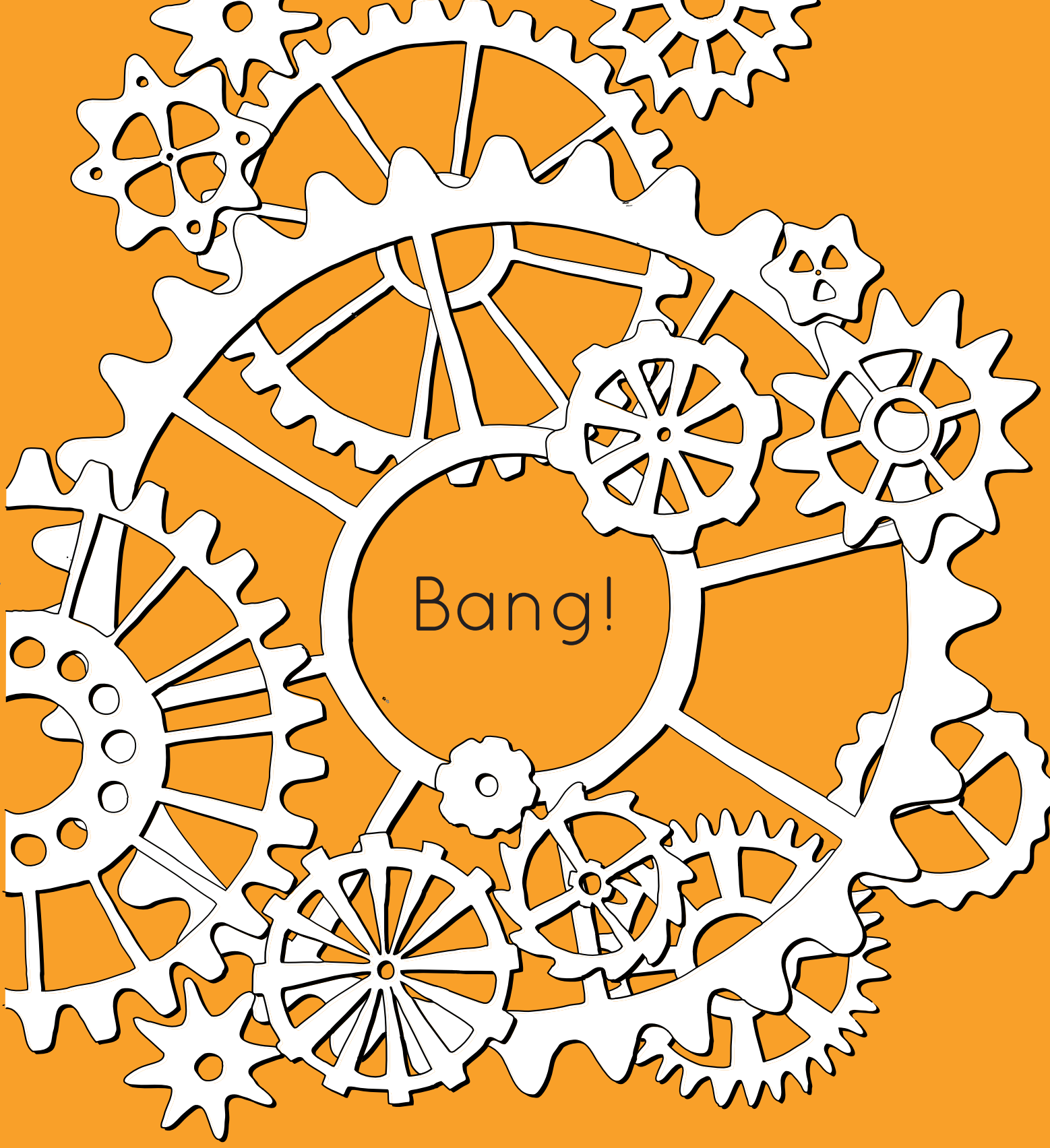

Oxford Science Magazine
6th Edition
Michaelmas Term 2010

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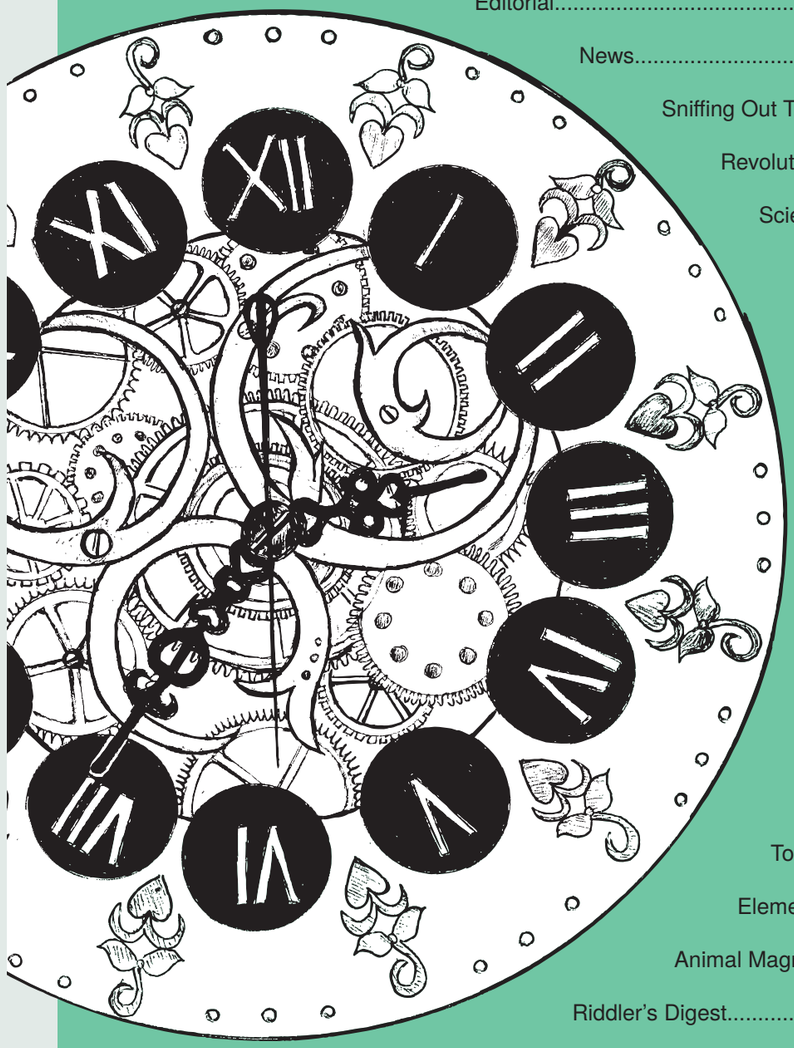

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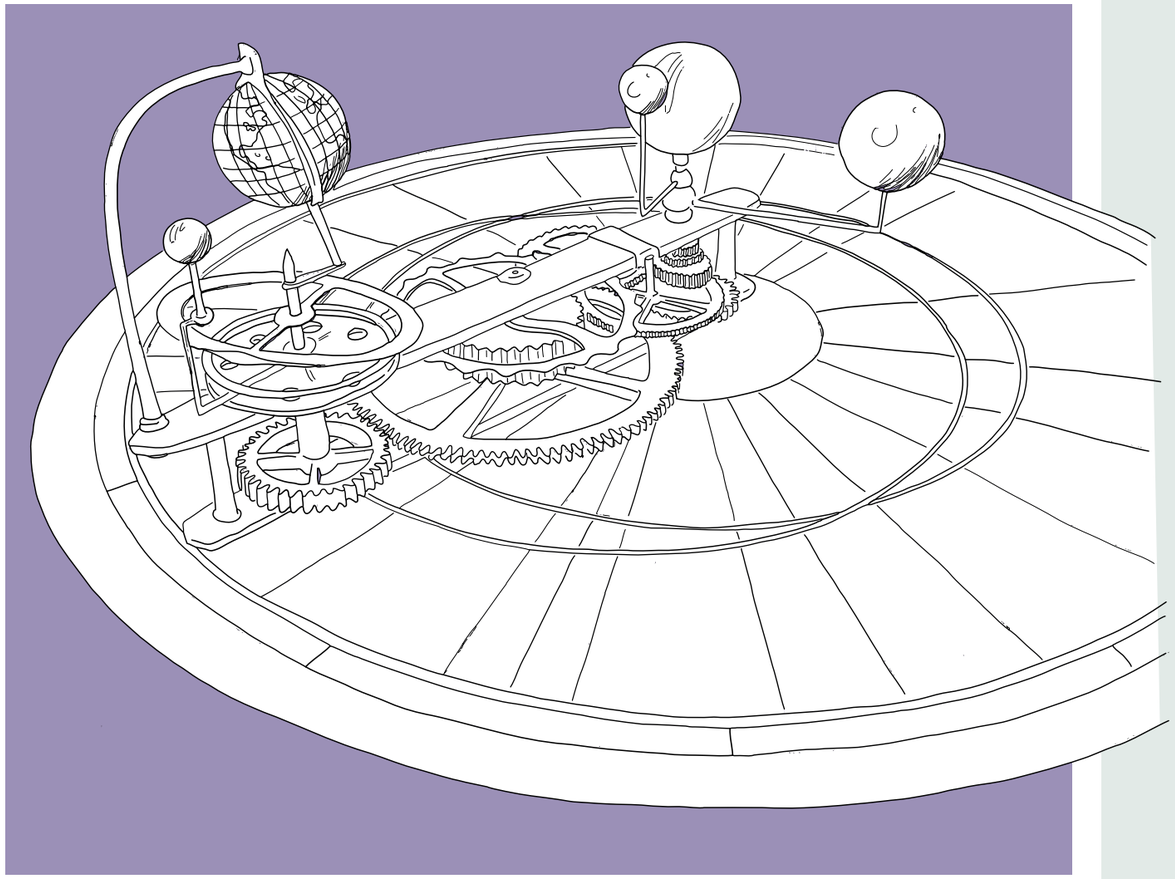

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Editorial

Hello there! Welcome to Michaelmas Term's issue of *Bang!*, Oxford's broadest-based, loveliest-looking and most rip-roaring science magazine.

This term, we've been turning our collective attention to technology — what, precisely, makes something 'technological'? A proclivity for clanking? A tendency towards the contraption-esque? Some of the most exciting technological innovations are about breaking this mould, and challenging our preconceptions about what properly constitutes a technological invention.

Combining science, engineering, and ingenuity can lead to all sorts of discoveries. Together they can test the authenticity of Tibetan art; manufacture never-before-seen elements; or even to make ever-more-effective anti-ageing creams. Moreover, the inventive drive is still running strong. Ever wished you had a magnetic tea towel? Then you should have been at the British Invention Show — and if you somehow missed it, then check out our centrefold piece.

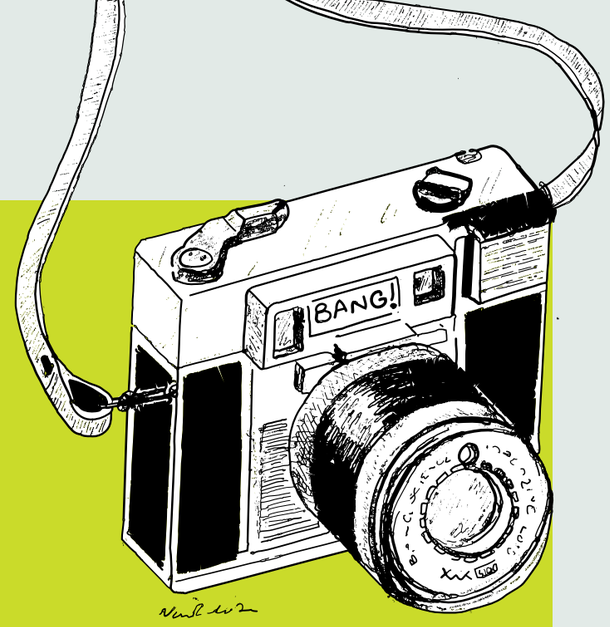
More and more though, technology is looking to learn from nature. After all, it's not like Mother Nature is short on ideas: from global navigation to extreme survival, nature is streets ahead of us. It is no surprise then, that we are looking to nature for technological solutions like upping the efficacy of hydrogen fuel cells with a little help from microbes. Indeed, problem solving lies at the heart of science; current inventors are faced with challenges more complex than fancy gadgetry — they must engineer technology to tackle issues far beyond the lab. Humanity relies on science to provide new opportunities in the face of adversity, from counteracting famine through hybrid plants to re-imagining complex technologies for use in resource-poor environments.

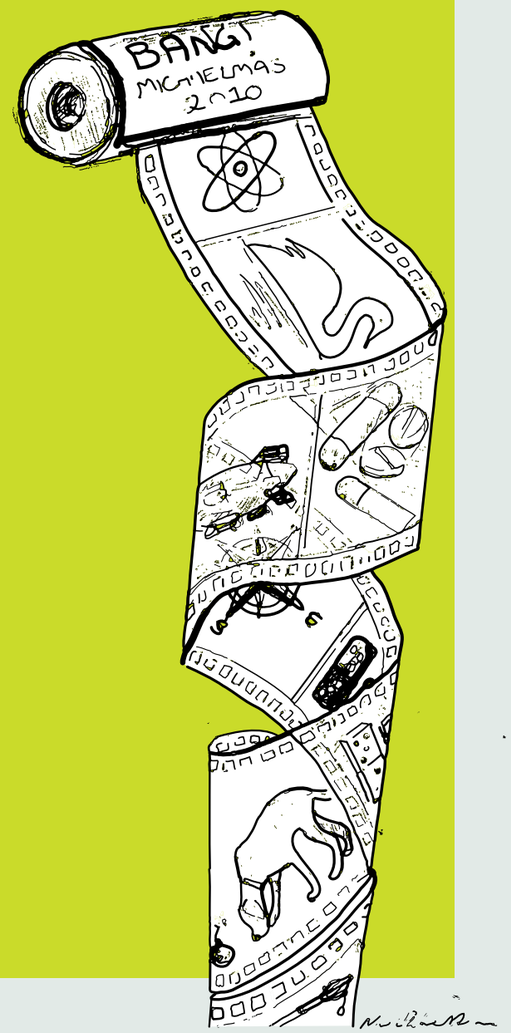
Science, however, is a constant experiment, and the answers it provides are not foolproof — an uncomfortable concept for many of us. If anything, it throws open the doors for debate, engaging in conflicts between scientific theories, libel laws, and even ethical issues.

This issue of *Bang!* aims to bring together the many cogs which turn the wheels of scientific progress — even the most confirmed luddite should find inspiration within these pages.

Adam Lacy and Neil Dewar
Editors

Art: Nicola Davis





News

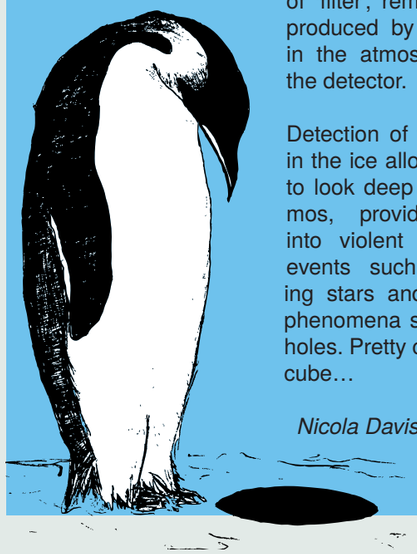
Marvellous Muons

Deep below the icy tundra of the Antarctic landscape lies one of physics' most exciting investigations: an international project (involving scientists from Oxford University) which delves into the mysteries of the cosmos.

