Bang!

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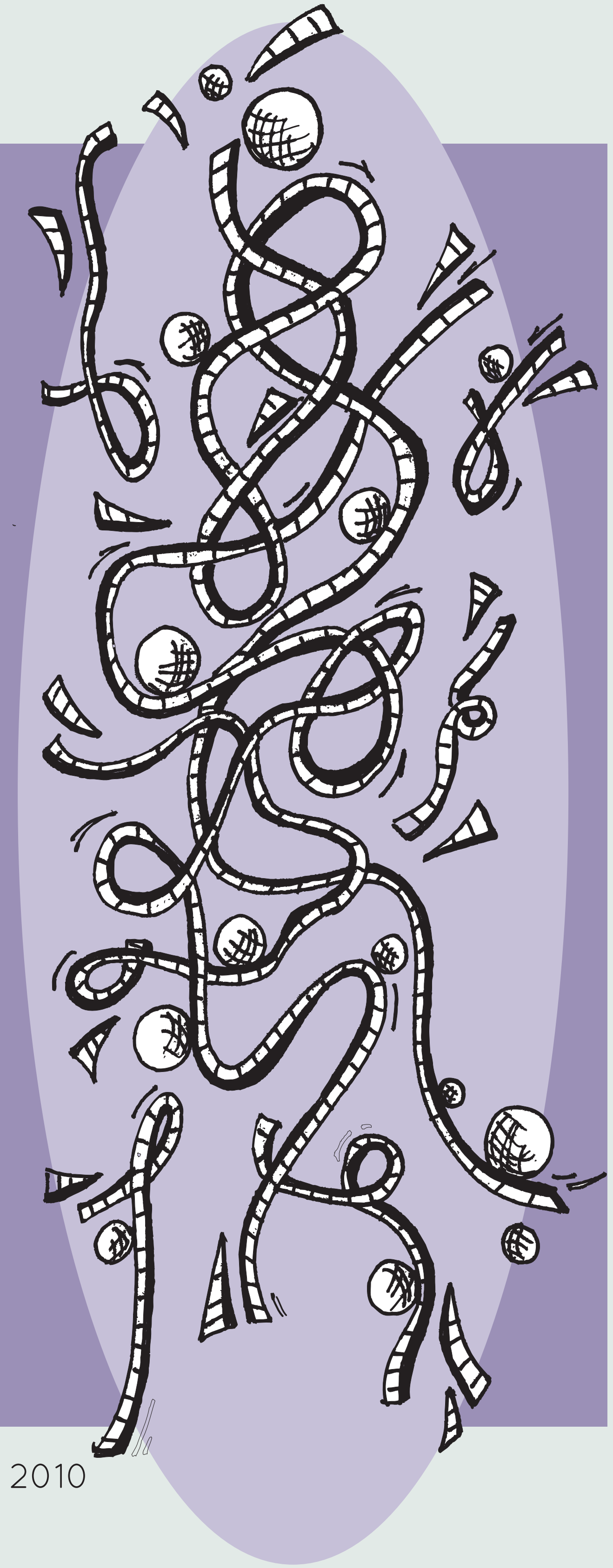
Trinity Term 2010

In this Issue



Art: Anna Pouncey

Bang Science Magazine, Trinity Term 2010

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Editorial

From the innermost workings of our bodies to the great mysteries of space, science has always tried to rationalise our world. Just as water seeps through the cracks of a container, so science seeks to fill the gaps in our understanding of how and why things work. However far from being a static super-glue, linking together observations and ideas, science, like water, is dynamic, gathering momentum or changing course as obstacles are encountered and new discoveries are unearthed.

This flow of ideas can be traced back to ancient times when philosophers opened the flood gates and tried to explain the world around us: from proposing that everything is made up of basic elements to offering mechanisms for quantifying time. While many of the conclusions they offered have since been rejected, a number of models and methods these great minds used have continued to permeate modern science. Appearing again and again in various guises, the recurrence of basic concepts show science as it really is: not fixed, isolated ideas attempting to confirm or reject current theories, but as a vibrant, evolving rationale of what we see around us.

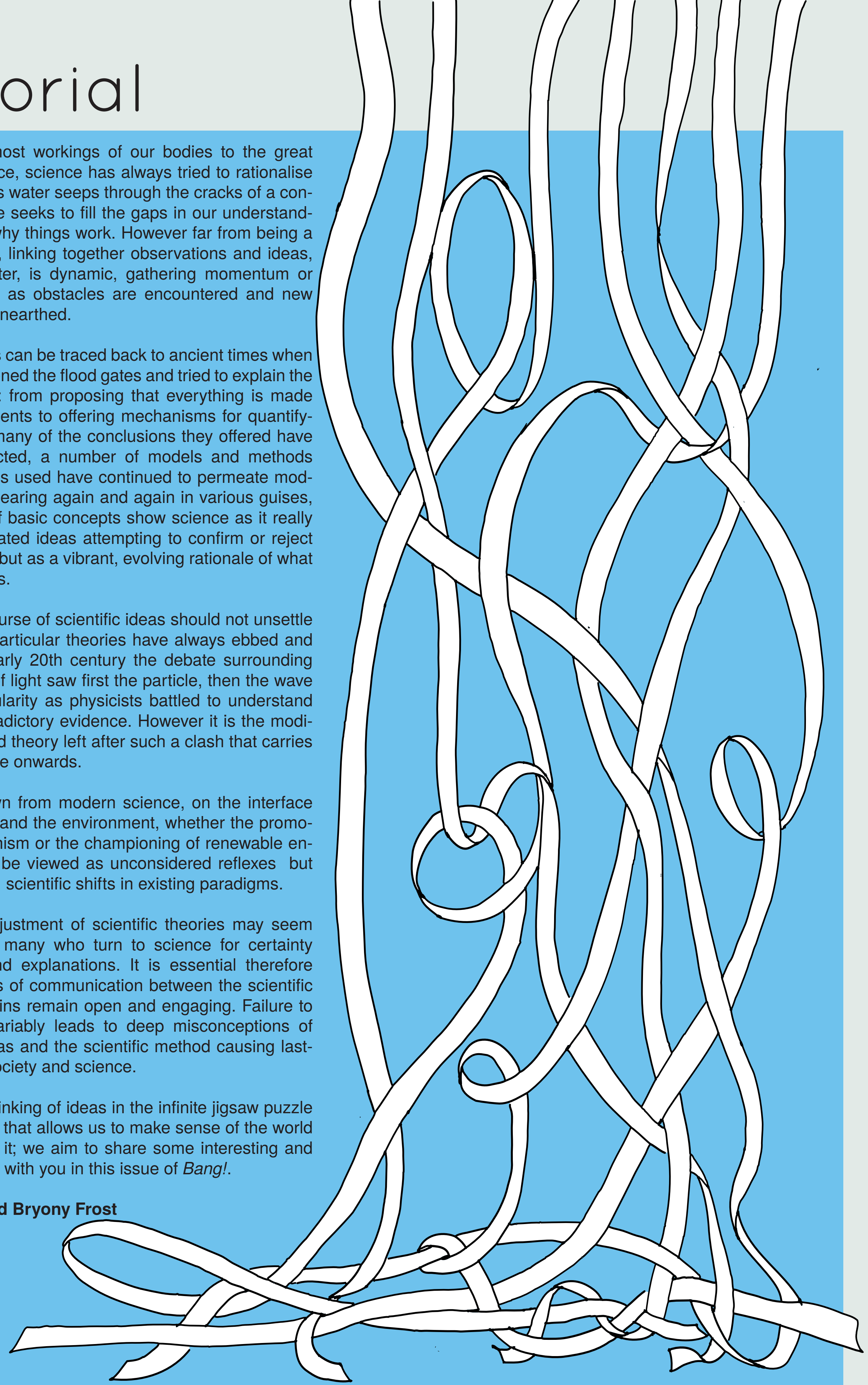
The changing course of scientific ideas should not unsettle us; support for particular theories have always ebbed and flowed. In the early 20th century the debate surrounding the very nature of light saw first the particle, then the wave model gain popularity as physicists battled to understand apparently contradictory evidence. However it is the modified and improved theory left after such a clash that carries the tide of science onwards.

Ideas then, drawn from modern science, on the interface between society and the environment, whether the promotion of vegetarianism or the championing of renewable energy, should not be viewed as unconsidered reflexes but rather as logical, scientific shifts in existing paradigms.

The constant adjustment of scientific theories may seem disconcerting to many who turn to science for certainty through facts and explanations. It is essential therefore that the channels of communication between the scientific and public domains remain open and engaging. Failure to achieve this invariably leads to deep misconceptions of both specific ideas and the scientific method causing lasting damage to society and science.

It is the gradual linking of ideas in the infinite jigsaw puzzle of understanding that allows us to make sense of the world and our place in it; we aim to share some interesting and surprising pieces with you in this issue of *Bang!*.

Nicola Davis and Bryony Frost
Editors



Art: Leila Battison

News

Ashes to Ashes

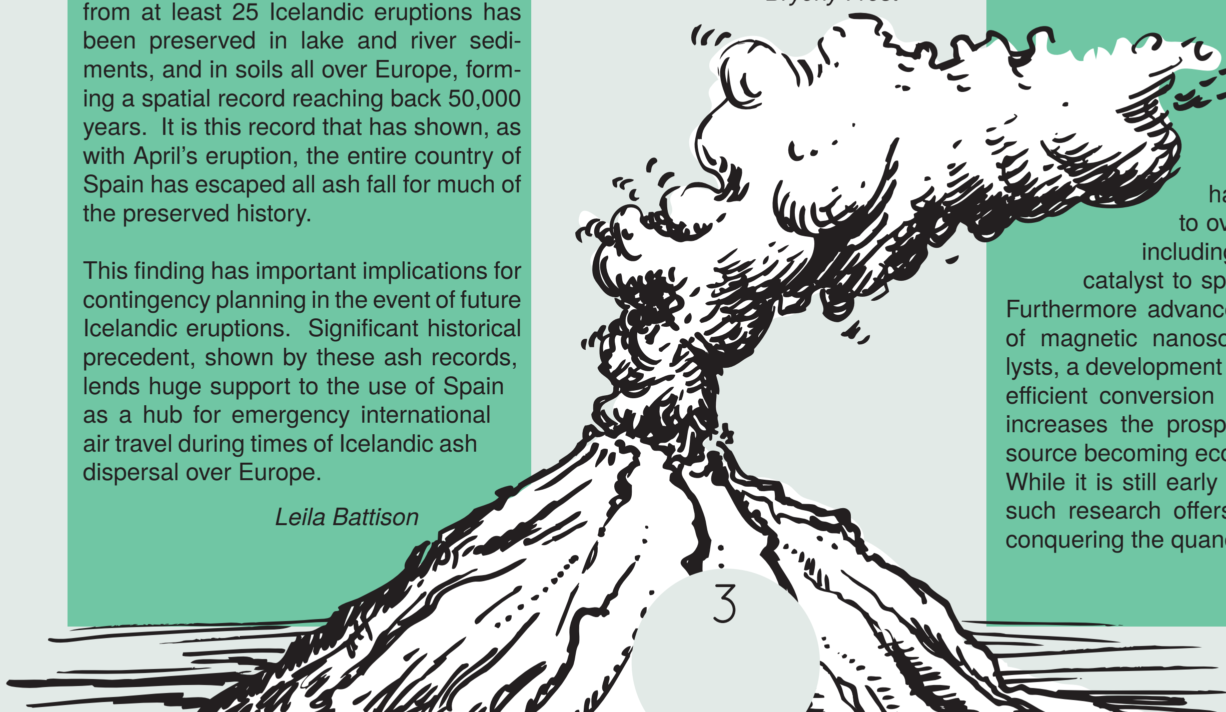
Over the last two months, the UK and Europe have suffered untold disruptions at the hands of the Icelandic volcano Eyjafjallajökull. But a team of scientists from Oxford and Royal Holloway Universities have uncovered patterns in volcanic ash movements that can be used for planning emergency measures in the event of another eruption.

A joint initiative between the Department of Geography at Royal Holloway, and the School of Archaeology at Oxford has built up a database of ash fall from Icelandic volcanoes over a period spanning the last 50,000 years. This historical ashfall map has brought to light some interesting trends: that transport patterns for each eruption in the past are extremely similar and, perhaps more remarkably, that Spain has remained ash free for the last 40,000 years.

Long ranging volcanic clouds are composed of tiny particles of volcanic glass, no more than one tenth of a millimetre in size and not visible to the naked eye except for when in dense plumes. These particles pose a great risk to jet engines if a plane were to fly through the invisible cloud. Building up in both air intake channels and in the engine itself, the ash can cause the engines to fail without warning. As such, following the eruption of Eyjafjallajökull in April this year, the UK and much of Europe announced an unprecedented airspace closure. But while an eruption of this scale is unique in human memory, it is certainly not the first. Volcanic ash from at least 25 Icelandic eruptions has been preserved in lake and river sediments, and in soils all over Europe, forming a spatial record reaching back 50,000 years. It is this record that has shown, as with April's eruption, the entire country of Spain has escaped all ash fall for much of the preserved history.

This finding has important implications for contingency planning in the event of future Icelandic eruptions. Significant historical precedent, shown by these ash records, lends huge support to the use of Spain as a hub for emergency international air travel during times of Icelandic ash dispersal over Europe.

Leila Battison



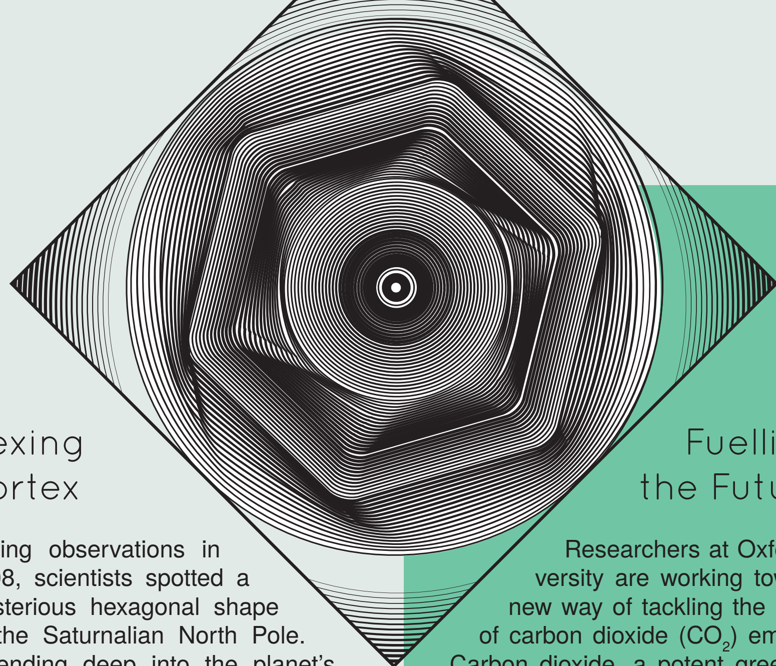
Vexing Vortex

During observations in 2008, scientists spotted a mysterious hexagonal shape at the Saturnalian North Pole. Extending deep into the planet's gaseous interior, with a 'hotspot' at the planet's core, scientists were mystified as to how it could have formed – until now.

Oxford University physicists Peter Read and Ana Aguiar have been performing experiments with tanks of fluid which mimic the behaviour of the dense gas on Saturn. To recreate conditions similar to those on the gas giant, a ring or disc at the base of the tank is set into rotation. White 'tracer' particles show the flow lines as they develop.

The flow produced by the rotating disc is unstable, spontaneously developing vortices and meanders. These eventually form a hexagonal pattern which wanders slowly about the tank, in a similar fashion to Saturn's hexagon. For the first time we have some clue as to how this bizarre polygon could have formed, offering furrther insights into the murky interior of this planet

Bryony Frost



Fuelling the Future

Researchers at Oxford University are working towards a new way of tackling the problem of carbon dioxide (CO_2) emissions. Carbon dioxide, a potent greenhouse gas, is released when fuels are burnt however this project proposes to harness this dangerous beast to make it work for us.

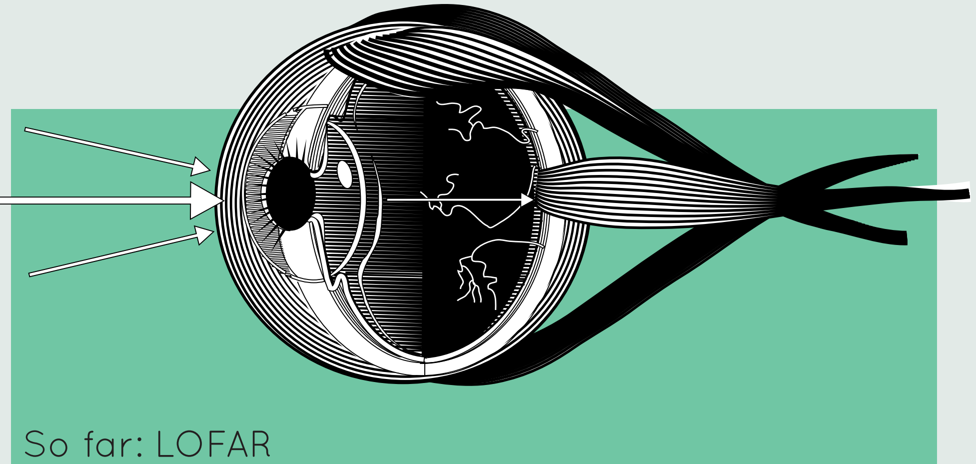
"The challenge for this project lies in utilising CO_2 released from power stations."

With project leaders including Peter Edwards from the Department of Chemistry, the fields of materials science, chemistry and engineering are united to turn CO_2 into a fuel. By reacting this gas with methane, methanol may be produced giving access to a wide range of fuels. Crucially, while methane itself is a fossil fuel, it may be produced in a sustainable way as 'biomethane'- a bi-product from the farming of livestock.

