85 miles plus, the Leaf is the ideal runabout for us. And now we're in winter, with the heat pump heating system giving instant warmth, the Leaf remains our first choice of vehicle.
Trevor Hunt, Wedmore

The Nissan Leaf charges itself on the cheaper night tariff

No nuclear?

The special report on climate change (January, p56), while interesting and thought-provoking, did not mention any role for nuclear power. For this reason I found it to be unbalanced in dealing with this important topic. Is there any chance of an article on nuclear power? I hope it would be an objective appraisal of the issues to give readers a more informed view of the role that nuclear power could play in reducing carbon emissions.
Joe Roberts

Why salt roads?

Helen Czerski's article about rust (January, p33) raises the question of why we insist on putting salt on the roads in the UK. This strikes me as a crazy example of pollution that nobody seems to speak out against. Apart from corroding cars, bicycles and lorries, it also affects wildlife, plants and farmland. I have heard that there are alternatives to salt, including one that is made from molasses. It would be interesting to know how they compare to traditional methods.
Mark Herbert

Icelandic volcano

In the January issue, there is a story about the Bardarbunga eruption in Iceland. Your article states that the lava erupted through the surface of Vatnajökkul glacier. This never happened, although it might do in the near future. The lava fissure appeared next to the glacier in the Holuhraun lava field, but not through it.
Liam Molloy, Reykjavik, Iceland

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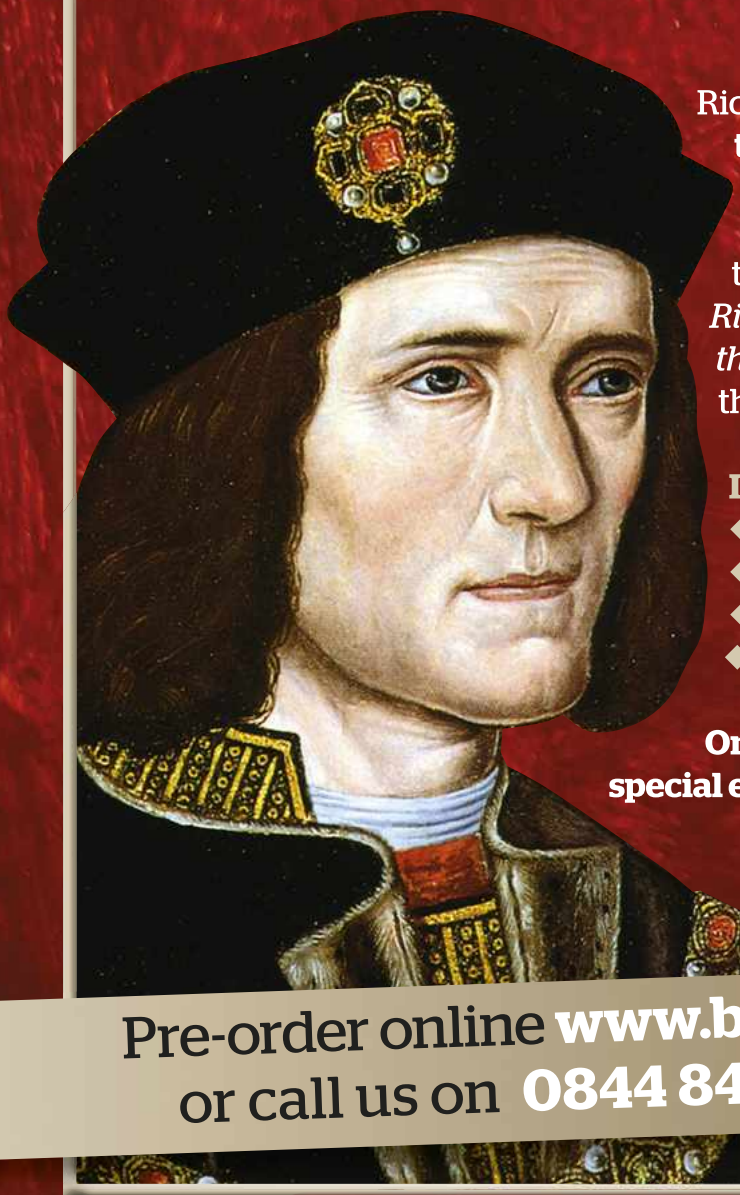
FROM THE MAKERS OF BBC HISTORY MAGAZINE

RICHARD III

THE STORY OF THE KING UNDER THE CAR PARK

A new special edition explores the life and times of a controversial monarch – whose legacy is still fiercely debated today



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DISCOVERIES

News and views from the world of science

EDITED BY **JASON GOODYER**

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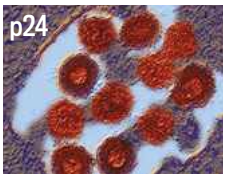
p22 **THE NEW NESSIE?** A prehistoric marine reptile has been uncovered in Scotland


p24 **WHY YOU'RE SMART** Ancient viruses help build networks in the brain

THE BIG STORY

NEW ANTIBIOTIC DISCOVERED

An innovative device has helped scientists develop the first new antibiotic for nearly three decades

SOON AFTER AN antibiotic is developed, pathogens begin developing a resistance to it and eventually render it ineffective. It's like an ongoing game of biological one-upmanship. To make matters worse, new antibiotics are notoriously difficult to discover. But things may be about to change.

A team at Northeastern University in Boston has discovered the first new antibiotic for almost 30 years, using a novel technique to grow

A diluted soil sample is poured onto the iChip. One microbe is trapped in each of the tiny holes. The chip is covered with a membrane to allow the microbes to grow without becoming contaminated by other bacteria

PHOTO: SLAVA EPSTEIN/NORTHEASTERN UNIVERSITY

Prof Kim Lewis (right) led the Teixobactin research

microbes under laboratory conditions. Named Teixobactin, the antibiotic may prove effective for the treatment of chronic infections caused by drug-resistant bacteria, researchers say. What's more, there are so far no signs of MRSA or tuberculosis bacteria developing resistance to it.

"Apart from the immediate implementation, I think there is also a paradigm shift in our minds because we have been operating on the basis that resistance development is inevitable, and that we have to focus on introducing drugs faster than resistance," says lead researcher Prof Kim Lewis. "Teixobactin shows how we can adopt an alternative strategy and develop compounds to which bacteria are not resistant."

In the past, most antibiotics were discovered through the screening of microorganisms found in soil. However, only 1 per cent of these can be grown in laboratory conditions, leaving a huge resource untapped. The team at Northeastern developed a method for growing the remaining 99 per cent – so-called uncultured bacteria – using a clever device called the iChip.

They have since assembled about 50,000 strains of uncultured bacteria and discovered 25 new antibiotics, of which Teixobactin is the latest and most interesting, Lewis says. They now hope to develop Teixobactin into an effective drug. However, even then it will only be effective in treating certain types of bacterial infection.

Most species of bacteria can be broadly divided into two groups, known as gram-positive and gram-negative. Gram-negative bacteria are more resistant to antibiotics because their cell walls are more complex than those of gram-positive bacteria.

"This new antibiotic, Teixobactin, is directed at gram-positive bacteria like MRSA," says Prof Timothy Walsh, from Cardiff University's Institution of Infection and Immunity, who was not involved in the study. "While anti-gram-positive antibiotics are useful, the global clinical community is desperate for new, and even novel antibiotics against multidrug-resistant gram-negative bacteria. However, further exploitation of this technology can, and potentially should, meet this clinical challenge."

TIMELINE
A history of antibiotics

1871
The pioneering surgeon Joseph Lister begins researching the phenomenon that urine-contaminated mould could inhibit the growth of bacteria.

1928
Sir Alexander Fleming (right) discovers that the bacterium *Staphylococcus aureus* can be destroyed by *Penicillium notatum* (now known as *Penicillium chrysogenum*), a kind of mould.

1943
Just four years after pharmaceutical companies began mass-producing the drug penicillin, microbes start appearing that are capable of resisting it.

1961
The bacterium MRSA (methicillin-resistant *Staphylococcus aureus*) is detected in Britain for the first time. It goes on to become a big problem in hospitals.

GOOD MONTH/ BAD MONTH

It's been good for:

COUCH POTATOES
IF SPENDING HOURS sweating in a gym doesn't sound like fun, read on. Researchers at Ohio University have found that carrying out five sessions of imaginary exercise per week reduced loss of grip strength in those wearing a wrist-immobilising cast by 50 per cent. The effect is thought to be due to the nervous system's role in strength development.

WANNABE CENTENARIANS

RESEARCHERS AT THE University of Bern have prolonged the lifespan of flies by activating a gene, azot, that destroys unhealthy cells. During ageing, cells accumulate random errors. But once azot is activated, it targets less fit cells to protect organs such as the brain and gut. The flies receiving the treatment lived 50 per cent longer.

It's been bad for:

WRONGFUL CONVICTIONS
EVIDENCE FROM SOME wrongful conviction cases suggests that suspects can be questioned in ways that lead them to falsely 'remember' and confess to crimes they didn't actually commit. A study at the University of Bedfordshire has found that 70 per cent of innocent adult participants were convinced that they had perpetrated serious crimes in their teenage years.

BEDTIME READERS
IF YOU READ a tablet in bed, you might want to rethink your habits. Dim light in the evening allows for production of sleep-regulating melatonin, but a study at Pennsylvania State University found that those using eReaders before bed had lower melatonin, took longer to drop off and were less alert in the morning.

PHOTO: NORTHEASTERN UNIVERSITY, PRESS ASSOCIATION, ISTOCK X2

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DAVID SHUKMAN

The science that matters

SESAME opens doors

The SESAME synchrotron is a model for international scientific collaboration

SHOULD ANYONE suggest that, in the heart of the tempestuous Middle East, they were planning to bring Israelis together with Arabs and Iranians, you might think the idea dangerous. Long-standing enmities would surely stand in the way?

Yet against all the odds, on a hill outside the Jordanian capital Amman, I witnessed the extraordinary sight of scientists from countries that are at loggerheads getting along professionally. It was a revelation to see researchers from Tel Aviv sitting with their counterparts from Tehran – it showed how doors usually welded shut can be opened by the language of science.

The project is to build a synchrotron – a high-energy light source – called SESAME. And despite endless setbacks with the design, the funding and the politics, the giant machine is achieving something unimaginable: it is inching towards completion. The first research may be possible in early 2016.

Dozens of synchrotrons operate in the developed world, but SESAME would be the first in the Middle East. It will elevate research in the region into a new league, its intense beams of X-rays offering insights into everything from the molecular structure of seeds to the workings of new medicines to the intricate detail of archaeological remains.

Nothing about SESAME is easy. Egypt nearly joined until its government changed, and Iran is committed to paying its share but sanctions make it difficult to transfer the cash. However, a major boost came when the European Union contributed five million Euros – money that will pay for CERN to build the key magnets. And in a very surprising move Iraq, despite its ongoing conflict with Islamic State, has recently shown interest in joining.

During my visit I could think of a dozen perfectly rational reasons for why SESAME should fail – more wars, new coups, unforeseen trouble with visas or travel or safety. Yet somehow it soldiers on. Those working on the project are determined to see it through.

The governments paying for it could not afford a synchrotron on their own. And the scientists? They all told me they want to leave politics at the lab door and just get on with doing what they love.

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc

THEY DID WHAT?!

Powerful people are messy eaters

What did they do?
Psychologists at the University of California, Berkeley divided volunteers into groups of three. They randomly chose one person to be the leader and then gave the group boring tasks to do, namely devising policies for the university.

That's it?
No, after a while the researchers brought in a plate with four chocolate chip cookies on it. In half of the groups, the leader grabbed the last cookie.

Perhaps the leaders of each group were just hungrier?
Maybe, but the psychologists think there's a link between power and eating habits. They spotted that the leaders were more likely to eat with their mouths open, smack their lips and get crumbs down their clothes. Watch a video on the 'cookie monster' study here: http://bit.ly/1yyNY1s

PHOTO: SESAME, ALAMY

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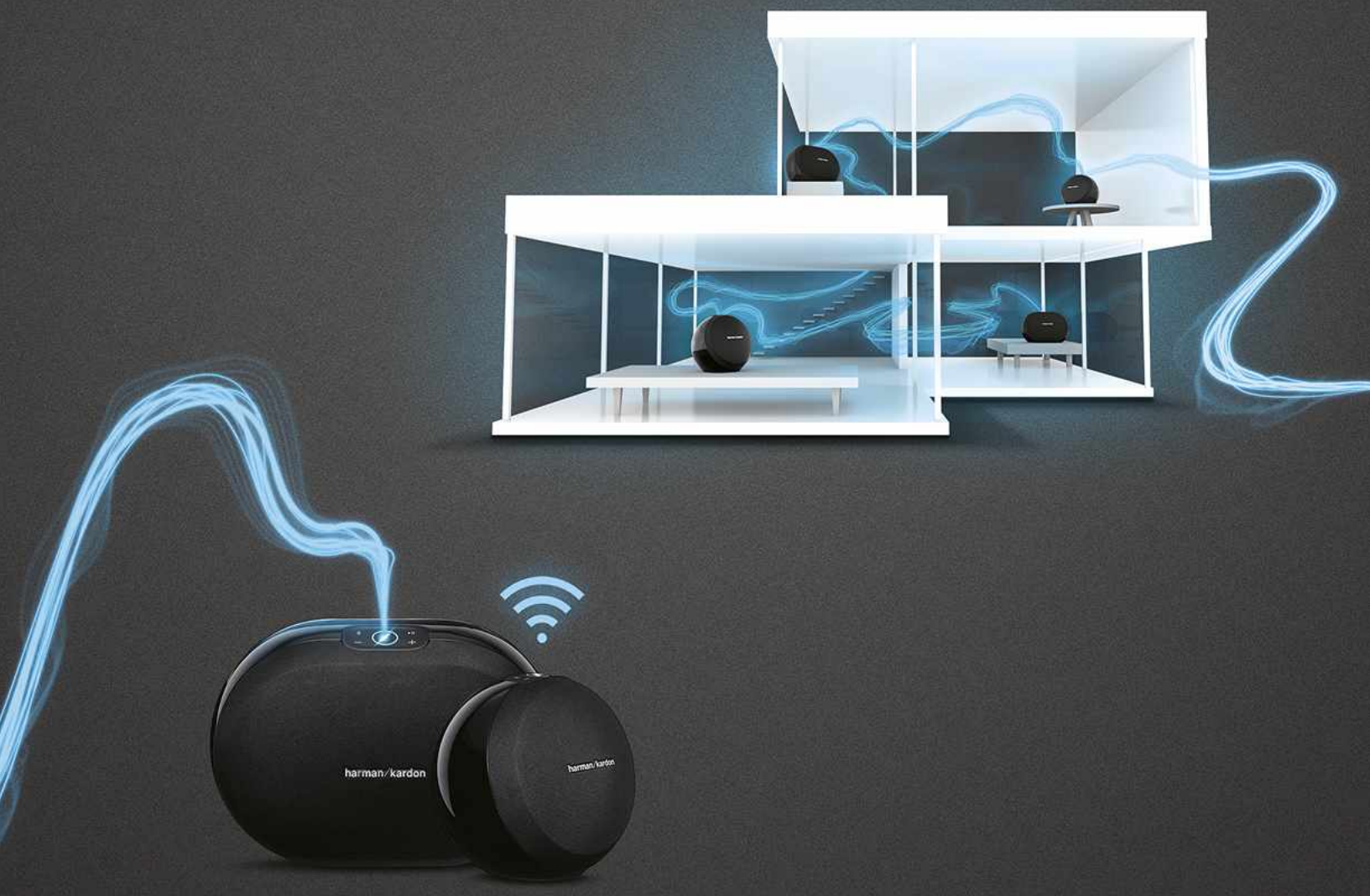

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1 MINUTE EXPERT
Kepler 438b

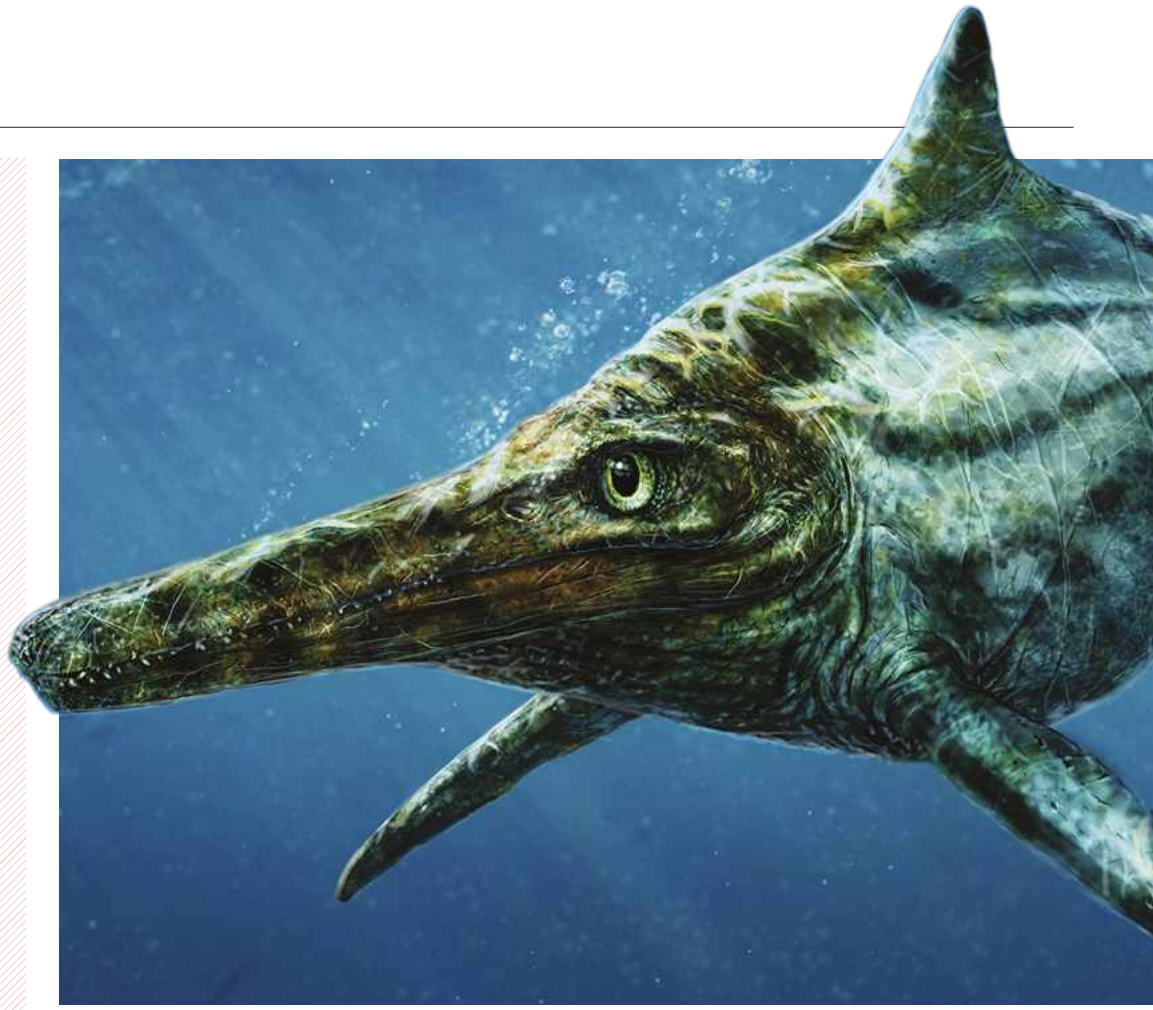
What's that?
The most Earth-like exoplanet ever found. It's located 470 light-years away from Earth, and was spotted by NASA's Kepler space telescope.

Right. Exactly how 'Earth-like' is it, though?
It scores 0.88 on the Earth Similarity Index – a measure, as you might expect, of how physically similar planets are to Earth. The ESI runs from 0, nothing like Earth, to 1, exactly like Earth. This figure is calculated based on the planet's radius, density, escape velocity and surface temperature. For comparison, Mercury scores 0.596 on the Earth Similarity Index, and Venus 0.444.

Can you be a bit more specific?
Sure. The diameter of Kepler 438b is just 12 per cent larger than that of Earth. It receives 40 per cent more light from its sun, and is 70 per cent likely to exist in the star's habitable zone – the region within which water is likely to exist on the planet's surface.

So could it be home to life?
Currently, it's impossible to say. However, researchers have gone so far as to describe 438b as a "promising candidate" for hosting extraterrestrial life.

Kepler 438b, as imagined by an artist



PALAEONTOLOGY

Ancient Scottish sea creature identified

MOVE OVER NESSIE: palaeontologists have identified the fossils of the first large, ocean-dwelling reptile known to be unique to Scotland.

The fossils were discovered on the Isle of Skye and were found to belong to a new genus and species of ichthyosaur, a type of predatory marine reptile. Dubbed *Dearcmhara shawcrossi*, the creature is thought to have been about 4m in length, roughly the same size as a great white shark. Its name is a combination of the Gaelic word for 'marine lizard' and the surname of Brian Shawcross, the amateur fossil collector who found the specimen.

"Not only is it a first for Scotland, but it's also scientifically important, because it helps fill a frustrating gap in the fossil record," says the University of Edinburgh's Stephen Brusatte. "The specimen is about 170 million years old, from

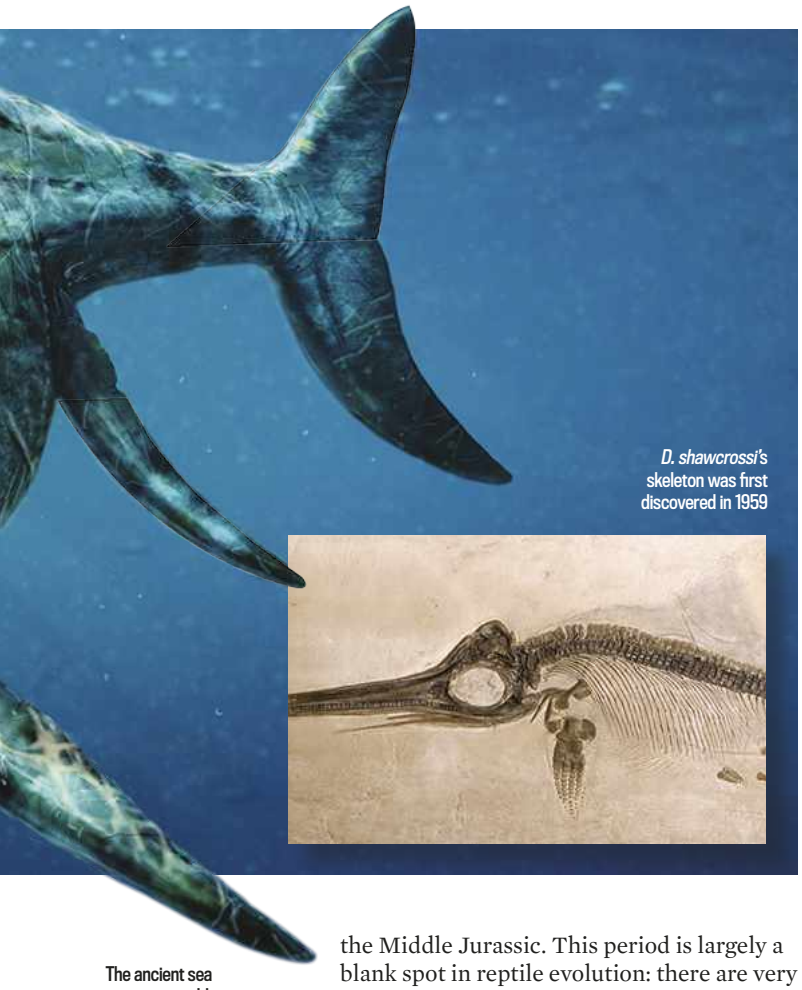
WHO'S IN THE NEWS?
Clarence Anglin, John Anglin and Frank Morris

Infamous inmates that staged a daring escape attempt from Alcatraz

What have they been up to?
In June 1962, the three felons escaped from their cells in the notorious San Francisco prison through holes they'd scraped in the walls with spoons stolen from the canteen. After scaling the perimeter fence, they attempted to paddle to land on an improvised dinghy fashioned from 55 prison-issue raincoats. They were never seen again.

Okay... so what's new?
While the subsequent FBI investigation was unable to determine whether or not they survived, experts at the time concluded that they had drowned. Now, a computer model created by researchers at Delft University of Technology has calculated that if they left when tides were favourable, they could have survived.

PHOTO: TODD MARSHALL, CORBIS, HARVARD/CFA



D. shawcrossi's skeleton was first discovered in 1959

The ancient sea creature would have eaten fish and smaller reptiles

the Middle Jurassic. This period is largely a blank spot in reptile evolution: there are very few fossils from this time anywhere."

During this time the more primitive ichthyosaurs began to die out, making way for a larger species. The fact that the Skye specimen is more primitive suggests this change happened more gradually, researchers say.

Shawcross discovered the fossil in 1959 and donated it to the Hunterian Museum in Glasgow, where it stayed until it was studied by the team in Edinburgh. "We hope this story is inspiring to other collectors. There are still many fossils to be found on Skye, so get up and go outside, and if you find something new and donate it to a museum so it can be studied, we promise to name it after you," Brusatte added.

Clockwise from top left: Frank Morris, John Anglin, Clarence Anglin

How so?

The Delft team's hydrodynamic model of San Francisco Bay shows there's a window of opportunity to cross from the prison island to the Golden Gate Bridge. If the trio left too early, the tides would've dragged them into the Pacific. But if they left at midnight, they would reach the bridge just as the tide turned, allowing them to paddle to land.

CLICK HERE

New websites, blogs and podcasts

CLIMATE CHANGE IN 60 SECONDS

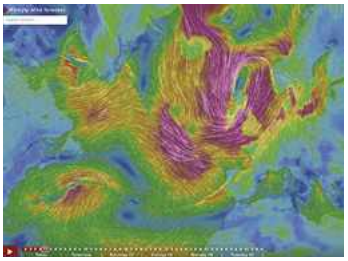
youtube.com/watch?v=n4e5UPu1co0

Watch this 60-second animation on the basic scientific principles behind climate change, then head to the Royal Society's website if you want more detailed answers to questions like why Arctic sea ice is reducing but Antarctic sea ice isn't.

THE COLLECTED EINSTEIN PAPERS

einsteinpapers.press.princeton.edu/

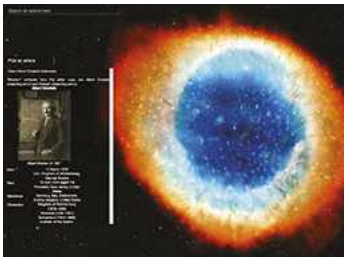
"If the rabble continues to occupy itself with you, then simply don't read that hogwash," was what Albert Einstein told Marie Curie in 1911. The letter in which he wrote that is now available online as part of his collected papers. Get digging and see what other gems you can unearth.



WINDYTY

windyty.com

When you're not battling against it on the way to work, it's easy to forget that wind is a fluid that's around us all the time. Windyty visualises data on wind speeds around the world and puts them on an easy-to-navigate map. Kite-fliers will find this site especially useful, but no specialist knowledge is required to start exploring.



WIKIGALAXY

wiki.polyfra.me

It's Wikipedia, but not as we know it. Computer science student Owen Cornec put together this galaxy-style visualisation of tens of thousands of Wikipedia pages to help you get lost down even more rabbit holes of useless but fascinating information. Click around the info cosmos at random, or get taken on a tour of a specific subject in 'fly mode'.

KELLY OAKES is science editor at BuzzFeed. She tweets from @kahoakes

ANTHROPOLOGY

Did ancient tools drive the evolution of language?

IT SOUNDS LIKE the set-up to a joke: what do a butcher and a linguist have in common? However, researchers from the University of California, Berkeley and the University of St Andrews, Scotland have discovered that the spread of butchering technology may have been a major driving force in the evolution of language.

Two and a half million years ago, our ancestors in Africa began shaping rocks into sharp cutting instruments known as Oldowan tools. Over the next 700,000 years this technology spread across the continent, causing advances in communication among early humans, researchers claim.

"Our findings suggest that stone tools weren't just a product of human evolution, but actually drove it as well, creating the evolutionary advantage necessary for the development of modern human communication and teaching," explains lead study author Thomas Morgan. "Our data show this process was ongoing two and a half million years ago, which allows us to consider a very drawn-out and gradual evolution of the modern human capacity for language, and suggests simple 'proto-languages' might be older than we previously thought."

Morgan and his team got volunteers to teach one another stone knapping, an ancient practice of creating sharp fragments of basalt or flint by hammering them with hard rocks. Spoken communication proved to be a more efficient method than imitation and gestures.

However, the relatively slow spreading of the technology indicates that hominins at the time were not using speech as we know it today.

"They were probably not talking," Morgan says. "These tools are the only tools they made for 700,000 years. If people had language, they would have learned faster and developed newer technologies more rapidly."

Oldowan tools like these take their name from the Olduvai Gorge in Tanzania, where they were first found

BIOLOGY

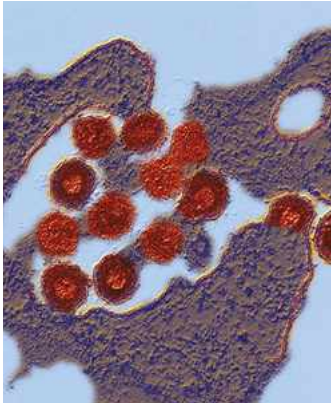
Viruses may have made us smarter

IT MAY SEEM difficult to believe that viruses have ever done anything good for us. But researchers from Sweden's Lund University have found that viruses that are millions of years old play an important role in building up the complex networks in the brain.

Around 5 per cent of the human genome is made up of strings of DNA known as endogenous retroviruses. It was previously thought that this chunk of the genome was of no real use and was a mere side effect of our evolution. Now, researcher Dr Johan Jakobsson has found that these viruses play a central role in the regulation of which genes are expressed in the brain.

"We believe that the role of retroviruses can help explain why brain cells in particular are so dynamic and multifaceted in their function. It may also be the case that the viruses' more or less complex functions in various species can help us to understand why we are so different," says Jakobsson.

The team found that neural stem cells inside the brain use specific molecular mechanisms to control the activation of retroviruses. The findings may lead to a better understanding of brain disorders with genetic components.



Human retroviruses (coloured red) copy their genome into the host cell's DNA. This can lie dormant and is passed on through generations

"I believe that this can lead to new, exciting studies on the diseases of the brain. Currently, when we look for genetic factors linked to various diseases, we usually look for the genes we are familiar with, which make up a mere 2 per cent of the genome. Now, we are opening up the possibility of looking at a much larger part of the genetic material which was previously considered unimportant," says Jakobsson.

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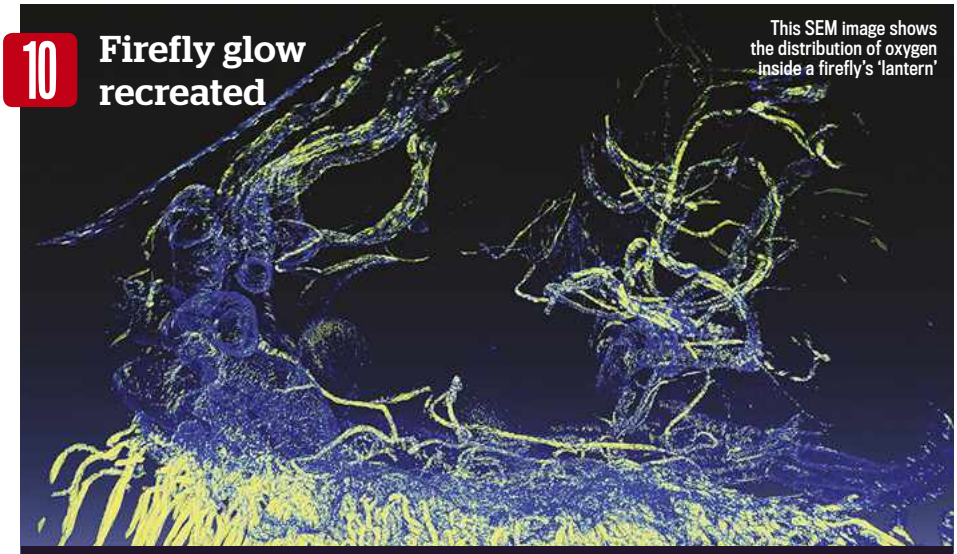
10 DISCOVERIES THAT WILL SHAPE THE FUTURE

10 Firefly glow recreated



This SEM image shows the distribution of oxygen inside a firefly's 'lantern'

SCIENTISTS IN TAIWAN have used cutting-edge imaging techniques to determine exactly how fireflies create their glow. Fireflies emit light when a compound called luciferin reacts with oxygen, but until now the mechanism behind this was unknown. Technology based on this mechanism could be used in everything from street lights to drug testing, say the researchers.

9 Human muscle grown in lab

WHO NEEDS PROTEIN shakes and hammer curls? Researchers at Duke University have grown functioning human muscle in the lab. The development could help scientists test new drugs and study disease in muscles without the need for human subjects. The team put human cells that had progressed beyond stem cells, but hadn't yet become muscle, onto a 3D scaffold. The resulting muscle responded to biochemical stimuli and drugs just like native tissue.

A micrograph of the lab-grown muscle tissue

8 New memory device

A TEAM AT Cornell University has created a magneto-electric memory device that may one day lead to the development of computers that require very little power and could greatly increase battery life. The device was made using bismuth ferrite, a material that is permanently electrically polarised. Data can be stored in the material by using an electric field to switch the direction of polarisation.

7 Quantum data encryption breakthrough

PHYSICISTS AT THE Australian National University have stored quantum information for a record six hours using europium atoms embedded in a crystal made from yttrium. The result is a major step towards more secure data encryption, say the researchers. The feat was achieved by writing a quantum state onto a europium atom and holding it in place using a magnetic field.

Writing quantum data onto an yttrium crystal

6 Treatment for sensitive teeth

FOR THOSE WITH sensitive teeth, eating a bowl of ice cream can quickly become painful. Now, a team at the National Taiwan University Hospital has created a biomaterial that can rebuild tooth enamel and reduce sensitivity. The treatment is a paste made from calcium and phosphorus that plugs the tiny holes that can form in tooth enamel.

