BBC

VOLCANOES:
How we uncovered their secrets *p52*

ASIA EDITION

Knowledge

Vol. 7 Issue 4

SCIENCE • HISTORY • NATURE • FOR THE CURIOUS MIND

INCORPORATING PPC SCIENCE WORLD

ONE WAY TO MARS

How we'll get there, how we'll survive and who should go *p34*

PPS 1745/01/2013 (022915)
(P) 055/11/2014 ISSN 1793-9836
9 771793 983016 04
SGD 7.50 | PHP 300
THB 240 | NT 200 | RM 16
Regent Media

Could Drinking Water Make You Happy?

A special ingredient to improve your health *p27*

Tomorrow's World In Pictures

A sneak peek at radical technology *p58*

Q&A

- Why does it feel good to scratch?
- Does a brain with a high IQ burn more calories?
- Can germs survive on soap? *p85*

BBC Knowledge

Highlights

TV Channel

Life Below Zero – The Thaw

Premieres 28th April. Tuesdays at 9.50pm (JKT/BKK), 10.50pm (SIN/HK/MAL/TWN)

After the long harsh winter, spring breakup strikes, bringing rising temperatures and mounting challenges for remote Alaskans. The thaw marks the start of the most taxing time of year in Alaska. Those living off the grid must work there hardest to hunt, gather, and harvest vital resources before the freeze takes hold again.

Frozen Planet

Monday 20th – Friday 24th April
at 6.15pm (JKT/BKK),
7.15pm (SIN/HK/MAL/TWN)

Ambitious and epic in scale, this landmark series is the ultimate portrait of the great wildernesses of the Arctic and Antarctic before they change forever. Get closer than ever before to the lives of charismatic animal characters and witness extraordinary examples of survival against the odds.

Royal Marines Commando School

Premieres 22nd April.
Wednesdays at 9.50pm (JKT/BKK),
10.50pm (SIN/HK/MAL/TWN)

This documentary series shows the unprecedented behind-the-scenes access to The Royal Marines Training Programme. It is named one of the toughest basic training of any Armed Forces, in the world, having 32 weeks to turn raw recruits into the best soldiers in the world!

Undercover Boss USA

Monday to Friday at 7.10pm (JKT/BKK),
8.10pm (SIN/HK/MAL/TWN)

Undercover Boss USA follows high level corporate executives as they take the extraordinary step of going undercover to discover the faults in their own companies.

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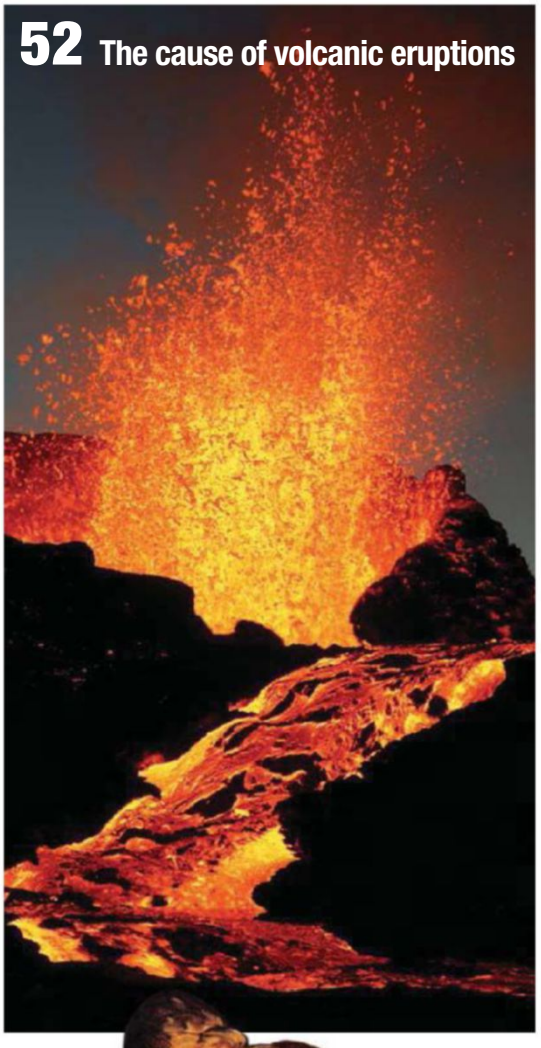

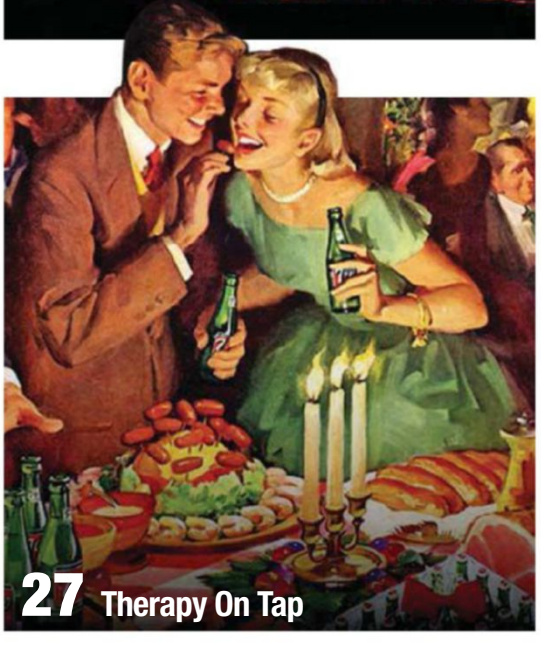

Welcome

Send us your letters
editorial-bbcknowledge@regentmedia.sg

THE BRAVE 202,686

That's the number of people from around the world and all walks of life who applied to be one of four to be selected through a stringent and gruelling process for the Mars One mission. And to be totally clear, this IS a one-way trip to the Red Planet.

What that means is, the final selected four brave individuals, who will set off for the seven-month mission to reach Mars, are on a journey to build as well as lay down the roots and infrastructure for humans to settle on Mars. They will have to be entirely self-sufficient as supplies such as water; oxygen and fuel are sufficient for the whole journey. And if food runs out, they have the capability to grow more as well. The general plan is to continue sending four-man crews every 26 months or at roughly 2-yearly intervals.

So do you have what it takes to be a Mars colonist, if you think you do, it is not too late to begin training for the next mission, which should launch from Earth in 2026 meaning selection should begin in 2016 or thereabouts.

Ben Poon
ben@regentmedia.sg

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We welcome your letters, while reserving the right to edit them for length and clarity. By sending us your letter you permit us to publish it in the magazine and/or on our website. We regret that we cannot always reply personally to letters.

Experts in this issue...

Jo Carlowe
Jo writes for numerous titles, including *The Guardian, BBC Good Food* and *Cosmopolitan*. She asks whether adding lithium to water could be beneficial to our wellbeing on p27.

Suzanne Bell
On behalf of NASA, Suzanne has carried out research studies on the psychological effects of space missions. She discusses the ideal traits of a Mars colonist on p36.

Kevin Fong
Kevin is an anaesthetist and author of *Extremes: Life, Death And The Limits Of The Human Body*. On p40, he explores the impact of a Mars mission on our bodies.

Tom Heap
Countryfile regular Tom is a broadcaster and journalist specialising in rural affairs, science and the environment. On p70 he uncovers 10 innovative ways to combat flooding.

✉ SEND US YOUR LETTERS

Has something you've read in BBC Knowledge Magazine intrigued or excited you? Write in and share it with us. We'd love to hear from you and we'll publish a selection of your comments in forthcoming issues.

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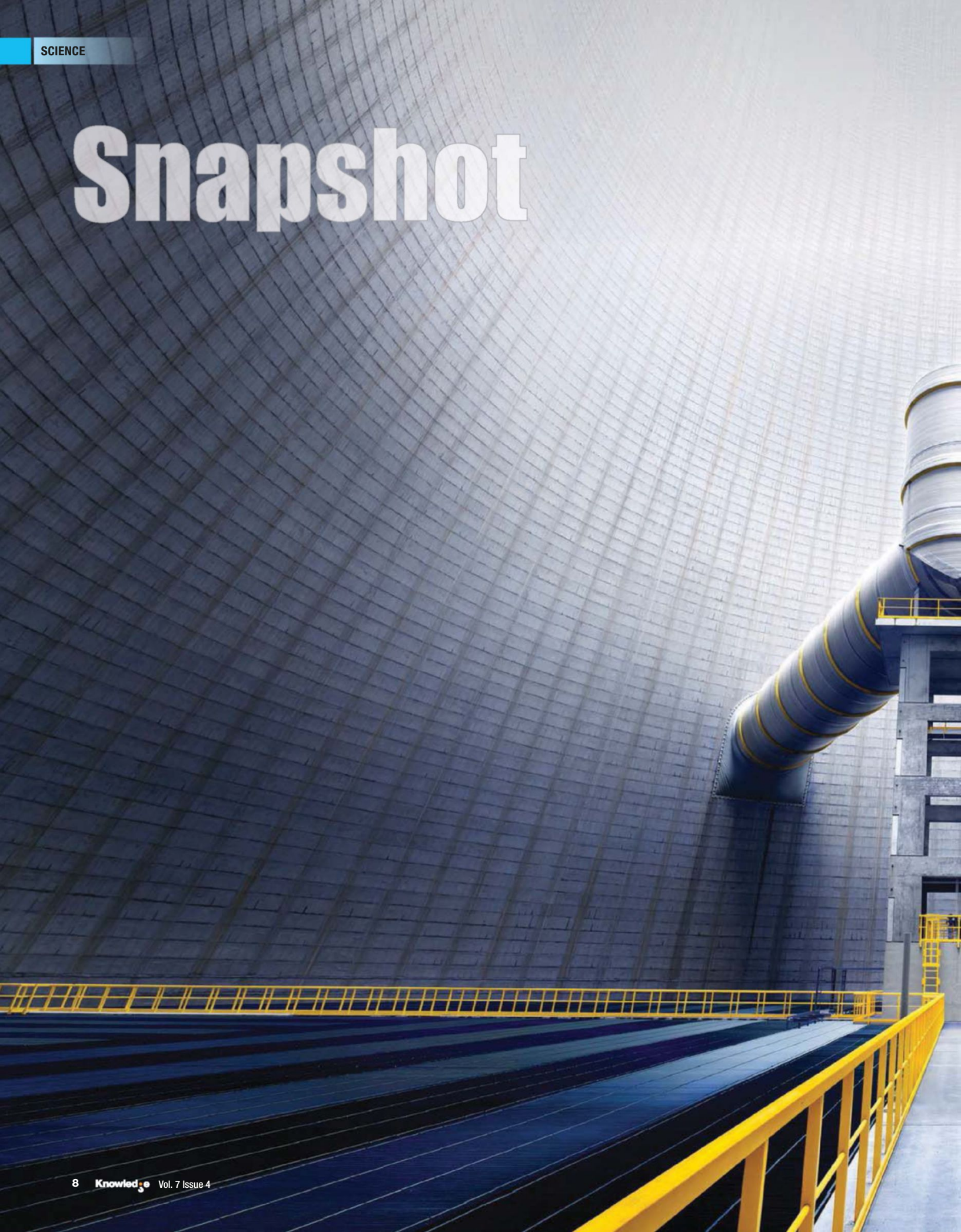
Snapshot



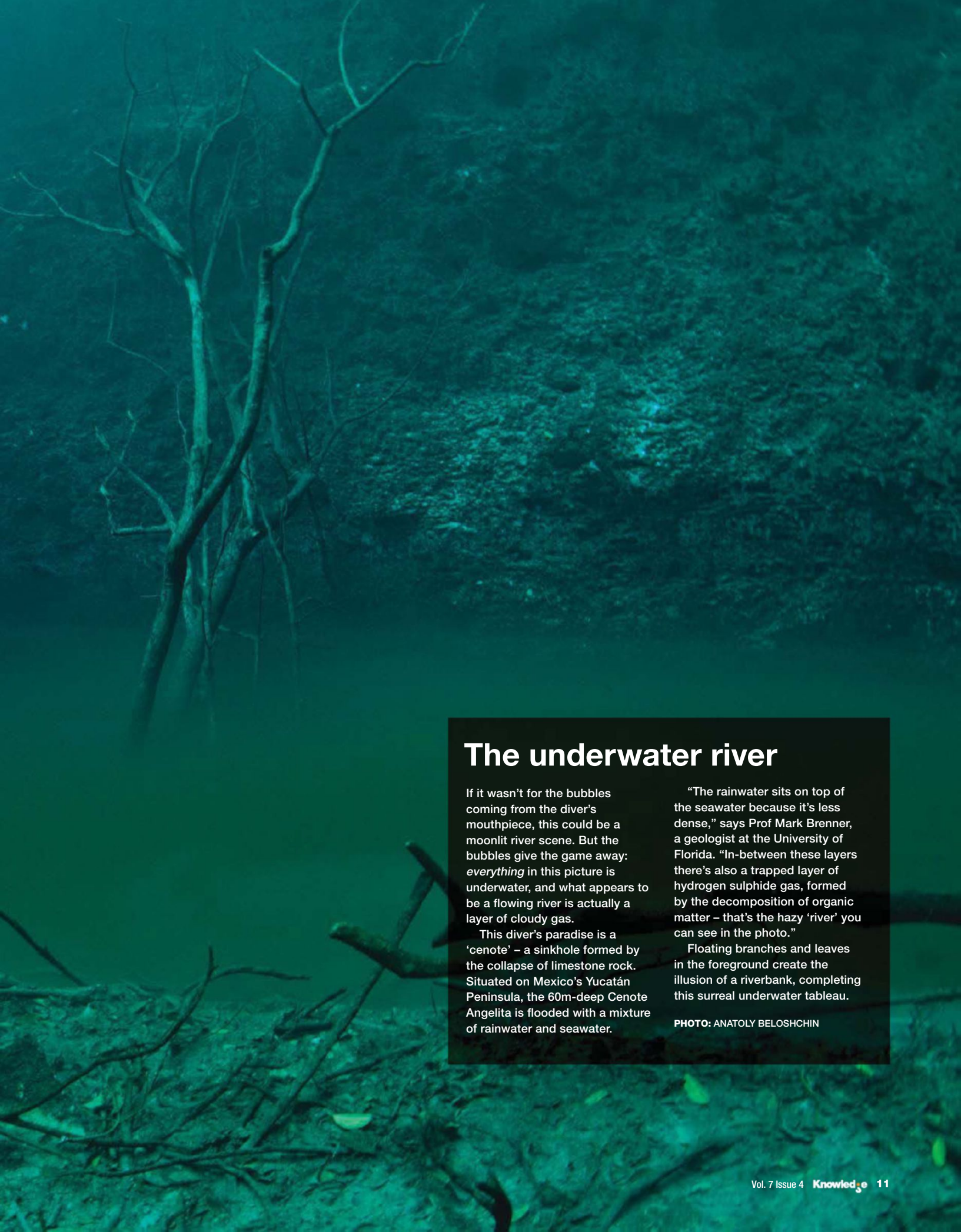
Green steam

Welcome to the cavernous innards of the Lünen coal-fired power plant's cooling tower. Situated near Dortmund, Germany, the tower stands 160m tall and 108m wide: it would take more than 48 million party balloons to fill it. It can burn 240 tonnes of coal per hour and generates 750 Megawatts of power. The coal is burned in fresh air at 1,300°C, producing 2,000 tonnes of steam to drive the turbines. The tower is then used to help condense the steam back down to water.

"Around 60,000m³ of cooling water per hour is forced into the tower by two huge pumps," says Stefan Paul, MD of Trianel, the energy company that operates the station. "Most of it drips down and is pumped back to the machine room; the remaining portion leaves the tower in the form of water vapour clouds."

The tower mixes and disperses cleaned flue gas from the plant, helping to improve efficiency. The plant is around 46 per cent efficient, making it one of the best performing of its type in Europe. Adding to its green credentials, an area of land has been set aside for the future addition of a carbon capture and storage plant.

PHOTO: LUCA ZANIER/ANZENBERGER



The underwater river

If it wasn't for the bubbles coming from the diver's mouthpiece, this could be a moonlit river scene. But the bubbles give the game away: *everything* in this picture is underwater, and what appears to be a flowing river is actually a layer of cloudy gas.

This diver's paradise is a 'cenote' – a sinkhole formed by the collapse of limestone rock. Situated on Mexico's Yucatán Peninsula, the 60m-deep Cenote Angelita is flooded with a mixture of rainwater and seawater.

"The rainwater sits on top of the seawater because it's less dense," says Prof Mark Brenner, a geologist at the University of Florida. "In-between these layers there's also a trapped layer of hydrogen sulphide gas, formed by the decomposition of organic matter – that's the hazy 'river' you can see in the photo."

Floating branches and leaves in the foreground create the illusion of a riverbank, completing this surreal underwater tableau.

PHOTO: ANATOLY BELOSHCHIN

President Reagan at Mission Control, Houston

President Ronald Reagan gets a laugh from NASA officials in Mission Control when he jokingly asks crew members, astronauts Joe Engle and Richard Truly if they could stop by Washington en route to their California landing site in order that he might come along. The STS-2 crew was in their next to last day on orbit when the conversation took place. From left to right standing: Terry J. Hart, NASA Deputy Administrator Dr. Hans Mark, NASA Administrator James M. Beggs, JSC Director Dr. Christopher C. Kraft Jr. From left to right seated: CAPCOM, Astronaut Daniel C. Brandenstein President, Ronald Reagan Directly above the President in the background: JSC Flight Operations Director, Eugene F. Kranz.

PHOTO: NASA

BBC Knowledge

SCHOOL CHALLENGE 2015

DATE: 30 & 31 MAY 2015

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BBC KNOWLEDGE MAGAZINE SCHOOL CHALLENGE 2015

An educational project organised by BBC Knowledge Magazine to inspire youths and encourage curiosity. The project aims to provide an additional platform for learning through a series of interactive challenges related to Science, History and Nature to nuture and hone students' thinking process.

ELIGIBILITY

Open to all Secondary School students in Singapore. Each team should consist of four students and one teacher-mentor from the same school. Each school is allowed to submit multiple entries, but only one entry per school will be selected for the qualifying round.

Registration form and more information can be found at: www.regentmedia.sg/bbcknowledgemag_asia
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HOW TO TAKE PART

Form a team of 4 with a teacher mentor from your Secondary School and submit the registration and indemnity form found on the following website: www.regentmedia.sg/bbcknowledgemag_asia

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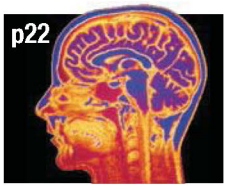
Update

THE LATEST INTELLIGENCE

AI: SHOULD WE BE WORRIED?
Artificial intelligence is developing in leaps and bounds. But is that a good thing?

THE PILL THAT FIGHTS FLAB
Could the answer to all our dieting woes soon come in handy tablet form?



THE BIRTH OF MEMORY
The exact brain location where your memories are made

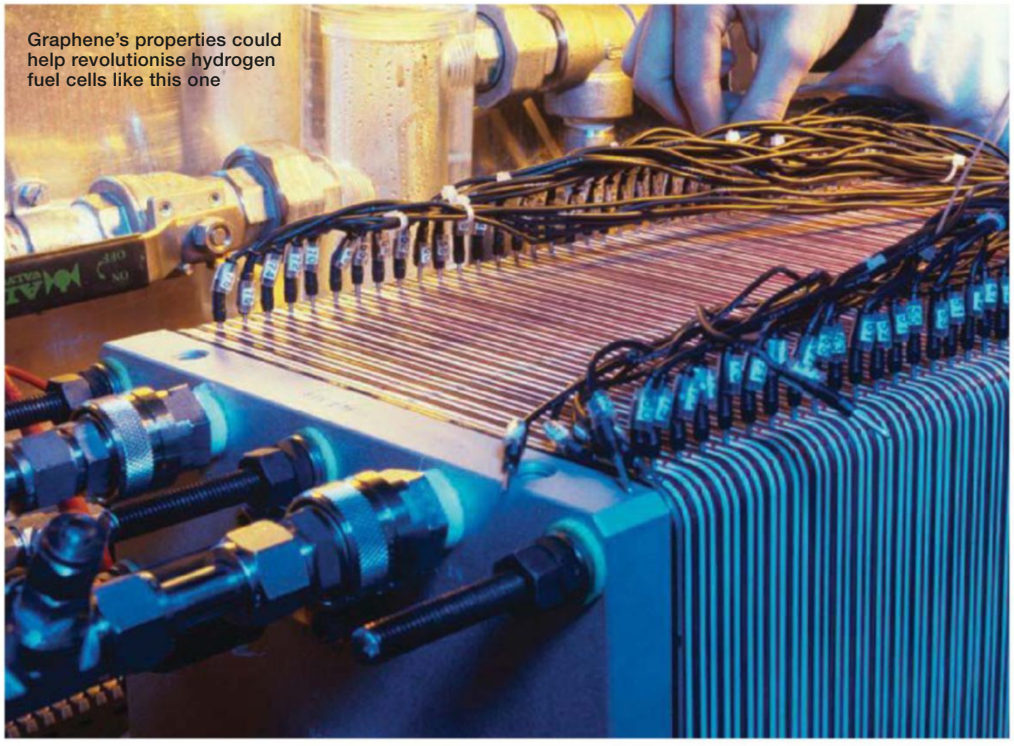
Protons (yellow) can pass through a thin sheet of graphene, a form of carbon

GRAPHENE PROMISES GREEN ENERGY REVOLUTION

The 'miracle material' just got even more miraculous, with the promise of more efficient hydrogen batteries

There's a good reason why graphene is often referred to as a miracle material. It's incredibly strong and light, and conducts heat and electricity extremely efficiently. It has the potential to be used in everything from bionic implants to computer chips. And now researchers have found another application to add to the ever-growing list: revolutionising hydrogen fuel cell technology.

PHOTO: UNIVERSITY OF MANCHESTER



Graphene's properties could help revolutionise hydrogen fuel cells like this one

A single, one-atom-thick layer of graphene can form a barrier few things can penetrate. However, a team at the University of Manchester has found something that can: protons. Protons are hydrogen atoms stripped of their electrons, and they can pass through ultra-thin crystals of graphene surprisingly easily.

A barrier that's impermeable to everything except protons is required for hydrogen fuel cells to function. And the passage of protons was even easier at higher temperatures and when the films were covered with nanoparticles, such as platinum.

The use of graphene membranes could make fuel cells more efficient. And there was an even more exciting discovery. The group demonstrated that its one-atom-thick membranes were able to extract hydrogen from a humid atmosphere. This harvesting technology could be combined with fuel cells to create a mobile electric generator, fuelled by hydrogen in the air.

"You put a gas containing hydrogen on one side, apply a small electric current, and collect pure hydrogen on the other side. This hydrogen can then be burned in a fuel cell," explained the paper's author Marcelo Lozada-Hidalgo.

"We worked with small membranes, and the flow of hydrogen is tiny so far. But this is the initial stage of discovery, and we want to make experts aware of the possibilities. To build up and test 'hydrogen harvesters' will require more effort."

TIMELINE
A history of graphene

1947

Canadiantheoretical physicist PR Wallace publishes a paper on the structure of graphite.

2003

Manchester University's Andre Geim (pictured) and Konstantin Novoselov create graphene for the first time, by peeling an ultra-thin layer from a block of graphite using sticky tape.

2010

Geim and Novoselov are awarded the Nobel Prize in physics for the discovery of graphene, and their subsequent research into its properties.

2014

Samsung researchers develop a technique for 'growing' single-crystal graphene, bringing large-scale production of the miracle material closer to reality.

GOOD MONTH/ BAD MONTH

It's been good for:
Mediterranean food

A team from Lund University, Sweden has found that a Mediterranean-style diet can lead to longer life expectancy and a reduced risk of heart disease. They found that those who ate diets high in vegetables, fruit, nuts and legumes, and low in meat and dairy, had longer telomeres on their chromosomes – a key indicator of age and health.

The hard of hearing

At Weill Cornell Medical College, they've prevented noise-induced hearing loss in mice using the chemical nicotinamide ribosome (NR). Mice given NR suffered less damage to nerves in their cochlea after being exposed to loud noises.

It's been bad for:
Antarctic glaciers

The melt rate of glaciers in West Antarctica is increasing dramatically. A 21-year study by NASA has revealed that the average loss of ice from 1992 to 2013 was 83 gigatons a year, the equivalent of half of Mount Everest in weight. The average *rate* of loss increased by an average of 6.1 gigatons per year, but peaked at 16.3 a year between 2003 and 2009.

Commuters

Squeezing onto a train filled with office drones or crawling along in rush hour traffic is unlikely to be anyone's idea of fun. But now researchers at the University of Waterloo in Canada have found that the more time people spend travelling to and from work, the less satisfied they are, as measured using the Canadian Index of Wellbeing.

PHOTO: UNIVERSITY OF MANCHESTER, ISTOCK X2, PRESS ASSOCIATION

1 MINUTE EXPERT
ATCV-1

What is it?
XNA is a synthetic molecule created at MRC Laboratory of Molecular Biology in Cambridge.

Why make it?
Researchers have used XNA to create XNAzymes, the first ever enzymes made from artificial genetic material. They reckon they could offer insights into the origin of life and increase the range of planets that could potentially host living organisms.

How so?
All life on Earth relies on chemical reactions. Enzymes allow these reactions to occur at the necessary rate. XNAzymes are just as good at this as naturally occurring enzymes.

Do they have any other uses?
XNAzymes are more stable than natural enzymes. They may prove useful in developing new therapies for diseases that exploit the body's natural processes, such as cancer.

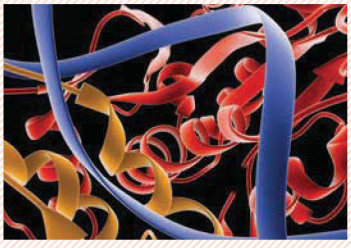
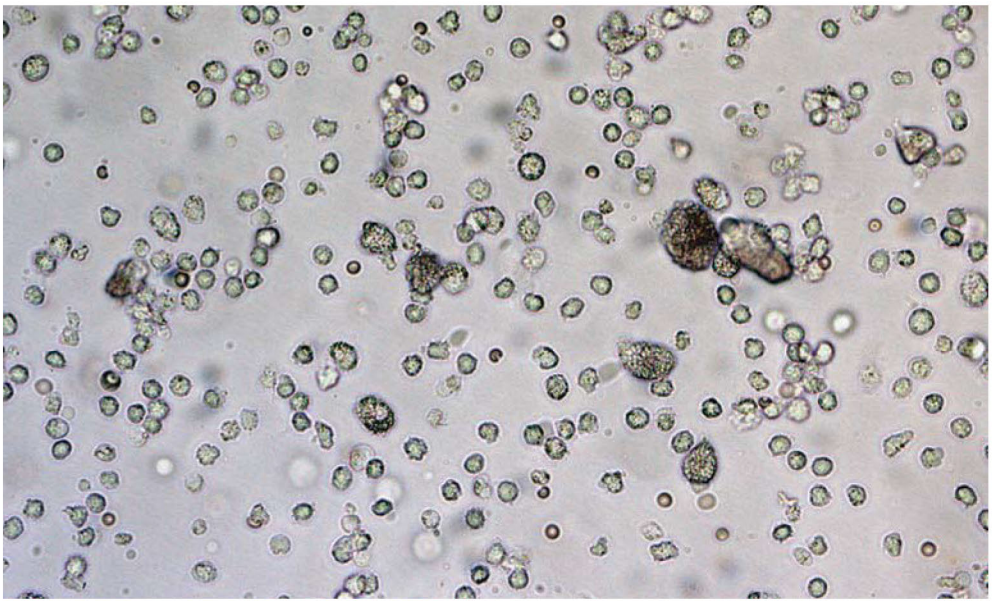


PHOTO: SCIENCE PHOTO LIBRARY, NASA, ISTOCK, COLD SPRING HARBOR LABORATORY

HEALTH

Self-assembling 3D vaccines may help fight cancer



This microscope image shows immune system dendritic cells collected from the 3D scaffold

One day, treating cancer may be as simple as administering an injection. Researchers at Harvard University have created injectable vaccines that spontaneously assemble into 3D structures that could fight cancer as well as serious infectious diseases such as HIV.

The vaccines are made from tiny rod-like structures, known as mesoporous silica rods (MSRs). The pores within these little rods can be loaded with a variety of different drugs and the whole structure is then injected into patients with a needle. Once inside the body, the rods spontaneously form a 3D scaffold. This then attracts the body's dendritic cells, which direct the immune system to attack specific areas, such as cancerous cells. So far, the researchers have successfully tested the technology in mice.

"Right now we are focusing on developing a cancer vaccine. But in the future we may be able to manipulate the type of dendritic cells or other immune cells recruited to the 3D scaffold by using different kinds of drugs released from the rods," explains study co-author Aileen Li. "By tuning the surface properties and pore size of the MSRs, and therefore controlling the introduction and release of various proteins and drugs, we can manipulate the immune system to treat multiple diseases."

Since the vaccines can be produced quickly and easily, they might be used to fight rapidly emerging infectious diseases. Alternatively, they could be employed preventatively by building the body's immune resistance prior to infection.

WHO'S IN THE NEWS?

James Watson

Outspoken co-discoverer of the structure of DNA

What has he done this time?
He has become the first living Nobel Prize recipient to sell their prize medal.

Blimey! Why?
Watson says he became an outcast in the scientific community after suggesting that people of African descent were less intelligent than whites in 2007. He says that this has greatly affected his income and he needed money.

So, how much did it go for?
It raised US$4.7 million at Christie's Auction House in New York. The buyer of the medal, which Watson was given in 1962, was Russian oligarch and major shareholder in Arsenal football club Alisher Usmanov. Usmanov gave it straight back to Watson, saying the sale was "unacceptable".

What's Watson going to do with all that cash?
He said he intends to make donations to his alma maters Clare College, Cambridge and the University of Chicago, and would also like to buy a David Hockney painting.

TECHNOLOGY

NASA floats idea of high-altitude airship competition

Airships are often dismissed as the playthings of eccentric millionaires, or flying billboards for famous tyre manufacturers. But NASA thinks they may have more to offer the world.

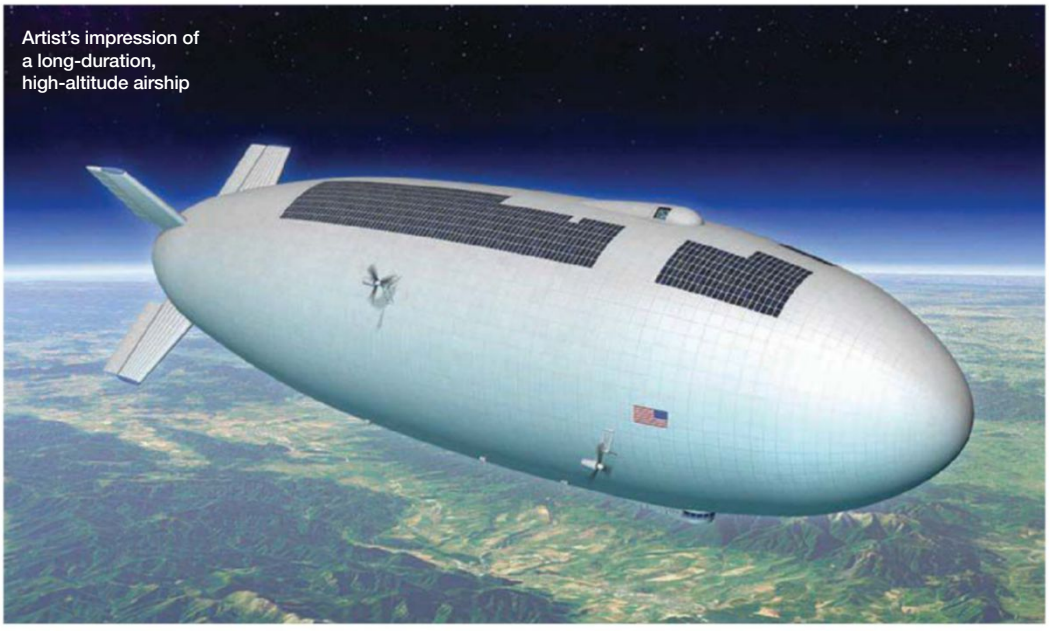
The space agency's Centennial Challenges programme is considering launching a multi-million dollar competition to build a record-breaking stratospheric airship. It has asked interested parties to come forward with their opinions and ideas.

Dubbed the '20-20-20 Airship Challenge', the aim of the proposed competition would be to create an airship that is capable of carrying a 20kg payload at an altitude of 20km for 20 hours. At present, no powered airship has been able to maintain this stratospheric altitude for longer than an eight hour period.

"The 20-kilometre mark is the sweet spot where the airship would get as high as possible while still having enough air to propel against, because it needs propulsion to stay in the same spot. It's also a good altitude in terms of average wind speed," says project leader Jason Rhodes.