The challenge for this project lies in utilising CO_2 released from power stations. These emissions are not pure but contain many other gases including poisonous nitrogen oxide (NO_x) which interfere with the methanol making process. Novel ideas have been proposed to overcome such issues including utilising NO_x as a catalyst to speed up the reaction. Furthermore advances in the production of magnetic nanoscale-structured catalysts, a development necessary to ensure efficient conversion of CO_2 to methanol, increases the prospects of such a fuel source becoming economically viable . While it is still early days for the project, such research offers new strategies for conquering the quandary of CO_2.

Nicola Davis

Eye Spy



New retinal implant technology could revolutionize treatment of inherited retinal degeneration diseases such as *retinitis pigmentosa* (RP). Researchers at Oxford University are carrying out the first UK trials which involve implanting the light-sensitive devices under a patient's retina. Developed by Retinal Implant, AG, these devices work with the eye to facilitate vision. Light, passing into the eye is focussed onto the retina stimulating the implanted device which boasts an impressive 1,500 pixel array.

This technique is expected to generate high resolution images since the neurons behind the retina are lined up towards the electrodes of the device. Furthermore, this technology is far more discreet than previous solutions which involved mounting external cameras onto glasses, instead requiring only an external battery fitted behind the ear.

Such trials, held at the John Radcliffe Hospital, are expected to offer new insights into the possibilities of integrating electronic technologies into the body.

Nicola Davis

So far: LOFAR

Not far away from Oxford, in a Chiltern field, a new radio telescope is being built, which will link up with sites across Europe in order to probe the night sky at a range of frequencies lower than those normally examined. The core of the telescope will be in the Netherlands, with several more sites distributed across that country. There will also be at least five outer stations in Germany, and one each in Great Britain, France and Sweden. These outer sites will increase the resolution of the telescope, as well as increasing the collecting field, which is expected to be about a kilometre square.

Dubbed 'LOFAR', the LOw Frequency ARray for radio astronomy, this huge endeavour will scan the night sky looking for several different things. One object of interest is pulsars – incredibly small, dense neutron stars which emit intense beams of radiation from their magnetic poles. These stars rotate very rapidly, so the beam of light 'flickers'. Therefore the telescope needs a high sensitivity, as well as very fast recorders, capable of sampling the incoming light at extremely short time intervals. LOFAR is very well placed to examine these objects, as pulsars are brighter at low radio frequencies.

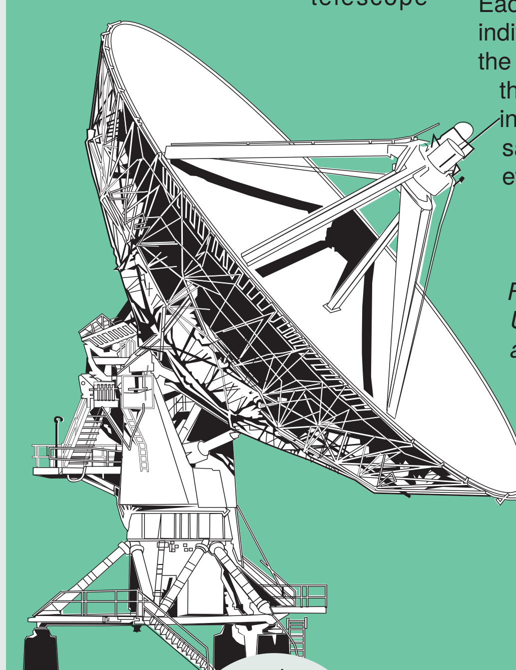
"As the Universe expanded and cooled, eventually conditions became such that atoms could form..."

Another thing the telescope is looking out for is data on 'recombination'. The early Universe was so hot and dense that atoms couldn't form – the Universe was a plasma of electrons and protons. As the Universe expanded and cooled, eventually conditions became such that atoms could form, and all the electrons and protons combined to form neutral hydrogen, in a very short space of time. It was at this point that the Universe that light could travel without being scattered: the Universe became transparent.

Each of the telescopes can also function individually, and Dr Aris Karastergiou at the University of Oxford hopes to exploit this as much as possible over the coming years, not only in the search for pulsars but also for other short-lived radio events in the sky.

Bryony Frost

For more breaking news from Oxford Univeristy, check out the science blog at www.ox.ac.uk/media/science_blog/



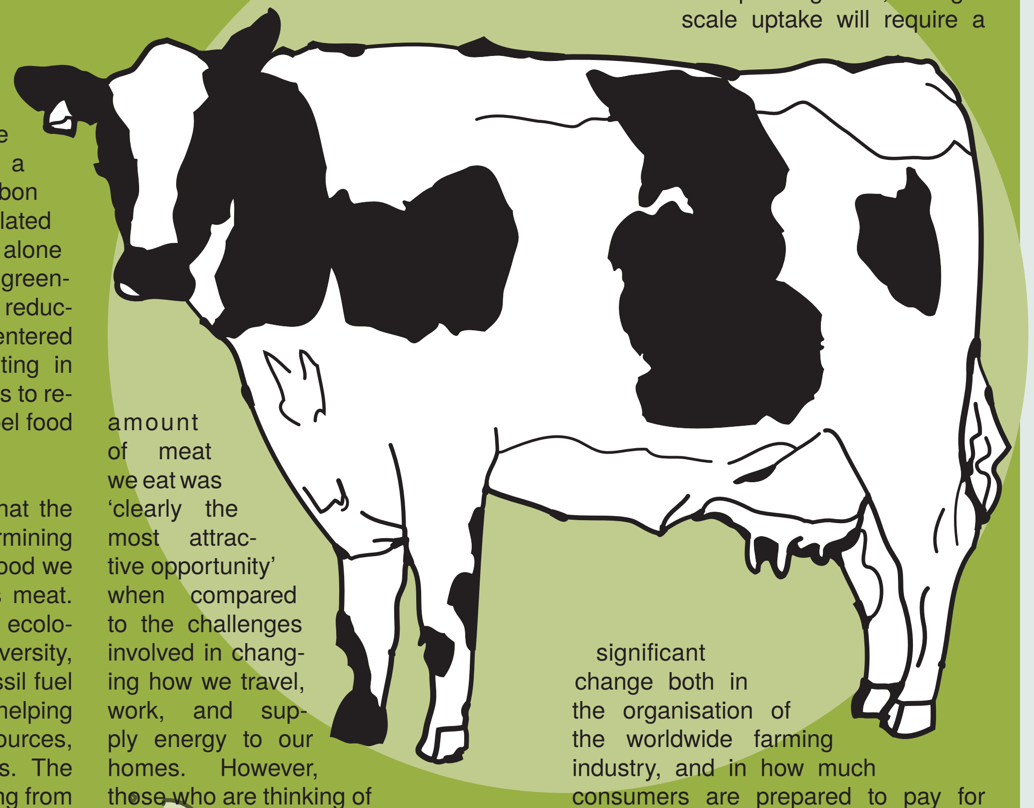
Art: Karis Flavell

Covering our Hoofprints

Investigating the rise of Environmental Vegetarianism

Last term, three Oxford college JCRs voted, after considerable debate, to encourage vegetarianism by introducing one meat free day in hall each week. Graduate student Alex Flint, who successfully petitioned Exeter College to remove meat from its menu every Thursday, said that this resolution was intended to "reduce the impact that our diet has on the environment".

It is true that the production, transportation and storage of the food that we eat accounts for a considerable portion of our carbon emissions: it has been calculated that the agricultural industry alone produces 20% of all man made greenhouse gases. The importance of reducing these emissions has already entered the public consciousness, resulting in growing pressure on supermarkets to reduce packaging and to clearly label food transported by air.



However, it is less well known that the single most important factor determining the environmental impact of the food we eat is whether or not it contains meat. This was established in 2003 by ecologist David Pimentel at Cornell University, who calculated the quantity of fossil fuel energy required to provide one helping of protein from meat–based sources, compared to vegetarian sources. The results show that protein originating from lamb and beef has 50 times the carbon footprint of an equivalent amount of protein derived from vegetables, pulses and grains. Not all meats are equally bad; the production of pork requires three times less energy than the production of beef, and those concerned about animal welfare will be disappointed to learn that factory-farmed chicken was the least carbon intensive meat of those investigated, requiring just four times more energy than vegetable sources.

According to this analysis, the enormous carbon hoofprint arises largely from the energy consumed in the production of all of the extra grains that are needed to feed livestock, and is exacerbated by the large quantities of methane, a highly potent greenhouse gas, which the animals release as they digest that food. Furthermore, the soaring global appetite for meat has led to a rapid increase in the demand for arable farmland on which to grow crops for animal feeds. This has catalysed the clearing of rainforests in South America, leading to the ongoing destruction of an ecosystem which currently acts as a powerful carbon sink.

In the light of this evidence, Rajendra Pachauri, chair of the United Nations' climate change panel, said that reducing the amount of meat we eat was 'clearly the most attractive opportunity' when compared to the challenges involved in changing how we travel, work, and supply energy to our homes. However, those who are thinking of giving up meat should be aware of the high carbon footprint of many vegetarian sources of protein. For instance, researchers at the University of Chicago have shown that hard cheese has a higher carbon footprint than beef, while the energy expended during the fishing process means that many types of seafood are also off the menu for the environmental vegetarian.

> **"...the single most important factor determining the environmental impact of the food we eat is whether or not it contains meat."**

Representatives of the British farming industry are keen to point out that these warnings about meat's environmental consequences are restricted to grain fed, intensively farmed livestock, and do not apply to many of the animals reared in Britain, which are grass fed on land that would otherwise lie barren. This position has been adopted by several environmental groups, such as the Sustainable Development Commission, who argue that a shift away from large scale intensive farming towards smaller, grass–fed herds would allow us to produce more meat with a lower carbon footprint. While buying such produce potentially allows us to keep eating meat, its large-scale uptake will require a significant change both in the organisation of the worldwide farming industry, and in how much consumers are prepared to pay for meat: currently 93% of meat consumed in Britain comes from cheaper, intensively farmed livestock.

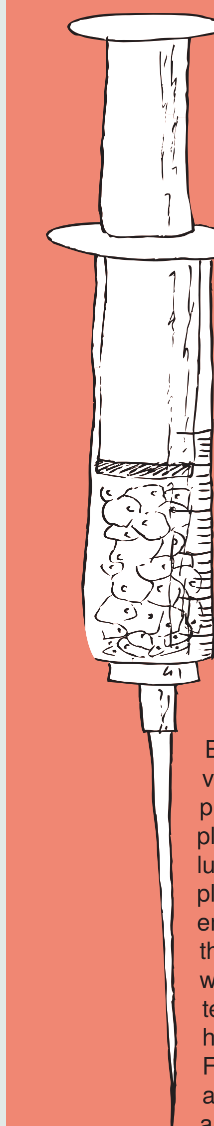
There are also several possible technological solutions to the problem. These range from the development of cell cultures capable of growing animal muscle tissue in a lab, to the genetic selection of farm animals that produce less methane. However, while these technologies remain in their infancy and high-hoofprint meat continues to fill our supermarkets, the environmentally minded gourmand could do worse than to follow the advice of biologist Colin Tudge, who contends that dishes from the world's greatest cuisines can be made using a simple combination: 'lots of plants, not much meat, lots of variety'. Let's hope the chefs at Exeter College are up to the challenge. ■

Text: Adam Lacy
Art: Genevieve Edwards

Lack-ing Culture

The unassuming benefactor of cell biology

On October 4th 1951 Henrietta Lacks died of cervical cancer. Her earthly remains may have long decomposed, but today she lives on in laboratories all over the world and has been involved in some of the biggest scientific and political events of the past sixty years.

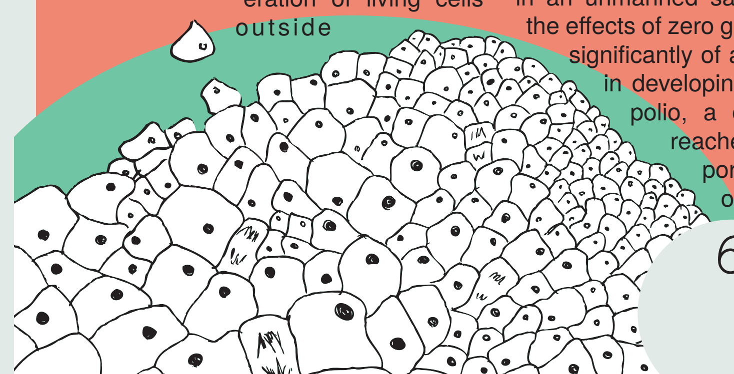


A tobacco farm worker from Virginia, Henrietta moved to Baltimore with her husband and family in 1942 with dreams of a more prosperous life. Baltimore was also the home of Dr George Gey, a cell biologist desperately trying to grow human cells outside the body. Today, 'tissue culture' is routinely performed by scientists using specialised equipment in a controlled environment - but in the 1940s, the technique was very different. With only a Bunsen burner to provide a sterile atmosphere, Dr Gey would place the cells in a solution of chicken blood plasma and pulped calf embryos bought from the local abattoir before work. Until 1951, his attempts at tissue culture had failed. Then on February 4th, one of his assistants brought him a sample from a biopsy of Henrietta Lacks' living cervical cancer tumour. Dr Gey followed the same procedure he had with all the other cells and, for the first time, observed the proliferation of living cells outside the human body. Henrietta's cells, named 'HeLa' to protect her anonymity, have been multiplying ever since that day.

Dr Gey had made a major scientific breakthrough; now almost anything could be tested on human cells with relative ease. HeLa is currently the most commonly used immortal cell line and this popularity is partly due to the cells' unusual ability to survive and multiply. Cervical cancer patients usually live for several years after diagnosis, but Henrietta died within four months, her body consumed by tumours. This unique aggression has made the cells a useful investigative tool, but has also lead to complications. After Dr Gey's discovery, it became mysteriously easy to culture human cells – and not just cancerous tissue: scientists were now growing normal human cells as well. Many of these cell lines became cancerous and died in a process named 'spontaneous transformation', and this was taken as evidence for a cancer virus. Only after millions of dollars had been spent trying to find a cure for the virus in President Nixon's 'war on cancer' was it discovered that these 'new' cell lines were in fact HeLa cells after all. The original samples had merely become contaminated, and no cancer virus existed.

> **"...knowledge of almost every process in human cell biology has been derived from investigations involving HeLa cells."**

Despite this controversy, science owes a huge debt to Henrietta Lacks: knowledge of almost every process in human cell biology has been derived from investigations involving HeLa cells. They were present at the first atomic bomb tests to examine the effects of radiation on human cells and they were sent to space in an unmanned satellite to investigate the effects of zero gravity. Perhaps most significantly of all, they were critical in developing a vaccine against polio, a disease which had reached epidemic proportions by the time of Henrietta's death.



The irony is that for all the medical advances HeLa cells have provided for humanity, Henrietta Lacks' descendants are too poor to be able to afford basic healthcare. Many see this as an injustice.

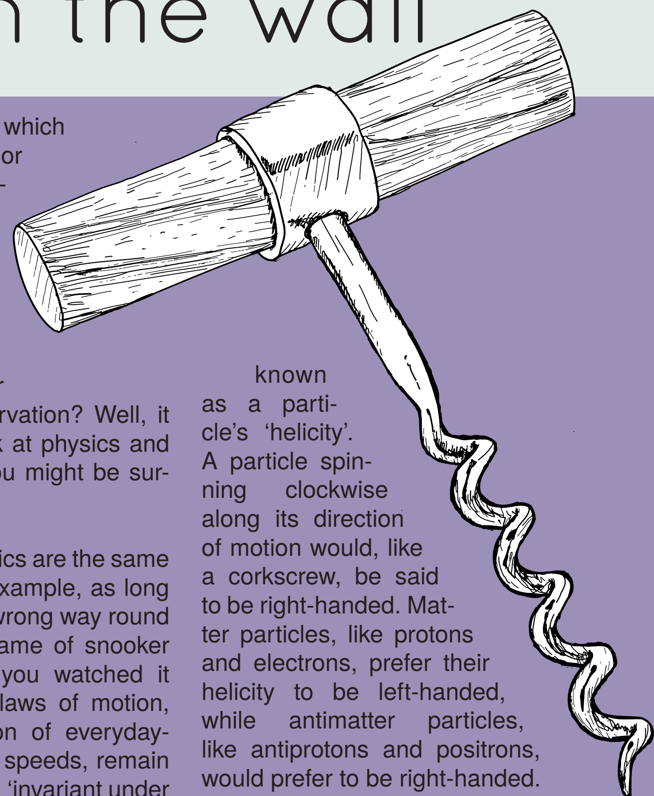
In 1990 a similar case resulted in a law suit when John Moore, whose leukaemia was developed into an immortal cell line without his knowledge, felt he deserved a share of the profits. 'Mo', as the patented cell line is known, is worth an estimated three billion dollars. In this case there was clearly a breach of trust as unnecessary appointments were made following the discovery of the cells' potential, just so that doctors could obtain further tissue samples. During the lawsuit this unethical behaviour was recognised and now doctors must declare the commercial potential of a sample; however, the court ruled that removed body parts are clinical waste and therefore belong to the medical facility, meaning no profit can be made by the patient.

Today HeLa cells are more important than ever. They provide the basis for nearly all laboratory cancer research and are increasingly used in the investigation of viruses such as HIV. Such is their continuing importance, it is estimated that cells totalling four hundred times Henrietta Lacks' original body mass are currently in use. She is the unsung, unpaid, unwitting heroine of cell biology and her contribution should never be forgotten. ■

Text: Philip Bennett
Art: Leila Battison

Mirror mirror on the wall

The curious consequences of chirality



Mirrors are endlessly fascinating, and not just for the serially narcissistic. Next time you're shaving, plucking your eyebrows, or just wondering how you came to look so much like Ronnie Corbett, stare deep into the silvery otherworld and ask yourself: "how do I know that that isn't the real world, and that I'm not trapped behind the glass in the alternate-reality of someone else's back-to-front bathroom?"