PHOTO: GIORGIO MARGARITONDO/EPFL, NENAD BURSAC/DUKE UNIVERSITY, UNIVERSITY OF BRISTOL, PETER ALLEN, APFL, ISTOCK X3, COLORADO STATE UNIVERSITY, SOLID STATE SPECTROSCOPY GROUP ANU

5 Shapeable light beams

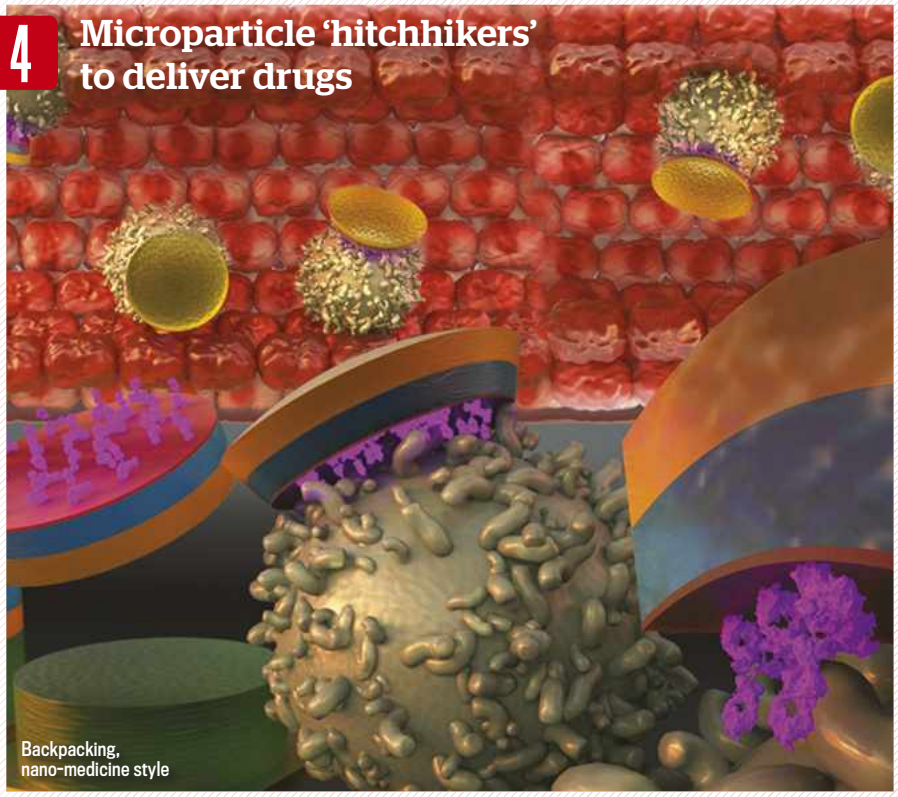
ENGINEERS AT THE University of Bristol have created an acousto-optical device that can shape beams of light at record speeds. The technique could be used to improve optical devices and communication systems. The device consists of 64 high-frequency piezoelectric loudspeakers. The sound field they generate can be used to alter the shape of light beams that pass through it.

3 Flexible spinal implant

SCIENTISTS AT THE Ecole Polytechnique Fédérale de Lausanne have created a spinal implant that may help the paralysed walk again. The device, e-Dura, is placed on the spinal cord and stimulates nerves and tissues electrically and chemically.

e-Dura has proved successful in rats: human trials will follow

4 Microparticle 'hitchhikers' to deliver drugs



Backpacking, nano-medicine style

RESEARCHERS HAVE CREATED microparticles that can 'hitchhike' to inflamed tissue to deliver their drug payload. The technology could lead to treatments that target cancer sites more effectively. The team attached cellular 'backpacks' to monocytes, a type of white blood cell known for their ability to respond to signs of infection and penetrate deep into tissue.

2 Jetlag drug

ANYONE WHO HAS suffered from jetlag has probably wished they could reset their circadian rhythm. Researchers at McGill University have found that taking glucocorticoids, a steroid hormone, may do just this, by resetting so-called 'clock genes' that are active in our organs. The finding could lead to the development of simple treatments for overcoming jetlag and sleep disorders.

A steroid hormone may help you feel better after long flights

1 Tongue-mounted hearing aid

A TEAM AT Colorado State University is developing a technology that could enable deaf people to hear through their tongues. The system uses a Bluetooth earpiece to detect sound and send signals to a mouthpiece which is covered in electrodes that vibrate. With training, the wearer can interpret these signals as sounds, researchers say. The device could be a cheaper, less invasive alternative to cochlear implants.

Obviously, some miniaturisation is still required...

CHEMISTRY

Was there life on Mars?

IT MAY BE an arid, inhospitable place nowadays, but scientists have known for a while that billions of years ago, the Red Planet had a climate that could potentially have supported life. And now, NASA's Curiosity rover has found the first definitively identified organic matter on the surface of Mars.

The rover collected samples of molecules consisting primarily of carbon, hydrogen and oxygen – elements considered to be the building blocks of life. The samples were found in mudstone at Gale crater, the vehicle's landing site and an area that resembles the rich clay environments found in dried-up lakes on Earth. Earlier analysis of this same mudstone had revealed that the environment was once abundant in water and chemical elements essential for life.

The molecules in question may have been created by chemical processes on the surface, or even brought to the planet in fragments of asteroids or interplanetary dust – there isn't currently enough evidence to accurately determine whether the matter came from ancient Martian life or from a non-biological source. But researchers say they can't rule out the possibility of life forms once existing on the Red Planet.

"We think life began on Earth around 3.8 billion years ago, and our result shows that places on Mars had the same conditions at that time – liquid water, a warm environment and organic matter," said Caroline Freissinet of NASA's Goddard Space Flight Center. "So if life emerged on Earth in these conditions, why not on Mars as well?"

New findings by the Curiosity rover hint at life once existing on the Red Planet, but the evidence is by no means conclusive

PHOTO: NASA ILLUSTRATOR: DEM ILLUSTRATION

PATENTLY OBVIOUS with James Lloyd

Inventions and discoveries that will change the world

Chew your ear off

IT'S FEBRUARY, AND those New Year diet plans are already looking decidedly ambitious. But if you're struggling to resist those tempting treats, help may soon be at hand. Meet BitBite, your personal dietitian.

Created by Israeli entrepreneur Etai Granit, BitBite is a device that's worn in your ear as you eat. You tell its voice-activated sensors what you're munching on, and the gadget will keep track and offer nutritional advice via an associated smartphone app. Scoffing too many chocolates? Eating the wrong kind of bread? At risk of developing scurvy? The app will flash up an alert. Using its in-built microphone, BitBite will also assess your chewing habits, letting you know if you're eating your food too quickly or not chewing it enough. After all, as health food enthusiast Horace Fletcher once said, nature will castigate those who don't masticate.

Patent pending

Water great idea

A RECENT SURVEY found that the average Brit spends eight minutes in the shower. With a power shower, that equates to twice as much water as a bath. In a bid to cut water wastage by half, a team in California has come up with Eva, the world's first smart shower.

Designed to work with standard showers, the gizmo uses a proximity sensor to automatically reduce the flow when you've stepped away from the water to shampoo or scrub, increasing it again when it's time to rinse off. So fresh, so clean, so green!

Patent pending

Puff a jacket

ANY LOVER OF the great outdoors will know that choosing a suitable jacket can be a tricky task. Do you wear one thick coat and risk overheating, or layer up like a cloth onion? An answer to this dilemma may be provided by NuDown. Their jackets come with a pocket-sized pump that lets you fill the garment's chambers with air. Simply increase the amount of insulation to warm up, or release some air to cool down. There's also the option to use argon gas, which will provide three times more insulation.

Patent pending

Parrot

Parrot

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INSIDE SCIENCE

ROBERT MATTHEWS

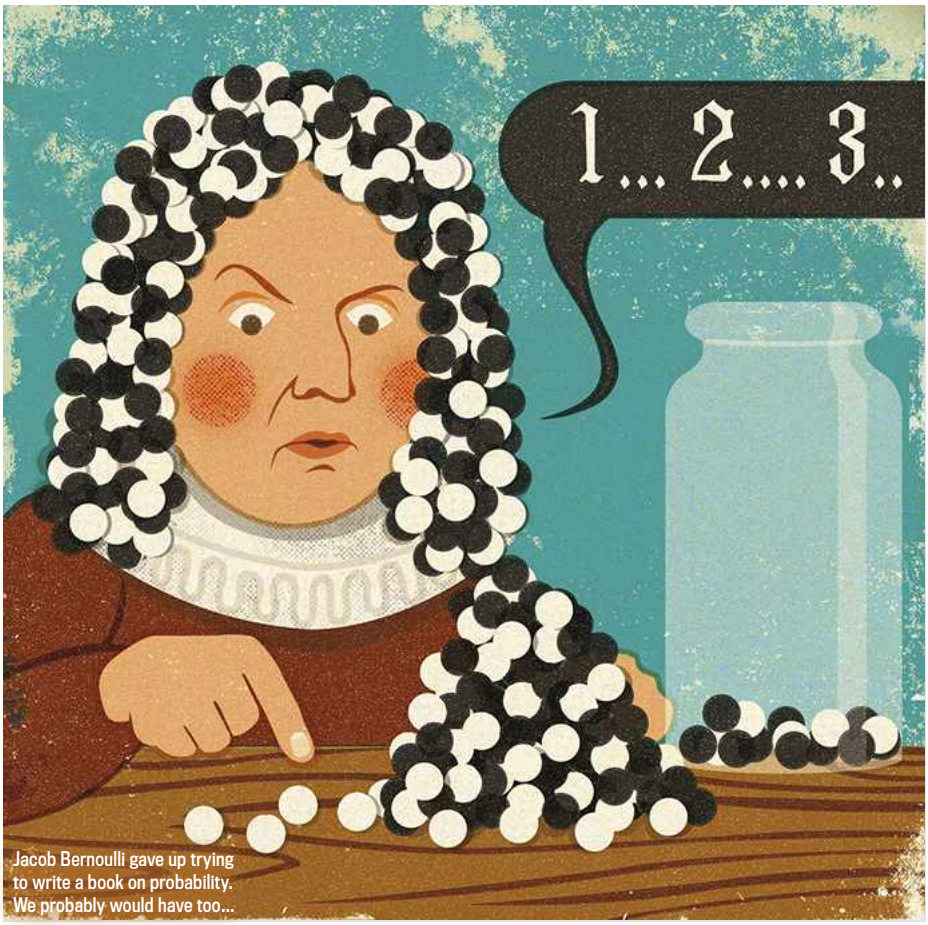
Results from the Philae lander are indicative of science's data problem

AS A SPACE-mad kid in the 1970s, I was spoilt rotten by the constant flow of amazing space missions, from the near-disaster of Apollo 13 to Pioneer 10's fly-by of Jupiter and the Viking Mars lander. Even so, the Rosetta mission to comet 67P/Churyumov-Gerasimenko has left me awe-struck at its audacity: a decade-long voyage to a tiny chunk of rock and ice, followed by weeks on triangular orbits looking for a landing spot, and then finally a soft(-ish) landing.

With luck, the Philae lander will come back to life in March and continue the studies of 67P it began last November. Arguably the only disappointment so far is that Rosetta has killed off the amusing idea that the colourless liquid we clean our teeth with was once inside a comet.

That, at least, was how the results of Rosetta's analysis of vapour coming from the comet were reported. Apparently the water it contains has high levels of a form of hydrogen called deuterium, quite unlike water on Earth. So that's that. The stuff in our taps must have come from within the Earth, asteroids or some other source – not, as some had suggested, from comets.

There is, of course, just one small problem with so huge a conclusion: it's based on a single data-point. Maybe comet 67P is a freak formed in some frigid, deuterium-rich corner of the Solar System. It's certainly possible: in 2011, studies of a related comet named Hartley 2 found deuterium levels strikingly close to those in our oceans. So on the basis of these two measurements, we can definitely say that we can say nothing definitely.



Jacob Bernoulli gave up trying to write a book on probability. We probably would have too...

In fairness, the Rosetta scientists were more cautious – almost laughably so, in fact. Reporting their findings in the journal *Science*, they stated that the results show only that these types of comet don't *all* contain Earth-like water, to which one can only say: "Well, duh".

"Even scientists don't always appreciate just how much data is needed to put a conclusion beyond doubt"

And that's the problem with so much of science: there's often just not enough data to say anything interesting either way. Even scientists don't always appreciate just how much data is needed to put a conclusion beyond reasonable doubt. The answer is often shocking, as the brilliant mathematician Jacob Bernoulli discovered over 300 years ago.

Keen to apply the emerging theory of probability to a practical problem, Bernoulli set about estimating how many stones should be taken from a jar containing black and white varieties in order to make a decent estimate of their relative proportions. The figure he reached was over 25,000. Forget sampling: it would be quicker just to empty the whole jar and count 'em. Bernoulli seems to have been so appalled he gave up writing his textbook on the subject.

It's now known that we can be pretty confident of pinning down the proportion to plus or minus 3 per cent by using a sample of around 1,000. But even that's often too vague (ask any opinion pollster). The trouble is that doing much better needs dramatically more data. Medical researchers have tried to get around this by setting up huge international studies of hundreds of thousands of people. Yet by the time they've screened out smokers, drinkers, duffers and the rest, they're often left with just a few hundred people – and thus pretty imprecise conclusions.

The upshot of all this is that scientists have to do their best with the data they've got. But let's not be in any doubt: getting enough data to answer some questions – such as where Earth's water came from – is never going to be cheap. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

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EVERYDAY SCIENCE

HELEN CZERSKI

A night on the cocktails has got Helen thinking... about bubbles

THE POLISHED WOOD of the bar is lit by dim light, a warm glow that's clearly been designed to whisper 'urbane sophistication' with all the subtlety of a lead balloon dropping hints about gravity. We are perched at one end, in a charmingly bookish corner with the added enchantment of being right next to the loo. The barman is fixing me a drink. As he finishes pouring, I realise my friends are laughing at me because I was completely distracted by the bubbles dancing just under the surface of the cocktail.

I'm a bubble physicist, so I suppose I have an excuse, but it astonishes me that people don't watch bubbles more often. In the dimly lit bar they look even prettier, although they're spectacular anywhere. You're seeing the invisible: invisible air inside invisible water. But never mind the beauty – why can you see it at all?

It's not just bubbles. Diamonds, the cocktail glass itself, Pyrex jugs, ice cubes, raindrops... they are all made of ostensibly invisible stuff, but we never have any problem knowing that they're there. We assume that we can see things because light bounces off them, or is produced by them. But that's not the case here, because light mostly goes straight through these materials.

From where I'm sitting, I've got a clear view of the entrance to the bar. A couple walk in, side-by-side and holding hands. As soon as she walks in the door, the woman slows down, scanning the room for her friends. The man is still walking a bit faster than her, and because they're holding hands, he swings around towards her side slightly, until he works out what's going on and slows down too.

By then the two of them are both moving more slowly, but in a different direction. Together, they've turned around to face the crowd on the woman's side. This is exactly what happens when a light wave passes into a transparent material. It keeps travelling, but it slows down. And if one part of the wave happens to hit the surface and slow down a bit earlier than the rest, then the whole wave changes direction.

"If you look at any transparent object, you'll notice that you can only really see how it's disturbed light at its edges"

We've all heard that the speed of light is the fastest that anything can travel, but what we mention less often is that light itself is only going at the 'speed of light' in a vacuum. Whenever it's passing through anything else, it slows down. In water, it travels at only 75 per cent of the speed of light, in glass 66 per cent, in Pyrex 68 per cent and in diamond only 41 per cent. So light passing from air into diamond, for instance, swerves a lot on its way in, and then all the way back on its way out. That's why diamond sparkles more than almost anything else – it slows down light more than almost anything else.

I stick my tongue out at my friends and stir my drink to make a few more bubbles. I can't really see the bubbles themselves, but I can see the dark bands where light has been bent out of my line of sight, and the bright lines where extra light has been bent into view. I can only see the effect that the bubble has on the light going through it, and I'm deducing where the edges of the bubble are from that. Sometimes, light does reflect off the surface of a bubble and we can see that, but it's relatively rare. If you look carefully at any transparent object, you'll notice that you can only really see how it's disturbed light at its edges, not the object itself.

I pick up my invisible glass, with its invisible contents, and take a sip. The unseeable is stunning, and it tastes as good as it looks! ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series was *Super Senses*

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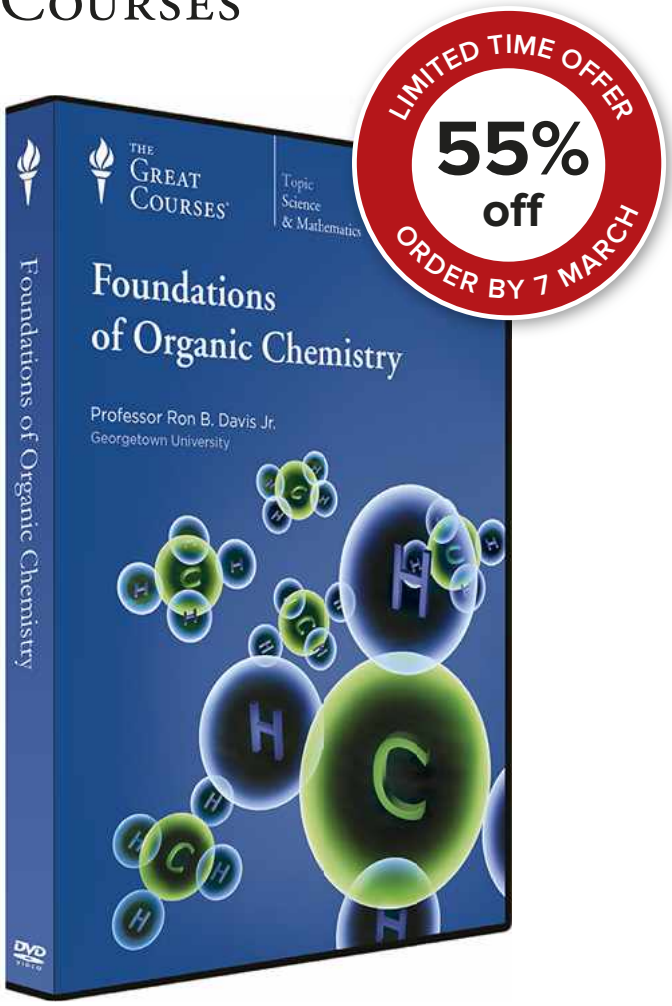

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INTO THE FUTURE

STEPHEN BAXTER

Science can explain why we fall in and out of love throughout our lives

WHY DO FOOLS fall in love? That was the question sung by Frankie Lymon back in 1956, but it's still relevant now as the shop shelves bulge with gifts and cards for Valentine's Day. A neurobiologist might give a rather cheerless answer: that love is a neurochemical phenomenon deriving from systems that evolved to serve the survival needs of our hunter-gatherer ancestors on the savannah. So is love just an addiction, of which we fools could be cured?

For most of our history, few humans lived longer than 35 years. Monogamy seems to have boosted children's survival chances, because the father and mother work together during the mother's pregnancy and the child's development. An interesting recent study by David McLeod and Troy Day of Queen's University, Belfast indicates that some sexually transmitted diseases could also have caused evolution to select for monogamy. Love is useful.

But that low life expectancy implies that, statistically, half of all monogamous relationships must have ended after 15 years, through the death of a partner. The median duration of marriages today is just 11 years – very close to that number of 15. Darwinian natural selection just hasn't equipped us, it seems, for relationships spanning modern adulthoods of 50 years or more. Maybe it's no wonder so many of us fall in love more than once.

What, though, is love? Psychologist Dr Helen Fisher of Rutgers University, New Jersey, breaks love down into three components: lust, which promotes mating with any partner; attraction, which makes you choose a particular partner; and attachment, which encourages pairs to stick together. Each of these is associated with biochemistry linked to the brain's reward systems – mechanisms we share with other animals. Lust, for example, shares some characteristics with obsessive compulsive disorder, which is associated with low levels of the hormone serotonin. As for attachment, the prairie vole is a monogamous beast – but when the animal's level of the hormone oxytocin is reduced it becomes polygamous.

"Natural selection just hasn't equipped us for relationships spanning modern adulthoods of 50 years or more"

This kind of analysis, while hardly romantic, deepens our understanding of the biological basis of our own behaviour. It also opens the eerie possibility of the technological adjustment of love. Perhaps a faltering marriage could be rescued by drug treatment; perhaps a widow or widower's grief could be chemically alleviated. But humans are hugely complex creatures, and without a deep understanding of a relationship and its context, it is easy to imagine doing much more harm than good.

Love itself is evolving, due to technological advances. Thanks to modern communications, many people already have deep platonic relationships with friends they never expect to meet in the flesh. And maybe the object of love does not need to be human. Computer systems are already learning to read our emotions through facial cues; perhaps an advanced artificial intelligence would be capable of the deep appreciation of the other that most of us might call 'love'. In Spike Jonze's movie *Her*, set in the near future, a lonely introvert called Theodore falls in love with his home's new operating system, Samantha. But Samantha eventually forms relationships among her own kind, of a sort Theodore can't share.

With time, Darwin's benevolent hand may help. If longevity increases in the future, maybe our capability to love for longer will evolve too. After all, vampire romances last for centuries... ■

STEPHEN BAXTER is a science fiction author who has written over 40 books. His latest is *Ultima*, published by Orion

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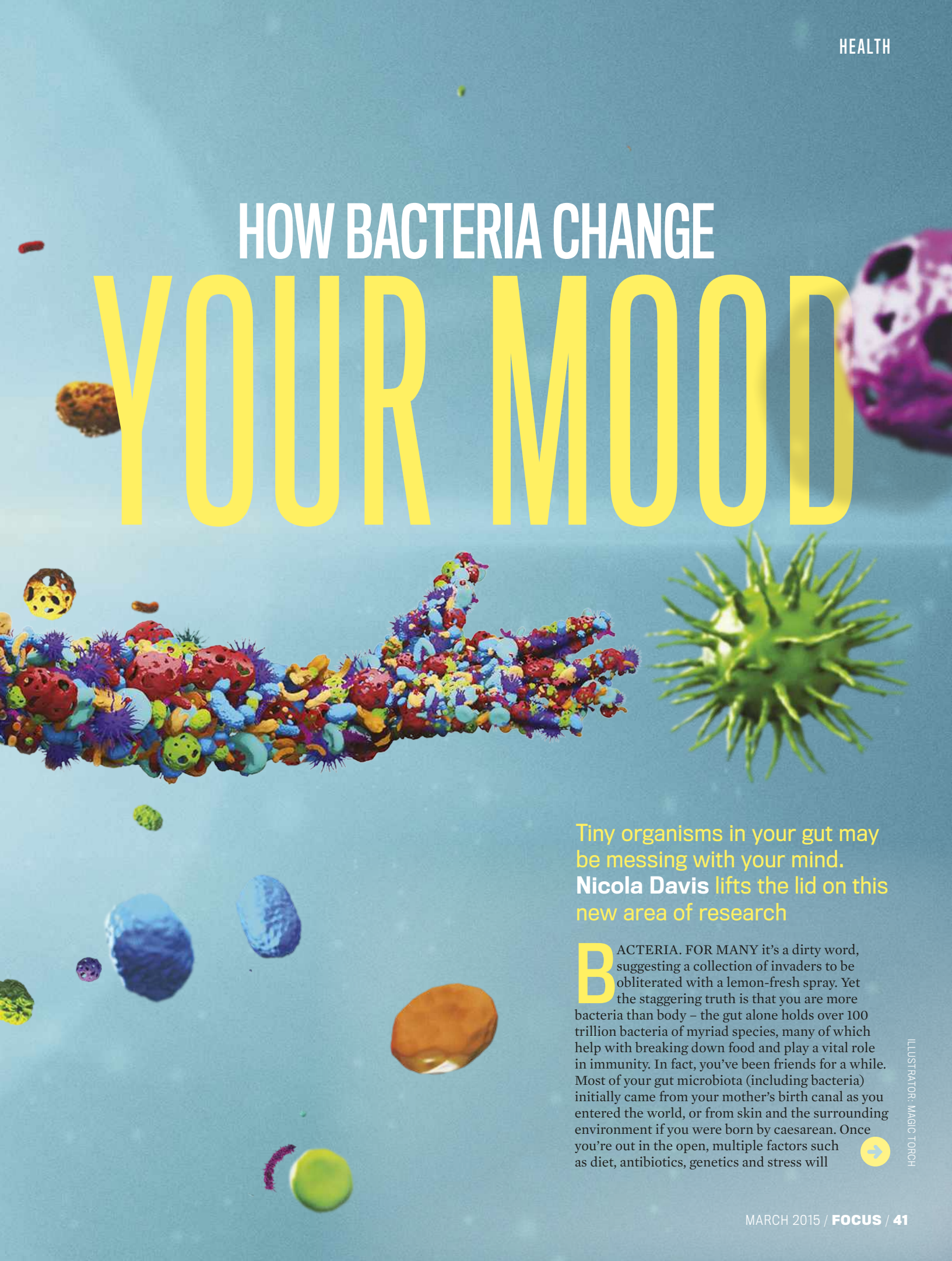
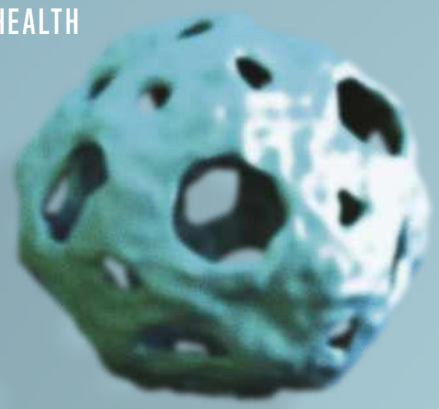
HOW BACTERIA CHANGE YOUR MOOD



Tiny organisms in your gut may be messing with your mind. **Nicola Davis** lifts the lid on this new area of research

BACTERIA. FOR MANY it's a dirty word, suggesting a collection of invaders to be obliterated with a lemon-fresh spray. Yet the staggering truth is that you are more bacteria than body – the gut alone holds over 100 trillion bacteria of myriad species, many of which help with breaking down food and play a vital role in immunity. In fact, you've been friends for a while. Most of your gut microbiota (including bacteria) initially came from your mother's birth canal as you entered the world, or from skin and the surrounding environment if you were born by caesarean. Once you're out in the open, multiple factors such as diet, antibiotics, genetics and stress will

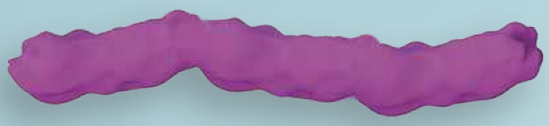
ILLUSTRATOR: MAGIC TORCH

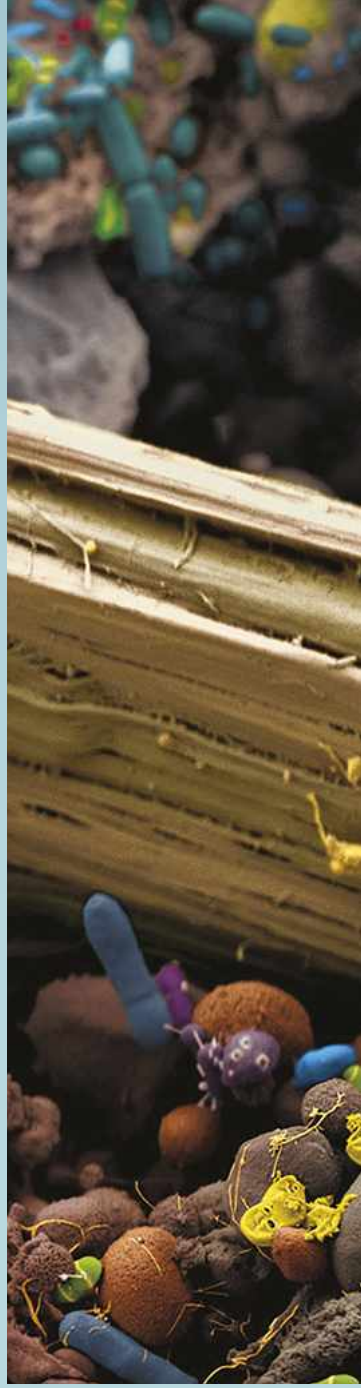


influence the microbiota. The upshot is a cornucopia of bugs that weighs about the same as a human brain. And perhaps that's fitting, for while it's long been known that the brain can influence the gut, modern science is showing that communication can go both ways. Indeed, recent studies have revealed that the gut microbiota could be involved in a host of conditions such as obesity, social behaviour deficits, Parkinson's disease and anxiety. That's right – microbes might be meddling with your mood.

It's a hot topic of research that exploded just 10 years ago when a team of Japanese researchers delved into the gut microbiota of mice. But these weren't any old mice. They were raised in a sterile environment, therefore making them 'germ-free'. This created a clean slate with which to study the brain and behaviour before and after bacterial colonisation. Surprisingly, the researchers found that the germ-free mice had greater amounts of stress-related hormones when restrained than animals with microbes. Yet when young germ-free mice were colonised by certain bacteria, their stress response changed. What's more, the germ-free mice also showed differences in the levels of a brain-derived neurotrophic factor (BDNF) protein

"Studies have revealed that the gut microbiota could be involved in a host of conditions"





Above: Intestinal bacteria help us to digest food and absorb nutrients

Left: Prof John Cryan is studying the other effects these microscopic organisms have on our physiology

PHOTO: MARTIN OEGGERLI, CLARE KEOGH/UNIVERSITY COLLEGE CORK

– a substance in the brain that affects the survival, growth and connection of neurones (brain cells).

A wave of research involving germ-free mice followed. One particularly intriguing study was carried out by Dr Jane Foster and her colleagues from McMaster University in Canada. Using a cross-shaped maze, they found that germ-free mice spent more time hanging out in exposed areas than their bugged-up peers. This suggested reduced levels of anxiety, despite having increased levels of a stress-related hormone. Furthermore, the germ-free mice showed changes to the levels of BDNF-encoding molecules, which suggests the gut microbiota might tinker with how the brain is wired for anxiety. "We know what brain regions are involved, and what's interesting is those brain regions are changed in these manipulations of microbiota," says Foster.

The interesting relationship between microbiota and behaviour, however, is far from simple. Changes to levels of BDNF-encoding molecules appear to differ between sexes. Meanwhile, a recent study using one strain of rat found that the animals actually appeared to behave in a more anxious way when they didn't have gut microbiota. Studies have also found that infecting mice with populations of 'bad' bacteria can increase their anxious demeanour.

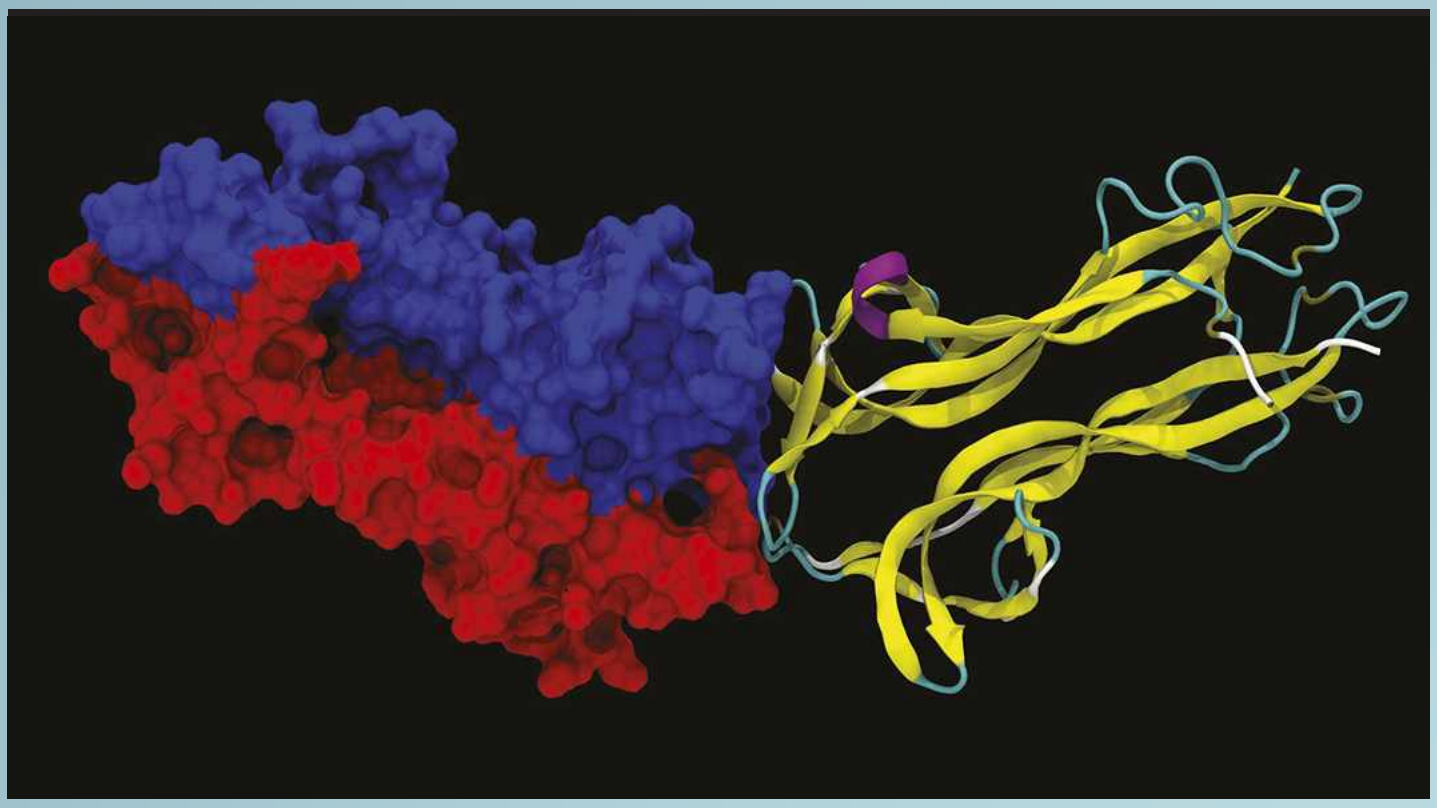
100

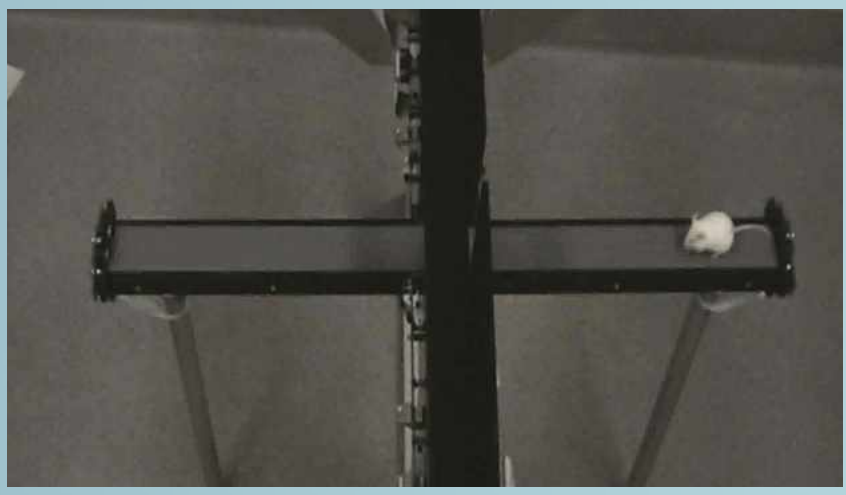
trillion bacteria are found in the gut

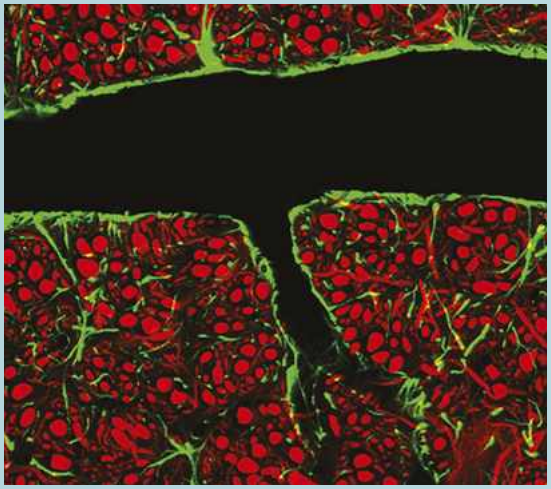
BUGGING OUT

Nevertheless, the notion that bugs can affect behaviour is pretty mind-boggling. In one of the most astonishing studies, a team of researchers transferred gut microbes from an anxious strain of mouse into a germ-free mouse of a more adventurous strain – and vice versa. The result? A behaviour transplant.