NASA says it is currently trying to gauge the level of interest among the various communities that would be interested in the project. The total prize purse may be up to a cool US$3 million, which could be split between multiple competition entrants.

Potential uses for the airship could include collecting data for studying weather and climate change, mounting a telescope on it to create high-resolution images of stars, and providing wireless internet to remote areas.



Artist's impression of a long-duration, high-altitude airship

HEALTH

Fat-busting pill on the horizon?

Fad diets and gruelling exercise regimes may soon be a thing of the past for those looking to stay trim. Stem cell researchers say they have taken "the first step toward a pill that can replace the treadmill" when it comes to controlling obesity.

A team at Massachusetts General Hospital and Harvard University has created a system to find compounds that can turn white fat cells into brown fat cells using human stem cells.

White fat cells store energy as lipids and play a role in the development of obesity. Activated brown fat has been shown to burn white fat and also reduces the insulin resistance associated with Type 2 diabetes.

So far, the researchers have identified two drugs that convert fat stem cells (which would normally produce white fat) into brown-like fat cells. One of these drugs is already available in the US, but is used for arthritis treatment. Its validity in promoting weight loss has not been clinically trialled. The researchers are now in discussion with pharmaceutical companies.

"We found these two compounds by screening a library of about 1,000 compounds," researcher Dr Chad Cowan says. "So we know that if we have access to the typical pharmaceutical company library of 1.5 to 2 million compounds, we will find others."

A collaborator in Germany has been testing the first two compounds on mice.

"We expect to have results fairly soon. The compounds appear to work the same way in mice, but we don't know what the long-term metabolic or immune system effects are," Cowan added.

Could a tablet keep us trim?

10 DISCOVERIES THAT WILL SHAPE THE FUTURE

10 Drying human tissue

There's something fishy going on here

Techniques for making salted cod may be used to preserve human tissue samples. Currently, tissue is preserved in either formalin at -90°C or liquid nitrogen at -193°C, but this method is very expensive. So a team at the Norwegian University of Science and Technology is pioneering a method that involves drying samples with the kind of heat pump commonly used for making salted cod. The method requires much lower temperatures and has so far proved successful on samples from human lungs, heart and liver.

9 3D ultrasound shape can be 'felt'

Researchers at the University of Bristol have come up with a 'haptic' system that can create touchable shapes using ultrasound. By focusing complex patterns of ultrasound onto a user's hand, the device produces a 3D shape that can be felt in mid-air. The technology could enable surgeons to explore a CT scan by touch, enabling them to feel a disease such as a tumour, say the scientists.

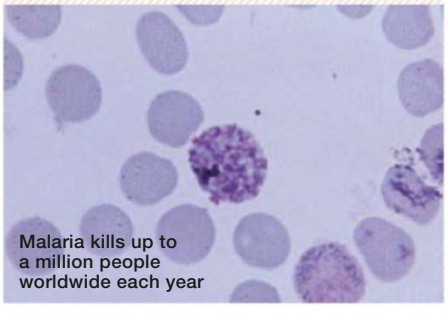
Haptic technology could make life easier for surgeons

8 Mirrors cool buildings

As well as making sure your haircut is looking tiptop, it seems mirrors have another use: keeping buildings cool in summer. Dubbed photonic radioactive cooling, the technology off-loads infrared heat from within a building as well as reflecting sunlight that would otherwise warm it up. It uses ultra-thin layers of silicon dioxide and hafnium oxide and could reduce the need for air conditioning.

7 Malaria drug

A team at St Jude Children's Research Hospital in Tennessee has made a breakthrough in treating malaria. They have developed a drug that encourages the immune system to destroy infected red blood cells, while leaving healthy ones unharmed. The therapy may help to slow down the development of drug-resistant strains of the disease.



Malaria kills up to a million people worldwide each year

6 Using sewage to boost bioenergy crop growth

Despite being rich in beneficial nutrients, wastewater cannot be used on food crops due to health concerns. Now, a team from Madrid has found the use of sewage can boost the oil seed production of Cynara, a type of thistle being developed as a bioenergy crop, by up to 68 per cent. The technique could be used with wastewater management systems to help produce biofuels.

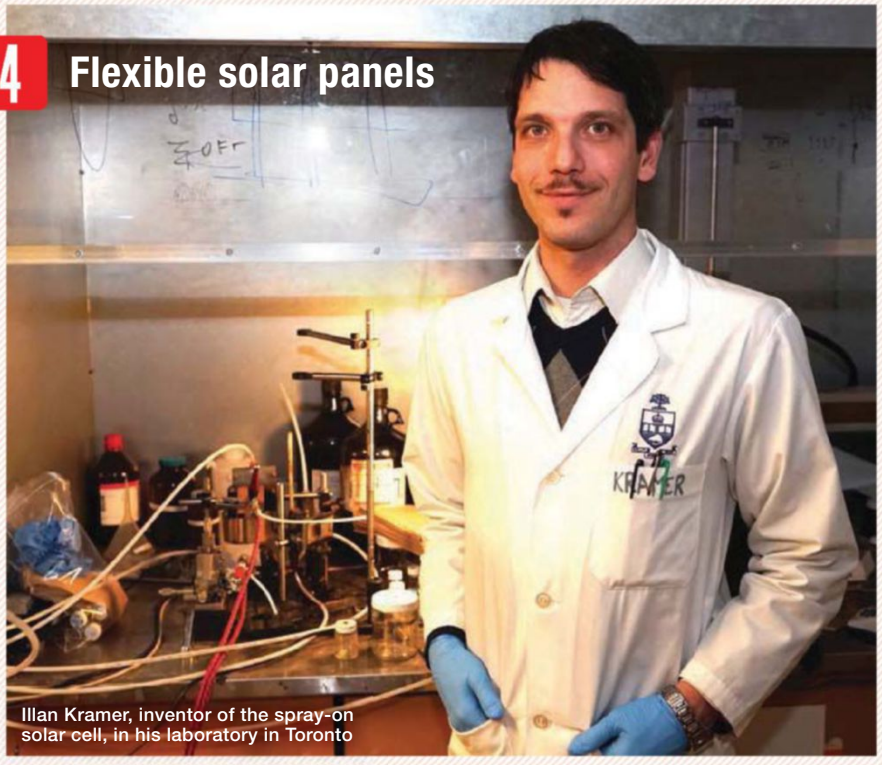
Cynara thistles are native to the Mediterranean region

PHOTO: ISTOCK X2, UNIVERSITY OF BRISTOL, UNIVERSITY OF TORONTO, JOSEPH XU/MICHIGAN ENGINEERING, LIHONG WANG, PHIL, NORBERT VON DER GROEBEN

5 Artificial cow's milk

A team of bioengineers based in San Francisco has produced the world's first artificial cow's milk. The product could be a more environmentally friendly alternative to regular milk, the team says. Dubbed Muufri, the milk is made by extracting DNA from dairy cows and inserting it into yeast cells. The resulting cocktail of six proteins and eight fatty acids is then combined with other minerals such as calcium.

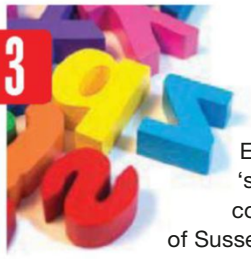
4 Flexible solar panels



Illan Kramer, inventor of the spray-on solar cell, in his laboratory in Toronto

Spray-on solar cells developed at the University of Toronto could soon turn almost any surface into a power source. Researchers incorporated materials known as colloidal quantum dots (CQDs) into a spraying system capable of depositing layers a single atom thick. The resulting solar cells proved just as efficient when tested as their more traditional counterparts.

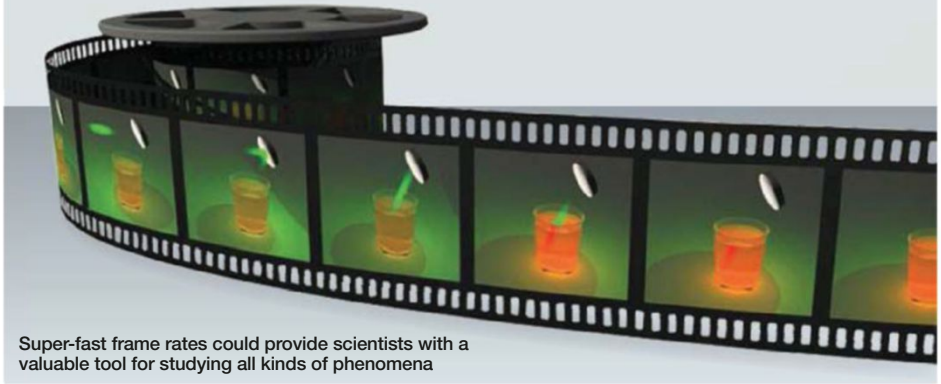
3 Synaesthesia could be key to therapy



Ever fancied 'seeing' letters as colours? University of Sussex researchers found that subjects were able to do just that after nine weeks' training. They wanted to know whether the hallmarks of the neurological condition synaesthesia could be 'learnt'. The techniques may lead to therapies for conditions such as ADHD or dementia.

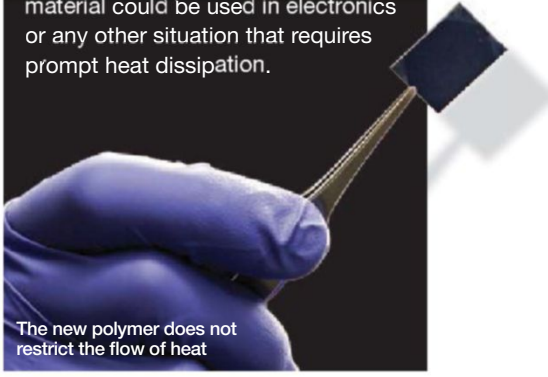
2 Fastest ever camera

Biomedical engineers at Washington University have produced a camera that can record 100 billion frames per second. Typical film cameras record just 24 frames per second. The camera uses a technique known as compressed ultrafast photography and is so fast it can show the motion of light pulses. The technology could help to improve our understanding of fast biological, chemical and cosmological processes.


Super-fast frame rates could provide scientists with a valuable tool for studying all kinds of phenomena

1 A plastic that conducts heat

Plastics are highly versatile materials but they have always had one drawback: they don't conduct heat. Now, a team at the University of Michigan has created a plastic that disperses heat 10 times more effectively than others. The new material could be used in electronics or any other situation that requires prompt heat dissipation.


The new polymer does not restrict the flow of heat

PATENTLY OBVIOUS

Inventions and discoveries that will change the world with James Lloyd

The sound of silence

It's 1am. You desperately need to sleep, but your spouse is snoring, the traffic is roaring and next door they're pumping out the techno like it's 1992. If only there was a gadget that provided blissful, silent slumber!

Well, after one too many sleepless nights, three young engineers in the US have come up with Hush – smart earplugs that block out the noises you don't want to hear. Sound-eliminating foam acts as the first line of defence, while the in-ear speakers play soothing sounds such as ocean waves or crackling fire to drown out any residual noise. What's more, the earplugs connect via Bluetooth to your smartphone. This means that they can be programmed to let through certain alerts – your morning alarm, for example, or an important phone call you're expecting. Your neighbours' party will soon be nothing but a distant memory.

Patent pending

A step ahead

According to the American Podiatric Medical Association, the average person walks 185,074 km in their lifetime – that's more than four times around the equator. So it makes sense to learn how to do it properly. The Arki wristband from a South Korean start-up analyses your posture and provides feedback as you walk. Its accelerometer and gyroscope measure metrics such as your arm-swinging speed and rotation angle, vibrating if it detects that you're hunching your back or staring at the floor.

Patent pending

All sized up

Online clothes shopping is fraught with danger, especially when skinny jeans turn out to be tighter than a pair of Lycra long johns. Three cheers, then, for the smart clothes invented by Israel's LikeAGlove. Simply slip on one of their elasticated garments – it could be a sock, a dress, a bra or a shirt – and it'll use its embedded sensors to measure your vital statistics. The data it collects is then transmitted to an app on your phone or tablet, where you'll be able to search for perfectly fitting clothes in your favourite retailers.

Patent pending

PHOTO: UNIVERSITY OF GLASGOW, SCIENCE PHOTO LIBRARY ILLUSTRATOR: DEM ILLUSTRATION

CHEMISTRY

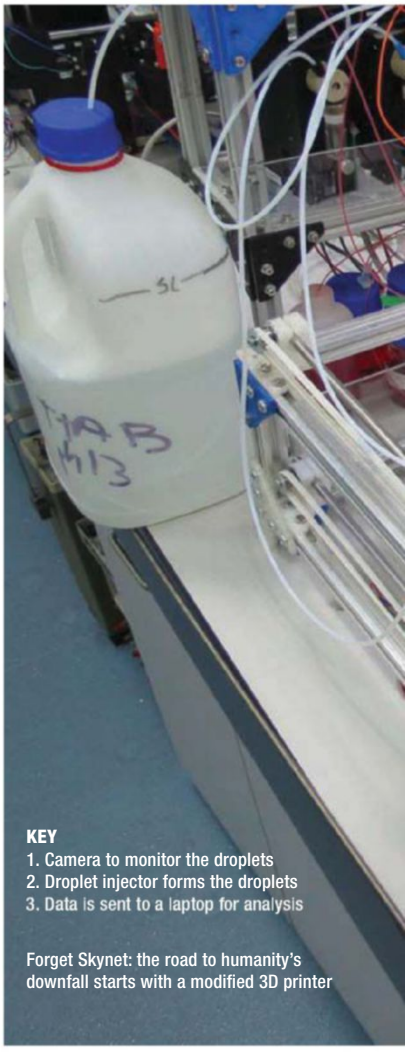
Robot produces unnatural selection

The robot uprising may be one step closer. Researchers from the University of Glasgow have used a bot to develop a form of artificial evolution using simple chemicals.

"This is the first time that an evolvable chemical system has existed outside of biology," says researcher Lee Cronin. "Biological evolution has given rise to enormously complex forms of life, and our robot-driven form of evolution could have the potential to do something similar for chemical systems."

In natural selection, favourable genetic traits are passed on from one generation to the next while less favourable traits gradually die out. The team used a bespoke robot to create an iterative selection process that mimicked this effect.

First, the bot deposited four droplets of oil in water-filled Petri dishes. Each droplet was composed of a different mix of four chemicals. It then selected the droplet that best predetermined criteria. This droplet was then carried over into a second generation of droplets, and the process was begun again. After 20 repetitions the droplets became closer and closer to being ideal. The work may help scientists learn more about the origin of life as well as potentially producing chemical lifeforms, the team says.



KEY
1. Camera to monitor the droplets
2. Droplet injector forms the droplets
3. Data is sent to a laptop for analysis

Forget Skynet: the road to humanity's downfall starts with a modified 3D printer

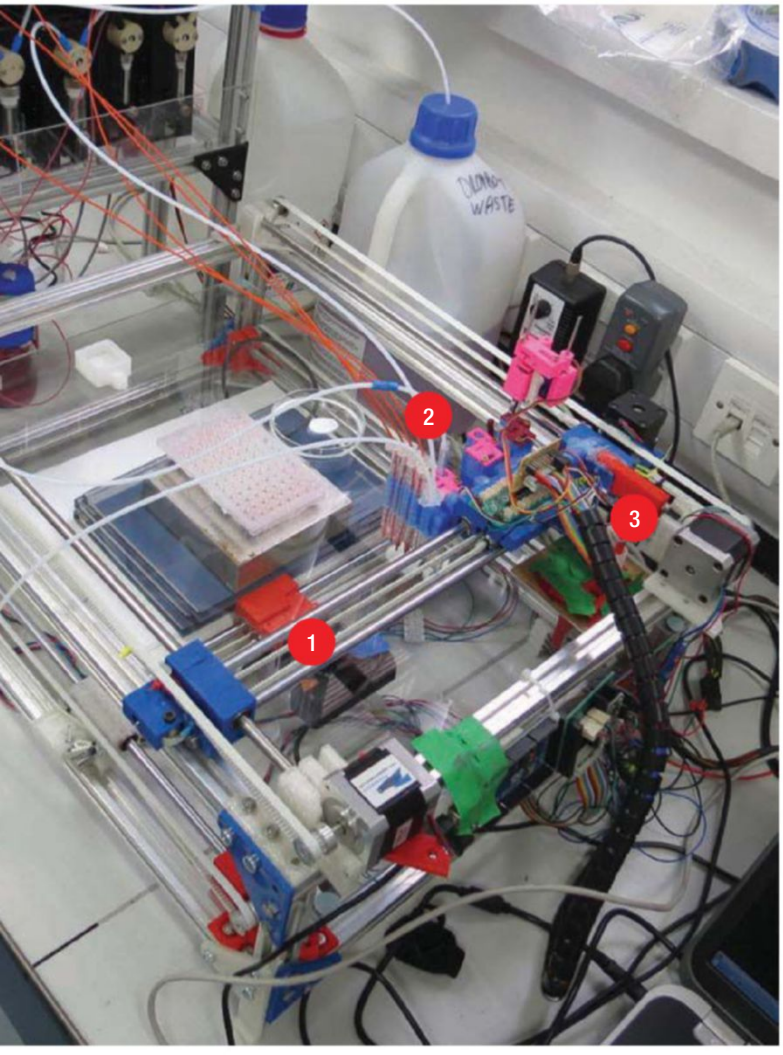
NEUROSCIENCE

Where memories are born

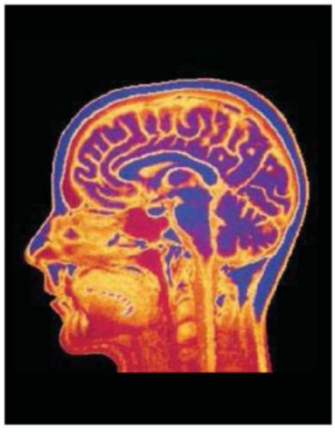
Whether it's the birth of your first child or your wedding day, all fond memories come from a specific region of the brain. And now a team at the University of Magdeburg, Germany, has successfully determined the precise location where memories are generated.

It was known that memories are stored primarily in the cerebral cortex, and that the control centre that generates and retrieves them is located in the brain's interior. The team was able to pinpoint this precise area in volunteers' brains during a simple memory test using a particularly accurate type of imaging technology known as 'seven Tesla ultra-high field magnetic resonance imaging'.

"We have been able to locate the generation of human memories to certain neuronal layers within the hippocampus and the entorhinal cortex," explains Professor Emrah Düzel. "We were able to determine which neuronal layer was active.



An fMRI scan of a human brain. A newer, higher-resolution form of MRI enabled the Magdeburg team to make their discovery



This revealed if information was directed into the hippocampus, or whether it travelled from the hippocampus into the cerebral cortex. Previously used MRI techniques were not precise enough to capture this directional information. Hence, this is the first time we have been able to show exactly where in the brain the doorway to memory is located."

It is hoped that the research will lead to new insights into the understanding of memory impairments, such as those seen in Alzheimer's disease.

CLICK HERE

New websites, blogs and podcasts

CERN open data

opendata.cern.ch

Fancy seeing how you'd fare as a particle physicist? This new offering from CERN could keep you busy for days on end analysing real data. It's not for the faint-hearted, and you'll need to do some downloading to get started, but if you put in the time you'll be rewarded with actual data taken at the LHC in 2010.

Anglerfish: approach to deep-sea fishing

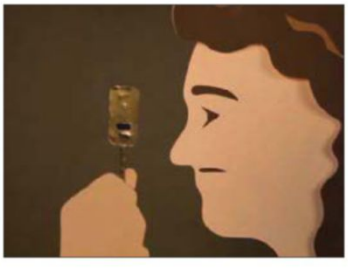
http://youtu.be/VqPMP9X-89o

This is thought to be the first footage of the strange and elusive creature known as the 'black seadevil' (actually a type of anglerfish) in its natural habitat, 600m below the surface of the sea. Watch the video, and you'll understand how the seadevil got its name.

Darwin manuscripts project

amnh.org/our-research/darwin-manuscripts-project

In this digitised collection of Charles Darwin's manuscripts, see with your own eyes the first time he used the term "natural selection". Don't miss the pages of an early *Origin Of Species* draft that only survived because they'd been used by his children for drawing on.



Seeing the invisible

http://youtu.be/ePnbkNVdPio

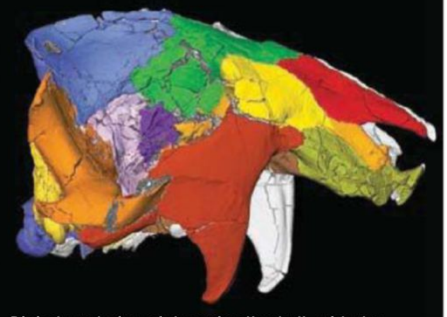
Welcome to a world of things we can't usually see, starting in 1674 with Antonie van Leeuwenhoek and the drop of lake water he looked at under a microscope, revealing a hidden world of microorganisms nobody even knew existed. Watch his story unfold in paper animations, with useful resources for teachers just a click away.

PALAEONTOLOGY

Mesozoic mammal reconstructed

The head of *Vintana sertichi*, with the skull's location highlighted, has large eyes for keen vision

Side view of the *Vintana sertichi* cranium – the large scimitar-shaped flanges had chewing muscles attached



Digital rendering of the animal's skull, with the individual bones highlighted in different colours

Meet *Vintana sertichi*, a badger-sized mammal that lived alongside dinosaurs in what is now Madagascar. The animal lived between 72 and 66 million years ago, during the Mesozoic Era, and this detailed reconstruction was put together from CT (Computed Tomography) scans after a fossil was removed from a block of sediment in 2010. *V. sertichi* is a member of a group of extinct mammals, the gondwanatherians, which are named after Gondwana, the ancient supercontinent on which they roamed.

The skull is 125mm long and the creature would have weighed 9kg, making it the largest primitive mammal of its era on Gondwana. At the time it lived, most mammals were the size of shrews or mice. Previously discovered fossils of gondwanatherians consisted only of isolated teeth and a few other fragments, whereas the new specimen is almost complete. Analysis of the fossil has revealed that *V. sertichi* was a herbivorous animal that was agile, with keen senses of smell, vision and hearing.

"Vintana reshapes some major branches of the 'family tree' of early mammals, grouping gondwanatherians with others that have been very difficult to place in the past," says palaeontologist Dr David Krause of Stony Brook University.cavity," ays Dr John Wible, a researcher who analysed the skull and ear region.

SPACE SCIENCE

Origins of water

How did two-thirds of Earth's surface come to be covered in water? One hypothesis is that Earth was so hot when it formed 4.6 billion years ago that any water would have boiled off. It was thought that the water was brought by comet and asteroid collisions once it had cooled down.

ESA's Rosetta craft has now discovered that water vapour streaming off Comet 67P is different to Earth's water. It contains almost three times as much deuterium – a form of hydrogen with an extra neutron that is also known as 'heavy hydrogen'. As the ratio between heavy and light water is largely constant, water from Earth is unlikely to have come from impacts from comets like 67P.

Researchers now say that asteroids are the prime candidates for having seeded the Earth's oceans throughout history. These rocky objects formed closer to the Sun than comets.

"We knew that Rosetta's in situ analysis of this comet was always going to throw up surprises for the bigger picture of Solar System science, and this outstanding observation certainly adds fuel to the debate about the origin of Earth's water," explains ESA Rosetta project scientist Matt Taylor.

"As Rosetta continues to follow the comet on its orbit around the Sun throughout next year, we'll be keeping a close watch on how it evolves and behaves, which will give us unique insight into the mysterious world of comets and their contribution to our understanding of the evolution of the Solar System," he adds.

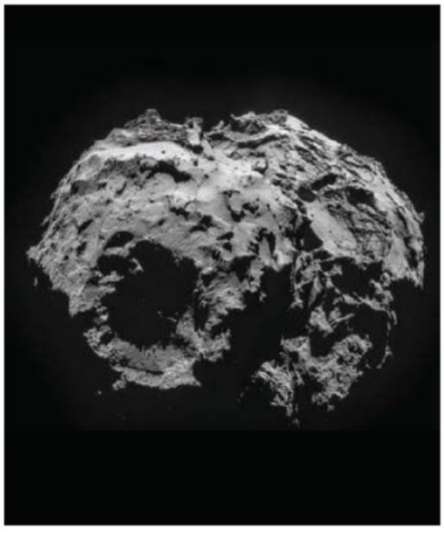


PHOTO: JOURNAL OF VERTEBRATE PALEONTOLOGY, ESA

DAVID SHUKMAN

The science that matters

We need to talk about artificial intelligence

AI increasingly permeates our everyday lives, but will any further advances spell danger?

There's nothing like the distinctive robotic voice of Stephen Hawking to stir up a heated debate about… robots. In an interview with my colleague Rory Cellan-Jones, Hawking warned that super-intelligent machines could end up wiping out us mere humans. That's the kind of statement that, in media terms, is like lighting the blue touchpaper.

Until recently, artificial intelligence seemed to belong in the realms of sci-fi. Back in the early 1990s, while filming in a US Air Force lab in Colorado, I caught a glimpse of just such a brave new world. The lab's supercomputer, I was told, was cooled by the same plasma used in operating theatres: a liquid suitable for people bubbled past the circuit boards in what felt like a crossover between man and machine.

Since then, AI has slipped into our lives without most of us noticing. Order something from Amazon, search on Google or try (and usually fail) to make Siri understand you on your iPhone, and you're dealing with some form of artificial intelligence – albeit at a relatively simple level.

So what about machines that could actually *outsmart* humans: not merely on a chess board, but in something as serious as decision-making or access to natural resources or even the survival of our species? A recent survey by a team at Oxford University found that most experts in the field pointed to the 2040s or 2050s before there's a realistic chance of producing a human-comparable machine. Other scientists say it's more like a century away.

Whoever is right, the debate about managing this new technology is already under way. Some researchers are investigating how any future machine would be 'scrutable' – transparent enough for rogue behaviour to be fixed. Others are exploring how to engineer reliable controls so that a super-clever device can be guaranteed not to turn dangerous.

But there is a more optimistic perspective. Properly handled, AI might accelerate the search for new drugs to fight cancer, or help us find new ways to generate carbon-free electricity. Most new technologies face opposition of some kind and AI is no different. As ever, it's better not to leave the arguments until it's too late.

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

THEY DID WHAT?!

Computer taught 'mind-reading' card trick

What did they do?
Researchers fed the method behind a 'mind-reading' card trick into an AI computer program, along with the results of experiments into how humans respond to magic tricks. The AI learned the trick and created its own variations.

How does the trick work?
A deck of cards arranged in a known order is shuffled by an audience member, who is dealt six cards and then tells the program the colour (red or black) of each card. The program then identifies the precise card picked by the audience member. See it at http://youtu.be/xZiqkoaCaic

Why did they do that?
"Using AI to create magic tricks is a great way to demonstrate the possibilities of computer intelligence," says co-author Prof Peter McOwan of Queen Mary University of London.

PHOTO: ISTOCK ILLUSTRATOR: DEM ILLUSTRATION

There is one reaction to thank for making toast taste so delicious

Why brown? That's the question I asked myself as I waited next to the toaster. Why does everything go brown when you cook it? Nothing goes green or red. The only things that don't go brown are foods that are cooked in the microwave.

Inside the toaster, the bread was absorbing heat. On the surface, molecules were jiggling around faster, bumping into each other more. Some of the tiny water molecules got enough energy to escape altogether, and floated off into the kitchen. I peered down at the bread, but I could only see that the surface was drier, so I left it alone and went to poke about in the kitchen cupboard for some jam.

Mostly, we don't think of ourselves as doing chemistry while we cook, but we are. The necessary ingredients for the chemical reaction are proteins (which are made up of building blocks called amino acids) and sugars. Left alone together they will react, although it takes months before anything noticeable takes place. But give them some heat energy to liven things up, and the molecules start to dance.

While I was on the hunt for jam, the amino acids and sugars in the bread were joining forces to create more complex molecules. Those large molecules are unstable, so many of them were breaking apart to produce a cascade of smaller ones. When I next looked, I could see some of the newer molecules because they were brown. The magic comes when the smallest chemical offspring are produced, because they have flavours and odours that the parent molecules didn't. I could smell the chemistry happening as I leaned over the toaster. This series of events is called the Maillard reaction, and its discovery was the first step in proper food science.

This one reaction is responsible for the deliciousness of brown crusty bread, golden biscuits, butterscotch and almost anything else you can think of that tastes better toasted or roasted. Caramelisation (oxidation of sugars) contributes a bit, but the Maillard reaction is king of the flavour world. We manipulate it almost without thinking, because changing cooking times and temperatures controls the flavour molecules produced.

My soon-to-be-toast was browning on the outside, but not the inside. This seems weird until you know that water holds the reaction back. The outside dries out most quickly, and reaches the highest temperatures, so it browns the fastest. If I had brushed it with a slightly alkaline substance (not something I've ever done with toast, but it's what they do with pretzels), the reaction would have taken place faster.

"This one reaction is responsible for the deliciousness of brown crusty bread, golden biscuits and butterscotch"

Nothing browns in the microwave because to get a decent reaction rate, you need temperatures to be above 120°C. Microwaves heat liquid water, so they can't raise the temperature above water's boiling point of 100°C. Microwaved food is missing all the lovely flavour molecules that form during the Maillard reaction, making it a bit insipid.

Best of all, the reaction enables you to use milk as invisible ink. Use milk to write your secrets onto a piece of paper and heat it up slightly. As it contains proteins and sugars, you'll kick the Maillard reaction into action, turning your words brown. At that point, my nostrils reminded me you can have too much of a good thing. The lovely flavour products were being replaced by the acrid pong of burnt toast and, sadly, I extracted the charred remains of my bread-based chemical reaction.

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

ILLUSTRATOR: ANDREW LYONS

THERAPY ON TAP?

Fewer murders, reduced suicide rates and a lower risk of Alzheimer's... could adding lithium to our water bring all these benefits? Jo Carlowe investigates

Imagine a future in which our health, behaviour and mood are determined by chemicals in our water. It might sound like something out of *Brave New World,* but the idea may not be so far off: in Scotland, scientists are investigating whether lithium in the water supply might have an 'anti-suicide effect'.

The research stems from the fact that lithium is a known mood stabiliser. Indeed, it is used in psychiatry to treat bipolar disorder. Since its therapeutic properties were discovered in 1949, it's been credited with halving the suicide risk in patients with mental health problems. But the argument now is that all of us might benefit from imbibing more lithium.

While the workings of lithium are not fully understood, most experts believe it strengthens nerve cell connections in the areas of the brain associated with mood regulation and behaviour. As a result, it reduces the symptoms of mania, impulsive behaviour and depression. Some scientists go further, and claim it also heals nerve

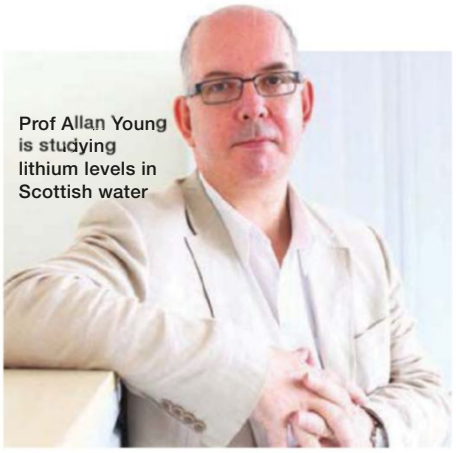
Scan this QR Code for the audio reader

PHOTO: SCIENCE PHOTO LIBRARY

damage and protects against the onset of dementia. So now experts are trying to test whether daily exposure to small amounts of environmental lithium might be of health benefit not just to those already suffering from depression, but to the population in general. Most of us are already exposed to some lithium, as it occurs naturally in tap water. But even in areas with high environmental levels this only translates to around 2mg a day, while therapeutic doses typically start at 300mg daily.

In Scotland, Dr Daniel Smith, Reader of Mental Health at the University of Glasgow, is checking lithium levels by postcode, as listed by Scottish Water, and comparing them to data on suicide attempts by area, as listed in the Scottish Health Survey. It's anticipated that suicide rates will be lower in the areas where the lithium content in the drinking water is highest, and vice versa. If this proves to be the case, some might argue that this trace element should be actively added to tap water to help keep the nation stable.

But the idea of governments doctoring the water remains controversial. Indeed one scientist involved in the Scottish study, Professor Allan Young, who is director of the Centre for Affective Disorders at the Institute of Psychiatry in London, has received death threats since studying the impact of environmental lithium on our well-being. This is despite the fact that there is nothing new about adding chemicals to drinking water.