Science has a word for this reflection - it's known as 'chirality'. An object is said to possess chirality if it is distinguishable from its mirror image. If an object is chiral, there is no combination of rotations or motions which you can perform which will result in it looking identical to its reflection.

"...if you look at physics and chemistry in a mirror, you might be surprised by what you see."

A classic example of an object with this property of chirality, or 'handedness', is your hand. It doesn't matter how you rotate or move your right hand, you simply can't make it look like your left hand; nor will your right glove fit comfortably on your left hand. However, in a mirror, the reflection of your right hand does look just like your real-world left and, similarly, if you turn your gloves inside-out — which is neither a rotation nor a motion, but an inversion — you should find that your right glove fits your left hand, er, like a glove.

So why does science reserve a special term for this rather prosaic observation? Well, it turns out that if you look at physics and chemistry in a mirror, you might be surprised by what you see.

Some of the laws of physics are the same in the mirrorverse. For example, as long as I set the balls up the wrong way round to fool sport nerds, a game of snooker would look identical if you watched it back-to-front. Newton's laws of motion, which govern the motion of everyday-size objects at everyday speeds, remain what scientists would call 'invariant under a parity transformation'.

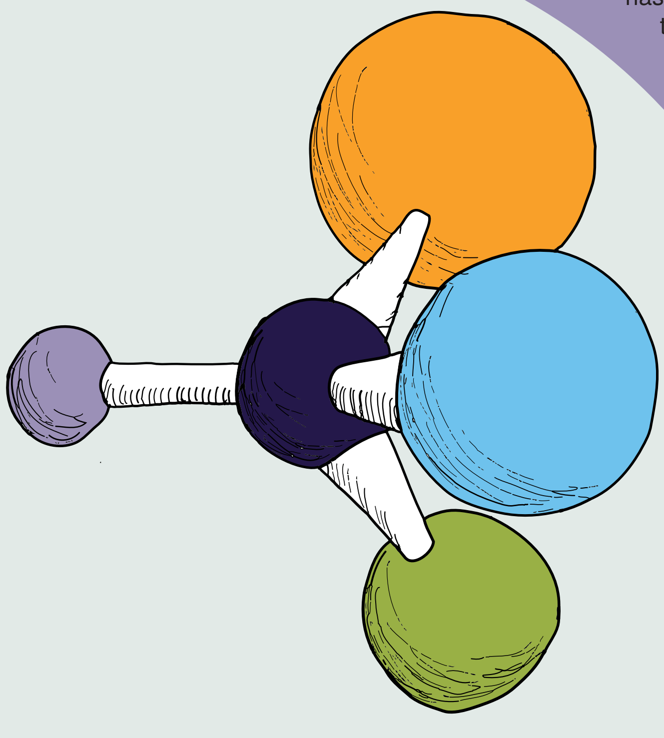
Another classic example of an object with chirality is a corkscrew. Turn it clockwise, and you drill into the cork in a wine bottle; turn it anticlockwise, and you ease it out. Lefty loosey, righty tighty — right? However, in a mirror-world, the rule would become lefty tighty, righty loosey: the corkscrew flips in its orientation, and you'd need to turn it anticlockwise to bore into the cork. Although a trip to the mirror-world is easy to deal with on a macroscopic scale, this inversion has profound implications on the tiny scales of quantum mechanics.

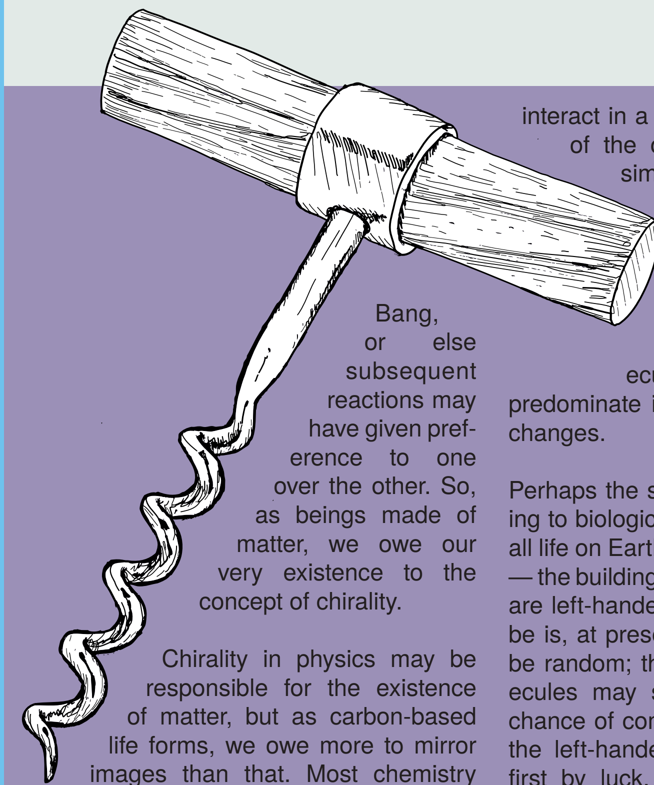
In fact, it turns out that subatomic particles such as protons and electrons act like tiny corkscrews. Every particle has a spin, and, if it's moving, a direction of travel. The relationship between the direction of spin and travel is known as a particle's 'helicity'. A particle spinning clockwise along its direction of motion would, like a corkscrew, be said to be right-handed. Matter particles, like protons and electrons, prefer their helicity to be left-handed, while antimatter particles, like antiprotons and positrons, would prefer to be right-handed.

Turning matter into antimatter is as simple as looking at it in the mirror and inverting the charge. The parity transformation reverses the particles' helicity, while the charge swap explains why antielectrons are called positrons: they're positively charged. So, for example, an antiproton is negatively charged (in contrast to the positively charged proton)and its helicity corkscrew spirals in the opposite direction.

"Where has all the antimatter gone?"

Now as any good sci-fi geek knows, matter and antimatter are not happy bedfellows: bring one into contact with the other and both are annihilated in a burst of gamma radiation. However, one might naïvely expect from our present understanding of physics that an equal quantity of matter and antimatter should have been made at the beginning of time...so how is it that matter, which we are made of, also makes up almost everything we can see? Where has all the antimatter gone? Our best guess is that there was a tiny excess of matter left over after the cataclysmic cancellation, and the reason for this tiny excess of matter is that our Universe does actually behave ever-so-slightly differently from the mirrorverse. This means that matter and antimatter are not quite equal and opposite in every respect, and thus may either not have been formed in precisely equal amounts during the Big Bang, or else subsequent reactions may have given preference to one over the other. So, as beings made of matter, we owe our very existence to the concept of chirality.





Chirality in physics may be responsible for the existence of matter, but as carbon-based life forms, we owe more to mirror images than that. Most chemistry would proceed identically in the mirror-verse, but carbon is capable of creating handed molecules which can confound expectations.

"...you could make a right-handed aubergine and cook it up into some chiral moussaka, but you'd be completely unable to digest it..."

Carbon is one of only a handful of elements able to make four bonds to atoms around it. Usually, it splays its bonds out into a tetrahedron — a triangle-based pyramid — with itself at the centre, and whatever it bonds with at the points. Imagine a carbon attached to four hydrogen atoms. This simple configuration is methane, the main component of the natural gas that probably powers your central heating. This looks identical to its mirror-image, and if you swap one of the hydrogens for something else, the molecule you've created still isn't chiral - you could just rotate the mirror-image around until the non-hydrogen was in the same place as before. This will work once more: two hydrogens, something else and a third thing is still rotatable into its mirror-image; but a third replacement, meaning that the carbon atom is now bonded to four different things, transforms the atom at the centre into a 'chiral carbon', and assigns the molecule a handedness.

Now this is all well and good, and perhaps slightly nitpicking, until you realise that chemicals of one handedness can interact in a very different way to those of the opposite handedness. For simple reactions, like setting a chiral hydrocarbon on fire, you won't see a significant difference between handednesses. However, when you get into the complex molecules and processes which predominate in biochemistry, everything changes.

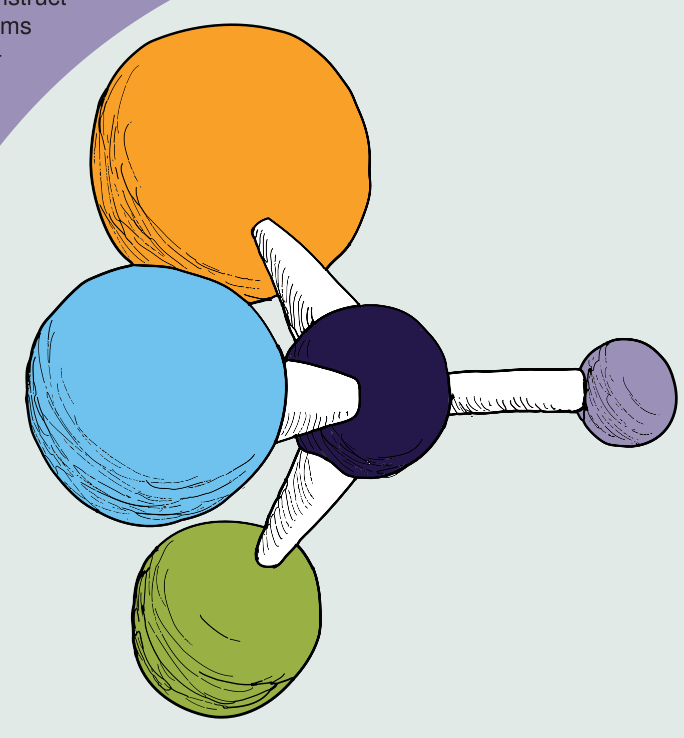
Perhaps the strangest observation relating to biological molecules is that almost all life on Earth comprises of amino acids — the building blocks of proteins — which are left-handed. Why exactly this should be is, at present, uncertain. It could just be random; the first self-replicating molecules may simply have had a 50:50 chance of coming out that way, and that the left-handed ones might have been first by luck, spread across the Earth and, ultimately, evolved into every stitch in the elaborate tapestry of life. However, there are other theories: one, for example, suggests that our planet was seeded with amino acids by comets from deep space, and that the amino acids on these comets were broken down according to their handedness by circularly-polarised interstellar UV radiation - in other words, chiral starlight destroyed the right-handed molecules by giving them preferential sunburn.

Back on Earth, the strange fact is that we could, theoretically, construct identical-looking organisms which were totally incompatible with everything in our biosphere. Similarly, you could make a right-handed aubergine and cook it up into some chiral moussaka, but you'd be completely unable to digest it because the enzymes in your body can only process left-handed proteins.

There is a risk that these mirror meals may taste very different: chirality is key in our intimately-linked senses of taste and smell. For example, the compound limonene, extracted from citrus fruit, comes in two forms: right-handed smells of oranges, while its opposite number has an aroma reminiscent of lemons. However, perhaps the bigger risk is that mirror-foods may be poisonous. When scientists cooked up chocolate bars which contained only the mirror form of glucose, they were reported to taste the same as usual. Unfortunately, because this unnatural glucose could not be broken down in the stomach, it continued into the intestines where the remnant sugar turned what was a cheeky calorie-free choccy into a powerful laxative. So powerful, in fact, that this synthetic glucose is undergoing clinical trials for use exactly as that.

Through chiral chocolate and cosmology, the creepy mirror universe is seeping through the cracks in your bathroom tiles into our reality. Is that just reflected light, or your antimatter self? What does their toothpaste taste like? Are they more scared of you than you are of them? From the Big Bang to biochemistry, only chirality has the answer. ■

Text: Andrew Steele
Art: Leila Battison



Let there be light

Getting to grips with one of the oldest problems in physics

What happens if you try to chase light? It was this question that perplexed a 16 year old Einstein, and started him on the trail to his theory of relativity. In just over thirty years, he and some of the world's best physicists revolutionized our understanding of space and time. The work they began heralded a new dawn in our understanding of the universe, and is still not complete. The questions they asked currently rest at the heart of the largest scientific endeavour ever created - the Large Hadron Collider (LHC).

Since the time of the Greeks, many theories as to the nature of light had been proposed. By the 1800s it had been established that light had many properties characteristic of waves, analogous to the flick of a taut rope or the ripples formed by dropping a stone in a pond. But while it is clear that such ripples travel through water, the question of what light waves travelled in, or why light took this form, was open.

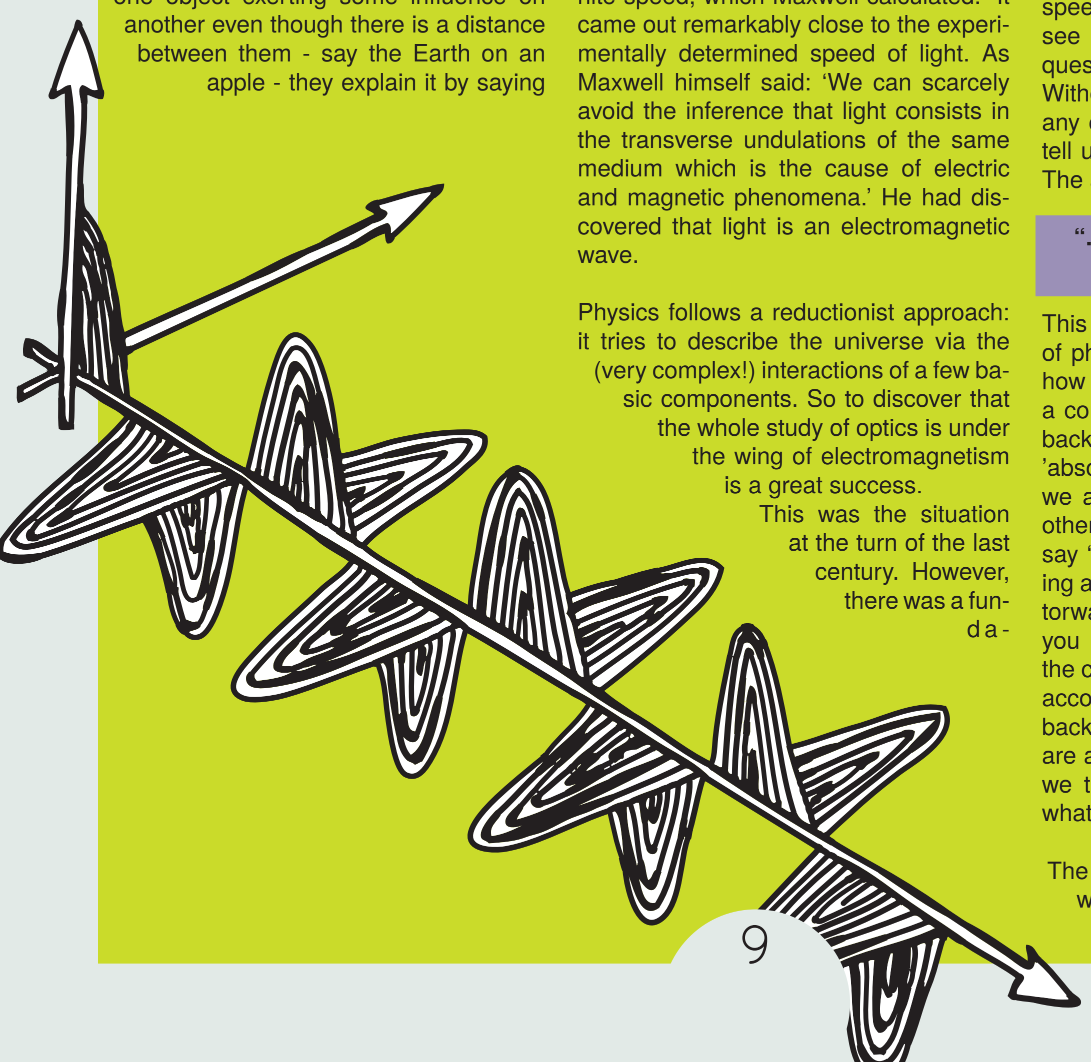
In 1884 Maxwell published his theory of electromagnetic fields. The concept of a field can be tricky: when physicists see one object exerting some influence on another even though there is a distance between them - say the Earth on an apple - they explain it by saying there exists some intermediate mechanism between the two, which transmits the Earth's influence to the apple. This mechanism is a 'field'. Newton's theory of gravity says that both the Earth and the apple will affect the form of the gravitational field but, as the Earth has a far greater mass, it has a much stronger influence. The net effect is that the apple falls towards the Earth. Look at it another way. Imagine we assign an imaginary arrow to every point in space; the mass of the earth tells the arrows how to point, and the direction and size of the arrows tell the apple how to move. That is all a field is!

"There is no universal backdrop against which we can define 'absolute' motion."

Maxwell's theory describes two fields: the electric and magnetic fields. These work in exactly the same way as above, except that they act on electric charge. One possibility that arises from his equations is an electromagnetic wave: a vibration which travels through these two fields. These vibrations have a very definite speed, which Maxwell calculated. It came out remarkably close to the experimentally determined speed of light. As Maxwell himself said: 'We can scarcely avoid the inference that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena.' He had discovered that light is an electromagnetic wave.

Physics follows a reductionist approach: it tries to describe the universe via the (very complex!) interactions of a few basic components. So to discover that the whole study of optics is under the wing of electromagnetism is a great success.

This was the situation at the turn of the last century. However, there was a fundamental conflict between this theory and the work of Galileo and Newton.