Yet questions abound, especially regarding the significance of age. Indeed, some studies suggest that stress responses and anxiety levels in germ-free mice can only be altered by







Clockwise from top: Brain-derived neurotrophic factor (BDNF); section through a blood vessel in the brain; germ-free mouse taking part in a study to monitor stress hormones

PHOTO: AYACOP/WIKI COMMONS, SCIENCE PHOTO LIBRARY, UCLA

colonisation with bacteria if such exposure occurs when the animals are young. If the same effect is observed in humans, it could imply a need for interventions in childhood and pre-adolescence. Interestingly, the composition of our own gut microbiota is unstable until we reach about three years of age. "It's just developing, and that is also the same period of life when the brain is developing," states Prof Emeran Mayer, a gastroenterologist at the University of California, Los Angeles.

Interventions in elderly people might also be important because our gut bacteria levels naturally start to decline as we age. "The microbiota composition, diversity [and] abundance kind of reverses back to the way it was in childhood," says Mayer. "So again it's quite possible that any manipulations or any influence on brain function will be greater at that time."

Exactly how the gut microbiota bring about changes to the brain and behaviour is far from clear-cut. "If I have a headache it could be because I bumped my head, or it could be because I am dehydrated. Those are two very different mechanisms where the readout is the same," says Foster. "It is the same thing here."

And the mechanisms are myriad. Among the mooted possibilities, gut bacteria – or the molecules they produce – could directly or indirectly interact with branches of the vagus nerve in the gut. They could signal to the brain, affect hormonal signalling routes, interact with the immune system or trigger responses via

pathways that include neurones within the gut lining and the vagus nerve. What's more, just a few months ago, researchers revealed that the gut microbiota could affect the permeability of the blood-brain barrier. It's a web of intrigue.

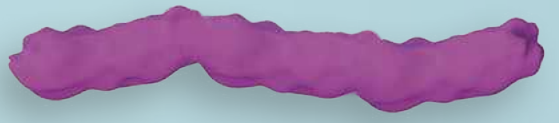
MOOD SWINGS

"There are so many different types of bacteria and they are all having very different effects on different aspects of physiology," says Prof John Cryan from the University of Cork.

In one study, scientists at McMaster University joined forces with Cryan and his team to probe the impact of the probiotic *Lactobacillus rhamnosus* on healthy mice. "It dampened down anxiety and made the animals more chilled out [and] changed the brain chemistry," Cryan explains. "When we cut the vagus nerve this didn't happen." But complexities are never far away. "Some of our colleagues in Canada have done similar studies with different bacteria and showed that it wasn't dependent on the vagus," he adds.

It's a problem worth probing. While human studies are few and far between, there is a tantalising suggestion that various *Bifidobacteria* and *Lactobacillus* species might influence mood in humans as well as rodents. In one trial, healthy people given a blend of such probiotics for 30 days

"There is a tantalising suggestion that various bacteria species might influence mood in humans"



were found to fare better in questionnaires probing anxiety, depression and stress than those who were given a placebo. But that doesn't mean we should be stocking our shelves with probiotics just yet. "For me, taking a probiotic is like saying I'll take a drug," says Cryan. "You might take a statin for cardiovascular disease, but you wouldn't take it if you had depression – that's where we are with probiotics. We need to get more precise about which bacteria are doing what and why."

OF MICE AND MEN

While it is still early days, Cryan foresees a future of 'psychobiotics' – probiotics that could be prescribed to help treat people who are suffering from mental health conditions.

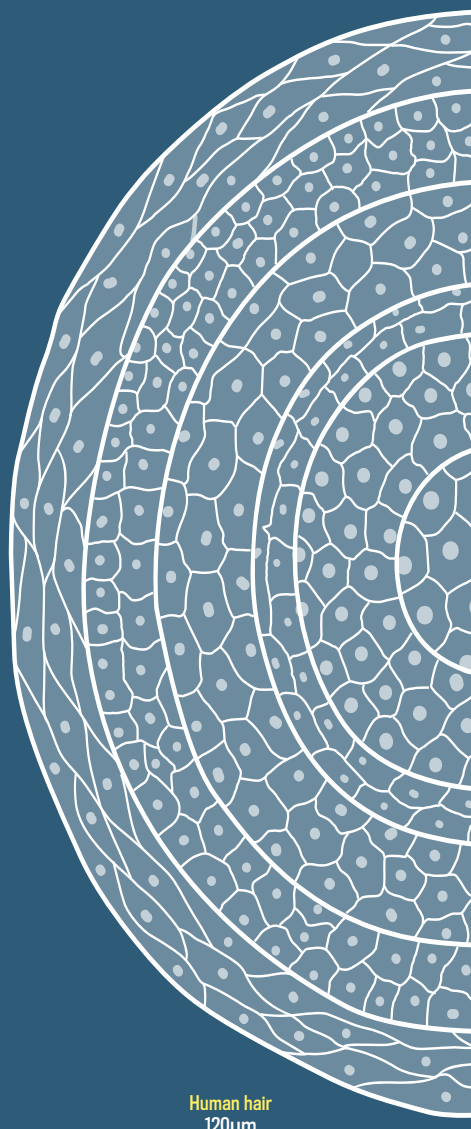
3 micrometres is the size of a *Lactobacillus* cell

SMALL BUT MIGHTY

Bacteria measure just a few micrometres across and are even smaller than red blood cells

BACTERIA ARE TYPICALLY made up of just a single cell each, but these cells are very different to those that make up the human body. Bacterial cells do not have a membrane-bound nucleus. And besides chromosomal DNA, bacteria can have 'extra' little loops of DNA called plasmids. They also lack membrane-bound organelles such as mitochondria – the 'batteries' of our own cells – and nearly all bacteria cells possess a cell wall.

Some bacteria are able to harness light energy, while others make use of chemical reactions involving organic or inorganic compounds to fuel processes in the cell. Bacterial cells are typically just a few micrometres (µm) in length. *Lactobacillus* cells, for example, are around 3µm long. Our own cells, however, can vary in size quite widely. Red blood cells are typically 7µm in diameter. And ova, the largest human cells, can reach 120µm – roughly the width of a human hair.

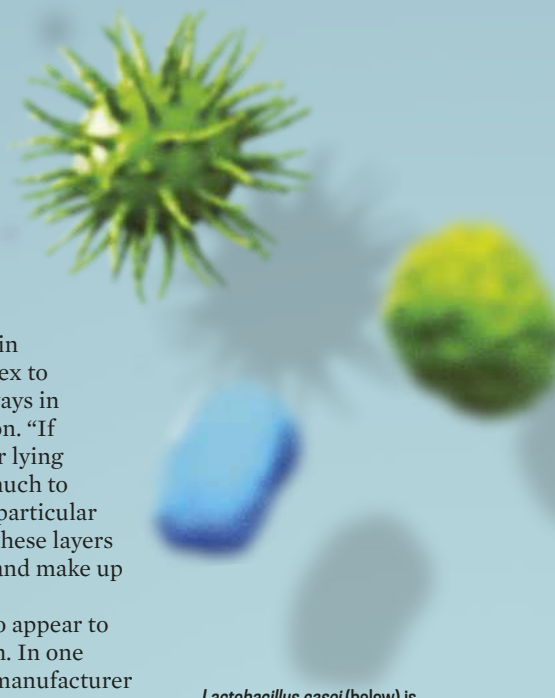


Lactobacillus
3µm

Red blood cell
7µm

Human hair
120µm

1 µm = 1 micrometre = 1 millionth of a metre



Taking substances that promote the presence of 'good' gut bacteria, known as prebiotics, might also prove beneficial.

"I think down the road there is a lot of hope that people will, in addition to getting their blood taken when they go to their GP, also get a quick snapshot of what's going on in their microbiome," states Cryan. That, he believes, could lead to the prescription of probiotics, perhaps in parallel to various other treatments.

Foster is cautious. "Until we have some evidence that the microbiome is different in different mental health disorders – and how it is different – we can't really talk about how relevant what we are learning in the mouse is to people," she explains. There are significant differences between mice and men, including the fact that the human brain boasts a very different prefrontal cortex to that of a rodent. This will affect the ways in which the gut microbiota may function. "If your microbiota send a signal to lower lying brain areas, the mouse doesn't have much to compensate for that and it exhibits a particular behaviour," says Mayer. "In humans, these layers of prefrontal cortex can compensate and make up for it."

As Mayer has found, gut bacteria do appear to have some impact on the human brain. In one small study funded by dairy product manufacturer Danone, Mayer's team split a cohort of healthy women into three groups. One group was given a probiotic yoghurt, one a probiotic-free dairy

Lactobacillus casei (below) is found naturally in the human mouth and intestines. It is often added to yoghurts

PHOTO: SCIENCE PHOTO LIBRARY, ALAMY

DNA

is present inside bacteria cells

product and the other nothing at all. The women's brains were scanned using functional magnetic resonance imaging (fMRI) at the start of the experiment, then again after four weeks of taking the intervention. The study found that there were differences between the three groups in the connectivity of various brain regions when resting. But when the women were asked to match images of angry or frightened faces to similar pictures, the

"The probiotic group showed a decrease in the activity of brain regions involved in emotion and sensation"

probiotic group showed a decrease in the activity of brain regions involved in emotion and sensation. It was a surprise. "I didn't expect it," says Mayer candidly. "I was a sceptic in the beginning of all these animal studies. They just seemed too outlandish – it seemed like it just didn't fit into our paradigm of brain-gut interactions." But, he points out, there's more to do. "It would be nice to repeat a study like the one we did, possibly in a population with anxiety so that we can determine [whether] these brain changes seen with the probiotic are also correlated with subjective changes in anxiety."

Just how big an influence microbes have over our mood has yet to be determined, but Cryan believes we might be surprised. "It's worth considering that they are the master puppeteers," he says. ■

Dr Kirsten Tillisch worked on the Danone study with Prof Emeran Mayer

GUT FEELING

Probiotics and prebiotics have alleged health benefits for us. But what are the differences between them?

PREBIOTICS ARE SUBSTANCES that we cannot digest, but are believed to promote 'good' bacteria in the gut. Prebiotics occur naturally in some foods and include carbohydrates such as fructo-oligosaccharides, galacto-oligosaccharides and inulin.

Probiotics are live microbes that are thought to bring a health benefit. They are often administered as liquid drinks, yoghurts or tablets. Some of the most studied probiotics are of the genera *Lactobacillus* and *Bifidobacterium*.

The health benefits of probiotics are specific to each strain and different commercial products contain different strains of bacteria.

Commercial products in the EU are banned from using the label 'probiotics' as the health claims of such products have not been approved, but manufacturers are allowed to list the strain of bacteria included.

According to market researchers BCC Research, the global market for such products is expected to be worth around $36.7bn (£24bn) by 2018.

NICOLA DAVIS is commissioning editor at Observer Tech Monthly and has a background in organic chemistry

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DATING TIPS FROM THE ANIMAL KINGDOM

With Valentine's Day upon us, **Jennifer Verdolin** says there is plenty we can learn about relationships from our furry, feathery and scaly friends...

Be picky

PERIODICALLY, WELL-MEANING friends suggest that those who are still single should lower their standards and stop being so choosy. Yet most other species would squawk, growl and tweet in disagreement. Peahens, for instance, are very particular about what they look for in a peacock. Research led by behavioural ecologist Prof Marion Petrie found that peahens have a fondness for males with over 150 eyespots and evaluate an average of three males before making a decision. Being selective is possibly one of the most important pieces of guidance we can take from animals, even if that means it takes a while to find your best match.

1,2,3,4,5,6... let's just say you have over 150 spots and get on with it, yeah?

Sure, peacocks are pretty, but black-bellied wrens trounce them in a singing contest

Communicate clearly

COURTSHIP, DATING AND relationships all require communication know-how. Miscommunication often comes down to individuals not listening to one another. Animals try hard to avoid miscommunication, and black-bellied wrens (pictured) are no exception. Research from the University of Lethbridge illustrates that by listening and paying attention, black-bellied wrens are able to stay in-sync with their partner, anticipating exactly when to start singing so there is no overlap and no gap. If a conversation isn't going well, they take a break and try again later.

Make false promises, Mr Cockerel, and you'll be left with egg on your face!

Don't talk rubbish!

ACTIONS ALWAYS SPEAK louder than words. No one knows this better than hens. Dr Peter Marler, the late neurobiologist and animal communication researcher, showed that some cockerels will give out food calls even when there is no grub to be had. As hens are always on the lookout for good sources of food, they come to check out what he claims to have. Should they arrive at the scene and discover that the cockerel can't offer what he said he could, they do not hesitate and move swiftly on. The bottom line? Talk is cheap – for cockerels as well as humans.

PHOTO: GETTY X2, JOHN EVESON /FLPA, MIKE DANZENBAKER, MARK NEWMAN /FLPA, GEORGETTE DOUWMA/NATUREPL.COM

Little known fact: siamangs are the world's largest consumers of Strepsils

Assess interest

DATING AND COURTSHIP takes effort, energy and resources. We know that many species engage in courtship feeding rituals. A study led by Dr Mariano Trillo found that not only does the *Paratrechalea ornata* spider male offer delicacies to females, but they also wrap them in an elaborate silk gift basket. The amount of energy an individual puts into courting and responding toward a potential mate is usually correlated with the degree of interest. Even seasoned romantic relationships require continued and equal investment by both parties. Thanks in part to research by the University of Michigan's Prof John Mitani, we know that socially monogamous siamangs (a type of gibbon, pictured left) wake up and sing a duet every single day, for the entire duration of their relationship. All relationships take work.

Set boundaries

HAVING LIMITS ON what we will accept isn't just important for people – it matters to animals, too. Sometimes, in those early stages of dating, we're more relaxed about our boundaries and will allow a potential partner to cross the line. Indeed, many of us resist the process of setting boundaries because we don't want to be rejected, to offend, or be seen as 'selfish'. Animals, however, have no such qualms. They establish boundaries quickly, they often say "no", and don't appear to feel the least bit bad about it.

Vampire bats (below) have cooperative natures, but research by Gerald Carter at the University of Maryland reveals that they are experts in how to give without becoming a doormat. They willingly share food with other group members, as long as those who receive give back in kind, regardless of the relationship status. However, they are not keen on other bats taking advantage, and will stop when their generosity is exploited. Knowing how, and when, to say "no" is vital in every relationship.

Despite their diet, vampire bats don't have a bloodsucking nature

Do French angelfish bicker over the washing-up?

Know what you want

CLARITY OF INTENTION is another must. That means knowing where you are coming from and what you are currently looking for in the dating game. Are you in it for a minute? A season? A lifetime? Whether you are an animal or a human, there are all sorts of different relationships out there.

Baboons have friends with benefits. Tuataras (a type of reptile from New Zealand) may switch partners every year. And French angelfish, like the ones pictured above, spend their entire lives with a single mate.

What you want out of any dating experience may change depending on where you are in your life plan, your personality, who's sitting across the table from you, or even your genetics.

What animals teach us is that you can behave promiscuously like a squirrel, or you can act like a loyal French angelfish. It's not a moral judgment, it's about what works for you at the time – but you shouldn't pretend to be something you're not. ■

DR JENNIFER VERDOLIN is an animal behaviour expert and the author of *Wild Connection.* She is a frequent guest on US radio

A NEW DAWN FOR NASA

Orion embarked on its maiden voyage in December 2014, putting NASA back in the manned space race. **Dr Neil Ashton** straps himself in for the ride...

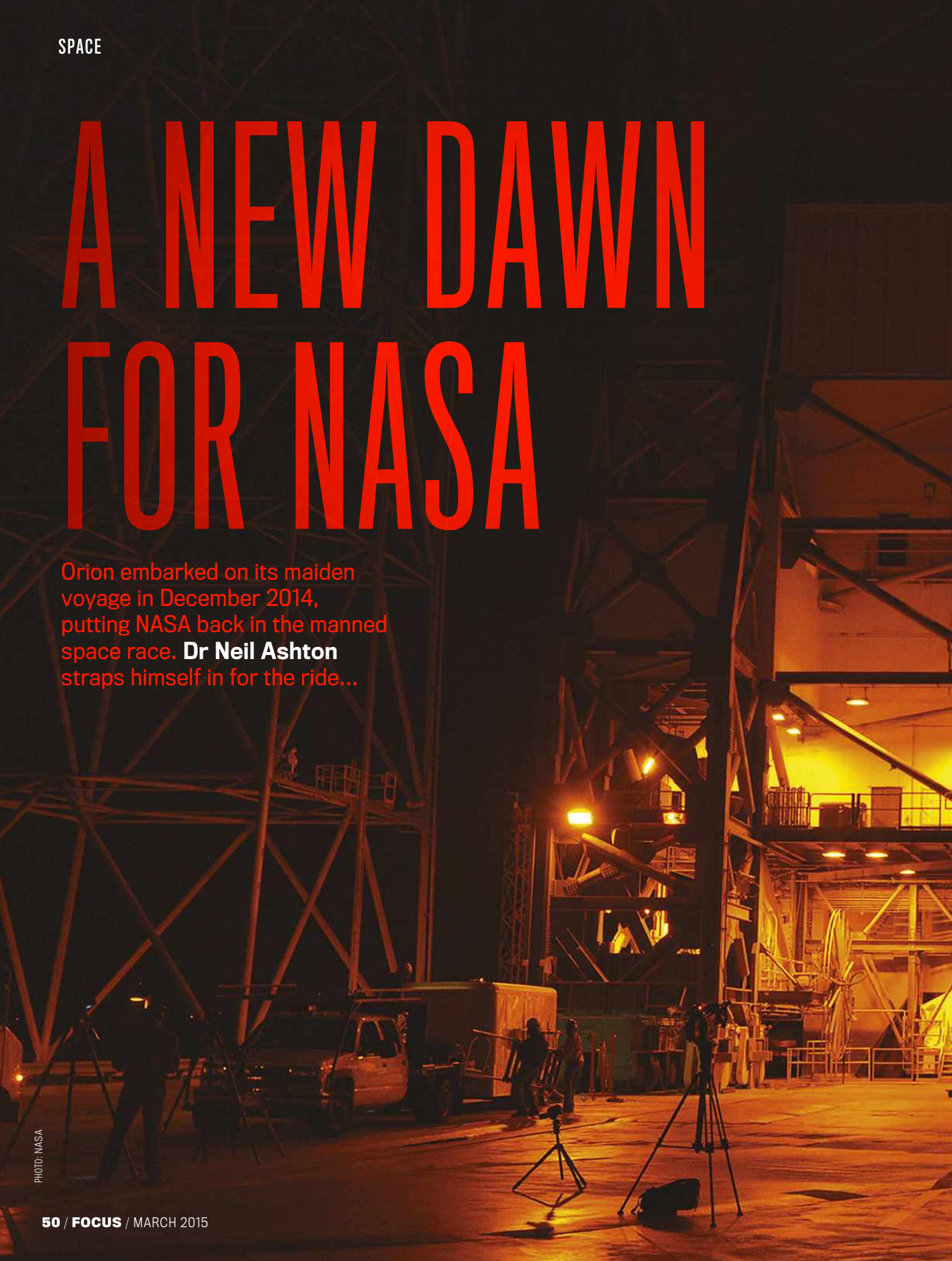


PHOTO: NASA

Technicians and engineers shifted the Orion craft into position on the service structure. It was then lifted and moved onto the Delta IV Heavy rocket

Orion undergoing final assembly at the Kennedy Space Center. Technicians ensured that no foreign objects contaminated the spacecraft while it was being put together

APOLLO 17 SPLASHED into the Pacific Ocean on 19 December 1972 after completing the final mission of the Apollo space programme. It marked the end of an 11-year effort to take humans to the Moon. NASA had first achieved this feat just three years earlier with Apollo 11.

NASA's latest craft, Orion, finally gives the space agency the ability to take humans beyond the Earth once again. On 5 December 2014 it completed its first test flight, dubbed Exploration Flight Test 1. For this flight, Orion was launched by the world's most powerful rocket, the Delta IV Heavy, taking it 5,794km (3,600 miles) above the Earth, more than 10 times further away than the International Space Station. After nearly four hours of spaceflight, it started its descent back to Earth. On the way down it reached speeds of over 32,187km/h (20,000mph) and then attained temperatures in excess of 2,000°C during its re-entry.

The first mission was designed to test the top risks that Orion would face on a mission into deep space. These included the ability of the heat shield to protect the spacecraft on return, the pyrotechnic-induced separations at various stages of the mission and the guidance, navigation and propulsion systems. While the data from the maiden flight is still being analysed, a first look at the information suggests it was a huge success for NASA. "We're ecstatic; there aren't adjectives that describe how well overall the spacecraft did," says Mark Kirasich, Orion's deputy programme manager at NASA. "Our exploration programme at NASA is all about re-establishing human exploration beyond low-Earth orbit."

The origins of Orion date back to 2004. A new crew module, service

Orion splashed down into the Pacific Ocean, 1,030km (640 miles) southeast of San Diego. Five balloons are used to ensure Orion stays upright, but only two of them correctly inflated

PHOTO: NASA X3

The Orion craft blasted into space on 5 December 2014 aboard the Delta IV Heavy, which is the most world's most powerful rocket

"BY 2021 THE FIRST MANNED MISSION WILL BE LAUNCHED"

"EVENTUAL MANNED MISSION TO MARS IN THE 2030S"

module and rocket were planned, together with a lunar lander. But a change in the US administration ultimately led to the programme being cancelled, and NASA went back to the drawing board.

Out of this rethinking came two objectives. First, to commercialise the re-supply of crew and cargo to the International Space Station. This has since led to two private companies, SpaceX and Boeing, being awarded contracts to take over the responsibility of ferrying astronauts and cargo to the space station. This capability allows NASA and its lead contractor, Lockheed Martin, to concentrate on the development of deep space human exploration missions.

BLAST OFF

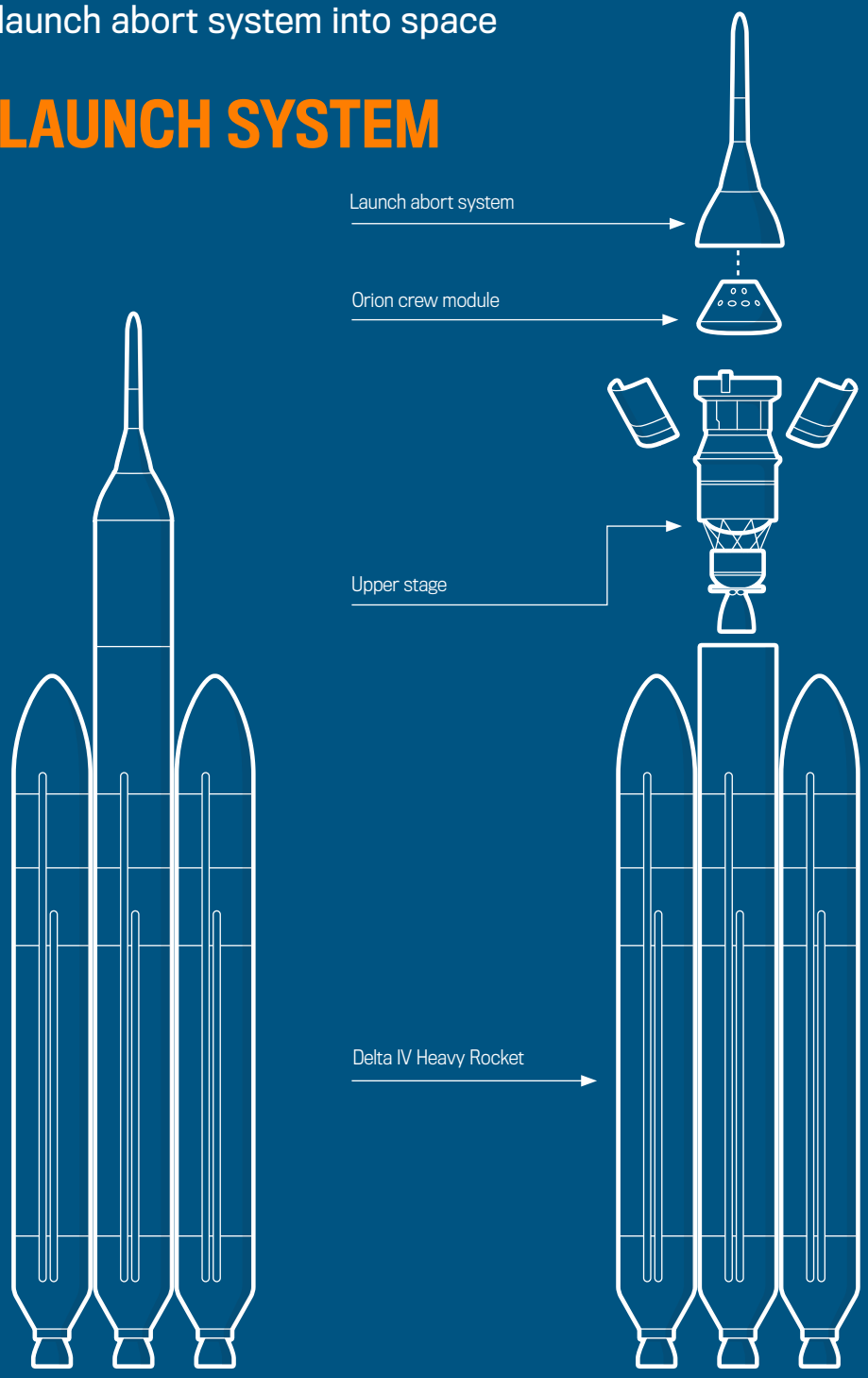
This second objective resulted in the Orion spacecraft, whose design came largely from the previously cancelled Constellation programme. In addition to Orion, a new and powerful rocket called the Space Launch System (SLS) has been developed. The SLS will have the capacity to eventually take Orion to Mars.

You could easily be forgiven for thinking that the Orion spacecraft is, in fact, Apollo in disguise. Larry Price is Orion's deputy programme manager at Lockheed Martin. As he explains, NASA's extensive storehouse of knowledge came in handy when designing Orion. "The shape reduces the time and cost to develop a system based upon the

BLAST OFF!

The Delta IV Heavy is the world's most powerful rocket. It launched the Orion crew module and launch abort system into space

LAUNCH SYSTEM



ILLUSTRATOR: ACUTE GRAPHICS

ORION'S FIRST FLIGHT

Hours: minutes: seconds after launch

1 **0:00:00**
On 5 December 2014, Orion launched on the Delta IV Heavy rocket from Kennedy Space Center

2 **0:06:10**
The service module and the launch abort system separated – this was a critical part of the mission

3 **1:57:11**
The upper stage of the system reignited after completing one orbit around the Earth

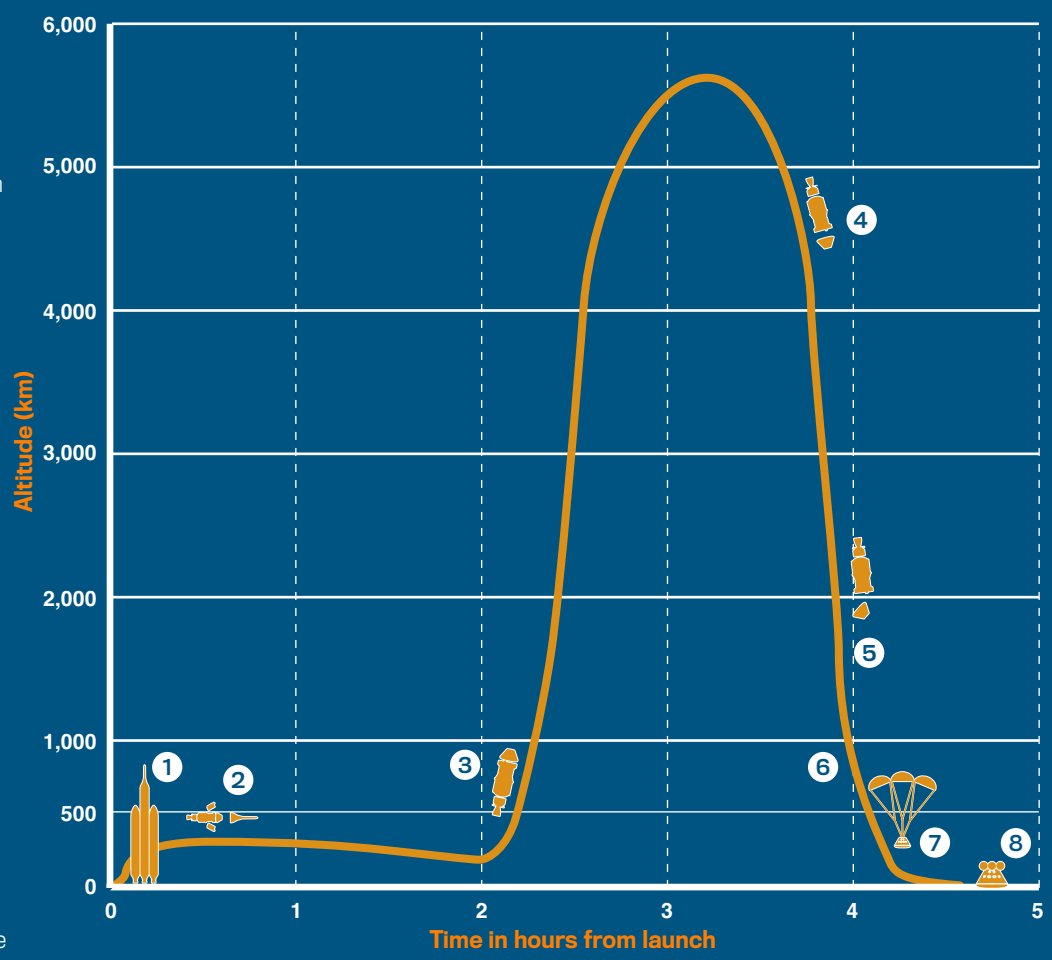
4 **3:23:41**
The Orion crew module separated from the service module and the upper stage

5 **3:57:00**
The crew module fired the control jets to orientate the craft correctly for re-entry into the atmosphere

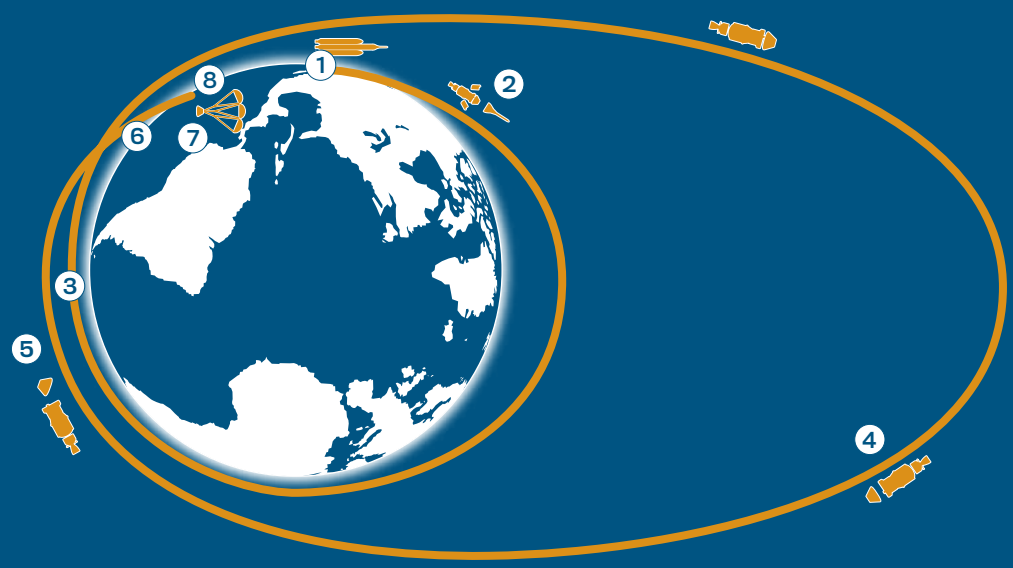
6 **4:13:41**
The Orion crew module made contact with the Earth's atmosphere at an altitude of 805km

7 **4:20:22**
Forward bay cover separated, starting the parachute deployment sequence

8 **4:24:46**
Orion landed safely in the Pacific Ocean and was recovered by NASA and the US Navy



HOW ORION ORBITED EARTH



"THIS IS THE START OF A NEW WAVE OF HUMAN EXPLORATION OF OUR SOLAR SYSTEM"