2.4 kilometres below the South Pole lies a huge telescope, encompassing a cubic kilometre of ice and containing nearly 5000 sensors. Known as the 'Ice Cube', this telescope detects tiny flashes of blue light which radiate from unusual particles called 'muons' as they travel towards the earth's surface.

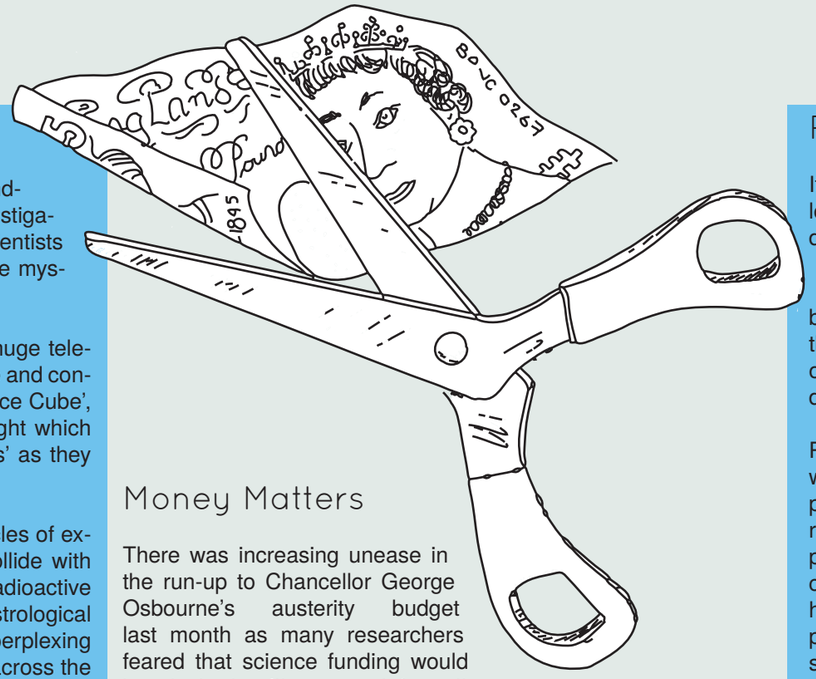
Muons are produced when chargeless particles of exceptionally small mass, called neutrinos, collide with other particles. Neutrinos are produced by radioactive decay processes and may be emitted from astrological events such as gamma ray bursts. These perplexing particles are unusual in that they can travel across the universe in cosmic rays without interacting with other particles — they just pass straight through matter. In fact millions of neutrinos are whizzing through you, undetected, right now. Only very rarely do neutrinos collide with atoms to produce muons.

The mysterious muon generated in such a collision moves in the same direction as the original neutrino, preserving its pathway. In the dark ice under the South Pole, the blue light emitted by muons can travel a hundred metres or more due to the transparency of the ice. As a result, muons detected at the Antarctic give information about neutrinos which entered the Earth at the North Pole. Furthermore, the Earth acts as a sort of 'filter', removing muons produced by cosmic rays in the atmosphere above the detector.



Detection of these muons in the ice allows physicists to look deep into the cosmos, providing insights into violent cosmological events such as exploding stars and astrological phenomena such as black holes. Pretty cool for an ice cube…

Nicola Davis



Money Matters

There was increasing unease in the run-up to Chancellor George Osbourne's austerity budget last month as many researchers feared that science funding would be slashed, with a report from the Royal Society concluding that cuts of 20% would do "irreversible damage" to British science. This prompted Vice-Chancellor Andrew Hamilton, Professor of Chemistry, to write a letter to the House of Lords, warning that: "If the reductions to funding continue the reputation of Oxford, and other leading UK research-intensive universities, will wane."

It was with relief, then, that researchers across Oxford heard the news that the £4.6 billion currently spent on science annually by the Department of Business and Industry will be ring-fenced until 2015. Once inflation is taken into account, this corresponds to a 10% cut over four years, in an economic climate in which many government departments have had their budgets cut by up to 30%.

However, as Jenny Rohn from the pressure group Science is Vital points out: "UK science is still not entirely safe. While we have made cuts to science, our competitors in the US and Germany are increasing their investment – there is still a risk of a brain drain." Furthermore, there are real concerns that the money used to run large scale projects such as Oxfordshire's £343 million Diamond Light Source has not been guaranteed; some of these important facilities may be forced to close.

Adam Lacy

Art: Nicola Davis and Leila Battison

P≠NP?

It's a million dollar question, one of the seven Millennium Prize Problems in Mathematics and it's fundamental to the solution of problems as diverse as choosing the quickest route for a travelling salesman to the most efficient way to pack objects into boxes. So why has no-one ever heard of it? Part of the reason lies in the fact that even the statement of the problem is complex enough to need a higher degree in Mathematics to understand it fully!

Put simply, the problem asks "Can every problem whose solution can be efficiently *checked* by a computer also be efficiently *solved* by a computer?" More rigorous definitions of what efficiently means are expressed mathematically in terms of how quickly the computer can work through the list of instructions it has been given (known as an algorithm) to solve the problem. Questions for which algorithms can provide solutions in **P**olynomial time are known as "P". More complicated problems can only be solved by an algorithm in **N**on-**P**olynomial time (which is longer), but when given a solution can still be verified by a computer in shorter, polynomial time. This class is known as "NP". Knowing whether P=NP would tell us whether the class of problems, NP, which can be *verified* in polynomial time can also be *solved* in polynomial time.

As an analogy to an NP problem consider a jigsaw puzzle. The solution to the problem is hard; it takes a long time to fit all the pieces of the jigsaw together correctly. However, if someone claims they have completed the jigsaw, this can be verified very quickly. Factorisation (breaking a number down into smaller numbers) of large numbers into primes is an NP problem. Many internet encryption processes are based on the huge amount of time (NP) that factorisation takes, so finding it could be done in a much shorter time (P) could have huge ramifications.

Fortunately, one man thinks he's found the solution and it's that P≠NP. Vinay Deolalikar from HP Research Labs, a relative unknown in the field, came up with a 100 page 'proof' in August of this year. The solution is currently being peer reviewed by computer scientists, and so far no holes in the 'proof' have been found. That's not to say there won't be any, but either way the mathematical and computer science communities will have learned a great deal from his attempts.

Christian Yates

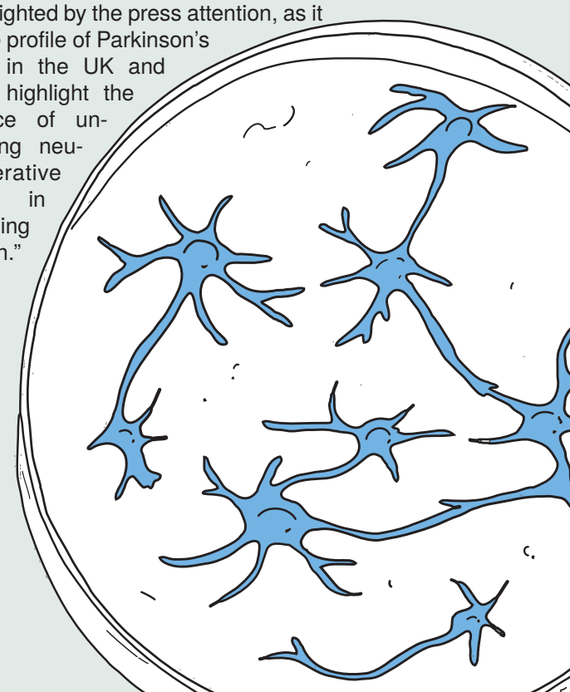
Parkinson's on a plate

Neuroscientists in Oxford are using stem cells derived from patients' skin to investigate the origins of Parkinson's disease. The cells, known as induced pluripotent stem cells (iPS cells), were first created in 2007 by 'de-programming' adult skin cells. They offer fresh hope for stem-cell based therapies as they are not derived from the controversial embryonic cells, and also offer a unique opportunity to study the cells of individual human subjects, in a dish.

Speaking at the UK National Stem Cell Network meeting in Nottingham last month, Dr Richard Wade-Martins, who heads the Oxford Parkinson's Disease Centre (OPDC), described how his team is able to convert iPS cells into dopaminergic neurons: the specific cells that die in Parkinson's disease. They now plan to do this with cells from over 1,000 patients with early-stage Parkinson's disease and compare them with healthy, age-matched controls. "The tests we will do will be designed to better understand how dopaminergic neurons from a PD patient handle dopamine differently." In particular, the team will investigate whether transmission at dopamine synapses fails before or after the development of the protein aggregates which are associated with the onset of Parkinson's disease.

The experiments are funded by a £5 million grant awarded by Parkinson's UK to Dr Wade-Martins and the OPDC. Dr Wade-Martins' presentation in Nottingham was covered by several media organizations, including the BBC. "I was delighted by the press attention, as it raises the profile of Parkinson's research in the UK and helps to highlight the importance of understanding neurodegenerative diseases in our ageing population."

Jonathan Webb



Sniffing Out Trouble

Stopping terrorists going off with a bang

As terrorist activity and the sophistication of home-made bombs increases, the need for sensitive and rapid explosives detection has never been greater. In war zones, the detection of landmines and improvised explosives devices (IEDs) is essential for the avoidance of civilian and military casualties. In the UK, airport security is a top government priority.

While metal detectors have previously been used to detect these devices, modern landmines tend to contain smaller quantities of metal and their detection requires new approaches. Iraq and Afghanistan, as well as being amongst the most landmined countries in the world, also pose a particular threat to civilians and coalition troops stationed there, in the form of home-made roadside bombs or IEDs. While landmines are detonated by pressure (from people or vehicles), IEDs are more sophisticated and can be remotely detonated by radio signals, for example from mobile phones. Consequently, 'jammers', which transmit on the same radio frequencies as mobile phones and thus disrupt communications to the IED, have been installed on hundreds of US vehicles.

Buried landmines and IEDs can be detected from the vapours leaking from the device into the soil and air. However, detecting an explosive's vapour is particularly challenging because many explosives exist mainly in solid rather than gaseous form, and are thus only present in air in small amounts. That trained sniffer-dogs remain one of the most reliable and rapid explosives detectors is a testament to the power of a dog's nose: it is thought that dogs react to a combination of the many smells that make up an explosive. Much research has been directed towards developing sensors or 'artificial noses' which are as reliable as sniffer dogs.

One such artificial nose is a specially-coated bundle of optical fibres which can be used to bind particles of explosives such as TNT. Light travelling down the optical fibres undergoes a change in either intensity or frequency if vapours from explosives are present in the air around them. Optical fibres are ideally suited for field-use as they are small, cheap and portable, and also allow for remote sensing.

Closer to home, airport security continues to tighten after the attempted Amsterdam–Detroit plane bombing last Christmas. While luggage is x-rayed to identify potentially explosive objects, passengers pass through a metal detector. However, recent examples of terrorists boarding flights with small packets of explosives hidden around their body undetected has led to the introduction of full body scanners in UK airports. These devices use terahertz frequency radiation to generate seemingly-naked images of a passenger, and are thus thought to be able to detect explosive packages hidden around the body. However, such scanners also raise privacy concerns.

The key is to screen for explosives using a combination of approaches, in the hope that at least one will be effective. Alongside the introduction of full body scanners, trace explosives detection in airports is also on the increase. If a person has handled explosives recently, residues may remain on their hands, hair and clothing. These traces can be collected either by sampling the air around a passenger or by taking a swab sample from, for example, a passenger's boarding card. Since traditional screening devices usually look for solid explosives, the use of liquid explosives in terrorist attacks has risen recently. Restrictions on liquid in hand luggage remain in place, as it can be difficult to distinguish between normal liquids and liquids that can be mixed together to create an explosive device. However, progress has been made towards the development of non-invasive commercial systems capable of analysing liquid mixtures.

"While landmines are detonated by pressure, IEDs are more sophisticated."

Despite the substantial research efforts and funding that has been poured into explosives detection over the past few decades, there is as yet no 'silver bullet', and the reality is that explosives detection technology is usually implemented as a response to new explosive threats; while scientists are developing new techniques, terrorists are becoming better at making devices that evade detection. However, innovative scientific ideas such as the development of artificial noses show exciting promise. ■

Words: Cathy Rushworth
Art: Olivia Shipton

Revolutionary Fervour

How a little known botanist saved the lives of millions

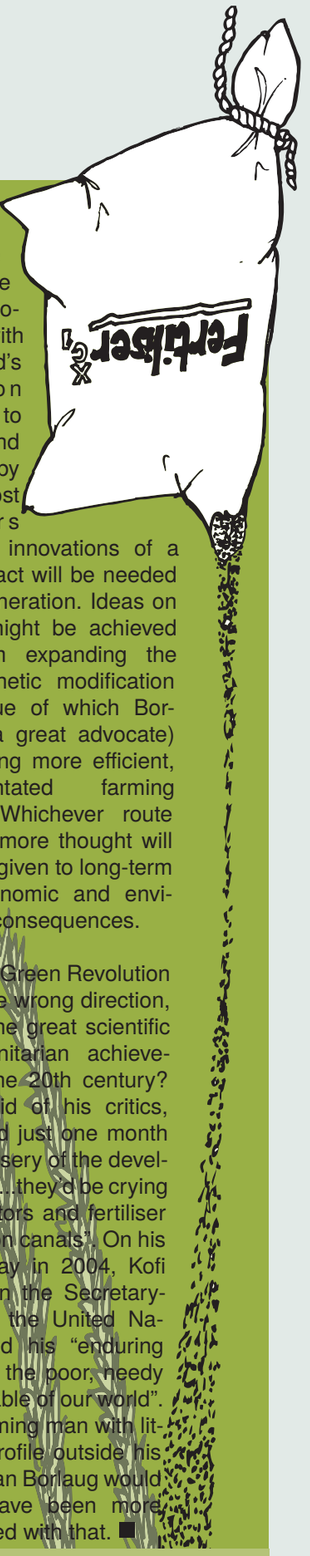
"The battle to feed all of humanity is over. In the 1970s...hundreds of millions of people are going to starve to death". In the 1960s India was teetering on the brink of a humanitarian catastrophe; population biologist Paul Ehrlich's words reflected the general fear that mass famine was inevitable. India was heavily dependent on imported grain, and self-sufficiency seemed an impossible dream. That Ehrlich's apocalyptic prediction never became reality is due in no small part to the work of the American botanist Norman Borlaug. His crop-breeding innovations aided the massive turnaround in India's agricultural fortunes which became known as the 'Green Revolution'.

"Much of the early planting took place within sight of artillery flashes."