Applications - Polarisation

Imagine holding a taut rope at one end. We view it end on. You could flick it up, or down, or any other direction. It is the same with light - the vibrations could be in any direction, and in the normal light we see there is a jumble of many different directions of vibration. Filtering out all but one of these directions is called polarisation. It's just like threading our rope through a fence - only vertical vibrations will pass through it. We can do this by placing a miniature fence, or polarising lens, in front of our eye.

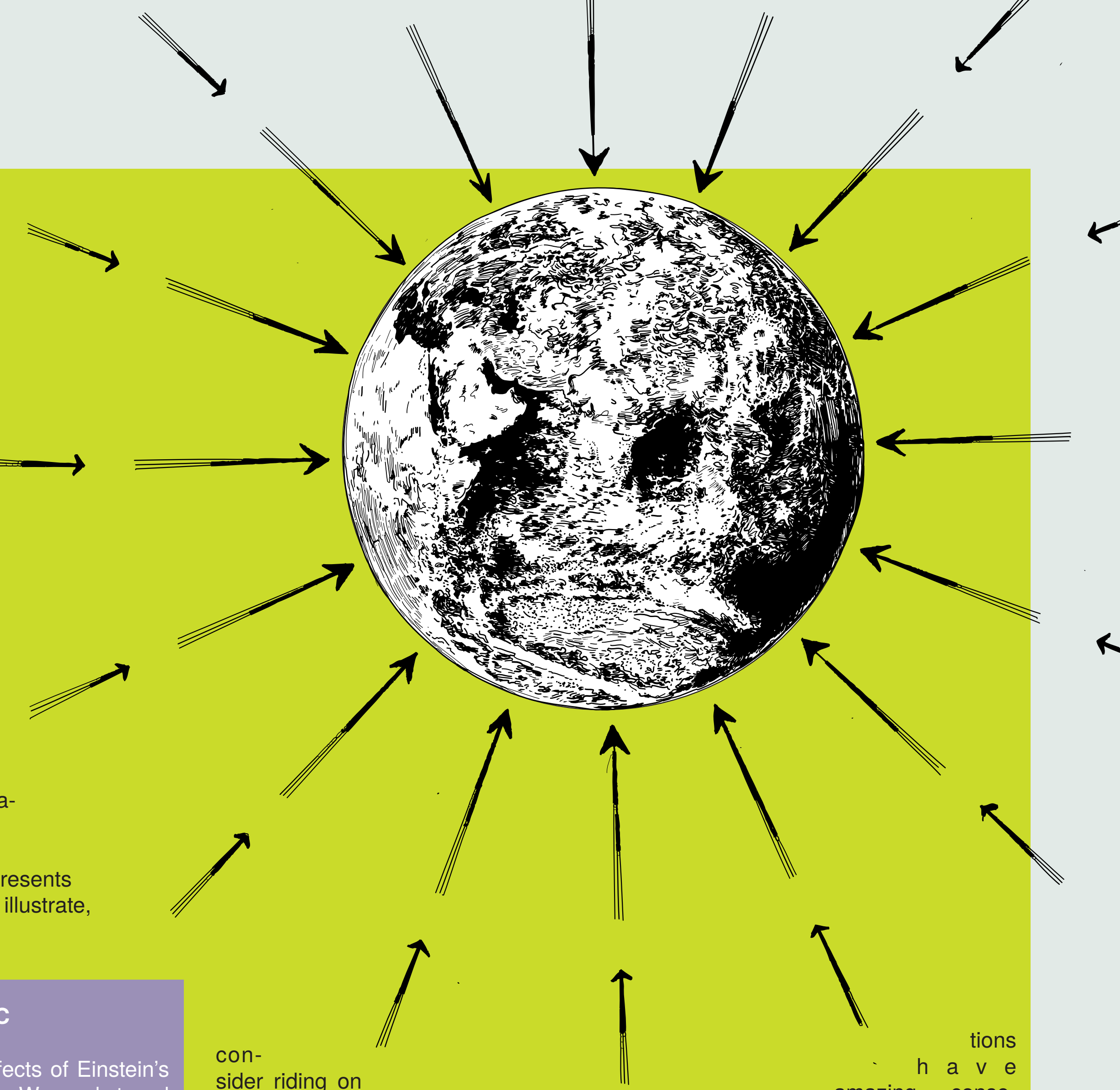
This is exactly what 3-D glasses do. Two images are projected onto the screen, one vertically polarised, the other horizontally. You have corresponding different lenses in your glasses. So the brain sees two slightly separated images, and from here produces the illusion of depth.

Galileo invites us to consider going into the belly of a ship, sailing with a constant speed. The sea is calm, and we cannot see anything of the outside world. The question is, can we tell if we are moving? Without looking outside the ship, is there any experiment we can perform that will tell us whether we are stationary or not. The answer, says Galileo, is no!

"...time and length are no longer absolute concepts."

This is the principle of relativity: the laws of physics do not change depending on how fast you move, provided you move at a constant speed. There is no universal backdrop against which we can define 'absolute' motion. All we can say is that we are all in motion relative to one another. When we choose a backdrop and say 'this is stationary', it is called choosing a reference frame. Driving on the motorway, your reference frame is the car you are in. According to the motorway, the car is moving forward at 70 mph. And according to you, the motorway is moving backwards at 70 mph! Both statements are as right as the other. Now, whenever we talk about motion, we must specify what the motion is relative to.

The problem is, this principle clashes with Maxwell's theory. The reason is that Maxwell makes no mention of any specific frame his laws are true in. Light can only ever travel at one speed, but Maxwell doesn't tell us what reference frame that speed is measured in!



If there is no absolute motion, no absolute reference frame to which we can ascribe a particular significance, then our conclusion can only be that the speed of light is the same in every reference frame! And this is exactly the conclusion Einstein draws in his theory of special relativity.

But this immediately presents us with a paradox. To illustrate, consider riding on the motorway again. We see another car pass us, going at 80 mph relative to the motorway. Common sense (and Galileo) tells us that relative to our car, he is going at 10 mph, since we are travelling at 70 mph.

But now consider a light beam overtaking us. What Einstein is saying is that both the motorway and our car see the light travelling at exactly the same speed!

Obviously, something has to give. Einstein's way out of this paradox is to attack an incredibly basic and seemingly self evident assumption that we all hold. The assumption is that everyone experiences the same flow of time. Einstein drops this assumption, and in its place takes up the principle that the speed of light is the same in all reference frames. From here he derives an entirely new set of equations relating measurements between frames, known as the Lorentz transformations. These equations have amazing consequences, among the most important of which are that time and length are no longer absolute concepts. The man on the motorway and the man in the car do not agree on how long objects are, or how long things take. As a result, speeds (constructed from distances and times) can no longer be straightforwardly added together like Galileo thought: hence no paradox!

After this, Einstein would go on to use the principle of relativity to derive his most famous equation, $E = mc^2$, which is put to great use in the LHC (see box) and a second theory which explained gravity. Einstein's work reshaped the entire edifice of physics, and central to it was the study of light. No concept is more important in science today. ■

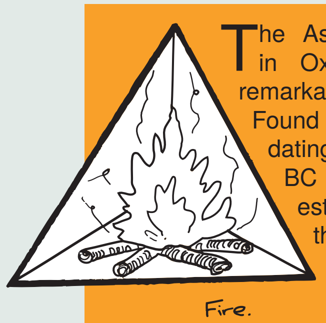
Applications - the LHC

In everyday life, the effects of Einstein's theory aren't noticeable. We rarely travel at more than 100 mph, and at this speed the difference between Einstein and Newton's predictions is one part in 1014. But in the LHC, relativity is crucial. As particles approach the speed of light their mass increases. If they actually got there, their mass would become infinite! This means is that, although we can only ever get particles up to speeds below that of light, we can theoretically have as much energy in a collision as we like, since things can get heavier with no end. In Einstein's theory, mass and energy are one and the same: particles are just a manifestation of energy, and as long as the total energy in a collision is conserved, they can be created and destroyed. This is all Einstein's famous equation is saying: that energy is proportional to mass squared. The exotic particles the LHC is looking for have enormous energies, which is why they have never been seen in a collider before. We haven't been able to make a collision energetic enough to produce them - until now.

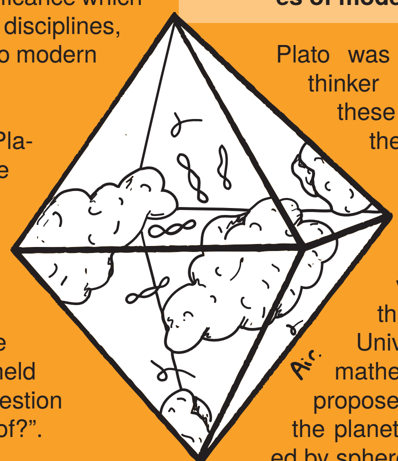
Text: Jack Binysh
Art: Sofia Kaba-Ferreiro

A Platonic Relationship

The seduction of science by five innocent solids

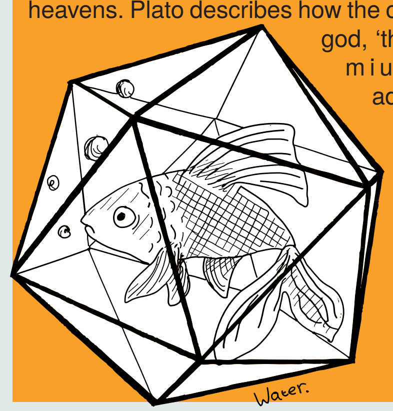


The Ashmolean Museum in Oxford houses five remarkable stone balls. Found in Scotland and dating from around 2000 BC these are the earliest known models of the five regular polyhedra: tetrahedron, cube, octahedron, icosahedron and dodecahedron. The stone balls also appear to indicate the concept of dual pairs: an octahedron may be constructed by linking together points placed at the centre of each face of a cube. Whether the ancient Scots fully understood the nuances of solid geometry is debatable, yet these shapes have a significance which stretches across time and disciplines, from early atomic theory to modern medicine.



Often referred to as 'Platonic solids', these five polyhedra are convex with identical faces composed of regular polygons. Plato was captivated by the perfect forms of these shapes, believing they held the key to the ancient question “What is the world made of?”.

In his dialogue 'Timaeus' (c. 360 BC), Plato proposed that these solids represent the four elements. The element earth took the shape of a cube due to its sturdy frame, air was an octahedron, fire became a tetrahedron with the sharp vertices indicating its destructive nature, while water was comprised of icosahedra the 'ball-like' shape allowing the polyhedra to move around each other and hence explaining the 'flow' of water. The fifth solid, the dodecahedron, was assigned to aether, the element which fills the space between the earth and the heavens. Plato describes how the creator god, 'the Demiurge', adorned each of the dodecahedron's twelve faces with figures, referring to the constellations and the Zodiac.

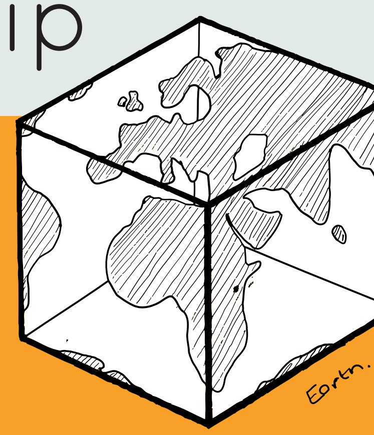


Plato's ideas may seem peculiar now, but they contain the first glimpses of modern chemistry. Plato believed that each polyhedron could be broken down to its constituent triangles and then put back together again to form the other elements. This concept is not far removed from the reality of modern chemistry where large molecules may be broken down into smaller components, then reassembled to create new compounds.

> **“Plato's ideas may seem peculiar now, but they contain the first glimpses of modern chemistry.”**

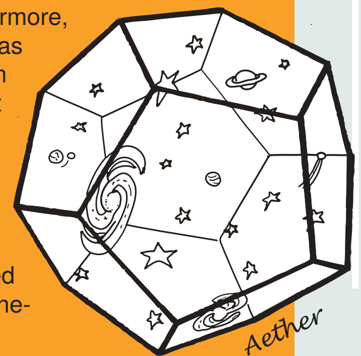
Plato was not the only great thinker to be intrigued by these beautiful shapes: the 16th century German mathematician and astronomer Johannes Kepler also saw their divine side. Convinced that God had made the Universe according to a mathematical plan, Kepler proposed a model in which the planetary orbits, represented by spheres, are spaced by the Platonic solids. Thus the path of Mercury around the Sun sits inside an octahedron such that the faces of the octahedron touch the sphere. The path of the planet Venus touches the vertices of this octahedron and is itself enclosed by an icosahedron. A dodecahedron lies between the orbits Earth and Mars, a tetrahedron sits between those of Mars and Jupiter and, finally, a cube separates the paths of Jupiter and Saturn.

Kepler believed this solved the mystery surrounding the number of known planets - there could only be six planets as there were only five Platonic solids to lie between the paths. Furthermore the spacing of the paths fitted reasonably well to the observed inter-planetary distances, adding weight to his theory. Ironically it was Kepler himself who proved his beautiful model wrong when he discovered that planetary orbits are elliptical.



So are these intriguing polyhedra just red herrings, cropping up over the course of scientific history to provide beguiling models for the natural world? If so, it would seem that modern science is also under their spell.

In 2003 Jean-Pierre Luminet, at the Paris Observatory, proposed that the universe may be finite, but wrapped around on itself. This theory was based upon the observation of patterns in the cosmic microwave background (radiation left over from the Big Bang). Subsequent research by Boudewijn Roukema, at the Nicolaus Copernicus University in Poland, found that patterns taken from opposite sides of the sky were found to match. Furthermore, this match was closest when one data set was rotated with respect to the other by 36 degrees - the angle predicted for a dodecahedral universe!



Nature has a strong affinity with the Platonic solids. The rhinovirus, responsible for the common cold, has an icosahedral shape; the high symmetry enables the virus to bind to a cell without requiring a particular orientation, while the low surface area to volume ratio allows a large amount of genetic information to be stored inside the structurally rigid cage. Moreover crystals often occur in nature in the form of the Platonic solids: sodium chloride has a cubic structure, while calcium fluoride is octahedral.

While the idea of a god delicately embroidering a dodecahedron with stars may seem like poetic fancy, it would appear that these perplexing polyhedra are, after all, some of nature's finest building blocks. ■

Text: Nicola Davis
Art: Anna Pouncey, Leila Battison

An Auditory Spotlight

Who invited Acetylcholine to the Cocktail Party?

Picture the scene. You're standing at a party, drink in hand, talking to an attractive man or woman while all around you small knots of other partygoers are engaged in conversation. How are you able to concentrate on what the person opposite you is saying while filtering out the distracting background noise? That you can do so at all is a testament to the impressive discriminatory properties of your auditory system and this 'cocktail party effect' is one which particularly interests audiologists, since it underpins many aspects of the way our brains process complex sounds.

Interpreting sounds is something of a computational headache for your brain, which has to make sense of the world using only a jumble of tiny changes in air pressure at your ear drum. From a pseudo-random assortment of sound waves, your brain can perceive a multitude of auditory events, from the beauty of a Rachmaninov piano concerto - or perhaps an AC/DC gig, depending on your musical sensibilities - to the less welcome sound of fingernails scraping down a blackboard. What happens when you increase the complexity of the surrounding auditory environment though? The distant hum of the washing machine, traffic passing outside your window or birdsong in the garden: these are all sounds you'd normally barely notice but whose acoustic vibrations still reach your ear drum. Professor Colin Cherry, when he first described the cocktail party effect in 1953, suggested a number of auditory characteristics or cues which might aid the separation of sounds: both perceived location and the rate of speech and voice pitch (how high or low it is) exert a substantial effect on our ability to successfully follow a conversation. While hardly surprising, this does pose an interesting question. How can the auditory system know which attribute is likely be the most useful in isolating a speaker's voice? Clearly our brains need a real-time mechanism for altering the fundamental neural responses to sounds.

> **“Interpreting sounds is something of a computational headache for your brain...”**

At the molecular level, neuro*transmitters* within the brain relay information from neuron to neuron while neuro*modulators* are responsible for altering the efficiency of these connections, directing which pathways are most active at any particular time. One such modulator, acetylcholine, is of special interest to neuroscientists because of its ability to increase the sensitivity of cells in the auditory cortex to sounds, and its widespread influence throughout regions of the brain associated with cognitive flexibility.

Dr Vinay Parikh, from the University of Michigan, used a complicated behavioural task involving competing sound and light stimuli to investigate how animals are able to focus on only one aspect of sensory input. He observed a substantial increase in acetylcholine throughout the prefrontal cortex, the region of the brain responsible for cognitive control and decision-making, when rats were concentrating hard on an auditory task. This result - which could potentially be extrapolated to many species with similar brain architectures, including humans - demonstrates that a general increase in acetylcholine release in those frontal regions of the brain is associated with increased cognitive flexibility during an auditory task. In addition, Dr Parikh observed short bursts of acetylcholine release which corresponded precisely with stimulus presentation. These transient spikes, originating outside the cortex in lower-order brain structures, increase the probability a cell will fire in response to a sensory stimulus; the coincidence of both sensory information and acetylcholine at a single location creates an association between the two stimuli and may help highlight important sensory information.

How might we take advantage of this dual role of acetylcholine to help us at our cocktail party? Acetylcholine may well hold the key to controlling our internal auditory spotlight, the system allowing us to selectively attend to only a small proportion of sensory information. By increasing the importance of certain pathways it could provide the filtering necessary to remove extraneous background chatter, a mechanism consistent with other aspects of auditory flexibility. The ability to overcome deficits in localizing sounds, for example, is thought to depend on the brain's ability to place more emphasis on certain auditory cues than others and modulation via acetylcholine has the potential to direct how the brain constructs its map of the surrounding auditory environment.