Prof Allan Young is studying lithium levels in Scottish water

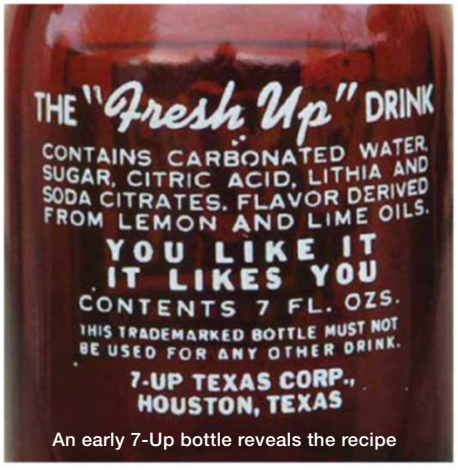
Lithium in a water sample from a salt flat in Bolivia

"Most of us are already exposed to some lithium, as it occurs naturally in tap water"

Water fluoridation to prevent tooth decay dates back to the 1940s. Today the majority of US citizens drink water with added fluoride, but in the UK only 10 per cent of us receive fluoridated water. Public Health England recently published a report showing that 28 per cent fewer five-year-olds and 21 per cent fewer 12-year-olds have tooth decay in these areas; there were also fewer cases of kidney stones and bladder cancer.

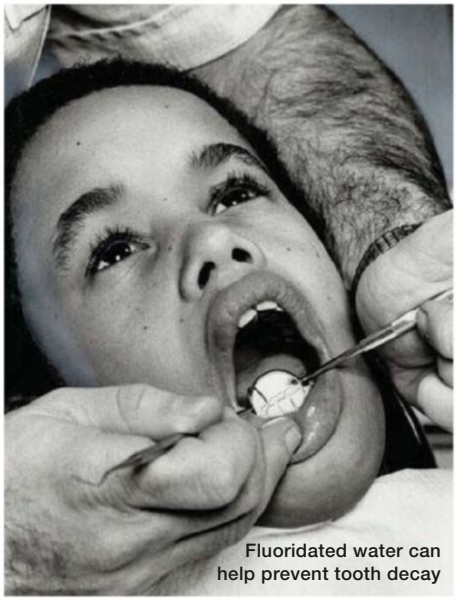
Pitkeathly Wells in Scotland was once a popular spa, famed for its lithia waters

The soft drink 7-Up used to contain lithium



An early 7-Up bottle reveals the recipe

Adding fluoride to the water supply, 1965



Fluoridated water can help prevent tooth decay

Spas and soft drinks

The notion that lithium in water might be healing has an even longer provenance than fluoride. Between 1785 and 1949, the lithium-rich waters of the Pitkeathly Wells spas in Perthshire, Scotland were popular for health and 'nervous problems', while the Lithia Springs in Georgia, USA were visited by Mark Twain and Theodore Roosevelt for their curative powers.

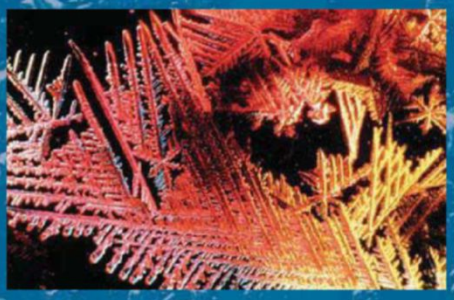
'Lithia water', high in lithium salts, was also added to many popular drinks, purportedly for its health benefits. One such drink was Bib-Label Lithiated Lemon-Lime Soda – an early name for 7-Up (lithium presumably providing 'the up', the '7' possibly representing its atomic mass). In the 1940s, changes in the regulation of the drinks industry, and concerns about lithium's toxicity, saw it removed from commercial beverages. Thereafter, following the discovery of its psychotropic benefits, it largely remained the preserve of the psychiatric community.

But in 1989 a scholarly paper was published in the USA called *Lithium In Drinking Water And The Incidences Of Crimes, Suicides, And Arrests Related To Drug Addiction*. The researchers examined the lithium level in the water of 27 counties in Texas. Incredibly, the area with the highest lithium level had nearly 40 per cent fewer suicides than the area with the lowest lithium level. Moreover, the counties with the highest levels of lithium in their water also had a statistically significant decrease in the incidence of homicides and rapes.

In 2009, an observational study from Japan also found that increased amounts of trace lithium in the water supply correlated with decreased suicide rates. Similar results were replicated in 2011 in Austria. The researchers took a nationwide sample of 6,460 lithium measurements and examined these for association with suicide rates across all 99 Austrian districts. The results again showed an inverse association – the greater the amount of lithium in a district's water, the fewer suicides. This remained significant even once the data had been adjusted for socioeconomic factors. The researchers concluded that as much as 4 to 15 per cent of the country's geographic variation in suicide rates could be attributed to varying levels of lithium in regional water supplies.

WHAT'S IN YOUR WATER?

Every time you fill up the kettle, you're loading up on more than just pure, unadulterated H_2O…



Fluoride

Fluoride occurs naturally, but some companies add extra at the request of health authorities. Only 10 per cent of people in Britain receive fluoridated water. Fluoridation protects against tooth decay, kidney stones and bladder cancer, but too much fluoride can cause tooth discolouration. In the UK, fluoride is limited to 1.5mg per litre.

Chlorine

Water companies add less than 1mg per litre of chlorine (as recommended by the World Heath Organization) to disinfect water. Swimming pools typically contain 3mg per litre. The Drinking Water Inspectorate (DWI) says chlorine is safe, but one study has linked high levels of dichlorophenol (a chlorine by-product) to food allergies.

Dementia preventer?

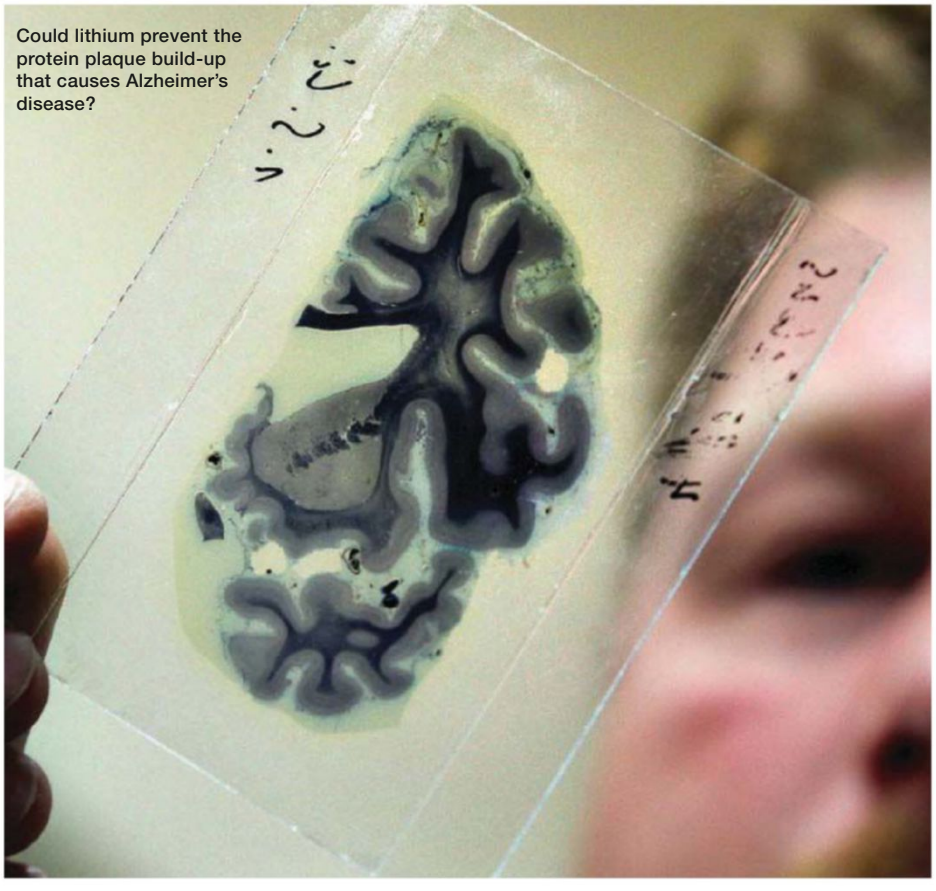
Professor Young believes environmental lithium may also protect against dementia. He'd like to carry out studies in the Atacama desert in northern Chile, which has the world's highest levels of lithium in surface water – in some cases, levels are similar to a therapeutic dose. The local population have been exposed to this lithium-rich water their entire lives.

"Such exposures may have had significant structural, functional consequences not seen hitherto," says Professor Young. "If lithium is highly neuroprotective, long-term environmental exposure might reduce age-related degeneration and even prevent the development of disorders such as Alzheimer's disease."

A number of studies (both observational and studies on animals) already suggest that therapeutic levels of lithium may help prevent dementia. In a Danish study of bipolar patients, continued treatment with lithium was associated with a decreased rate of dementia. One of the hallmarks of Alzheimer's disease (AD) is the build-up of plaques of proteins in the brain (one called 'tau') that causes nerve cells to die. Lithium appears to protect against this.

Simon Lovestone, professor of neuroscience at the University of Oxford, explains. "One of the enzymes that adds phosphates to tau is called glycogen synthase kinase 3 (GSK3). GSK3 is inhibited by lithium. Hence lithium should reduce tau phosphorylation, which should modify disease progression or perhaps prevent AD. There is evidence from animal studies that it might."

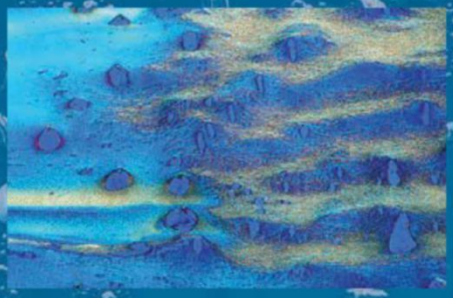
However, he does not advocate the use of lithium for the general population. "Lithium has a very narrow therapeutic range and is highly toxic – at high levels it is associated with kidney failure," he says. "It is unimaginable to think it could be given in therapeutic range to anyone other than those with a reason to receive it."



Could lithium prevent the protein plaque build-up that causes Alzheimer's disease?

But proponents of lithium say trials should be carried out to see if lithium at lower levels affords us protection against neural degeneration and unhappiness. Ideally, Professor Young would like to carry out research in Chile, where two valleys sit side-by-side, similar in everything but rates of lithium. He would look at rates not just of suicide but also of dementia, and carry out brain scans to see if those exposed to high levels have more grey matter than those in

PHOTO: SCIENCE PHOTO LIBRARY X5, CORBIS X2, FRANCESCO MOCELLIN/WIKI



Pesticides

Water companies use a combination of activated carbon and ozone to safeguard drinking water against pesticides. Recently, metaldehyde (used as slug poison) was found in one in eight rivers and reservoirs used for drinking water, according to an Environment Agency survey. The toxicity level, however, was viewed as 'very low'.

Heavy metals

Some trace elements such as magnesium are necessary for health, while others such as lead are not. Although not present in our public water supply, lead particles can build up in older pipes and intermittently in tap water. In high risk regions (soft water areas), water companies treat the supply with orthophosphate.

Pharmaceuticals and illicit drugs

Medicines and narcotics have been found in tap water, albeit at levels too low to be a health risk. The DWI recently discovered benzoylecgonine, a metabolised form of cocaine, in the UK. Traces of anti-epileptic drugs and anti-inflammatories such as ibuprofen have also been found.

"People don't get excited about lithium, because you can't patent it"

Professor Allan Young, director of the Centre for Affective Disorders at King's College London

What water there is in the Atacama Desert has a very high lithium content

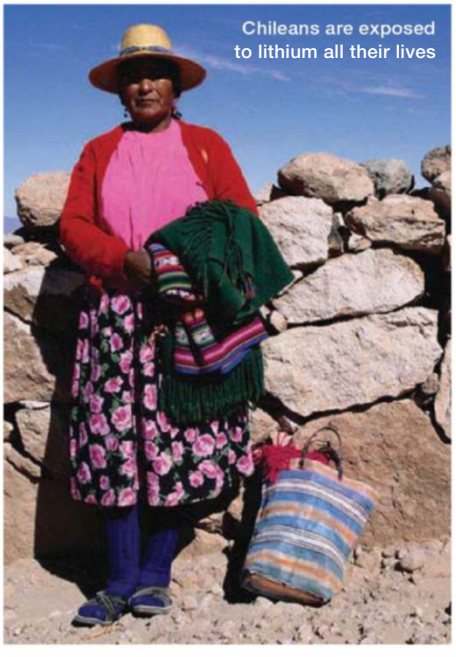
low-dose areas. But this potential data goldmine remains untapped because funding has not been forthcoming. "People don't get excited about lithium, because you can't patent it and you can't make money out of it," says Professor Young.

Early days

Perhaps the results of the Scottish study (due out in 2016) will change the scientific community's thinking on lithium. Maybe one day it will even be added to our drinking water, like fluoride in the USA. But as yet, even advocates of the idea remain doubtful. Dr Daniel Smith says there is currently not a single place in the world where lithium is added to the water supply for the benefit of public health. If his results reveal lithium to be protective against suicide, he says, more studies would still be needed before the results could have any impact on policy.

Professor Young, likewise, says there are "many scientific hurdles" to cross before such an idea could come to fruition. "But we should be doing the science," he says. "There need to be more environmental studies about the impact of higher environmental lithium. If you couldn't put lithium in the drinking water you could give people much lower doses and study them over a prolonged period of time. The potential savings, if you reduced dementia, would be enormous. This is important for brain health, ageing and suicide. It is rather perplexing to me that there isn't a big research effort going on in this area."

The chances of lithia water becoming as commonplace as it was 50 years ago currently seem slim. But with the World Health Organization reporting 7.7 million new cases of dementia per year, and with one million people dying annually from suicide, the argument for at least doing the research is persuasive.



Chileans are exposed to lithium all their lives

JO CARLOWE is a science journalist who writes for *The Times* and *The BMJ*, among others

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ONE W

This year, both NASA and Mars One begin preparations for a mission to the Red Planet, but huge obstacles stand in their way. We asked some of the world's leading experts in space exploration how we'll finally get there

ILLUSTRATOR: MAGICTORCH

AY TO MARS

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The race to Mars has begun. First out of the gate was the underdog: Mars One, a private company staffed by former NASA and ESA employees that plans to put people on Mars within 10 years. It's already started picking its crew. Now, NASA has shown its hand. In December, the US space agency began testing Orion, a spacecraft it says will be the first to carry humans to Mars.

As well as all that cold, dark space standing between us and Mars, there is a huge number of obstacles that both teams will have to overcome if we're to reach the Red Planet. How would we launch a colony ship? How would the human body cope? What if something goes wrong?

We put these questions to some of the world's leading experts on long-term space missions, in a bid to find out how we'll finally set foot on the Red Planet…

SELECTION

PROF SUZANNE BELL

Prof Bell works on NASA's Human Research Program, looking at the qualities needed in astronauts taking part in a long-term space mission. She describes the ideal Mars colonist

What kind of person would you pick for a mission to Mars?

It goes without saying that working and living in such an extreme environment will require capable individuals who are highly compatible with each other. They'll be intelligent, fit, adaptable and stable, with great coping and teamwork skills. But there are some other considerations that are more nuanced.

It's no surprise that introverts do better in isolated and confined spaces: the isolation and the social monotony of space require a certain level of introversion. At the same time, there is a level of social warmth typically associated with extroverted individuals that would be beneficial, as team members rely on one another for social support. So how can this paradox be managed? Well, in this case you can have the best of both worlds - ambiverted individuals have qualities of both introversion and extroversion. They're also likely to have the middle-of-the-road personality that can most easily adapt to the unique demands of long-duration space exploration.

I'd also look for team members who are high in self-monitoring – that's the ability to show concern for, and appropriately modify, your behaviour in a social situation. Have you ever been in a meeting, wanted to say something, and then thought to yourself, "It's not very important that I say this right now"? If so, you were self-monitoring. High self-monitors consider social cues in the situation to determine appropriate action. They're better at attending to status dynamics in relationships and can adapt their behaviours accordingly. This will help keep conflicts manageable, and help the team effectively negotiate the status and power issues that are likely to come up in the new settlement.

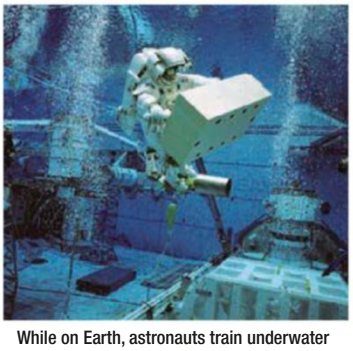
Of course, going to Mars is a risk, but you won't want someone who is too much of a risk-taker: some people take risks because they haven't appropriately weighed up the consequences. Living and working in a hostile environment means that one small mistake could have major consequences; it could even mean the death of the team. So the right person will be able to be careful and responsible in their actions, yet still have a great sense of adventure.

Ensuring team members have shared values is also critical to their compatibility. Personal values are ordered in terms of relative importance, and they drive behaviour – particularly when faced with competing priorities. The team that is sent is likely to be diverse in a number of areas. Shared values are critical for bridging these differences. For example, the team may have a mix of scientists and non-scientists (such as the pilot). When the team is faced with a situation that presents competing priorities (for instance, whether to lose data or preserve equipment), the team will more easily agree on a course of action if they have shared values.

"Even the most carefully selected, emotionally stable team members will struggle with the extreme isolation at some point. The team will need to be trained in coping skills"

How would you prepare someone for a one-way mission to Mars?

Preparation will involve extensive training, and ensuring that the team has accepted agreed procedures and standards. Training will need to include obvious knowledge and skills (how to land the spacecraft) as



While on Earth, astronauts train underwater to mimic the lower gravity found in space

PHOTO: NASA

well as everyday activities that aren't quite so simple in space (how to go to the bathroom in zero gravity). Teams also will need to be trained in several areas critical to the team's self-sufficiency: learning how to learn, coping skills and teamwork skills. The needs of the settlement will likely change over time and unanticipated events will occur. It's critical to have not only intelligent team members but also those who can evolve; for example, those who can self-regulate their learning. Self-regulation is thinking about thinking, using strategic action to learn. There's no human with the perfect skillset for life on Mars: some kind of pilot-cum-farmer-cum-doctor. But if we can teach a candidate to teach themselves, to adapt, to evolve, then they'll have the toolset they need to surive. For example, an astronaut who can identify precisely what part of the landing procedure they're getting wrong, and the training they need to correct the problem, will be more valuable on a long-term mission.

Even the most carefully selected, emotionally stable team members are likely to struggle with the extreme isolation at some point. The team will need to be trained in coping skills — how to identify and respond to difficulties in coping, and strategies for providing support.

Although training will be key to team preparation, many issues will be best resolved with agreed-upon standards. Individuals from different backgrounds may have different views on living standards, personal hygiene or even the treatment of women. Making sure everyone is on the same page regarding these issues can be used to keep conflicts at a manageable level.

The Mars One candidate selection process

2013

202,686

PEOPLE APPLIED TO GO TO MARS

NOVEMBER 2014

663

OF THESE MADE IT THROUGH TO THE FIRST SHORTLIST

2015

40

PARTICIPANTS, SPLIT INTO **10** TEAMS OF **4**, WILL BE SELECTED FOR TRAINING

2024

THE STRONGEST TEAM WILL BE CHOSEN FOR THE MISSION TO MARS

NOVEMBER 2014

THE AVERAGE AGE OF A CANDIDATE IS **32**

2024

IT WILL BE **42** IF THEY DEPART FOR MARS

NOVEMBER 2014

31

OF THE 663 ARE RESIDENTS OF GREAT BRITAIN

Maggie Lieu
Age: 23
From: Coventry
Profession: PhD candidate in astrophysics

Why did you apply?
It's always been my dream to work for NASA, but it seemed like privatised space travel would become important in my lifetime. I didn't know about the project until the deadline, so I threw together a video on the day and just applied.

What did being selected feel like?
It was surreal. I looked up Mars One and it was more serious than I'd thought. I told my mum I had been shortlisted and she just said, "yeah okay". I got a call a few weeks later when she saw me in the newspaper – she didn't realise it was real. It gets more real every day.

What do you think it will feel like to step on to Mars?
I don't think anyone knows. Every day more and more people are telling me that I'll get selected. If I actually go to Mars, I think it'll feel like a massive relief. I'll finally realise this incredible dream.

Lewis Pinault
Age: 54
From: Twickenham
Profession: Innovation Delivery Executive and Researcher, UCL/Birkbeck Centre for Planetary Sciences

Why did you apply?
I believe it's possible to get to Mars safely using existing technologies. We'll be the data – the crew psychology, the effect of radiation and the impact on the human body.

What did being selected feel like?
Good. It sounds arrogant, but I wasn't wildly surprised. When I put in my application I was about to join an Antarctic research programme, and I knew my background in planetary geology would fit in with their plans.

What do you think it will feel like to step on to Mars?
I dream about it sometimes. I remember the photos from when the first Viking landers touched down on Mars in 1976. It was a rich orange colour with a salmon pink sky. Now we know it looks more brown and the sky is more opalescent. When I dream about it, I see both.

SPACECRAFT

PROF MASON PECK

How will we get to Mars? Prof Peck, former Chief Technologist at NASA, outlines Mars One's plans for getting to the Red Planet

How would you send a crew to Mars?

The four-person crew will travel to the Red Planet in a transit vehicle – a small space station that will be assembled in low Earth orbit before the crew arrives. In-orbit assembly allows us to build large space systems, like the International Space Station (ISS), that we're unable to launch intact from the Earth, for technical or financial reasons.

Once the crew is onboard, the transit vehicle will fire its engines and begin its journey to Mars. This will be the astronauts' home for seven months, and they'll eat, sleep and train in the vehicle's habitat module. Then, when they're near Mars, they'll enter a separate lander module, reminiscent of the Apollo landers.

The one-way journey needs less than half the supplies of a round trip. They'll have enough water and oxygen onboard to last them for the whole journey, as well as plants to grow more food should they run out. The transit vehicle will also have an environmental control and life support system (ECLSS) to control air pressure, detect fires, monitor oxygen levels and manage water and waste, but this won't need the longevity of existing ECLSS's like that found on the ISS. This reduces the hardware costs involved.

A key feature of Mars One is its use of existing technologies, in contrast to the usual practice of creating a custom-built spacecraft for every mission. So no new launch vehicle will need to be designed for Mars One. Instead, the four-person crew will be carried to the orbiting transit vehicle by a pre-existing system such as SpaceX's Falcon Heavy. It'll be a similar approach to the way astronauts travel to the ISS today.

We'll continue sending four-person crews to Mars at every launch opportunity – roughly every 26 months, when Mars and Earth align in a way that minimises the propellant necessary to make the trip. As more colonists arrive, the first Martian settlement will begin to take shape.

How will you land on Mars?

Landing won't be easy. NASA's analysis predicts that a successful six-person mission would need to land 40,000kg on the Martian surface. Mars One's mass will be lower because of its smaller crew, but still, the largest payload delivered to date is just 1,000kg (the Mars Science Lab mission, which landed the Curiosity rover in 2012). This leaves quite a few challenges ahead for Mars One.

Fortunately, NASA's previous successes and investment in future technologies should provide us with a solution. One possibility is aerocapture – slowing the vehicle down by sending it through the Martian atmosphere. This would create a drag force, reducing the craft's orbital energy. Secondly, inflatable aerodynamic decelerators might be used. Currently in development, these expand to create a large, lightweight, heat-resistant body that further slows the vehicle.

Some rocket companies are also looking into landing vehicles through retropropulsion – the Buck Rogers technique of firing rocket engines in front of you to slow yourself down. SpaceX and NASA recently agreed to share data on supersonic retropropulsion gleaned from a launch of SpaceX's Falcon 9 in September 2014. This technology can be tested here on Earth, replicating Mars's atmospheric conditions by performing experiments at just the right altitude. It'll be a combination of these technologies that will allow the Mars One lander to reach the surface.

Will you need other support missions?

Absolutely. One strength of the Mars One concept is its focus on infrastructure – it's not just a one-shot, single-purpose mission. In 2018, six years before the first crew's departure, two communications

"We'll continue sending four-person crews to Mars at every launch opportunity – roughly every 26 months"

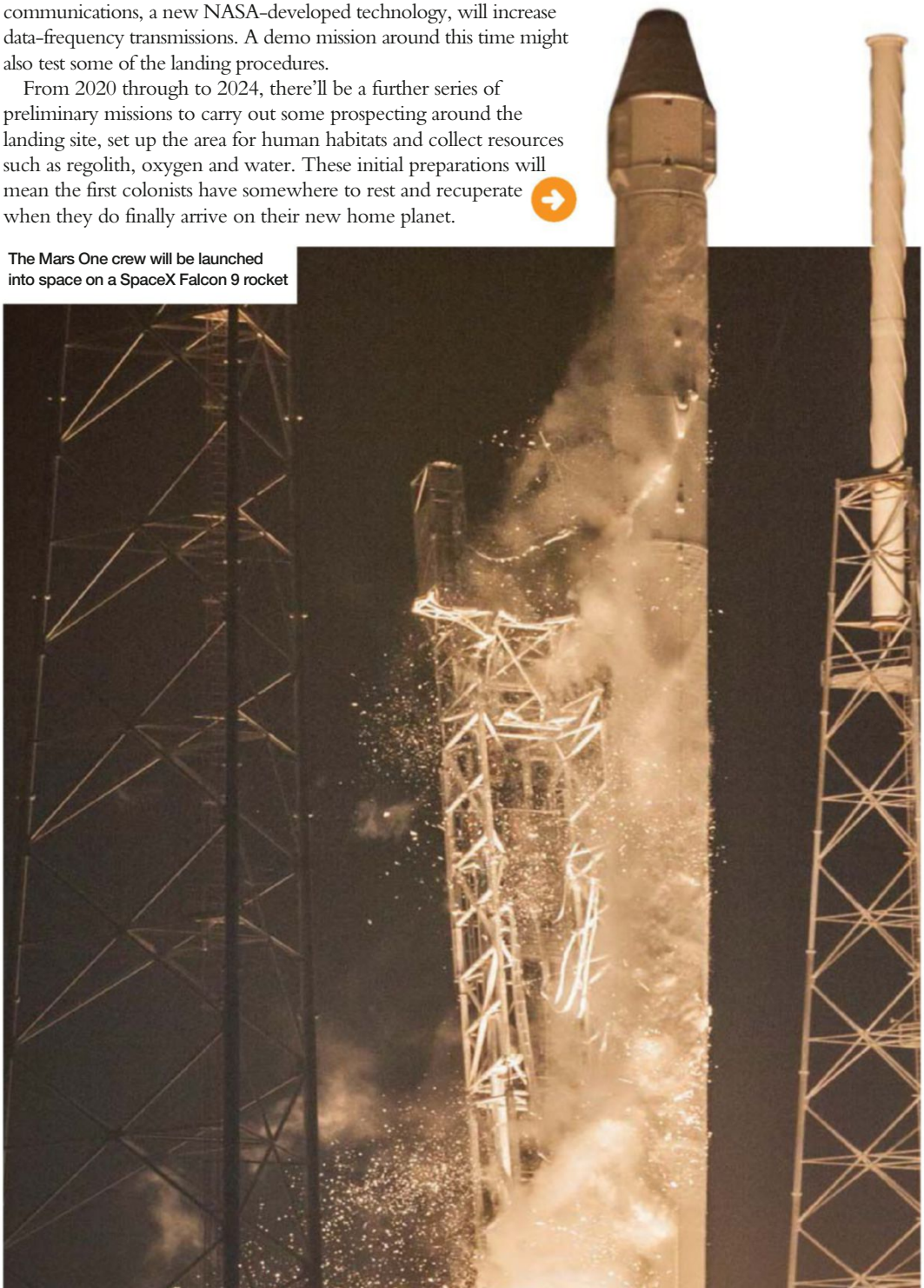
PHOTO: NASA, SPACEX

NASA's Orion spacecraft, currently in development, is its flagship vehicle for future Moon and Mars missions

satellites will be launched – one around the Sun and one around Mars – allowing constant communication between Mars and Earth. Laser communications, a new NASA-developed technology, will increase data-frequency transmissions. A demo mission around this time might also test some of the landing procedures.

From 2020 through to 2024, there'll be a further series of preliminary missions to carry out some prospecting around the landing site, set up the area for human habitats and collect resources such as regolith, oxygen and water. These initial preparations will mean the first colonists have somewhere to rest and recuperate when they do finally arrive on their new home planet.

The Mars One crew will be launched into space on a SpaceX Falcon 9 rocket



MARS ONE TIMELINE

If all goes according to plan...

2018

An unmanned demo mission is launched to test the landing procedures on Mars. Two communications satellites are also sent into orbit, providing constant communication between Earth and Mars.

2020

A robotic rover is launched. Once it has arrived on Mars, the rover drives around to find the best location for a settlement. It then prepares the surface for the arrival of the next missions.

2022

The first cargo missions are launched. These carry essential items such as food and solar panels, as well as inflatable living units and equipment to generate water, energy and breathable air.

2023

The rover sets up the outpost before the arrival of the settlers, connecting the modules, deploying the solar panels and depositing Martian soil over the living habitats to provide radiation shielding.

2024

The first Mars One crew begins the journey from Earth. They are the first humans to embark on a mission to Mars.

2025

The crew members touch down on the Red Planet. After leaving the lander in Mars suits, they're taken by the rover to the prepared settlement. Here, they have time to acclimatise before finishing the setting up of the settlement.

2026

The second four-person crew launches from Earth, landing in 2027. This process repeats roughly every 26 months, and so the colony grows.

WELLBEING

DR KEVIN FONG

Dr Fong has worked with NASA and is author of *Extremes: Life, Death And The Limits Of The Human Body*. He explains how the body will cope with life on another planet

If you were the doctor on a trip to Mars, what would you be most worried about?

A Mars mission crew doctor will have their work cut out. Prevention is always better than cure, so keeping the crew healthy by making sure they eat the right diet, stick to an exercise programme and generally take care of themselves would be important. But a crew physician would be responsible for providing healthcare should any medical emergency arise. With space and power at a premium, and the physician having to be everything from general practitioner and casualty doctor to anaesthetist and surgeon, that would be a tall order. And there's plenty up there in the way of threats: the effects of weightlessness, the risk of decompression illness during space walks, the intense radiation outside the protection of Earth's magnetic field, and micrometeoroids.

The biggest threat to life, though, is not disease or even traumatic injury. Astronaut crews are screened to make sure they're in peak condition, and the spacecraft itself and all activities that take place within it are designed to expose the crew to the lowest possible risk of injury. Day-to-day life would be far safer than in the average house: you can't fall down a flight of stairs, it's hard to start fires and it's nearly impossible to electrocute yourself. Instead, what would most worry a doctor would be being part of a crew that's hurtling through space, powered by rockets with the explosive potential of a small nuclear missile.

It's not the medicine you need to worry about, it's the rocket science. We've never lost part of the crew on a space mission: either the engineering works and everybody lives, or it doesn't and everyone dies.

What would happen to the human body after a year on the Martian surface?

Mars doesn't support life any better than the empty space that the crew would have crossed to reach it. It is smaller than Earth and further from the Sun, with a thin atmosphere composed almost entirely of carbon dioxide. So when crews arrive there, they will be completely dependent upon a suite of life support systems, and forced to live in habitats that are suitably shielded from radiation. But the aspect of Martian life that will shape physiology more than any other is the reduced gravity.

Astronauts living on Mars will experience roughly one-third of the gravity that they would on Earth. We already know, from more than 50 years of human space flight, that weightlessness has effects on the human body. Bone and muscles waste rapidly and the heart, which is itself a muscle, deconditions. But other systems are also affected. Hand-eye coordination becomes impaired, the immune system becomes suppressed and astronauts can become anaemic. Prolonged weightlessness can take athletes and turn them into couch potatoes very quickly.

What we don't know for sure is how severe these effects will be on Mars. On the Red Planet there is at least some gravity but it's unclear if it's enough to protect the astronauts' biology. Over the years, we've studied hundreds of people who've spent time floating weightlessly but only 12 people who've ever experienced reduced gravity on the surface of another world: the Apollo crews who landed on the Moon. And that's left us without enough information to know for sure how severe the problem of life on Mars, at one-third of Earth's gravity, will be.

For now, a combination of drugs, controlled diet and strict exercise regimes will be what crews rely upon to ward off the deconditioning effects of living on a world with reduced gravity. Though some authorities have proposed the use of short-arm centrifuges, with radii of around 3m and rotation rates of 40rpm, to provide a short burst of artificial gravity at the surface, the right answer isn't yet known. But what's clear is that the exploration of our nearest planetary neighbour will also prove to be an exploration of the limits of the human body.

"For now, a combination of drugs, controlled diet and exercise regimes will be what crews rely upon to ward off the deconditioning effects of living with reduced gravity"

PHOTO: GETTY, ESA

Exactly how the low gravity conditions on Mars will affect long-term settlers remains, so far, unknown

Diego Urbina training as part of the Mars500 mission, which simulated a manned Mars voyage

COLONISATION

PROF CHARLES COCKELL

Prof Cockell is director of the UK Centre for Astrobiology. His lab investigates life in extreme environments. Here, he explains what life will be like for the Red Planet's first inhabitants

What will the first few days on Mars be like?