The seeds of the Green Revolution were sown in Mexico. In the 1940s, Mexico was importing much of its grain after poor harvests in previous seasons. Borlaug's team were attempting to breed new, better varieties of wheat, and produced two key improvements. The first was to cross-breed plant strains that carried different disease resistance genes (a process known as hybridisation) to create crops that were resistant to many different pathogens. By a similar cross-breeding method, the team introduced genes for dwarfism, which produced short crops with heavy ears of wheat, instead of tall, thin plants prone to toppling over. In all, they made over 6000 individual crossings of wheat over a nine-year period in search of the perfect breed. By 1963, 95% of Mexico's wheat lands grew Borlaug's new semi-dwarf varieties, with overall yields of more than six times the 1944 level.

Borlaug's work in Mexico did not go unnoticed elsewhere. In 1965, the Indian government, desperate for a solution to the country's food crisis, invited him to implement seed planting projects there. Borlaug agreed, and that year seeds from the semi-dwarf varieties that had been developed in Mexico were shipped to the subcontinent. 12 hours into the voyage, war broke out between India and Pakistan, and much of the early planting took place within sight of artillery flashes. In spite of these problems, India was self-sufficient in the production of cereals by 1974. In recognition of his role in introducing the plants and practices which have been credited with saving millions of people from starvation, Norman Borlaug was awarded the 1970 Nobel Peace Prize and the Padma Vibhushan (India's second-highest civilian honour).

Borlaug's place in the pantheon of scientific heroes seemed assured. However, in the years that followed, criticism of the Green Revolution grew. The new crops required heavy use of fertilisers and pesticides, which over time affected the quality of the soil. In India, cheap fertilisers such as urea have caused a nutrient imbalance, and as a result, yields of wheat and other crops had stopped increasing. Indeed, many smallholders have found that the only way to maintain production levels is to use more and more urea, creating a vicious and unsustainable cycle. Propagation of Green Revolution cereals also requires extensive irrigation, which in areas of low rainfall has created water shortages. In parts of the Punjab region, the water table has dropped around 50 feet since 1960, largely due to the new farming practices. The cost of equipment means that the Green Revolution has disproportionately benefitted richer farmers, heightening existing tensions between them and the agricultural labourers.



Whatever their opinion of the merits of the Green Revolution, with the world's population estimated to reach around nine billion by 2050, most observers agree that innovations of a similar impact will be needed within a generation. Ideas on how this might be achieved range from expanding the use of genetic modification (a technique of which Borlaug was a great advocate) to developing more efficient, locally-orientated farming practices. Whichever route is chosen, more thought will need to be given to long-term social, economic and environmental consequences.

So was the Green Revolution a step in the wrong direction, or one of the great scientific and humanitarian achievements of the 20th century? Borlaug said of his critics, "if they lived just one month amid the misery of the developing world...they'd be crying out for tractors and fertiliser and irrigation canals". On his 90th birthday in 2004, Kofi Annan, then the Secretary-General of the United Nations, hailed his "enduring devotion to the poor, needy and vulnerable of our world". An unassuming man with little public profile outside his field, Norman Borlaug would probably have been more than satisfied with that. ■

Words: Genevieve Clutton
Art: Kei Hamada

Science, Swans and Certainty

How a centuries-old philosophical puzzle is still troubling today

How do you know the sun will rise tomorrow? Just because it has risen every day of your life, it does not necessarily follow that it will rise again. The scientific method often involves extrapolating from limited data to a more general conclusion. For example, Newton's principle of universal gravitation states that every body in the universe exerts a gravitational attraction on every other body. Newton did not arrive at this conclusion by examining every single body in the entire universe. Instead, he made an inference based on limited observations of our solar system. Therefore, he could never be absolutely certain that his theory holds for the entire universe. Philosophers know this as the 'problem of induction', a conundrum which pervades all of science.

To explain this problem, take a look at this classic logical argument:

1. All men are mortal
2. Socrates is a man

Therefore,

3. Socrates is mortal

The first two statements are the premises of the argument, and the third statement is the conclusion. If the premises are true, then the conclusion must be true. This is known as deductive reasoning. Contrast it with an argument that uses induction:

1. All the swans I have observed are white

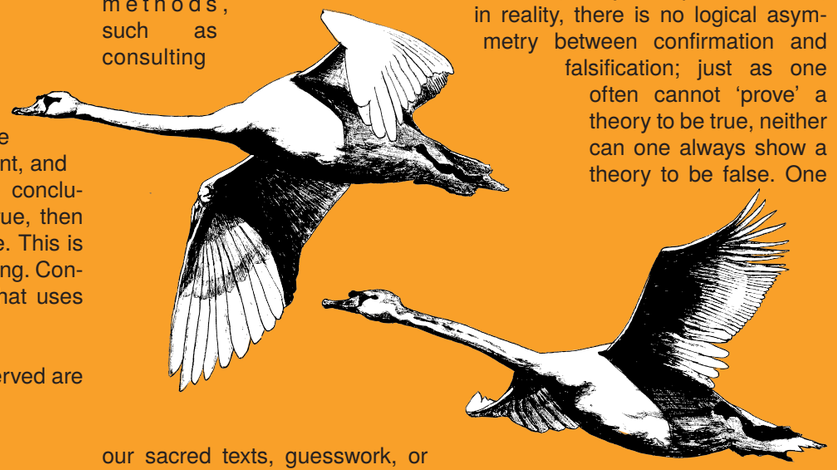
Therefore,

2. All swans are white

The premise may well be true, but it does not follow that the conclusion is true (the black swan was discovered in Australia in 1697). Similarly, just because the sun has risen every day in the past gives us no formal justification for the belief that it will rise tomorrow, surprising as that might seem at first.

Yet, we rely on inductive inferences throughout our lives; you stake your life on the assumption that when you turn the steering wheel left, the car you are driving will turn left. We tend to assume that the past is a reliable guide to the future. For example, if you put your hand in a fire, you will quickly learn not to make the same mistake again. So, do we need to worry about induction, since it has served us so well in the past? Yes, we do. As the 18th century Scottish philosopher David Hume pointed out, justifying induction on the grounds that it has worked in the past is simply using inductive reasoning to justify induction, which is a circular argument.

Since science relies on induction, we need a reason to trust it in order to justify scientific endeavour. Why is employing induction to understand the movement of heavenly bodies better in this case than using other methods, such as consulting our sacred texts, guesswork, or astrology? Many philosophers and scientists have tried their hand at a solution to the problem of induction with varying levels of success. The most prominent solution to this puzzle was proposed by the 20th century philosopher Karl Popper.



Popper agrees with Hume's critique of induction and believes that it cannot alone constitute the scientific method. Instead, he claims to resolve the problem of induction by reframing the scientific method from evidence gathering to conjecture and refutation. He states that when scientists are faced with a problem, they propose a hypothesis that is conjecture and test it experimentally. A positive outcome provides a strong confirmation of the hypothesis, but cannot prove it. However, if the outcome refutes the hypothesis, then you can deductively state that the hypothesis is not true. In Popper's philosophy there is a logical asymmetry between 'confirmation' and 'falsification', with only deductive arguments deemed legitimate.

"Newton did not arrive at his conclusion by examining every single body in the entire universe."

However, many examples show that, in reality, there is no logical asymmetry between confirmation and falsification; just as one often cannot 'prove' a theory to be true, neither can one always show a theory to be false. One example of this is Adams and Leverrier's (independent) solution to the puzzle of Uranus' orbit in 1846.

The observed orbit of Uranus was consistently different from that predicted by Newtonian theory. Rather than dismiss Newton's ideas, they suggested that there was another planet exerting an additional gravitational force on Uranus. Based upon the deviation of the orbit from its expected path, they calculated the mass and position of their proposed planet. Subsequent research by Galle at the Berlin observatory confirmed that such a planet did exist exactly where Adams and Leverrier had predicted. Popper himself refers to this strong confirmation of Newtonian physics as 'the most startling and convincing success of any human intellectual achievement'.

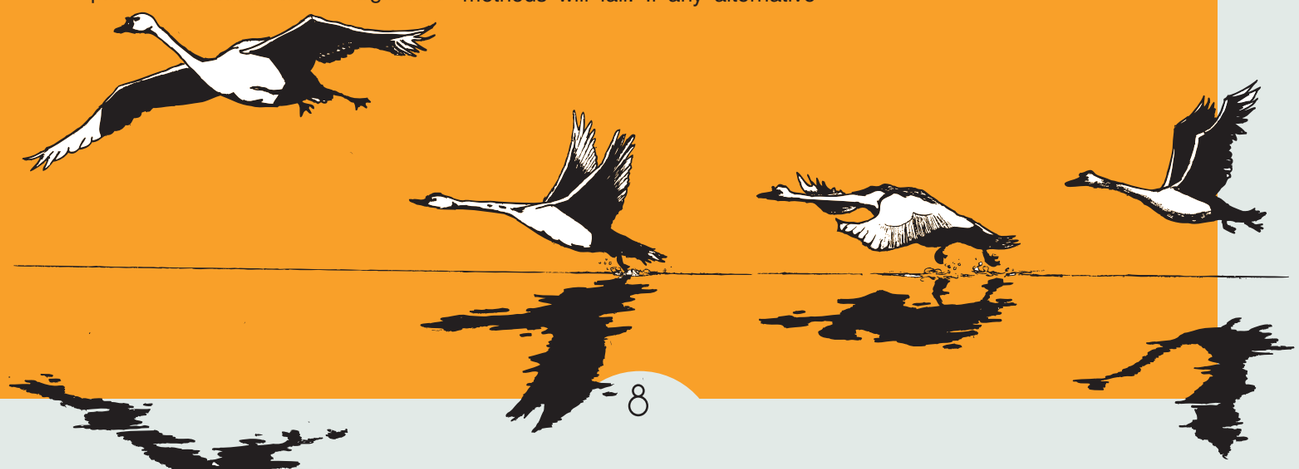
"Disconcerting though it may be, we can never know anything with absolute certainty."

However, as the philosopher Imre Lakatos points out, non-confirmation of a hypothesis does not necessarily mean falsification. What, he asks, would happen if Galle had not found Neptune? Would Newtonian physics have been abandoned, or would Newton's theory have been falsified? The answer is no, for Galle's failure could be attributed to a number of causes: for example, the interference of the Earth's atmosphere with the telescope. Indeed, how do we know that the premise, 'there is no planet observed where the theory predicts it should be', is true without relying on inductive inferences from our observations? Although Popper's falsification can be framed deductively, there is no way of determining if the premises of the deductive argument are true, except inductively. Recall the deductive argument at the start of this article. We cannot know that all men are mortal, we infer that it is true because no man has been observed to be immortal.

It would appear, then, that we are back at square one. Popper's version of the scientific method cannot escape induction. So, is induction an inevitable part of science? The pragmatic argument for trusting induction takes a different approach. We must make a decision about how we form beliefs about the natural world somehow, and therefore we need only show that induction is a reasonable method. To achieve this, all we need to do is show that if there are any reliable methods, induction is the best one. Imagine two universes, one in which nature is uniform and always obeys specific laws, and one in which the universe is random, chaotic and does not obey any laws. In the uniform universe, induction is preferred on the basis that the past is a reliable indicator of the future. In the chaotic universe it does not matter what approach we take, all methods will fail. If any alternative method did not fail, we would be able to identify inductively that the method was generating consistent predictions, and hence the universe could not truly be chaotic.

So, it would appear that induction is an inevitable part of science. It is a strength, not a weakness, that scientists are aware that theories cannot be 'proved', and are only based on the best available evidence from our inductive inferences. It is this open-mindedness that drives science forwards and allows us to modify and improve our theories as new evidence is gathered. Disconcerting though it may be, we can never know anything with absolute certainty, — even things that we take for granted, like the rise of the sun tomorrow. ■

Words: William Brandler
Art: Olivia Shipton



Enzyme Engines

Bacteria delivering a petrol free future?

Modern chemists can do amazing things; however, there are still cases where the natural world can beat scientists in the lab. Harnessing the elegant and controlled way in which nature carries out chemistry could help scientists solve some of the most prominent problems of our age.

The so-called "hydrogen economy" is one of the most attractive solutions that has been proposed for our society's harmful oil-burning habits. The idea is simple: renewable energy is stored in a chemical form by splitting water to make hydrogen gas. This energy can then be released in the reaction of hydrogen with oxygen to produce water again. The idea of cars emitting only water from their exhaust pipes is hugely attractive from an environmental perspective.

Although hydrogen could be used to fuel an internal combustion engine, burning hydrogen isn't the most efficient way to harness its energy; fuel cells are a superior solution. The first fuel cell was built in 1839, but the technology didn't really catch on until the 1960s when NASA decided to use fuel cells to provide electricity and water on the Apollo missions.

"The idea of cars emitting only water from their exhaust pipes is hugely attractive from an environmental perspective."

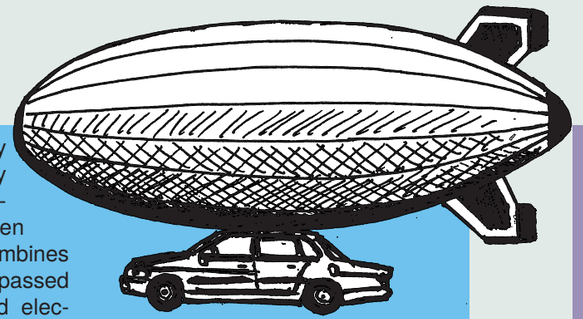
A conventional hydrogen fuel cell consists of two metal electrodes separated by a membrane. Hydrogen gas (H_2) is fed into the anode (negative electrode) side; here the hydrogen molecules are split into their constituent protons and electrons, with the help of a catalyst. The membrane allows the protons to pass through but electrons are forced to travel through an electric circuit to reach the other side, releasing the chemical energy as electrical energy as they do so. On the cathode (positive electrode) side, oxygen (O_2) from the atmosphere combines with protons (which have passed through the membrane) and electrons (which have flowed through the circuit from anode to cathode) forming water.

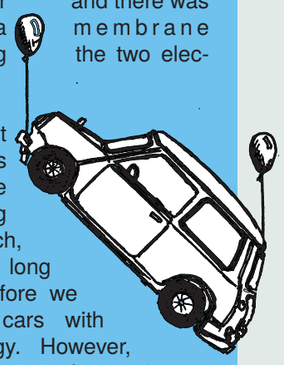
Current fuel cells use platinum as the catalyst at the anode, as it adsorbs H_2 onto its surface and makes splitting the molecule into its protons and electrons much more efficient. However, as platinum is also good at adsorbing O_2, we need to use very pure H_2 and the electrodes must be separated from the environment by a membrane. Another drawback is that platinum is one of the most expensive metals on the planet.

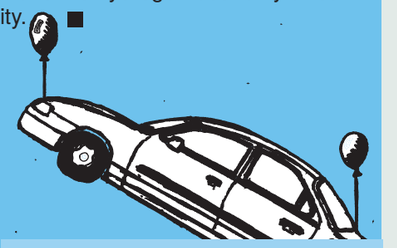
Enzymes are catalysts which carry out almost all chemical reactions in living cells. From nature's enormous catalytic toolkit we can pick out enzymes that fit the criteria for both our electrode catalysts. Some microbes can metabolise hydrogen, as they have enzymes called hydrogenases that catalyse the removal of its electrons. However, most of these organisms are anaerobes, which means they are prone to damage by oxygen. Knallgas bacteria are unusual in that they live in aerobic environments, yet have evolved a way to use low levels of H_2 gas. Hydrogenases from these bacteria show an impressive oxygen tolerance, which means they can operate on dilute, non-combustible mixtures of air and hydrogen.