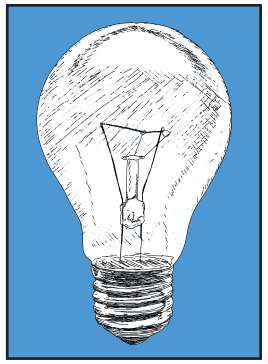
A powerful and dynamic auditory spotlight, flitting seamlessly from one sound source to another, would undoubtedly enable us to make sense of an often confusing environment. So the next time you're at that cocktail party, spare a thought for acetylcholine and give a quiet thanks that it provides your auditory system with the helping hand it needs to hear the telephone number you're being given. ■

Text: Nick Leach
Art: Anna Pouncey

In Their Element

What is the most significant and beautiful discovery in the history of science? A tough question which is sure to induce many exciting and passionate debates, wherever it is asked! But for many scientists the answer can only be the Periodic Table of the Elements. This systematic ordering of the elements, originally created in the late nineteenth century based on chemical similarities between them, was later confirmed and explained by the quantum theory of atomic structure. Although much of the joy of learning about the periodic table lies in its initial development, it is the elements themselves which are truly fascinating. These building blocks display a diverse range of reactivities and properties; not only as pure elements, but also in the compounds they form. It is surprising to see how many of the less-familiar elements have vital roles in biological process, banishing the idea that they are just 'filling the gaps' between better known elements. *Bang!* has selected a couple of illustrative examples of how these elements are used both in the organic and inorganic world, and how their properties are linked to their position in the periodic table. ■

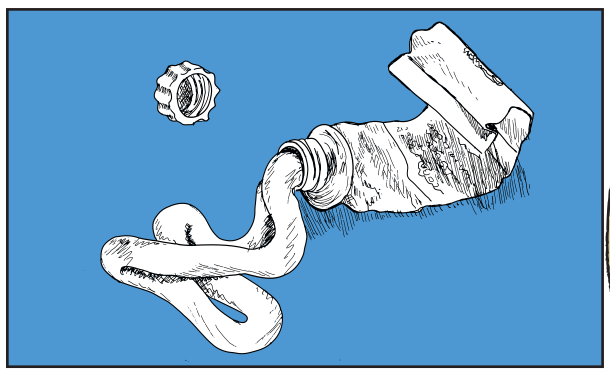
Tungsten (W)



Naturally occurs as: Wolframite mineral – $(Fe,Mn)WO_4$
Melting point: 3422 °C
% in human body: 0
Useful application: Bulb filaments

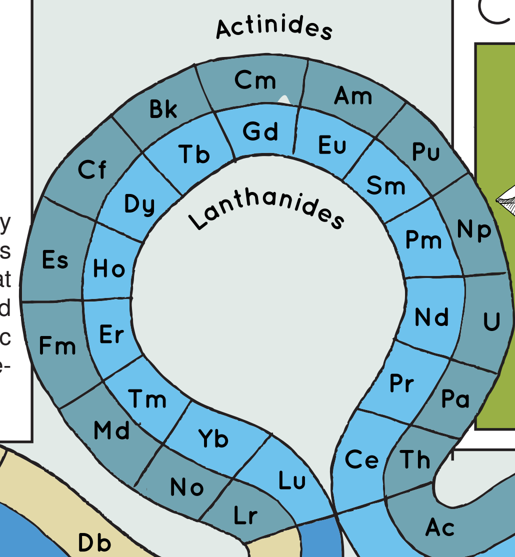
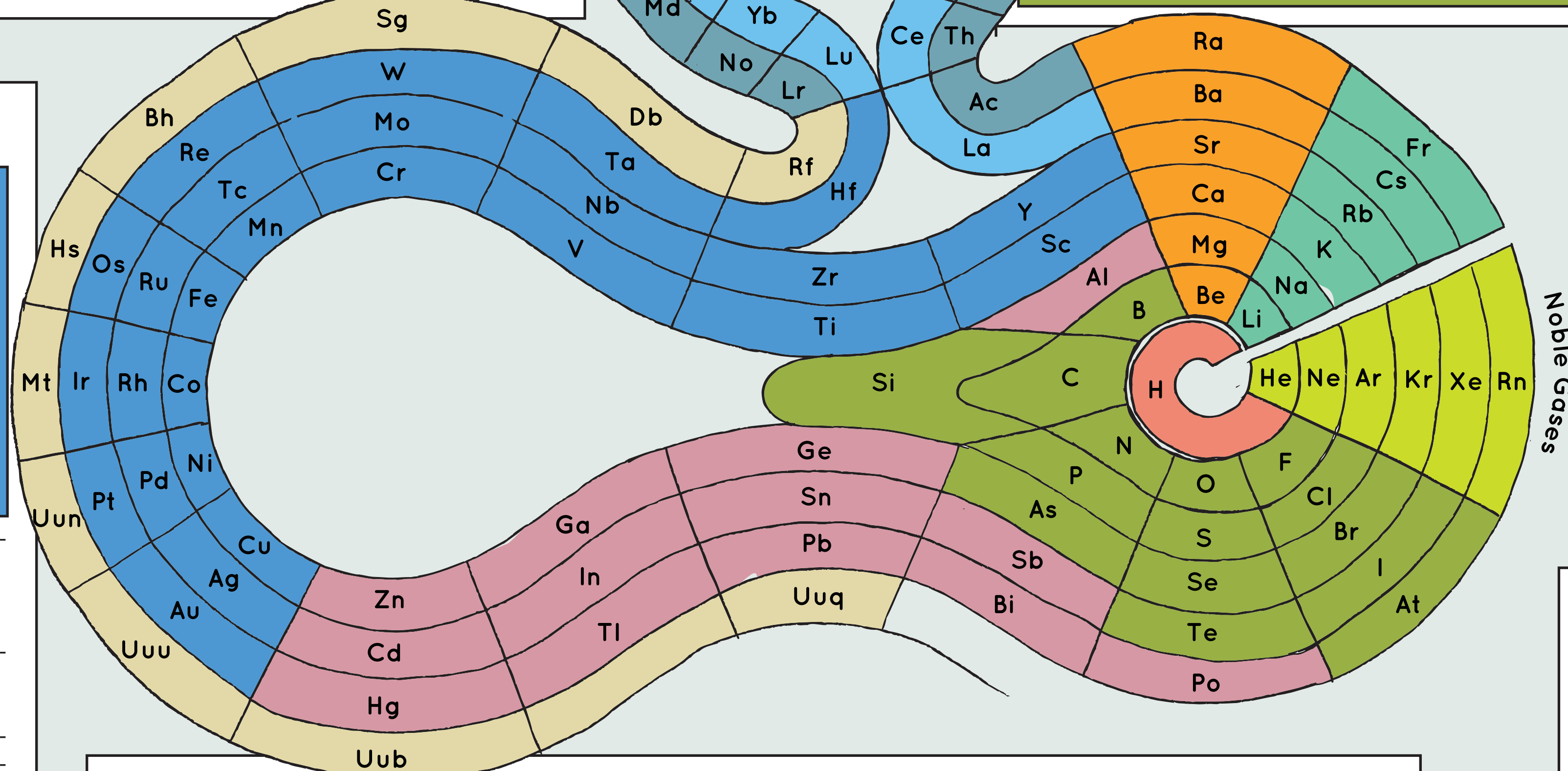
Why: The crucial property for a bulb filament is to be able to withstand the immensely high temperatures needed to cause a wire to glow. Clearly, a melting point top trump is deserved here - with the highest melting point of all metals at a punishing 3422 °C, that is indeed what tungsten delivers. This incredible property is an example of increased bonding between metal atoms as we descend the transition metal block of the Periodic Table. Tungsten being at the bottom of this block therefore has very strong bonds between its atoms and so a very high temperature is required to melt it.

Cobalt (Co)



Naturally occurs as: Cobalt sulfide (Co_3S_4) and arsenide ($CoAs_3$).
Melting point: 1495 °C
% in human body: 0.0000021
Useful application: Food sterilizing by radioactive decay.

Why: Cobalt isotopes (a form of the element with a different mass) which are radioactive decay to stable isotopes of elements with lower atomic number by emitting gamma radiation. Depending on the radiation dose, this process may be used to sterilize food, destroy pathogens, extend the shelf-life of food, delay ripening, and retard sprouting.

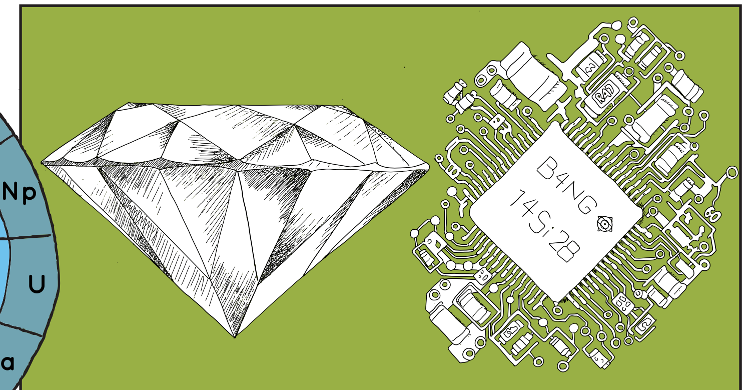
Zinc (Zn)

Naturally occurs as: Zinc blende (ZnS) and calamine ($ZnCO_3$)
Melting point: 419.5 °C
% in human body: 0.05
Useful application: Coenzymes in the body

Why: Another vital element needed only in modest quantities is zinc. Zinc functions as a coenzyme; that is, it helps other enzymes – the proteins that speed up chemical reactions in the body – to function. One of the key jobs that zinc needs to do is to activate an enzyme necessary for the creation of collagen, the main protein in connective tissue. Zinc is an excellent coenzyme since is it has good binding properties and so can readily bind to amino acid side chains on enzymes. Also, zinc has the ability to readily change the geometry of the arrangement of ligands bound to it, this rapid change in shape helps biological reactions to take place.

Text: Matthew Robinson
Art: Leila Battison
Periodic Table after J. F. Hyde 1975

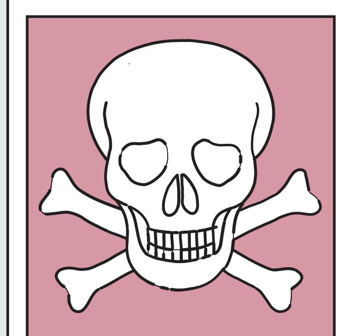
Carbon (C) & Silicon (Si)



Naturally occurs as: C – Graphite and diamond (pure elements), and calcium and magnesium carbonates, Si – SiO_2 makes up most of the Earth's crust
Melting point: C – 3827 °C, Si – 1420 °C
% in human body: C – 18 %, Si – 0.002%
Useful application: Carbon is arguably the most essential element in the entire table

Why: Carbon forms the structure and basis of life; it is present in all organic molecules from fatty acids, which form cell membranes, to the cellulose which makes up this very paper. But out of the 90 naturally occurring elements, why is carbon the building block of life? The properties of carbon exploited by nature are its ability to form four strong covalent bonds, and to bond not only to itself, but also to a variety of other elements. Elements in the same group have similar chemical properties as a result of having the same number of outer electrons. So what about considering silicon or even germaniuim, tin or lead as a possible basis for molecules in living organisms? The fact is, we have overlooked an important criterion – the bond strength. Carbon forms strong bonds and so easily forms long chains and rings of varied sizes which are stable enough to exist and participate as functional molecules. Silicon, germanium and the other elements in this group are not capable of forming strong enough bonds, and so are unlikely to be able to support life.

Antimony (Sb)



Naturally occurs as: Stibnite (Sb_2S_3)
Melting point: 631°C
% in human body: Desirably, none!
Useful application: Flame retardants in paints and for binding dyes to fabrics.

Why: Antimony is one of the most poisonous elements and has very similar properties to arsenic (which is above it in the periodic table). The toxicity of antimony and of arsenic is due to the fact that when it gets inside the body it binds to enzymes and inhibits cellular metabolism, i.e. all the reactions that take place in the cell to keep the body alive.

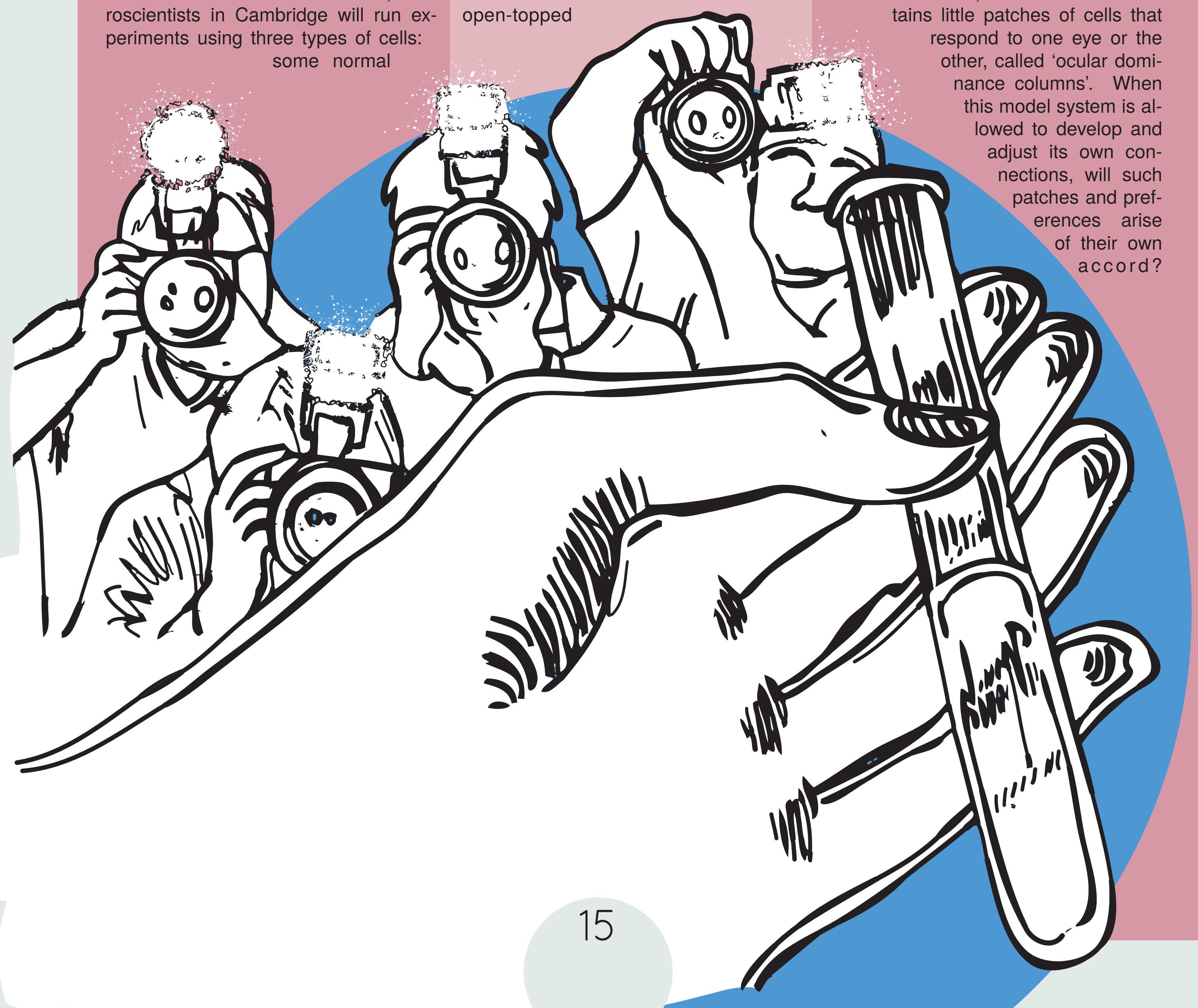
Neurons and Neuroses

Exploring the fears and dilemmas that lurk between science and the media

"Isn't it cool?" says Jan Schnupp with a cheeky grin. Dr Schnupp, a neuroscientist at Oxford University, has just explained to me the aims of a new project that will occupy a large team of scientists for the next five years. With a budget of £2.8 million, it will explore how networks of live brain cells develop and work together, combining cutting-edge techniques from cell biology, tissue engineering, neuroscience and optics.

"...experimenters will be able to turn on specific combinations of cells, and watch which other cells turn on as a result - all using light."

Firstly, engineers in Oxford and Birmingham will busy themselves constructing surfaces and scaffolds suitable for culturing brain cells and encouraging them to connect with each other. Next, neuroscientists in Cambridge will run experiments using three types of cells: some normal neurons, some which have been engineered so that they will fire when they are hit by specific wavelengths of light, and some which will emit light themselves when they are active. This combination means that the experimenters will be able to turn on specific combinations of cells, and watch which other cells turn on as a result - all using light. There will be many microscopes, lenses, lasers and computers involved, and the formidable task of designing the experiments and analysing the data falls to Dr Schnupp, together with Oxford colleagues from the Maths Institute. Their intention is to set up the cells as a loosely structured network, and see what sort of properties arise spontaneously, or in response to different, light-driven patterns of activity. In a very primitive way, the network will 'develop' and 'learn'. It will be an open-topped model of how things work in the human brain.



One example experiment would be to set up two groups of brain cells to receive input as if they were the retinas of two eyes, 'seeing' images from slightly different angles. This is where the light-sensitive cells offer a great advantage: two images of the same scene, taken from slightly different angles, can be shone directly at the two populations of cells, and the cells hit by bright parts of the image will fire. These two groups of cells could be connected to a subsequent 'processing' population of cells, a bit like the brain's visual cortex. If this third population contains cells of the light-emitting variety, the scientists will be able to watch and record the activity of the whole system in real time. In the human brain, the visual cortex contains little patches of cells that respond to one eye or the other, called 'ocular dominance columns'. When this model system is allowed to develop and adjust its own connections, will such patches and preferences arise of their own accord?

These are fascinating questions for neuroscientists, so much so that many processes like this have been modelled before, but only using computer simulations. This project will be doing it with real cells.