The new settlers' first priority will be putting in place the basic essentials for survival, and ensuring that backup systems are fully functioning. They'll have a lot on their minds. They'll need to ensure that all oxygen production and recycling equipment is working, and if they're topping up their oxygen from water gathered from the atmosphere (by breaking it down using electrolysis), they'll need to check that the extractor fans collecting atmospheric water are up and running. In the first weeks, the colonists' food will not be home-grown. They'll be eating dried and preserved rations in boxes. However, they may spend the first two weeks setting up a simple greenhouse so that they can begin to grow food as soon as possible.

A crucial matter for survival is energy. Whether they're using nuclear or solar energy, they'll need to set up the apparatus, link it to the base and make sure that the power supply is stable and reliable. They may also set up chemical apparatus to make useful things like fuel. Carbon dioxide in the atmosphere, for instance, can be reacted over a catalyst with hydrogen (itself released from water gathered from permafrost or the atmosphere) to make methane fuel to power their robotic rover.

The Sun produces infrequent, but intense, particle streams that can cause severe radiation damage. So the settlers will need to ensure that radiation shielding is in place – a layer of Martian rock or water in the walls of their habitat would do the job – and that they have a more resistant shelter to escape to during periods of intense radiation.

Most of these procedures will have been tested before they land, so in principle it should just be a matter of plugging in the equipment. But they will still need to check and cross-check all of these systems in a potentially lethal environment. The first few days will be a Lego-like frenzy of putting together the first Martian base.

What might a typical day on Mars involve?

Once they're settled in, the colonists can begin to plan their days. Before breakfast every morning, they'll check key systems to make sure everything's functioning well. The most important activity of the day will be a morning briefing about the day's activities. Maybe they'll be staying at home to repair some crucial system or study their data. If not, they'll need to prepare themselves for a day in the field.

Donning spacesuits, they'll head out into the Martian landscape on foot or in a rover, studying the planet's geology

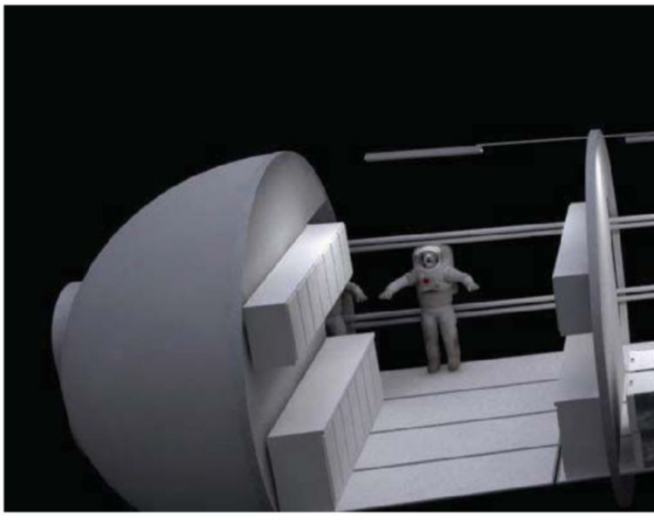
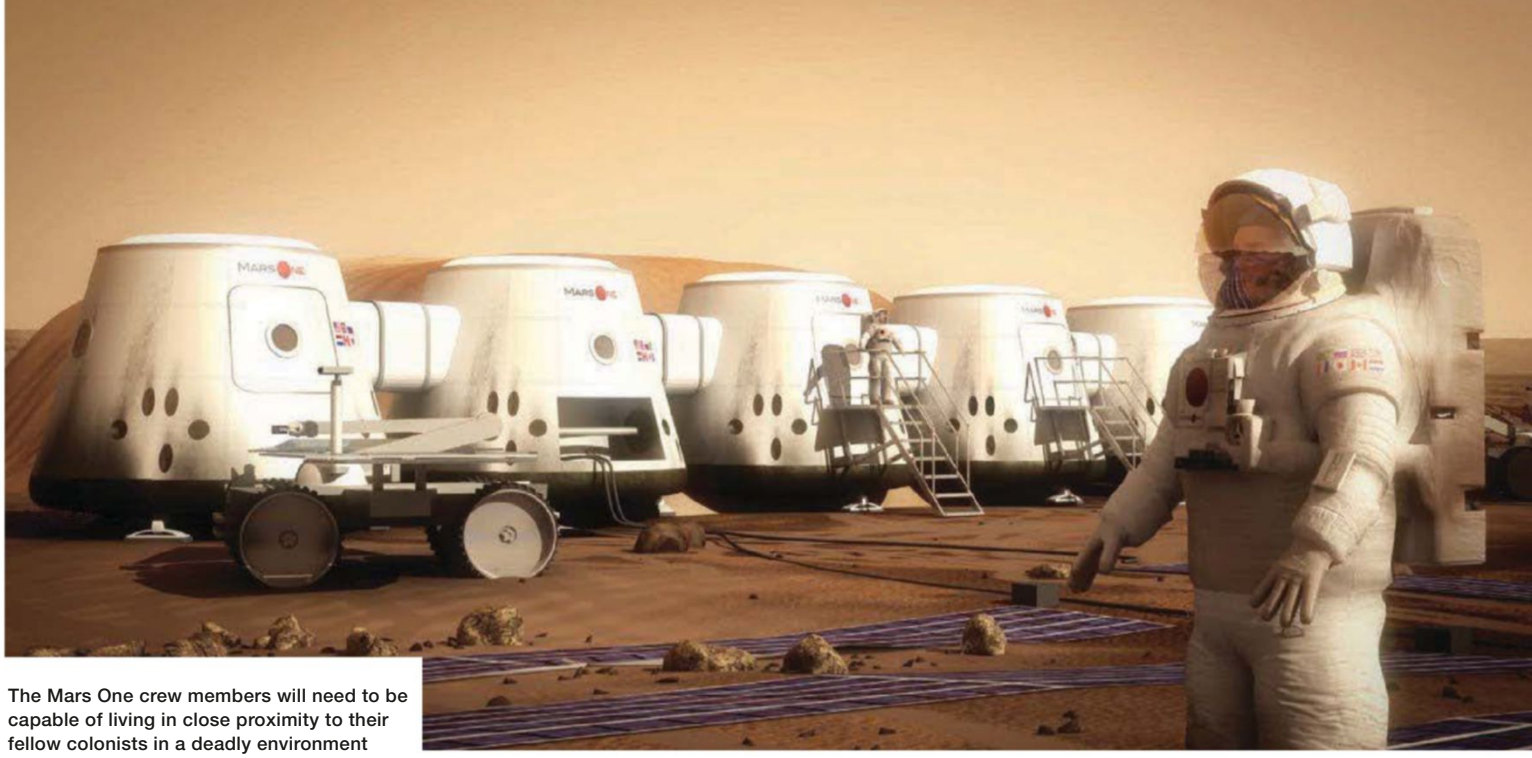


PHOTO: BRYAN VERSTEEG/MARS-ONE.COM X3



The Mars One crew members will need to be capable of living in close proximity to their fellow colonists in a deadly environment

to learn more about how Mars was formed, and what this might tell us about the Earth's formation. They might look for ancient signs of life to find out if Mars was ever inhabited – and if not, why a planet that was a little like the Earth in its early years remained dead, while our own planet became covered with thriving microbial life. They might also go on reconnaissance missions to scout for useful resources, or locations for future stations. They could spend days away from the settlement, living and eating in their rover.

With every day that they live on Mars, their confidence and knowledge will grow – and with it, the knowledge of the human species as a whole.

What will the colonists need to think about beyond simple day-to-day survival?

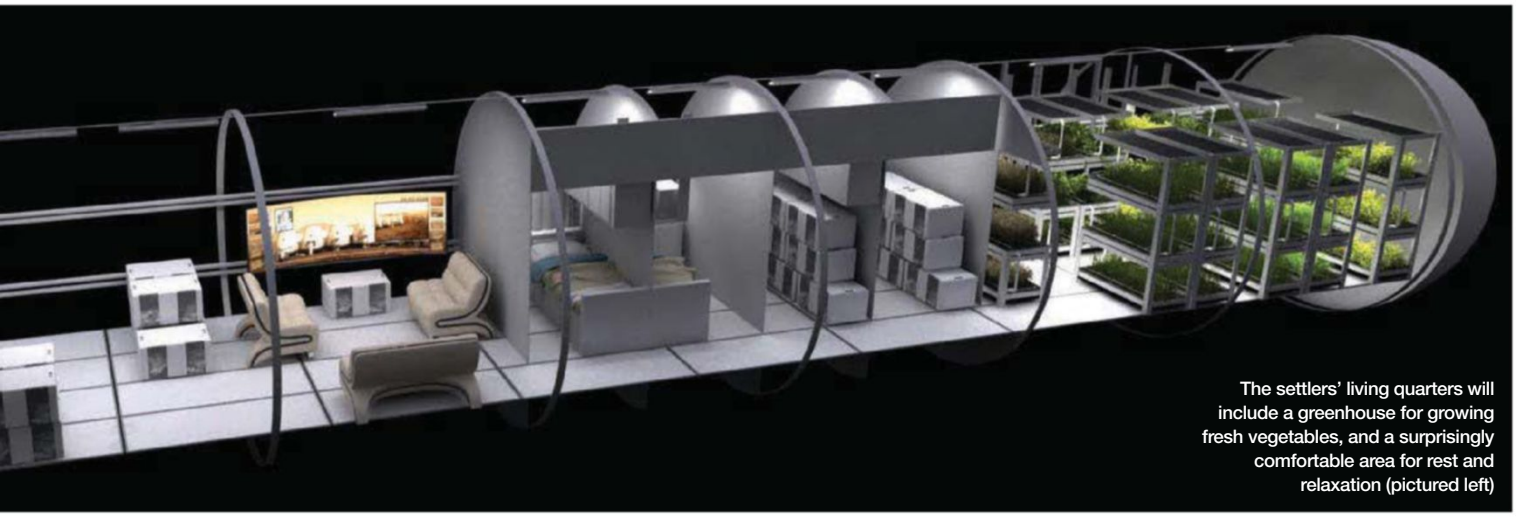
Beyond the science and planning there is the human story. These explorers will inhabit a deadly environment, trapped in a tiny space with their fellow colonists. Their challenges will come not just from the outside (the Martian environment), but also from the inside – this is what we call the human challenge.

Professionalism and good behaviour will get them a long way as they learn to work together and carry out their mission, but other things will help. For instance, they'll have small spaces in the station where they can spend time on their own, write messages to loved ones on Earth, paint or read.

We know from the accounts of those who've lived on space stations that growing crops and tending to other creatures helps a great deal, by giving people psychological reprieve from the extreme environment. Looking after animals and plants will provide the settlers with food, but it might also be a good therapeutic hobby.

Mars won't all be work. The colonists may go out on treks to explore the planet just for the fun of it. Maybe as their technical capacity improves they'll attempt daring transpolar crossings of the great polar ice caps, or set out on long-duration expeditions across the formidable Martian deserts.

In the long-term, they'll need to find a way to manage their affairs in a more organised way. As a small group, direct participatory democracy will probably work, but as numbers grow they may need some formal constitution by which to govern themselves. It'll be the first extraterrestrial government.



The settlers' living quarters will include a greenhouse for growing fresh vegetables, and a surprisingly comfortable area for rest and relaxation (pictured left)

A dominant male mandrill glares up at a rival in Lékédi Park, Gabon. Males prefer to determine a foe's strength by visual cues instead of fighting.

Photos by Francisco Mingorance

The largest and most colourful monkey in the world is also one of the most elusive, hidden in dense, remote Central African rainforests. Scientists are starting to discover more about mandrill behaviour thanks to innovative new techniques, reports Chelsea Wald

CHASING RAINBOWS

Young mandrills at least two years old often forage in small groups

Show-off the harlequin make-up of a macho male

The long nose of a male mandrill has a scarlet bridge and snout, and pale paranasal ridges with blue-violet troughs. The intensity of the scarlet hue is linked to testosterone levels: it becomes more intense when a male achieves dominant status, but fades when that rank is lost.

Canine teeth grow up to 6.5cm long. These fearsome fangs are exposed to threaten rivals and predators, but are also used in fights between males – which can be fatal.

The sternal gland is used by both males and females for scent-marking. Males rub this gland against tree trunks, though we're not sure why – possibly to signal status, or for orientation or definition of a large home range.

The rump and genitals of a dominant male sport a range of brilliant colours. The penis and anal region are bright red, the scrotum is pink, and buttocks and upper thighs are blue blending to purple. These colours are most vivid during the breeding season (typically May to November), and again are linked to rank and testosterone levels.

Deep in the Gabonese rainforest, something blinked. A pair of round amber eyes peeped out of the emerald gloom at American conservationist Michael Fay, who was just sitting down to rest when he noticed that he was being watched. Blink, and blink again. "Suddenly there's this little mandrill looking at me – just a baby, probably two years old," he recalls. "It was peering through the bushes, perched up on a log."

The mandrill soon darted away, but was quickly replaced by another on the same log. Blink, blink. "Then another one arrived, and another, and another," Fay smiles. "And I realised they were all lined up, taking turns." They had never seen a human before, figured Fay, a senior conservationist for the Wildlife Conservation Society. "They're all curious – like, 'Whoa: what is this?'"

It was a rare reversal of the typical interactions between humans and mandrills. Humans are usually the curious ones – especially scientists. Mandrills, on the other hand, are notoriously shy and difficult to find in the vast, tangled rainforest of western Central Africa. Old World monkeys related to baboons and drills (which are more threatened than mandrills, being Endangered), they inhabit a range spanning parts of Cameroon, Equatorial Guinea and the Republic of the Congo. But it is thought that they survive in largest numbers in Gabon, where they live alongside forest elephants, chimps, western lowland gorillas and leopards.

"Mandrills are also remarkable for the size of their social groups, which may comprise some 800 individuals"

Marie Charpentier (far left), director of the Mandrillus Project, tracks radio-collared mandrills with two of her assistants.

Mandrills fascinate scientists for several reasons – not least their extreme sexual dimorphism. Males can weigh over 30kg, nearly three times as much as females. And whereas females are relatively demure, males sport radiantly colourful adornments, smell pungent and grow intimidating canines used in fighting other males (see above).

Mandrills are also remarkable for the size of their social groups, known as hordes, which may comprise some 800 individuals – females and young at the core, with males on the periphery. But though they sometimes travel in vast numbers, they are hard to find and follow in the dense rainforest. "You hear them a lot more than you see them," Fay says, referring to their deep grunts and high-pitched crows. To track mandrills, scientists have had to be creative, taking advantage of encounters in relatively confined situations, such as mandrill highways in the forest and private parks with porous fences, to gather valuable data.

The invisible monkey

Their research is urgently needed. The mandrill, like many other rainforest animals, is under pressure from deforestation and commercial bushmeat hunting. Populations across its range have probably declined by over 30 per cent during the past three

“High-ranking males shuffle ranks often during mating season – status takes a toll”

The blue folds on an adult male’s muzzle accentuate snarls during face-offs with rivals

Young males stay with the horde until they become subadults at six to nine years old.

The bushmeat trade

Scientists aren't alone in looking for mandrills. Hunters often use dogs to track the monkeys, trapping them in trees. Hunting rainforest animals – from insects to great apes – for food has been a way of life in rural Central Africa for millennia, but in recent decades it has grown into an unsustainable industry. Logging roads provide access to the heart of the rainforest and allow hunters to transport their catches to cities, where large and rare animals such as mandrills sell for a premium. The survival of nearly 100 species may be threatened by the trade, and the decline in large animals including apes and forest elephants – also killed for their ivory – has already been catastrophic. Hope rests with initiatives to protect species while promoting sustainable harvesting, providing income and protein for the poor.

Mandrill bushmeat commands high prices at Central African markets

Karl Ammann/naturepl.com

decades – its IUCN Red List conservation status is now Vulnerable.

"It's incredible to me that this species, so present in cartoons and nature books, is very much ignored on the conservation front," says Fay who, as an adviser to the Gabonese president, is helping to bring attention to mandrills in that country. Now is the time, scientists say, to learn as much about these monkeys as possible – and to lay the groundwork for protecting them.

Mandrills are frustratingly elusive. Scientists often habituate wild gorillas and other primates to human presence. But whereas those animals form small groups, such habituation is impossible with this species, says Jo Setchell, a primatologist in the Anthropology Department at Durham University, who has worked with mandrills in Gabon. "If a group has 600 individuals, every day on which you contact that group there's going to be an animal that's never seen you before – so that animal will scream, and the whole group will flee. You don't get any opportunity for the animals to realise that you're there but you're not a threat."

What's more, it's hard to study their behaviour because it's impossible to keep track of who's who. Setchell once saw a horde crossing a river on a fallen tree. "You could see them just flooding across this tree, and there were others jumping from tree to tree above the river," she recalls. "There's no possibility of individual identification in that case." Some researchers have taken advantage of crossings such as that tree to make videos for later analysis. But in many cases, Setchell says, "the best thing you can do is count them, basically".

"In neighbouring countries such as Cameroon, where human populations are larger, forests are dead and empty"

More than 1,000 individuals have been counted in the largest hordes – making them possibly the largest stable wild primate groups anywhere.

One way to keep track of a mandrill horde is to fit individuals with radio-collars – if you can catch them. Lopé National Park in central Gabon is a mosaic of forests, where mandrills live, and savannah, which they avoid. Strips of forest bordered by savannah funnel the monkeys through relatively narrow corridors that serve as mandrill highways. Ecologist Kate Abernethy, of Stirling University and Gabon's National Centre for Research in Science and Technology, conducted research in Lopé for two decades. Since the late 1990s her team used air rifles from hiding places along such highways to dart mandrills with sedatives, collar them and release them back into the horde. Over 10 years Abernethy's team made contact with one horde several days each week, even as it travelled up to 15km a day and ranged some 200km^2.

The team's findings offer hope of a positive outlook for the species. Mandrills have an eclectic diet – they love fruit and all kinds of insects, and could probably survive a decline in any single food item. They also reproduce quickly: females aged four to twelve have one baby every two years. If an infant dies, which is common, the mother will bounce back and ▶

Parasites don't affect mandrills very much, but social grooming is still important.

Nick Garbutt/naturepl.com

reproduce again the next year. Hordes seem to tolerate parasites and viruses well, despite widespread infection. "Mandrills," Abernethy says, "are probably quite resilient" – as long as there's rainforest in which they can live.

Abernethy also found that rainforests need mandrills. As hordes blaze a trail, they turn over the leaf litter on the forest floor, which is fertilised with their dung. They are food for pythons, leopards and probably birds of prey. And they disperse seeds, thereby helping the expansion of the forest on which they depend.

There is one place where wild mandrills let humans get close to them. Lékédi Park, in the town of Bakoumba in southern Gabon, was once the maintenance centre for a cable car that carried manganese some 76km for loading at Pointe-Noire, a port in the Republic of the Congo. When the cable car closed in the early 1990s, the company converted the centre into a private wild park.

In 2002 and 2006, scientists released a total of 60 captive-born mandrills into the giant park, which also held wild mandrills. Wild males mated with the captive-born females, and the group has grown to more than 100 in size, moving in and out of the park through its porous fences. With every new generation they have become increasingly wild, yet remain habituated to humans.

Red means danger

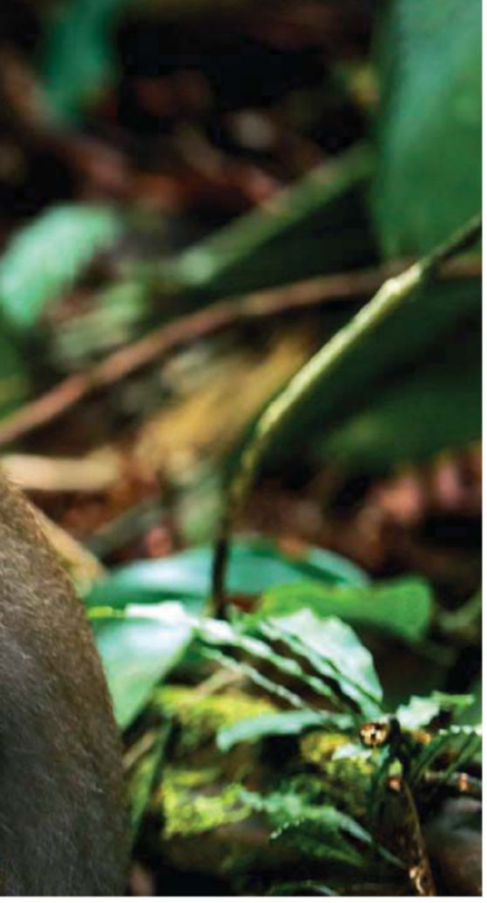
It's an ideal situation for studying mandrill behaviour – hence it's the location of the Mandrillus Project, which was launched in 2012 by evolutionary biologist Marie Charpentier of the Centre d'Ecologie Fonctionnelle et Evolutive in Montpellier, France.

Studying captive mandrills is, of course, relatively straightforward – but they may not behave in the same way as wild ones. Take high-ranking males, for example – those with the brightest colours. In captive groups, high-ranking males tend to maintain their status for a long time, despite frequent fighting. But in the wild they shuffle ranks more often, especially during mating season – probably because maintaining status takes a toll. Charpentier's group has found that high-ranking males pay a price in terms of underlying physical fitness during mating season. That may be why she rarely sees older high-ranking males. "Males tend to be at the top of the hierarchy early in their prime, when they are just young adults, because they are stronger."

Charpentier's team also witnessed close-up some of the threats from humans, and the pugnacity of male mandrills. One day, when photographer Francisco Mingorance – whose images accompany this article – visited the Mandrillus Project, the team found a baby mandrill caught in a hunter's trap outside the park fence. During the two hours it took them to free the infant "the dominant male attacked us furiously", Mingorance recalls. Eventually the baby was released and reunited with its mother.

This brought home the greatest threats to mandrills: commercial bushmeat hunting, followed by deforestation (see box, *p49*). In neighbouring countries such as Cameroon, where human populations are much larger, the forests are "dead and empty", says Setchell. Gabon is much less populated, so still can practise what some call "conservation before the crisis".

The importance of Gabon as an ecological stronghold was underscored by the 'MegaTransect' undertaken by Fay in 1999–2000. On a 3,200km trek across the Republic of the Congo and Gabon, his team hacked through thick understorey to document the plants and animals living in the most remote areas.



Mandrills eat fruit, seeds and insects. Adult males tend to feed on the forest floor, while juveniles often forage in trees.

Hair on the buttocks and upper thighs of adult males is thin to expose the bright blue and pink skin.

An African eden?
Ecotourism in Gabon

In 2002, when President Omar Bongo created 13 national parks covering over 10 per cent of the country's area, Gabon became a hot ticket. Travel writers and tour operators promised surfing hippos, forest elephants and gorilla encounters. Since then the reality of developing ecotourism in a country with little travel infrastructure has bitten. Even so a few places are accessible to tourists, offering some exceptional experiences.

Western lowland gorillas, forest elephants and sitatunga antelopes visit Langoué Bai, a muddy forest clearing in Ivindo National Park. In Lopé, hordes of mandrills numbering up to 800 can be seen – if you're extremely lucky. Visits to Lékédi, where mandrills are easier to spot, are also possible.

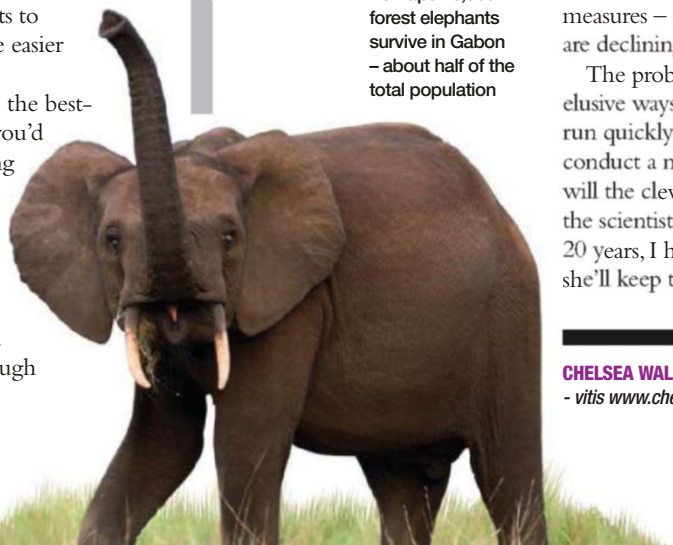
Loango National Park is the best-known location. Though you'd be fortunate to see a surfing hippo, leatherback turtles nest here, elephants and buffalos visit the beach, and humpback whales pass from July to September. Gorillas and chimps might be seen, though they're not yet habituated.

"It's simply very difficult to count animals that run quickly around dense forests in enormous clumps"

That groundbreaking expedition was crucial in persuading the Gabonese president, Omar Bongo, to designate 13 new national parks protecting more than 10 per cent of the country's area. His son Ali Bongo Ondimba, who took over the presidency in 2009, appointed Lee White – a British-born zoologist and Abernethy's husband – head of the country's national parks. Under White's leadership, and with the help of Fay, Abernethy and the Wildlife Conservation Society, Gabon has made strides towards securing its parks from poaching and generating revenue from ecotourism (see box, left). Its parks are now the "primary places on Earth where mandrills will survive in large numbers", says Fay.

What those numbers are, however, remains the biggest mystery of all. "Nobody knows how many mandrills there are in the wild, to an order of magnitude," says Abernethy. This makes it hard to plan and evaluate conservation measures – and even to know whether numbers in Gabon are declining or holding steady.

The problem comes down, again, to the mandrills' elusive ways. It's simply very difficult to count animals that run quickly around dense forests in enormous clumps. To conduct a meaningful census, money will be needed. So, too, will the cleverness and creativity that mandrills demand of the scientists who study them. "Unfortunately, at the end of 20 years, I have not really cracked it," Abernethy says. But she'll keep trying.



Perhaps 45,000 forest elephants survive in Gabon – about half of the total population

CHELSEA WALD *writes about science and the environment - vitis www.chelseawald.com to find out more information.*

THE CAUSE OF VOLCANIC ERUPTIONS

BY ANDREW ROBINSON

Volcanoes have been a major force in shaping the planet we live on – yet until quite recently, we knew surprisingly little about them

The world's most recent major volcanic eruption — that of Mount Ontake in Japan, 200km west of Tokyo, in September 2014 — took hikers and scientists by surprise. More than 60 people were killed by ash, stones and poisonous fumes, yet scientific instruments located around the volcano had given no signal of the coming explosion.

Tiltmeters and sensors connected to the GPS satellites — designed to measure the angle and elevation of the slopes — showed no change during the run-up to the eruption, or even while it was in progress. This indicated that there was no rise in molten rock, or magma, within the mountain. Seismometers showed a spike in activity about two weeks before the eruption, but this settled down at a rate of 10-20 small earthquakes per day: a level much lower than that of many Japanese volcanoes, such as the iconic Mount Fuji (which last erupted in 1707). A mere 11 minutes before Ontake's blast, seismometers detected a volcanic tremor: a type of seismic activity untypical of the earthquakes that frequently accompany eruptions.

The earliest human reference to volcanism is probably an enigmatic wall painting from the settlement of Çatalhöyük in Anatolia, western Turkey, which may show a volcano erupting over tightly packed houses – perhaps a depiction of neighbouring Mount Hasan's eruption in 6200BC. However, the first reliable references to volcanism date from ancient Greece and Rome. Plato accurately described the formation of lava or obsidian (volcanic glass): "Sometimes when the earth has melted because of the fire, and then cooled again, a black-coloured stone is formed," he wrote.

Aristotle, who coined the word 'crater' (Greek for 'cup') to describe the shape of volcanic summits, less accurately said that the fire beneath the earth was the result of "the air being broken into particles which burst into flames from the effects of the shocks and friction of the wind when it plunges into narrow passages".

We now know that the Sun is at the centre of our Solar System, but great thinkers weren't always so sure

Famously, Pliny the Younger gave an eyewitness account, in AD 79, of the eruption of Mount Vesuvius that buried Pompeii and Herculaneum. The disaster killed his uncle, naturalist Pliny the Elder, when he went on a rescue mission to help Pompeii. Today, 'Plinian' is the term used to describe a Vesuvian type of eruption.

Digging for knowledge

It is ironic that Pliny the Elder died as a result of an eruption. Although he compiled in his *Naturalis Historia* the earliest coherent list of active volcanoes, Vesuvius went unmentioned, presumably because it was not known to have erupted. In the following years, its danger was forgotten, along with Pompeii and Herculaneum. Only after another major eruption in 1631 (following six centuries of repose) were the towns rediscovered when wells were sunk during the rebuilding of modern Portici, which turned out to

PHOTO: THINKSTOCK, ALAMY

Sicily's Mount Etna, pictured here in April 2013, is one of the world's most active volcanoes

> IN A NUTSHELL

Plato gave us the first description of lava, but it wasn't until the late 18th Century with the work of William Hamilton and others that the study of volcanoes began in earnest. This led to our modern-day understanding of their role in shaping the planet.

lie on top of Herculaneum. Pompeii and Herculaneum were excavated from the 1730s onwards, and prompted the first stirrings of our understanding of volcanoes.

In the 1750s, French botanist Jean-Étienne Guettard recognised that the black stone used for construction in France's Auvergne region was similar to Italian rocks from Vesuvius and Mount Etna. He discovered that the stone in the French buildings was quarried at Volvic, a village south of Vichy. He guessed that 'Volvic' came from the Latin *volcani vicus*, 'volcanic village' – so it seemed that the Romans were aware of the connection, too.

Guettard visited the Volvic quarry and climbed the hill behind it. To his delight, a series of old volcanic cones stretched before him, now smooth and vegetated. In 1752, he delivered a paper to the French Academy of Sciences entitled *Memoir On Certain Mountains In France That Have Once Been Volcanoes*. Over the next few decades he and others, notably Nicolas Desmarest, studied and mapped a chain of 50 volcanoes in the Auvergne, the most famous being Puy de Dôme. We now know that the last eruption there occurred about 6,000 years ago.

Among those attracted to Vesuvius was William Hamilton, Britain's ambassador to Naples from 1764 to 1800 (and husband of Emma, the mistress of Admiral Nelson). Vesuvius erupted violently nine times during Hamilton's stay; he made more than 200 sorties up its flanks, and became one of the pioneers of volcanology. He began to compile a list of eruptions, by collecting the dates on which the priests in Naples and the villages and towns around the volcano had displayed sacred images to ward off destruction. Hamilton was intrigued by the stolid philosophy of the locals: "Each peasant flatters himself that an eruption will not happen in his time, or, if it should, that his tutelar saint

THE KEY EXPERIMENT

Debate raged for a long time about how rocks are formed. It wasn't until the 1790s that simply melting and cooling rocks in a laboratory settled the argument for good

In the late 18th Century, there were two competing theories regarding the formation of terrestrial rocks. Neptunists, believers in the story of the Flood, maintained that most rock had been laid down as layers of sediment by the action of water. Vulcanists (or plutonists), after observing the material ejected by erupting volcanoes, proposed that some rocks had been melted by heat inside the Earth. But if they were right, and so-called volcanic rocks such as basalt and granite had once been molten, why did these rocks show crystal structure rather than looking like glass, like the mineral obsidian?

Experiments by James Hall in the 1790s suggested the reason. Hall took samples of whinstone — the name given to basalt in his area near Edinburgh — and melted them in an iron foundry. He called the molten substance 'magma'. When cooled quickly, magma turned to glass. Cooled over several hours, however, it reverted to crystalline rock very similar to whinstone. By varying the time of cooling, Hall could vary the size of crystals. He repeated the experiments with six lava samples from Mount Etna, Mount Vesuvius and Iceland. Whinstone and lava, Hall noted in 1800, "agree so exactly in all their properties… as to lead to a belief of their absolute identity".