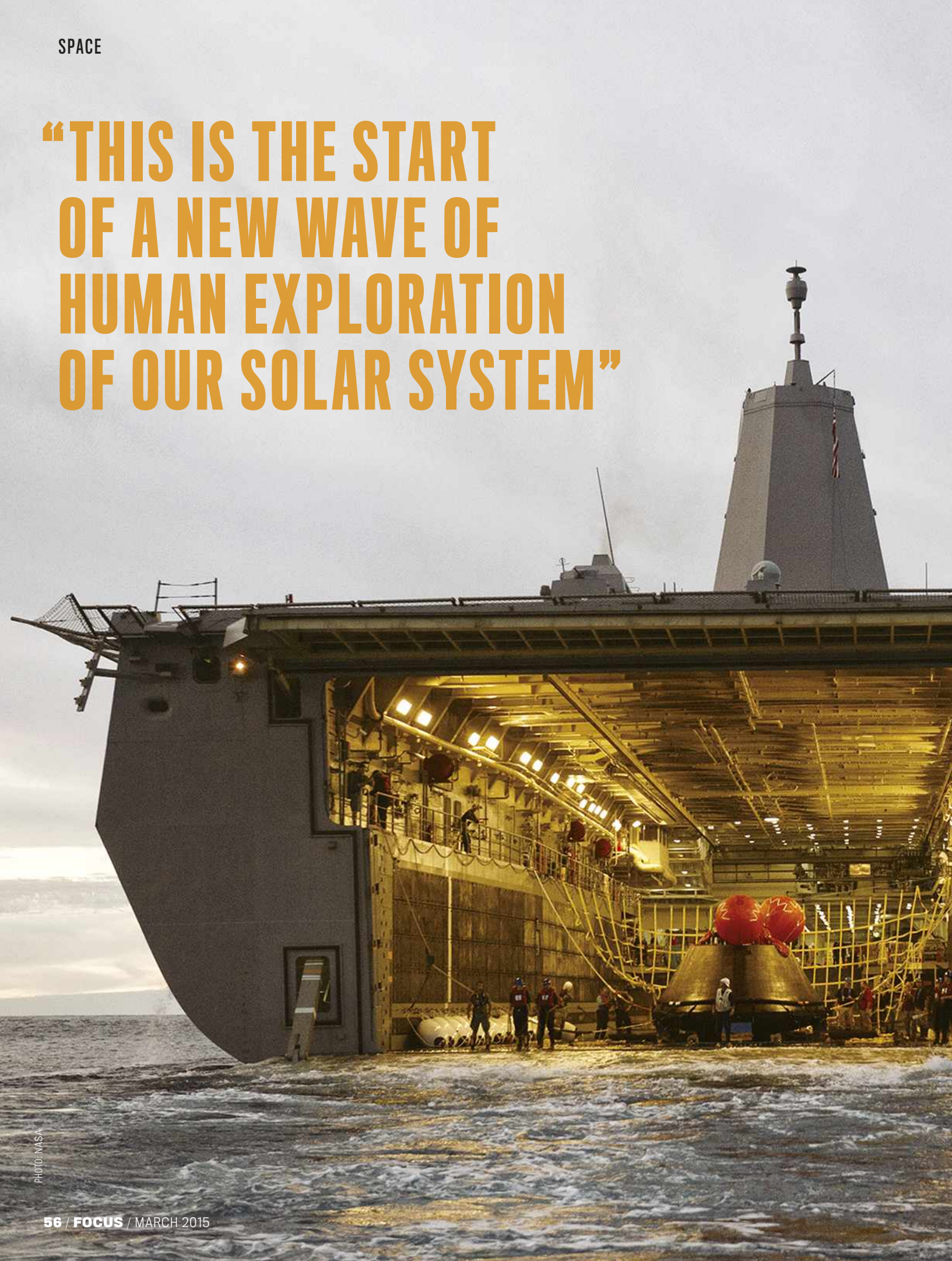
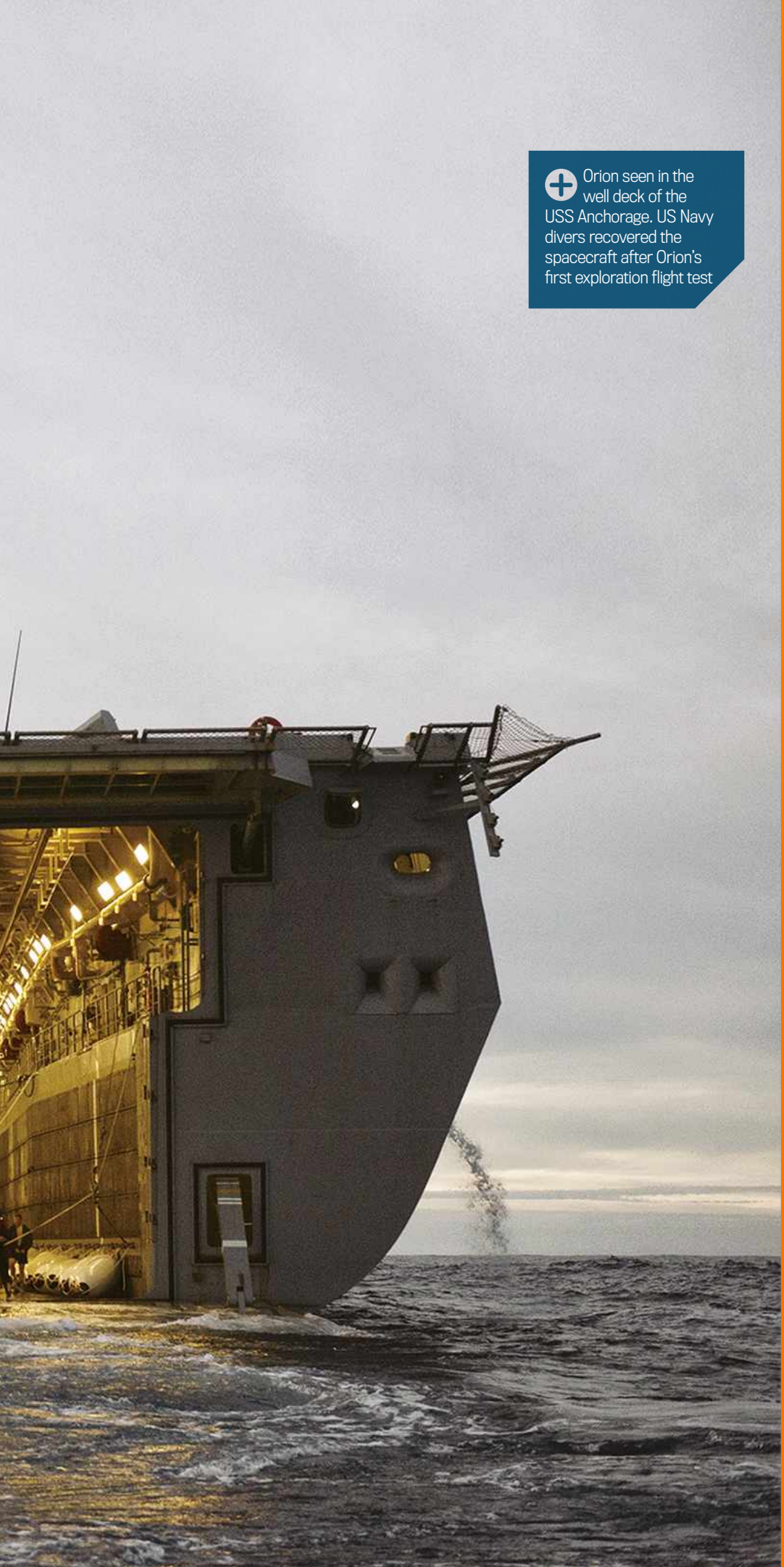


PHOTO: NASA



Orion seen in the well deck of the USS Anchorage. US Navy divers recovered the spacecraft after Orion's first exploration flight test

existing data we've got from the Apollo programmes," he says.

This mission marks the first step towards an eventual manned mission to Mars in the 2030s. Next year, further test flights with updated hardware will take place. And in 2018, Exploration Mission 1 will launch an unmanned Orion aboard the new Space Launch System, sending it into orbit around the Moon. This will be used to test the guidance and navigation systems as well as the radiation protection equipment. By 2021 the first manned mission will be launched, called Exploration Mission 2. This mission is currently proposed to send astronauts to a captured asteroid, so they can collect samples and bring them home.

Before any humans fly onboard Orion, one hugely important part of the system will be thoroughly tested. The Launch Abort System (LAS) fits around the crew module, with a spike housing three rocket motors. If the main rocket should fail, the LAS's rockets would fire within milliseconds to pull the crew module out of harm's way before deploying parachutes for a safe landing.

MARS MISSION

Many challenges lie ahead before the final goal of sending astronauts to Mars, however. At present Orion is designed to only take four astronauts for missions lasting up to 21 days. This is because there isn't enough space to store water and supplies for longer missions. An eventual mission to Mars would rely on various other components, such as a habitat module.

But the need for humans to undertake such missions is something that NASA is convinced is necessary. Exploration Flight Test 1 was just the start of a long journey for NASA, but it is one that could ultimately mark the start of a new wave of human space exploration of our Solar System and will inspire a new generation of scientists and engineers. ■

DR NEIL ASHTON works at The University of Manchester's School of Mechanical, Aerospace and Civil Engineering

Listen to BBC World Service's *Science In Action* on the background to the Orion project: **http://bbc.in/XgHm9s**

THIS MAN COULD SAVE YOUR LIFE

Neuroscientist **Daniel Levitin's** new book explores information overload – he tells editor **Graham Southorn** how to cope with it

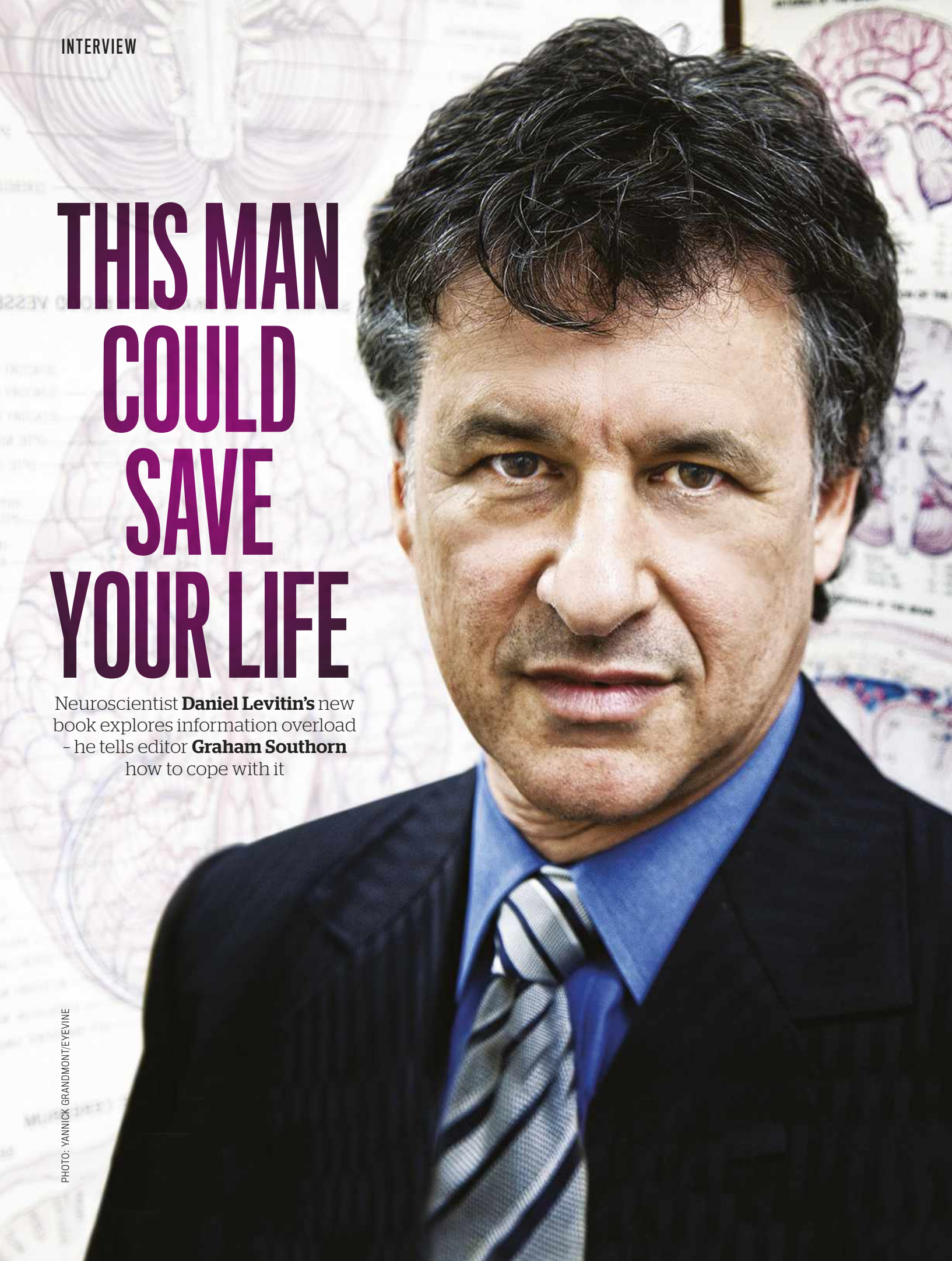
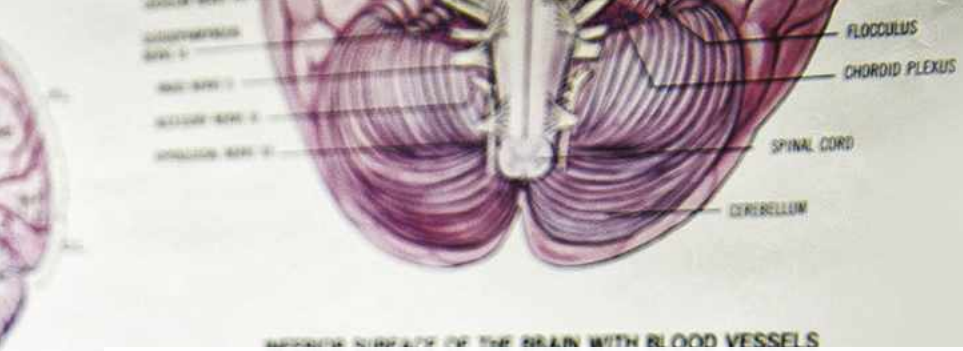


PHOTO: YANNICK GRANDMONT/EYEVINE



THE TORRENT OF text messages, emails and social media updates seems to grow bigger every day. In *The Organized Mind: Thinking Straight In The Age Of Information Overload*, Daniel Levitin investigates this modern phenomenon. We asked him what effect it has on our brains, and for some practical tips.

What's the evidence that we live in an age of 'information overload'?
The amount of information is increasing at a really rapid rate – in the last two years we've created more information than we did in all of human history up to that point. Several studies show that, as individuals, we're being inundated. The average American took in five times more information every day in 2011 than they did in 1986. That's the equivalent of reading 175 newspapers every day from cover to cover. People say they're overwhelmed – they feel like they can't keep up no matter how hard they work.

Is it because of the way our brains store information?
That's part of it, but I think the real culprit is our attentional capacity. It was first documented in the 1950s that attention is a limited resource and there's a fixed number of things we can deal with at any one moment. That number is surprisingly small – it's about four. If you think you're dealing with more, you're shortchanging your attention. If you're driving a car with the radio on and looking for a parking space, often you'll turn the radio off, even though it wouldn't seem to interfere with the visual task. However, it is sapping your attentional resources.

Are some people better at coping than others?
Yes, but the best of us aren't all that much better than the worst. The real difference is between how well people think they are doing, compared to how well they're actually doing! People grossly overestimate their ability to multitask. Multitasking feels good because you feel like you're getting a lot done. But feeling like you're getting a lot done and getting a lot done are not always the same. The brain is really good at self-delusion!

What can we do to help ourselves?
Don't try to keep things in your head because they're crowding out your attentional capacity to do other things. Writing to-do lists is a very powerful technique. And you could do what the efficiency guru David Allen calls a 'mind-clearing' exercise. On a regular basis, write down everything you are thinking about. Prioritise things you can actually do on your to-do list.

If you're using a physical system like a filing cabinet, think about all the places you might look for something later if you can't find it. Say you've got a folder called 'passport' and another labelled 'travel' – you could put a note in your travel folder that says 'things related to my passport are in the passport folder'.

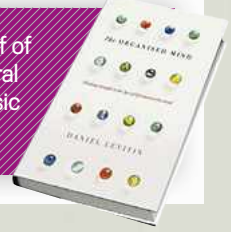
> **"As individuals, we're being inundated. The average American took in five times more information every day in 2011 than they did in 1986"**

I feel overloaded with emails...
Email is a tremendous distraction – we need to exercise self-discipline. I've spoken to many successful people and they turn their email off for vast stretches of the day. They have a dedicated time for checking it, which avoids the constant ping of interruption when you receive a new message.

Does information overload affect our social lives too?
We're meeting more people than ever before, both in person and online. Our hunter-gatherer ancestors might only have known a couple of hundred people in their whole lives. Walking through London you'll easily pass a thousand people in an hour. We evolved in a time when social judgments could be built up over long periods of time, but we now have to make very rapid judgments. The brain, as [psychologist] Daniel Kahneman has shown, didn't evolve to make very good quick decisions because our brains employ 'heuristics', or shortcuts, that are often wrong. We need to train ourselves how to make better decisions, such as when a co-worker passes you in the hall and doesn't return your hello. It doesn't necessarily mean they're mad at you. They might just have something on their mind or be late for an appointment.

Is social media bad for us?
It's neither good nor bad. Social media allows us to stay in touch with people we know in a very efficient way, especially when those people are in far-flung places. The problem is that social media engagement has an addictive quality. In our hunter-gatherer days we evolved what neuroscientists call 'novelty detectors'. Ten thousand years ago things didn't change very fast, so if something novel presented itself it was a good adaptive strategy to pay attention. We evolved a chemical system whereby we get a little shot of dopamine that makes us feel good every time we encounter something new. Our ancestors with good novelty detectors were more likely to remember the location of a new fruit tree or a novel way of catching fish. Today, every Facebook update is a novelty and it engages the dopamine system. Dopamine is the chemical released when you eat chocolate, when gamblers win a bet and that gets people addicted to cocaine. Social media also becomes addictive, and successful people enforce time limits and times of the day when they engage with it. ■

DANIEL LEVITIN is Prof of psychology, behavioural neuroscience and music at McGill University



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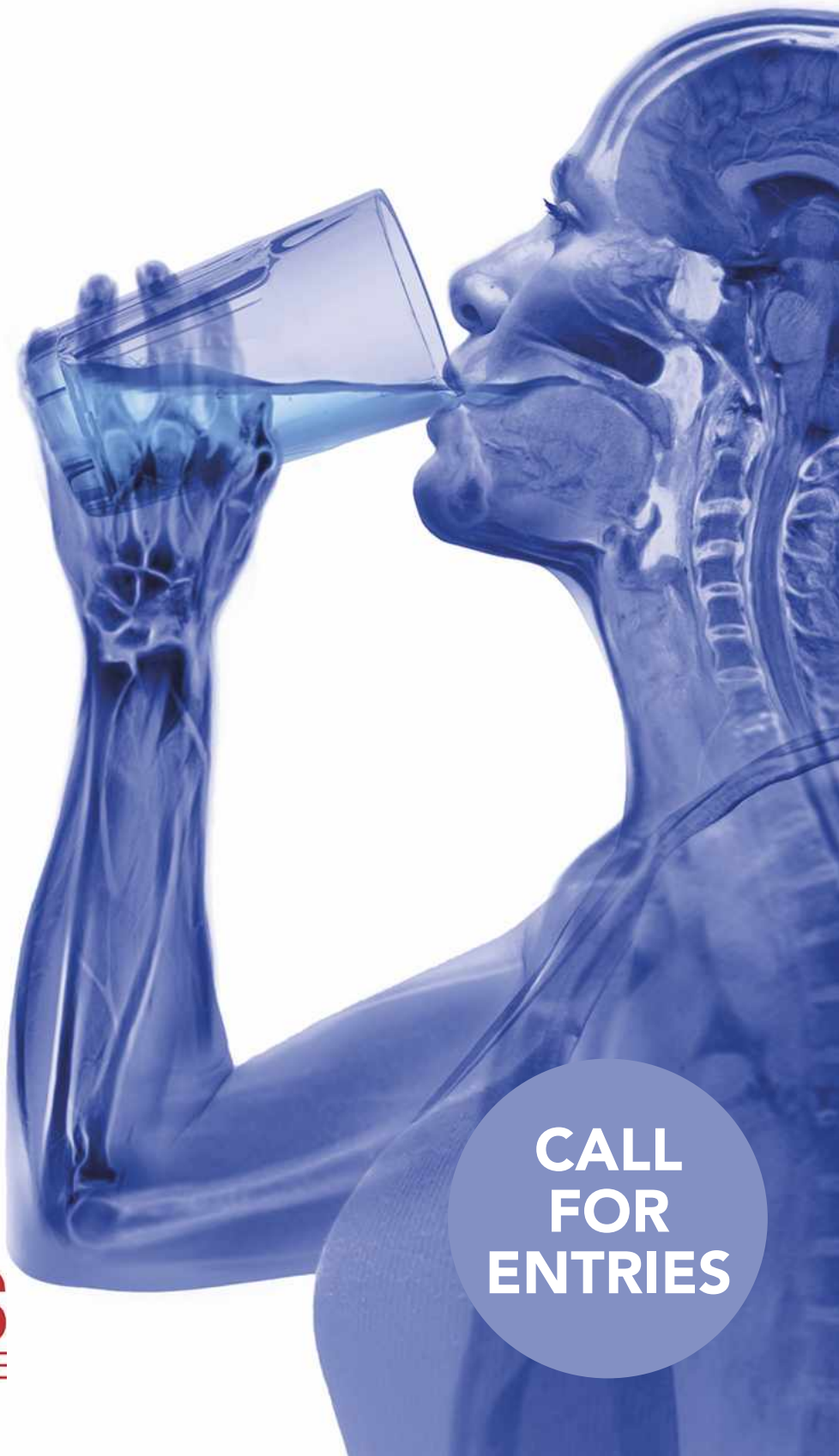


CALL FOR ENTRIES

BBC FOCUS MAGAZINE

RIGHT TO RULE

DNA analysis of Richard III's skeleton has cast doubt on his title. **Zoe Cormier** examines the genetic evidence and finds a monarchy muddied by infidelity

RICHARD III (1452-1485) is about to be reburied in Leicester, the city where his skeleton was discovered under a car park in 2012.

DNA tests the following year made him the most ancient specific individual to be identified by genetic analysis. A follow-up study, published last year in the journal *Nature Communications*, revealed a case of regal infidelity. It seems a 'false paternity' occurred sometime between the 14th and 19th centuries. Does this mean, as some have claimed, that the Windsor monarchy is illegitimate?

Richard III was killed at the Battle of Bosworth in 1485, the last of the Plantagenet kings and the last English monarch to die in battle. His remains were buried unceremoniously at the Greyfriars medieval church. They were then forgotten, and when the monastery was closed by Henry VIII

The latest computer modelling techniques were used to create this reconstruction of what Richard III would have looked like

PHOTO: GETTY ILLUSTRATION: CHRISSTOCKERDESIGN.CO.UK

in the Dissolution, his final resting place was paved over. But in 2012, the Richard III Society joined forces with a team from the University of Leicester to dig into the car park that stands there today, in the hope of finding his remains.

The skeleton they unearthed was promising: it had a curved spine due to scoliosis, and radiocarbon dating indicated the person died in the late 15th Century. Most excitingly, they found that the skeleton was male, and bore the scars that historical records say the king suffered, including a fractured skull from an axe wound.

"It was like a 'missing persons' case. Richard was last seen here, with a twisted spine, and died of battle wounds. But to really prove his identity we needed genetic evidence," says Dr Turi King of the University of Leicester, who proved her case by grinding up teeth from the skeletal remains in order to extract DNA.

But there was one problem: Richard did not leave any descendants behind. Enter genealogist Prof Kevin Schürer, who painstakingly traced the family trees of the monarch and all his relatives, going back four generations to Edward III

"Both daughters and sons receive mitochondrial DNA from their mothers, but only daughters will pass it on"

(1312-1377), and then down to anyone living today related to the 14th Century king. "But of course, many people are related to Richard III in some distant way – only people related to him in a specific way were useful to us," he explains.

The key was tracking down the direct descendants of Anne of York (1439-1476), Richard's sister. Eventually the team found one: Michael Ibsen, a London cabinet maker. A comparison of the matrilineal DNA of Richard III and Ibsen proved an exact match. What's more, Ibsen and Richard III shared one of the rarest types of mitochondrial DNA, known as 'haplotype J1C2C', which is carried by just 1-2 per cent of the population. Subsequent analysis of another living descendant of Anne of York also showed a match, though not as exact.

Matrilineal DNA is inherited from mothers and is found in the mitochondria of cells. The mitochondria are the 'batteries' of cells. While both eggs and sperm contain mitochondria, those found in the sperm are broken down shortly after fertilisation. This means there are no paternal mitochondria present as an embryo develops (see 'DNA detectives'). Both daughters and sons receive mitochondrial DNA from their mothers, but only daughters will pass it on.

DNA was extracted from Richard's skeleton by grinding up his teeth

Injuries to the skeleton found in Leicester were consistent with contemporary accounts of Richard's death in battle

The archaeological dig in a Leicester car park that unearthed Richard III's skeleton in September 2012

WHO'S THE DADDY?

Next, King and Schürer examined the patrilineal DNA. This is the DNA in the Y-chromosome, which is passed down from fathers to sons only. Human DNA comes in packages called chromosomes, and each of us has 46 of them in each of our cells – 23 from each parent. One of these pairs can come in either XX (female) or XY (male) combinations.

PHOTO: UNIVERSITY OF LEICESTER X2, CORBIS X2 ILLUSTRATION: ACUTE GRAPHICS

DNA DETECTIVES

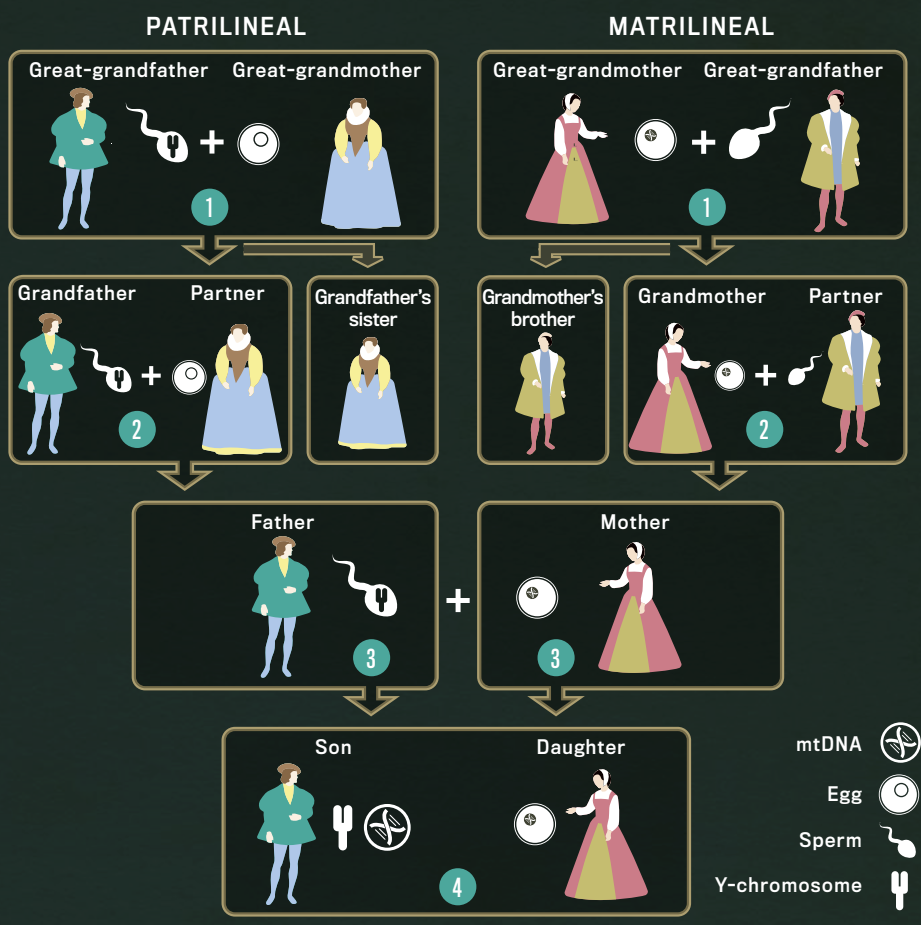
How your genetic material has been passed down to you – and how it can be used to trace your family history

1 Only great-grandmothers pass on eggs with mitochondrial DNA, and only great-grandfathers pass on sperm with Y-chromosomes.

2 Grandmothers and grandfathers both inherit mitochondrial DNA from their respective parents, but only the grandfathers inherit Y-chromosomes. In the next generation, the pattern repeats: only grandmothers pass on mitochondrial DNA and only grandfathers pass on Y-chromosomes.

3 The pattern repeats: everyone inherits mitochondrial DNA, but only uncles and fathers inherit Y-chromosomes.

4 In sons and daughters, both inherit the mitochondrial DNA, and both are part of the matrilineal line, but only sons inherit the Y-chromosome DNA and are part of the patrilineal line.



London cabinet maker Michael Ibsen (left) meets a model of his distant ancestor, King Richard III

The skeleton's Y-chromosome DNA did not match any of the five male descendants of Henry Somerset, the 5th Duke of Beaufort (1744-1803). King and Schürer say that there must have been a case of "false paternity" at some point after the reign of Edward III, the last common ancestor of the Duke of Beaufort and Richard III. But 15 generations separated Edward III and the Duke of Beaufort, and four separated Edward III and Richard III – so the infidelity could have occurred in any of 19 generations.

Newspapers seized on this to suggest that the entire Tudor dynasty, and therefore Queen Elizabeth II, may not have a claim to the throne. However, the only case of unfaithfulness that would make this true would have had to involve John of Gaunt (1340-1399), son of Edward III and the last common ancestor of the current royal family and the descendants of the Duke of Beaufort.

Tudor historian Alison Weir says there have long been rumours that John of Gaunt was a changeling. Gossip in the late 1300s suggested that his mother, Philippa of Hainault (1314-1369), had accidentally killed her firstborn son in infancy by crushing him in her sleep, and – to hide her shame from her husband Edward III – replaced him with another baby. "But this was propaganda spread when John was in his 30s by his political enemies – there is nothing to substantiate this," says Weir. "People love conspiracy theories, but we really shouldn't pay much attention."

Indeed, the genetic analysis indicates the cuckolding could have occurred on either side of Edward III's descending lineage, and is statistically most likely in any of the 15 generations between John of Gaunt and the Duke of Beaufort.

Multiple scientific surveys have indicated that between one in 50 and one in 100 people are not the children of the men believed to be their fathers, so it's not surprising that there was some case of false paternity in the regal lines. A case in point: King and Schürer's analysis also showed that one of the five male descendants of the Duke of Beaufort did not have the same Y-chromosome as the other four, revealing that there must have been another genetic break somewhere along the line.

"When I started going into this, I knew that infidelity was something we may find," says King. "It's very common." ■

ZOE CORMIER is a science journalist and author with a background in biology

BRITAIN'S MOST DANGEROUS ROADS

Sat navs give you the quickest route but is it the safest? Should you take a winding country lane or stick to motorways? Tobias Jolly works out which roads to avoid and how to beat the odds of an accident...

IMAGINE THAT YOU'RE driving and you come to a fork in the road, where both roads lead to your destination. One is a dual carriageway: it's a wide, straight road, but it's heaving with traffic and you know that going that way will take you right through town. The other way is a country road: there's not much traffic but it's single-lane, it'll take you through the woods and over the hilltops and you can be sure there'll be plenty of blind corners and hairpin bends. You check your sat nav, and it calculates that the country lane is going to be the quickest route. But is it safe?

We may feel happier travelling on some roads than others, but it's hard to know just how much safer they are. Fortunately, there is a common scale with which we can measure risk – the micromort. If an activity exposes you to one micromort, you have a one in a million chance of sudden death while engaged in that activity. The average person in the UK is exposed

to around one micromort per day from a combination of acute risk sources such as venturing out onto the roads, participating in sports, operating machinery and simply getting out of bed.

CALCULATING MICROMORTS

The maths for working out how many micromorts an activity exposes you to are pretty simple: just divide the number of people that have died while doing that activity by the number of times it's been done, then multiply by one million. So, using data from the Department for Transport, you can divide the total number of car occupant road deaths (785 in 2013) by the number of car miles driven in the UK (240 billion in 2013 – note that the figures are supplied in miles, so we're breaking *Focus*'s metric-first rule here) and multiply that by one million to get 0.0033 micromorts per mile. This means you can travel around 300 miles by car before you're exposed to a whole micromort.

While micromort values are useful for helping you make informed choices, they can't account for all the complexities that lead to a death and they're always limited by the quality of the data. But, with that in mind, here are some micromort values that you should expect for a few activities:

TRANSPORT

MOTORCYCLE
7 miles per micromort

BICYCLE
20 miles per micromort

CAR
300 miles per micromort

TRAIN
6,000 miles per micromort

INCREASING RISK

SPORT

SKY DIVING
8 micromorts per jump

HANG GLIDING
8 micromorts per flight

MARATHON RUNNING
7 micromorts per marathon

SCUBA DIVING
5 micromorts per dive

PHOTO: DAVE SPICER, ISTOCK

The A285 is several times riskier than the average rural A road

The risk of driving a particular road is never fixed – bad weather changes the odds of accidents

"The safest types of road by far are motorways, which allow you 1,000 miles per micromort"

Of course, when it comes to road safety, the overall average of 300 miles per micromort for car travel conceals a complex picture which we can examine by looking at different types of road.

HOW MUCH DO ROADS VARY?

The safest types of road by far are motorways, which allow you 1,000 miles per micromort. The most dangerous are minor rural roads at 160 miles per micromort. The fatality rate also varies according to other road characteristics, including the speed limit and the number of lanes.

But these are just averages. What about the safest and most dangerous individual roads in the UK? There's no definitive answer to the question of what is the UK's most dangerous road: depending on how you ask the question, you can come up with a variety of different answers. But if we just look at the risk to car drivers and passengers – that is, if we exclude the deaths of pedestrians and cyclists from our calculations – then it could well be the A18 between Laceby and Ludborough in Lincolnshire.

This stretch of the A18 takes drivers through woods and farmland on the northeast edge of the Lincolnshire Wolds, and only allows you 20 miles before you've been exposed to a micromort. So driving its 10-mile length exposes you to 0.5 micromorts – equivalent to a full day skiing.

Other high-risk roads include the A937 north of Montrose in Scotland, and the A285

785

is the number of car occupants who were killed on the UK roads in 2013, according to information from the Department for Transport

Minor rural roads are the most dangerous routes in the UK

Driving at night increases the risk for drivers and passengers

The A1307 in Horseheath, Cambridgeshire is considered an accident blackspot

PHOTO: ALAMY X2, ISTOCK

"In a six-month period, dying on the M42 motorway is about as likely as being killed by lightning in the UK"

in Sussex, north of Chichester. Both these roads are also several times riskier than the average for rural A roads of 180 miles per micromort.

BRITAIN'S SAFEST ROAD

Finding the safest road is even trickier. There are many quiet access roads and side streets that have never seen a single casualty. But knowing you're unlikely to die at 10mph isn't that useful, so it's best to look at roads with a significant traffic volume.

Since motorways are so much safer on average than A roads, the safest individual road is probably also a motorway. There are several motorways that have had few or no fatalities in the past eight years, but these are all short roads such as the M898 (0.5 miles in length), where the low fatality rate is more likely to be the product of chance. After accounting for this, the motorway that allows us the greatest

confidence about its low fatality rate turns out to be the M42, which confers one micromort for every 2,000 miles. Were you to drive the full 40 miles of the M42, you'd be exposed to only 0.02 micromorts. In a six-month period, this makes dying on the M42 about as likely as being killed by lightning in the UK.