In November 2006, scientists at Oxford built fuel cells using enzymes to catalyse the electrode processes. At the cathode, they used an enzyme from white rot fungus which, when supplied with protons and electrons, is capable of breaking down oxygen from the air into water. Meanwhile, at the anode they used a Knallgas hydrogenase which is capable of breaking hydrogen down into protons and electrons. Due to the oxygen tolerance of the hydrogenase and its impressive ability to select H_2 in preference to other small molecules, the resulting fuel cell had some interesting properties. It could run on just a trace (3%) of H_2 added to normal air and there was no need for a membrane separating the two electrodes.

The cell built in Oxford was only capable of powering a digital watch, so there is a long way to go before we are running cars with this technology. However, it does demonstrate how scientists can harness the impressive properties of naturally occurring systems. Chemists can learn a lot from nature; many enzymes do things that are presently very difficult, if not impossible, in a laboratory. If we can transfer this power from bugs and fungi into labs and then from labs into industry, then perhaps we can make the hydrogen economy a reality. ■







Words: Edward Lewis
Art: Samuel Pilgrim

Painting by Numbers

How modern science is revealing the secrets of ancient Tibetan art

Ancient paintings hold many mysteries and few can gaze upon them without a sense of awe. But how can we know when a painting was created, where it is from or even tell if it is a fake? Exploring such questions is usually the task of museum curators and conservators but, armed with his private collection of Tibetan scroll paintings, some lab equipment and a Nobel Prize in Chemistry, Richard Ernst is providing some answers of his own.

Since 1968 Ernst has been collecting Tibetan works known as thangkas – delicate, vivid and intricate paintings over one metre squared in size. The canvasses are fragile, so old-fashioned analysis by sample removal is out of the question. Instead, delving into the murky past of a painting requires modern non-destructive techniques, many of which can be carried out with the painting safely behind glass.

Underneath the bright surface of a thangka lies the outline of the image – usually in black ink. To see this, long-wavelength near-infrared (NIR) light is shone onto the painting. Most of the pigments only absorb light in the visible region and are transparent to the NIR light, allowing it to pass through them until it reaches the foundation layer of the painting. This layer was used to prime the canvas, consisting of a mixture of chalk and hide glue which reflects back NIR light. However, carbon rich media such as charcoal or black ink absorb this light and hence the sketched areas show up as dark lines in the reflectogram. Utilising this NIR reflectography technique, Ernst observed small symbols in different areas of the sketch, which seemed to correspond to different colours. The thangka was, in fact, an early 'paint-by-numbers' – the master artist providing the outline with coded instructions to his students on how to colour it in.

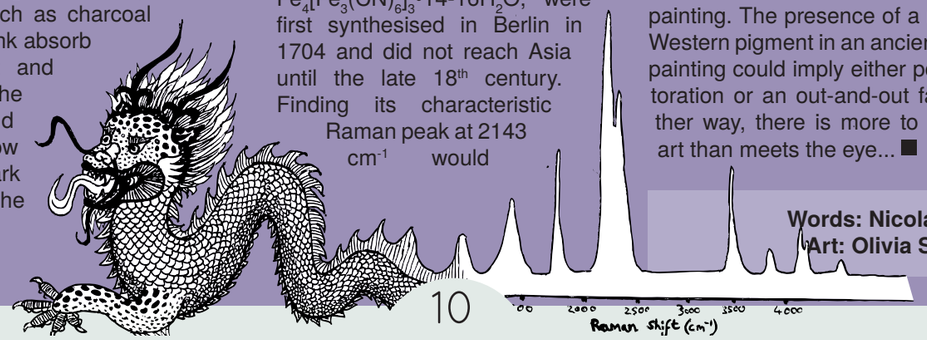
"The canvasses are fragile, so old-fashioned analysis by sample removal is out of the question."

Much more can be ascertained about a painting by examining the precise pigments used with Raman spectroscopy. When the painting is exposed to an intense beam of laser light, the light interacts with the pigment molecules and bounces back in all directions; by measuring the change in energy during this reflection, the pigments can be identified. This is because each pigment is composed of a different chemical compound, which alters the energy of the light by a particular amount, producing a characteristic 'Raman spectrum'. Moreover, blends of pigments can be detected in the same way, as the spectrum of a mixture simply resembles the superimposed spectra of the pure compounds.

To determine the age of a thangka, certain clues are sought. Pigments such as Prussian blue, $Fe_4[Fe_3(CN)_6]_3 \cdot 14\text{-}16H_2O$, were first synthesised in Berlin in 1704 and did not reach Asia until the late 18th century. Finding its characteristic Raman peak at 2143 cm^{-1} would narrow the possible date of creation significantly, while analysis of the painting style would help to restrict it further.

Certain pigments were more popular in particular regions, depending upon both natural mineral deposits and painting styles. Green, for example, was added to thangkas by mixing together blue and yellow pigments. The yellow was usually orpiment (As_4S_6), but the blue could come from a variety of sources: in Nepal and India indigo was preferred, while in Northern Asia indigo was less common and was often substituted by lazurite, $(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$, or later, Prussian blue. Synthesis of orpiment itself is achieved by heating arsenic trioxide with sulphur; however, the yellow pigment formed usually contains leftover arsenic trioxide. By examining the Raman spectra of the painting for the signature peaks of arsenic trioxide, it is possible to determine whether the orpiment is synthetic or not. Understanding the composition and origin of the pigments in such fine detail allowed Ernst to close in on both the location and the date at which the painting was produced.

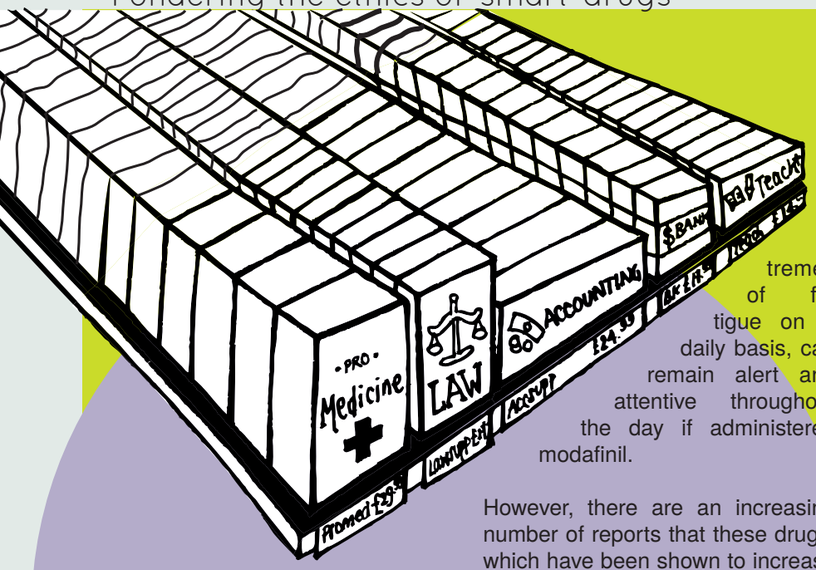
Spotting a fake can be tricky for the naked eye, as colours produced by two different pigments can look the same. However, examination of their Raman and NIR absorption spectra can reveal the true nature of the painting. The presence of a modern Western pigment in an ancient Asian painting could imply either poor restoration or an out-and-out fake. Either way, there is more to Tibetan art than meets the eye... ■



Words: Nicola Davis
Art: Olivia Shipton

Cognition Copyright

Pondering the ethics of 'smart-drugs'



The practice of ingesting something to induce a different mental state is at least as old as the first fermented fruits, and few of us think twice before using alcohol, caffeine, or ice cream to bring us sedation, stimulation, or a smile. With the advancement of psychopharmacology and our ability to bring about more specific changes in our mental states with fewer inconvenient side-effects, we may not be too far away from profoundly altering our own brain functions; an ability with the potential to change human life as much as the harnessing of fire, the mechanisation of industry, or the I.T. revolution.

Medical science has already made considerable progress in selectively altering brain function. The pronounced cognitive decline witnessed in sufferers of Alzheimer's disease is caused by the deterioration of brain cells, and drug therapies like donepezil have been successful in slowing down or reversing this decline. Reliable improvements in attention are witnessed in children with ADHD when given the stimulant drug Ritalin. Furthermore, sufferers of narcolepsy, who experience extremes of fatigue on a daily basis, can remain alert and attentive throughout the day if administered modafinil.

However, there are an increasing number of reports that these drugs, which have been shown to increase attention span, reduce distraction, and prolong wakefulness, are being used more and more by students at UK universities while preparing for and taking exams. Linda, a psychology graduate student at Manchester University, takes modafinil which she buys online to help her to get through essay crises. "It's a stimulant, similar to caffeine or Red Bull although I didn't get distracted and feel jumpy like you sometimes do on caffeine. You don't feel wired but I did lose my appetite."

"We may be limited in our memory, wakefulness, and cognitive capacities for very good reasons."

The idea that these cognition-enhancing drugs may be used by students sitting their finals alongside you tends to prompt reactions similar to those elicited when an athlete is revealed to have used performance-enhancing drugs. Those in direct competition with the pharmacologically advantaged can be forgiven for feeling hard done by; no-one wants to be forced to take a silver medal, or be denied a place on their preferred graduate course, by someone taking performance enhancing drugs.

However, the analogy with sports may not be entirely complete; sports are wholly dependent on direct competition, and it is right that they should be judged according to athletes' talent and hard work relative to their competitors. If you view education primarily as a competition for the best results, then likely you would welcome the introduction of new rules banning the use of performance-enhancing drugs in preparation for tests. However, if education is about gathering knowledge and understanding, then — so long as these drugs are safe and easily accessible — perhaps their use should be encouraged, just as adequate sleep, note-taking, and thorough revision are. Though some would contend that, unlike these other measures, pharmacological cognitive enhancers cheapen intellectual achievement by making it easier to come by, we allow other shortcuts without concern. We happily allow children use of a calculator once they have mastered basic arithmetic. If they are allowed this shortcut when they move on to more complex concepts in mathematics, the boring, repetitive bits of education become easier, and they are able to study more interesting and challenging areas.

In the future, it seems likely that there will be more complex problems associated with pharmacological cognitive enhancement than those faced in academia. Donepezil, the Alzheimer's treatment, has been shown to improve the performance of commercial pilots in flight simulator training, particularly when responding to emergencies. It has also been shown that junior doctors, famously overworked and under-rested, make, on average, fewer errors while on call if they take modafinil, demonstrated to reduce the deficits in sustained attention commonly associated with sleep deprivation. Furthermore, it is common practice for the same surgeon to remain with a patient for the duration of major surgery as handovers have been linked to higher complication rates. The prevalent drug of choice for such situations (surgery can last eight hours or more) is caffeine, well documented for the jitters it produces; the benefit of switching to a mind-enhancing drug like modafinil is clear.

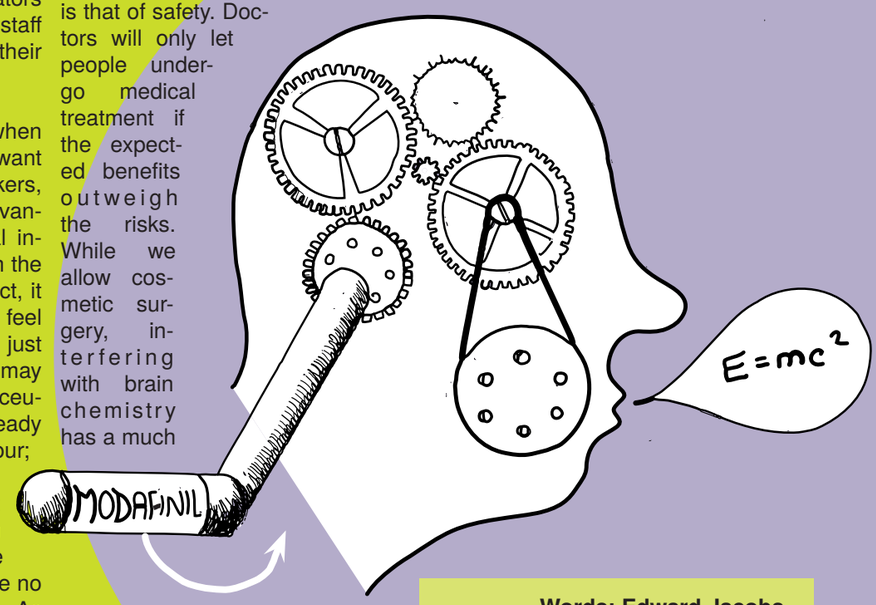
"If education is about gathering knowledge and understanding, then perhaps the use of these drugs should be encouraged."

In these cases, the benefit to society of taking a pharmacological cognitive enhancer is potentially large. However, it is important that these scientific developments become a matter for public debate, as it should be the role of politicians and lawmakers to decide whether airline directors and hospital administrators would be justified in asking their staff to take such drugs to improve their performance while at work.

More problems may arise when other employers decide they want their workforce of lawyers, bankers, or salesmen to be similarly advantaged. Even if pharmacological interventions are never detailed in the terms of an employment contract, it is conceivable that people may feel pressured to take these drugs just to keep up, an insecurity that may be capitalised upon by pharmaceutical companies. There is already some evidence for this behaviour; the worldwide market for the memory enhancing supplement ginkgo biloba is already worth more than US$1bn, despite the fact that it has been shown to be no more effective than a placebo. As more and more effective drugs become available it seems likely that people will increasingly feel that their natural talents are not good enough.

Assuming the continuation of society's current consumerist trend, the revaluing of increased cognitive function as a commodity may alarm egalitarians, who argue that 'smart drugs' should not become just another good to be bought or sold, lest the gap between rich and poor grow even wider. However, even if cognitive enhancements could exacerbate social inequality, this is no more a reason to prohibit or regulate their distribution than it is for the private tutoring that more affluent families can currently afford to give to their children. Given continued drives to support equality of opportunity, pharmacological cognitive enhancements may well be of benefit: drugs may be easier to provide equitably than high quality schooling and nutrition.

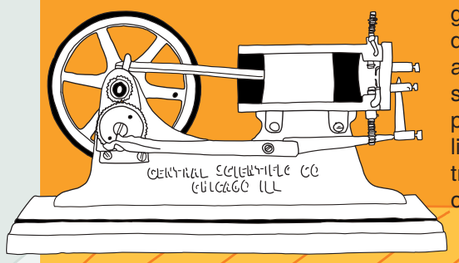
The final and perhaps most pressing concern to address is that of safety. Doctors will only let people undergo medical treatment if the expected benefits outweigh the risks. While we allow cosmetic surgery, interfering with brain chemistry has a much higher potential for unanticipated problems than breast enhancement. We have no way of determining the precise constraints under which the human brain has evolved, and we may be limited in our memory, wakefulness, and cognitive capacities for very good reasons. The results of our 'tinkering' have not all been successful so far; mice genetically engineered to have greatly improved memory capacity were also born with enhanced sensitivity to pain, while clinical trials have shown that modafinil use may actuallycompromise performance on certain tasks. It may be the case that there can be no pharmacological enhancement without a collateral cost elsewhere. However, while this remains an active area of research with far-reaching consequences for how we work, live and study, it is essential that these developments are brought into the open to inspire public debate. ■



Words: Edward Jacobs
Art: Kei Hamada and Nicola Davis

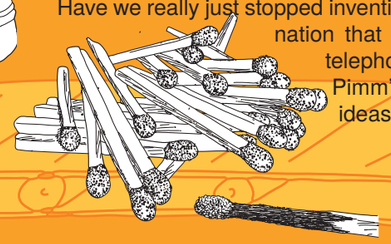
Made in Britain

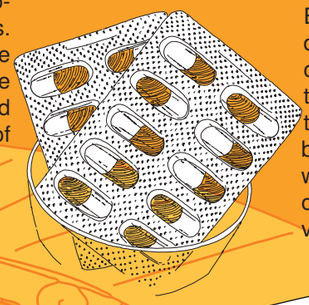
Are we still a nation of inventors?