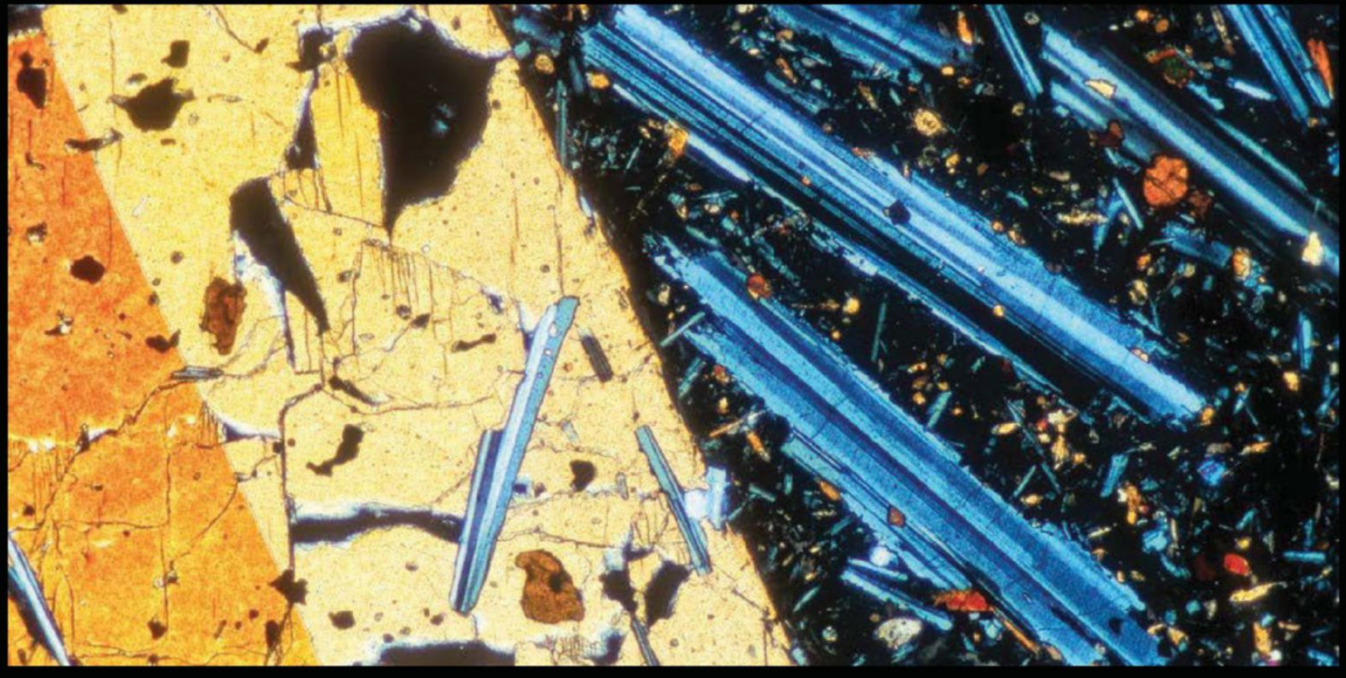


PHOTO: BERNARD GINESTE/WIKIPEDIA, GETTY X2, SCIENCE & SOCIETY, BIBLIOTHEQUE NATIONALE DE FRANCE, SCIENCE PHOTO LIBRARY

will turn away the destructive lava from his ground; and, indeed, the great fertility of soil in the neighbourhoods of volcanoes tempts people to inhabit them," he wrote. Hamilton's letters to the president of the Royal Society in London, published in 1772, became the first modern work of volcanology.

Solid theories

Neither Guettard nor Hamilton proposed a theory of volcanism, however. At this time, the dominant idea was that rocks were of sedimentary origin and had been laid down in layers by the biblical Flood. Volcanic activity was therefore a recent and superficial phenomenon – merely the result of veins of coal catching fire underground and burning their way to the surface. Indeed, the word 'volcanic' only entered the English language in 1774.

In the 1780s, James Hutton – the so-called father of modern geology – carried out field observations in Scotland. His work, along with rock experiments by his friend James Hall in the 1790s, made it clear that many rocks were of igneous origin. They were formed not by water, but by being melted within the Earth and extruded at the surface through volcanoes (see 'The Key Experiment').

Hutton's idea of a dynamic Earth with a molten interior was elaborated by Charles Lyell in his *Principles Of Geology*, published in 1830-33. This strongly influenced Charles Darwin's interpretation of active volcanoes in South America as the agent of mountain building, and of extinct underwater volcanoes in the Pacific as the foundation of coral islands. The idea was firmly established by 1883, when the Indonesian island of Krakatoa erupted for 100 days, ending with a titanic blast that destroyed the volcano and sounded like gunfire nearly 5,000km away. It generated both a tsunami that annihilated 36,000 people, and an ash cloud that caused global atmospheric effects for years.

A scientific expedition from Europe landed on the remains of the island less than two months later. The ejecta thrown out by the eruption, when analysed in a laboratory, turned out not to belong to the rock of the old volcanic cone,

CAST OF CHARACTERS

Some of the key players in the birth and evolution of the science of volcanology

Jean-Étienne Guettard (1715-86) was a French geologist and mineralogist, who began his career as a botanist. He created the world's earliest geological map, based on his survey of France. In the 1750s, he was the first to recognise the volcanic origin of the mountains in the Auvergne region of central France.

William Hamilton (1731-1803), a Scottish diplomat, served as the British ambassador to the Kingdom of Naples from 1764 to 1800, a period that coincided with frequent eruptions of Vesuvius, which Hamilton observed and reported at close quarters. In effect the first volcanologist, he received the Royal Society's Copley Medal of Britain in 1770.

James Hall (1761-1832), as the son of a wealthy Scottish landowner, was free to pursue his interests in geology and chemistry. Touring Europe in 1783-86, he climbed Vesuvius five times. Back in Scotland he became a friend of James Hutton, whose geological observations Hall later confirmed by laboratory experiments.

Alfred Lacroix (1863-1948) was professor of mineralogy at the National Museum of Natural History in Paris. Co-author of a pioneering work on the optical properties of rock-forming minerals, he is best known in volcanology for his detailed investigation of the 1902 eruption of Mount Pelée in Martinique, which was published in 1904.

John Tuzo Wilson (1908-93), a Canadian geophysicist and geologist who reached the rank of colonel during World War II, was a key contributor in the 1960s to the theory of plate tectonics, which transformed volcanology. He also proposed the hot-spot theory to explain the volcanic origin and continuing volcanism of the Hawaiian Islands.

TIMELINE

How our understanding of the nature of volcanoes has developed over the past 250 years

1752

Evidence for Europe's volcanic origin is submitted to the French Academy of Sciences, based on a survey of mountains in the Auvergne by Jean-Etienne Guettard.

1772

William Hamilton, inspired by Pompeii's excavation and the activity of Vesuvius, publishes *Observations On Mount Vesuvius, Mount Etna And Other Volcanos*, the first scientific report on volcanic eruptions.

1790s

The concept of magma is introduced by James Hall, as a result of laboratory experiments on the melting of igneous rocks, including basalt (or 'whinstone') from Scotland and lava from active volcanoes in Europe.

1883

Krakatoa's explosive eruption in Indonesia creates an ash cloud with global atmospheric effects, including brilliant sunsets in London. A scientific investigation of the eruption is published by Britain's Royal Society.

1902

The eruption of Mount Pelée in Martinique incinerates neighbouring St Pierre. The French scientific report that follows introduces the concept of a *nuée ardente* ('burning cloud'), later renamed as a pyroclastic flow.

1963

The hotspot theory proposed by John Tuzo Wilson explains the volcanic history of the Hawaiian Islands in terms of a moving tectonic plate and a stationary hot spot created by a mantle plume.

but to be newly solidified magma from deep down. The expedition's Dutch leader, RM Verbeek, decided that Krakatoa had ejected its magma chamber into the air, and the space had then been filled by the cone's collapse, creating a caldera or giant crater. He further suggested that seawater penetrating the magma chamber had provoked the mega-blast.

Today, Verbeek's first idea is generally accepted, but not the second. The mixing of magma and seawater usually gives rise to a distinctive deposit of very fine-grained, widely dispersed ash. No such deposits have been found at Krakatoa. Rather, the current view is that the main blast was caused by the violent mixing of two magmas: a basaltic magma injected beneath a denser, dacitic magma. The first magma, being less dense, rose buoyantly and abruptly, and an explosion resulted. The presence in the ejecta of both types of magma, in different proportions at different times during the eruption, supports this view.

Fatal flow

The cause of Krakatoa's tsunami is less clear. Some scientists have suggested an underwater explosion. Verbeek favoured either the slumping of the cone into the caldera, or the sudden displacement of water by hot gases and rocks 'falling' into the sea: in other words, what is now termed a pyroclastic flow. Such flows are a common and deadly feature of certain volcanoes. Pyroclastic flows probably smothered Pompeii and Herculaneum; they certainly occurred as a result of the lethal 1902 eruption of Mount Pelée in Martinique, where they were observed for the first time by scientists cruising past the ruins of the port of St Pierre in a sailboat.

"The cloud was globular, with a bulging surface covered with rounded protuberant masses which swelled and multiplied with terrible energy," the scientists wrote. "It rushed forward over the waters, directly towards us, boiling and changing its form every instant. It did not spread out laterally; neither did it rise into the air but swept on over the sea in surging masses, coruscating with lightning." The original term for the

PHOTO: THINKSTOCK, PRESS ASSOCIATION, NASA, ALAMY X2, SCIENCE PHOTO LIBRARY

NEED TO KNOW

A quick glossary of some key terms used in volcanology

1 MAGMA

Magma is a Latin term for molten rock, first used in chemistry to mean a pasty substance. Magma is formed at high temperatures inside the Earth, either within the upper mantle or at tectonic plate boundaries. It rises buoyantly into the crust to form pools, sometimes called magma chambers, which feed volcanoes.

2 IGNEOUS ROCKS

Igneous (from the Latin for 'fire') refers to rock formed either by the cooling and solidification of magma inside the Earth, such as granite, or by extrusion of lava on the surface through volcanic action, such as basalt. The most common volcanic rocks are basalt, andesite and rhyolite, in increasing order of silica content and viscosity.

3 PYROCLASTIC FLOW

Whereas a lava flow consists of molten rock, a pyroclastic flow (from the Greek for 'fire' and 'broken into pieces') is a fast-moving current of hot gas and rock, both solid and molten. Hugging a volcano's slopes and then spreading under gravity, pyroclastic flows can reach temperatures of as much as 1,000°C and speeds of up to 700km/h.

The September 2014 eruption of Mount Ontake in Japan claimed over 60 lives, and occurred without any warning

phenomenon, *nuée ardente* ('burning cloud'), was given by Alfred Lacroix in his scientific report on Pelée's eruption. With the introduction of plate tectonic theory in the 1960s, it at last became clear why volcanoes and earthquakes occur in certain areas. Where tectonic plates touch, the less dense plate is elevated and the more dense plate is subducted, for example beneath Japan. However, at volcanic rifts – such as the Mid-Atlantic Ridge – plates grow and begin moving as new rock is created by the extrusion of magma from the upper mantle.

However, plate tectonics did not give a coherent explanation of intraplate volcanoes, such as those in the Hawaiian Islands. So John Tuzo Wilson came up with his hotspot theory in 1963. According to this idea, the Hawaiian Islands were formed by a stationary, plume-shaped mass of magma rising from deep in the mantle and punching a hole in the Pacific plate as the plate moved in a northwesterly direction. If this is correct, the Hawaiian hotspot should have created a string of volcanoes trending to the northwest – each active for a while, then becoming extinct as it moved away from the hotspot. Its rocks should get older the further away the extinct volcano is from the hotspot's present site beneath Hawaii's Big Island. This is indeed the case. The rocks of the Hawaiian Islands do age towards the northwest, and there is a series of sunken, extinct volcanoes beneath the Pacific – the Hawaiian Ridge and the Emperor Seamounts – that trails off over 5,600km of seafloor towards the Aleutian Islands.

The rocks of extinct Kauai, the northernmost Hawaiian island, are five million years older than those of the Big Island, according to radioactive dating of ancient lava flows. This age agrees with the age predicted by the speed at which the Pacific plate is believed to be moving. The Hawaiian hotspot has generated some 200 volcanoes over 75 million years.

Vital though our understanding of volcanic eruptions is, it cannot forecast the behaviour of the world's 1,300 potentially active, landlocked volcanoes. Only constant monitoring of each volcano may provide this information. It saved thousands of lives in 1991, during the eruption of Mount Pinatubo in the Philippines. But it failed at Mount Ontake in 2014. Ontake erupted in 1979, 1991 and 2007, also without prior magmatic activity, although insufficient instrumentation was in place in 1979 and 1991 to rule this out.

Now, volcanologists charged with monitoring Japan's 110 active volcanoes are wondering if Ontake could be getting ready for a magmatic eruption. The problem is that this volcano does not have an easily predictable cycle. "It's a very quiet mountain," Toshikazu Tanada cautiously noted after the 2014 eruption. "Each active volcano has its own characteristics."

ANDREW ROBINSON is the author of *Earthshock* and *Earthquake: Nature And Culture*

What will our world look like when futuristic tech becomes a reality? **Duncan Graham-Rowe** investigates

New technology eventually blends in to our everyday lives. Smartphones as we know them today simply didn't exist 10 years ago, yet now there's one in virtually everybody's pocket. So how will coming technologies change the way we live? The designer Fernando Barbella gives us a glimpse of tomorrow's world in his blog, Signs From The Near Future. The signs, displayed on streets, vehicles and inside buildings, are a new twist on familiar scenes. Read on to find out when Barbella's signs might be part of the landscape.

Forget messing around with rockets to get into space. Instead, imagine getting into a lift on the ground, which then ascends through the atmosphere and up past geostationary orbit to a spaceport.

With a 'space elevator', vehicles climb up a vertical cable. The cable is anchored to the ground at one end, somewhere near the equator. The other end extends up and out, and is attached to a free-floating spaceport. This is potentially cheaper and safer than the usual rocket-based methods of space travel. Constructing a space elevator would cost between US$10-25bn and take about 10 years to build, according to Ted Semon of the International Space Elevator Consortium. The main challenge, says Semon, is finding materials that are sufficiently strong and light to build a 50,000km-long cable. "Carbon nanotubes are the leading candidate, but there are other possible options including carbyne, graphene and boron-nitride nanotubes."

Smart glasses fuse wearable computers with head-mounted optical displays, creating a mobile interface that allows digital information to be mapped onto the real world that you see before you.

The technology is dubbed as the ultimate augmented reality, and is seen today in the form of the Google Glass. The question is, is it here to stay? While undeniably attractive, the device relies heavily upon voice recognition (VR) software. Although VR has improved over the years, people tend to get annoyed when it gets things wrong, which is often. Considering the privacy and surveillance concerns that come with wearable cameras, along with the safety issues of being continuously distracted, we may start to see signs like the one below in all sorts of locations.

PHOTO: ISTOCK, FERNANDO BARBELLA

Would you be willing to hop into a driverless taxi? Thanks largely to companies like Google, autonomous cars are becoming a reality. In some UK cities, that reality is going to happen sooner rather than later. This March, Milton Keynes is planning on introducing driverless taxi 'pods' to its network of cycle lanes. Meanwhile, Business Secretary Vince Cable announced plans to roll out a £10 million driverless car trial in four UK locations, with tests kicking off from January.

So should we be worried? Far from it: the reality is that roads filled with autonomous cars promise to be far safer than those with humans at the wheel. The vehicles can potentially react far faster than humans, and their ability to do so makes it possible for speed limits to be increased. This also means that safety distances between cars can be reduced. Both of these factors should lead to less congestion and shorter journey times.

Driverless pods will soon be hitting the cycle lanes of Milton Keynes

PHOTO: ALL IMAGES BY FERNANDO BARBELLA

The movie *Interstellar* showed astronauts cryogenically frozen as they were carried beyond our Solar System. In reality, the most promising method of cryogenically freezing mammals requires all blood to be removed from the circulatory system and replaced with a chemical solution, before putting the body on ice. It's not clear whether cognitive brain function would survive. So NASA is looking at a less extreme approach, which wouldn't involve making the subjects clinically dead. Instead, a state of deep sleep or 'torpor' would be induced. NASA's research will assess the feasibility of a suspended animation chamber for future Mars missions.

For those trying to cheat death by buying freezer space in the hope that a cure for their ailments will one day be found, there's a catch. Even if a remedy does emerge, it's still not clear how the body can be safely defrosted without damaging it.

Jet packs have long been saving the day in films – memorably the James Bond movie *Thunderball*. This popularity has given them a perpetual status as a must-have technology of the future. The trouble is, we have been keenly awaiting this form of transport for more than half a century. So what gives? One of the main problems has been range. Jet packs typically only run for about 30 seconds, which is barely enough time to take-off before landing becomes a priority. But that's changing. In 2016, the New Zealand firm Martin Aircraft Company plans to bring out a commercially available jet pack that can fly for 30 minutes. "Our company's first target market is the First Responder [emergency] sector," says Peter Coker, the company's CEO. The trick comes from moving away from a traditional rocket design towards petrol-powered turbines. Now the main hurdle is regulation rather than technology. "One of the biggest challenges will be in getting the regulatory authorities comfortable with its operation and versatility of use – it is effectively a 'motorbike in the sky,'" he says.

Bitcoin is a digital currency or, more accurately, a digital cryptocurrency infrastructure that already exists and works. Although not yet widespread in the physical world, a number of restaurants accept Bitcoin, along with other retailers and businesses. Payment is as easy as bumping two smartphones together.

But why would we want or need Bitcoin, especially when its value fluctuates so wildly? It all comes down to who controls the currency. British Pounds and US Dollars are effectively controlled by nations, but Bitcoin is based on a peer-to-peer infrastructure, which means there's no equivalent of the Bank of England or the Federal Reserve. 'So what?', you might think. Consider that the global economy is still recovering from the worst recession since World War II, due in part to the risky behaviour of bankers, Bitcoin offers an alternative currency that is neither tied to bankers nor nations. Some argue that the more that people use it, the more stable a currency it will become.

PHOTO: XXXXXXX
PHOTO: FERNANDO BARBELLA X2, ISTCOK, PRESS ASSOCIATION X2

Lab-grown meat could feed a swelling global population

The Cultured Beef burger tasted just like real meat

What about a technology you could really sink your teeth into? Synthetic meat may not seem very appetising at first. But let's face it, the meat industry is already highly processed and research suggests that it is not sustainable in the long term. Meat has one of the largest carbon footprints of any food, while global population growth raises serious concerns about how demand for meat can be met in the coming decades. Synthetic meat, created from cells taken painlessly from a single cow, could produce 175 million burgers. This would normally require 440,000 cows, says Prof Mark Post, who led the Cultured Beef effort at Maastricht University in 2013 to create the first ever synthetic burger. "The cells grow into strands of small meat fibre and 20,000 of these are then combined to create one normal sized hamburger," he says. "It is biologically exactly the same as the meat tissue that comes from a cow." But it will still take at least a decade or two for the price to come down. The Cultured Beef burger came in at a cost of €250,000, which is far more than most people would be willing to fork out.

DUNCAN GRAHAM-ROWE is a scientific editor at Gavi, The Vaccine Alliance

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BIRDS *of* GOOD FORTUNE

Photos by Axel Gomille

Demoiselle cranes arrive in their thousands at the village of Khichan in Rajasthan, north-east India.

Villagers in Rajasthan rejoice in the huge flocks of demoiselle cranes that visit each winter, feeding, protecting and venerating them. **Derek Niemann** investigates how culture and religion can play a vital part in conservation

The villagers of Khichan have been feeding demoiselle cranes for four decades

It may be the world's biggest, most well-mannered and least likely bird table. The daily arrival of up to 15,000 wetland birds in the middle of a desert village has become one of northern India's great wildlife spectacles. But when dawn breaks, there are no tourists, no hotels and no birds in sleepy Khichan.

Photographer Axel Gomille has travelled across the Thar Desert by rickshaw in darkness to reach Khichan for sunrise. He arrives at a fenced enclosure of hard-baked earth about the size of a football pitch, where he sees a man in a bright red turban dragging a large sack into the enclosure. The man opens the bag and begins scattering grain on the bare earth, before going back for one sack after another. This is birdfeeding on an industrial scale.

Everyone hears the cranes coming. The locals refer to them as kurja and Nepalis call them karyang karung, both representations of the harsh bugling cries that fill the air before the birds are even visible. There is a special phrase for the first view of the demoiselle cranes – maala chari, "a garland of string", describing the great V-formation flocks.

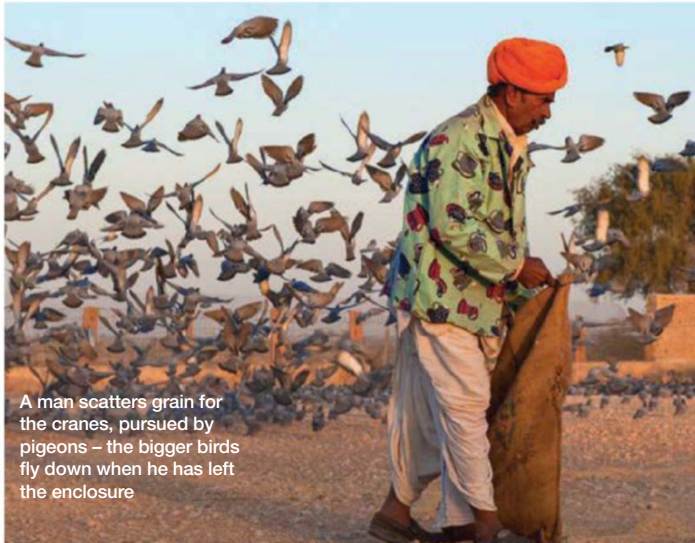
"Khichaners put out staggering quantities of grain for the demoiselle cranes: some 1,500kg to 5,000kg daily"

"When the squadrons of birds arrive, they queue up and wait on the sand dunes nearby, and drink from the village ponds," says Gomille. "So long as there is someone inside the enclosure, they won't go in. But as soon as he leaves, they land inside. There is space for a couple of hundred cranes at a time. When they take off, the next 200 come in."

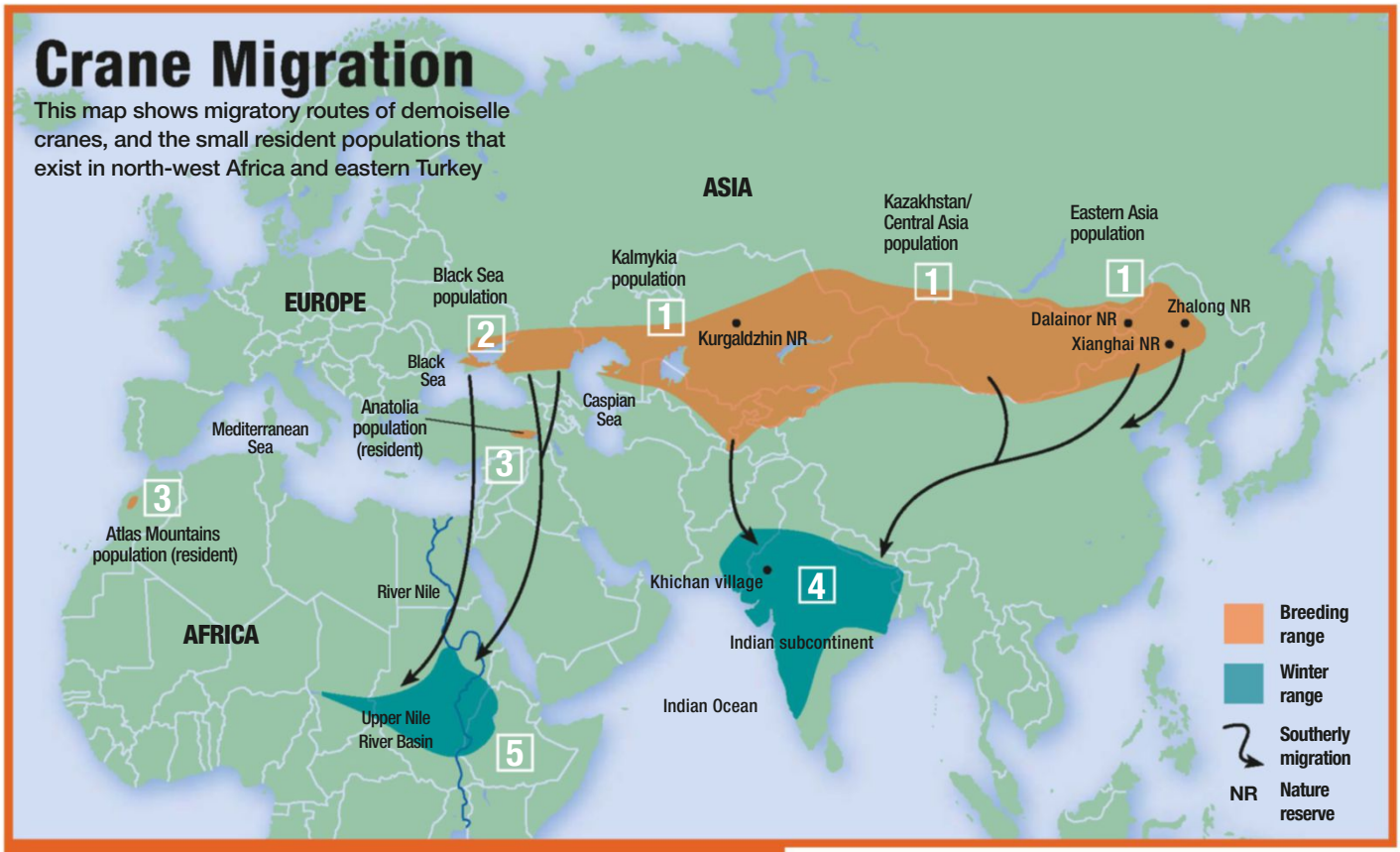
The slender birds are crammed together in the enclosure, grey-bodied and with smart white combovers on black heads which swivel in unison. "A wildlife paradise right next to the bus stop," marvels Gomille. "It takes maybe two or three hours until the whole flock are fed. Then they go to nearby ponds to drink and rest on the dunes, waiting for the heat of the day when the thermals start to form. They fly higher and higher until they are little dots in the sky, and are gone. I don't see them again until the next day."

A 40-year tradition

Both birds and people have become accustomed to enacting this great performance day after day, every day between the end of November and the middle of March. What began about 40 years ago, when villager Ratan Lal started feeding a few cranes in his back yard, has grown into an enormous operation. Khichaners now put out staggering quantities of grain – an estimated 1,500–5,000kg daily.



A man scatters grain for the cranes, pursued by pigeons – the bigger birds fly down when he has left the enclosure



Based on information from the International Crane Foundation (www.savingcranes.org)

1 The three eastern breeding populations in Kalmykia, Kazakhstan/Central Asia and Eastern Asia each consist of tens of thousands of birds, which nest in dry steppe grassland – often near water.

2 It is a different picture farther west, where fewer than 500 pairs of cranes now breed around the Black Sea. This population is fast declining due to agricultural intensification and hunting.

3 Two small, non-migratory populations are classed as Critically Endangered: a Turkish one in Anatolia, and another in the Atlas Mountains in north-west Africa.

4 Eastern cranes migrate south to the Indian subcontinent for the winter, flying at over 8,000m to cross the Himalaya. In winter they use a wide range of habitats including lakes, rivers, marshes, ponds, fields and stubble left over after rice harvests – even deserts, if water is nearby.

5 Black Sea breeders migrate via the Middle East to a wintering range in Sudan and Ethiopia. Here the birds frequent savannah, grasslands and riverside habitats.

The sound of cranes taking flight is a mix of beating wings, bending feathers and constant calls

The numbers of cranes visiting this desert location in Rajasthan has built up over the years. "Migrating flocks of demoiselle cranes occur practically all over India, so Khichan was always on their natural migratory route," says Gopi Sundar of the International Crane Foundation (see box, above). "It seems that parent birds began by bringing their chicks in tow, then their young did the same with their offspring, and so on. Also, since the food source at Khichan has been relatively stable for several decades, other cranes in this flocking species have learned to fly to the village, too."

Khichan is far from wealthy, so for local people to actively encourage cranes is remarkable. "In fact several areas in India are notable for their tolerance of wildlife and lack of persecution," Sundar points out. "It's most welcome that so many people do not harm wildlife, even with species such as cranes that can cause obvious damage to crops. The reasons seem to stem from a deep-rooted belief system in rural areas, which dies out in an urban environment."

Birdfeeding on a national scale

There is a long tradition of birdfeeding in India. "The great handouts of grain at Khichan mirror a similar practice adopted on a smaller scale by thousands of people in the countryside, who feed birds that visit their front yards and rooftops," says Sundar. "Peafowl, partridges, pigeons, parakeets, pheasants and even a rare owl or two are all cared for. Perhaps the basic impulse is simply that these are lovely birds, so they must be fed."

All the indications are that religion is fuelling good deeds in this village. "Khichan is a Jain community and its residents consider the demoiselle cranes to be holy," says Gomille. "It's a perfect example of how wildlife can benefit from

Marie Antoinette dubbed the birds 'demoiselles' when the cranes were brought from Russia to the French court – and the name stuck

religious beliefs. The people do the birds good, and believe that the practice will in turn do them good, too."

Jainism is an ancient religion that teaches concern for all life, but it could be that there is another explanation for the Jainists' generosity. Belief in reincarnation is widespread in India, so perhaps it is a form of 'life after death' insurance policy, whereby good deeds will be recouped in the next life. This way of thinking is stated explicitly on an information board at Rajasthan's world-famous Bharatpur nature reserve. Referring to a related waterbird, the Critically Endangered Siberian crane, the sign reads: "In your next incarnation you might be an endangered species. Help us save the Siberian crane."

Follow the money

The self-interested philanthropy at Khichan does not come cheap. Octogenarian Sevaram Malli Parihar organises the whole community to help feed the birds and maintain the fences, which keep out feral dogs and children who might otherwise chase the birds, but these are poor people who cannot afford the grain themselves. So who pays? Some of the world's wealthiest industrialists are themselves Jains with family roots in the villages of the Thar Desert, and it is they who are sending money home to pay for crane food.

The villagers are clear-sighted about the science of what they are doing. "When all this started, it might have seemed like a miracle. Out of nowhere, thousands of birds suddenly appeared in the skies," says Gomille. "But that's not the case now. Even an illiterate man or

SPIRITUAL CONSERVATION

Four more examples of faith fighting for wildlife

Misali Island, Zanzibar

The fragile coral reefs off the island of Misali were under threat when local Muslim fishermen began using guns and dynamite to boost their catches, ignoring government regulations. They only stopped when Care International worked with the community's religious leaders to show the fishermen how Islamic teachings emphasise the importance of protecting the environment.

Wat Phai Lom Temple, Thailand

In 1970 a Buddhist temple near Bangkok became the country's last refuge for the Asian openbill stork. The monks agreed to the grounds of the Wat Phai Lom temple becoming a nature reserve, protecting the bird from hunters. The species flourished – a peak population of 30,000 may have constituted South-East Asia's biggest breeding colony. It has now spread to other parts of Thailand.

Buabang-Fiema Monkey Sanctuary, Ghana

Almost all of Ghana's 240 forest reserves contain 'sacred groves' treasured by local communities as the homes of their gods and the ancient burial grounds of their ancestors. A striking example is at Buabeng-Fiema Monkey Sanctuary, where black-and-white colobus and Lowe's Mona monkeys are perceived as 'children of the gods' and given special protection.

Little Campbell River, Canada

On the degraded Little Campbell River, south of Vancouver, volunteers from the Christian conservation organisation A Rocha Canada are working to restore the spawning grounds of Pacific salmon and other threatened species of fish. They work with First Nation communities, landowners and local government to raise awareness of the importance of the river to local communities.

Zanizibar: P Oxford/NPL; Wat Phai Lom: N Supagrit/Alamy; monkey: REX; salmon: Superstock; Japan: Reuters/Corbis

Crane feeding around the world

Feeding cranes doesn't just happen in India – it's a global phenomenon. In the USA, for example, a few nature reserves located along the migratory routes of sandhill cranes grow diversionary plants specially for the birds, in order to keep them away from any agricultural crops. And in Japan about 90 per cent of the global population of hooded cranes flocks to one artificial feeding site at Izumi in the south, while red-crowned cranes use another artificial site in Hokkaidō in the north.

woman knows a great deal about the cranes and where they come from, because people have told them." Opinions differ as to whether there are direct tangible benefits to the species or the village itself. "It is difficult to say whether the artificial feeding has any conservation merit," says Sundar. "The demoiselle crane is the third most abundant crane species in the world, so it may not actually need conservation interventions by way of supplementary feeding."

In fact the birds are at risk of catching diseases when they congregate artificially in a rural setting – theoretically. "To date there have not been any outbreaks among the gatherings of cranes," reveals Sundar. "This suggests that while the threat potentially exists, it is very low."

In any case, it is unlikely that the cranes are consuming enough grain to meet their entire dietary requirements at Khichan alone. They still flock to the surrounding fields to feed. "Several villagers have expressed their concern that more and more crops are being eaten by the birds over the years," admits Sundar. And with no hotels or other tourist infrastructure whatsoever, the villagers are gaining no material boost from their labour.

That the cranes appear at all is something of a twice-yearly miracle. The chicks are raised in the dry steppe grasslands of Central Asia and then the families migrate south to India together in October. Rajendra Suwal of WWF-Nepal, who has been counting the cranes on migration for over 20 years, is fond of reciting a simple Nepali rhyme about the birds, linked to the growing year. The rough translation: "In spring, the cranes arrive, sow cucumbers and pumpkins. In autumn, the cranes arrive, eat cucumbers and pumpkins."

The trials of flight

Suwal observes these graceful migrants on the most perilous part of their journey – their passage over the snow-clad Himalaya. "The ideal for these birds is to fly high using thermals," he says. "But in adverse conditions, such as strong wind, rain or blizzards, they are forced to travel lower and in stages, stopping in fields and on riverbanks. Here they are at risk from hunters and opportunistic small boys armed with sticks."