It should be emphasised that the above calculations are limited by the road accident data that is available, and we can't give the precise reasons for there being more casualties on a given road – it could even be that drivers in the area are just more reckless! Micromorts simplify complex phenomena in order to give us straightforward numbers that we can use to help us make more informed decisions.

The variation in the risk of roads is quite large, with the most dangerous road being over 100 times riskier than the safest. This isn't the whole story, however. There are many other variables that can and do change the risk of any given road regularly.

M42

is statistically the safest motorway in the UK. It runs from Bromsgrove, Worcestershire to just southwest of Ashby-de-la-Zouch

Weather is the clearest example: rain, ice and snow will change the risk on some roads more than others. Fluctuations in the amount of congestion and level of pedestrian activity will also increase or decrease your chance of crashing on a daily basis – schools in particular are regularly surrounded by large groups of apparently risk-seeking pedestrians.

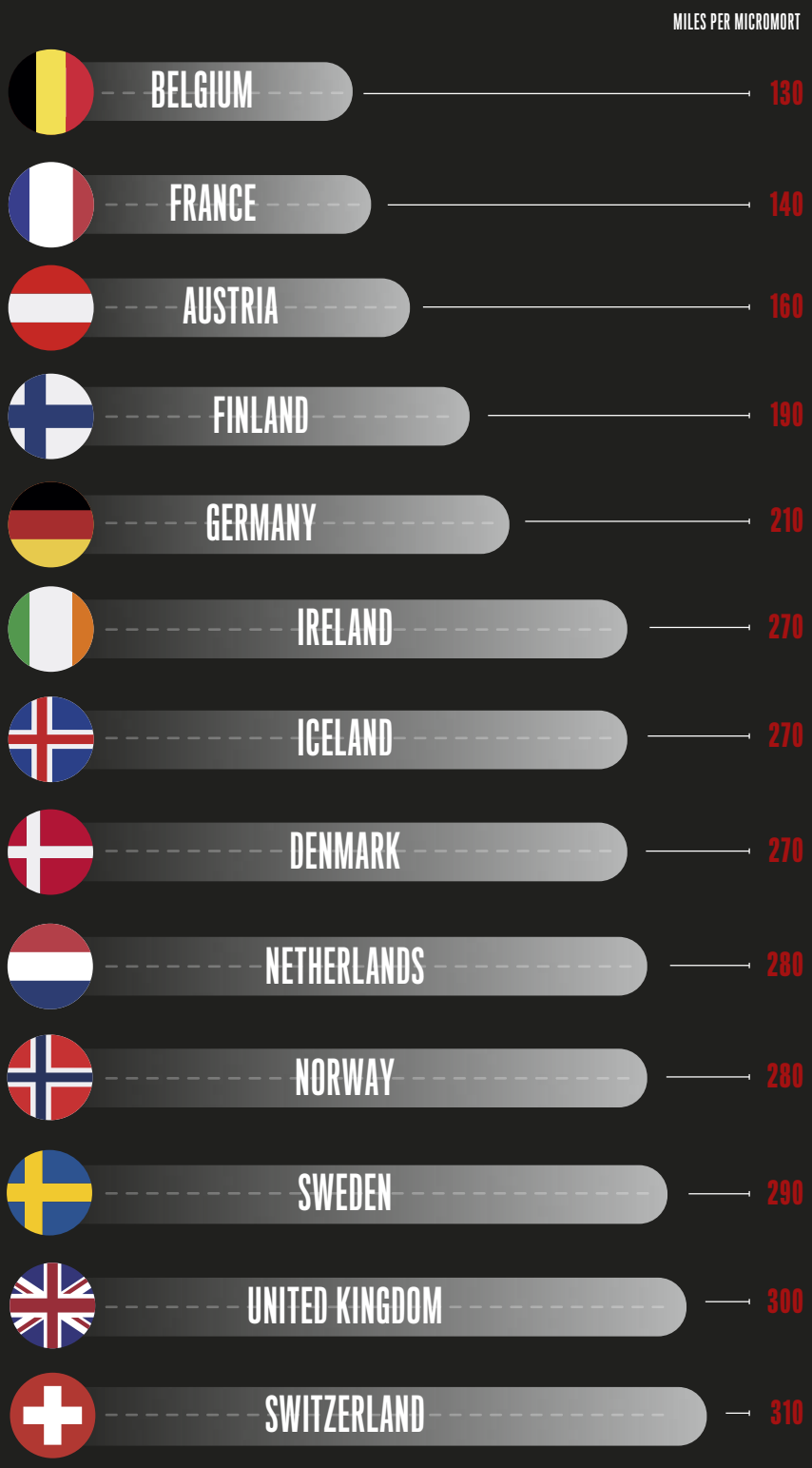
Another variable factor that affects your risk should come as no surprise: road deaths occur at almost three times the frequency at night than during the day. Driving between 8pm and 6am exposes you to an average of one micromort for every 130 miles you travel.

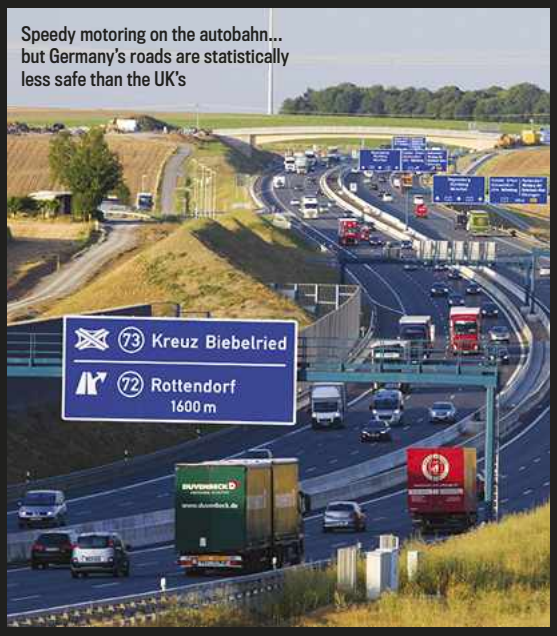
HOW TO BEAT THE ODDS

There are many ways in which we can reduce the risk of roads, such as lowering

WHICH COUNTRY HAS THE SAFEST ROADS?

Car drivers in the UK are exposed to much less risk than those in most of Europe. Here's a list of European countries with estimates of car occupants' exposure to acute risk (using data from Eurostat and the International Road Traffic and Accident Database). There are many explanations for these differences, including infrastructure, traffic density and driving culture.





Speedy motoring on the autobahn... but Germany's roads are statistically less safe than the UK's

speed limits, separating carriageways and erecting more crash barriers. However, all of these options come with costs and limitations attached. So how about if we just avoid the more dangerous routes altogether when it doesn't cost us too much time? Having an appreciation for the huge variation in risk between roads is the first step towards making better route choices.

You may be able to make use of the knowledge that motorways today are safer than A roads if you happen to have a choice of two routes, one of which is mostly on the motorway. But most journeys don't offer simple motorway alternatives, and if you're ever choosing between the A18 and the M42 you're probably just lost!

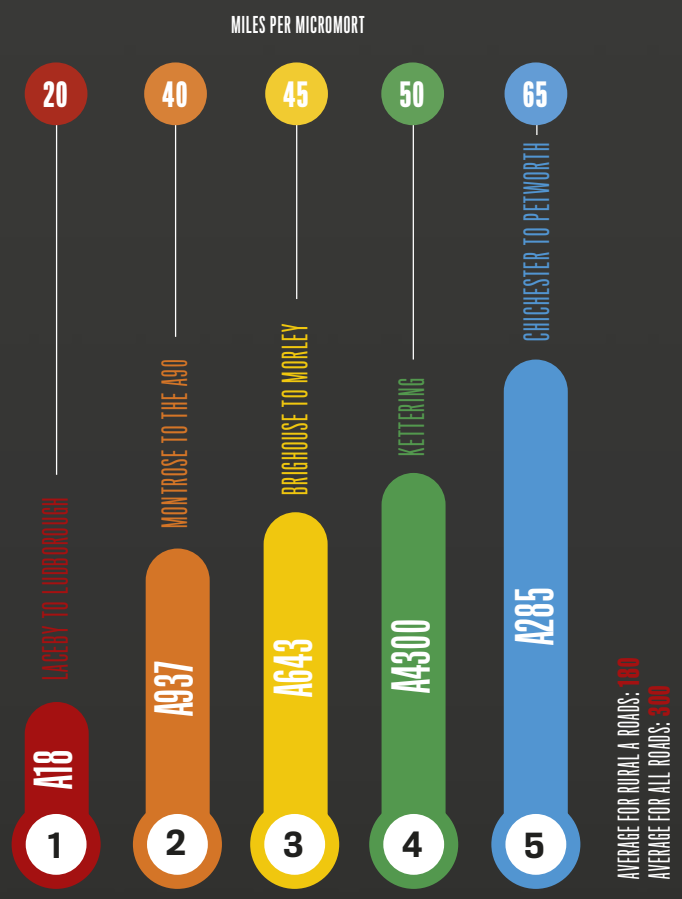
But what if sat navs considered the relative risk of different roads when planning our journey? Many sat navs already give you the option to travel the shortest or most economical route, along with the usual default of the quickest. But when we consider the huge range of micromort per mile values of different roads, the possible benefits of having a 'safest route' option become evident. In an article for UnderstandingUncertainty.org and *Significance* magazine (July 2014), I estimated that the average journey in the UK could be made over 10 per cent safer when compared to the quickest route offered by Google. Depending on how many people travelled

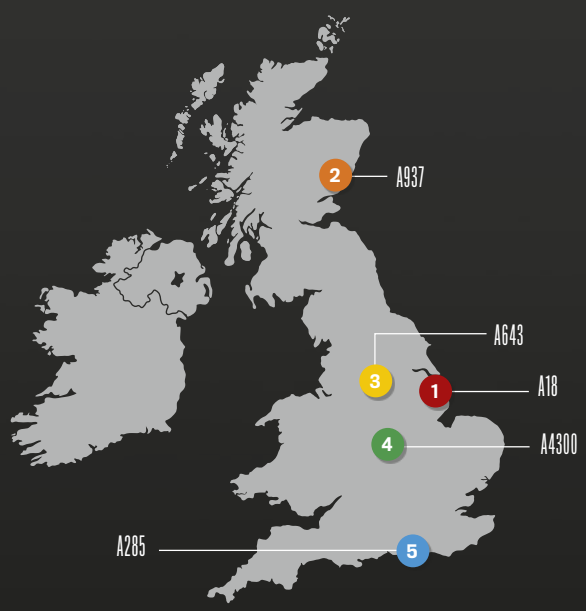
"A risk-balancing sat nav would be able to steer you away from the country lane in favour of the safe highway"

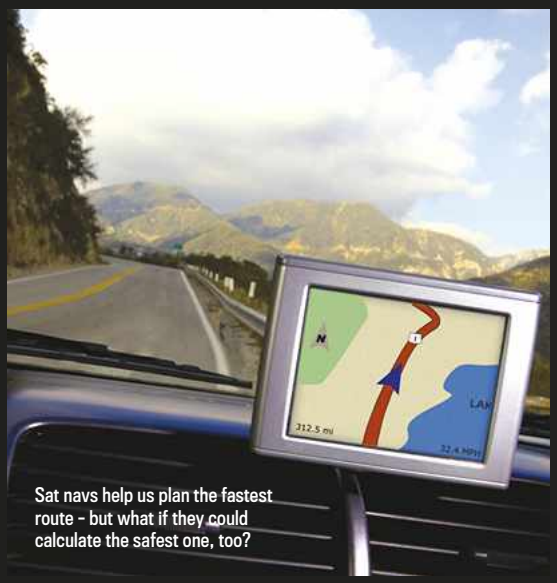
PHOTO: ALAMY, GETTY

THE TOP FIVE MOST DANGEROUS ROADS IN THE UK

The five riskiest sections of road in the UK for car occupants. Estimates of acute risk exposure are derived from data provided by the European Road Assessment Programme and based on small fatality numbers (less than 10) on each road, so should be considered rough estimates.







Sat navs help us plan the fastest route – but what if they could calculate the safest one, too?

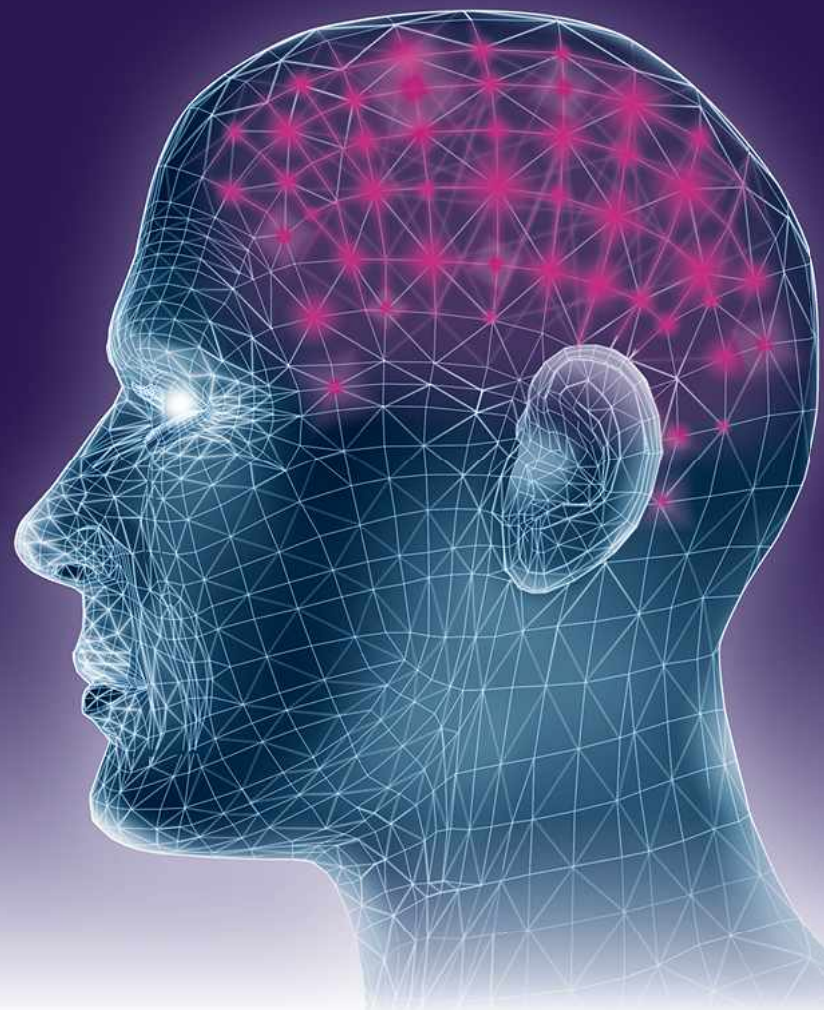
130

miles of night-time driving exposes you to roughly one micromort. This is almost three times more than driving during the daytime

the safest route, the number of lives saved could be over 100 per year in the UK. Safety is not the be-all and end-all, of course, and few of us would be willing to double all our journey times for marginal improvements to our safety – though there are many instances in which we are currently doing the precise opposite, choosing to take high-risk routes for marginal gains in time. In practice, we'd want to balance time against risk, by working out how much extra driving time saving a micromort is worth. So if you came to a fork as described at the start, a risk-balancing sat nav would be able to steer you away from the country lane in favour of the safe, well-lit highway.

Avoiding this unnecessary risk would mean you could use your precious micromort allowance on risky things that are much more fun... such as running marathons.

Feed *your* mind



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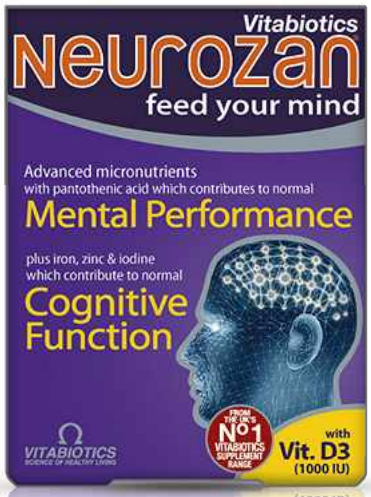

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Q&A YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL

SUSAN BLACKMORE
Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*

DR ALASTAIR GUNN
Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester

ROBERT MATTHEWS
After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University

GARETH MITCHELL
Starting out as a broadcast engineer, Gareth now writes and presents *Click* on the BBC World Service

LUIS VILLAZON
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com
or post to *Focus* Q&A, Tower House, Fairfax Street, Bristol, BS1 3BN

Q ANDY FRENCH, READING

Has stealth technology made radar useless?

The Artisan system can simultaneously track over 900 objects

A RADAR TECHNOLOGY was made famous by its pivotal role in WWII. Since then, it has been locked in a battle against various different countermeasures. The best-known is stealth technology, where radar-absorbing compounds are used to minimise the radio energy reflected back to the radar detecting scanner. Although stealth was made famous by its use on US aircraft in the first Gulf War, a crude form of it was used on German U-boats. The snorkels of the U-boats were coated with carbon-impregnated rubber compounds to reduce their visibility to radar aboard the Allies' aircraft.

While today's stealth techniques can drastically reduce the effective size of craft as seen by radar, they can't hide them completely – and radar systems have evolved to keep up. The Royal Navy's latest Artisan radar system, developed by BAE Systems, can spot 'stealthy' objects as small as tennis balls, travelling at three times the speed of sound more than 25km away. **GM**

PHOTO: BAE SYSTEM

In Numbers

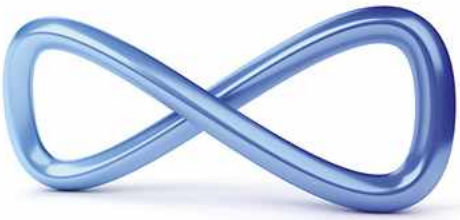
23

species of British pollinating bees and wasps have become extinct since 1850. The decline is due to changing agricultural practices

Q REBECCA IRELAND, LONDON

Are some infinite numbers really bigger than others?

A MATHEMATICIANS HAVE identified a family of so-called transfinite numbers, which are bigger than the largest finite numbers. The smallest of these is called omega, formed by adding one to each whole number after zero, and continuing forever. And ultimately there is Absolute Infinity, which is so colossal that attempted descriptions always describe something smaller. **RM**



Infinity: just how big is 'endless'?

Photos of star trails show just how fast our planet is spinning

Q JOHN SIMPSON, BURGESS HILL

Why do planets and solar systems travel so fast?

A IF WE CHOOSE a suitable reference point to which we can relate the motion of Earth, we can deduce that our planet spins at about 1,609km/h (1,000mph) at the equator. It travels around the Sun at approximately 106,217km/h (66,000mph), moves around the centre of the Milky Way galaxy at about 777,000km/h (483,000mph) and travels towards the Virgo galaxy cluster at about 2 million km/h (1.3 million mph). All of these motions are a result of the gravitational interaction of astronomical bodies and the 'law of conservation of angular momentum'.

During the Solar System's formation, the momentum of the cloud from which Earth formed was conserved as it collapsed, resulting in high speeds. The same is true of the Milky Way. As the galaxy collapsed from a huge cloud of spinning gas, it span ever faster, and the stars formed within it retained those high orbital speeds. **AG**

Q ANDREW CROWHURST, SHEFFIELD

Do plants have a form of consciousness?

A PLANTS DON'T HAVE nerve cells, let alone a brain. Some plants can signal to each other, and to insects, using chemical messenger compounds, but that's quite different from consciousness. Plant 'thoughts' would be at the level of an unconscious reflex at most. Human concepts such as emotion and self-awareness simply don't apply when talking about plants. **LV**

Criticise his leaves all you want – you won't upset him!

Q CHRIS JACKSON, HALIFAX

What is the difference between venomous and poisonous?

A IT'S ALL DOWN to the method of delivery. Venoms must be injected to be effective, whereas poisons can come into contact with skin, or be inhaled, eaten or touched. So the puffer fish is poisonous if you eat the wrong part, because its liver contains tetrodotoxin, but its bite contains no toxins. The blue-ringed octopus, however, can inject the same tetrodotoxin with its bite, so it is venomous. There is only one species of snake that is both venomous and poisonous. The Asian tiger snake has one toxin for its venomous bite, but it also stores a poison in its skin that comes from the toads that it eats. **LV**

The spitting cobra: not a popular party guest

PHOTO: ISTOCK X4, JELGER HERDER/FLPA, ALAMY

QUESTION OF THE MONTH

WINNER! Kathy Curtis wins a copy of *Stories In The Stars* by Susanna Hislop (Hutchinson, £20)

A good family environment can help nurture empathic behaviour

Q **KATHY CURTIS,** WINCHESTER

Can you teach empathy?

A EMPATHY BUILDS ON the ability to see things from another person's point of view, which most children acquire at around four or five years. But being fully empathic also means being able to regulate your own emotional responses, care about how others feel, understand what they need and respect differing views.

Studies suggest that all of these skills can be taught or encouraged. For example, discussing the emotional content of stories has been shown to increase empathy in school-age children, as does getting children to practise imagining how other people might be feeling.

Children also tend to adopt their parents' values. So if parents strive constantly for fame, academic achievement or monetary gain at any cost, then their children are unlikely to value empathy very highly. Therefore, teaching empathy begins with showing empathy, and children who feel cared for and secure are more likely to show empathy towards others.

Rewarding empathic behaviour is not helpful, but giving praise can be. **SB**

Q **NICK MANN,** ROYAL WOOTTON BASSETT

What was the earliest written language?

This cuneiform tablet dates back to around 1500BC

A CAVE PAINTINGS CAN tell the story of a hunt, so humans didn't really need a formal written language until agriculture, cities and taxes made accurate record-keeping important. Around 3000-3200BC, the cuneiform script of Sumeria (Iraq) and the hieroglyphs of Ancient Egypt emerged. There are a few inscribed tablets from the Indus Valley Civilisation (Pakistan) that pre-date this by 300 years, but whether they are a proper language or just symbols isn't clear. **LV**

Q **MOHAMMED RASHID,** DEWSBURY

How can phones get thinner and lighter yet improve their features?

A TO GET BETTER features, you need greater processing power, and to get that you must squeeze more transistors into the phone's chips. A handset today crams in twice as many transistors as one from two or three years ago. It's a feat of miniaturisation where each component is smaller and lighter, allowing you to squeeze more processing out of a slice of silicon. Battery improvements are not quite as dramatic, but lithium-ion devices store ever more charge per kilogram, doubling performance since the 1990s. **GM**

Modern phones can cram in loads of processing power

Safe bets exist, but they're complicated to figure out

Q TIM BUTCHER, ABERDEEN

Is there such a thing as a bet you can't lose?

A IT'S POSSIBLE TO place bets that will pay off regardless of the outcome, using a trick called arbitrage. Imagine a Cup Final involving Chelsea and Spurs. Bookmakers will offer odds for either team to win, and as this represents all the possible outcomes, the odds should tot up to 100 per cent. Yet they don't: it's always more, which is how bookies lock in a profit. But by finding two bookies offering odds that combine to give less than 100 per cent, it's possible to lock in our own profit. If Bookie A is offering evens odds for Chelsea, while Bookie B has Spurs at 5/4, these tot up to 94 per cent. A quick sum then shows that if we put 53 per cent of our money on Chelsea with Bookie A and the rest on Spurs with B, we'll make a profit of 5 per cent, whoever wins.

So why isn't everyone doing this? First, 'arbs' are hard to spot, and they usually last only minutes. If the odds change while you're putting your stakes on, the arb becomes a bet – whose outcome isn't guaranteed. The profit margins are also small, making it all too much trouble for most punters. **RM**

In Numbers

6.56 seconds

is the time it took the Pomeranian, Jiff, to run 10 metres on his hind legs. This makes him the fastest dog on two legs

Eagles handle turbulence better than planes

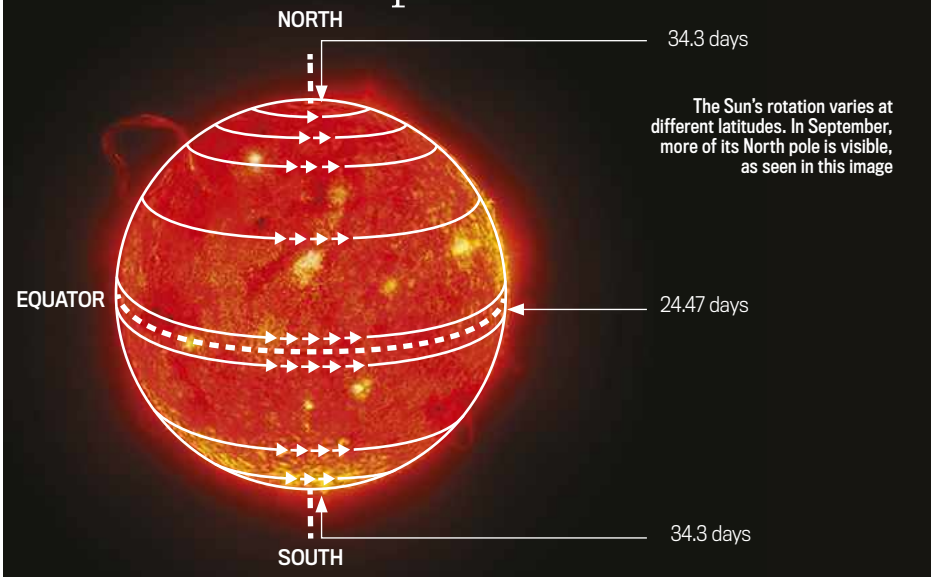
Q BRIAN MCFARLAND, NORTHERN IRELAND

Do birds suffer from turbulence when flying?

A BIRDS NORMALLY FLY close to the ground, around trees and buildings, or soar in the rising air of thermals. Both are high-turbulence environments, but birds have two adaptations that make them much better at coping with it than planes. Nerves at the base of their feathers allow them to detect the flow of air over their wings and monitor turbulence very accurately. Instead of waiting for an air gust to buffet the entire wing, they can anticipate each minor eddy and continuously make tiny adjustments. Large soaring birds, like eagles and vultures, can also quickly tuck their wings downward and coast through a small patch of turbulence. Each tuck lasts just a third of a second but it greatly reduces the sudden loading on their wings. **LV**

Q JONATHAN ROUND, LONDON

Does the Sun spin?



The Sun's rotation varies at different latitudes. In September, more of its North pole is visible, as seen in this image

A YES, THE SUN does spin, but not quite like the Earth. The Sun displays something called 'differential rotation' which means that some parts of it spin faster than others. The Sun spins once every 24.47 days at the equator but only once every 34.3 days at the poles. Of course, since the Earth is orbiting the Sun and moves relative to the solar rotation, these lengths appear slightly longer to us on Earth.

The Sun's rotations vary because the Sun is gaseous, although its interior actually does rotate like a solid body. Astronomers often refer to the Sun's rotation period at 26° latitude, the typical latitude of sunspots. This period is 25.38 days, or 27.28 days measured from Earth. The Sun's differential rotation combined with the convection of material within it drives its magnetic cycle. **AG**

PHOTO: ALAMY, ISTOCK X2 ILLUSTRATION: PAUL WESTON

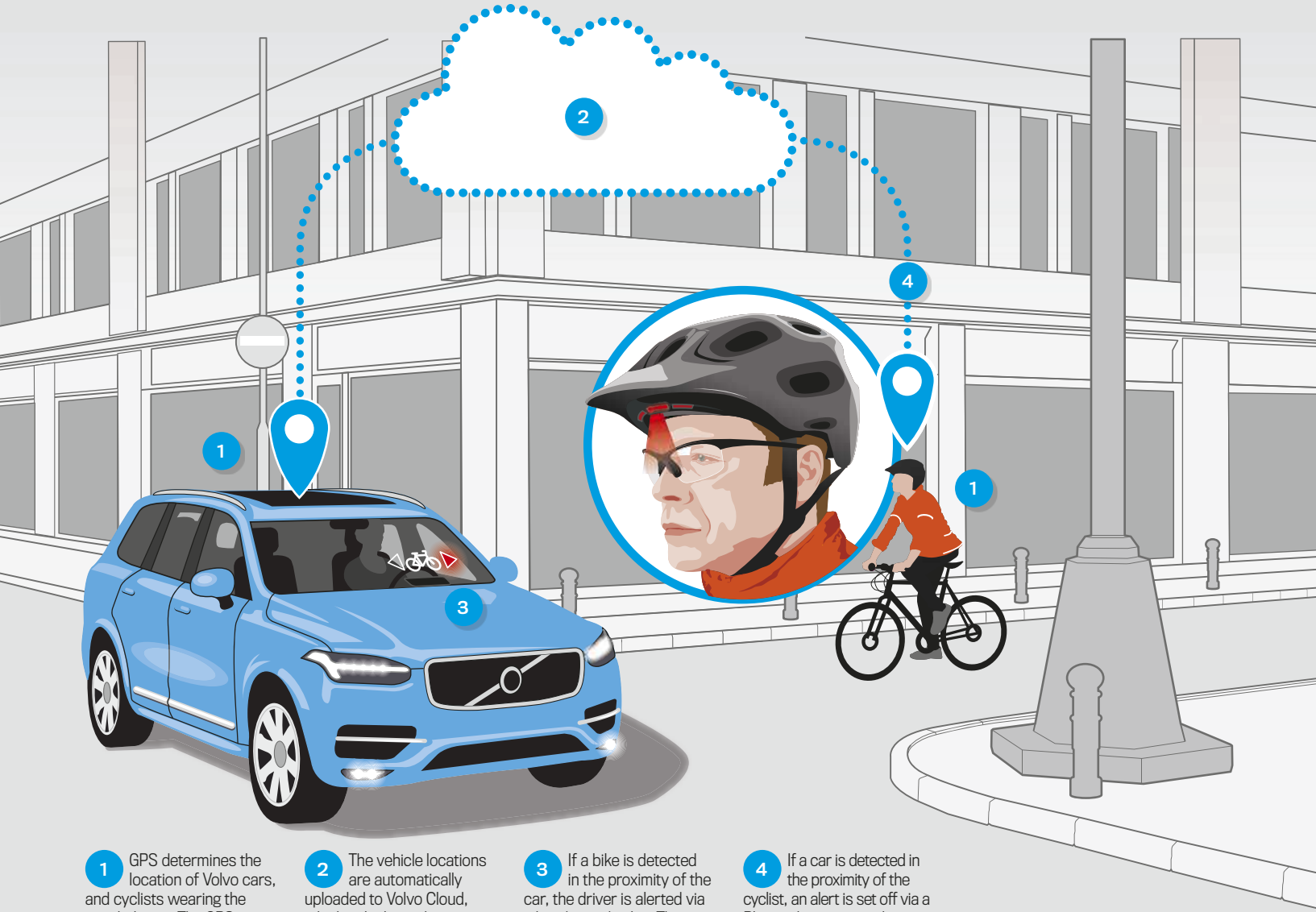
HOW IT WORKS

VOLVO CYCLIST DETECTION

A PROTOTYPE HELMET that warns both cyclists and drivers of potential collisions has been unveiled by Volvo Cars.

The helmet connects to a cyclist's smartphone using Bluetooth. Used in conjunction with common cycling apps such as Strava, the cyclist's position, speed and direction are tracked via GPS. This information is uploaded to the Volvo Cloud and the cyclist's likely trajectory is calculated. This data is sent to nearby Volvo cars possessing "City Safety" technology. If a car detects a bike nearby, there's an audible warning and a visual alert on a heads-up display. The car can even brake automatically if a collision is imminent, thanks to its built-in radar.

The car's position is also uploaded to the Volvo Cloud and sent to the cyclist's phone. If a collision looks likely, the phone signals the helmet, which vibrates and flashes its built-in lights to alert the cyclist. GPS can't place a car to pinpoint precision – 95 per cent of the time, it's only accurate to within 3m. But Volvo doesn't see this as a drawback. "An increased awareness of potential dangers can help reduce possible crashes," claims Volvo's vice president Klas Bendrik.



1 GPS determines the location of Volvo cars, and cyclists wearing the new helmets. The GPS is integrated in the car and in the cyclist's smartphone.

2 The vehicle locations are automatically uploaded to Volvo Cloud, which calculates their trajectories based on speed, position and direction.

3 If a bike is detected in the proximity of the car, the driver is alerted via a heads-up display. The car brakes are automatically applied if a crash is imminent.

4 If a car is detected in the proximity of the cyclist, an alert is set off via a Bluetooth connection between the helmet and phone. The helmet vibrates and flashes.

TOP TEN
FASTEST FLYING INSECTS
(BY TOP FLIGHT SPEED*)

1. Horsefly
Speed: Up to 145km/h
Range: Worldwide

2. Black cutworm moth
Speed: Up to 113km/h
Range: Worldwide

3. Green darner dragonfly
Speed: Up to 85km/h
Range: North America

4= Deer botfly
Speed: Up to 80km/h
Range: North America

4= White-spotted prepona butterfly
Speed: Up to 80km/h
Range: Mexico to Bolivia

4= Brown planthopper
Speed: Up to 80km/h
Range: Australia and Asia

7. Regent skipper
Speed: Up to 60km/h
Range: Australia

8. Death's-head hawkmoth
Speed: Up to 53km/h
Range: Europe, Middle East and Africa

9. Asian giant hornet
Speed: Up to 40km/h
Range: East Asia

10. Desert locust
Speed: Up to 33km/h
Range: Africa, Middle East and Asia

*INSECT FLIGHT SPEEDS ARE POORLY STUDIED, SO THESE TOP SPEEDS ARE APPROXIMATE

Q **JAKE BOGDAN,** ST GALLEN, SWITZERLAND

Why does looking down from the top of an object seem further than looking up from the bottom?