It all sounds pretty exciting, even to someone who doesn't know an ocular dominance column from a bar of soap. You might expect such a major scientific undertaking to make something of a splash in the news, but in fact the project has received very little interest. Furthermore, some members of the team have been reluctant to seek out coverage, partly because the building blocks for the brain-cell network will be neurons generated from human stem cells. Quite apart from the fact that stem cells themselves remain a sensitive subject in the more conservative corners of the media, there is the possibility that constructing a 'learning' network of cells might be misconstrued as a brain-in-a-jar scenario straight out of Roald Dahl. Dr Schnupp finds this patently ridiculous. "It's not a brain," he explains. "It's a tiny collection of cells. Calling it a bionic neural net is closer to the mark." He is also firmly of the belief that there is nothing to hide. "At the end of the day, if the taxpayers pay for it, they might as well hear about it."

"...there is the possibility that constructing a 'learning' network of cells might be misconstrued as a brain-in-a-jar scenario straight out of Roald Dahl."

Dr Schnupp does, however, understand his colleagues' sensitivity - nobody wants the starring role in a scare story. "Unfortunately, it's become part of the culture of many newspapers to be negative about science," he says, citing the apocalyptic coverage of GM foods as an example. "There's a very old belief that fear sells papers. Deadlines are tight, and if you don't have an obvious angle, you can always try and scare people. So in our case, you might get 'The cyborgs are coming, it must be stopped!', instead of 'Look, this tiny pile of cells will hopefully tell us a few interesting, geeky little details about how neurons work'."

Maybe the scaremongers have the wrong end of the stick. "I personally find it very difficult to believe that you can't sell good news." says Schnupp. But the broader problem seems not just to be negativity, but superficiality. This may be partly because plummeting profits have forced many newspapers to relinquish science writers, leaving non-specialist journalists to cover science. Ill-equipped to dig deep into a story, their sources might be releases from university press offices anxious for headlines, or the baseless pronouncements of self-promoting academics. One side of this coin is the 'X linked to Y' scare stories, where X could be flapjacks, flip-flops or Facebook and Y could be breast cancer, brain damage or birth defects. The other side, equally problematic, is the over-interpreted new finding blown up into false hope for thousands: 'Pistachios reduce Alzheimer's risk' or 'Scientists announce cure for baldness'. Should newspapers give their readers more credit? If someone wrote a story about the brain modelling collaboration that wasn't exaggerated or alarming, would anybody read it?

Dr Schnupp thinks so, although he acknowledges that it's not quite that simple. "Look, to do good science journalism is really very hard - and making it pay is even harder. I just hope that little magazines like *Bang!* go on to be the success that they deserve to be." He takes comfort in the rising popularity of events like the Cheltenham Science Festival, which last year clocked 35,000 visitors. With any luck, the trend will continue. "Then perhaps the mass media might cotton on to the fact that there is a market out there, of people who are just curious about how the world works." Let's hope so. But what can we do in the meantime to improve science coverage?

Some commentators believe that the agents of change will be the various phenomena of Web 2.0 - blogs, Twitter, Facebook and other schemes whereby users generate and share content themselves. It is difficult to see these networks replacing traditional news altogether, but they certainly offer a democratising influence. The science blogosphere is enormous, and thousands of science stories whizz around the world on Twitter every day. Some blogs are written by scientists themselves, others by science writers, and all are blissfully independent of the traditional media. But blogging is also problematic. That same independence can make it difficult for a reader to tell a hotshot professor from a total crackpot. In terms of audience, the simple fact that blogs need to be looked up or clicked on means that they largely 'preach to the converted', and are a poor substitute for science coverage in the daily newspapers: there is still nothing quite like a front-page splash for bringing the water to the horse. Today's era of podcasts, YouTube experiments, open-access journals and live-tweeting conferences is a hugely exciting one for science communication, but all this rapid change has fractured the media landscape and not yet thrown up a coherent mechanism for reaching the masses.

"If someone wrote a story about the brain modelling collaboration that wasn't exaggerated or alarming, would anybody read it?"

While we are waiting for a new model to emerge, however, we might as well exploit the tools that are available - from blogs and tweets to status updates, 'likes', 'diggs', and whatever turns up tomorrow. Given the choice, Dr Schnupp wouldn't be hiding his lasers under a bushel. "The only thing that's holding me back is a lack of time!" In between research, writing, reviewing, teaching, marking and managing, "there's just not enough time left to write a blog that you update often enough for people to want to read it." If academics don't have time to wield the web effectively, then perhaps their students can step in: a veritable army of scientifically literate volunteers, with a well-known talent for procrastination. If you're a scientist, get involved! You are interested, you know other people who are interested, and they know even more people. Thanks to the explosive nature of this connectivity, an astute and timely tidbit can gain surprising mileage. So blog about your own stuff — or get involved with *Bang!* — or tweet about other people's stuff, and expose sensationalist reporting for what it is. We all know science is fun and not frightening; let's light up some brain cells of our own! ■

Text: Jonathan Webb
Art: Sofia Kaba-Ferreiro

One, Two, Three and away...

Counting to infinity and beyond

We use counting for all sorts of things, from calculating the change in our pockets to working out the number of days until our next holiday. Counting is so fundamental to human culture that it's one of the first things we teach our children and sometimes we do it without even realising. But how did counting come about?

Dated to approximately 35,000 BC, the earliest recorded example of counting is found on the Lebombo bone, discovered in the Lebombo Mountains of Swaziland. Twenty-nine lines were scored on a baboon's fibula, supposedly to record a lunar or menstrual cycle. It seems that counting was used to keep track of time, initially in units of days.

The first well-documented use of counting was by the people of Mesopotamia (modern-day Iraq), otherwise known as the Babylonians. Whereas we use a base 10 number system (decimal) the Babylonians used the sexagesimal system based on the number 60. This means they counted up to 60 objects before they grouped them together. This concept is analogous to the modern-day method for recording time. Each hour comprises 60 minutes, each comprising 60 seconds.

> **"Counting is so fundamental to human culture that it's one of the first things we teach our children..."**

The Babylonians (and, independently, the Maya civilization of South America) have been credited with the first 'place value system'. Today, we take for granted that in the number 333, for example, the same digit '3' can represent different values depending on where it sits in the number: 300, 30 or 3 - but to the Babylonians this was something revolutionary. With the aid of their place values system and a finite set of symbols, they could represent any desired number, instead of having to create a new symbol every time a number became too cumbersome to be written easily (compare 999 with DCCCCLXXXXVIIII in Roman numerals, for example). However, to represent a number in the Babylonian place value system it was necessary to have 60 different digits for units, where we need a mere 10. Ten corresponds to the number of fingers (or digits) we have on two hands which makes the decimal place value system a logical choice. It seems likely that if the *Simpsons* had evolved their own counting system then they would be using base 8!

The fact that lots of important numbers divide 60 without remainder made it a natural choice of base for the Babylonians. Indeed 60 is the smallest number divisible by 1, 2, 3, 4, 5 and 6. Imagine at your birthday party you want to divide the cake so you can share it evenly between your guests, but you don't know how many will turn up. If you're thinking in decimal, dividing your cake into 10 pieces, then you'd better hope that 1, 2, 5 or 10 people attend the party so you can give them all the same amount of cake. However, if you think in base 60 then you can afford to have 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30 or even 60 people show up without hurting anyone's feelings. So, although the Babylonian system made representing some numbers quite difficult, their special base 60 made representing fractions a piece of cake!

However, the real masters of fractions were the Greeks. The most famous of all Greek mathematicians was Pythagoras. Pythagoras is thought to have lived in the 6th century BC, in Croton, a Greek colony in southern Italy, where he established a religious brotherhood/school, 'The Pythagoreans'. The motto of the Pythagoreans is often expressed by the phrase 'all is number' and is said to refer to their belief that every object in the universe had a number associated with it and that each of these numbers could be expressed as a fraction. They are also credited with the first proof of what is now commonly known as Pythagoras' theorem:

"The square of the longest side, h (the hypotenuse) of a right-angled triangle is equal to the sum of the squares of the other two sides, a and b."

Or, more succinctly, $h^2 = a^2 + b^2$.

While travelling on board a ship, a member of the brotherhood, Hippasus, used the Pythagorean theorem with a right-angled, isosceles triangle (two sides the same length), with shorter sides of length 1, to prove that the length of the hypotenuse must be √2 (the square root of two), and that √2 can't be expressed as a fraction. Any number with this property is known as an irrational number because it can't be expressed as the ratio of two whole numbers. Legend has it that, so deep-held was the Pythagorean belief that all lengths should be fractions, that Hippasus was thrown overboard so as not to shame the brotherhood. In a further ironic twist, despite this attempt to suppress the knowledge of irrational numbers, the Pythagoreans are widely credited with their discovery.

> **"...if the *Simpsons* had evolved their own counting system then they would be using base 8."**

Long after the Greeks had finished arguing about the existence of irrational numbers, the focus of much mathematical attention was again turned to counting. In the late 19th century German mathematician Georg Cantor was dreaming of counting higher than anyone had ever counted before. Cantor wasn't interested in counting sheep or money or indeed anything physical. Cantor was thinking about counting the infinite.

Cantor proved that there are different sorts of infinities, some bigger than others: a surprising fact, you may think. To do this he used the idea of a 'one-to-one correspondence' or bijection. The idea is a relatively simple one. Imagine a dance attended by 20 men and 20 women. We can easily pair each woman with a man in a 'one-to-one correspondence' to show that there is the same number of men as women. Now imagine that there are infinitely many men and women at the dance. If we get them to stand in height order then we can easily pair the shortest man with the shortest woman, then the second shortest man with the second shortest woman and so on, in order to show that there must be the same number of dancers of each sex. Providing we can find a way to pair the objects of the two sets in an ordered way we can prove that the sets are of equal size. Conversely, if we can find no way to pair two sets then one set must be larger than the other. Finding ways of pairing sets was Cantor's speciality.

Using this logic we can prove the seemingly counterintuitive fact that there are the same number of even integers (2,4,6,8...) as there are integers (1,2,3,4...), where the word integers is synonymous with 'whole numbers'. All we have to do is to pair 1 (the first integer) with 2 (the first even integer), then pair 2 (the second integer) with 4 (the second even integer). If we were trying to play this game with two finite sets, we'd soon exhaust all the even numbers, but because we're considering two infinite sets we can always continue to pair numbers from the two sets in the manner described. In this way we can prove that both infinite sets are the same size. Every set of numbers that can be paired with the integers (or counting numbers) we call countably infinite.

> **"Cantor wasn't interested in counting sheep or money or indeed anything physical. Cantor was thinking about counting the infinite."**

It turns out that there is also a way to pair all the fractions with the whole numbers in this manner, thus proving that the fractions are also countably infinite. The problem arises when trying to pair the irrationals (numbers that can't be expressed as a fraction, √2 or π for example) with the integers. No matter how hard you try, it's impossible to find an ordering of the irrational numbers that gives a 'one-to-one correspondence' with the integers; however you write the them down, you can always find, between two irrationals, another one that you haven't put on your list. Cantor called the irrationals uncountably infinite. Cantor went on to show that there were not just two different types of infinity, but infinitely many!

There was, at first, a lot of opposition to Cantor's idea from the mathematical community and it is easy to see why. One type of infinity being bigger than another seems quite a bizarre concept. For example Kronecker, the head of the mathematics department at the University of Berlin, described Cantor as a 'scientific charlatan' and a 'corrupter of youth'. Mathematician and friend of Cantor, David Hilbert, did his utmost to defend his colleague, declaring:

"No one shall expel us from the paradise that Cantor has created."

Bouts of depression, at one time thought to have been brought on by the savage criticism of his work (although posthumously attributed to undiagnosed bipolar disorder), plagued Cantor for the rest of his life. As his faith in the veracity of his results dwindled, his mathematical output diminished and, after several drawn out spells of depression, he eventually died in the sanatorium where he spent the final year of his life. A tragic end, unbefitting of such a brilliant visionary, whose work is often said to have come one hundred years too soon - banished from the Eden he created, the 'infinity of infinities'. ■

Text: Kit Yates
Art: Karis Flavell

The Heart of a Lion and Flying Feet of a Gazelle

Delving into the secrets of racehorse biomechanics

"A little horse with the heart of a lion and flying feet of a gazelle proved his place as the gamest thoroughbred that ever raced over an American track."

— Grantland Rice in the Baltimore Sun, reporting on Seabiscuit's 1938 Pimlico Special match race victory over War Admiral

Given Grantland Rice's penchant for beautiful prose and romanticism of sport, his depiction of one of the greatest horse races in history was surely written more with drama and poetry in mind than modern science. However, this line is surprisingly telling of characteristics found by today's equine biomechanists, physiologists, and geneticists to be common features in top thoroughbred racehorses.

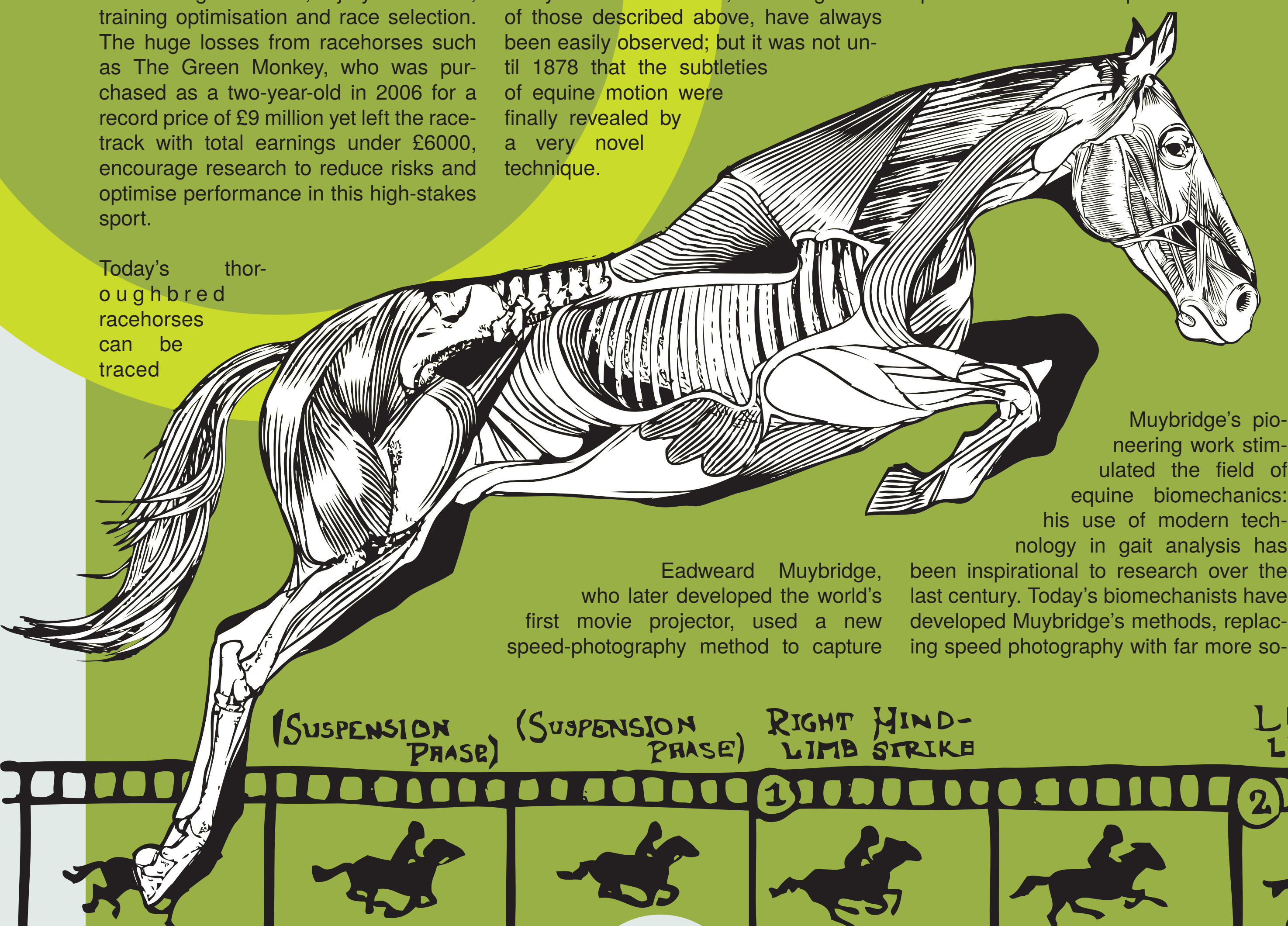
In today's multimillion-pound horseracing industry, owners, breeders and trainers are turning to science to give an edge in breeding decisions, injury treatment, training optimisation and race selection. The huge losses from racehorses such as The Green Monkey, who was purchased as a two-year-old in 2006 for a record price of £9 million yet left the racetrack with total earnings under £6000, encourage research to reduce risks and optimise performance in this high-stakes sport.

Today's thoroughbred racehorses can be traced back to three stallions imported to England from the Mediterranean Middle East in the late 1600s and early 1700s, approximately 30 generations ago. Over the years, these horses have been selectively bred for performance, producing some of the world's most amazing athletes. Standing on average at just under 16 hands (5'4") at the shoulder and weighing 450-550 kilograms, these lean-bodied sprinters have powerfully muscled hips, thighs, and buttocks, with extensive skeletal muscle geared toward explosive short-term speed. Performance doesn't just rest with power: a thoroughbred has elongated, sloped shoulders which facilitate great stride lengths, as well as a short back and long legs with disproportionately small, lightweight hooves, allowing for quick recoil. The force sustained by these delicate hooves is incredible, analogous to a human balancing his entire weight on his middle finger.

Many features of build, including most of those described above, have always been easily observed; but it was not until 1878 that the subtleties of equine motion were finally revealed by a very novel technique.