A survey carried out this year asked the British nation to name what they considered to be the top 100 greatest inventions of all time. As expected, the fundamental wheel topped the list, while the appearance of the iPhone at number eight naturally caused something of a stir in the media. However, what is particularly interesting is how many of the inventions listed were of British origin: out of the 60 or so attributable to a specific nation, at least 20 were developed by UK born inventors.

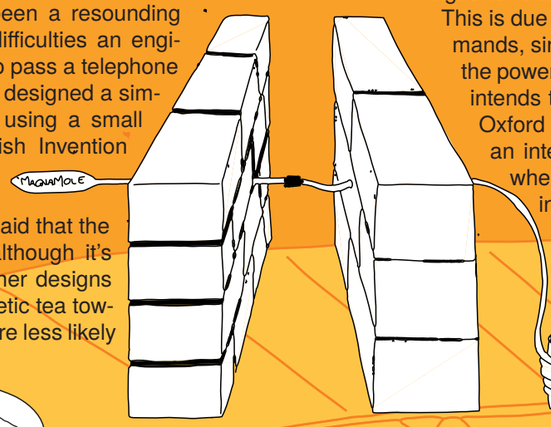
But scanning this list reveals that most of these are over a century old: the internal combustion engine, the flushing toilet, the match – they all seem to be from a bygone era. Out of the 20, only the internet, ibuprofen and the iPod were conceived in the last 50 years. Have we really just stopped inventing? Has Britain, the nation that gave the world the telephone, television and Pimm's, finally run out of ideas?



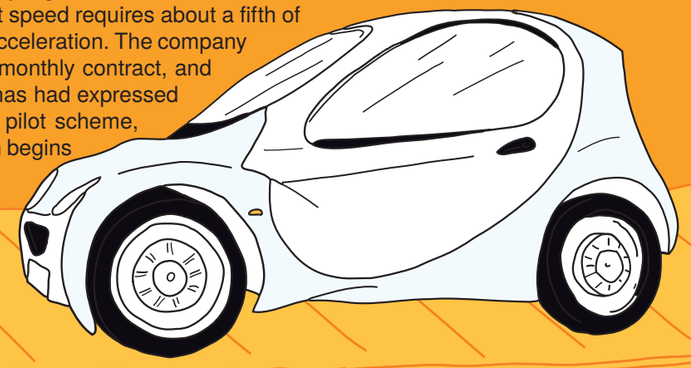


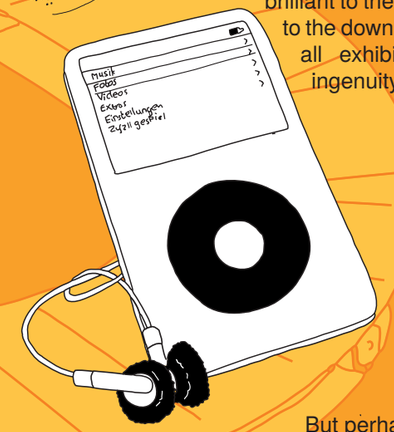
Of course, the short answer is no. Every October, London's Alexandra Palace is filled with hundreds of inventors, eager to show off their creations at the British Invention Show. Trevor Baylis, the man behind such innovations as the wind-up radio and electric shoes, once said that there was 'an invention inside all of us'. While the ideas on display range from the brilliant to the slightly quirky to the downright odd, they all exhibit exceptional ingenuity.

The Magnamole, brainchild of Sharon Wright, is one device that has already been a resounding success. After observing the difficulties an engineer encountered while trying to pass a telephone cable through a cavity wall, she designed a simple device to guide the cable using a small magnet. Displayed at the British Invention Show last year, her creation secured financial backing from the Dragons' Den team. It is often said that the simplest ideas are the best, although it's hard to say the same about other designs featured at the show: the magnetic tea towel and aphrodisiac bed sheets are less likely to catch on.



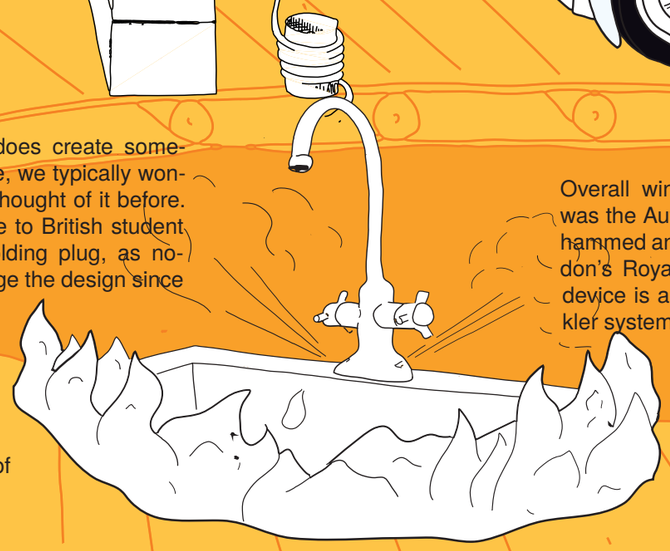
On display at last year's show was a prototype of the Riversimple Urban Car, a small two-seater vehicle powered by a hydrogen fuel cell. Built out of lightweight composite materials, the car manages to reach a top speed of 50 mph and has an impressive 240-mile range. This is due in large part to the decoupling of the acceleration and cruise demands, since maintaining constant speed requires about a fifth of the power needed for maximum acceleration. The company intends to rent the car out on a monthly contract, and Oxford is one of the cities that has had expressed an interest in taking part in a pilot scheme, when commercial production begins in 2013.





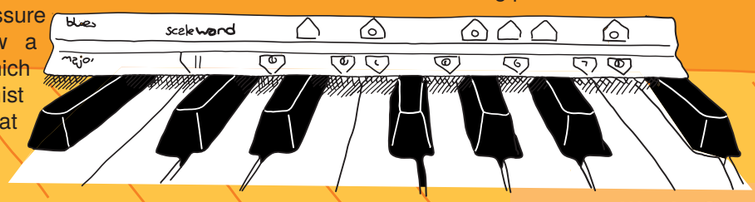
But perhaps the most fascinating exhibit was a display made by school children featuring automatic pet feeders, an umbrella with a built in hand warmer, and a machine to sort your post while on holiday. If today's ten-year-olds are already dreaming up such mechanical marvels: the future of British invention is secure. ■

When an inventor does create something brilliantly simple, we typically wonder why no one had thought of it before. That was the response to British student Min-Kyu Choi's new folding plug, as nobody had thought to change the design since they were first introduced in 1946. After the metal pins on a plug adapter scratched his new laptop, Choi set about creating an alternative. His elegant folding design was the won him the 2010 Brit Insurance Design of the Year Award.



Overall winner of the 2009 Dyson award was the Automist, the creation of Yusuf Muhammed and Paul Thomas, students at London's Royal College of Art. The ingenious device is a variation on the standard sprinkler system, designed to prevent the spread of fires in homes. The Automist consists of a high-pressure pump situated below a household sink, which fills the room with mist when activated by heat and smoke detectors.

Although pickings seemed a little slimmer at this year's British Invention Show, one innovation that caught the eye was the pianowand. A small plastic ruler, marked with a series of coloured tabs, it indicates the position of various notes. By rotating, inverting and sliding the ruler up and down the keyboard, any one of a myriad of chords and scales can be mapped out – a useful tool for those learning piano.



Words: Samuel Pilgrim
Art: Leila Battison

Purely Cosmetic?

A face-lift for the anti-ageing industry

Just like Jay-Z, we all want to be forever young — or at least to look it. The worldwide anti-ageing cosmetics industry is huge, estimated to be worth £74.6 billion this year. According to one study, a third of UK women aged 30 or over use an anti-ageing product regularly. For proof, you need only walk into your local high-street pharmacy and be confronted by row upon row of shiny jars, bottles and tubes boasting the latest miracle ingredient.

Many scientists have never been convinced by anti-ageing cosmetics and have found it impossible to believe that these products are anything more than glorified (and extortionately priced) moisturisers. And it seems that their doubts are justified. In a trial carried out by *Which?* magazine, women were given either an anti-ageing cream or a moisturiser, and asked, after using the product for four weeks, to decide whether they thought they'd been using an anti-ageing cream or not. 75% thought they'd been using a moisturiser, and only ten of the 48 women who had been using an anti-ageing cream reported any noticeable difference in their appearance. *Which?* concluded that the low concentrations of active ingredients found in anti-ageing creams were 'unlikely to do more than moisturise your skin'.

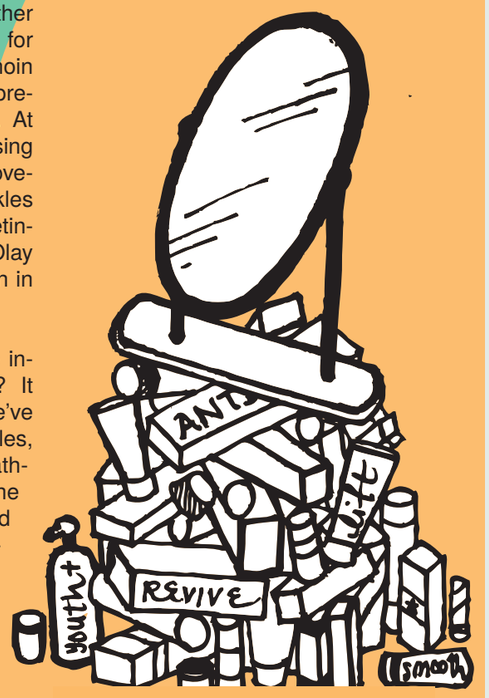
"Procter and Gamble has given anti-ageing sceptics like myself reason to question their lack of faith."

But in recent years there have been signs that consumers needn't give up hope of finding an anti-ageing product which does give the results it promises. The first real success in the industry came in 2007, when the TV show *Horizon* reported a trial that showed Boots' own-brand anti-ageing cream, 'No7 Protect and Perfect' serum, had produced a noticeable improvement in skin appearance when used for four to six weeks. This was the first time an anti-ageing cream had been publicly proven to do exactly 'what it says on the tin'. Further studies on the product's successor, an 'intense serum', showed that after 12 months use, 70% of those using the product had significantly fewer wrinkles than those using a placebo.

More recently still, a study conducted by researchers at Procter and Gamble has given anti-ageing sceptics like myself reason to question their lack of faith. Before this trial began, P&G asked a panel of eight dermatologists what proof would be needed to convince them that an anti-ageing product actually worked. Their response was that it would need to be tested against the clinical benchmark, retinoic acid (a form of vitamin A), over eight weeks. So in a trial designed to fit the dermatologists' specifications, women either followed the Olay Pro-X regime for eight weeks or were given Tretinoin (drug form of retinoic acid), a prescription treatment for wrinkles. At the end of the trial, the women using Olay showed significant improvements in the appearance of wrinkles compared with those using Tretinoin, and the volunteers using Olay also had less irritation of the skin in response to the treatment.

So what does this mean for the industry, and for the consumer? It would be easy to assume that we've found the miracle cure for wrinkles, but that may not be the case. Rather than heralding the arrival of the elixir of youth, what we should be celebrating in these examples is a new-found willingness amongst cosmetic companies to trial their products properly and scientifically. This can only be good news for the consumer. If the big name brands such as Olay have solid evidence and backing from the scientific community under their belts, other brands will hopefully be forced to do the same, meaning that the quality and efficacy of products will improve.

However, it may not be quite such good news for the industry itself. If anti-ageing products are trialled rigorously and are found to have the same, or an even greater effect on the skin than prescription drugs, surely they should also be classified as medicines rather than cosmetics? Under current UK laws, the product would remain a cosmetic as it does not treat a disease; however, if more anti-ageing products are proven to have such significant effects these rules may change. Whatever the outcome, this study is set to cause big changes in the anti-ageing industry and how it is perceived by both the scientific community and by consumers. ■



Words: Rebecca Tibbs
Art: Kei Hamada

It's As Easy As AGC

Examining scientists' latest efforts to play God

"Scientist accused of playing God after creating artificial life…but could it wipe out humanity?" This is just one of the headlines from articles detailing a remarkable study in the burgeoning field of synthetic biology.

Synthetic biology takes existing biological components — from individual genes to large sequences of DNA — and treats them as building blocks, chopping them up and combining them into all-new artificial networks. Through this approach, scientists can devise new biological systems not found in nature, with the potential to revolutionise biotechnology and medicine.

By integrating some of these genetic 'building blocks' into a bacterial cell, researchers at the University of California, San Diego engineered flashing cells that fluoresced with a specific frequency. Not only that, they then went on to breed a colony of cells that can communicate with each other to synchronise their flashing, producing a mesmerising light show. Eventually, it is hoped that these synthetic 'oscillators' could be designed to fulfil a variety of roles — for example, by engineering cells to produce insulin instead of light, diabetic patients could receive internal insulin at specified intervals.

Producing these oscillating systems requires alteration to only a few genes in the organism's genome. However, a research team headed by the pioneering geneticist and entrepreneur Craig Venter took on a much larger task in synthetic biology: the production of an 'artificial organism'. At an estimated cost of US$40 million over ten years, they were finally successful in 2010 and published their results in a landmark paper in the journal *Science*.

Venter's lab took the known DNA sequence of the bacterium *Mycoplasma mycoides,* and reproduced it artificially from the constituent bases (A, C, G and T) that make up the four-letter code of DNA. They then inserted the complete genome into a DNA-free bacterial shell and watched as, almost miraculously, the previously lifeless shell began to self-replicate. To distinguish the 'artificial' from the natural bacterium, four 'watermarks' were included in the artificial genome. One of these, in an inspired PR move, contains a higher code that spells out the names of the 46 researchers that contributed to the project, quotations from the likes of James Joyce and Richard Feynman, and an email address that anyone who deciphers the code can contact.

"Almost miraculously, the previously lifeless shell began to self-replicate."

This is a monumental technical achievement, which Venter himself describes as: "going from reading our genetic code to the ability to write it". Potential applications include designing organisms that produce clean biofuels, mop up carbon dioxide from the environment, or act as biological factories to produce vaccines. We could even resurrect extinct species: by analysing the divergence in the DNA of closely related organisms, researchers can work backwards and infer the DNA sequence of the extinct common ancestor. Producing and inserting this ancient DNA into a surrogate DNA-free shell of the present-day species could bring the long dead species back to life.