A DISTANCE ESTIMATION ITSELF is complicated: it can involve binocular vision, overlaps and shadows, changes in colour with distance and many other cues. Also, vertical distances and sizes are generally overestimated compared with horizontal ones. This is especially the case for larger objects, and particularly when looking down from the top. When the explorer Louis Hennepin first saw the 51m (167ft) Niagara Falls in 1677, he estimated them to be 183m (600ft). He said that they "are so prodigious high, that it would make one tremble". His fear may have actually led to this gross overestimate: experiments show that people who are afraid of heights overestimate more when looking down than those who are not. **SB**

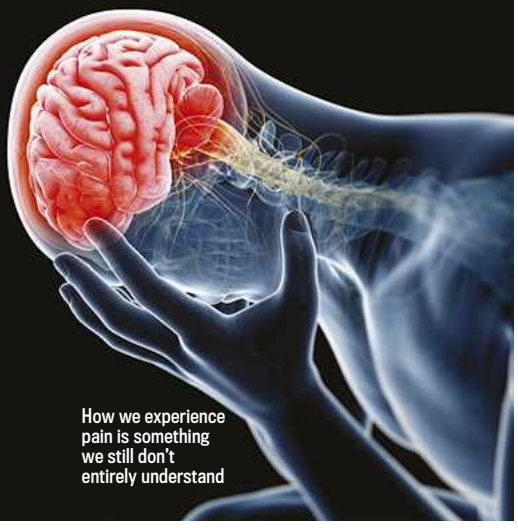
Horseshoe Falls, Niagara: tall, but not 183m tall

Q **ALEX ROUND,** LONDON

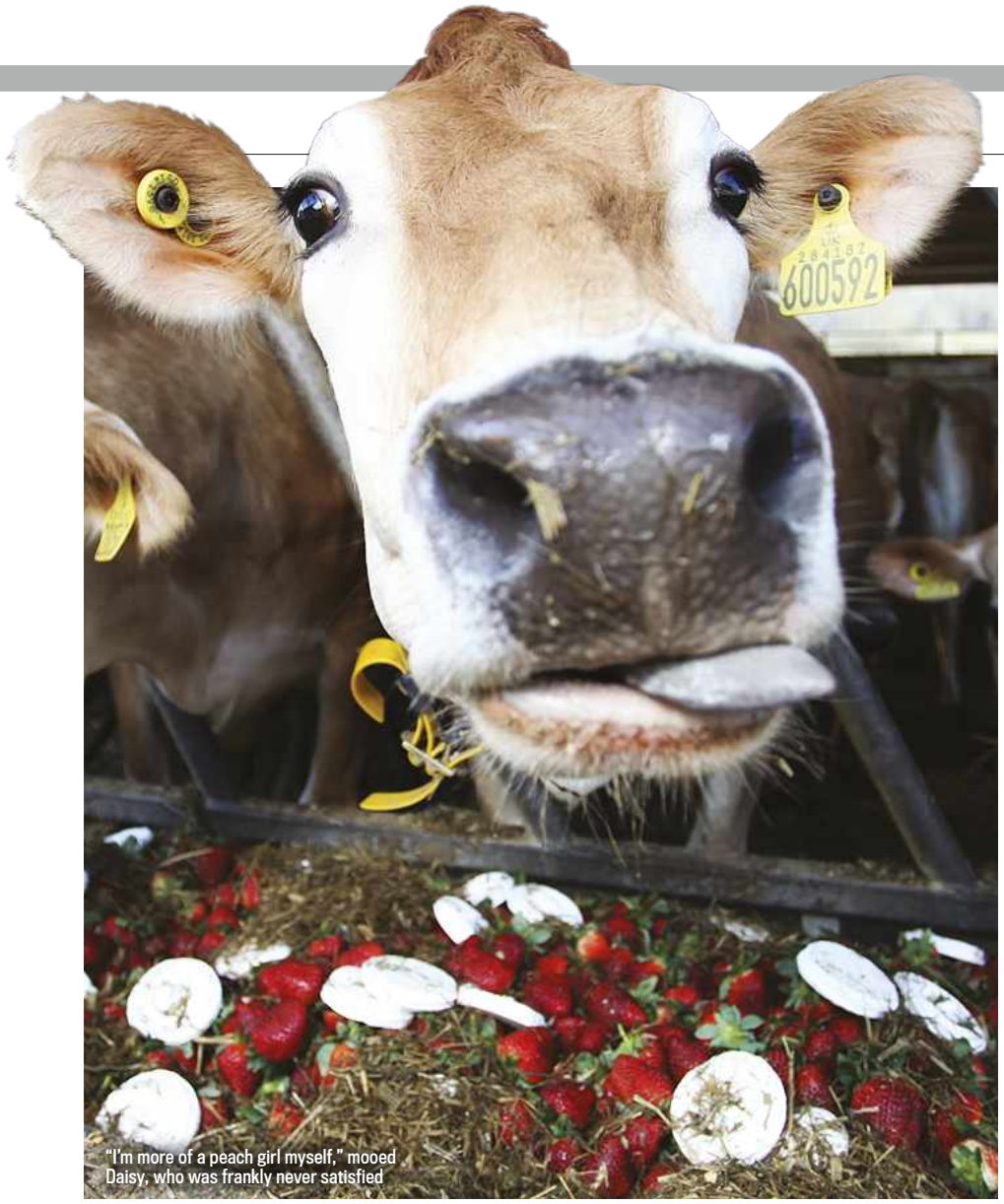
How does the brain register pain?

A SUPPOSE THAT, FOR example, you cut your foot. The damage activates specialised pain receptors called nociceptors. Two types of informat then run up your leg, through the s cord, and into the thalamus. One de with sensory discrimination, to wo out what caused the pain and what means. The other deals with your emotional and motivational respon including that you don't like it, you want it to stop and it feels horrible.

How does this work? The brain registers the pain as bad by divertin attention to it, by activating plans t avoid similar injuries in the future, by relating it to other unpleasant experiences. But what about the conscious sensation of pain itself? This, along with the whole questio of subjective experience, is a myste It's called the 'hard problem of consciousness', and pain is an especially good example of something we do not yet understand. **SB**



How we experience pain is something we still don't entirely understand



"I'm more of a peach girl myself," mooed Daisy, who was frankly never satisfied

Q **AMANDA HART,** CARDIFF

If you fed cows strawberries, would it give their milk a strawberry flavour?

A DIET DEFINITELY AFFECTS the flavour of the milk of all mammals. A 2008 study at Copenhagen University gave flavour capsules to nursing mothers and found that the taste made its way into their breastmilk within minutes. And dairy farmers have long known that weeds in the pasture can taint the taste of cow's milk. It's said that French Gruyère de Comté cheese even tastes different when it is made from the milk of cows fed on mountain grass, rather than in the valley pastures.

Feeding strawberries to cows might seem extravagant, but fruit farmers often have a lot of leftover produce that isn't good enough to sell. A 2007 study looked at the practicalities of feeding leftover pears and peaches to dairy cattle, but it made no mention of any effect on the taste of the milk. This may be because fruit flavours don't hang around for long – the Copenhagen breastmilk study found that non-citrus fruit flavours only affected the milk for a few hours.

You can add fruit flavour to milk indirectly though, and it isn't always desirable. The Dairy Research Laboratory of Australia experimented in 1989 with an oat and sunflower seed supplement in cattle feed, as a way of increasing their milk's fat content. Researchers found that the oats stimulated the bacteria in one of the cows' stomach compartments to turn the sunflower oil into a chemical called gamma-dodec-cis-6-enolactone. This gave a noticeable raspberry flavour to the milk, and even the beef! **LV**

Q **KAI SHITAMOTO,** KOBE, JAPAN

Why do men grow beards but not women?

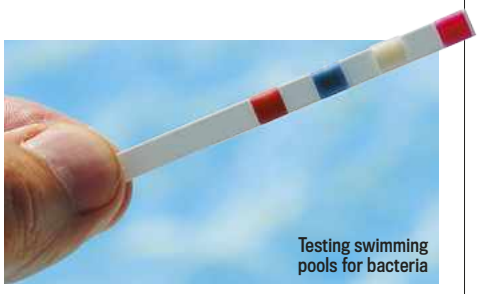
A MEN GROW BEARDS because the hair follicles on their jaw are stimulated by the hormone dihydrotestosterone, which is produced from testosterone. Women have the same number of follicle cells on their faces as men, but these are less sensitive to dihydrotestosterone, and females also have lower testosterone levels to begin with. Beards may have evolved as a signal of the testosterone levels of a man, and women came to find thicker beards attractive because it implied that their owner would be stronger or more dominant. **LV**

Hipsters rejoice – beards are officially sexy

Q **JON GARTON,** DERBY

Can bacteria become resistant to chlorine?

A YES. CHLORINE KILLS bacteria because it is a very reactive element. It attacks many enzymes, and damages the cell walls of some bacteria. But chlorine-resistant strains of bacteria have been found in swimming pools and drinking water. They survive by evolving a much slower metabolism and alternative pathways for their enzyme reactions. But for now at least, a mixture of chlorine and bromine can still kill such bacteria. **LV**



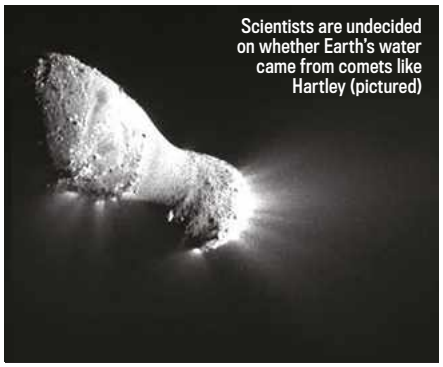
Testing swimming pools for bacteria

PHOTO: TEXAS EAGLE/FLICKR, KARSTEN HEINRICH/WIKI, DIDIER DESCOUENS, IRRI PHOTOS/FLICKR, VIJAY ANAND ISMAVEL/FLICKR, RUSHEN/FLICKR, PETER G W JONES/FLICKR, ALAMY, ROBERT HARDING, POPCORN PR, SCIENCE PHOTO LIBRARY

Q LES WILLIAMSON, JOHANNESBURG, SOUTH AFRICA

If Earth's water came from comets, where did their water come from?

A A NUMBER OF astronomers have suggested that some of the water on Earth could have originated with comets, though there are good arguments both for and against this proposal. During the formation of the Solar System, volatile compounds (such as water) in the inner Solar System either remained gaseous or were blown away by the Sun's energy. Further out in the Solar System there was more water available in solid form. Comets formed in this region, so they naturally have high water content. **AG**



Scientists are undecided on whether Earth's water came from comets like Hartley (pictured)

Q JAMIE BAUER, GLASGOW

Would it be possible to make a new internet?

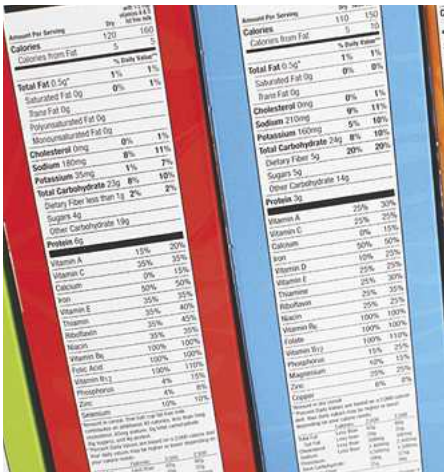
A THE INTERNET DATES back to ARPANET, a computer infrastructure built in the 1960s by the US Defense Department to link research labs around the country. These days, the net is a sprawling collection of servers and computer systems around the world. For a network to be part of the internet, it must exchange information according to internationally agreed protocols. Being a network of networks, one can think of the overall internet as a mosaic of mini-internets. So private networks, or 'intranets', might qualify as a 'new' internet: they're self-contained internets based on the same protocols as the wider net. But the idea of anyone building a new global infrastructure with its own protocols seems pretty far out. **GM**

Q JOHN HAYWARD, PLYMOUTH

How is the nutritional information on food labels worked out and how accurate is it?

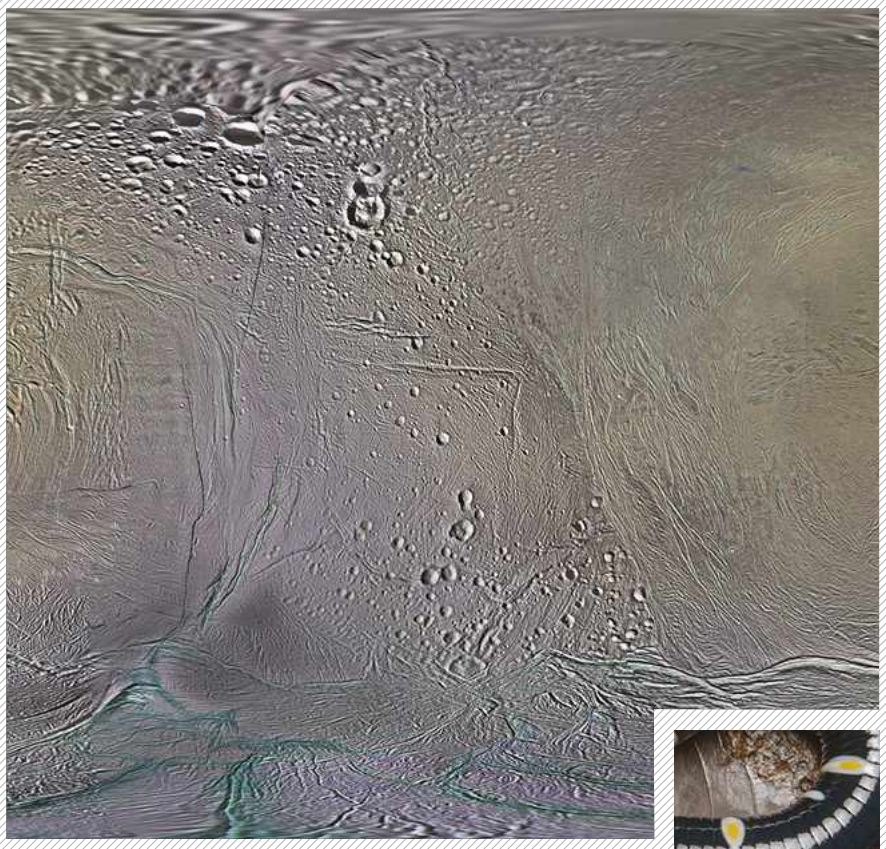
A IN THE UK, nutritional labels are regulated by the European Food Standards Agency. The actual quantities of nutrients such as fat, sugar and protein aren't directly measured; instead, manufacturers consult the nutritional information for all the ingredients they use in a particular recipe. Those values have already been worked out by independent laboratory analysis and published for all ingredients used in the food industry.

EU regulations allow quantities to be rounded to the nearest gram or 0.1g, and for errors of around 20 per cent. If a health benefit is made, such as 'reduced fat' or 'a source of vitamin C', then manufacturers have less leeway on one side of the figure than the other. **LV**



Nutritional labels are regulated at a pan-European level

WHAT IS THIS?



KNOW THE ANSWER?
Submit your guess now at **sciencefocus.com/qanda/what**

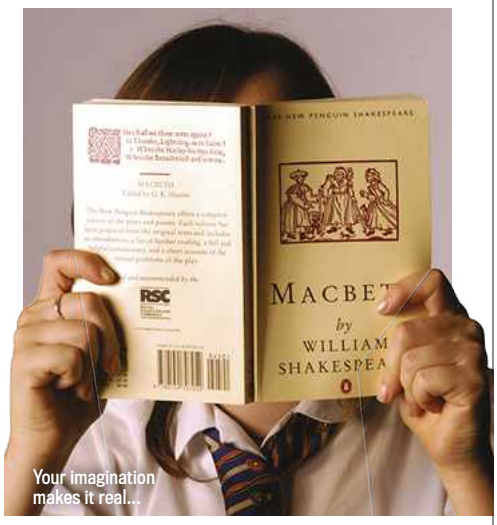
LAST MONTH'S PICTURE
Lauren Armani correctly identified this picture of a fried egg worm

PHOTO: NASA X2, ALAMY, GETTY

Q **MEGAN MALPAS,** CAMBRIDGE

Why do we get a mental picture when reading?

A READING IS A complex, multi-layered process, starting with detecting letters, recognising words and groups of words, then analysing sentence structure and meaning. Different areas of the brain build up information about the scenes, actions and characters, relating them to what you already know and feel. Visual and auditory areas of your brain are at work when you read, as you subvocalise the words when one of the book's characters is speaking. Your lips and tongue may even move, your spine might tingle and your muscles may tense in response to the story. All this contributes to what we think of as pictures in our head – yet in reality our brains probably contain no such thing. Indeed, recent theories treat vision more like an activity or interaction with the world rather than a picture-making process. Oddly enough, more detailed written descriptions may not result in richer or more satisfying mental imagery. Sometimes, the simplest descriptions allow you to create your own imagined world with far more detail and emotional involvement. **SB**



Your imagination makes it real...

Q **LOUIS GOODWIN,** LEWES

Could a train break the sound barrier?

A A CONVENTIONAL TRAIN never could, because the friction of metal on metal would melt the wheels and the track. But in November 2014, Japan's experimental Shinkansen maglev ('magnetic levitation') train managed 500km/h (311mph), which is about Mach 0.4. Levitating the train over the tracks reduces friction. The entrepreneur Elon Musk has proposed the 'Hyperloop' concept, in which a train zips along at near supersonic speed through a partially evacuated tunnel. But there are no serious plans for a train that crosses the sound barrier, because coping with the pressure wave at the front of the vehicle remains an insurmountable problem for currently available technology. **GM**

Would the wrong type of snow still be an issue with Japan's maglev train?

Q **BRIAN ROCHE,** CORK, IRELAND

Why are MRI scanners so noisy?

A MRI SCANNERS PRODUCE very powerful, rapidly fluctuating magnetic fields, and work by measuring the radio waves that are given off by the hydrogen atoms in your tissues as a result. The magnetic fields are generated by passing electrical pulses through large, heavy coils of wire. The wire expands and contracts very slightly as the magnetic field rises and falls and this makes the coil vibrate. MRI scanners use fields 60,000 times greater than the Earth's magnetic field, so these vibrations can be quite strong. The noise is the coils banging against each other, and it can be as loud as a balloon popping next to your ear. **LV**

MRI scanners are far too noisy to offer the chance of a cheeky nap

NEXT MONTH Over 20 more of your questions answered

For even more answers to the most puzzling questions, see the Q&A archive at **www.sciencefocus.com/qanda**

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93711 - NexImage 5MP Solar System Imager
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THE FUTURE OF GADGETS

TECHHUB

EDITED BY **DANIEL BENNETT**

THIS MONTH

BILL THOMPSON
You, I and AI
p85

JUST LANDED
LG quantum dot TV
p86

ULTIMATE TEST
Smartwatches
p89

ON THE HORIZON

GIROPTIC 360CAM

The camera that sees everything

www.360.tv

AT THIS YEAR'S Consumer Electronics Show (CES) – the annual event where the world's tech companies showcase their wares – one piece of kit was ubiquitous: the selfie stick. Around every corner of the Las Vegas Convention Centre you'd find a selfie stick thrust into the air with an iPhone or GoPro strapped to the top, looking back at its owner.

Selfies, and any accessory, app or gadget that helps you take them, are going to be huge in 2015, and though you won't find the *Focus* team uploading selfies to Instagram any time soon, one selfie-related piece of technology did catch our eye: the 360cam.

Giroptic, a French company, has created a $499 camera that sees a full 360° around itself and 300° from top to bottom. This means you simply hold the camera out in front of you and it will record (almost) everything around it. You can then watch these videos back and explore your recording as you would an image on Google Street View. From there, you can either select the portion of the image you'd like to keep as a still or video, create a panoramic image, or simply keep it as an

Different mounts for the 360cam include (left) a light bulb fitting and (above) a video streamer

interactive 360° video (see bit.ly/360F1vid for an example).

Until now, if you wanted to create this kind of footage you'd have to strap together several cameras (usually GoPro action cams) and then use some clever software to stitch their footage together – a process that typically takes a long time, and usually leaves imperfections where the images from each camera are glued together. However, the 360cam is the first device to stitch together the footage while you film. This means you don't have to wait to watch your footage back, and better still, you can use it to stream video live, or even broadcast it in full HD.

Of course, the 360cam will take some incredible selfies as well, but imagine watching a tennis match or a football game where you can control the camera. That's precisely what a 360cam can deliver. It's even decked out with three microphones, giving your videos surround sound. Indeed, the team from Giroptic is already working with YouTube so that interactive 360° film can be uploaded to the site and watched live.

YouTube isn't the only big company Giroptic has attracted interest from. Oculus Rift, the virtual reality (VR) company that was recently bought by Facebook for $2bn (£1.3bn), is working with Giroptic to see if it can use the cams to create virtual experiences. The idea is that you could take your camera with you on holiday, film your adventures without having to worry about where to point the cam, then experience it all over again at home on a VR headset. That's the future that the two companies could create together.

It's not just for your holiday pictures, either. In an ingenious move, Giroptic also offers a mount for the 360cam that lets you screw your device into a light bulb socket, transforming it into a wireless security camera for your home. And yes, there *is* a selfie stick mount... so you can expect to see a lot more of both products in 2015.

DANIEL BENNETT is the reviews editor of *BBC Focus Magazine*

TECHOMETER

WHAT'S HOT

ASSISTED DRIVING

Tech companies are planning to get us used to the idea of handing over the wheel to a robot with 'assisted driving tech'. Nvidia, for example, has come up with a chipset for cars that has the ability to drive for you. But since that's not legal yet, the system currently just helps drivers on the road, warning about potential collisions or suggesting when to pull out at a junction or roundabout. It could be a real boon for learner drivers.

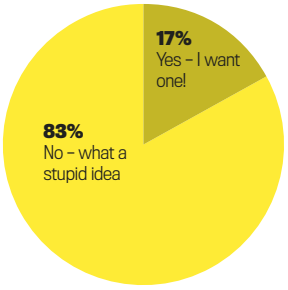
WHAT'S NOT

GOOGLE GLASS

Last year Google launched Project Glass to a select group of 'Explorers' for £1,000. Tech press events were crammed with early adopters shouting 'OK glass' at their specs. This year at CES, however, Google's glasses were notably absent. The novelty, it seemed, had worn off. Now, just a few weeks after the event, Google has announced it will stop selling the specs – with no indication of whether it'll make a new model.

READER POLL

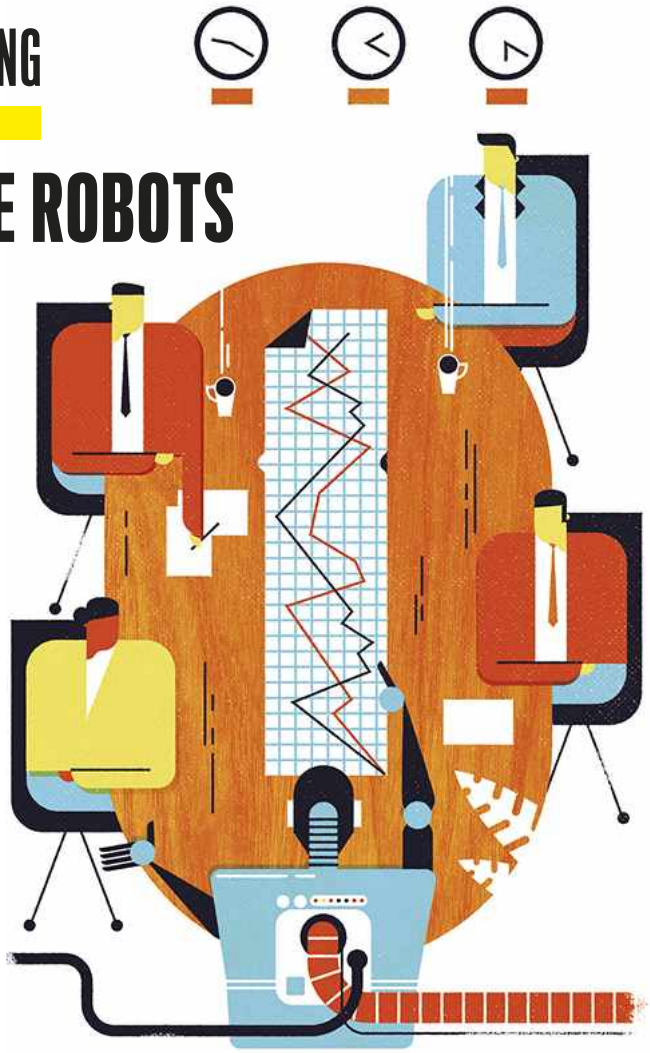
Would you buy a selfie stick?



ILLUSTRATOR: DEM ILLUSTRATION

THE NEXT BIG THING

SELF-AWARE ROBOTS



WHETHER OR not you believe Professor Stephen Hawking's rather hyperbolic prediction that building a 'strong' artificial intelligence could lead to the end of the human race, it's clear that AI is reaching the point where soon it will affect almost every aspect of our interaction with computers and other machines. We're going to have to get used to computers that talk back.

Last year, investment fund Deep Ventures got a lot of publicity when it reportedly appointed an AI to its board of directors to help decide its investment strategy. What actually happened was that the company used a program called VITAL to analyse potential investments in life science firms and gave it voting rights on the board. But VITAL doesn't attend board meetings: it's just a program. It wasn't up there with putting a HAL 9000 in control of the mission to Jupiter in *2001: A Space Odyssey*, but it was still significant, marking an acknowledgement that computers are more than glorified spreadsheets.

Other AI systems will be driving our vehicles, interpreting our facial expressions as we perform complex tasks, translating our voices into different languages and building other machines for us in factories around the world. But they won't look like us or pretend to be human.

In the new film *Ex Machina*, a computer scientist is asked to assess whether a robot is conscious. Unlike the Turing Test, where you interact with a range of participants, in the film there is only one AI, Ava. Although Ava has a human-looking face, it is clearly a robot, since if something that is so clearly a machine can convince you that it has a mind, then we can really be sure we've created an AI. I won't spoil the film for you, but it occurred to me that one of the reasons we believe other human beings are conscious is that we're told they are all the time. Indeed, if you stopped believing other people had minds you would quickly find yourself unable to function in the world.

Google's Eric Schmidt argues that we shouldn't worry about AIs and autonomous systems, and that we need instead to tailor education systems around the world so that we learn how to get on with the machines. But as powerful computer-based intelligences emerge, we may simply let go of the belief that only organic systems can act as the basis for intelligence and consciousness. Just as we have accepted the reality that the self-awareness that makes minds possible exists within the animal world, we may soon accept that it can also exist within the machine world.

BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service

COMING SOON

3 MONTHS

PARROT ZIK SPORT

These are the most comfortable sport headphones we've tried on. They'll track your heart rate, eliminate noise and even tell you if your cadence is a little off-kilter. *parrot.com*

+ HTC M9
HTC's last smartphone was a huge critical success, so we're eager to see what the Taiwanese manufacturer has in store for its mystery device launching in March. *htc.com*

+ Blackphone App Store
The high-privacy phone is rolling out an app store with software to keep your personal information personal. *blackphone.ch*

6 MONTHS

RAZER OSVR

Virtual reality is coming to gaming in a big way, and now consumers will have several options. While Oculus Rift leads the field, Razer, which makes hardcore gaming laptops, has built an open source headset that anyone can build games for. *osvr.com*

+ LG Watch
Little is known about LG's next smartwatch, but it could be the first watch to help you lock and unlock your car thanks to a new partnership with Audi. *lg.com*

+ Apple Watch
Expect to see Apple's take on the smartwatch arrive late this summer. Could this be the device that actually makes all our wrists a bit smarter? *apple.com*

9 MONTHS

GOGORO SMARTSCOOTER

This smart bike has dozens of sensors to warn users if it might break down, and swappable batteries so you can switch over if you forget to charge it. *gogoro.com*

+ LG 77EG9900 4K flexible OLED TV
While we're not convinced a curved TV is any better than a flat one, having a TV that can switch between the two is a neat trick. It'll be out before the end of the year. *lg.com*

+ Samsung smartwatch
Rumour has it Samsung is planning a complete redesign of its Gear smartwatches in response to Apple's watch launch. Watch this space. *samsung.com*

JUST LANDED: LG UF9400 QUANTUM DOT 4K UHD TV

QUANTUM LEAP

Yet another new display technology is about to reach the high street. Daniel Bennett checks out one of the first quantum dot TVs

PRICE: TBC
WWW.LG.COM

What's a 'quantum dot' TV?
It's a new type of LED display technology that you can expect to see a lot more of in 2015: not just in TVs, but in phones, tablets and monitors. As you might have guessed, it relies on quantum dots – tiny nanocrystals smaller than bacteria – that glow when a light is shined on them. The exact colour of the light that's emitted depends on the size of the dot – smaller ones appear blue and larger ones glow red. It's a technology that's been around for a couple of years, but now it's about to hit the mainstream.

So why are quantum dot displays better?
An LED TV typically has three components: a white LED backlight; a colour filter that turns this white light red, blue or green; and a liquid-crystal panel that controls how much of each colour gets through. These three panels work together to create the image you see on-screen.

The problem with this setup is that LEDs naturally shine with a blue light, so they're coated with a yellow phosphor that creates an approximation of white light. This 'fix' means the light emitted by the LED lacks the red end of the light spectrum. This in turn has a knock-on effect on every colour the TV tries to recreate.

The quantum dots help the LEDs produce a fuller, cleaner white light in the first place. This is done by placing a film of the dots over the LED. The dots are made at precisely the right size to emit green and red, balancing out the blue LED and creating a pure white light in the process.

This means the RGB filter on top is working with the purest white light possible, and so can recreate colours more accurately.

How good are they?
We spent half an hour with LG's first quantum dot television in the flesh, and we were impressed. The images seemed to glisten on the screen, with the whites appearing much cleaner, which created better contrast across the whole picture.

In fact, the effect was so dramatic that the colours seemed a little oversaturated – everything took on a slightly unreal quality. Right now, it's an effect that would put us off handing over our own cash, but it's one that LG and its rivals hope to remedy fast.

That's because quantum dot is definitely a technology that's worth getting excited about. Displays will use less energy (and so offer better battery life on smartphones) and create bolder, more vivid images without costing as much as an OLED – the current king of displays. ■

DANIEL BENNETT is reviews editor of *Focus* magazine

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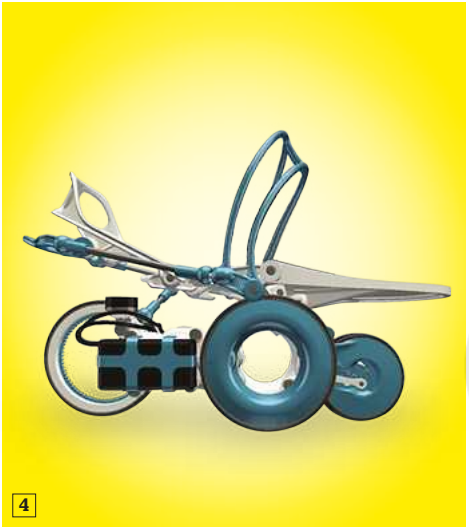

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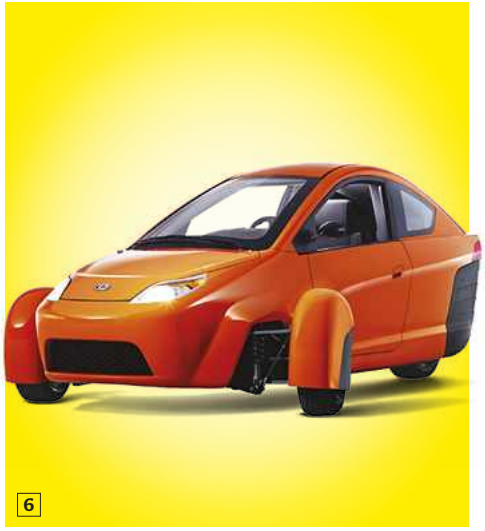

6

APPLIANCES OF SCIENCE

1 UP IN SMOKE

E-cigarettes are everywhere, but it's still not clear how healthy they are and whether they really help you kick the nicotine habit. The Smokio hooks up to a free smartphone app so that you can keep track of exactly how much nicotine you're inhaling each day. It provides handy regimes to help you scale back, then shows you how much money you're saving and how close you are to reaching your goal.

Smokio
From €59.90 (£46), smokio.com

2 FLASH LIGHTNING

This car looks like it drove straight out of 1960s, but beneath the Shelby Daytona chassis is one of the most high-tech rides money can buy. It's an electric supercar that reaches 97km/h (60mph) in 3.4 seconds and charges in 30 minutes. It's built for speed, but the coolest feature is the ability to tune the power output to match attributes from other cars, letting you pick a different ride every single day.

Renovo Coupe
$529,000 (£348,152), renovomotors.com

3 BEAM BOX

This other-worldly device is currently being crowdfunded. The idea is that you'd position a television in the centre of the room and play a game like *Battlefield* on it. The Catopsys Immersis then nestles behind your sofa and projects out images from the periphery of the game onto three walls surrounding you, using its camera to map around your furniture, creating a totally immersive experience.

Catopsys Immersis
$2,600 (£1,711), www.catopsys.fr

4 THAT'S HOW I ROLL

It's not just kids who can get wheels on their shoes. These electric wheels clip onto your boots and let you double your walking speed. As they've got a motor attached, the wheels don't roll around freely so, unlike rollerskates, you won't be spending a lot of time on your backside. Just strap the Rollkers on, move your legs forwards and the motors speed you along, leaving pedestrians in the dust.

Rollkers
Price TBC, rollkers.com

5 SOUND BOMB

It's only slightly bigger than a football, but the Silver Phantom sound system can pump out 3,000W. Roughly speaking, that's almost enough power to produce 125dB – the level at which your ears hurt. It uses what Devialet describes as "cybernetic sound" to get the most out of your digital music through software and hardware, meaning that the sound system can be digitally upgraded over time.

Devialet Silver Phantom
€1,990 (£1,524), en.devialet.com

6 THREE-WHEELING

You know fuel is getting expensive when the latest super-efficient car comes from... America. This funky three-wheeler uses just 3.4 litres per 100km (84mpg). It seats two people and comes with all the mod cons. And if you're doubting the green credentials of a car made almost entirely in the US, Elio claims their vehicle produces less annual emissions than the average flatulent cow.

Elio
$6,800 (£4,469), eliomotors.com

Galloway Forest Park

home to the UK's first Dark Sky Park

Dark sky at night, stargazer's delight

See the wonders of the universe at the UK's first dark sky park.

Home to some of the darkest skies in Europe, the **Galloway Forest Dark Sky Park** is the perfect winter destination for an exceptional view of our celestial neighbours.

With astronomer friendly accommodation, **regular stargazing events**, welcoming astronomy groups and the Scottish Dark Sky Observatory; you can enjoy **spectacular views of the Milky Way,** meteor showers and planetary bodies over the next few months.

With big skies, **beautiful settings,** quiet roads, miles and miles of walking and biking trails and fantastic access to wildlife; the **Galloway Forest Dark Sky Park** delights both night and day.

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For more information visit our website or call us on 01671 402420

www.forestry.gov.uk/darkskygalloway

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ULTIMATE TEST

SMARTWATCH SHOWDOWN

Smartwatches are getting smarter all the time. **Paul Lamkin** straps on four of the latest models...

SMARTWATCHES HAVE come a long way since our last wearable tech test. The first wave of devices suffered from short battery lives, grainy displays and clunky interfaces, and didn't stay on our wrists for long. But now, with the help of Google's Android Wear platform, the world's biggest tech companies have given their smartwatches a new lease of life. We asked Paul Lamkin of wareable.com to put four to the test.

PHOTO: THESECRETSTUDIO.NET

MOTO 360

MOTOROLA

£199.99

Weight: 49g
Display: 1.56-inch
Wireless: Bluetooth
Battery life: One day
Processor: 720MHz

THE MOTO 360 created the smartwatch revolution's first real 'wow' moment when it was shown at Google's I/O conference in 2014. Not only was it one of the first devices to run the all-new Android Wear OS, it also came with a round watch face – its Korean rivals from Samsung and LG both combined dull rectangular faces with lacklustre designs.