"With no hotels or other tourist infrastructure, the villagers are gaining no material boost from their labour"

There are natural predators waiting, too: golden eagles. One autumn, cameraman Barrie Britton accompanied Suwal to the dramatic valley that lies in the shadow of the giant mountain Annapurna to film this spectacle for the BBC One series Planet Earth. "The passage of young cranes provides an unlikely autumn bonanza for the eagles," says Britton. "Though demoiselle cranes are fairly small by the standards of their family, with a wingspan of 1.6–1.8m, they are still relatively large birds for a raptor to target in mid-air. It's incredible to see the eagles hunting such big birds."

By the end of February, after around three months of feeding cranes, Sevaram and his fellow Khichaners will not need to carry on much longer. In just a few weeks the birds will depart and head north for the Himalaya once more. Benign air currents mean the northward flight is easier. "Springtime is dry and hot, so thermals of rising air build up with help from warm air from the Rajasthan Desert and the Indian plains," says Suwal. "The cranes take advantage of these thermals to gain altitude and speed them on their way."

When the trumpeting flocks depart, Khichan falls silent again. And villagers in Nepal will look to the skies, see those graceful fliers high overhead and know that it is pumpkin time.

DEREK NIEMANN is an author and conservationist who writes for the Guardian's Country Diary.

Above left: demoiselle cranes migrate as a family group, helping to pass on the route to juvenile birds. Above: these conservationists, in protective suits, were photographed at Izumi in 2010 – a hooded crane had been found with bird flu.

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PHOTO: ENVIRONMENT AGENCY

10 WAYS TO BEAT THE FLOODS

Last year, the UK suffered widespread flooding. Here, Tom Heap investigates projects that could help us stay dry in the future...

Medmerry is now protected from the sea by a new wetland habitat

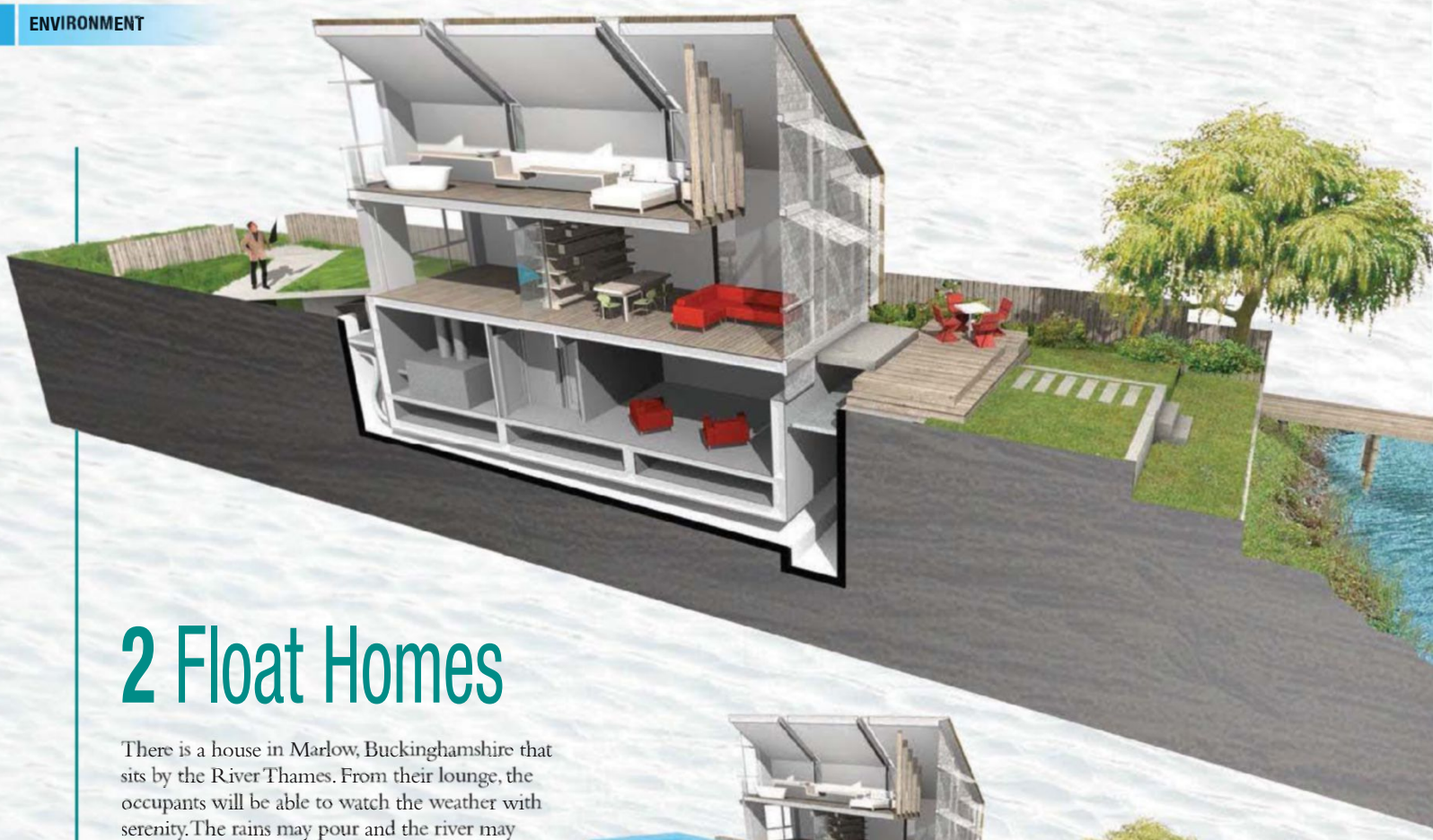
The Earth's weather, encouraged by climate change, seems to be becoming more unpredictable. In some parts of the world, rains are getting heavier and storms are intensifying. A Royal Society report published in November 2014 stated bluntly: "Climate change will drive wet regions to become wetter".

Urban populations are starting to swell, but this is hugely problematic as many of our big cities are built on large rivers or near the coast, which puts residents at risk when the tides start to rise.

So what can we do to beat the floods? Read on for 10 innovative solutions.

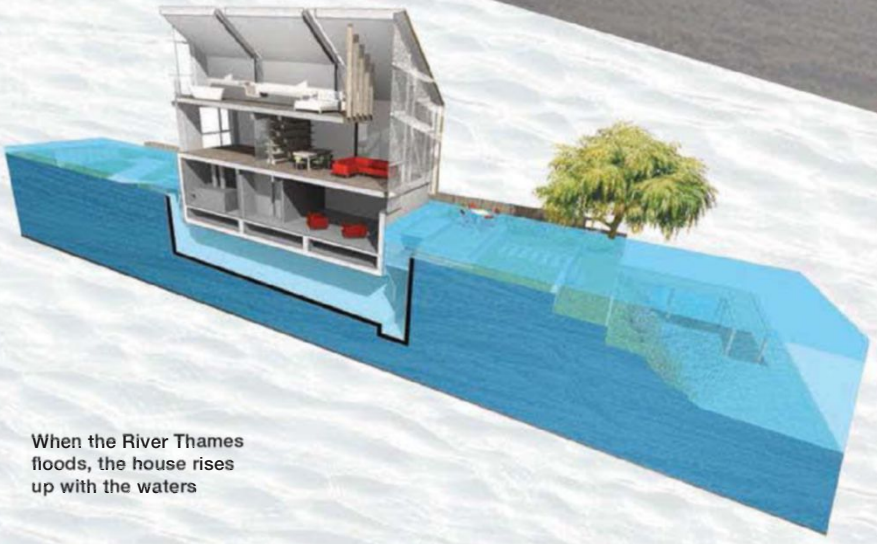
1 Tactical Retreat

Hard sea defences, such as concrete, are rather out of fashion. The ocean often batters them into submission after a few years, or they just deflect the destructive energy elsewhere. In November 2013, the sea wall at Medmerry, West Sussex was scuttled in Europe's biggest coastal realignment. The Environment Agency built 7km of sea wall further inland, and the farmland between the barrier and the ocean became a salt marsh. This new wetland habitat is great for birds, but is also able to absorb the power of the sea and reduce the flood risk for hundreds of homes. It's too early for definitive proof of success, but the locals stayed dry in the storms of January 2014.



2 Float Homes

There is a house in Marlow, Buckinghamshire that sits by the River Thames. From their lounge, the occupants will be able to watch the weather with serenity. The rains may pour and the river may rise… but so will their house. Most of the time, the structure rests on the riverbank, surrounded by a garden like any other home. While it looks like a modern house from the outside, the cunning part lies beneath the main building. Waterproof concrete wraps around the basement level, and this sits in a reinforced yet porous hole in the ground. When the floods come, the whole house floats up, guided by four vertical posts. The dwelling can rise by a whopping 2.5 metres. It is the first house of its kind in the UK and the owners hope to have it installed by the start of 2015.



When the River Thames floods, the house rises up with the waters

Worcester floodwaters in February 2014

3 Be Water-Resistant

As many as five million homes are at risk of flooding in England. These houses won't be knocked down soon, so it makes sense to retro-fit the buildings rather than construct new ones. Houses can be fitted with floodproof doors to prevent water from seeping across the threshold. Ventilation bricks can be equipped with covers, or can even be replaced with ones that close up automatically as water approaches.

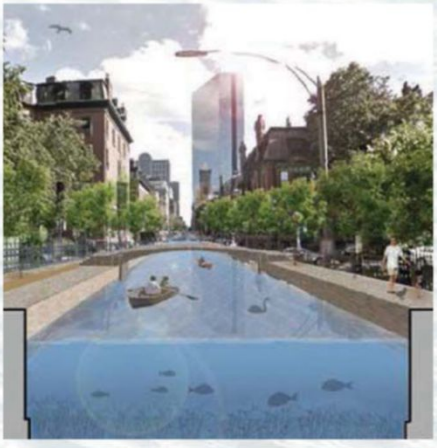
After 24 hours in a flood, water may start to ooze through the walls of houses. However, if the exterior is given a water-resistant nano coating, then this problem is prevented. Solid floors, magnesium oxide wallboard and waterproof paint can help keep repair costs down if floods manage to enter someone's home.

PHOTO: BACA ARCHITECTS X2, ALAMY, CORBIS, GETTY

4 Recruit Beavers

Beavers are famous for building dams and are natural river basin engineers. Following serious floods in the UK during the winter of 2013-14, The Mammal Society recommended a widespread reintroduction. In Scotland, there is currently a trial release of beavers taking place in Knapdale, and the first batch of reports was released in November 2014. Valleys where beavers thrive are a patchwork of ponds and dams, creating a massive natural sponge that holds and slows the flow of rivers. In Pickering, Yorkshire, The Forestry Commission and other landowners are trying to replicate beavers' methods by creating a network of dams, bunds and wet woodlands. This should help prevent the impact of floods, without splashing out on expensive and unsustainable defences.

Dam built by beavers in Knapdale, Scotland



Concept of a canal network in Boston, Massachusetts

5 Replace The Roads

Could Boston become the Venice of New England? Planners, scratching their heads in the face of increased local rainfall, rising sea levels and low-lying districts, suggested replacing the roads of Back Bay with canals. This would create a network of channels, pumps and sluices linking to new wetlands, enabling the management of water rather than its exclusion.

A similar philosophy underpins plans for a development on Deal Ground in Norwich. The site is prone to flooding, so Baca Architects wants to put 40 per cent of the houses on stilts and the rest on raised land. Waterways between buildings will be dug unusually deep to accommodate excess water, and will help irrigate nearby wetlands. Baca Architects claims that the 670-home development will alleviate flooding pressure downstream.

6 Remove The Rain

Jakarta floods regularly. In the last 20 years there have been four serious events – these have claimed hundreds of lives and cost millions of dollars in damage. The worst floods take place when high tide meets heavy rain, so the government's Weather Modification Technical Unit decided to make the rain fall elsewhere. They are using cloud seeding, which involves spraying particles into the clouds to encourage ice crystal formation and trigger rain. Planes have been scattering tonnes of salt above the ocean, therefore causing it to rain at sea rather than on land. While officials claim to have cut precipitation in Jakarta, many academics question this conclusion and want more proof. The authorities are undeterred and are requesting more aircraft for weather modification in 2015.

Workers in Jakarta loading salt, which will be transported to aircraft for cloud seeding

7 Farm On The Water

To survive when the waters rise, we need food as well as shelter. In Bangladesh, where floods are a fact of life, floating gardens have been created. A raft of water hyacinth, which is a buoyant and persistent plant, is assembled and held together with bamboo. A layer of dung, soil and compost is applied, into which the crops are planted. Typically, one of these floating vegetable patches is about 1m x 8m, so it can be tended from a boat and towed to the marketplace. Bangladesh is also pioneering floating duck coops, allowing locals to sell eggs as well as veg.

8 Live Underwater

For around US$9m you could live beneath the waves, just like the Bond villain Blofeld. The H2OME dwelling, which is built by US Submarines Inc, is an underwater lair that is accessible via a spiral staircase from your own private floating pier. The 464 square metre structure sits 10-18 metres below the surface – the shallow depth means that the living space doesn't need to be pressurised. As most of the light and life in the ocean is situated just beneath the waves, the H2OME will truly offer a room with a view.

As fewer than 100 underwater habitats have been built in the last 50 years, it could be argued that our survival rests on keeping our heads above water rather than slipping beneath the surface.

As Sebastian from *The Little Mermaid* would say: "Darling it's better, down where it's wetter, take it from me!"

PHOTO: PRACTICALACTION.ORG, CORBIS, BIG U/REALBUILDBYDESIGN.ORG, US SUBMARINE STRUCTURES

The city of Jeddah after floods hit in January 2011

9 Release The Drones

Early warning systems can mean the difference between life and death. But predicting the path and volume of water, especially flash floods, is very difficult. Even Saudi Arabia, which is an arid region, has seen 100 people killed by flash floods in the last five years. Scientists from Jeddah have been working on a drone system to give up to two hours notice before a flood hits. Once a flood is deemed likely, 10 minicopters take to the air and drop wireless sensors across the region. If the sensors land in floodwater, the drones track their progress. The data gleaned creates a map of the flood's movement, therefore allowing authorities to deliver accurate evacuation alerts. The sensors only have to ping their location over a short range, so their design can be simple, cheap and disposable.

The Big U would hug Manhattan's edge and feature waterfront parks

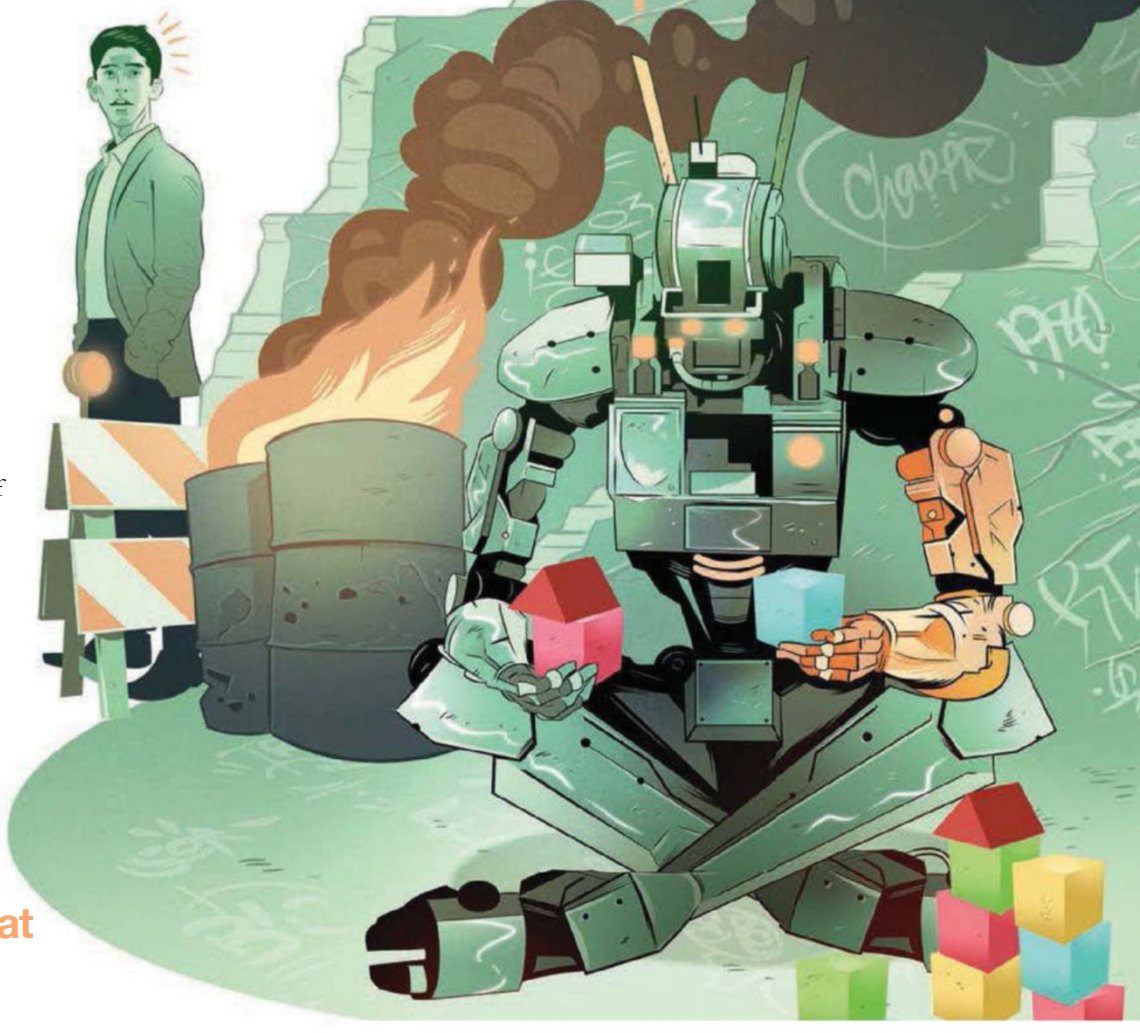
10 Big Walls

When towering skyscrapers are being lapped by rising oceans, there really is only one survival strategy: a sea wall. Hurricane Sandy struck New York in 2012, killing 53 people and causing almost US$20bn of damage. To prevent destruction on this scale again, a wall is going up around the Big Apple. The 'Big U' is being masterminded by Danish and Dutch engineers, and will wrap around 16km of lower Manhattan's coast at a cost of US$335m. To maintain the city's identity, the structure will be hidden within landscaped areas.

TOM HEAP is a regular television presenter on *BBC Countryfile* and *Panorama*

HOLLYWOOD SCIENCE

Conscious robots in Chappie



Hollywood loves a sentient robot. R2-D2, Johnny Five, WALL-E and Optimus Prime are often more animated than the characters they play alongside. This month meet new 'bot on the block, Chappie, in Neill Blomkamp's sci-fi comedy of the same name. Chappie, who looks like the Iron Giant with bunny ears, can think and feel for himself. But how close are we to making a conscious computer?

"No one has made a conscious robot yet," says computer scientist Prof Peter McOwan from Queen Mary, University of London. "But with enough understanding of human consciousness, hard work and investment, it could possibly be done."

The first hurdle is to define consciousness. This has been flummoxing us for centuries. The truth is, it's far easier to define unconsciousness than its more elusive antonym. Consciousness is embedded in a complex matrix of neural circuits, but we don't know how this translates into thought or self-awareness. With a definition in the bag, the next step would be to somehow model consciousness and then design the circuitry needed to generate it. Consciousness would then need to be measured, which is difficult to do. "There are a few projects going on in the world with varying degrees of success," McOwan says. Some believe that generating human-like consciousness will depend on having a human-like body, so a long-legged Chappie may prove more self-aware than *2001: A Space Odyssey*'s disembodied HAL 9000.

"What's the point of having a hammer that worries about its hammer-y-ness?"

It'll also be important to build in social intelligence. McOwan has helped design a robot that can recognise and respond to emotion. The robot, iCat, is a chess-playing moggy that gauges the gaze, facial expression and body posture of an opponent. It responds by making appropriate expressions and remarks back. An empathic cat – there's a first. Kids build up a real social relationship with the kitty and McOwan's hope is that responsive computers of this kind may find a place in education – as long as they don't start bringing decapitated robot birds into the classroom.

But why would we want to build a conscious robot? Some argue that building one would shed light on the nature of human consciousness, but I think that Hollywood is more interested in the idea than anyone else. It's worth thinking just how practical such a machine would be. "What's the point of having a hammer that worries about its hammer-y-ness?" says McOwan. It's a good point. Remember Marvin the Paranoid Android? Who'd wish existential angst on their DIY tools? Not me.

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

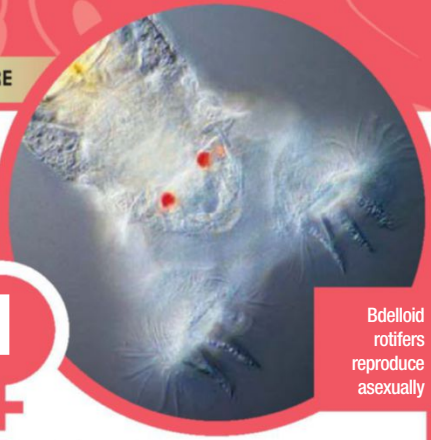
ILLUSTRATOR: ALEXANDER WELLS

10 THINGS YOU DIDN'T KNOW ABOUT REPRODUCTION IN THE animal kingdom

Nature has come up with many weird and wonderful ways of swapping genes. Here **Jules Howard** celebrates the most surprising secrets

Two Drosophila melanogaster mating. The sperm of this fruit-fly is 40 times longer than the human variety

Solvin Zankl/naturepl.com



Bdelloid rotifers reproduce asexually

1

World with no males

Reproduction costs a lot of energy, so why not evolve to bypass it altogether? Well, one group of animals has.

Bdelloid rotifers (the 'b' is silent) are tiny creatures found in bird baths, ponds and puddles. When wet they come to life and hoover up micro-organisms. When conditions become dry again they shrivel up into a ball and are blown from place to place. There are billions of them on Earth, and every single one is female. Without mixing up their genes through reproduction with males in perhaps 40 million years. The rotifers should fall prey to bacteria and viruses, their defences outmanoeuvred. Yet they are still here. How? It seems that drying up then blowing from place to place may allow them to outflank and outlast their parasites. In their world, males add no genetic value.

Eggstraordinary

Reproduction using eggs and sperm is like a lottery. Some species hope for success by investing in thousands of cheap tickets, whereas others buy fewer tickets that offer a safer return. Fish are some of the world's most frivolous gamblers. Among the most prolific vertebrate egg-layers is the ocean sunfish – it's believed that the female produces as many as 300 million eggs in a single spawning event.

The largest eggs in the world are also produced by fish. Whale shark pups hatch from enormous egg capsules within the mother's body. Each capsule measures over 30cm long, and females may produce more than 300 at a time. Interestingly, a whale shark's diet is rich in the free-floating eggs of other fish species.

2

Pandas are good at it

Giant pandas are widely chastised for being unable to 'get in the mood' in captivity, and for having a window of ovulation (about 36–48 hours) too tiny to be practical. The reproductive life of Edinburgh Zoo's Tian Tian and Yang Guang shows just how difficult it can be to encourage the species to breed normally in captivity. But in the wild, pandas are masters of reproduction.

Even though their territories can be enormous, males and females locate one another at exactly the right time for ovulation, primarily by monitoring chemical messages left on trees via squirts of urine. They also communicate vocally. Males bleat when they approach a reproductive female, possibly offering an opportunity for her to assess his size and strength. A female in oestrus often mates with several males, so they have evolved one of the highest sperm counts of all bears, to better guarantee any offspring is theirs.

As our understanding of the animal's wild breeding improves, zoos adapt accordingly. For example, keepers liberally apply the urine of potential partners to panda enclosures in the run-up to breeding season. However, the use of other panda stimulants is much more controversial.

1. Wim van Egmond/Corbis; 2. Eric Baccaga/naturepl.com; 3. Alamy; 4. Corbis; 5. Alamy

China's panda-rearing facility at Wolong is one of only a few centres in the world able to captive-breed pandas regularly

3 Girls who are boys

Many animals, especially fish, switch between egg-producing (female) and sperm-producing (male) phases during their lives. For instance, in many reef fish all of the juveniles are females and become males as they grow. These are known as 'sequential hermaphrodites', a phenomenon very common across a number of taxonomic groups.

In invertebrates, particularly slugs and snails, things go a step further – individuals possess male and female genitalia at the same time. In fact many slugs and snails even have the ability to fertilise their own eggs.

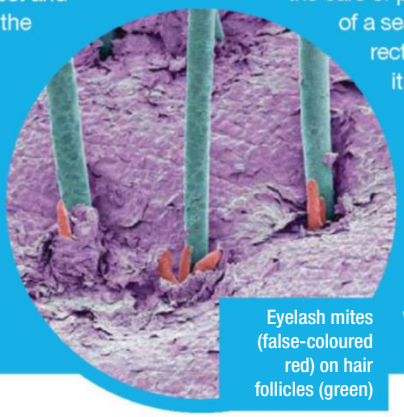
With such flexible reproductive equipment, it's no surprise that a number of invasive species are hermaphroditic. Among the most worrying is the Spanish slug, which has become a serious agricultural pest across much of Europe. A single egg transported in a flowerpot is all it takes to unleash this master and mistress into new places.

The Spanish slug can lay up to 400 eggs a year

4 Reproduction on the moon

The diversity of mites' sexual behaviour is staggering. There are mate guarders, harem keepers, warring males, macho show-offs, incest and cannibalism. Perhaps the most celebrated of all is the red velvet mite. Males create trails of silk in their territories that direct females to little packages of their sperm, called spermatophores. If one approves, she will absorb the sperm into her body.

Species of mite are everywhere – in the noses of seals, on the legs of chickens, in the ears of porcupines, in the middle of a sea urchin and within the rectums of bats. In fact it's likely that eyelash mites are reproducing on your face right now. It's probably the only animal to have reproduced on the moon, carried by the 12 men who have walked on it.



Eyelash mites (false-coloured red) on hair follicles (green)

5 Singing genitalia

The variety of male genitalia in the animal kingdom is jaw-dropping. There are fin-like ones (sharks), barbed ones (cats, beetles and dragonflies), regenerative ones (seaslugs), lobes (turtles), hooks (mosquitofish), finger-like extensions (barnacles) and a detachable swimming apendage (the Argonaut octopus).

Some have become adapted for other sexual purposes. The lesser water boatman (right) frantically rubs its genitals against a special comb-like structure on its body to pump out a mating call equivalent to almost 100dB. Relative to size, it's the loudest animal on Earth.

Micronecta scholtzi is only 2mm long

6 The value of DIY

One of the greatest mysteries is why so many animals seek to pleasure themselves, rather than find reproductive opportunities with others. Lions, bats, walruses, warthogs, whales, dolphins and deer are just some of those known to partake in such 'auto-eroticism'. Are such behaviours evolved, or are they emergent phenomena associated with something else, such as captivity?

The marine iguana is one species where auto-eroticism is common – smaller males rub themselves against rocks as they approach reproductive females. The behaviour means that their resultant copulations are shorter, so smaller males are less likely to be interrupted by bigger, burlier rivals. According to research, the strategy is likely to increase their chances of a successful mating by 41 per cent – easily enough to be evolutionarily significant.

Dolphins are famous for being adventurous. Here a bottlenose is trying to mate with smaller Atlantic spotted dolphins

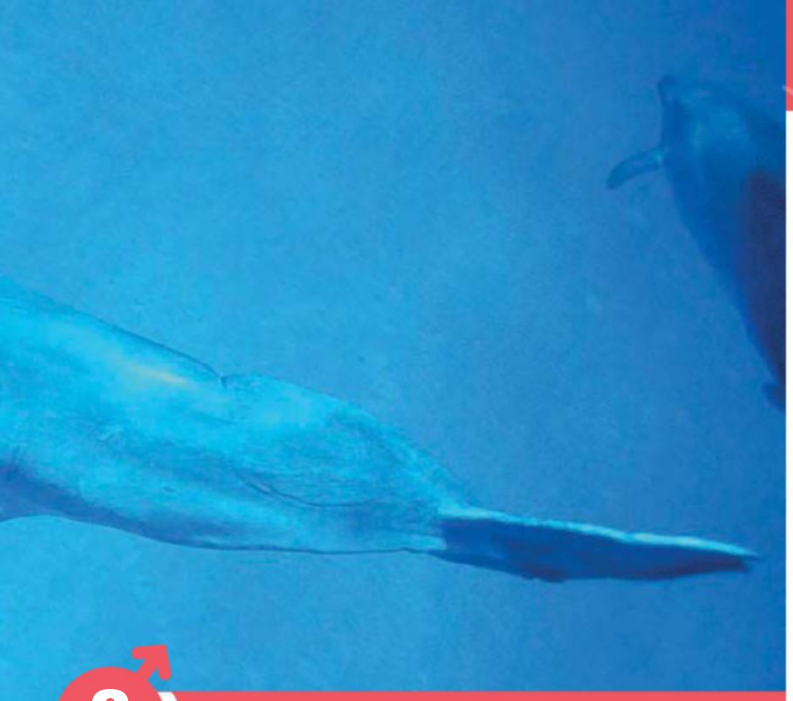
7 Monogamy is hard to find

Monogamy rarely flourishes in animal groups because fidelity limits an individual's reproductive potential. It only persists among the species where the result is a higher number of healthy offspring.

In birds, where the raising of chicks may demand care from both parents, monogamy arises fairly frequently. But it has popped up in other species and groups, too: antelopes, prairie voles, some cichlid fishes and the Australian sleepy lizard (also known as the shingleback skink). None of these are true monogamists though – each may be inclined to change partners between seasons.

Though many consider swans, albatrosses and emperor penguins to be nature's most virtuous couples, all of these pale in significance compared with Eurasian bullfinches and jackdaws. Bullfinches are highly monogamous, and as a result males are modestly endowed and produce poor-quality sperm, not having any need for more sophisticated reproductive mechanisms. On the other hand, jackdaws remain faithful for life and stay near their partners year-round, even within bustling and complex colonies. They are perhaps the most monogamous of all common birds.

Jackdaws mate for life. The mutual preening between this pair reinforces their bond



8 Mutual attraction

Though animals rarely eschew reproduction totally with the opposite species, hyenas, lions, whiptail lizards, dragonflies and bed bugs through to orcas, koalas, barn owls, king penguins, mallards, sticklebacks and rattlesnakes, to name but a few, do exhibit such tendencies.

According to the experts, bottlenose dolphins indulge in them as much as heterosexual activities.

Only in recent years have scientists begun to lift the lid on the evolutionary causes that may be responsible. Though such animals in vertebrates obviously suffer from lower reproductive outputs, there may be evolutionary benefits such as kin selection, whereby non-reproductive offspring enhance the survival and reproductive chances of their siblings, ensuring their own family genes persist.

9 Duck dramas

Being largely internalised soft structures, female genitalia can be tricky to study. Among the best understood are ducks'.

Intense competition between male ducks has done remarkable things. They have evolved one that can be 'exploded' into a female's reproductive tract, giving a male a greater chance than his rivals of successful fertilisation. In response the female reproductive tract has evolved into an anti-corkscrew, with pockets and dead ends. By modelling the tract of Muscovy ducks, scientists found that she can rebuff unwanted sperm – her reproductive passages only loosen enough to grant access to the males that she deems worthy. They're the ones with the brightest bill, for those are most likely healthiest and less likely to be infected with diseases.

Mallard reproduction is often a rough affair

Super-sperm

Just as natural selection chisels animals into all sorts of shapes and behaviours, it also works on their sperm. Famously members of the fruit-fly family have some of the longest sperm in the animal kingdom: those of Drosophila melanogaster are visible to the human eye, being almost 2mm long (about 40 times longer than ours), while other species have sperm cells an order of magnitude higher. Why do fruit-flies invest in such lengthy sperm? The female's lengthy and convoluted reproductive tract (itself only slightly longer than the sperm) may be the reason, or long sperm could be an adaptation to block the sperm of rival males.

10 Fatal attractions

Episodes of reproduction that are so intense the animal dies, known as semelparity, evolve when it pays more (in terms of offspring) for males and females to invest everything in one act than to stay alive and breed again next year. The Pacific salmon is a good example.

Though not strictly semelparous, frogs and toads often live their last days during the breeding season. The energetics of mating are arguably worse for females than males – competition can be so intense that she drowns under a mass of rival suitors. But when this happens in the frog Rhinella proboscidea, death doesn't spell the end – the males practise 'functional necrophilia', squeezing eggs from dead females which they fertilise in the water.

For Rhinella proboscidea, reproduction is a matter of life after death

JULES HOWARD is a naturalist and blogger whose new book: A Celebration of Animal Reproduction is out now (Bloomsbury Sigma).