Eadweard Muybridge, who later developed the world's first movie projector, used a new speed-photography method to capture images of a galloping horse, allowing the first in-depth analysis of the complex equine gait (step) cycle.

While the gait cycle of a human moving at any speed is relatively straightforward, the horse's four natural gaits — walk, trot, canter and gallop — vary drastically. The fastest of the gaits, the gallop, is at the centre of most studies. The gallop is a complex four-beat gait, as illustrated below. At the start of the cycle, on beat one, contact is made between the ground and the hindlimb of the horse - the right for this example. Beat two is marked by the planting of the left hindlimb, just prior to the planting of the right forelimb on beat three. Beat four is marked by ground strike of the left forelimb. This is followed by a fully airborne phase. The cycle then repeats. Each foot is in the air for approximately 80% of the cycle, which an elite horse completes up to 150 times per minute at 24 feet per stride, at a top speed of over 40 miles per hour.



Muybridge's pioneering work stimulated the field of equine biomechanics: his use of modern technology in gait analysis has been inspirational to research over the last century. Today's biomechanists have developed Muybridge's methods, replacing speed photography with far more sophisticated high-speed video and, more significantly, motion tracking. This allows three-dimensional tracking of infrared light reflected from 'retro-reflective' markers, a technique which is increasingly popular in the film and gaming industries in modelling life-like movement for animated figures. Tests may be conducted in 'natural' settings or on specially designed treadmills, and results are often integrated into computer models to allow for more detailed analysis.

These techniques permit thorough analyses of a given horse's gait, as well as comparison of these details to those of other horses, and to ideals determined through computer simulation. Crucially, details invisible to the naked eye, such as a slight side to side wobble of the front legs during extension, may now be observed. These previously unseen traits are now clear indicators of high injury risk, inefficient energy use, or other detrimental characteristics.

Results are sometimes surprising. When researchers at the Royal Veterinary College analysed the unbeaten 18th century racing great *Eclipse*, they found that it was his *averageness* that made him, well, extraordinary. Using a combination of structural information and motion analyses, the researchers created mathematical and computer models of equine movement. The team then created "theoretical limbs" and analysed their effect on a horse's speed, balance, force transmission, and even injury likelihood. In the case of *Eclipse*, they relied on paintings, race reports, and computed tomography scans of his skeleton to acquire model parameters. Study leader Dr Alan Wilson credited *Eclipse*'s smallness — a trait generally seen as detrimental — for some of his success: *Eclipse* was able to bring his legs forward more quickly than his longer-limbed counterparts and, all in all, was a study in perfect balance of the factors for speed. It may be that Seabiscuit, the "little horse" Grantland Rice described so eloquently, was not at a disadvantage after all.

"...an elite horse's heart may be the size of a basketball (24 cm diameter) and weigh over 9 kilograms..."

While a thoroughbred's gait is the most visible physical indicator of its potential as a racehorse, its internal make-up is also critical. This internal physiology is similar to that of a human, but a horse has several evolutionary advantages which result in superior athletic performance. In humans, a state of high exertion and the subsequent oxygen deficiency in the muscles triggers several automatic responses: the breathing rate increases; the heart directs more blood to oxygen-deficient muscles; and the muscles themselves increase their rate of oxygen use. Though these coping mechanisms help, the supply of oxygen is limited by the number of red blood cells (RBCs) available for its transport, a number generally increased by athletes through training at high altitudes.

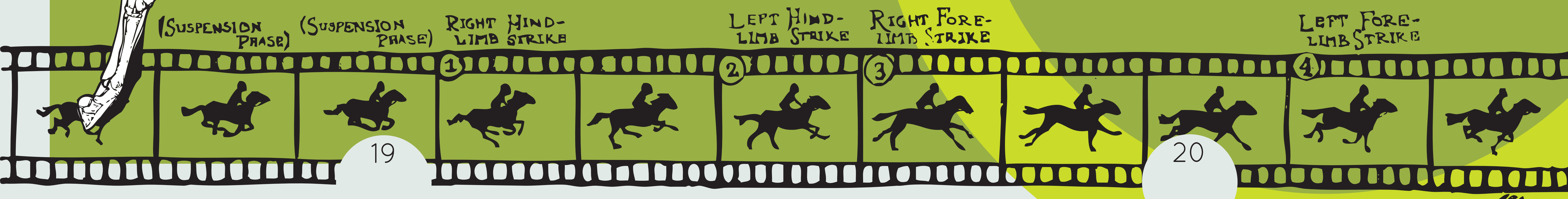
A horse experiences the latter two responses, but with more power and efficiency. First, it processes the oxygen brought to its muscles at a rate of over 150 millilitres of oxygen per kilogram of weight per minute, far outpacing the 70-90 millilitres per kilogram per minute metabolised by a top flight human athlete. Second, an elite horse's heart may be the size of a basketball (24 cm diameter) and weigh over 9 kilograms, allowing it to pump out an astounding 300 litres of unusually thick blood in each minute of a race.

The thickness is due to the blood's high RBC content, which reaches more than 65% by volume during races. At rest, however, the RBC content of horse blood matches that of humans. The extra RBCs come from an exertion-controlled reserve in the horse's spleen, which contracts during running to pump oxygen-laden RBCs directly into the bloodstream. It's a natural, on-demand doping system which more than makes up for the horse's one cardiopulmonary handicap: its inability to increase breathing rate without also increasing its stride rate (inhalation can only take place as the forelimbs reach forward, while exhalation occurs only during the suspension phase).

In a broad sense, the field of equine biomechanics has followed a trajectory from the outside inward, from simple observations about build to the current frontier of genetics. One of the latest breakthroughs in this burgeoning field occurred in late January 2010, when a team led by Dr Emmeline Hill at University College Dublin announced via an article in Public Library of Science ONE (PLoS ONE) the identification of an equine 'speed gene' which contributes to specific athletic traits in thoroughbreds. Hill claims that their recently commercialised 'Equinome Speed Gene test' can predict a given horse's sprinting ability and racing stamina — information which would drive purchasing, training and race entry decisions, as well as revolutionise breeding strategy. While such predictive powers may initially seem implausible, similar genetic-athletic associations have been found in humans. Variations of the NRF2 gene, for instance, have been found in significantly more elite endurance athletes than elite sprinters.

Although modern equine biomechanics, physiology and genetics can tell us a lot about a racehorse, perhaps in the end the best predictor of success is a horse's unquantifiable will to win. Turning again to Grantland Rice's myth-like accounts of the Pimlico Special, "The race, they say, isn't to the swift. But it is always to the swift and the game." ■

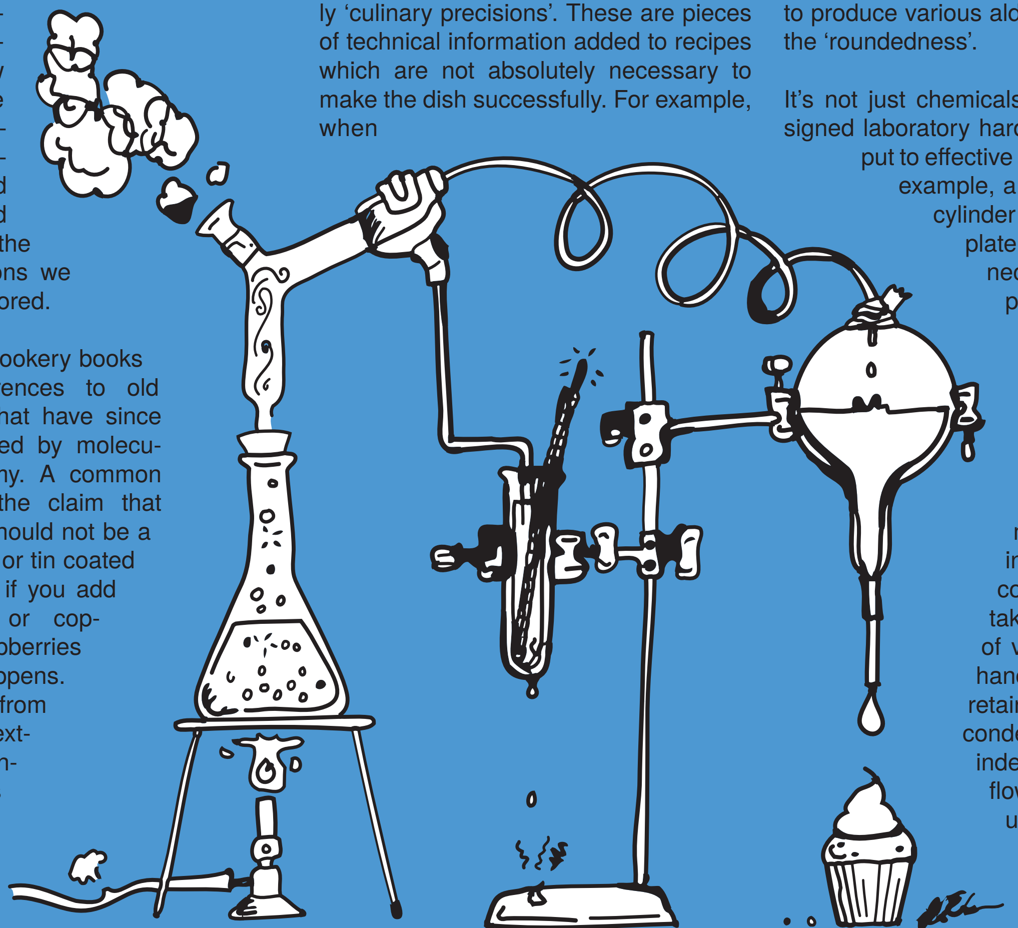
Text: Lisa Martin
Art: Karis Flavell & Anna Pouncey



Synthesising Souflées

Creating a stir through kitchen chemistry

Over the past two centuries science has progressed by leaps and bounds. Yet, with all this expertise at our disposal, there has been little probing of the scientific basis of cooking. Fortunately, this oversight came to the attention of a French physical chemist 20 years ago. Hervé This and his colleagues created a new discipline called 'Molecular Gastronomy' and set out to find answers to the many questions we have long ignored.



Even today, cookery books include references to old wives tales that have since been explained by molecular gastronomy. A common example is the claim that raspberries should not be a put in copper or tin coated vessels - yet if you add metallic tin or copper to raspberries nothing happens. It is known from chemistry textbooks that anthocyanidins (pigments in many red, blue or purple fruits) can bind to metal ions, so if a small amount of the ionic form of tin is added to raspberries rather than the metallic form, it causes them to turn dark purple and so look spoiled or toxic. Therefore it's not the copper vessel itself, but the residual metallic ions in a corroded container that cause the colour change.

> **"If you can't afford a good whisky, try adding a few drops of vanillin solution to make it 'round'."**

Through the use of molecular gastronomy, we have also learnt how to make a perfectly soft boiled egg - heat it at 65 °C for an hour. Why is this? Egg is mostly protein, but it turns out none of the yolk proteins are denatured – destroyed by heating – below 70 °C and thus the yolk does not solidify even with prolonged cooking. The egg white, on the other hand, is made up of proteins that denature at a lower temperature, and so it does solidify.

The discipline also strives to understand culinary processes and recipes, especially 'culinary precisions'. These are pieces of technical information added to recipes which are not absolutely necessary to make the dish successfully. For example, when making cheese soufflés, it is often advised that the egg white must be whisked thoroughly with the cheese in order to introduce as much as air as possible to the mixture. It is said that this air is subsequently released on heating, causing the soufflé to rise. But according to ideal gas law calculations this trapped air should only cause the soufflé to rise by 20% and yet, it is observed that it swells to almost double its size. The main rising effect in fact comes not from trapped air but from the vaporisation of the water contained in milk.

Molecular gastronomy creates new products, new tools and new methods for use in a kitchen. Cooks are taught how to skilfully use herbs and spices to create the right taste and smell. But what if we know what chemical or combination of chemicals produce a certain taste or smell? If you can't afford a good whisky, try adding a few drops of vanillin solution to make it 'round'. This can be used as a substitute for the years that it takes for ethanol to react with lignin extracts from wooden vats to produce various aldehydes that give it the 'roundedness'.

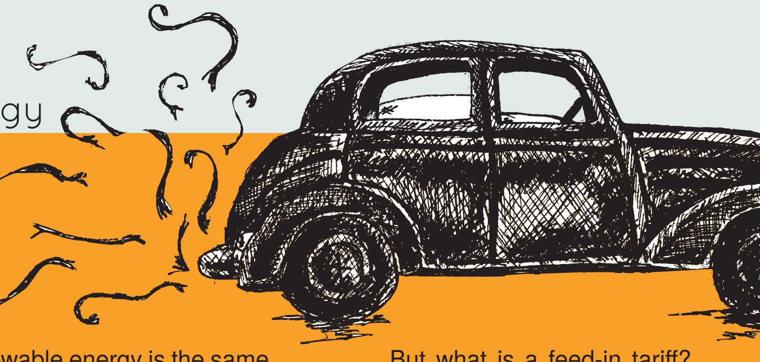
It's not just chemicals but also well-designed laboratory hardware than can be put to effective use in cooking. For example, a Büchner funnel (a cylinder with a perforated plate which can be connected to a vacuum pump for efficient filtration) will give a clearer stock than a culinary sieve and ultrasound (high frequency) boxes can be used to make an emulsion in seconds which could traditionally take many minutes of vigorous mixing by hand. Furthermore, to retain flavours, a reflux condenser, a glass cylinder encapsulating a flow of water, may be used in place of the traditional lid over a pan to more efficiently condense steam.

With a looming food crisis, food of the future is often portrayed as being heavily dependent on pills and protein shakes, akin to the porridge-like gruel Keanu Reaves eats in *The Matrix*. But actually, with every passing day chemists are understanding more and more about the taste-giving and smell-producing properties of compounds. Why then should we think that the future of food will be bland rather than delectable? At TEDx Warwick, an independently organised TED conference, Hervé This has already exhibited a prototype for a machine that synthesises tasty food. May be the fantasy of having a food machine, like in *The Jetsons*, that makes fresh Irish Stew on the press of a button, is not far away. ■

Text: Akshat Rathi
Art: Genevieve Edwards

FiT-ting In

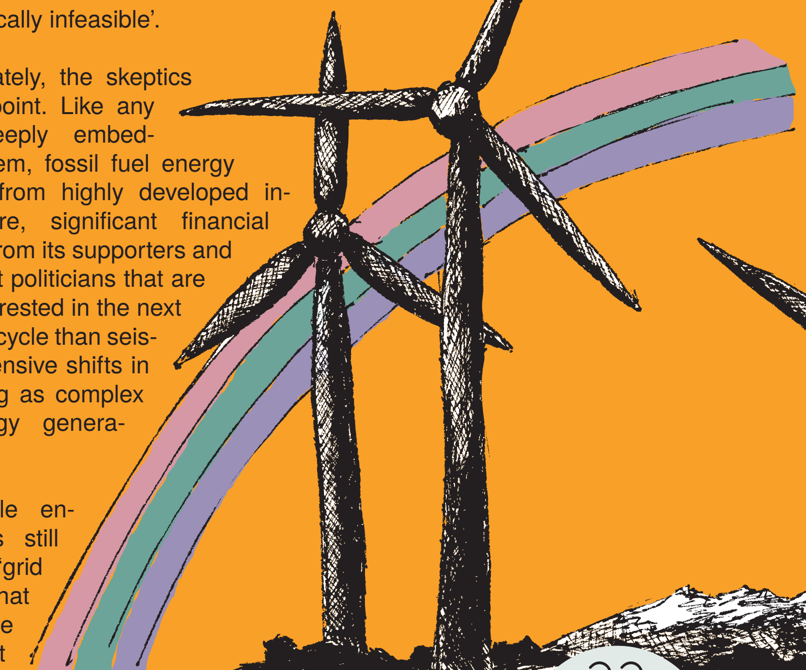
The long road to renewable energy



Renewable energy development. These three simple words are often enough to elicit a wide smile on the countenance of any environmentalist. Policy strategists enthusiastically endorse it, businessmen approve of it, and non-governmental organizations devote countless campaigns to its potential. Even right-leaning politicians, albeit a small minority, have recognized that meeting the needs of a burgeoning population through coal, natural gas and oil is environmentally, economically and perhaps even morally unsustainable. It has become increasingly clear that we need to start planning a long-term shift for our energy-hungry world.

Of course, it is easy to wonder why it has taken so long for us to widely adopt renewables. The list of the benefits of renewable energy for the collective are quite impressive: a decreased dependence on despotic petro-dictatorships, reductions in the hefty greenhouse gas emissions of countries around the world and the opportunity for grassroots energy generation that does not rely on an oligarchy of energy businesspeople. More subtle benefits are also possible, including new (and high-paying) green collar jobs, a revival of manufacturing sectors around the globe, and reductions in air pollution and biodiversity loss. Perhaps the only people that are fully informed, yet knowingly oppose, renewable energy are a few neo-conservative economists and oil tycoons, who will scour disapprovingly and mutter that it remains 'economically infeasible'.

Unfortunately, the skeptics have a point. Like any other deeply embedded system, fossil fuel energy benefits from highly developed infrastructure, significant financial backing from its supporters and indifferent politicians that are more interested in the next electoral cycle than seismic, expensive shifts in something as complex as energy generation.



Renewable energy has still not hit 'grid parity': that is, the price at which renewable energy is the same as fossil fuel based sources. So what is the best method for quickly and effectively deploying non-fossil fuel energy to millions of people around the globe? Is there a way to achieve the highly publicized concept of 'sustainable development' in the context of a capitalistic, globalized and largely integrated world economy that is almost entirely reliant on antiquated energy generation processes?