It's a fine looking watch, if a tad on the chunky side, but the display is a disappointment, and not just because it's a standard LCD. The 360's biggest crime is the dead area at the bottom of the face that makes a mockery of the 'first circular smartwatch' claim.

This display is off most of the time, and automatically turns on to reveal the clock face as you look at the screen – a feature designed to save the battery. But getting your horological fix requires an exaggerated, theatrical movement to illuminate the screen, and we often found ourselves having to tap the screen just to check the time.

Fitness is a big theme of the Moto 360. It keeps track of your step goals and heart rate; Heart Activity sets you a target of 30 minutes' moderate activity a day and tracks your progress.

Google Keep enables you to make notes using your voice. Voice recognition is generally good, but in a moderately noisy environment the system soon falls apart. What's more, if you're replying to messages by speaking there's no opportunity to verify the content.

GEAR S

SAMSUNG

£329.99

Weight: 67g
Display: 2.0-inch
Wireless: 3G, Wi-Fi, Bluetooth
Battery life: Not specified
Processor: 1GHz

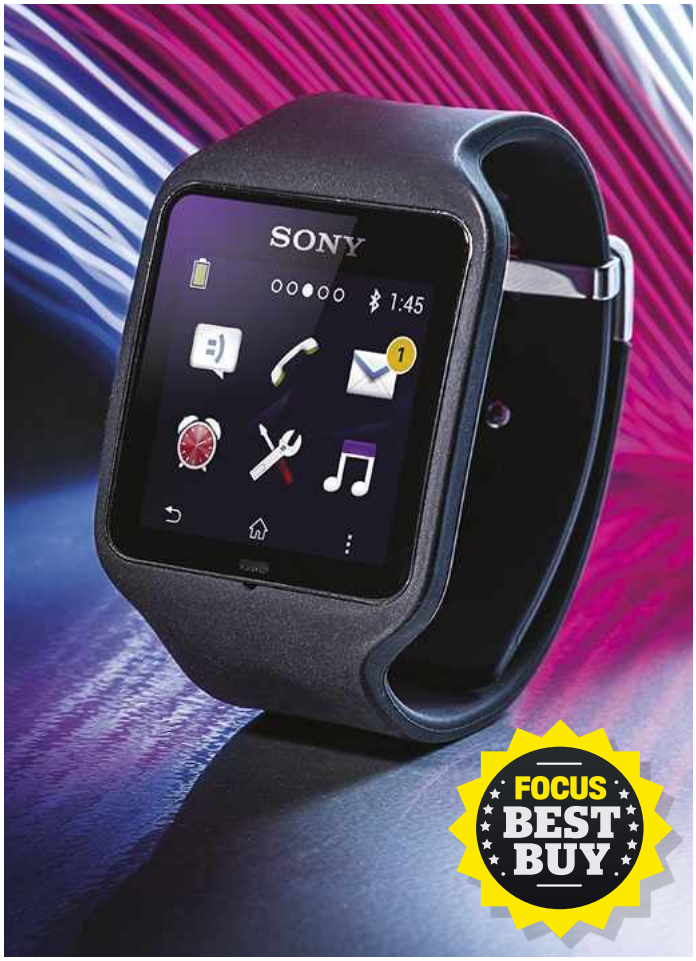
SAMSUNG'S PLAN OF attack with its products – be they TVs, tablets, smartphones or kettles – is to throw a load of products at the wall and see what sticks. The smartwatch is no exception. The Korean company has launched no fewer than six Gear-branded wearables in the last 12 months, the most intriguing of which is the flagship Samsung Gear S.

Marketed as a 'standalone' smartwatch – one that can work without being tethered to a smartphone – the Gear S offers 3G, Wi-Fi and GPS connectivity on the go. You can make and receive calls on it and even send text messages using the tiny keyboard. In reality, you'll do neither, and the fact you'll need a Samsung Galaxy phone to activate it in the first place seems lost on its makers.

Once you're past the initial fiddly set-up process you're presented with a massive smartwatch running Samsung's own Tizen OS – a platform with over 1,000 apps, we're reliably informed, though good luck finding one you'd consider essential.

The real beauty of the Gear S is that two-inch, 480 x 360, curved Super AMOLED display. In the screen stakes, Samsung's smartwatch has no competition. Its pixels per inch count of 300 is pretty much unrivalled and if you're looking for a wearable that's going to be a head-turner, look no further. However, costing over £300, it's almost impossible to recommend the Gear S: it feels at best like a work in progress, at worst like a jumbled mess.

PHOTO: THESECRETSTUDIO.NET



SMARTWATCH 3

SONY

£189.99

Weight: 45g
Display: 1.6-inch
Wireless: Bluetooth, NFC
Battery life: Two days
Processor: 1.2GHz

SONY'S SMARTWATCH 3 may not be the best looking smartwatch on the block but it may well be the most useful. And that's because it includes GPS connectivity – essential for accurate run-tracking – and a battery that's bigger than any of its Android Wear rivals.

All Android Wear watches allow you to use apps like RunKeeper and MyTracks to record running routes and distances covered, but right now it's only the Sony offering that lets you do this without having to lug your smartphone around with you. We compared it against dedicated running watches from the likes Garmin and Adidas and found the accuracy to be pretty much on the money, so it's ideal for anyone considering both a smartwatch and a specialised running watch.

As well as running smarts, the SmartWatch 3 also gives you all the usual Android Wear functionality such as notifications, navigation and music controls, and that 420mAh battery should mean that you'll only need to charge it every other day (unless you're training for a marathon, that is). The design may be a little on the basic side – Sony misses the target in its attempt to look sporty, but it's a comfortable fit and is pretty durable.

The SmartWatch 3 also has NFC (near-field communication) and Wi-Fi connectivity, and there's a good chance that future Android Wear updates will add functions that make use of these – Google Wallet, for instance. So it should be fairly future-proof, too.

PEBBLE

PEBBLE TECHNOLOGY

£99

Weight: 38g
Display: 1.26-inch, ePaper
Wireless: Bluetooth
Battery life: 5-7 days
Processor: ARM, 80MHz

THE PEBBLE IS pretty ancient in wearable tech terms, having first burst onto the scene with a crowdfunding campaign back in 2012. But it's only recently that it went on sale in the UK, so we thought it only right we include the device that, literally, kickstarted the smartwatch movement.

Despite still being a big seller, the Pebble now looks pretty dated compared to its wrist-seeking rivals. And while its e-paper display will go a long way to boosting battery life – you can realistically expect five to six days of 'normal' usage – it's housed in a clumsy-looking plastic chassis that looks anything but cutting edge, and has fallen behind in an industry determined to align itself with traditional watch design and luxury fashion brands.

The huge interest in the Pebble however, means that there are now thousands of apps and extensions designed to make this smartwatch more than the simple notification assistant it was built to be. You can only store eight apps on the Pebble at any one time, but thanks to the Pebble Locker, syncing apps from your smartphone is a painless affair.

On the notification front, the Pebble will buzz you for incoming calls, texts, emails, Facebook messages and so on. So while the Pebble is showing its age a little in tech terms, it's still pretty useful.

PAUL LAMKIN is editor-in-chief of Wareable.com, a website dedicated to wearable technology

THE NATURE OF GRAVITY

BY BRIAN CLEGG

What goes up must come down, as the old saying goes. But why that's the case is a mystery that took some of humanity's greatest minds centuries to figure out – and some aspects of gravity remain a puzzle

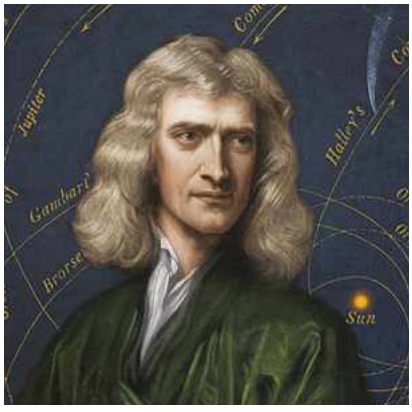
THERE ARE FOUR fundamental forces that operate in the Universe: the strong nuclear force, the weak nuclear force, the electromagnetic force and gravity. Gravity is the most obvious of these – yet it has proved a difficult puzzle to crack.

To the ancient Greeks, gravity reflected the nature of the elements. Aristotle described how earth and water had gravity, and there was a tendency of motion towards the centre of the Universe (the Earth). Air and fire, he said, had levity, which encouraged them to move away from the centre. But these tendencies were only present in the imperfect, sub-lunar realm. In the Greek world view, everything from the Moon upwards depended on the fifth element, quintessence, which allowed the heavenly bodies to rotate undisturbed.

To understand Aristotle's viewpoint, we need to forget all we learned about physics at school. Gravity was not a force – it simply described the nature of earth and water. It was their natural tendency to seek out the centre of the Universe, just as it is a dog's natural tendency to fight cats. Although gravity would be refined over the years, there were few serious challenges to Aristotle's domination of the physical sciences for 2,000 years.

DOWN TO EARTH

The great 7th Century Indian mathematician Brahmagupta briefly flirted with the idea that gravity might work in a similar way to a magnet, as did the Islamic scholar al-Biruni 300 years later, but this wasn't enough to shake Aristotle's dominance. The first cracks appeared with the transformation of the Solar System by Copernicus and Galileo. If they were correct, and the Earth travelled around the Sun – making that the new centre of the Universe – then Aristotle's model of gravity fell apart. Based on reasoning rather than observation and experiment, Aristotle's ideas required the Earth to be the centre of the Universe. If it were the Sun instead, all heavy matter should fly off into space.



Newton was the first to realise that gravity is a force that all objects, however small, exert on each other

What's more, Aristotle's model of gravity made heavy objects fall faster than light ones. With more material in them, the heavy objects should feel a stronger urge and therefore move faster. Aristotle stated this as fact – yet Galileo demolished the idea. He asked what would happen if you tied together two objects of different weight. The heavier weight, according to Aristotle, would want to fall faster and would speed up the lighter one – but the light weight should slow down the heavier one, leaving them falling at an intermediate speed. Yet the combined object was heavier than either, so the whole should fall faster. It didn't make sense.

Although Galileo almost certainly didn't, as legend has it,

PHOTO: CORBIS, SCIENCE PHOTO LIBRARY

> IN A NUTSHELL

The ancient Greeks thought that earth and water were drawn towards the centre of the Universe, then believed to be the Earth. But thanks to Galileo, Newton and Einstein, our knowledge of this fundamental force has come a long way since the 4th Century BC.

drop weights off the Leaning Tower of Pisa to discover that they arrived at the ground at the same time, he did experiment with pendulums that had bobs made of cork and lead, one "more than 100 times heavier" than the other, and showed that they swung (and hence fell under gravity) at the same rate. He also repeatedly rolled balls down sloping channels to measure the effects of gravity. And Galileo explicitly described a 'force of gravitation' that pulled weights towards the Earth.

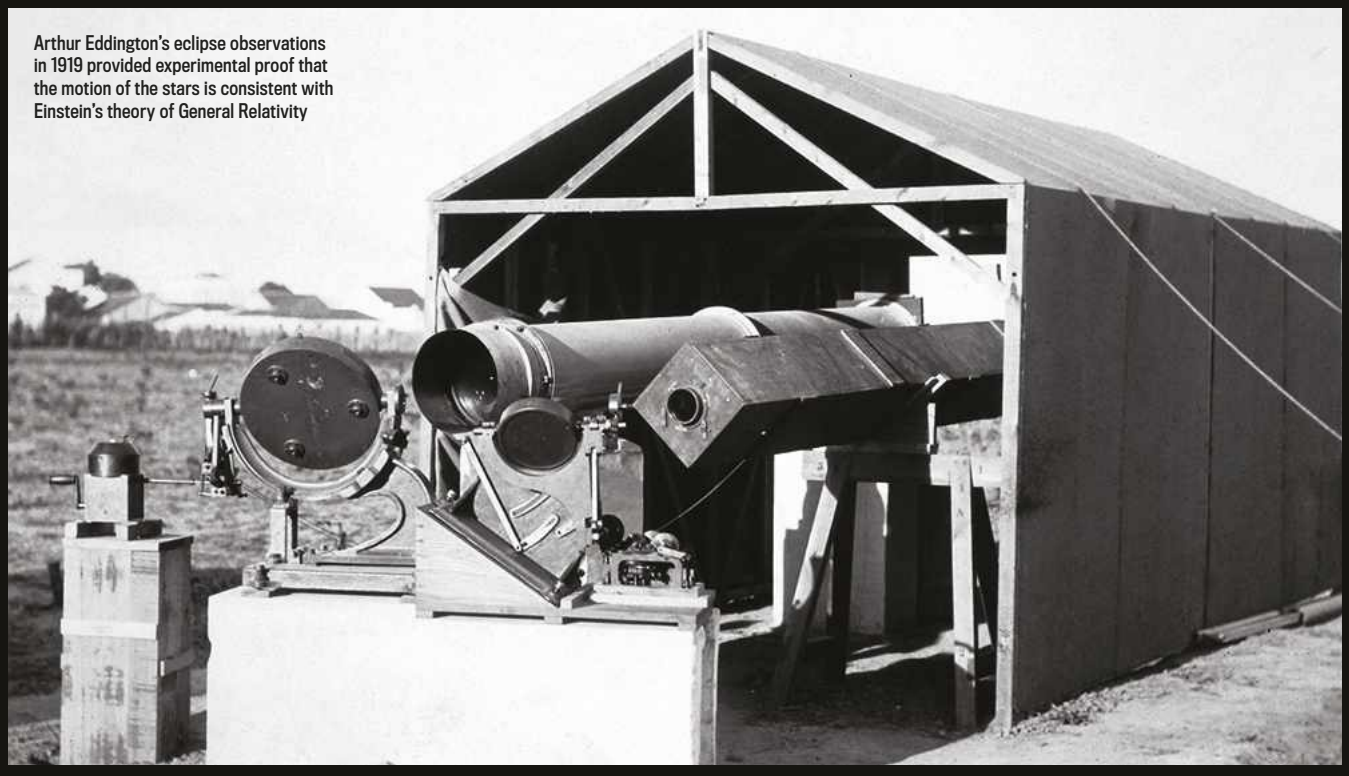
But it was Isaac Newton who brought gravity fully under the auspices of science and mathematics. It's not clear whether he was truly inspired by seeing an apple fall (it certainly didn't fall on his head), though he did make this claim. In a long chat with the antiquarian William Stukeley in April 1726, the elderly Newton described how the fall of an apple made him think, "Why should the apple always descend perpendicularly to the ground?"

In Stukeley's account, Newton says that the apple is pulled by a 'drawing power' to the Earth, and that this force must be proportional to its quantity. The apple draws the Earth, and the Earth draws the apple. But more than this, Newton made the leap of proposing 'universal gravitation'. He broke Aristotle's lunar barrier and applied the same force throughout the Universe, realising that gravity was responsible for keeping the planets in their orbits, where otherwise they would fly off in a straight line.

All this and more Newton put into his masterpiece, *Philosophiae Naturalis Principia Mathematica*, usually known as the *Principia*. The book itself, originally written in Latin, is not easy to read and relies far more on geometry than we would expect today, but here we get the key understanding that the force of gravity is dependent on the masses of the

THE KEY EXPERIMENT

Published in 1915, Einstein's theory of General Relativity caused a stir, but it wasn't until four years later that its practical effects were observed for the first time



Arthur Eddington's eclipse observations in 1919 provided experimental proof that the motion of the stars is consistent with Einstein's theory of General Relativity

GENERAL RELATIVITY LARGELY agrees with the predictions of Newton's theories, but the most obvious difference is in the way gravity bends the path of light. When light from a star passes close to the Sun, its path should, according to General Relativity, bend inwards, shifting the star's apparent position. This could only be seen when the Sun's light is blotted out.

In 1919, Arthur Eddington led an expedition to Principe Island off West Africa to make measurements during the total eclipse on 29 May. That morning brought thick cloud and rain until around noon. With the eclipse due at two, hopes were low. Eddington commented, "We had to carry out our photographs in faith. I did not see the eclipse, being too busy changing plates, except for one glance to make sure that it had begun, and another halfway through to see how much cloud there was. We took 16 photographs." But image after image showed no clear stars; only two plates proved usable. Yet with supporting information from an expedition to Sobral in Brazil, Eddington confirmed General Relativity's predictions and boosted Einstein to celebrity status.

Ironically, later tests suggest Eddington could not have had accurate enough measurements to confirm the theory. But since then, huge amounts of data have proved Einstein's predictions rock solid.

PHOTO: ISTOCK X3, CORBIS X2, GETTY

objects involved divided by the square of the distance between them. This and his laws of motion were enough for Newton to describe the way that planets and moons move and the way that things fall when they drop. It was, without doubt, a triumph.

However, Newton did leave one aspect hanging – which is how this strange force acting at a distance could work. He writes in *Principia* 'hypothesis non fingo', translated as 'I frame no hypothesis'. This was a sly comment: in using the word 'frame', as in framing someone, Newton was suggesting that his competitors were making things up. Still, this gap in explanation left Newton open to attack, particularly for his use of the word 'attraction'. Today we are familiar with 'attraction' being applied to gravity, but at the time it was only used in the romantic sense. He seemed, to 17th Century ears, to be saying that the Earth orbited the Sun due to some kind of planetary crush.

Newton had not worked in isolation. His great rival Robert Hooke, for instance, had suggested that gravity was an 'inverse square law' that reduced with the square of the distance, but Hooke had been unable to manage the maths to support his idea. It took Newton to assemble the magnificent whole.

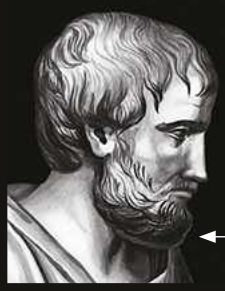
GRAVITY EXPLAINED

Despite his protestations, Newton did have some thoughts on how gravity might work. He suspected, as many did, that there was an invisible material in space that could transmit the force. Such mechanical models for gravity became more sophisticated with time. The most popular was that of Nicolas Fatio de Duillier and George-Louis Le Sage, both Swiss scientists who independently developed the idea that space was full of tiny invisible particles that constantly bombarded bodies from all directions. When something got in the way, like the Earth, it sheltered other objects from particles coming from its direction. This meant that the remaining particles pushed objects towards the Earth.

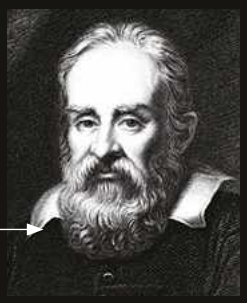
This sounded very unlikely. But it would take the remarkable mind of Albert Einstein to come up with a better suggestion. His breakthrough thought on gravity came shortly after the remarkable year of 1905,

CAST OF CHARACTERS

Five great thinkers whose work was crucial in shaping our understanding of gravity

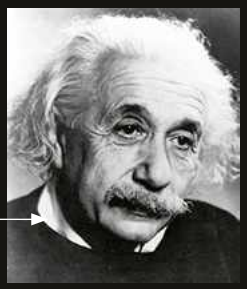


Aristotle
(384–322 BC)
The definitive ancient Greek philosopher, born in Stagirus, Aristotle set the agenda for science for over 1,800 years. This is a pity, as his theories – based on reasoning rather than observation – were almost universally misleading. Gravity as Aristotle saw it was a tendency for heavy things to prefer the centre of the Universe.



Galileo Galilei
(1564–1642)
This natural philosopher from Pisa believed in the importance of experiment, and as a result dismissed Aristotle's ideas on gravity. Though famous for being tried for promoting the Copernican model of the Solar System, Galileo's greatest contribution was his methodical exploration of mechanics and motion, including the influence of gravity.

Isaac Newton
(1643–1727)
The greatest English physicist. Most of his work on light, motion, gravity and calculus was done in Cambridge, though much was achieved when he was confined to his home in Lincolnshire due to the plague. He was later an MP, Master of the Mint and President of the Royal Society – but physics remains his most significant legacy.



Albert Einstein
(1879–1955)
Einstein was born in Ulm, Germany, though he was a Swiss citizen from his teens. He produced three papers in 1905, while working in the patent office, that would show atoms were real, lay the foundation of quantum theory and establish Special Relativity. His theory of General Relativity from 1915 is still the standard theory of gravitation.

Arthur Eddington
(1882–1944)
Born in Kendal in the Lake District, Eddington worked as an astronomer and astrophysicist in Cambridge. When asked if it were true that only three people in the world understood the theory of General Relativity, Eddington is said to have replied, 'Who is the third?'

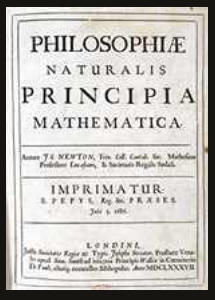
TIMELINE

Six important steps on the road to our modern understanding of how gravity works

350 BC — Aristotle adds *The Physics* to his works, a collection of eight books that describe his theories on the behaviour of natural and moving things, including gravity and the opposing concept of 'levity'.

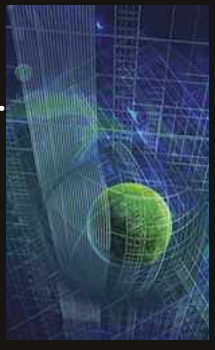
1638 — Galileo's last book, *Discorsi E Dimostrazioni Matematiche, Intorno À Due Nuove Scienze* [*Discourses And Mathematical Demonstrations Relating To Two New Sciences*] is published, including his ideas on gravitation.

1687 — Newton's *Philosophiae Naturalis Principia Mathematica* is published, a three-volume work in which he outlines his theory of gravity as well as his famous laws of motion.



1907 — Sitting in his office in the Swiss Patent Office in Bern, the amateur scientist Albert Einstein discovers the 'principle of equivalence', which states that gravity and acceleration are indistinguishable.

1915 — Albert Einstein publishes a series of papers on his General Theory of Relativity, which describes gravity as a warp in spacetime that is caused by massive objects.



1919 — Arthur Eddington observes a solar eclipse on Principe Island, demonstrating the shift of stars appearing near the Sun. He uses this as confirmation of General Relativity.

when Einstein wrote three papers that transformed physics. These established the existence of atoms, formed the foundations of quantum theory (for which he won his Nobel Prize) and introduced Special Relativity, which showed how apparently fixed quantities like mass, length and the flow of time varied depending on your viewpoint.

Two years later, Einstein was sitting in the patent office in Bern and had what he described as his happiest thought. Einstein later commented: "All of a sudden a thought occurred to me: if a person falls freely, he will not feel his own weight. I was startled. The simple thought made a deep impression on me. It impelled me towards a theory of gravitation."

GRAVITY AND LIGHT

What Einstein had realised was that gravity and acceleration were equivalent and indistinguishable. If, for instance, you were in a spaceship with no windows and found that you were experiencing a pull of 1g, there are two possible explanations. You could be sitting still on the surface of the Earth, or you could be in space and the craft could be accelerating at 9.81 metres per second per second – the same acceleration as due to Earth's gravity. Your instruments could not detect a difference. But if this is true it tells us something odd about gravity.

If we imagine a beam of light crossing the accelerating spaceship, the beam will appear to bend to someone inside the ship as a result of its motion. But since acceleration and gravity are equivalent, the same light beam should also bend in a gravitational field. Einstein had realised that gravity warps space, twisting it near a massive body so that anything travelling in a straight line curves around it. This is as true of an orbiting planet as it is of a beam of light.

In fact, his discovery proved stranger still. While the warping of space explains the orbits of the planets, it doesn't tell us why the apple falls. There is no reason for something to start moving. But it is space-time – the mash-up of space and time that emerged from Special Relativity – that is warped by massive objects, and it is the warp that initiates motion. The mathematics to support all this is fiendishly complex – even Einstein had to get help to understand it – but

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NEED TO KNOW

Key terms used when discussing the nature of gravity

1 FUNDAMENTAL FORCES
The four forces of nature: gravity, electromagnetism and the strong and weak nuclear forces. Between them they're responsible for all interactions between particles (and between matter and light).

2 INVERSE SQUARE LAW
This describes a quantity that gets smaller as the square of a value gets bigger. For instance, if you double the distance between two bodies the gravitational pull is reduced by a factor of four.

3 MASS
A concept introduced by Isaac Newton to describe the amount of matter present. The mass of a body is what causes its gravitational attraction and doesn't vary, whereas its weight is the force of gravity on the mass at a particular location.

4 RELATIVITY
Galileo observed that motion is relative. If we move at the same velocity as something else, it doesn't move with respect to us. Einstein developed this idea in his theories of Special Relativity, reflecting the effect of the fixed speed of light, and General Relativity, which brings in gravity and acceleration.

String theory, also known as M-theory, is an attempt to reconcile gravity and quantum mechanics, but supporters of the theory have so far been unable to demonstrate any of its predictions experimentally

the principle is simple enough.

Einstein had given Newton's theory a framework, a reason for working. More than that, General Relativity, as Einstein's theory became known, made some predictions that were different from those Newton would have expected – and experiments have verified that it is General Relativity that matches reality.

It seemed in many ways that the theory of gravitation was complete. Einstein's development would be used to predict everything from the existence of black holes to the way the Universe changes with time. But there is still one big gap in our understanding. All the other forces of nature are quantized. They aren't continuous, but are granular with tiny divisions called quanta. The expectation is that there should also be a quantum theory of gravity, but as yet one has not been established. For a while it seemed as if string theory would provide the answer, but there is increasing concern that this mathematically-driven concept will never make useful predictions, leaving growing interest in alternative theories like loop quantum gravity.

GRAVITY AND US

Our modern understanding of gravity reveals that it's far more important than the ancients thought. Gravity not only keeps things in place on the Earth, it was responsible for the formation of the Solar System as it coalesced out of a spinning cloud of dust and gas. It's gravity that produces the temperature and pressure in the Sun that, along with quantum effects, make it undergo nuclear fusion to generate the heat and light that gives us life.

Experiments in space have even shown that gravity is essential for living things. Plants struggle to grow with no gravity to direct their roots. In an experiment on the International Space Station, it has been shown that birds' eggs need gravity to develop. And human beings deteriorate in low gravity, losing bone density and muscle tone, while lungs suffer compression as organs drift upwards with no gravity to keep them in place.

Gravity maintains some secrets. We don't know, for instance, why it is so much weaker than the other forces. If you doubt this, compare it with electromagnetism: in picking up a paperclip, a small fridge magnet overcomes all the gravity the entire Earth can muster. Nor do we know how to bring gravity into the quantum fold. But thanks to the work of Newton and Einstein, this fundamental force is no longer a total mystery. ■

BRIAN CLEGG is a popular science author with books including *Gravity: Why What Goes Up, Must Come Down*

Find out more

Listen to an episode of BBC Radio 4's *In Our Time* with Melvyn Bragg on the hunt for the graviton: **http://bbc.in/KsKLYr**

A Startling Memory Feat That *YOU* Can Do!

"How I learned the secret in one evening. It has helped me every day."

When my old friend Richard Faulkner invited me to a dinner party at his house, I little thought it would be the direct means of doubling my salary in less than two years. Yet it was, and here is the way it all came about.

Towards the end of the evening things began to drag a bit and finally someone suggested the old idea of having everyone do a 'party-piece'. Some sang, others forced weird sounds out of the piano, recited, told stories and so on.

Then it came to Peter Brown's turn. He said he had a simple 'trick' which he hoped we would like. First he asked to be blindfolded. Then he asked someone to shuffle a deck of cards and call them out in order. Still blindfolded he instantly named the cards in their order, backwards and forwards, without making a single mistake.

On the way home that evening I asked Peter how it was done. He said there was really nothing to it - simply a memory feat - and that anyone could develop a good memory by following a few simple rules. And then he told me exactly how to do it.

What Peter told me that eventful evening was this: "Send for details of Dr. Bruno Furst's Memory Course." I did. That was my first step in learning to do all the remarkable things I have told you about.

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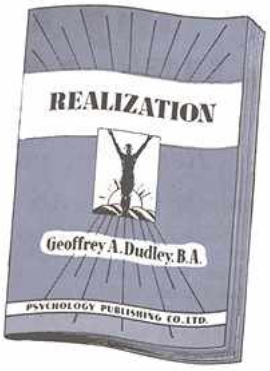

What is the unique influence of this amazing book? From where comes this almost uncanny power to help the timid to a new self-confident personality — the unsuccessful to positions of importance and authority — the sick in their fight back to normal health? It seems incredible! Yet timid, colourless people can simply read this book — and instantly gain courage that performs seeming miracles. Downhearted, frustrated people can scan its pages — and quickly begin to overcome their handicaps. Men and women from every walk of life feel a new vital power surging within them — an irresistible force leading them to undreamed-of success.

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PLAN YOUR MONTH AHEAD WITH OUR EXPERT GUIDE

PICK OF THE MONTH

Old forensic kit from The Metropolitan Police. Modern kits include similar items, such as bags, tape measures and swabs

Forensics: The Anatomy Of Crime

FORENSIC SCIENCE HAS come a long way since its earliest days. The 13th Century Chinese book *The Washing Away Of Wrongs* is thought to be the first guide to forensics: it describes how a cunning magistrate solved the murder of a peasant who'd been hacked to death. Ordering the local peasants to place their sickles in the village square, he simply observed which one attracted flies.

Forensic scientists now have a whole suite of tools at their disposal, from fingerprinting and DNA analysis, to serology, toxicology, entomology and countless other techniques. Forensics: The Anatomy Of Crime is the latest exhibition to open at The Wellcome Collection and provides an in-depth look at the history and art of this fascinating field.

Among the highlights is a 1950s dollhouse-style diorama of a crime scene, complete with miniature corpse, fun-sized furniture and electric lights. Millionaire heiress and forensic science enthusiast Frances Glessner Lee created the model to test police officers' crime-solving skills, and visitors to the exhibition will be able to examine it for clues and have a go at piecing together the sequence of events represented for themselves.

Elsewhere, we see the work of forensics pioneer Alphonse Bertillon, who developed the 'God's eye' method of photographing crime scenes from above, and an installation by Mexican artist Teresa Margolles, featuring floor tiles from the room in which her friend was murdered. There are also nods to more recent developments, with Sir Alec Jeffreys' first DNA 'fingerprint' displayed alongside the techniques of blood and poison analysis that cast new light on previously traceless crimes. But the science is still far from infallible, as Taryn Simon's poignant photos of wrongly convicted people at the scenes of crimes they never committed reveal.

It all promises to make for a thought-provoking, if unsettling day out. "It's certainly not for the faint-hearted," says curator Lucy Shanahan, "but you can't have an exhibition about forensics without a certain element of blood and gore."

JAMES LLOYD

The Wellcome Collection, London, from 26 February to 21 June 2015. Entry is free. www.wellcomecollection.org/forensics

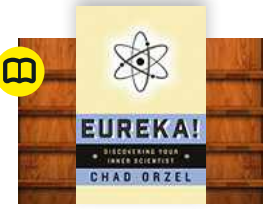
DON'T MISS!

Climate Change By Numbers

Making sense of the statistics behind global warming. p100

Coral Reefs: Secret Cities Of The Sea

A new exhibition at the Natural History Museum explores these living subaquatic worlds. p103



Risk Wise

Our everyday exposure to danger, and the different strategies we adopt to deal with it. p104

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The Truth About Over The Counter Medicine

BBC One, dates and times TBC

WE ALL KNOW it's pointless to bother a doctor with a cough, cold or headache. Instead, we pop to the pharmacy and spend over £2 billion a year on non-prescription products. Dr Chris van Tulleken (left) enlists volunteers to show the science and economics behind the chemist's shelves. Could we do just as well with cheaper home remedies?

8 FEBRUARY

Sky At Night: What Have UFOs Ever Done For Us?

BBC Four, 10pm

NO, WE DON'T know either. Did they engineer the pyramids for the Egyptians? Design the Nazca Lines? Abduct thousands of Americans and do unspeakable things with probes? Guest presenter Dallas Campbell (left) has some more sensible suggestions in this special edition of the long-running astronomy programme.

FROM 11 FEBRUARY

Science Of Stupid

National Geographic, 10pm

REMEMBER NEWTON'S THIRD Law? The internet is full of people who don't. Richard Hammond gives you a scientific excuse to watch some of the most painful, ill-advised stunts ever filmed and uploaded onto the web. Learn how *not* to do one-handed press-ups, and find out why you shouldn't pile up wheely office chairs and roll them downhill...

TIMANDRA HARKNESS is a stand-up comedian and a presenter on BBC Worldwide's YouTube channel Head Squeeze

PHOTO: BBC X2, ISTOCK X2, UKTV X2, NATIONAL GEOGRAPHIC CHANNEL

Since the Coca-Cola ads, Eric's TV work had boomed – the phone hardly ever stopped ringing!

FEBRUARY

Climate Change By Numbers

BBC Four, date and time TBC

MEASURING AND PREDICTING climate change relies on highly complex mathematical models. As the world debates making big changes to the way we live, this 90-minute documentary tries to explain where some key numbers come from. How do we know that the planet has warmed by 0.85°C since 1880? When scientists claim to be 95 per cent certain that at least half of that warming is man-made, what do they mean? And how did they arrive at a trillion tonnes of carbon as the limit to what we should burn?

Three mathematicians are dispatched to tell the story. So Dr Hannah Fry of UCL reveals the tools that statisticians use to make sense of data, Prof Norman Fenton of Queen Mary University of London studies the pitfalls of probability, and Prof David Spiegelhalter at Cambridge looks at the public understanding of risk. Can they help us better get to grips with the uncertainty around climate predictions, and how we can arrive at enough understanding to make informed decisions about the future?

FROM 16 FEBRUARY

Big Cat Week

National Geographic Wild, 9pm

GET READY FOR a whole week of documentaries about the wild cousins of your furry household friends. Roam the Serengeti, track the Nambiti game reserve and discover a soap opera whose stars are Indian tigers. Then, in *Future Cat*, see how experts think the big predators could evolve, with CGI bringing their speculations to life.

FROM 18 FEBRUARY

Kangaroo Dundee

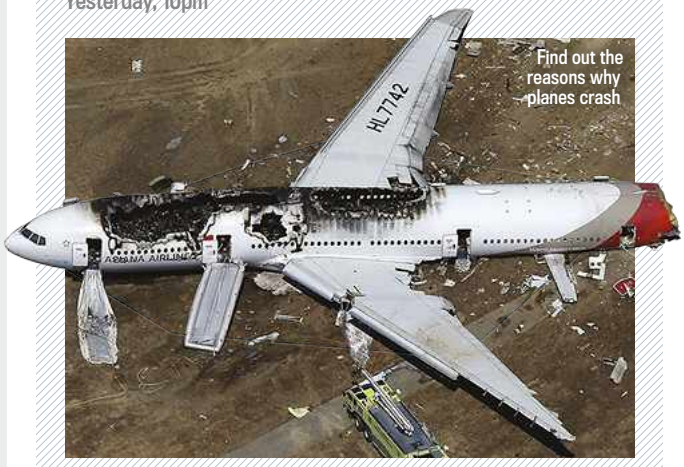
Eden, 7pm

THIS SERIES, FIRST seen in 2014 on BBC Two, goes inside a kangaroo sanctuary near Alice Springs. If the sight of a tough Australian man (Chris Barnes, left) bottle-feeding a joey doesn't make you go "awww!", then you may be taking part in an unethical neuroscience experiment in which scientists removed the cute-ability cortex in your brain.