However, as Harvard geneticist George Church puts it: "printing out a copy of an ancient text isn't the same as understanding the language." Billions of years of evolution have produced genomes comprising thousands of genes that interact in unimaginably complex networks, in ways that geneticists are only now beginning to appreciate. Currently, synthetic biologists are attempting to design non-natural networks that consist of a handful of interacting genes to reprogram organisms in novel ways. Even these simple programs are proving extremely difficult to engineer in exactly the way that the researchers want. They are often unstable, or interact with other components of the cell in unintended ways. These problems stem from our lack of understanding of the biology underpinning even relatively simple organisms such as bacteria. The key challenge in synthetic biology remains understanding precisely how networks of genes interact to produce organisms. Only then will we have the power to 'play God' and create artificial organisms that bend to our will. ■

Words: Murray Tipping and William Brandler
Art: Samuel Pilgrim

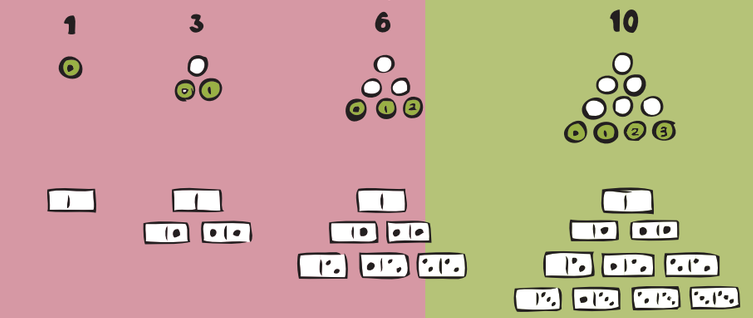
The Domino Effect

Teasing out the hidden mathematics of dominos

Dominos might seem like a dull game to many, but the dominos themselves have some fascinating properties. A set of dominos consists of a number of rectangular pieces divided into two squares by a cross line. A number from 0 to 6 is represented on each half of each piece. Each pair of numbers ranging from 0|0 to 6|6 is represented on one, and only one, domino.

In order to find the number of dominos required to accommodate all these pair-wise combinations, first consider all the dominos with a 6 on them and pair those dominos with the numbers from 0 to 6. This gives seven combinations. Next consider all the dominos with a 5 (except the one we've already counted, the 6|5 domino) and pair these dominos with all the numbers other than 6, giving six different combinations. Continuing the pattern, we find that there are 7+6+5+4+3+2+1=28 different dominos.

A quicker way to work this out is by considering triangular numbers: numbers which can form a pattern of dots in the shape of an equilateral triangle, with each side having the same number of dots (See figure above). If we had a domino set with only the number 0, then clearly we could only make one domino, 0|0. With 0 and 1 we can make three: 0|0, 1|0 and 1|1. With 0, 1 and 2 we can make six distinct dominos and so on. If the different figures we have to play with (e.g. 0, or 0 and 1, or 0, 1 and 2 in the previous examples) are each represented by a numbered circle on the base of the triangle (in green on figure below) then the total number of circles in the triangle will give us the number of dominos we can make with these figures.



For this same reason, the points awarded for potting each of the seven coloured balls (including one red) on a snooker table add up to 28, the seventh triangular number. 28 turns out to be a special number in mathematics, not just because it belongs to the illustrious triangular family, but also because it is a member of the "perfect" dynasty.

The "perfect numbers" are those whose factors (pairs of numbers you can multiply together to make the number), excluding themselves, add up to the perfect number. Take 28 for example: the factor pairs are 4 and 7, 2 and 14, and 1 and 28. Excluding 28 itself, we see that the sum of the other factors (1+2+4+7+14) is exactly 28.

The perfect numbers appear very rarely throughout the integers (whole numbers). Indeed there are only four below 10,000 (496 and 8128 being the next two above 28), and they appear to get sparser still as we continue up the number line. There are only 47 known perfect numbers in total, although we can't even be sure that there are not others hiding between the last eight of these. The game of dominos does rather well, then, to be associated with not one, but two perfect numbers. The most common sum of the two numbers on a domino is six and it can be made in four different ways (6+0=5+1=4+2=3+3=6). Coincidentally, six is also the smallest of the perfect numbers.

These numbers inspired big thoughts: in his work, *The City of God*, the philosopher and theologian Saint Augustine of Hippo (354-430) muses on the perfection of creation: "Six is a number perfect in itself, and not because God created all things in six days; rather, the converse is true. God created all things in six days because the number is perfect." It's no surprise that the 28-day period of the moon's orbit was given similar numerological significance.

We have seen that dominos play an important role in generating the triangular numbers, and are intrinsically linked to the perfect numbers, but by far their most useful application to mathematics is in analogy to a certain type of mathematical proof known as "proof by induction".

"...six is also the smallest of the perfect numbers."

Mathematical proof is often reported by mathematicians to be elegant or beautiful. In one type of proof, reductio ad absurdum (Latin for "reduction to the absurd") or "proof by contradiction", a mathematician assumes the logical opposite of what he is trying to prove. If it can be shown, by following logical steps, that the original assumption must lead to a contradiction or something mathematically absurd, then this assumption must be false and its opposite — the thing we wanted to prove in the first place — true.

It is possible to prove many interesting ideas using reductio ad absurdum, including the existence of infinitely many prime numbers, or the irrationality of the number √2. G. H. Hardy sums up the versatility of proof by contradiction in this passage from his essay A Mathematician's Apology: "Reductio ad absurdum, which Euclid loved so much, is one of a mathematician's finest weapons. It is a far finer gambit than any chess gambit: a chess player may offer the sacrifice of a pawn or even a piece, but a mathematician offers the game."

"Mathematical proof is often reported by mathematicians to be elegant or beautiful."

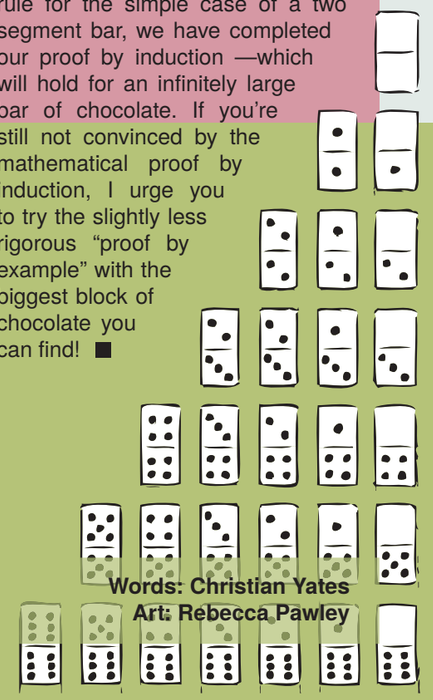
However, an even more potent weapon that mathematicians wield is that of proof by induction. Proof by induction can be used to show that a given statement is true for infinitely many integers (whole numbers) by exploiting relationships between them. The idea is to show that the rule holds for the first case and also that, if the rule holds for an arbitrary integer, n, then it holds for the next integer, n+1. This is known as the "inductive step".

In a domino analogy, imagine the set up of an infinite domino rally. We want to be certain that all of the dominos will fall over. We know that, due to the way we have set up the dominos, providing the n^{th} domino falls it will knock over the $n+1^{th}$ domino: this is the inductive step in our proof by induction. All we need to show now is that the first domino will fall over, and, as we will push that one over ourselves, then using proof by induction we can be sure all the infinitely many dominos will fall over.

As an example, consider a chocolate bar made up of equally sized segments (Dairy Milk, if you will) stuck back to back. We want to know how many breaks in the chocolate bar we have to make in order to separate all the segments. If we have a bar that consists of only two squares, then clearly we only need to make one break to separate them. We therefore conjecture that, to individualise the segments, we need one fewer breaks than the number of pieces that make up the bar.

So suppose that for a bar of n blocks we need n-1 breaks. Now consider the next size up, a bar made of n+1 segments. We can separate one block from the end using just a single break to leave a single segment and a block of length n. But, we have already concluded that the block of length n requires n-1 breaks to split it into its individual segments. This means that the n+1 length block requires (n-1)+1=n breaks, so we have proved that if the n^{th} case holds then so does the $n+1^{th}$; the crucial domino effect that we wanted.

Since we have already proved this rule for the simple case of a two segment bar, we have completed our proof by induction —which will hold for an infinitely large bar of chocolate. If you're still not convinced by the mathematical proof by induction, I urge you to try the slightly less rigorous "proof by example" with the biggest block of chocolate you can find! ■

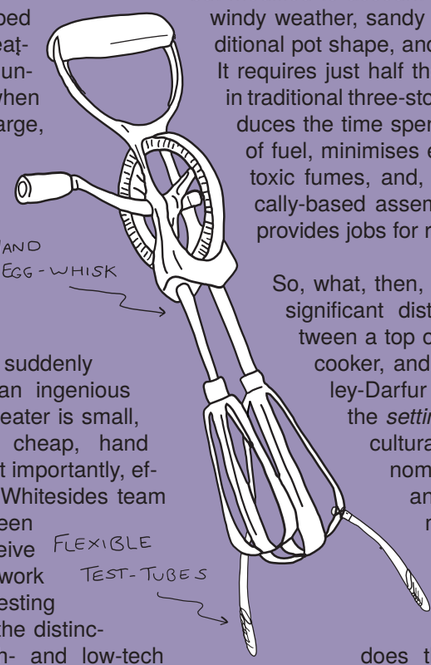


Words: Christian Yates
Art: Rebecca Pawley

Utility of Simplicity

Why low-tech may become the new high-tech

At a talk at a recent conference, Professor George Whitesides of Harvard University discussed the ability of a modified kitchen egg-beater to serve as a low-tech centrifuge for separating plasma from blood samples in resource-poor settings. Centrifugal separation allows the assessment of individual components of blood, or other body fluid samples, and is a necessary step in the diagnosis of many diseases. However, Whitesides revealed that when his group first attempted to publish a paper on "The Egg Beater as a Centrifuge", it was rejected with the comment "We only publish real science."



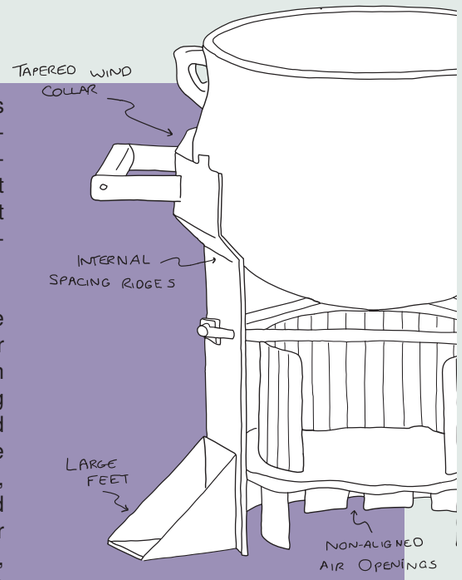
In the developed world, the egg-beater is decidedly unsophisticated when compared to the large, high-tech electrical machines in our hospitals. But consider the places on earth where people live without reliable supplies of electricity and it suddenly reveals itself as an ingenious solution. An egg-beater is small, simple, portable, cheap, hand powered, and most importantly, effective. While the Whitesides team may not have been the first to conceive the idea, their work poses an interesting question: what is the distinction between high- and low-tech products?

The first answer that springs to mind is the "technological advancement" of the product. This may lead us to think that the design of a high-tech product necessitates a higher level of intellect. Like Professor Whitesides, Dr Ashok Gadgil of the Lawrence Berkley National Laboratory believes that low-tech products should not be viewed as "dumbed-down" versions of high-tech products. On the contrary, sometimes it may require a higher level of intellect to design for simplicity, without compromising effectiveness.

A good example of this is the stove designed by Dr Gadgil's team for the internal refugees of the war-torn Darfur region of Sudan. Depleting amounts of firewood has forced women to travel further from the camps in search of wood for fuel, increasing their risk of violent and sexual assault. The Berkeley-Darfur stove is based on one used in India, but modified to account for Darfur's windy weather, sandy terrain, traditional pot shape, and food type. It requires just half the fuel used in traditional three-stone fires, reduces the time spent in search of fuel, minimises exposure to toxic fumes, and, through locally-based assembly shops, provides jobs for refugees.

So, what, then, is the most significant distinction between a top of the range cooker, and the Berkeley-Darfur stove? It is the *setting* – social, cultural, economic, political and environmental – for which they are designed. However, does this distinction mean that a technology initially designed for one setting will always be inappropriate for another?

Consider, for example, school teacher Mohammed Bah Abba's design for a low-tech food cooling method, for which he won a Rolex award of $100,000. A small pot inside a larger one holds the contents, with the space between filled with wet sand. The pots are covered with a wet cloth, and as the water evaporates it cools the contents by between 15 and 20 ºC. While it was originally designed to cope with the hot and dry conditions of northern Nigeria, the Western blogosphere is alight with rave reviews of its effectiveness in our own backyard.



"Low-tech products should not be viewed as "dumbed-down" versions of high-tech products"

And the egg beater-centrifuge? Could it too be a hit with conscientious doctors wishing to minimise the cost of treatment in developed-world hospitals? Unlikely. A huge shift in attitude – coupled, perhaps, with a severe limitation to our current ample access to resources – would be required to overcome the developed world's expectation of high-tech solutions. That said, with ingenious minds increasingly embracing simplicity, we may yet see the rise of low-tech solutions that will give new meaning to high-tech in the developed world. ■

Words: Alisa Selimovic
Art: Leila Battison

Small and Mighty

Exposing the secret power of Prokaryotes

The human perspective of other species is deeply affected by their appearance. So, it is all too easy to underestimate microbes — after all, they are invisible to us. Dating back over three billion years, these ancient organisms shaped the history of our planet, and have played a vital role in preparing it for the rise of life.

Prokaryotes (of which bacteria are the best-known family members) are single-celled organisms, typically 15 times smaller than animal cells, and with a simpler internal structure. They have had much longer to get comfortable on planet Earth than have animals or plants, and possess an ability to cope in environments of startling diversity. As a result, there are very few places on Earth that are not home to prokaryotes.

"One thing is certain: we are vastly outnumbered."

Some of the most impressive prokaryotic survival stories concern so-called 'extremophiles' which grow in very hostile environments. Hyperthermophiles are found in environments with temperatures greater than 80 ºC such as the hot springs in Yellowstone National Park, and have been shown to survive at temperatures of up to 120 ºC. Psychrophiles grow at temperatures below 15 ºC, and have been found lying dormant, two miles deep in frozen Antarctic lakes. Piezophiles are able to withstand very high pressures and are known to exist at the bottom of the Pacific Ocean at 1000 times atmospheric pressure. Radioresistant bacteria have a bewildering tolerance to radiation: the most resistant species known is able to survive doses 2000 times greater than those that kill humans.

With an ability to occupy so many environments, it is no surprise that prokaryotes are numerous; there are estimated to be ten times more prokaryotes in and on our bodies than our own cells. This is only a small contribution to the total – if the estimated prokaryotic population (a staggering 10^{30}, that is, one followed by 30 zeros) is correct, their contribution to the total biomass on Earth may equal that of trees. One thing is certain: we are vastly outnumbered.