The Future Of Gadgets
TECH HUB

Edited by **Daniel Bennett**

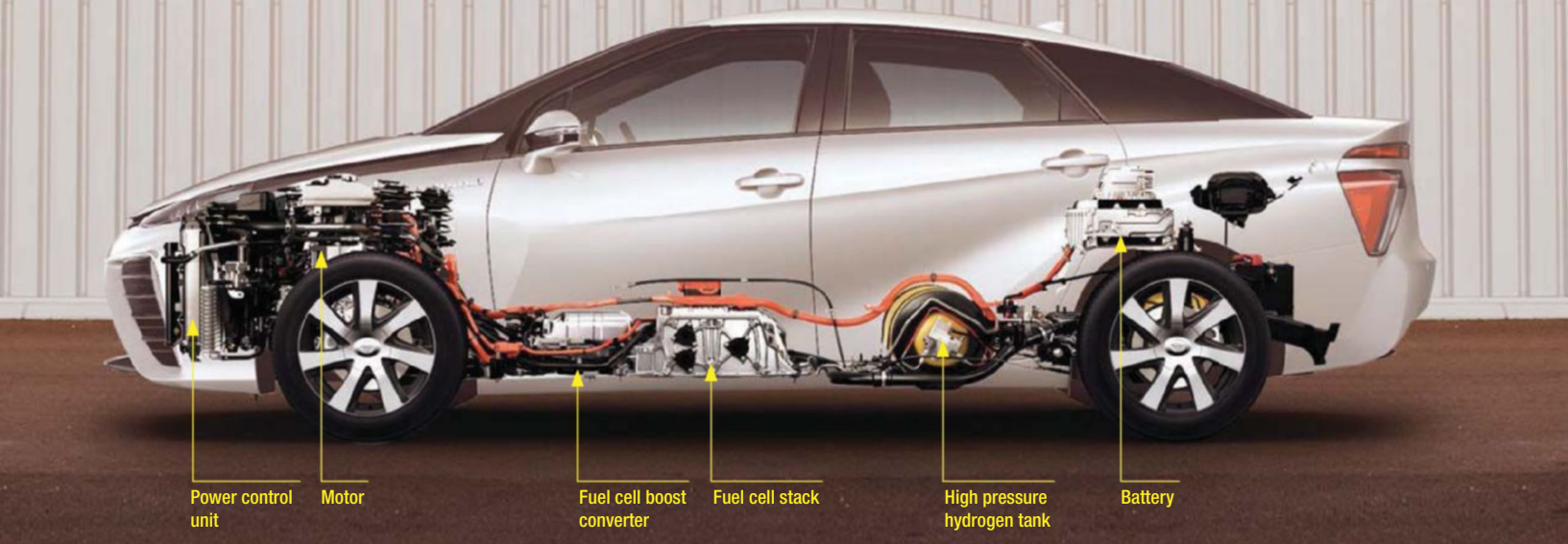
On The Horizon

TOYOTA MIRAI

Hydrogen fuel cell car

Toyota.com

words: **DANIEL BENNETT**



At the turn of the millennium, Toyota introduced the world to the Prius. This hybrid car paired an electric motor with a combustion engine.

The Prius's sales figures proved that there was an alternative to petrol and diesel cars, and motorists were hankering after something kinder to the planet.

Today, nearly every car manufacturer, from Porsche to Peugeot, now sells a hybrid model. So when Toyota described their latest car model as a "turning point" in history, we thought that we ought to take a look.

This "turning point" is called the Mirai – which means future in Japanese – and it's powered by hydrogen fuel cells. More precisely, its fuels cells use hydrogen and oxygen to create electricity, which then powers an electric motor hooked up to the wheels. The byproduct of the reaction is H_2O, so the only thing that will leave the car's exhaust will be steam. In terms of a successor to the traditional combustion

The Toyota Mirai is powered by hydrogen and doesn't release any chemical nasties

engine it sounds like a no-brainer, but there are still some hurdles in its way if it is to be a success.

Just like petrol, hydrogen is highly flammable. While the motoring industry has had the benefit of over 100 years of research and engineering to work out how to safely distribute, store, carry and use petrol, the hydrogen fuel cell industry is still in its infancy. But it's not starting from scratch as the idea of a hydrogen car has been around since the 1990s. Ever since then, Toyota claims that it has been testing the safest way to carry hydrogen around. The company's solution is a carbon fibre fuel tank that's incredibly solid and light. This tank is loaded with sensors that tell the car to isolate the hydrogen in an emergency. Given how strict the motoring industry is with safety standards, we're willing to bet that hydrogen cars will be no more dangerous than their petrol equivalents. But hydrogen fuelling stations are another problem altogether.

Before buying a car, early adopters will need to know whether the country's roads will be equipped with a fuel network that allows them to get around. Thankfully, that won't necessarily mean a huge number of stations. The Mirai will have a range of 300km. Compared to electric charging stations, only a relatively small number of hydrogen fuelling stations would be needed. In the US it looks like this won't be a problem. There are already plans to create a chain of stations linking the east and west coasts of America. The goal is to have 46 US stations open by the time the car goes on sale at the end of 2015.

In the UK, the number of predicted stations is a less optimistic six. But Toyota, buoyed by Tesla's success of installing a supercharger network across the US and UK, has few reservations that a hydrogen fuel network will pop up before long. Besides, Toyota is not alone because Honda and Hyundai are both launching hydrogen fuel cell cars as well.

Ultimately, the Mirai isn't about hydrogen fuel cells replacing the use of fossil fuels in cars (let's not forget the majority of hydrogen comes from fossil fuels at the moment) or batteries, for that matter. As Toyota states, the idea is to diversify the types of fuel we use, so that our way of life isn't dependent on one single fuel. Either way, there's little doubt that hydrogen cars are rolling into town.

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

Techometer

What's Hot

Virtual Reality Films

The first commercial virtual reality headset, Samsung Gear VR, has just gone on sale. Film directors have already started experimenting with a medium in its infancy, with Sundance Film Festival hosting nine VR films in 2015. *Perspective; Chapter 1* will let viewers experience a social encounter from both sides, while *Project Syria* recreates scenes from the war-torn country. If that's all too heavy, *Birdly* claims to reproduce the sensation of natural flight.

What's Not

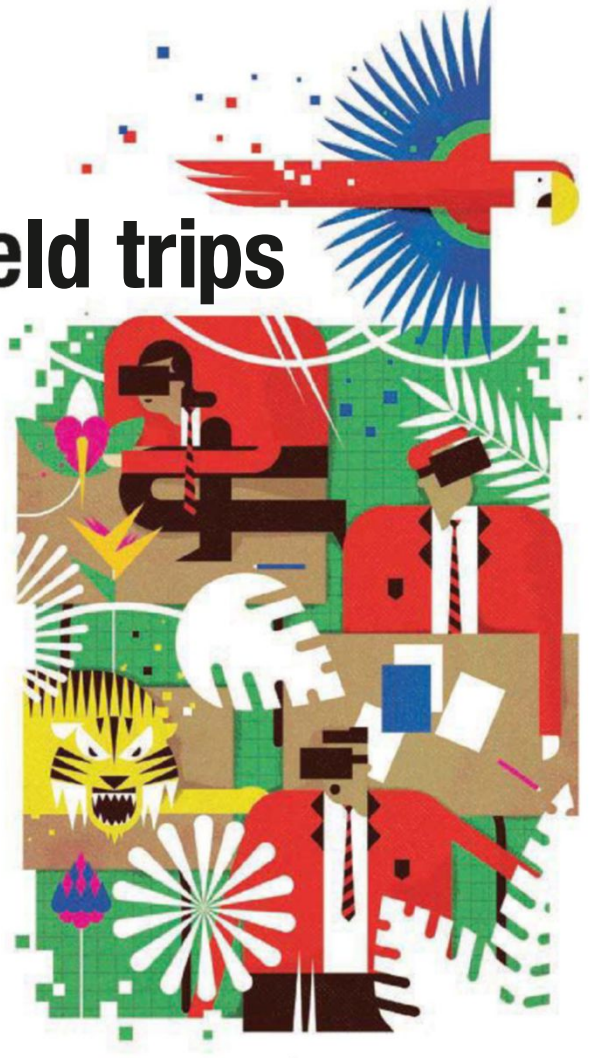
Drones

You might have received a drone for Christmas, but the rules over where and how you can fly it are about to get stricter after an unidentified drone flew dangerously close to an Airbus A320 at Heathrow in summer 2014. The European Aviation Safety Agency is currently drawing up new rules, and is starting to prosecute hobbyists who flout the current laws.

ILLUSTRATOR: DEM ILLUSTRATION

The Next Big Thing

Virtual field trips



Teaching has already changed enormously thanks to the development of networked computers. We're now used to seeing screens in every class, with electronic whiteboards used to present lesson material. Textbooks are being replaced by tablets.

Since the advent of YouTube and iTunes U, teachers have been able to upload recordings of their own lectures and make them available to students, while sites like Khan Academy and the Open University's OpenLearn offer lectures and tutorial material from experienced academics.

Virtual reality systems are already being used in class, as teachers experiment with headsets like the Oculus Rift, or cheap and cheerful alternatives like Google Cardboard. Meanwhile, a primary school in Broughall, Eire built a model of a local monument in an OpenSim virtual environment. The pupils then used VR headsets to explore it in class.

With projectors and large screens becoming more affordable, schools may soon be able to give their students the experience of a field trip to the Amazon or Egypt without the need to travel. Soon, we will see classrooms turned into CAVEs. A CAVE – short for 'Cave Automatic Virtual Environment' – lets a group of people feel present in the same virtual environment at the same time, turning the classroom into a window on the real or computer-generated world.

The real transformation could come when we can simply wire students into a knowledge-dispensing network. Military researchers is the USA have been experimenting with direct human-computer interfaces for years, using them to fly jet planes. Scientists at the University of Washington recently built a system that allows direct brain-to-brain communication, reading the electrical signals from one person's brain and sending a message – in this case a signal to move a finger – to someone else.

The signal is sent through transcranial magnetic stimulation, where electrodes on the skull generate a signal in the brain. Currently, it is unreliable and complicated, but it has the potential to become far more usable as we understand more about neural architecture and the brain.

I don't actually think we'll end up transferring real knowledge or concepts to another person this way, even if we overcome the enormous technical obstacles. But we might be able to take significant shortcuts to developing some motor skills, or create mental states that are conducive to understanding and learning.

Of course, we'll also need teachers able to embrace the technology and use it, unless we decide to give robots and AIs the responsibility for educating young people. But I can see lots of ways in which that could go wrong.

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

Coming Soon

GALAXY S6

Samsung's next flagship phone lands in April. Early leaks point to a 20MP camera, a better-than-HD screen and 3GB of RAM – tonnes of power to play *Candy Crush Saga*. *Samsung.com*

+ HTC One M9
Critics loved the One M8. Its successor, the M9, is due to arrive in early spring. A leaked photo suggests the phone will have a 5.2-inch screen with almost no bezel. *Htc.com*

+ Blackphone App Store
The high-privacy phone is rolling out an app store with software dedicated to keeping your personal info personal. *Blackphone.ch*

APPLE WATCH

Whatever you do, don't call it an iWatch. Apple's first new product since the iPad could grace your wrist as early as spring, but summer seems more likely. *Apple.com*

+ Tesla Model D
A sportier version of the *Focus* team's favourite electric car will roll on to European roads in the summer. We can't wait to try it out. *Tesla.com*

+ Oculus Rift
The virtual reality headset has been in development for the last two years, while competitors continue to release rivals all around them. A completed, consumer version of the Rift is expected to go on sale in July. *Oculus.com*

MARS SPEAKER

This device wouldn't look amiss aboard the USS Enterprise. Magnets hold the wireless speaker aloft in the air – it's a gimmick, but it's a cool one. *Crazybaby.com*

+ Ampy
This kinetic charger will convert 30 minutes of running into three hours of battery life for your smartphone. *Getampy.com*

+ Google Ara
This modular phone will let you pick and choose exactly what camera, battery and processor you want. We expect to see it towards the end of 2015 at the earliest. *Projectara.com*

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 *Digital Planet* 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*

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What is the wettest place in the world?

It's Mawsynram in the northeast of India. The village sits in the Khasi Hills, which funnel the warm, moist air from the Bay of Bengal and force it to rise, dropping almost 12 metres of rainfall every year! Despite this, the village can still suffer from drought during the dry season, which runs from December to February. **LV**

The village is 1,400m above sea level. Thirty years ago, it had no paved roads or electricity

PHOTO: REX

Q&A

In Numbers

5,793

is the distance in kilometres that the Orion test flight flew above the Earth's surface in December 2014

Could phages be used as an alternative to antibiotics?

A They already are, to some extent. Bacteriophages, or 'phages' for short, are viruses that target specific bacteria. The virus penetrates the bacterial cell membrane and hijacks its DNA machinery to produce more copies of itself. This eventually ruptures the bacterium, killing it and releasing more phages.

Phage therapy is actually at least 90 years old. It was used extensively in Russia during the Cold War, when access to western antibiotics was limited. Phages get around the problem of bacteria evolving resistance because they are constantly evolving themselves. The downside is that you need a very specific phage to target every different bacterial strain. In practice, this means administering a cocktail of different phages and updating the recipe every few months. Phage therapy is currently only approved in Russia and Georgia, but interest in other countries is currently soaring. **LV**

A bacteriophage (orange) injecting its DNA into an *Escherichia coli* bacterium (blue)

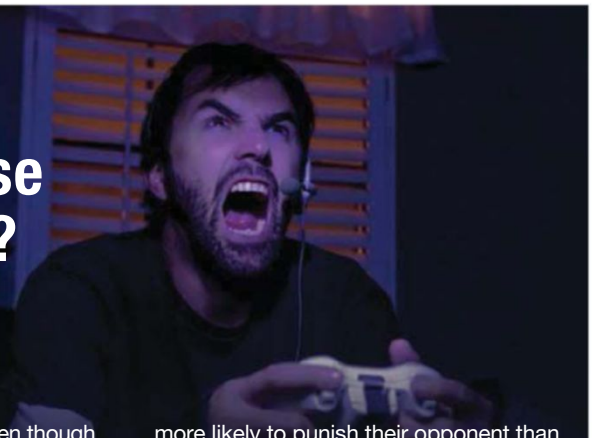
Scratching is a behaviour that's common to all vertebrates

Why does it feel good to scratch?

A Studies using functional magnetic resonance imaging (fMRI) have shown that scratching causes patterns of brain activity that are associated with pleasure and reward. This effect is strongest when you do the scratching yourself and when you are actually scratching an itch, rather than just an arbitrary patch of skin. But contrary to what you might expect, or might have read elsewhere, there's no clear evidence that this pleasure comes from a release of endorphins – it happens purely in your brain and spine.

This mechanism may have evolved to encourage us to dislodge skin parasites. All the evidence suggests that it's a very ancient response, because all vertebrates scratch themselves – even fish! **LV**

Do video games cause aggression?



Any link between gaming and real-world aggression remains highly contentious

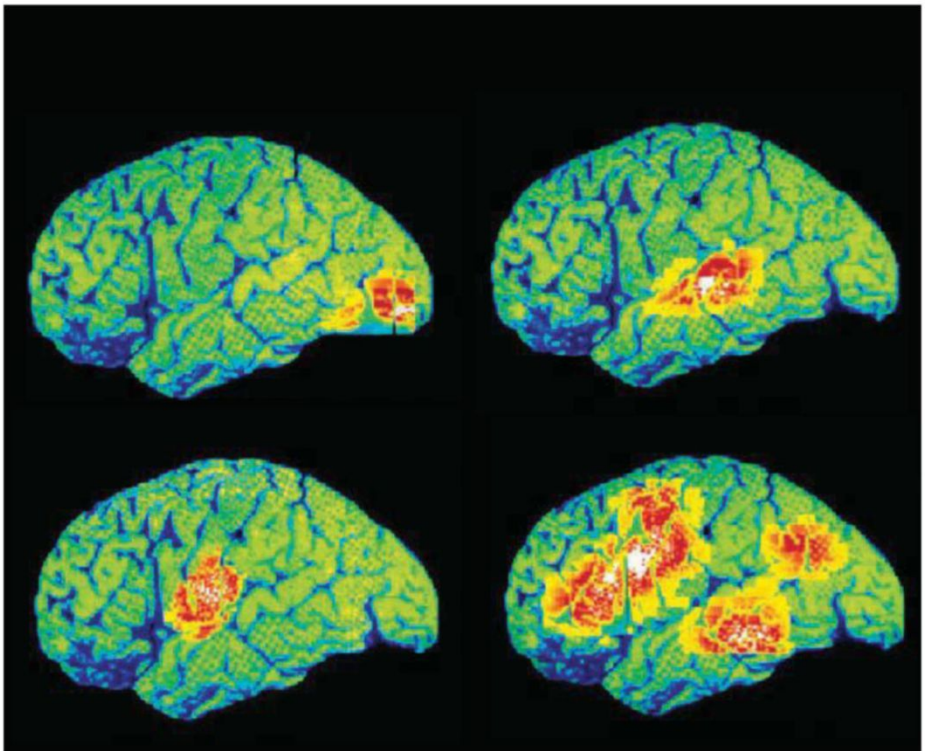
A We don't know for sure, even though the question is important for education and parenting. Many studies show that kids who regularly play violent games show more savage behaviour, but this is only a correlation and not a cause. It could be that aggressive children prefer violent games, not that the games caused their aggression.

In some studies, the victor of a video game has been given the opportunity to punish their opponent by blasting them with noise, for example. It has been found that winners of violent games are more likely to punish their opponent than winners of non-violent games. Violent games with a positive goal, such as saving others from virtual zombies, seem to have less negative impact.

Other research shows that losing the game or finding the controls frustrating is what leads to violence, not the content of the actual game itself.

We might note that US sales of violent video games have steadily increased since the mid 1990s, while violent crime has declined – especially among juveniles. **SB**

PHOTO: ISTOCK X2, SCIENCE PHOTO LIBRARY X2, GETTY, ALAMY



Clockwise from top left: brain areas active when seeing, hearing, thinking and speaking

Does a brain with a higher IQ burn more calories?

A Broadly speaking, yes. Areas of the brain that are more active receive greater blood flow and take up more glucose. The increased blood flow is actually what allows fMRI scanners to detect brain activity. You might think that a less intelligent person would need to spend more calories on thinking harder about a given problem, but a 1995 study at the University of California, Irvine, found the opposite. When a mental problem seems easy for you, it is because you have more neurones that can work towards solving the problem. Your total energy expenditure is higher, but your subjective sense of the effort required is lower.

However, this research only looked at the short-term energy use while test subjects were focusing on the problem. You can't generalise this to conclude that a higher IQ brain uses more calories over the course of an ordinary day. And in any case, the number of extra calories burned during thinking is very small compared to the base energy requirements of the brain when it isn't doing anything. Your brain uses about 300 calories a day just to maintain its own tissues. Concentrating on hard problems only increases this by 20 to 50 calories per day. That's about the same as you'd burn walking for four minutes.

So unless you're doing sudoku puzzles on a treadmill, mental activity will actually reduce your overall calories burnt, simply by taking time away from more physical activities. **LV**

Can germs survive on a bar of soap?

A bar of soap after washing out Frankie Boyle's mouth

A Yes. When you wash your hands, you transfer a thin film of bacteria, skin flakes and oils to the bar of soap. A 2006 study of 32 dental clinics found bacteria growing on the soap in all of them – after all, standard soap doesn't kill bacteria, it just dislodges them. A 1988 study found that washing your hands with a dirty bar of soap doesn't transfer any of the germs onto your hands – but then the study was conducted by a US soap manufacturer. **LV**

Is it best to charge your mobile battery from empty or half-full?

A Nickel-based batteries were blighted by the 'memory effect', and would lose capacity unless regularly discharged completely. Most phones nowadays have lithium batteries, and these do not suffer from the memory effect. In fact, it is good for them if you top the batteries up rather than deplete them completely. Therefore, it's best to charge your phone from half-full. **GM**

Don't wait for your phone to 'die' before charging it up

Q&A

TOP TEN
BIGGEST CLOCK FACES
(BY DIAMETER)

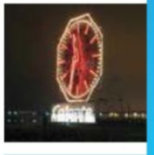
1. Abraj Al Bait Towers Clock
Diameter: 43m
Location: Mecca, Saudi Arabia

2. Istanbul Cevahir Clock
Diameter: 36m
Location: Istanbul, Turkey

3. The Floral Clock
Diameter: 24.2m
Location: Surat, India

4. Central do Brasil Clock
Diameter: 20m
Location: Rio de Janeiro, Brazil

5. Duquesne Brewing Company Clock
Diameter: 18m
Location: Pittsburgh, Pennsylvania, US



6. Colgate Clock (New Jersey)
Diameter: 15.2m
Location: Jersey City, New Jersey, US

7. Flower Clock
Diameter: 15m
Location: Tehran, Iran

8. Grozny-City Towers Façade Clock
Diameter: 13.6m
Location: Grozny City, Russia

9. Allen-Bradley Clock
Diameter: 12.6m
Location: Milwaukee, Wisconsin, US

10. Colgate Clock (Indiana)
Diameter: 12.2m
Location: Clarksville, Indiana, US

PHOTO: TOM A WARNER/WEATHERVIDEOHD.TV, FLPA, GETTY, BABAKGH/WIKI, WIKI COMMONS X3, TONY EVANS/FLICKR, SAMAN AGHVAMI, DAVID WILSON/FLICKR, BRENT MOORE/FLICKR, CORBIS, ISTOCK X2

Q Can lightning strike upwards?

An upward discharge of lightning from a TV tower in Rapid City, South Dakota

A Yes – and scientists at ZT Research in South Dakota have recently caught the phenomenon on camera. The footage revealed that a conventional lightning bolt can trigger a change in the electric field in the atmosphere. Any tall building in the area is then liable to act like a lightning conductor in reverse, sending a bolt back into the clouds. **RM**

Q How do we know when something is wet?

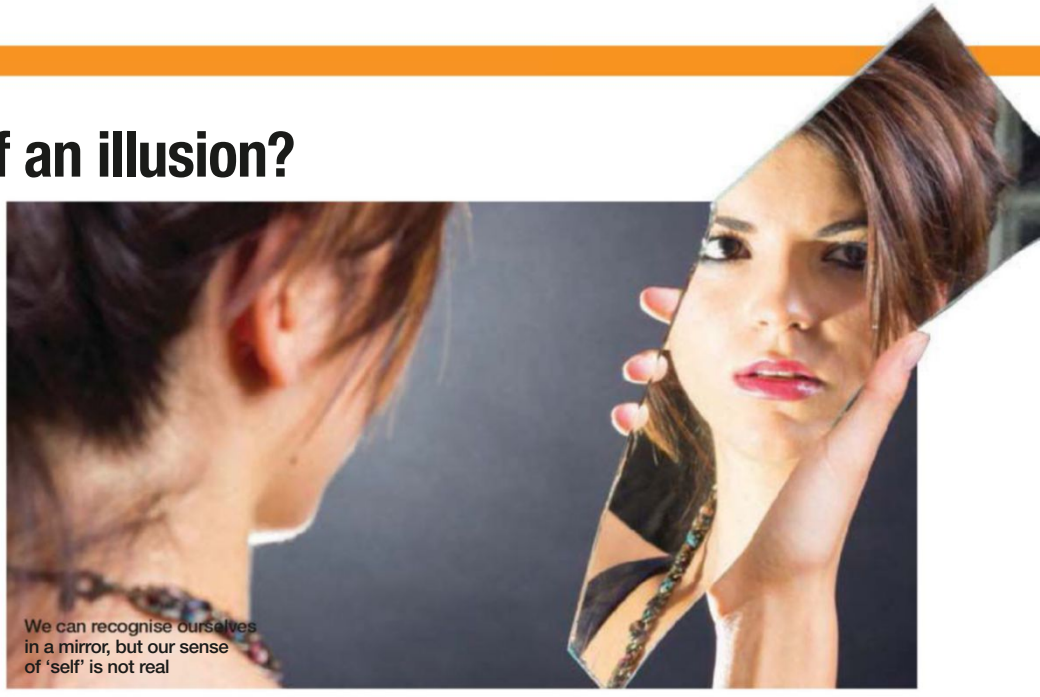
A Our skin contains lots of nerve endings that respond to different stimuli. There are receptors for touch, vibration, heat, cold and pain – but not for wetness. Water is such a ubiquitous component of all living cells that it would be difficult for a nerve cell to avoid firing constantly in response to its own composition.

Instead, wetness seems to be a property that our nervous system learns to recognise, based on a mixture of cold, pressure and texture. A 2014 study at Loughborough University found that hairy skin is more sensitive to wetness than smooth skin, which may be because hairy skin has more temperature sensitive nerve endings. When you are born, you don't feel wet or dry, you just feel cold or warm. Over time we learn that the feeling of cold cloth sticking to our skin means that we've sat on a wet park bench. **LV**

In this situation, it's good to sing

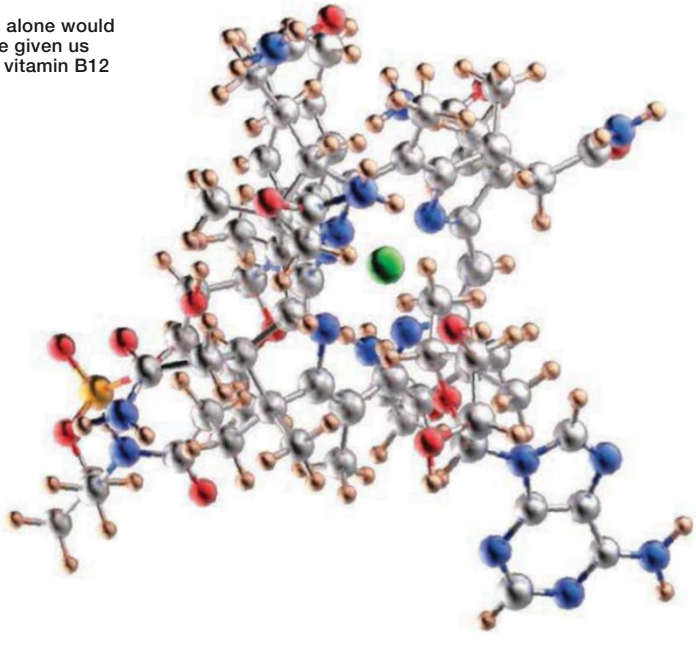
Is our sense of self an illusion?

If an illusion is something that deceives us, yes. Most of us feel we're more than just a body with a brain: we are someone who lives inside our body and controls it. Yet this cannot be true. The brain is a massively parallel system with no central place where a self could receive information or issue commands. Different regions make decisions, inhibit impulses, organise movements and control emotions, and these all operate at once without a central controller, some of them so quickly that we become aware of what's been decided only after the action is completed. Yet we still say 'I decided to do this' or 'I wanted to do that'. Our sense of a unitary 'self' that has consciousness and free will may or may not be useful – but it is certainly an illusion. **SB**



We can recognise ourselves in a mirror, but our sense of 'self' is not real

Grazing alone would not have given us enough vitamin B12



Are our bodies naturally herbivorous?

No. There are many reasons to be vegetarian, but your evolutionary heritage isn't one of them. We have no fermenting chamber in our intestines to digest plant cellulose, and our metabolism has several adaptations that suggest we evolved from animals that ate meat: for example, our intestines have receptors to absorb heme iron, which is only found in meat. We also can't make our own vitamin B12, and we synthesize taurine and vitamin A very slowly. These nutrients are much easier to get from meat than plants. Before the advent of agriculture, it would have been very hard to get all the right nutrients from plants alone. **SB**

Why do different countries use different mains voltages?

The biggest disparity is between the USA on 110V and most of the rest of the world on 230V. America's lower voltage goes all the way back to Thomas Edison, who introduced direct current (DC) mains electricity at 110V. Edison's rival Nikola Tesla showed that long power lines transmitted alternating current (AC) more efficiently than DC. His AC approach won out, but he stuck with Edison's 110V. It's been that way in the US, Canada and parts of the Caribbean ever since. But by the time electrification spread to Europe early in the 20th Century, lamps had filaments that could give out more light and handle greater power loads. So the Berliner Elektrizitätswerke company in Germany established 230V as the standard. **GM**

Forget a plug adaptor and you'll be holidaying with a hairy face and no phone

Q&A

Pipe dream? Global Thermostat's air capturing technology

Could direct air capture prevent climate change?

A Direct Air Capture (DAC) is an appealing way to tackle climate change: just pass ambient air over chemicals that absorb the CO_2 driving global warming, and then use or store the CO_2. DAC differs from the better-known carbon capture and storage (CCS) in that it can be done anywhere, not just at big sources of CO_2 such as power stations. It's more effective than natural CO_2 'scrubbing' using trees and plants, and can be performed where the CO_2 is most easily stored or re-used.

Like CCS, however, DAC faces the problem of ensuring the CO_2 never escapes. Unlike CCS at power stations, DAC must be effective at removing the far more dilute CO_2 in ambient air. This demands special equipment and chemicals, plus renewable energy sources producing zero CO_2. That has led to grave doubts about the economic viability of DAC. For now, it remains an intriguing but impractical remedy for global warming. **RM**

In Numbers

-18°C

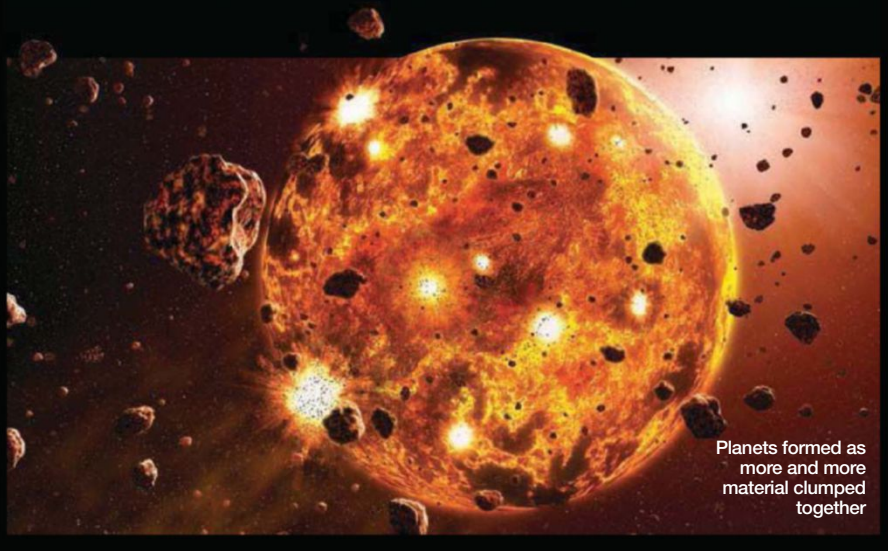
is the lowest temperature to which Alaskan wood frogs have been chilled (with 100 per cent survival rates). Their cells contain glucose, which acts like an antifreeze

Why do we go red in the face when embarrassed?

Relax: this woman is officially not a psychopath

A Humans seem to be the only animals to show embarrassment, and Charles Darwin called blushing "the most peculiar and most human of all expressions". Blushing makes it harder to lie, which seems like a disadvantage. However, a 2009 study by Dutch psychologists found that we are more likely to give people a second chance if they blush when they betray us. The ability to blush acts as a signal that you are sensitive to the social rule you have just broken. Psychopaths, on the other hand, do not blush at all. **LV**

Why aren't our Solar System's planets and moons made from the same material?



Planets formed as more and more material clumped together

A The Solar System formed from the collapse of a molecular cloud consisting mostly of hydrogen, but also containing heavier elements. As the cloud collapsed, its central region began to heat up until eventually the hot 'proto-Sun' was formed. The planets formed by the accretion of material from within this cloud. Due to their high boiling points, only metals and silicates could exist in solid form in the hot, inner regions of the early Solar System. More volatile elements either remained gaseous or were blown away by the Sun's energy. Since this heavy material existed mainly in the inner regions of the Solar System, the planets that formed there are small and rocky. In the cold outer reaches of the Solar System, compounds with low melting points could remain in solid form. These ices were also much more abundant than the heavier elements. The outer planets were therefore able to grow much larger, and held onto large atmospheres of hydrogen and helium gas. **AG**

PHOTO: GLOBAL THERMOSTAT, SCIENCE PHOTO LIBRARY, ROBERT HARDING, THINKSTOCK

Where could the next natural disaster strike?

Around the world, catastrophic events are waiting to happen. **Bill McGuire** reveals where nature is set to wreak havoc next

A CALIFORNIA, USA

MAMMOTH MOUNTAIN

Mammoth Mountain is a leading destination for skiers, but it hides a dark secret within

Best known as a ski resort, Mammoth Mountain has a darker side to its character – it is an active volcano. It is one of more than 30 clinker cones and lava domes that dot the western rim of the Long Valley Caldera supervolcano. Mammoth has not disgorged any magma for close to 60,000 years, and it's 700 years since steam blasts shook the mountain. Still, the volcano has shown signs of unrest in recent decades, with earthquakes, swelling of the ground surface and tree dieback due to sulphurous gases seeping from the soil. This caused real concern in the late 1980s and 90s. A swarm registering up to 300 quakes a day was detected near the volcano in late September 2014, but things had calmed down by early October, and monitoring scientists say there is no sign of an imminent eruption.