FROM 23 FEBRUARY

Why Planes Crash

Yesterday, 10pm



Find out the reasons why planes crash

THE MAIN MESSAGE here seems to be: "Planes don't crash – people crash!" Eyewitness accounts, archive footage and stomach-churning reconstructions uncover the explanations behind air tragedies and near-misses, and most involve human error. For pilots, everyday distractions can prove disastrous. For engineers, maintenance crews and air traffic controllers, a small mistake can have huge consequences. But human heroism can also save the day against all odds. Just don't watch it the night before you fly.

DVD & BLU-RAY

Ancient Aliens: Season Six

History Channel, £17.75

ANYTHING FROM BIBLICAL tales of burning chariots to Indian half-snake deities could, it seems, be evidence of alien visitations...

Out Of The Unknown

BFI, £50.93

A SEVEN-DISC boxset of this classic sci-fi series, first shown on BBC TV in 1965 and written by Isaac Asimov, JG Ballard and John Wyndham.

ONLINE

BBC

Secret Life Of A Coral Reef

bbc.co.uk/news/science-environment-25762906

Setting up time-lapse photography in the lab

THIS AMAZING TIME-LAPSE film shows the activity in and around Australia's endangered Great Barrier Reef, revealing it to be a world of vivid colour, high drama and gruesome fights to the death.

BBC

Cat Watch 2014: Interactive Videos

bbc.co.uk/news/science-environment-29465660

Go undercover in cat world

MADE TO ACCOMPANY last year's BBC *Horizon* programme of the same name, these three cat's-eye views of the world starring Tigger, Sandwich and Dad's Cat have interactive extras – just click on the video.

EMPIRE

Inside The Imaginarium

empireonline.com/news/story.asp?NID=43058

Andy Serkis, pictured right

CYBER-THESPIAN ANDY Serkis, AKA Gollum from the *Lord Of The Rings* movies, takes us inside his hi-tech facility for creating characters, environments and shots to tell stories in movies or video games.

LISTEN

BBC RADIO PROGRAMMES

WITH TIMANDRA HARKNESS

8 FEBRUARY

Private Passions

BBC Radio 3, 12pm

PROF NICKY CLAYTON, a keen flamenco dancer and Fellow of the Royal Society, specialises in comparative cognition. She shares with Michael Berkeley her personal choice of music and her fascination with crows, the intelligent birds she studies at Cambridge University.

FROM 9 FEBRUARY

The Cliff

BBC Radio 4, 1.45pm

THE CLIFF IS a resonant image in our culture, whether we're talking about the fiscal cliff that threatens the collapse of capitalism, or the Hitchcock movie *Vertigo*. Professor Alan Read looks at cliffs from all angles in this series of 15-minute explorations.

Not a bluebird in sight, you notice...

1 MARCH

Memoirs Of The Spacewomen

BBC Radio 3, 6.45pm

MARY SHELLEY MAY have invented science fiction, but how many other British sci-fi writers were women? More than you might think, as Matthew Sweet finds out...

Sci-fi writer Naomi Mitchison in 1920

2 MARCH

Spoilsport: Science Stops Play

BBC Radio 4, 11am

DEMENTIA PUGILISTICA, OR 'punch-drunk syndrome', is well documented in boxers, but competitors in other contact sports also suffer from this neurodegenerative disease. Should rugby and ice hockey be doing more to prevent cumulative concussion?

ONLINE

Can Maths Combat Terrorism?

bbc.co.uk/programmes/b04v4sxd

CAN SOMETHING AS senseless as terrorism be understood, or even predicted? Can thousands of horrific attacks fit onto a graph? Mathematician Dr Hannah Fry from UCL investigates in this documentary from the BBC World Service *Frontiers* series.

PHOTO: GETTY, ISTOCK

TOUCH

SMARTPHONE & TABLET APPS

WITH KATE RUSSELL

Meteor Counter

iOS, Dr Tony Phillips, free

IF YOU'RE LUCKY enough to catch a meteor shower on a clear night, it's a spectacular sight – but there's some important science to be learned, too. So NASA has created an app to help stargazers count the number of meteors they see and then feed the data back to its dedicated researchers. It's no mean undertaking, as around 25 million pieces of space rock slam into Earth's atmosphere every day. As well as tapping to record the number and brightness of the meteors in sight, you can opt to add personal observation notes verbally.

Orca Health Decide Series

iOS 7.0 or later, iPhone/iPad/iPod Touch, Orca Health, free

THE HUMAN BODY is a complex organism and understanding how it works can be a big help in treating and avoiding health issues. Orca Health Inc has created this suite of free apps – *Eye Decide*, *Knee Decide*, *Heart Decide* are among nine apps in the series – detailing the inner workings of our bodies, with 3D models to show how everything fits together. Animations depict what happens when patients suffer some of the most common conditions, and if you have a strong stomach the 'procedures' tab delivers video footage of operations and treatments.

Science Radio

iOS 5.0 or later, iPhone/iPod/iPod Touch, Android 4.2 or later, National Science Foundation, free

FEED YOUR CRAVING for knowledge any time of the day or night with the *Science Radio* app, which delivers continuous radio programming 24 hours a day, seven days a week. The content is drawn from podcasts and news sources from across the world, and curated by experts from the National Science Foundation's Science360 network. The app itself is almost frustratingly simple: you can't pick and choose what to listen to, you just have to hit 'play' and absorb the latest information on topics ranging from molecular engineering to interstellar exploration.

KATE RUSSELL is a technology journalist and BBC *Click* presenter

VISIT

EVENTS & EXHIBITIONS

WITH JHENI OSMAN

12 FEBRUARY

The Oldest Light In The Universe

Royal Institution, London, 7pm, £12/£8, www.rigb.org

DID YOU KNOW we can actually see the Big Bang? Well, sort of. Discover what its echo can tell us about where it all began.

24 FEBRUARY

Introduction To Astrophysics

Royal Observatory Greenwich, 7pm, Tuesdays, £78, rmg.co.uk

IN THIS SIX-WEEK course, find out about the current limits of human knowledge and the latest cutting-edge research on everything from exoplanets to the Big Bang.

27-29 FEBRUARY

Peninsula Arts Contemporary Music Festival

Plymouth University, most events are free, cmr.soc.plymouth.ac.uk

MUSIC MEETS SCIENCE at this festival with a difference. Hear a string quartet piece generated by the audience's brain signals, and a composition modelled on the evolution of humpback whale song.

28 FEBRUARY - 19 APRIL

Super Cells

Life Science Centre, Newcastle, 8pm-10pm, life.org.uk

IN THIS EXHIBITION, get to the core of stem cells: what are they, what do they do and how can they be used in medicine?

2 MARCH

The Robots Are Coming

Emmanuel Centre, London, 7pm, £30, intelligencesquared.com

ONE IN THREE jobs could be taken over by a robot in the next 20 years, but some think the AI revolution may lead to more careers.

5 MARCH

Planet Oil: The Story Of A Modern Addiction

Turner Sims Concert Hall, University of Southampton, 8pm, www.rgs.org/rtp

GEOLOGIST AND TV presenter Professor Iain Stewart looks at how a sixth of the global economy depends on hydrocarbons, and the social and political consequences of our 'addiction' to fossil fuels.

Christmas tree worms found on the Great Barrier Reef

EDITOR'S CHOICE

FROM 27 MARCH

Coral Reefs: Secret Cities Of The Sea

Natural History Museum, London, nhm.ac.uk

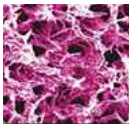
IF YOUR WALLET can't stretch to flights to exotic destinations, then take heart. This exhibition contains a real, live reef along with more than 200 specimens of coral, fish and fossils. Coral reefs only make up around 0.1 per cent of Earth's surface, but they're home to almost 25 per cent of all living marine species. And with over 500 million people depending on them for their livelihood, they're estimated to be worth more than £200 billion each year from fishing, tourism and protection from storms. Now, this exhibition enables you to take a virtual dive and explore the world hidden just below the sea surface.

10 MARCH

The Cosmic Chemical Cauldron

Royal Geographical Society, London, 1pm, www.ras.org.uk

JOURNEY FROM THE cold, dark cores of protostars to newly formed exoplanets, discovering how these cosmic bodies – and life itself – are created from the 118 elements in the Universe.



12-19 MARCH

Sci-Art Synergy

CentreSpace Gallery, Bristol, http://bscia-bsba.org.uk

ENJOY ART INSPIRED by science at this week-long exhibition. For private viewings on 13 March, contact bobfostertuition@gmail.com

UNTIL MARCH 2016

Churchill's Scientists

The Science Museum, London, free, sciencemuseum.org.uk

THIS 14-MONTH EXHIBITION celebrates the boffins and 'backroom boys' whose efforts helped ensure Allied victory in WWII. It covers everything from the inventors of radar to pioneers in nutrition.

READ

THE LATEST SCIENCE BOOKS REVIEWED

H Hardback P Paperback

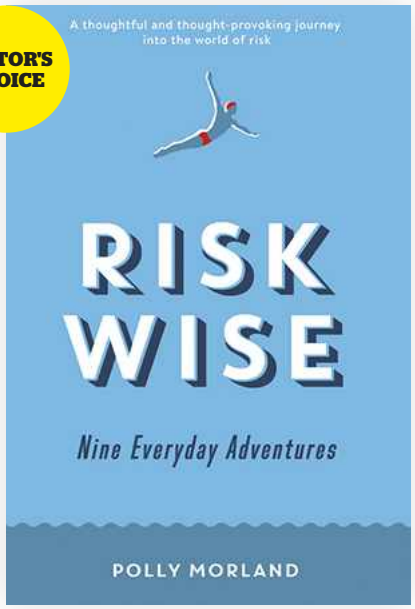
Risk Wise

Nine Everyday Adventures

Polly Morland

Profile Books P £8.99

EDITOR'S CHOICE



WHAT'S THE CHANCE that you'll be run over by a bus, hit by an asteroid, or develop cancer if you scoff too many bacon butties? Risk is all about odds – we can count the bodies and work out what proportion of people come to grief. Ignore the data altogether and you might not live long enough to regret it.

But while horse riding and taking ecstasy have surprisingly similar risks of fatality, numbers alone are not the whole story. We are not probability machines bent only on survival – we are people. And people have a vast diversity of different hopes, fears, values and objectives that influence their judgements.

This human factor is starting to attract increasing attention in research on risk, and it's what makes *Risk Wise*, by award-winning documentary maker Polly Morland, such a great project.

The book contains a series of short stories about real people making hard choices, often with life or reputation at stake. *Risk Wise* sets out to discover how they do it, keeping an open mind throughout the process.

The stories in this book cover a wide range of attitudes towards risk, from surviving on sheer gut instinct to managing risk with an obsessive attention to rules and detail. There are those who find a great deal of fulfilment through risk, and others who think about how they can run away from the situation.

"The ballet dancer who moves in the space between grace and calamity is no model for the relief worker"

We hear of kids who are thrilled by danger, even as one hurts his foot on a nail in the kind of council-sanctioned adventure playground that would give others palpitations. We meet a man who prevents our planes colliding, and a ballet dancer whose success depends on reaching for the margins of disaster. Then there is the demolition man who picks his way through a collapsing building.

If you were hoping for a self-help manual, you may be impatient at the lack of a single formula for success – there is no thesis here. Instead, through the variety of interesting stories, we see the colour and sophistication of people's reasoning. There is the sharp fact that air traffic controllers cannot work on instinct in the same way as the demolition man does. The ballet dancer who moves in the space between grace and calamity is no model for the humanitarian relief worker. All must pick out their own best answer to the problem of uncertainty in life: knowing what we want, knowing that it can all go wrong.

■■■■□

MICHAEL BLASTLAND presented *The Human Zoo* on BBC Radio 4

MEET THE AUTHOR

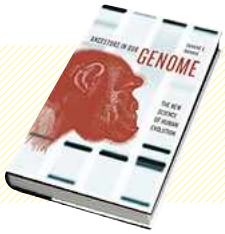
Polly Morland

How did you decide who to feature in your book?
I believe that all of us live with little fragments of risk, even if we lead quite danger-free lives. So I wanted to find people who would allow us to reconnect with the human experience of risk. I was keen not to focus on the extremes – I wasn't looking for BASE jumpers or health and safety campaigners. I was specifically interested in those who live and work alongside risk every single day.

In one chapter, you meet families living on the slopes of Mount Vesuvius. How do they cope with the risk of an eruption?
I met three generations of a family who live in Somma Vesuviana, a town about 1.5km from the volcano's vent. The elderly couple [I met] were teenagers when the volcano last erupted in 1944, and they told me incredibly vivid stories of huge rocks raining down. But the intensity of that threat has dwindled over the years. They know that the volcano might erupt again, but they lead a good life up there, above a city [Naples] that's riddled with crime and the ills of urban life. They value that so strongly that they've made a decision to live with the risk.

Has writing this book changed the way you think about risk?
Much more profoundly than I expected. I started the process thinking that in an ideal world, there would be no risks. But meeting all these people taught me that, sometimes, it's best not to run from risk, but to walk towards it. If you revise your view of risk to embrace things that may go right, as well as those that may go wrong, it can become a force for good.

MORE ON THE PODCAST
Listen to the full interview with Polly Morland at sciencefocus.com/podcasts



Ancestors In Our Genome

The New Science Of Human Evolution

Eugene E Harris

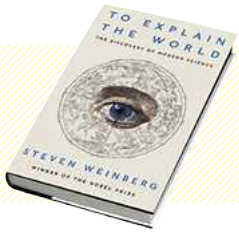
Oxford University Press (H) £18.99

IN 2001, THERE was a hope that knowing the sequence of the human genome would transform our understanding of health and disease. While this is yet to happen, the genomic era has been a tremendous boon. In *Ancestors In Our Genome*, molecular anthropologist Eugene Harris shows how genomic data has revolutionised the study of human evolution, revealing our relationship to the other great apes. It has also given insight into prehistoric population crashes, patterns of migration, evidence of natural selection, interbreeding with Neanderthals and much more besides.

Harris is at his most engaging when he describes the genomic evidence for adaptations to diets, UV exposure, diseases and altitude, and the secrets inferred from DNA recovered from extinct hominids. Unfortunately, these treats come towards the end of the book and after a particularly jargon-heavy opening on taxonomic theory.

The scientists that come and go throughout could have been used to inject momentum into the text. But regrettably, they appear more like institutions than characterful beings.

HENRY NICHOLLS specialises in evolution. His latest book is *The Way Of The Panda*



To Explain The World

The Discovery Of Modern Science

Steven Weinberg

Allen Lane (H) £20

STEVEN WEINBERG HAS been hailed as the greatest living physicist. As well as being a Nobel Prize winner, he is a driving force behind the Standard Model of particle physics and also unified two of nature's fundamental forces.

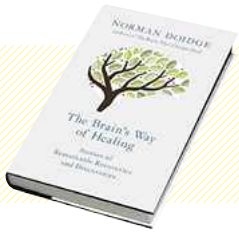
Now, Weinberg has combined these credentials with his knowledge of the history of science to examine a fascinating issue: how attempts to explain the world have evolved over time.

Weinberg shows that while Aristotle's ideas about physics seem silly today, he was no fool. He was simply labouring under the prevailing view that there must be a purpose to everything. Today's theorists have no such beliefs, having found that mathematical beauty is a far surer guide to fundamental truth.

Despite the tricky subject, Weinberg writes clearly and simply, and includes many telling insights – such as how the Greek scholar Strato used dripping water to prove that falling objects accelerate.

Inevitably, most of the book is about theories now known to be nonsense. Still, it's hard not to admire the determination of early scientists to bring us closer to the truth.

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham



The Brain's Way Of Healing

Norman Doidge

Allen Lane (H) £20

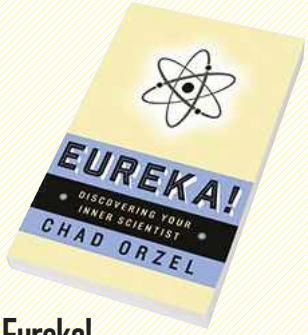
I'VE COMPLAINED BEFORE about the fashion of invoking neuroscience to lend credibility to dubious claims. *The Brain's Way Of Healing* is an example of this.

It's not totally without merit. The book focuses on how the brain's plasticity can be used therapeutically. Norman Doidge is engaging and seems to care deeply for the subject and the people involved.

But therein lies the problem. Interested non-scientists would probably be caught up in the tales of medical miracles, but even the most basic scientific knowledge throws up warning flags. Doidge refers to 'neuroplasticians' – a term he uses to explain anyone who uses the brain's flexibility to treat illnesses. Talk of 'healing energy' belongs in texts on spiritualism or alternative medicine. Also suspicious is the unquestioning support of those who claim to have received or caused miraculous breakthroughs; those who disagree are given perfunctory mentions.

References are used enough to show that Doidge knows their importance, but he doesn't invoke them where they could do most good. You can certainly see that many desperate people will be taken in by the encouraging 'revelations' here. But that is far from a recommendation.

DEAN BURNETT is a neuroscientist who lectures at Cardiff University



Eureka!

Chad Orzel

Basic Books (P) £11.99

SCIENTISTS ARE OFTEN portrayed as a breed apart from everyone else. There is the assumption that science is done not by 'us', but by 'them'. These human oddballs are possessed of intimidating intelligence, an emotional void and zero dress sense. In *Eureka!*, Chad Orzel sets out to change that view by demonstrating that all of us apply science skills in our everyday lives. Cooking, reading detective novels and following sport are all used as examples of data gathering, puzzle-solving and statistical interpretation. Interesting personal stories and a good dollop of history carry all of this along. While the writing in *Eureka!* is lucid and lively, it seems to be pitched at very variable levels. The book is better at illuminating the day-to-day struggles of a working scientist than providing an understanding of the philosophy behind scientific thinking. Nevertheless, *Eureka!* is a good reminder that we are all capable of looking at the world scientifically and working things out, and we should all have the confidence to do that a bit more often.

HELEN CZERSKI is a BBC presenter and a physicist and oceanographer at UCL

NEXT MONTH

THE PLACE WHERE TIME RUNS BACKWARDS

How a groundbreaking new theory flips our understanding of time on its head

PHOTO: ISTOCK

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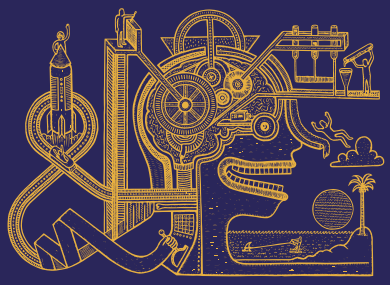

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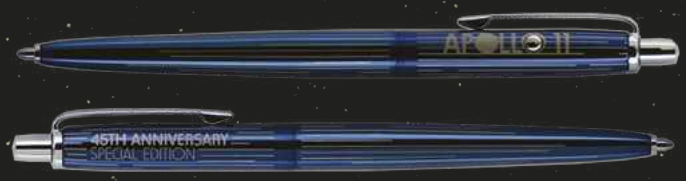

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Visit astro.qmul.ac.uk/teaching/msc-astrophysics
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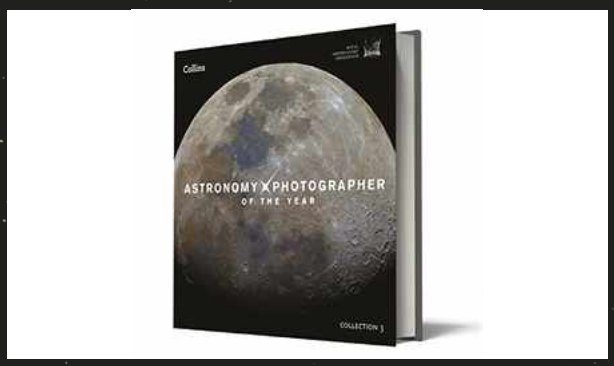

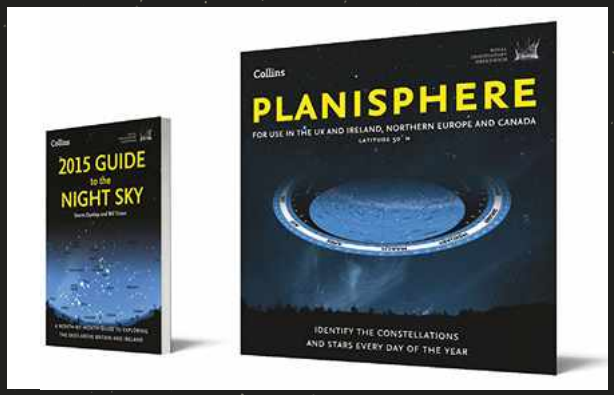

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How to Become a Successful Writer!

By Marian Ashcroft

If you've ever fancied being a writer but don't know where to start – here's the answer. For the past twenty-six years The Writers Bureau has been running a home-study Creative Writing course that teaches ordinary people how to write, get published and earn an extra income.

'Most people can be taught to write for publication,' claims Susan Busby, Head of Britain's largest writing college, 'as long as they want to write, are willing to learn and put in the time and effort required. Our students prove that. They come from all walks of life and have very different educational backgrounds. Yet, after studying with us many will see their name in print for the first time.'

The Creative Writing course offered by The Writers Bureau covers all genres – articles, short stories, novels, books, scripts etc. so students get a chance to explore all types of writing to find where their interests and talents lie.

Students also receive individual, personal tuition from a professional writer who gives guidance on style, technique and marketing.

'The course gives a student confidence in their work and the know-how to increase their chances of publication,' explains Susan. 'Unfortunately, the untrained writer is more likely to have their work returned to them, not because they can't write, but because they haven't followed the rules of the publishing world. And that, in a large part, is what we teach – how to make your work acceptable to those who will pay for it.'

The college also provides a whole support system to novice writers that includes their tutors, their advisors, free resources and chance to converse with other writing students on their website.

The Writers Bureau is so confident in the training and support it provides that it gives an amazing money back guarantee – if a student doesn't earn their fees back through published writing by the end of their course the college will refund them in full. Plus, the course comes on 15-day trial so you can see for yourself the quality of the training on offer.

To find out more about how The Writers Bureau can help you become a successful, published writer contact them for a free prospectus:

0800 856 2008
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Tim Skelton "Besides seeing my first book in print, I've appeared in The Times and The Independent, and updated yet more guide-books for Fodor's, Thomas Cook, and the AA. I am writing flat-out, and getting paid what I can now describe with pride as a decent salary. And it is thanks to The Writers Bureau that I got this chance. It provided me with the opportunity to realise an ambition which I didn't know how to nurture. I do now."

Published

Hannah Evans "I've been published in The Guardian and Good Life earning £400. And now I've got my first book published by Bloomsbury called MOB Rule: Lessons Learned by a Mother of Boys. The Writers Bureau course provided me with structure, stopped my procrastination but most importantly it provided the impetus to try something different."

Published

Chris Green "I've had 30 pieces of work accepted by various publications since I started my Writers Bureau course – a mere 18 months ago. I contemplate that fact and I am amazed to have come so far in such a short time. Thanks to the careful and patient tutoring provided by The Writers Bureau and the boundless confidence this has given me, I can continue to explore my potential and see where it takes me."

Published

Jane Isaac "When I started the Writers Bureau course, I wanted to explore avenues for my writing and develop and strengthen my personal style. I had no idea that it would lead to me being a published writer of novels and short stories. I still pinch myself when I receive emails and messages from readers who've enjoyed my work or when I give talks to book clubs and visit bookstores to do signings."

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MINDGAMES

Test your knowledge with our Big Quiz set by **James Lloyd**

1 **Prof Stephen Hawking has warned that what could bring on the end of humankind?**

a) Artificial intelligence
b) Drones
c) Sea level rise

2 **The world's most complete Stegosaurus skeleton has gone on display in London's Natural History Museum. Roughly how old is it?**

a) 50 million years old
b) 100 million years old
c) 150 million years old

Roughly how old is this spiny specimen?

3 **Complete the recent headline: 'Brain changes seen in young _____ _____'**

a) Black belts
b) Heavyweight boxers
c) American footballers

4 **Scientists in the UK have developed a chemical that can be added to food to do what?**

a) Make you feel full
b) Make anything taste like chocolate
c) Make it smell better

5 **Which video recently broke YouTube's view counter, amassing more views than the website's 32-bit counter could cope with?**

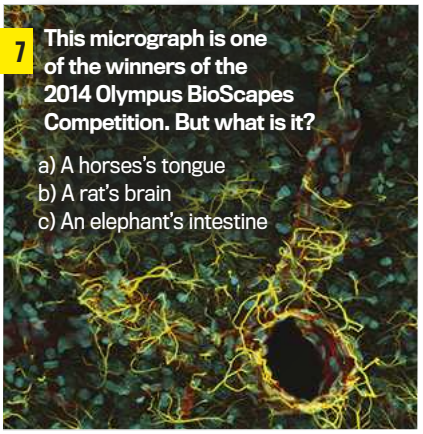
a) PSY – 'Gangnam Style'
b) Justin Bieber – 'Baby' ft Ludacris
c) Miley Cyrus – 'Wrecking Ball'

6 **According to a new study, people who are left-handed...**

a) Earn less money than right-handers
b) Have a higher IQ than right-handers
c) Tend to be more musically gifted than right-handers

7 **This micrograph is one of the winners of the 2014 Olympus BioScapes Competition. But what is it?**

a) A horses's tongue
b) A rat's brain
c) An elephant's intestine



8 **To help them explain the science of polymers, two physicists at the University of Warwick have invented a new kind of...**

a) Bread
b) Pasta
c) Beer

9 **UFO enthusiasts claim to have spotted a rock on the surface of Mars resembling what?**

a) Barack Obama's head
b) Kim Kardashian's derrière
c) Mickey Mouse's ears

10 **Which of these English locations has *not* been chosen as a host for driverless car tests next year?**

a) Greenwich
b) Milton Keynes
c) Birmingham

11 **Researchers working with the Curiosity rover recently reported detecting 'belches' of which gas on Mars?**

a) Nitrogen
b) Methane
c) Oxygen

12 **Scientists at Bielefeld University have created Hector, a robot based on which creature?**

a) Hummingbird
b) Stick insect
c) Hedgehog

13 **Which of these was selected as 2014's Breakthrough Of The Year by the journal *Science*?**

a) The development of 'neuromorphic' computer chips that mimic the brain
b) The discovery of the world's oldest cave art in Indonesia
c) The European Space Agency's comet-landing mission, Rosetta

14 **Complete the recent headline: 'NASA emails _____ to space station'**

a) Spanner
b) Hammer
c) Screwdriver

15 **Scientists exploring the Mariana Trench have discovered the deepest known fish. How far beneath the waves was the snailfish discovered?**

a) 4,145m
b) 6,145m
c) 8,145m

More puzzles online

BBC TWO

Try solving puzzles from the BBC quiz *Only Connect* hosted by Victoria Coren online at **http://bbc.in/1vCOzuY**

PHOTO: NATURAL HISTORY MUSEUM, OLYMPUS BIOSCAPES

QUIZ ANSWERS

1a, 2c, 3c, 4a, 5a, 6a, 7b, 8b, 9a, 10c, 11b, 12b, 13c, 14a, 15c

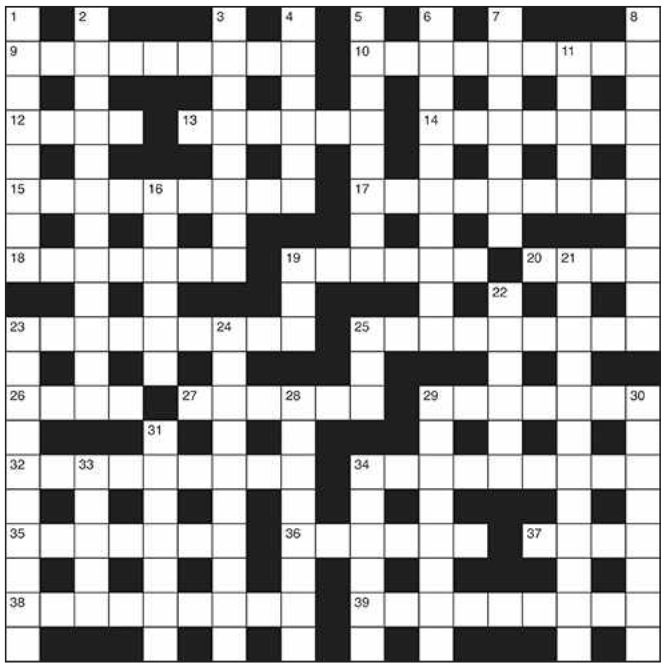
HOW DID YOU SCORE?

0-5 SHALLOW END

6-10 DEEP END

11-15 MARIANA TRENCH

FOCUS CROSSWORD No 174



ACROSS

9 Suffocating mixture of gag, attorney and politician (9)
10 Vegetarian chap takes mineral after four (9)
12 Flutes conceal another instrument (4)
13 Steer new course, only using two speakers (6)
14 Circus act to catch relaxation, say (7)
15 Rule again about pain (9)
17 Yet another speed is inferior (5-4)
18 Having money, yet getting thinner (7)
19 Discover depth (6)
20 Was obliged to get hitched before getting old (4)
23 Capital Frenchman finds a dough is wrong (9)
25 Religious belief has to notice tyranny (9)
26 Carry drink to get energy (4)
27 Poison seldom spotted by copper first (6)
29 Fellow on about liberty endlessly is a nut (7)
32 Solved crime, bit using old and new type of data (9)
34 Single professor takes on strange mammal (9)
35 Look round first for spear (7)
36 One bear wandering around one peninsula (6)
37 Lack a young woman (4)
38 Stands awkwardly on single rock (9)
39 About student solving a clue, having time to compute (9)

DOWN

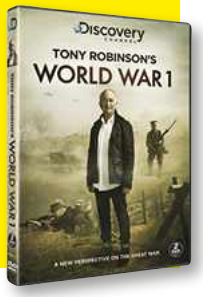
1 Muscle needed to climb sun, improbably (8)
2 Model village left with natural illumination (4,8)
3 King has a race around gate to strait (8)
4 Betting craft reaches a former Greek city (6)
5 Cooked the roast with variable resistance (8)
6 Life-sustaining expert wears one suit (10)
7 Primarily seasonal composer (7)
8 Vote to mention conclusion with hesitation (10)
11 Last character only played game (5)
16 Time and motion schedule (6)
19 Reportedly rushed to bring complaint (3)
21 Flier broke warhead limit (5,7)
22 Mythical creature rewrites blog at home (6)
23 Mobile mast affected chemical processes (10)
24 Old-fashioned origin of 100 would be 10 (6,4)
25 Dutch and Old English word for an animal (3)
28 Records herb the other side of a river (8)
29 Wrong of students to force lice into cavity (8)
30 Snug tent made out of metal (8)
31 Medic to study its fluctuating temperature (7)
33 Alternatively charge to see some stars (5)
34 Smell of small fish (6)

SOLUTION TO CROSSWORD No 171

Margaret Baxter, Alan Pyatt, J Bainbridge, Ellen MacLeod and Derek Gregory each solved issue 275's puzzle and receive a copy of *Stem Cell Universe With Stephen Hawking* (£9.99).

WIN! *TONY ROBINSON'S WORLD WAR 1*

The first five correct solutions drawn will each win a copy of *Tony Robinson's World War 1* (Discovery, £14.99). Entries must be received no later than 5pm on 5 March 2015. See below for more details.



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Post entries to *BBC Focus Magazine*, March 2015 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to march2015@focuscomps.co.uk by 5pm on 5 March 2015. Entrants must supply name, address and phone number. Immediate Media, publisher of *BBC Focus Magazine*, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

TERMS & CONDITIONS

Entrants must be UK residents (inc Channel Islands) aged 18 or over. Immediate Media employees are not eligible to enter. By entering participants agree to be bound by these terms and conditions and that their name and county may be released if they win. Only one entry permitted per person. No responsibility is accepted for lost, delayed, ineligible or fraudulent entries. Entries received after the closing date will not be considered. Immediate Media (publisher of *BBC Focus Magazine*) will only ever use personal details for the purposes of administering this competition unless you permit otherwise.

Read more about the Immediate Privacy Policy at www.immediatemedia.co.uk/privacy-policy. The winning entrants will be the first correct entries drawn at random after the closing time. The prize and number of winners will be as shown above. The winners will be notified within 30 days of the closing date by post. Immediate Media's decision is final and no further correspondence relating to the competition will be entered into. If the winner cannot be contacted within one month of the closing date, Immediate Media reserves the right to offer the prize to a runner-up.

HOLLYWOOD SCIENCE

Separating science fact from mo ction

Chimerism in Jupiter Ascending

HOLLYWOOD SCIENCE WELCOMES the return of the Wachowskis, of *The Matrix* fame. In their space opera *Jupiter Ascending*, janitor Jupiter Jones (Mila Kunis) meets Caine Wise (Channing Tatum), a genetically engineered interplanetary warrior with a mix of wolf and human DNA.

Let's get one thing straight. Scientists have never added wolf genes to humans. Why would they? After all, most men can grow hairy ears all by themselves, and don't need lupine DNA to pee in their own backyard. But researchers do, often, alter the genetic make-up of animals to try to make them more human-like. The goal is to understand human development and disease, and to devise and test new therapies. So when researchers fused human DNA with rabbit eggs, the plan was not to create a child that would cheerfully eat carrots, but to harvest and study stem cells – a versatile cell type with great potential for regenerative medicine. And when human DNA was added to miniature pigs, the aim was to create a source of transplantable organs that human recipients would not reject.

"Complex traits such as behaviour and appearance are not coded in a single gene"

Putting genes from one species into another may produce scientifically valuable results, but often yields little in the way of obvious, external change. "You can put fly genes into a mouse, and you don't notice much difference," says neurobiologist Prof Jack Price from London's Institute of Psychiatry. "Most animal and human genes are pretty similar, so if you put a human gene into an animal it doesn't make the animal any more human. It's the way the genes are controlled that makes the difference."

There are, of course, exceptions. When the language-related human gene FOXP2 was put into mice, the rodents started to squeak at a lower pitch. The goal was not to create rodents that could chat about how much they liked cheese, but to help explain the biology underpinning that most human of characteristics – the ability to have a natter.

But should scientists ever decide to add a human gene to a wolf, or vice versa, the results would probably be unspectacular. There's no single gene for howling at the Moon any more than there's a sensible explanation for Caine Wise's Spock-like lugs. Complex traits such as behaviour and appearance are not coded in a single gene, but in many genes and other complicated mechanisms. So were a human-wolf hybrid required, its creators would be better sticking to the tried and tested method: send two Americans backpacking on the Yorkshire moors and wait for a full Moon. ■

HELEN PILCHER is a science writer and comedian. She tweets from @Helenpilcher1

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