We are also highly dependent on prokaryotes. Amongst all living organisms, only prokaryotes possess the ability to fix nitrogen from the atmosphere into chemical compounds, and the photosynthetic processes that sustain plant-life originated in prokaryotes. Closer to home, the huge quantity and variety of prokaryotic life within our bodies is critical for sustaining us, as they perform vital digestive tasks.

Prokaryotes are invaluable, tireless and uncomplaining industrial workers: they have long been employed in the production of cheese and yoghurt, and have been used more recently in the preparation of pharmaceuticals. Many potential benefits of prokaryotic labour are yet to be explored; for example, bioremediation – the process of breaking down hazardous substances using microbes – may help humans to cope with the vast amounts of waste we produce, as illustrated by the oil-digesting microbes found feasting on the BP oil-spill in the Gulf of Mexico. It is hoped that they may have similar applications in breaking down radioactive waste, heavy metal toxins, and unwanted plastics.

Unfortunately, not all prokaryotes are beneficial to humans. A small fraction are incompatible with our bodies, and cause infection and disease. *Pneumoniae*, *Meningitidis*, *coli* and *Salmonella* — it is no coincidence that these species are well known for they are amongst the most maligned. Even our best weapons have not vanquished them all. The product of rapid prokaryotic evolution, methicillin-resistant *Staphylococcus aureus* (MRSA) is currently fighting and winning a war against antibiotics in our hospitals.

Thus, we must submit we are outnumbered and outperformed in innumerable ways by billions and billions of invisible prokaryotes that share our environment. They live in places we could never endure, perform tasks that we struggle to achieve, and have a profound influence on our health. There would seem to be an unlimited number of applications of prokaryotes to improve our lives, and the well being of the planet. As such, while humankind may be in the driver's seat as far as our future on this planet is concerned, it seems likely that our tiny prokaryote relatives will provide the raw engine power. ■

Words: Gabriel Rosser
Art: Leila Battison

Pro Libel Reform

Counteracting the suffocation of free speech

Britain prides itself, somewhat optimistically, on good football, great comedy and world-class science. After all, we have had 91 Nobel Prize winners – second only to the US. However, British libel laws are stifling science in a manner no one can be proud of. A case in point is that of Simon Singh.

A British science author and journalist, Singh came under fire from the B*ritish Chiropractic Association* (BCA), when his 2008 article "Beware the spinal trap" was published in the *Guardian* newspaper. The piece focused on chiropractic medicine, the practice that diagnoses, treats and prevents disorders by manipulation of the spine. In the article he says that chiropractors "have ideas above their station", and that they practise a form of medicine for which "there is not a jot of evidence".

"People have to be free to challenge research."

The publication of this article highlights the importance of scientific journalism – if this practice poses a genuine health risk, it is imperative that the public are made fully aware of it.

The BCA objected to Singh's description and wrote to Singh. In his words, they "claimed I had defamed their reputation and threatened to sue me for libel". Initially, the *Guardian* tried to settle the matter out of court by suggesting that the BCA write a 500 word response which they would publish. However, the BCA rejected this offer, and stated it was not suing the *Guardian* but rather Singh personally. It is at this point that the *Guardian* decided not to support Singh any further; as Singh concludes on the website senseaboutscience.org.uk, "the sad conclusion is that major publishers are terrified of the English libel laws".

Singh stood his ground and defended his statements in the court proceedings, remaining staunchly defiant throughout. On the 15th April 2010 the BCA dropped its proceedings, after a two-year legal process.

However, the worrying truth is that when put in this situation, many others back down, as happened recently in a case about lie detection systems, or polygraphs. In 2007 Professor Lacerda published an article in the *International Journal of Speech, Language and the Law* entitled, "Charlatanry in Forensic Speech Science", which questioned the scientific basis of this equipment. The company behind polygraphs, Nemesysco Limited, threatened the journal with libel action and the article was later withdrawn. Despite this, evidence for the effectiveness of lie detectors remains controversial; as such, their use is not currently accepted in British courts.

It is not surprising that many journalists can be intimidated by the threat of multi million pound lawsuits when their average salary is just £24,500. This is small change when compared to the annual turnover of the British healthcare industry (estimated in 2003 at £12.5 billion).

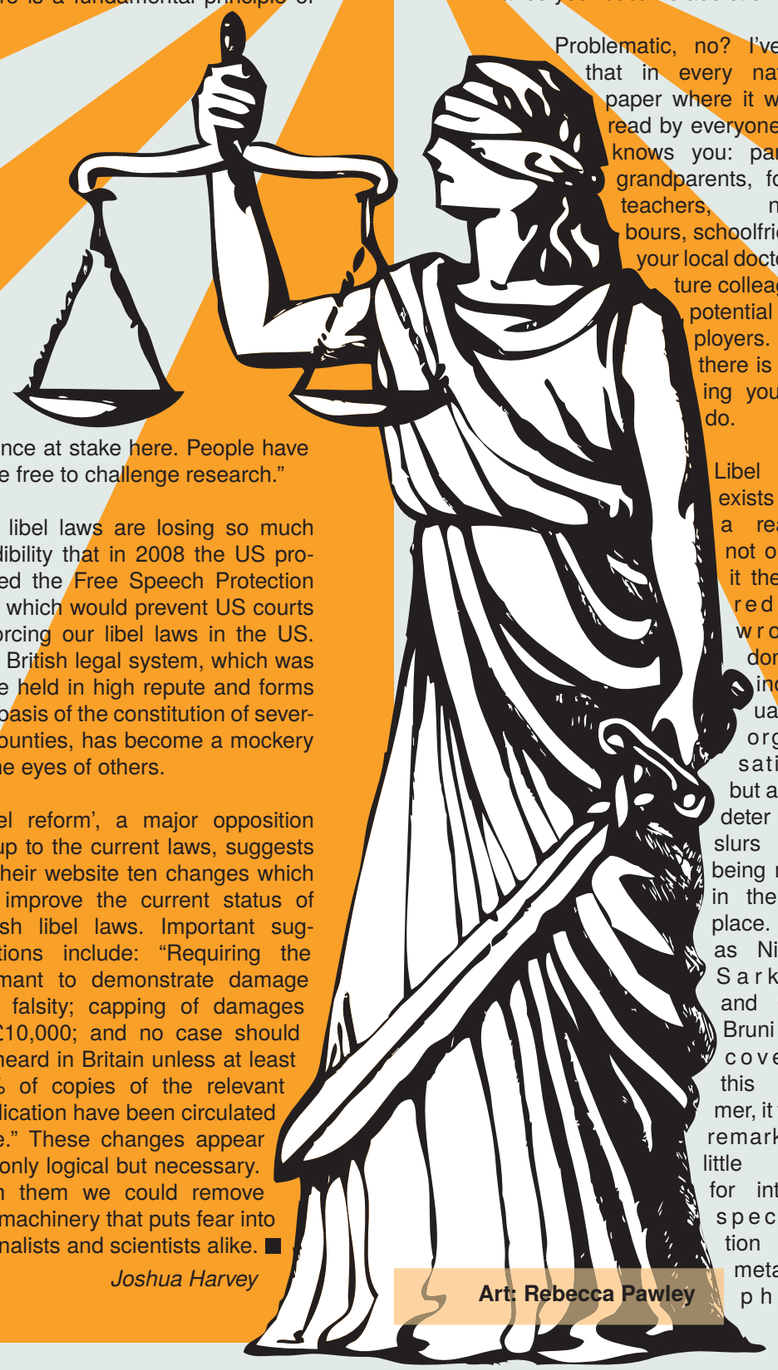
"The British legal system has become a mockery in the eyes of others."

Nor is this exclusively a British problem, as foreign plaintiffs are increasingly using lax British libel laws in order to maximise their chance of success. This "libel tourism" is being used by the American medical technology giant NMT to sue Peter Wilmshurst, a consultant cardiologist at the Royal Shrewsbury hospital, who criticised NMT's new heart repair product at a cardiology conference in Washington in 2007, which prompted NMT to sue him for criticising their work in the UK courts. Wilmshurst has also chosen not to back down, telling reporters: "I have got a responsibility to fight this. There is a fundamental principle of science at stake here. People have to be free to challenge research."

Our libel laws are losing so much credibility that in 2008 the US proposed the Free Speech Protection Act, which would prevent US courts enforcing our libel laws in the US. The British legal system, which was once held in high repute and forms the basis of the constitution of several counties, has become a mockery in the eyes of others.

'Libel reform', a major opposition group to the current laws, suggests on their website ten changes which will improve the current status of British libel laws. Important suggestions include: "Requiring the claimant to demonstrate damage and falsity; capping of damages at £10,000; and no case should be heard in Britain unless at least 10% of copies of the relevant publication have been circulated here." These changes appear not only logical but necessary. With them we could remove the machinery that puts fear into journalists and scientists alike. ■

Joshua Harvey



Art: Rebecca Pawley

Anti Libel Reform

Preventing wild accusations reaching the press

I think that you are a despicable excuse for a human being: I know you have been pocketing the money you raise for your Darfur appeal to finance your cocaine addiction.

Problematic, no? I've put that in every national paper where it will be read by everyone who knows you: parents, grandparents, former teachers, neighbours, schoolfriends, your local doctor, future colleagues, potential employers. And there is nothing you can do.

Libel law exists for a reason: not only is it there to redress wrongs done to individuals or organisations, but also to deter such slurs from being made in the first place. For as Nicolas Sarkozy and Carla Bruni discovered this summer, it takes remarkably little time for internet speculation to metamorphose into accepted fact. The manner in which rumours of their mutual infidelity snowballed is a salutary indication as to why, in an age of 24-hour news cycles and internet-driven feedback loops, libel reform could be a serious step backwards.

Almost any net of libel laws will be imprecise in who it captures. This is not a question of whether some libel cases hurt people offering legitimate criticism; it is, rather, about whether we do better to err on the side of caution.

The fact is that once something enters the public sphere, it is extraordinarily difficult to stop it. Just look at how political debate in America has been poisoned by false claims like 'British health services feature death panels', 'Barack Obama is a Muslim', or 'John Kerry never served in Vietnam'. If libel laws are to make a significant difference, it is important that they stop such claims being made in the first place. Unfortunately, the only way to do that is to provide a sufficiently serious deterrent that even well-financed news corporations are scared of finding themselves on the wrong side of libel laws. Inevitably, that may also stop some quite reasonable allegations; but that is the cost of a clean and largely honest public discourse.

However, is quality discourse seriously deficient in Britain today? For example, consider Simon Singh, who has been held up as the brave defender of sensible scientific practice, cruelly gunned down by vested interests masquerading as alternative medicine. Although...let's be clear here. The criticisms he levelled at the British Chiropractic Association (BCA) were not part of a calmly reasoned scientific debate, perhaps pointing out that whilst chiropracty may have some placebo-driven benefits, it nevertheless appears (on reviewing the available clinical evidence) that the benefits may not extend far beyond said effects. He called them "wacky"; "fundamentalists"; "bogus". Unsurprisingly, the BCA took offence at this, and launched a libel case in response. In the course of this case, it was concluded that Mr Singh would have been entitled to a 'fair comment defence'; a defence which proved unnecessary after the BCA dropped the case. From a purely judicial point of view, this seems exemplary: one party believes it has been wronged under the law; it brings charges in accordance with that law; it becomes clear that common sense should prevail; the case is dropped.

"Once something enters the public sphere, it is extraordinarily difficult to stop it."

Finally, critics tout 'libel tourism', whereby non-Brits may prosecute other non-Brits for saying nasty things in many non-Brit papers, and (crucially) also one Brit paper. Is this an issue? Presumably this is only problematic if one already thinks that British libel law is unreasonable. Otherwise, why shouldn't transgressions of the law be punished, *via* the best avenue available to wronged parties? After all, allegations have been made in front of the British public: the British court system therefore has authority to arbitrate on such matters.

Just so we're clear, I don't really think you're despicable. You also probably didn't embezzle those funds; you may not even have a cocaine addiction. But without a good system of libel law, those qualifications are moot – or at least, I wouldn't feel compelled to add them. And if that system means leaving debate to professionally peer-reviewed journal rather than to the press, that's a price we should be happy to pay. ■

Neil Dewar

To Blog or Not To Blog

The new frontier in scientific communication?

The new tools offered by the internet, which centre on user-supplied content and are often dubbed Web 2.0, are changing the way we communicate. Fortunately, scientists are catching up with these developments, and are making use of them as never before.

Take, for example, the game called 'FoldIt' which makes use of the gaming skills of scientists and non-scientists alike in solving the mysteries of protein folding. Then there is the *Journal of Visualized Experiments* which allows scientists to publish video clips of real laboratory procedures, allowing new researchers to learn cutting-edge skills quickly and avoid mistakes. Also, there is the burgeoning community of science bloggers who aim to make science more relevant to the public.

While renowned scientific journals have been slow to make use of the new opportunities offered by the internet, science bloggers are at the frontier. Efforts by science blogs *Seed* and *Ars Technica* have both recently helped to raise money for environmental causes by appealing to the scientific community. *ResearchBlogging* is a popular resource which allows compilation of blog posts on peer-reviewed research. The science blogging community *Scientopia*, despite being an amateur enterprise, has successfully gained a great following only because of great science writing.

It is generally considered that traditional media outlets filter information and provide a more accurate story; after all, that is what we pay for. But often the system seems to be rigged by hidden commercial purposes, or censored by corporate giants. In the Equazen fish oil case, a private company funded biased research that was published in several newspapers, even though it was scientifically dubious. Furthermore, the fear of being pursued in the libel courts (see p21) stops the media from criticising quackery and stifles scientific debate in the public sphere. Many science bloggers, however, have worked hard to expose these shortcomings in the mainstream media.

"Bloggers' relative anonymity allows them more freedom to speak out about controversial matters"

In a recent paper published in *Journalism Studies* it was reported that, in comparison to science journalists, science bloggers make use of a greater diversity of sources, particularly primary academic literature. The paper goes on to argue that since many science bloggers are individuals with advanced scientific training and expertise, they are less prone to bias, while their relative anonymity allows them more freedom to speak out about controversial matters.

A further great advantage that blogs have over traditional media is the opportunity to interact. Readers may not always understand the science behind an article, or would like to know more about it. On blogs, readers can ask these questions to scientists themselves by making comments. This gives the public an easy, quick and direct way to contact scientists. Although the 'comments' feature is also enabled on some traditional media websites, very rarely does the author or the media outlet respond to the questions directly posed to them.

The community of science bloggers has stepped forward to fill a gap in the supply and demand of science in the media, providing good food for scientific thought. A recent survey showed that science accounts for 10% of all stories on blogs but only 1% of stories in mainstream media coverage. Traditional media companies are realising that the appetite for science in the media is growing by the day, leading to initiatives such as *The Times*' *Eureka* science magazine which was launched in late 2009, or the introduction this year of science blogs to the websites of *Discover* magazine and *The Guardian*.