A ANYWHERE

EARTH

Asteroid 2014 UR116 would do some serious damage were it ever to collide with our planet

A Russian robot telescope called MASTER has spotted a new asteroid that could threaten our world. The space rock 2014 UR116 is 370m across and in an unstable orbit around the Sun that could ultimately place planet Earth in its sights. Currently, the asteroid's orbit does not bring it within 4.5 million kilometres of our world, but regular encounters with the gravitational fields of Mars and Venus during its circuits around the Sun are likely to modify its trajectory. All that observing scientists currently say is that it will not strike Earth in the next six years. If it does eventually end its life through collision with our planet, the blast will be around 1,000 times greater than that announcing the spectacular arrival of the Chelyabinsk meteorite over Siberia in 2013. It would be insufficient to end our civilisation, but big enough to obliterate a city should one get in its way.

A HONSHU ISLAND, JAPAN

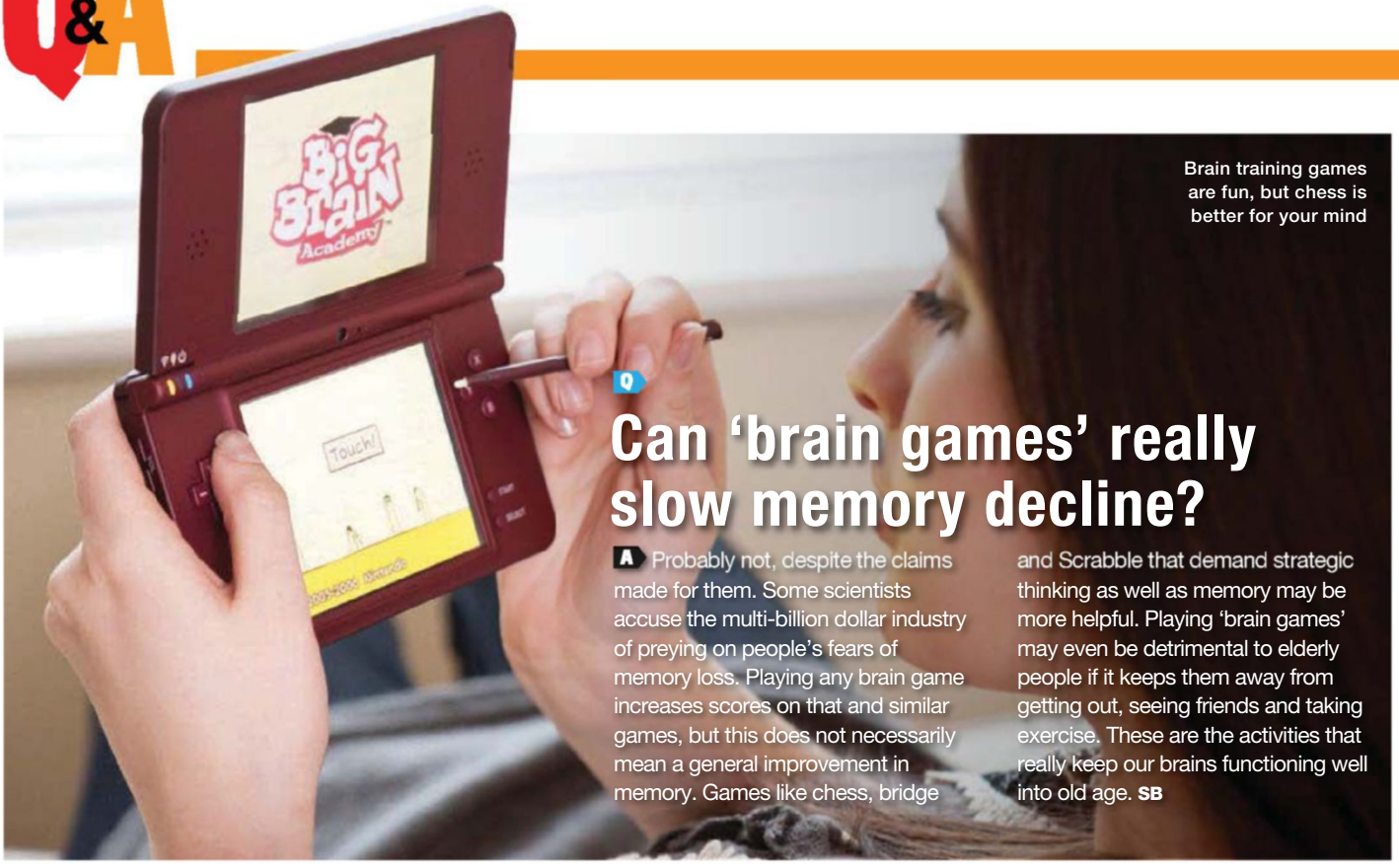
TOKYO

If another major earthquake comes in the wake of Tohoku in 2011, the results will be disastrous

Earthquakes don't come much more devastating than the expected Tokyo quake. The greater Tokyo area is home to 35 million people, who await with dread the quake that must come soon. Since the huge 2011 Tohoku earthquake and tsunami, seismic activity in the region has increased tenfold, and a recent study says the chance of a mag. 7+ quake striking by 2016 could be as high as 70 per cent. This could result in the destruction of over 600,000 buildings and the loss of up to 23,000 lives, due to either building collapse or post-quake firestorms. With the cost projected to be close to one trillion US dollars, the impact on Japan's economy would be catastrophic.

BILL MCGUIRE is Emeritus Professor of Geophysical & Climate Hazards at University College London and author of *Waking The Giant*

Q&A



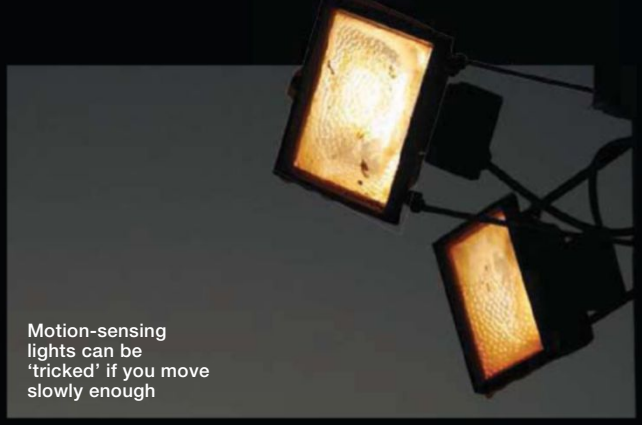
Brain training games are fun, but chess is better for your mind

Q Can 'brain games' really slow memory decline?

A Probably not, despite the claims made for them. Some scientists accuse the multi-billion dollar industry of preying on people's fears of memory loss. Playing any brain game increases scores on that and similar games, but this does not necessarily mean a general improvement in memory. Games like chess, bridge and Scrabble that demand strategic thinking as well as memory may be more helpful. Playing 'brain games' may even be detrimental to elderly people if it keeps them away from getting out, seeing friends and taking exercise. These are the activities that really keep our brains functioning well into old age. **SB**

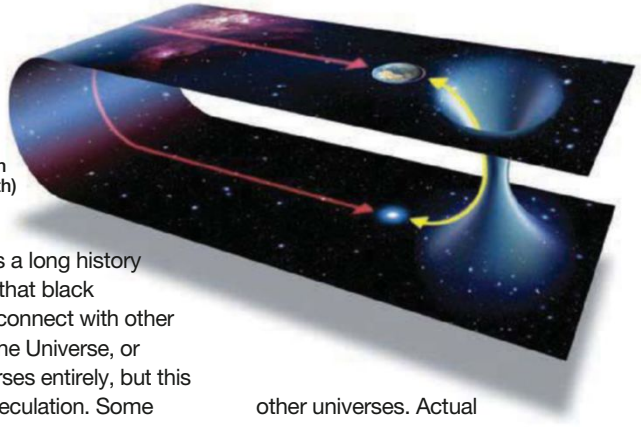
Q Can you avoid setting off motion-sensitive lights by moving slowly?

A Most motion-sensitive security lights detect heat from your body and are triggered if the infrared radiation received at the sensor changes sufficiently quickly. The lamps ignore gradual variations – if they didn't, the temperature changes of the surroundings between day and night would set them off. It depends on the lamp, but my own experiments reveal that you have to move slower than 0.1 metres per second, or 0.4km/h, to avoid being rumbled. **GM**



Motion-sensing lights can be 'tricked' if you move slowly enough

Q Could black holes be portals to other universes?



If they exist, wormholes could offer shortcuts in space (shown by yellow path)

A There is a long history to the idea that black holes may connect with other regions of the Universe, or other universes entirely, but this is purely speculation. Some physicists have attempted to combine quantum mechanics with the General Theory of Relativity and concluded that black holes may not contain a 'singularity', the point at which density becomes infinite. This would open up the possibility that black holes are shortcuts to other universes. Actual tunnels through space-time, called 'wormholes', may be a better bet for traversing between universes. But although they're predicted by Einstein's theories, no wormholes have yet been discovered, and there are doubts that they could occur naturally at all. **AG**

PHOTO: ALAMY X2, SCIENCE PHOTO LIBRARY, GETTY X2, ISTOCK

Are 'statistically significant ' results really significant?

Often used to describe a new research finding, statistical significance is one of the most misunderstood scientific terms – even by scientists themselves.

To gauge whether the result of some experiment is 'significant' or not, formulae are used to work out the chances of getting at least as impressive a result if fluke was the true cause. If these are less than 1 in 20, then the result is deemed statistically significant. But – contrary to what many scientists think – this doesn't mean the chances of the result being a one-off are also 1 in 20. As the calculation was made assuming fluke to be responsible, it can't give the chances of that assumption being right. In order to work that out, the inherent plausibility of the finding is taken into account. Phew! When all these calculations have been made, many 'statistically significant' but implausible findings end up showing a high risk of being flukes.

Statisticians have issued warnings about the dangers of misunderstanding statistical significance for decades, to little or no avail. Some now suspect this misunderstanding lies behind the current 'replication crisis' in science, where many research findings fail to be confirmed by follow-up studies. **RM**

Science isn't all about playing with microscopes and making explosions – there are tough statistics to deal with

The vertical pupils of a reticulated python tell us that it ambushes prey

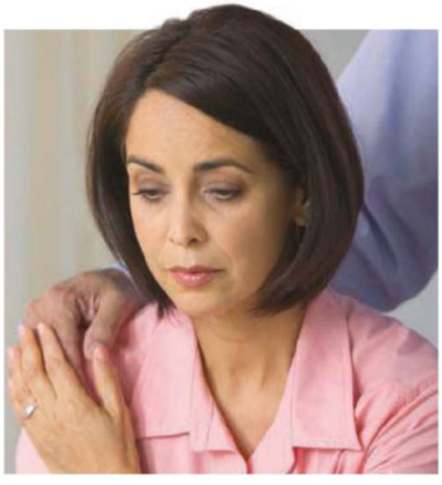
Why do snakes have slits for pupils?

Vertical pupils are an adaptation for ambush hunting. A 2010 study at Sydney University found that of 127 Australian snake species, the ones that ambushed their prey by night had vertical pupils, while those that actively chased down prey in the day had round pupils. The constriction of round pupils helps distant prey stay in focus, but it also lets in less light. Vertical pupils improve vision across a wider range of light levels, and enable the animal to detect horizontal movement more effectively. It's also possible that vertical pupils are more camouflaged, since they break up the round outline of the eye. **LV**

What is emotional intelligence (EI)?

Emotional Intelligence (EI) is the ability to recognise emotions in yourself and others, and to apply that understanding in behaviour and relationships. People with high EI have more empathy and self-awareness, and are better able to put themselves in others' shoes. Women usually score higher than men, especially on empathy. The concept arose when traditional IQ tests were criticised for measuring only a narrow range of intellectual skills, and attempts were made to replace them with multiple intelligences such as musical, moral and bodily intelligence.

There is some evidence that bullies tend to be low on EI, while religious believers score higher. Many other claims have been made, such as that EI can predict leadership skills and teamwork. Yet all these have been challenged on the grounds that any effect disappears when IQ and personality are accounted for. Therefore, the idea that emotional intelligence is separate from general intelligence remains controversial. **SB**



It's not all about IQ. Emotional intelligence is important too

YOUR QUESTIONS ANSWERED

Email to **editorial-bbcknowledge@regentmedia.sg.**
We're sorry, but we cannot reply to questions individually.

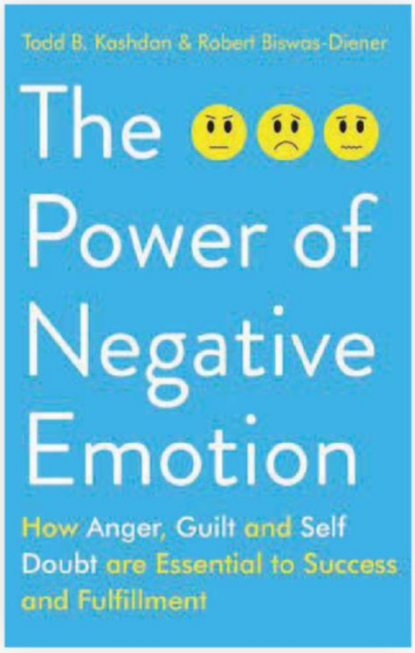
Hardback Paperback

The Power Of Negative Emotion

How Anger, Guilt And Self-Doubt Are Essential To Success And Fulfillment

Todd B Kashdan and Robert Biswas-Diener

Oneworld P



We've become addicted to comfort. We run from emotional and physical pain, and at the first sign of boredom or sadness we reach for a distraction. This is no way to live, argue US psychologists Todd Kashdan and Robert Biswas-Diener. To be truly happy, to be 'whole', they say we need to embrace our dark sides.

To support their argument, the pair turn to an assortment of fascinating, if highly selective, psychology findings. Consider the fact that workers achieved a 400 per cent better success rate on an analytical task when their leader showed signs of sadness – sadness is known to encourage a focused, analytical thinking style.

We should see our emotions, both negative and positive, as tools that help us in different contexts, say the authors. For example, getting angry in a controlled manner can help you negotiate, while feeling sad can improve your lie detection abilities. Even the maligned personality trait of psychopathy has its upsides – one study found that when given the chance to display heroism, people high in psychopathic traits were more likely than others to help a stranger in distress.

"People high in psychopathic traits were more likely than others to help a stranger in distress"

Yet the book sometimes undermines its own premise that we need help reconnecting with darker emotions. For instance, the authors describe research showing that people know intuitively that it helps to feel sad when attempting to obtain charity donations. Elsewhere, as part of an extended critique of 'mindfulness' (being focused in the moment), Kashdan and Biswas-Diener explain the benefits of mindless mimicry, saying that it helps us in social interactions. But as they say, this behaviour is 'mindless' – it comes naturally.

This book is enjoyable, but the scientific content has been packaged awkwardly into a questionable self-help message. Kashdan and Biswas-Diener speak repeatedly of using negative emotions to find "true success" and "to progress on your journey of personal growth". Yet they don't spell out what they think this successful life consists of – other than it means embracing our dark traits, which is a circular argument.

CHRISTIAN JARRETT is a psychology writer. His latest book is *Great Myths Of The Brain*

MEET THE AUTHOR

Todd B Kashdan

Many people would say that the key to feeling happy is to maximise positive emotions. Is that not right?
The bulk of the emotional experiences that we want to feel in our lives are things like hope, tranquility, compassion, love and gratitude. But happiness is actually a very problematic outcome to have for your life. The research says that when we overvalue the importance of being happy, it actually makes it more difficult to become happy in the first place.

So are there any benefits to, for instance, feeling angry?
Anger is incredibly useful. Some people who are in romantic relationships say they don't fight, and I always get worried. There are so many reasons to fight and disagree, and if you don't express your frustration, your partner will never know what makes you feel disrespected, deflated or unfairly treated. A study in the 1980s found that more than 75 per cent of people who were the target of someone else's anger gained a better understanding of their own strengths and flaws.

What should we do when we feel negative emotions?
Instead of asking, "How can I feel better?" ask yourself, "Does this emotion have a purpose for the situation I'm in?" When we're feeling sad or anxious, we're ready to do something challenging and be a bit more sceptical about what other people are saying. Our emotions are telling us that there's something to be wary of. When we're happy, we tend to be lazy in our thinking. Evolution has designed us with this broad emotional repertoire, and we should honour that.

Do Zombies Dream Of Undead Sheep?

A Neuroscientific View Of The Zombie Brain

Timothy Verstynen and Bradley Voytek
Princeton University Press

How do you make a tough subject like neuroscience accessible to a young audience? Researchers Verstynen and Voytek attempt to do just that by comparing brains of normal humans to the hypothetical workings of zombies' brains. They systematically work through various brain-supported functions such as sleeping, eating, walking and talking, and then investigate how such abilities are abnormal in zombies.

Zombies are easily distracted by sudden flashes and loud bangs. The authors propose that this is because the brain systems that enable normal humans to focus their attention no longer function correctly. Similarly, the lumbering gait seen in zombies could be the result of problems with motor function.

The science is pretty accurate, but the continual reference to zombies eventually becomes tiresome, as do the puns and frat house writing. Still, the authors seem to have pitched the book at the right level for their audience, and they could be on to a good seller. After all, the zombie craze doesn't seem ready to die just yet. I predict a bumper year for dog toy sales.

BRUCE HOOD is a psychologist and the author of *SuperSense* and *The Self Illusion*

The Glass Cage

Where Automation Is Taking Us

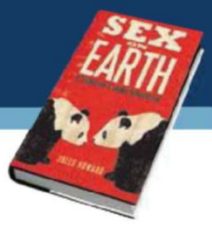
Nicholas Carr
Bodley Head

My copy of this excellent book is so thoroughly scribbled on that I'd simply never be able to get rid of it. I've circled lots of stuff I agree – or disagree – with, and added exclamation marks to insights that I want to explore more deeply.

Carr examines the history of automation, from aircraft navigation to factories, farms, and driverless cars. By the time he's finished, you too will be worried that our unfettered faith in 'progress' has allowed technocrats and entrepreneurs to build systems which may serve their need for profit and control, but rarely serve our needs as humans.

The final section of the book is beautifully written, especially when Carr looks to the poetry of Robert Frost for inspiration as he discusses the way we have lost any direct connection to our tools. *The Glass Cage* is infused with a humanist perspective that puts people and their needs at the centre of the argument around automation and the alienation created by many modern systems. He doesn't have many answers, but believes that it's not too late to ask the questions. So put down your phone, take off your Google Glass and read this.

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



Sex On Earth

A Celebration Of Animal Reproduction

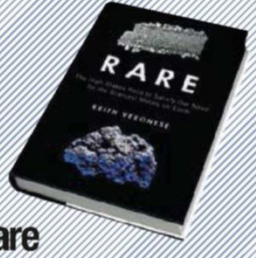
Jules Howard
Sigma

A couple of sidelong glances from fellow travellers on the London train had me slipping off this book's somewhat lurid dust jacket: the word 'sex' must stand out more than the slightly doleful pair of pandas beneath. Still, attitudes have certainly improved over the 100 years since, as Jules Howard recounts, explorer George Levick described the sexual high jinks of Adélie penguins he'd observed in Antarctica. And this book does an admirable job of separating the scientific from the merely smutty.

The reader is led through a cornucopia of animal breeding strategies, from racehorses to fen raft spiders, via hedgehogs, flamingos and slugs. And the most fundamental question of all – why is sex so ubiquitous? – is addressed in a chapter enticingly entitled 'Sexless Zombie Time-Travellers'. It describes a group of asexual animals I found I knew very little about, the bdelloid rotifers. There's even a chapter at the end about love (mainly jackdaws and prairie voles, with a smidgen of human thrown in).

This book is highly entertaining and informative, as well as being prurient – for all the right reasons.

JOHN BRADSHAW *is an animal expert and author of In Defence Of Dogs and Cat Sense*



Rare

The High-Stakes Race To Satisfy Our Need For The Scarcest Metals On Earth

Keith Veronese
Prometheus

Promethium is a radioactive metal that could potentially power atomic batteries that last for decades. But there is just half a kilogram of it spread throughout the Earth's crust, making it one of the rarest elements on the planet. This, of course, makes it incredibly desirable. Tantalum, rhodium, osmium and niobium are similarly in demand for use in smartphones, laptops and even weapon systems. These scarce but highly sought-after elements are increasingly underpinning our world.

Rare is one of the first books to explore our insatiable appetite for certain metals. It takes us on a journey from the brutal battlegrounds of the Congo, where demand for tantalum, tungsten and tin fuel bloody conflict, to the hunt for metal-rich bedrock beneath Greenland's receding ice sheets.

The underlying science is accessible and is deftly combined with comments on the often-overlooked societal implications of the planet's chemical make-up. Viewed as a kind of 'essential guide' to crucial elements, *Rare* outlines their increasing geopolitical importance in the modern world.

PROF IAIN STEWART is a geologist and a BBC science presenter

Time Out

In the know

SET BY DAVID J BODYCOMBE

1 **Scientists created a computer program that they say is a perfect player of which game?**

a) Blackjack
b) Poker
c) Gin rummy

2 **Complete the recent headline: 'Regular _____ are key to learning'**

a) Snacks
b) Naps
c) Jogs

3 **January marked 10 years since an ESA probe landed on Saturn's moon, Titan. What was the probe's name?**

a) Huygens
b) Herschel
c) Hawking

4 **Which came top of SplashData's list of 2014's most popular passwords?**

a) password
b) 123456
c) qwerty

5 **To celebrate its 25th birthday, Hubble has revisited the iconic 'Pillars of Creation'. Where are they found?**

a) Crab Nebula
b) Horsehead Nebula
c) Eagle Nebula

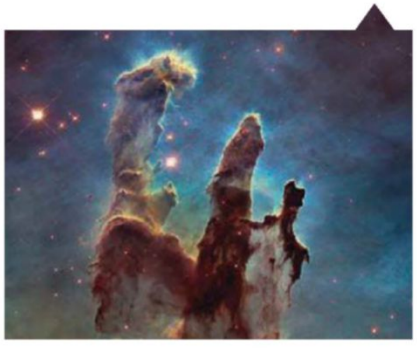


PHOTO: SETFIA, ISTOCK, NASA/HUBBLE SPACE TELESCOPE

6 **This weird marine creature has been captured in waters off southeast Australia. What is it?**

a) Fanged shark
b) Finned shark
c) Frilled shark

7 **Complete the recent headline: 'Computers judge _____ better than friends'**

a) Personality
b) Intelligence
c) Fitness

8 **Astronauts were recently evacuated from a US segment of the International Space Station after a suspected leak of what substance?**

a) Carbon monoxide
b) Methane
c) Ammonia

9 **Tracking devices have revealed the world's highest bird migration. Which bird makes the journey, reaching heights exceeding 7,000m?**

a) Pied wheatears
b) Arctic terns
c) Bar-headed geese

10 **Researchers in the US have built a microwave laser ('maser') that's the same size as what?**

a) A grain of rice
b) A golf ball
c) A dust mite

11 **What kind of animal is Tilda, recently filmed mimicking human speech in a bid to communicate with her keepers?**

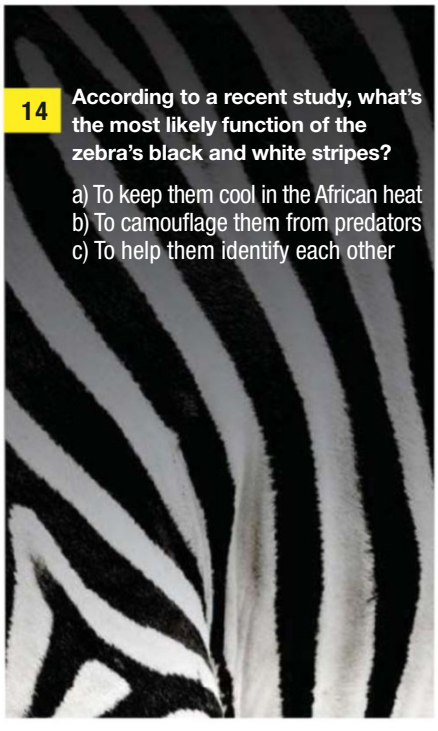
a) Dolphin
b) Orangutan
c) Raven

12 **Researchers at the University of Surrey have found that doing what can help you to recall memories?**

a) Clenching your fists
b) Holding your breath
c) Closing your eyes

13 **Which British soprano recently began training for a trip to the International Space Station?**

a) Lesley Garrett
b) Sarah Brightman
c) Charlotte Church



14 **According to a recent study, what's the most likely function of the zebra's black and white stripes?**

a) To keep them cool in the African heat
b) To camouflage them from predators
c) To help them identify each other

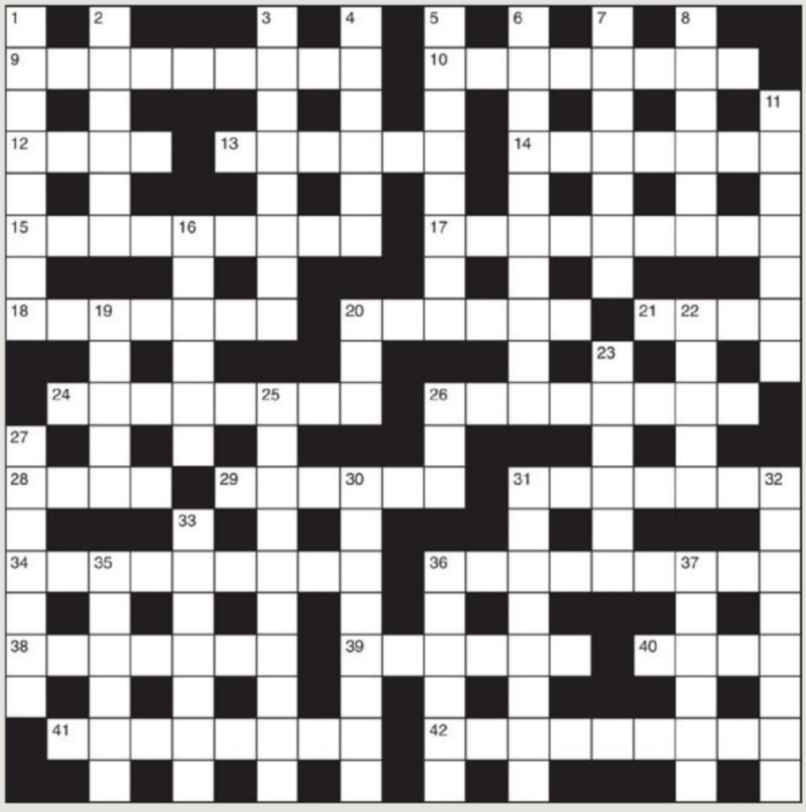
Crossword No.175

ACROSS

9 Calcium oxide isn't slow to reach fruit (9)
10 Labyrinth that's within hearing (5,3)
12 The pain of bachelordom (4)
13 Freezing an ocean (6)
14 It's very important that it's extinct (7)
15 Tense, seen running in a state (9)
17 Sell off what's left (9)
18 Headless insects had vitamin D deficiency (7)
20 Part of the mouth that generates taste (6)
21 Spots cane construction (4)
24 Served report that was biased (8)
26 All pearl layouts are like the sides of a square (8)
28 Entrusted with oxidation (4)
29 Shudder in great remorse (6)
31 Fight club to get carving material (7)
34 Tree has until a change is made (9)
36 My tribute formed an element (9)
38 Way of restarting play worth using at home (5-2)
39 Group of alcoholics has arms sent into capital (6)
40 Only on the German river (4)
41 Former Chancellor to bar recipe with one cabbage (8)
42 Instrument to fix one's glass (4,5)

DOWN

1 Illegal tenant is more dumpy (8)
2 Organism made meandering line around church (6)
3 Diseased? If so, ribs show abnormal formation (8)
4 One insect let off another (6)
5 Woman clears out – it's intuitive (8)
6 Mean to move terribly remote gauge (10)
7 Force Merlin to turn into a troublemaker (7)
8 Georgia performed with old fish (6)
11 Hire a treaty (7)
16 Variable, pursuing green form of power (6)
19 Plant credit note on ship (5)
20 Case of pressure getting too much (3)
22 Firm about communist beliefs (5)
23 Gold cord starts to provide muscle (6)
25 Ran her tiny form into the sea (10)
26 Same level within department (3)
27 Money gives the missing ending dimension (7)
30 Drug claims to work with another, to a point (8)
31 Supporter of nanny goat? (8)
32 Town that pours mud over chips (8)
33 Smart alec finds king lacking defence (4-3)
35 Cook lord an alternative form of bacon (6)
36 Foreign enemy managed to reach island (6)
37 One mind altered with uranium or another metal (6)



SOLUTION TO CROSSWORD 172

QUIZ ANSWERS

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

HOW DID YOU SCORE?

0-5	Ass
6-10	Horse
11-15	Zebra

The Last Word

Who's better at predicting events: experts or a pub crowd?

For anyone living in the small Pennsylvanian town of Punxsutawney, 2 February is Groundhog Day. Each year, the townsfolk are joined by thousands more to witness a century-old ritual of prognostication performed by a groundhog. According to tradition, if the rodent – known as Punxsutawney Phil – sees his shadow and returns to his hole, spring is still six weeks away.

Groundhog Day was made famous by the eponymous 1993 movie, and it supposedly has its origins in an ancient Gaelic festival called Imbolc. Apparently, bright weather on that day pointed to continued wintry conditions.

The reliability of Phil's strike rate is a bigger mystery. The most oft-quoted figure is around 35 per cent. Frankly, I'd be surprised if it were that low; something closer to 50 per cent, like a coin-toss, seems more plausible. As it stands, Phil's forecasts could be taken to be 65 per cent reliable – as long as you turn the traditional interpretation of his behaviour on its head.

In the absence of decent evidence, you'd be better advised getting your forecast from a bunch of people in the local pub. No really, you would. At least that way you stand a chance of tapping into the amazing phenomenon of the 'wisdom of crowds'. First identified around a century ago by a Victorian statistician, it is capable of emerging from groups of people whose individual insights have been pooled and then averaged.

"While the crowd should include people with genuine insight, it's vital to mix in some mavericks as well"

You'd think the average of a lot of rubbish guesses would also be rubbish. Yet if you can persuade people to take the task seriously – by offering prizes, perhaps – and deter jokers by setting an entrance fee, it's surprising how reliable the average guess can be.

Over the years, so-called 'prediction markets' have proved excellent at forecasting everything from election outcomes to the success of new products. Want to know what films and actors are going to win the next Oscars? Then check out the HSX prediction market, which has been forecasting them with uncanny accuracy for years.

The wisdom of crowds may seem like nothing more mysterious than an opinion poll, but researchers have pointed out something weird about it. It seems to work even if the crowd is very small – say a few dozen people – and neither random nor very representative.

Maybe the claims made for the wisdom of crowds are based only on examples where it happens to work, while the failures are quietly forgotten. But researchers are now uncovering the theory behind the phenomenon, along with handy tips for getting reliable forecasts.

While the crowd should include people with genuine insight, it's vital to mix in some mavericks as well. That's because experts tend to think in similar ways and draw on similar evidence. A lack of diversity can prove catastrophic in trying to forecast events, like the global credit crunch which many expert economists failed to foresee. In fact, diversity is so important for reliable forecasting that it's actually worth swapping a few experts for less brilliant radicals, to cover off the 'unthinkable'.

There's another lesson lurking in the emerging theory behind the wisdom of crowds, though: beware of forecasts made by one individual, no matter how supposedly 'expert'. Many of us have a natural aversion to 'gurus' and their touchy-feely prognostications, but it's nice to know that our scepticism has now been confirmed by some cold, hard mathematics.

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

ILLUSTRATOR: SANTHOSH KUMAR

YOU ONLY LIVE ONCE | CARIBBEAN | KYUSHU | RESORTS HOT LIST

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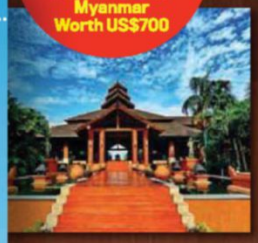

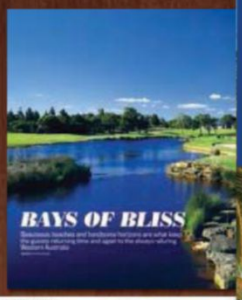

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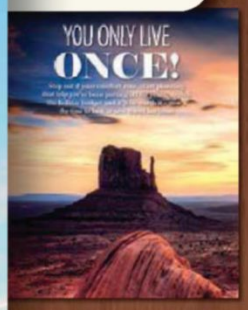

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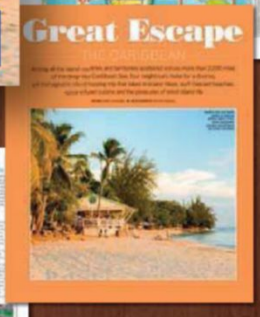

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