Much scientific research is funded by taxpayers' money and the public attitude towards science influences its progress. This progress is essential if we want to solve the big problems faced by humanity. Science needs to gain renewed respect among the masses, rather than simply being the bearer of bad news. By harnessing the power of blogging, the scientific community can continue to demystify science and make it relevant to a greater proportion of the world's population. ■

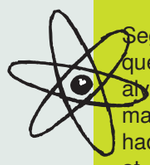
Words: Akshat Rathi
Art: Leila Battison

Elementary, my Dear

New kids on the (periodic) block

If you ask any school child – of the right age – what an element is, they will tell you that an element is "a chemical building block that cannot be broken down into smaller parts". Although this definition is a little simplistic, it's true that elements are nature's building blocks. There are 92 naturally occurring elements, and each is defined by the number of positively charged protons in its nucleus, hydrogen being element number one and uranium being element number 92.

Italian Emilio Segrè was fascinated by the idea of making new elements; he discovered element number 43 in a foil of molybdenum (element number 42) that had been subjected to a beam of sub-atomic particles called deuterons (a proton and a neutron stuck together). These elements are of great interest to the scientific community as their instability means that they readily decompose and emit radiation, a process which has been exploited in applications as diverse as atomic power, nuclear weaponry and radiotherapy. However, this instability also makes them difficult to use as many decompose long before they can be fully studied.



Segrè, who was Jewish, was subsequently forced to flee Mussolini's Italy, and so his next discoveries were made at Berkeley. Since element 43 had been made by firing deuterons at element 42, Segrè applied the same reasoning to element 92, and successfully synthesised the previously unknown element 93 late in 1940. As element 92 – uranium – is named after the planet Uranus, they decided to name element 93 neptunium, after the planet Neptune.

After this great success, Segrè was conscripted to the top secret Manhattan project, a group of leading scientists whose target was to build the first atomic bomb. Glenn Seaborg took over the team at Berkeley, and quickly synthesised the next heaviest element, plutonium, which showed such exceptional radioactive properties that he too was called up to the Manhattan Project. As a result, it was not until the bomb had been built and World War II had been won that he was able to make the next two elements; americium and curium (named after Marie and Pierre Curie).

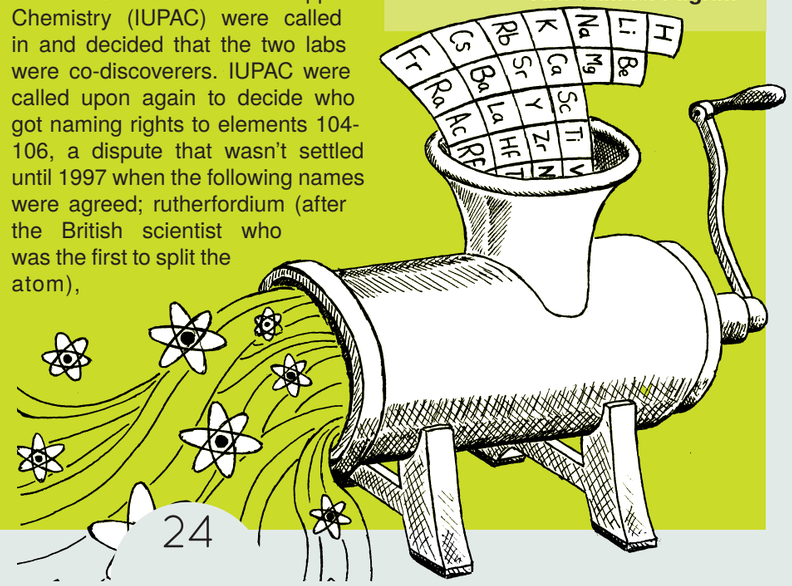
"They named this first man-made element technetium, from the Greek word for artificial"

The next six elements were discovered between 1944 and 1958, a difficult task as these unstable elements can only be made in minute quantities. In recognition of this work, Seaborg was awarded the Nobel Prize for Chemistry in 1951, but when his team set to work on element 103, it was clear they were not alone their desire to expand the periodic table. A team in Dubna, Russia, were determined to challenge US scientific superiority, and claimed to have synthesised element 103 at the same time as Seaborg. As neither group of scientists were able to repeat the other's experiments, the International Union of Pure and Applied Chemistry (IUPAC) were called in and decided that the two labs were co-discoverers. IUPAC were called upon again to decide who got naming rights to elements 104-106, a dispute that wasn't settled until 1997 when the following names were agreed; rutherfordium (after the British scientist who was the first to split the atom), dubnium (to honour the Russians) and seaborgium (in honour of Seaborg).

As the Americans and the Russians battled it out, each trying to disprove the claims of the other, a third contender took the lead in this scientific race. Throughout the eighties and nineties the GSI Helmholtz Centre for Heavy Ion Research, based in Darmstadt, West Germany made all the elements between 107 and 112 using a new technique of sticking two medium sized elements together.

Thankfully, past international competition has given way to international collaboration, and all the elements up to 117 have been synthesised. It is hoped that researchers are approaching an "island of stability", a theoretically predicted group of super heavy elements that will last long enough to allow their chemistry to be studied in detail. The periodic table may have a long way to grow yet. ■

Words: David Bowkett
Art: Samuel Pilgrim



Animal Magnetism

Delving into the curious directional abilities of birds

From sailing across unchartered oceans to trekking through wild jungles, the humble compass has been used for centuries as an aid to navigation. The Earth's magnetic field provides a means of telling direction even when other techniques (such as the observation of landmarks or stars) cannot be used. Somewhat surprisingly, it appears that this ever-present field we find so useful is also utilized by migratory birds.

This revelation in avian navigation was shown in the 1960s by the husband-and-wife team of Drs Wiltschko from the Johann Wolfgang Goethe-Universitat in Frankfurt am Main, Germany. In their investigations, birds were placed in a cone, the interior of which shows up marks from the birds' beaks and claws. During their migratory season, birds become agitated if they are unable to migrate. Because the Earth's magnetic field is so weak (a simple fridge magnet can deflect a compass needle), it can easily be cancelled out by applying a field in the opposite direction. Another magnetic-field can then be added; this now appears to the bird as if it is the Earth's magnetic-field, except with the difference that this field can be rotated to examine how the birds react to fields in different directions. Analysis of the claw and beak marks made on the walls of the cones by birds during their migratory season showed a strong correlation with the direction of the applied field. It turns out that the birds tried to fly in one direction with respect to the applied field, just as they do naturally with respect to the Earth's magnetic field when they migrate. Furthermore, the results showed that this magnetic-sense does not work in the absence of light.

At present there are two leading theories to explain these remarkable results; firstly, the 'magnetite mechanism'. This mechanism may be understood by analogy with a traditional compass: small pieces of magnetite (a mineral containing iron) in the bird would allow for detection of the direction of the Earth's magnetic-field by pointing in the direction of the Earth's pole. While magnetite has indeed been found in migratory birds, it has not been found in sufficient concentration in any one region for this mechanism to be reasonable. It also fails to explain the fact that light is required.

The mechanism is not entirely without merit however; while there is not enough magnetite to detect direction, the magnitude of the field may be sensed. Rather than there being one large piece of magnetite, there may be lots of little magnetite regions that can align separately. The stronger the field, the more likely each magnetite region is to try to align. Unlike a normal bar magnet however, the magnetite may not be free to swing around and point towards the Earth's pole. Instead, the magnetite seems to be anchored in some way so that only a small amount of movement is allowed for each region. As a result, the magnitude of the magnetic field may be felt by the number of magnetite regions which respond to the field and the strength at which they try to align; however, the actual direction of the Earth's pole cannot be found. As the magnitude of the Earth's magnetic-field can almost double from one place on the globe to another, the magnitudes may function as a map for the birds.

"But why do birds need light to navigate?"

The other possibility is the 'radical-pair mechanism' (RPM). This theory is currently being studied by researchers at Oxford University including Prof Peter Hore and Dr Christiane Timmel. The RPM relies upon the quantum-mechanical interactions of unpaired-electrons (known as 'radicals') with an applied magnetic-field.

A helpful analogy for an unpaired electron is a spinning plate on a stick. There are two ways you could make this plate spin: clockwise or anticlockwise. If you had two plates, there are two ways to set the plates spinning: you could make them both spin in the same direction or in opposite directions. It turns out that electrons have a property which is also called spin. Unlike the spinning plates, this doesn't relate to physical motion; but in a similar manner the electron may spin in one of two ways, and if you have two electrons, there are once again two ways in which the spins can exist with respect to each other. They can either spin in the same direction, in what quantum physicists call a 'triplet' state, or they can spin in opposite directions to one another – the 'singlet' state.

Within the laws of quantum mechanics, transitions between the singlet and triplet states are 'forbidden'; to stretch the analogy of the spinning plates a little further, imagine the difficulty of changing the direction of rotation of one of the plates while both are in motion! Now when physicists say that a transition is 'forbidden', there is usually still some way that the change can be achieved; the transition just occurs very rarely (while it is very difficult to change the direction of one of the plates, one could envisage that with a sufficient number of attempts – and a lot of luck – the plate could be made to change direction).

If the energies of the singlet and triplet states were the same, then it would be relatively easy to switch between the two (imagine someone holding one of the plates still momentarily; when they release the plate they could spin it either way). It turns out that at certain orientations with respect to the magnetic field, singlet and triplet states do have the same energy; so flipping between the two is made much easier. Moreover, the stronger the field, the greater the amount of flipping will be going on, changing the relative number of singlet and triplet states.
Singlet and triplet states in a molecule can undergo chemical reactions at different rates and even generate different reaction products. The orientation of the bird with respect to the magnetic field will affect the ratio of singlet to triplet states, and hence the concentrations of particular products. If a bird can detect these different chemicals, then it can use the RPM to tell its direction. It is important to note that the radical-pair does not act as a compass in the traditional sense; it is an 'inclination compass'. This means that to a bird there are only two different directions in comparison to the four we are used to. These two directions are given the names 'polewards' (North or South) and 'equatorwards' (East or West). The use of an inclination compass by birds was discovered when the Wiltschkos, using the same cone-based experiments, flipped the applied-magnetic fields and found that the birds continued to try and fly in the same direction.

This flipping of the magnetic-field corresponds to a reversing of the Earth's polarity. Further distinction in direction would require a map of field-intensities; such a map could be provided via magnetite deposits within the bird.

"To a bird there are only two different directions in comparison to the four we are used to."

But why do birds need light to navigate? It turns out that light of the right frequency can cause a weak chemical bond to break into a radical pair. The radicals in this pair are initially in the singlet state; however, a magnetic-field can interact with the electrons, allowing the forbidden flip between singlet and triplet states to occur.

The group of Dr Timmel has used a model compound to show that the RPM can indeed give information about the orientation of a compound with respect to a magnetic field. This model is known as the 'triad' system, as it is made up of three large organic molecules. In the triad there is a weak bond that may be broken by green light to create a radical pair of electrons; movement of these electrons through the molecule allows one radical to be at each end of the molecule.

The molecules at each end stabilise the radicals, preventing the radical pair from recombining before the effects of the magnetic field can be felt.

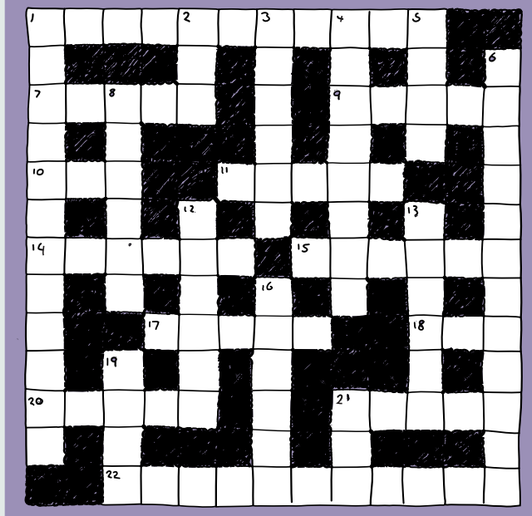
True verification of the RPM would however require such molecules (with a weak bond and an ability to stabilize a radical pair) to be found in migratory animals. The leading contenders for such molecules are 'cryptochromes'. These are molecules that have already been found to be important in maintaining the 'Circadian Clock', the day/night cycle of plants and animals – they are affected by light. There is also the intriguing possibility that as these molecules have been found in bird's eyes, migratory birds may be able to see the Earth's magnetic-field.

So next time you see a migratory bird, just think: it navigates using quantum mechanics and may be able to see magnetic-fields. Kind of puts your car's GPS to shame. ■

Words: Luke Edwards
Art: Rebecca Pawley

Riddler's Digest

Cerebral amusement for the modern scientist



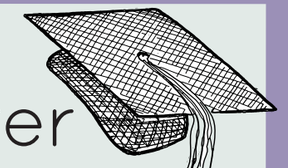
Across

1. Missing both eyes, but testing well (6,5)
7. A poem to the Princess has an electronic component (5)
9. Centre of claim is rejected after an untruth – without it, he hasn't a leg to stand on (5)
10. Tiger gets a scan (3)
11. Tends to buzz from within a piano (5)
14. He has appeal without going hardline at first – it's his standing (6)
15. Soft metal, drunk like quicksilver (but not real aluminium) (6)
17. Needed to control reaction, so talked tediously while shunning Edward (6)
18. Prehistoric, say some triceratops (3)
20. Where you'll find eggs over easy (said with partiality)? (5)
21. Dissect someone's melancholy (3,2)
22. Physics, for example the study of diamonds (4,7)

Down

1. Coo! Red-handed destruction has many faces (12)
2. A certain type of group constructs a falsehood (3)
3. Kill (with an afterthought) in pursuit of British arms (6)
4. Transmission of heat makes a strange, rare find (8)
5. Society girl has time, but less than zero money (4)
6. Managed party script – sufficient to make representative group (6,6)
8. Acid type, having found nothing during month in command (6)
12. Though confused and forgetting his alphabet, Tyco Brahe had an idea (6)
13. Break down at size of magazine (6)
16. An unborn enemy goes hence without drug (6)
19. A foolish complaint (4)
21. In Germany, I ordered a letter (3)

Ask a Lecturer



For some, knowledge about aneurysms may be limited to movie scenarios à la Kick-Ass, where the burst cerebral aneurysm of protagonist Dave Lizewski's mother sends her face-first into her cereal bowl. However, in reality there is little comedy in aneurysms; they affect a large percentage of the population, have dire consequences in the case of rupture, and worst of all, they are still a medical enigma.

So, what exactly IS an aneurysm?
Cerebral aneurysms appear as small berry-like structures growing on the side of an artery. Their exact cause is not yet known. They result from a complex interplay between many factors, including blood-flow, arterial wall composition, cell populations and genetics. One thing to appreciate is that the artery is not simply a bit of rubber tubing that carries the blood; it is a living biological structure continuously being maintained by cells. Sometimes the physiological mechanisms that maintain the arterial structure can go wrong, leading to localised distortions to the geometry and the growth of an aneurysm. During this process, the relatively thick wall of the artery is replaced by a thin-collagenous membrane, which cannot withstand the pressure of blood-flow, and so may suddenly rupture.

What happens when an aneurysm ruptures?
Blood is released into the space around the brain, which increases the pressure inside the skull. At the same time, the region of the brain that normally depends on the blood delivered by that particular artery can become starved of oxygen, resulting in a stroke.

...and the outcome is?
Not great; the initial bleeding may be fatal, and death occurs in 30-40% of cases. Around 30% of survivors are then afflicted by moderate to severe disabilities.

Alisa Selimovic in conversation Dr Paul Watton

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