> **"...the UK has the potential to unleash a cleaner, profitable and more responsible energy future..."**

The answer lies with an increasingly high profile instrument known as a 'feed-in tariff' (FiT). This innovative policy instrument, designed to increase investment in renewable sources, has been around for a long time. Most famously, FiTs have been successfully deployed in Germany under the German Renewable Energy Act, resulting in tens of billions of euros worth of solar panels being installed around the country. Other countries have also realised their potential and have enacted similar tariffs of their own, including Spain, Canada and South Africa.

But what is a feed-in tariff? There are some differences in definition, but the classical model is generally composed of three essential elements. First, it provides an elevated and fixed price for energy that is derived from renewable sources. Second, it provides a long-term purchasing guarantee, allowing investors assurance that someone will be buying the power that they generate for the next 20-25 years. Third, it guarantees grid connectivity. This means that existing power distribution systems will necessarily be connected to new projects at low or no cost to the renewable energy generator. These measures are largely funded through minor increases in consumers' power bills, allowing governments to avoid enormous cash outlays.

The UK has recently passed FiT legislation and will begin to pay any renewable energy generating sites a fixed price for energy exported back on to the grid. However, it is important that the UK does not replicate the mistakes of other countries. Germany, for example, paid an excessively high price for solar energy, even though it is definitely not the most appropriate technology for Germany's climate and weather patterns. Furthermore, The UK should take measures to ensure that the tariff is not set too high for too long: the Greek economy is currently suffering a severe financial crisis, not aided by their inability to reduce the losses they are making through subsidising FiTs.

By negotiating the delicate balance of these complex issues, the UK has the potential to unleash a cleaner, profitable and more responsible energy future, finally banishing the looming spectre of antiquated fossil fuels. ■

Text: Joel Krupa
Art: Anna Pouncey

Switching Sides

Probing the hidden depths of anatomical asymmetry

In 1835, a young man named John Reid died in a London hospital. The enigma of his death attracted an enquiring young physician, Dr Thomas Watson, who performed the autopsy. Though the cause of the patient's demise was never ascertained, Dr Watson discovered something remarkable about John Reid – his heart was on the wrong side. Watson continued the autopsy and found that, in fact, all of John Reid's organs were on the opposite side of his body compared to the vast majority of people. He was a mirror image, as if living in Alice's looking glass.

This was one of the earliest documented cases of *situs inversus*, the reversal of positioning of the internal organs that affects 1 in 8,000 people. Nevertheless, it has taken scientists over 150 years to begin to understand how our heart and other organs come to be positioned in their asymmetrical arrangement. Only by understanding the origin of asymmetry during the development of the embryo can we explain the John Reids of this world who live among us, their intriguing differences hidden by the symmetry of their skin.

Four weeks after fertilisation we, as embryos, exist as tiny (and symmetrical) clumps of cells, with our heart beginning to form as a hollow tube running down the middle. Soon after this, the tube kinks towards the right and for the first time during development we become left-right asymmetric in shape. How do we make this transition from symmetry to asymmetry? It seems that the whole process of becoming asymmetrical is governed by genetic switches that become active on the left and remain off on the right.

Scientific research into the genetic origin of asymmetry took a leap forward in the mid-1990s, when a team led by Clifford Tabin working at Harvard Medical School found a whole family of genes that acted only on the left side of the embryo. These genes remained switched off on the right hand side. Remarkably, the pathway of genes that they discovered also operates in a wide variety of other vertebrates — mouse, chicken, fish, frog — and even some invertebrates: the very same genes control the direction of shell coiling in snails, another form of asymmetrical development.

Crucially, these 'asymmetrical' genes are switched on before structural asymmetries develop. The genes are telling the cells of the primitive heart which way to bend and kink, instructing which side the stomach forms on, informing which way around the lungs should be (the right and left lungs are different in size and structure). As a result, in mutants where the genes are absent, asymmetry does not develop properly. This framework allows us to explain the case of John Reid: when these genes are flipped so that they operate on the right hand side rather than the left, asymmetries develop in reverse.

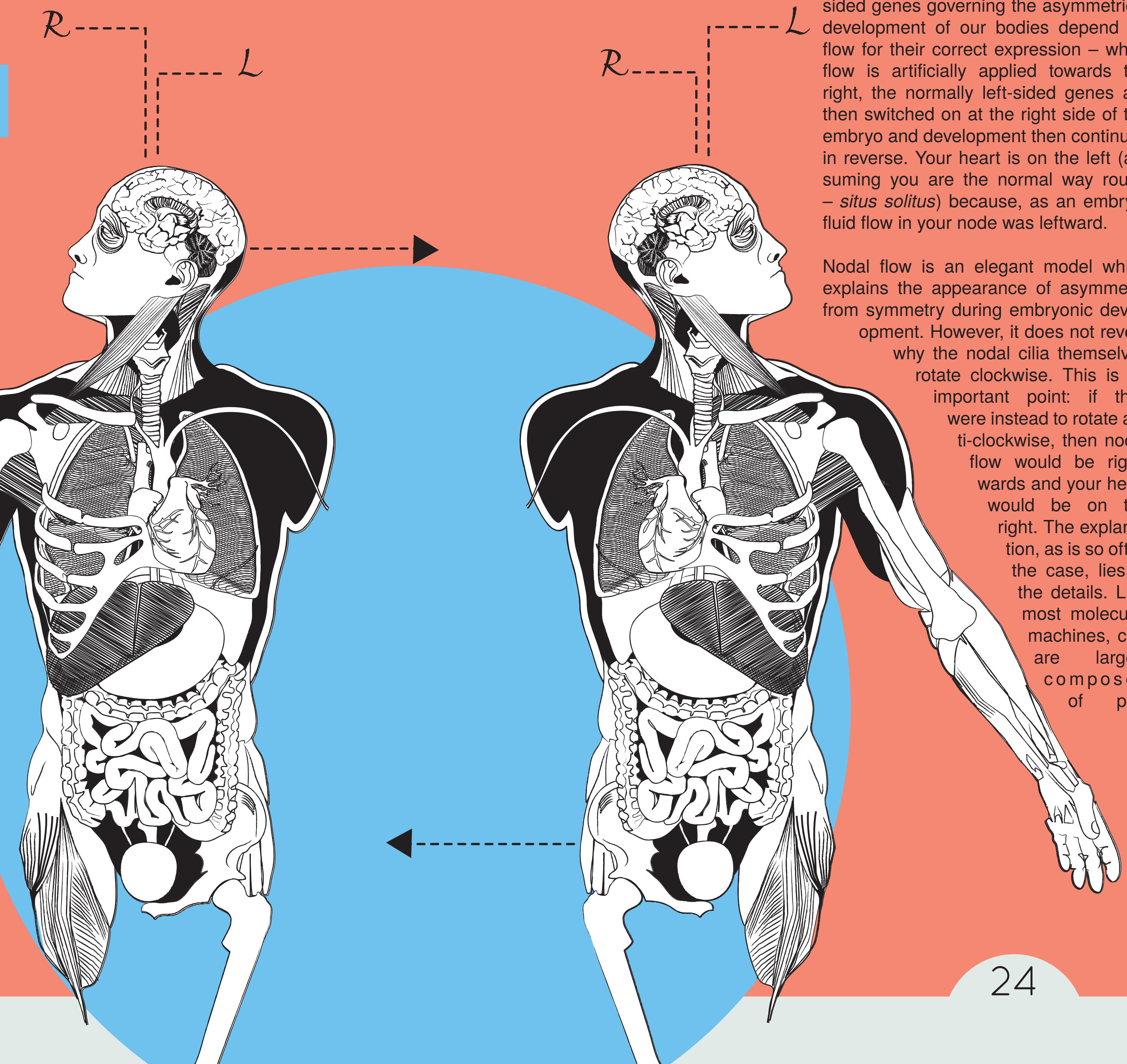
So we know that it is the action of these asymmetric genes within the embryo that instructs the positioning of gross structures under our skin. But how do these genes come to be expressed in such a strikingly asymmetrical manner?

"How do we make this transition from symmetry to asymmetry?"

To gain some insight into this problem, we have to go back to the clinic. Kartagener's syndrome, first described in 1933, is an inherited disorder affecting 1 in 32,000 births. Patients suffer with chronic respiratory infections, infertility, and *situs inversus*. The underlying cause of this condition remained unknown until 1975 when it was discovered that immotile (paralysed) cilia were at the root of the problem. Cilia are microscopic hair-like structures that protrude from almost every cell in the body. Some cilia are special because they can move, for example cilia lining the airways beat to move mucus out of the lungs, while the tails of sperm move to provide mobility. Though it is easy to see why cilial immotility leads to lung infections and infertility, this defect also holds the key to our understanding of asymmetrical development.

On the surface of the early embryo, there is a small cavity called the node, which is crucial to many aspects of embryo development including the formation of left-right asymmetry. In the late 1990s, a close examination of the node pit by Nobutaka Hirokawa's lab at the University of Tokyo revealed that the cells within possess a single motile cilium. The so-called nodal cilia don't beat back and forth like lung cilia or sperm tails, but instead they rotate like a boat propeller, elegantly swirling in the clockwise direction. The same scientists went on to show that embryos with paralysed cilia randomly expressed the left-sided genes in four possible ways: on the left, on the right, on both the left and right, or not at all. Thus, in the majority of these mutant embryos, the left-right axis did not form properly, conclusively demonstrating the need for rotating nodal cilia to determine left and right. But how does the rotation of cilia in the cavity of the embryonic node determine the side on which the heart is positioned?

"Your heart is on the left assuming you are the normal way round..."



The key to this puzzle lies in the ability of cilia to move fluids, exemplified by their transport of mucus in the airways. In Tokyo, Hirokawa's team injected tiny fluorescent beads into the node pit and monitored their movement. They were expecting to see rotational motion, with the beads being spun around by the cilia in a mini-vortex. What they actually saw was more spectacular – the beads moved from right to left in the node across the surface of the embryo. The motion wasn't bumpy (strictly speaking, turbulence doesn't exist in such small fluid volumes); it was smooth and unidirectional (see 'Why Leftward?' box). Consequently, the 'nodal flow' hypothesis was born: the left-sided genes governing the asymmetrical development of our bodies depend on flow for their correct expression – when flow is artificially applied towards the right, the normally left-sided genes are then switched on at the right side of the embryo and development then continues in reverse. Your heart is on the left (assuming you are the normal way round – *situs solitus*) because, as an embryo, fluid flow in your node was leftward.

Why Leftward?

How do rotating cilia produce a leftward, unidirectional flow?

- Nodal cilia don't point straight up out of cells, they tilt towards the posterior side at an angle of over 30 °.
- This tilt means that their leftward stroke, being perpendicular to the cell surface, is very effective at moving fluid.
- The rightward stroke, however, is close to the cell surface and therefore fluid movement is impeded.
- The result of effective leftward and ineffective rightward strokes is overall leftward fluid flow.

Nodal flow is an elegant model which explains the appearance of asymmetry from symmetry during embryonic development. However, it does not reveal why the nodal cilia themselves rotate clockwise. This is an important point: if they were instead to rotate anti-clockwise, then nodal flow would be rightwards and your heart would be on the right. The explanation, as is so often the case, lies in the details. Like most molecular machines, cilia are largely composed of proteins, giant molecules themselves made of smaller subunits called amino acids. Amino acids have an interesting property – they are chiral (see *Mirror Mirror on the Wall* by Andrew Steele, also in this issue). This means that each amino acid can have two possible forms that are mirror images of each other, though nature overwhelmingly uses only one of these. If we consider a hypothetical embryo made from proteins built from the other mirror image form, then all of the internal workings of the cilia would be reversed, and we could well imagine that the nodal cilia would rotate anti-clockwise. This would produce rightward nodal flow during embryonic development, and John Reid's inverted internal structure would be the rule rather than the exception!

It is fascinating to consider that the complex asymmetry we find hidden beneath our skin is due to the chiral nature of amino acids that stems from the chemistry of carbon atoms. Perhaps this scientific mystery would have been solved much sooner had Sherlock Holmes been present to remind Dr Watson that the answer is invariably 'elementary'. ■

Text: Daniel Grimes
Art: Karis Flavell

Intelligent Life: Apply Elsewhere

The changing search for life beyond Earth

Are we alone? Is there life out there in the vast expanse of space? Such questions have long been the domain of fantastical science fiction, and when we muse on extra-terrestrial life, we think inevitably of tall green anthropomorphic aliens – the eponymous ET. But for nearly 50 years, the search for life in the universe has been a scientific pursuit. In 1961, the field of astrobiology – the search for life beyond our terrestrial backyard – was born with the formulation of a simple equation.

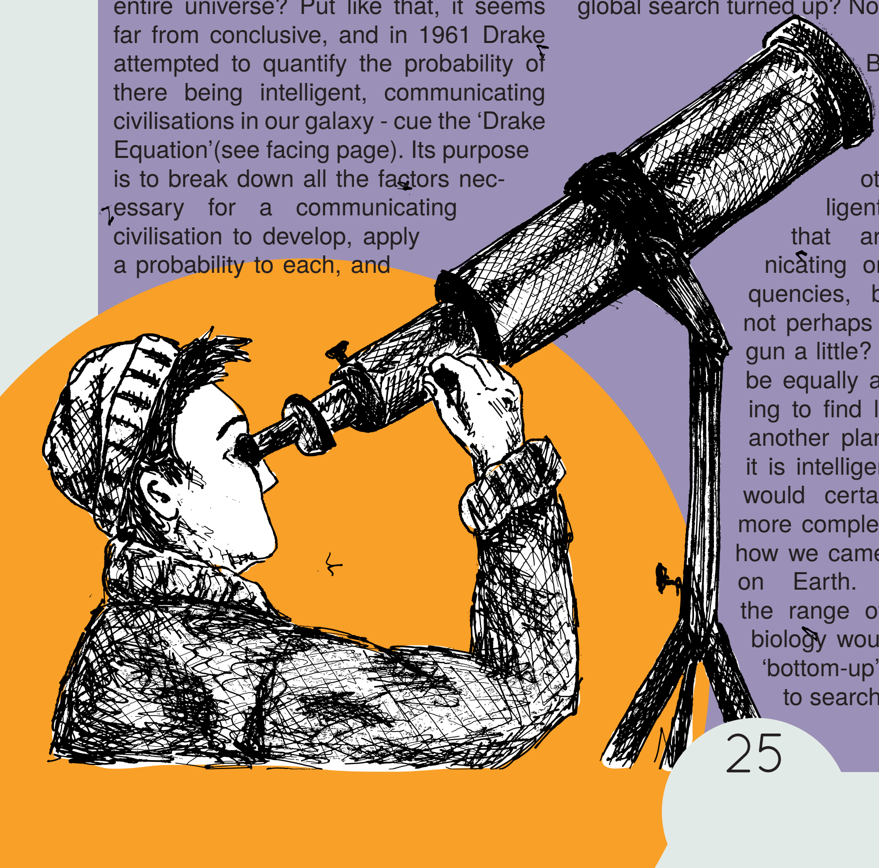
Frank Drake, an astronomer and astrophysicist, was one of the first scientists to start looking for life in the universe. Using radio-astronomy, scanning celestial objects on radio frequencies, he chose normally quiet frequencies to listen for possible alien communication. Listening to two stars, both a similar age to our sun, for six hours a day over four months, Drake was confident that if there were communicating life forms out there, we would find them. When the vast data set was examined for patterns, all that was discovered was a secret military satellite. No, "Hello, we're over here!" from 11 light years away; no help beacon from a dying civilisation; no indication, in fact, that anything was out there.

So is that it? Does a lack of radio signals on a single frequency mean that humans are the only intelligent life form in the entire universe? Put like that, it seems far from conclusive, and in 1961 Drake attempted to quantify the probability of there being intelligent, communicating civilisations in our galaxy - cue the 'Drake Equation'(see facing page). Its purpose is to break down all the factors necessary for a communicating civilisation to develop, apply a probability to each, and thus predict the number of civilisations we could list in our galactic phonebook.

This was an insightful, reductionist way of dealing with the problem. Unfortunately, many of the factors were either unknown or unknowable. The 'lifetime' of a communicating civilisation, for example, lies more in the social sciences, and cannot even be statistically tested with our current sample size of one. Nevertheless, even conservative estimates of each of the factors gives a number greater than this. As such, enthusiasm for the search for life in the universe has blossomed, giving rise to the suite of projects allied to SETI – the Search for Extra-Terrestrial Intelligence.

"How do you go about finding life if it isn't actively trying to communicate?"

SETI projects have mostly continued to focus on scanning the skies for alien transmissions. The global following of the search is immense: the non-profit organisation The SETI League have created a global network of amateur-built radio telescopes pointed skywards, watching and waiting. Similarly, the SETI@Home project invites internet users to contribute computer power to analysing radio-astronomy data for signs of communication. Truly, the worldwide scientific collaboration is commendable. And what has this global search turned up? Nothing.



But stop there! OK, we haven't found any other intelligent life forms that are communicating on radio frequencies, but are we not perhaps jumping the gun a little? Would it not be equally as enlightening to find life at all on another planet, whether it is intelligent or not? It would certainly give a more complete picture of how we came to be here on Earth. Discovering the range of interstellar biology would provide a 'bottom-up' approach to searching for more advanced organisms and, ultimately, intelligence. The modern incarnation of the field of astrobiology is concerned more with this, with the active search for life and its repercussions in the universe, than the somewhat stay-at-home approach of SETI. Astrobiology today is a broad collaboration between astronomers, cosmologists, earth scientists, biologists, chemists and engineers, with over 30 research groups working on different approaches to understanding the place of life in time and space.

How do you go about finding life if it isn't actively trying to communicate? The first problem is what exactly to define as life. There are as many as 60 different definitions of life, depending on your point of view – for example the widely used biological MERRINGS (movement, excretion, respiration, reproduction, irritability, nutrition, growth) system, which is little use in testing fossil organisms, or atypical life forms, or in fact, anything we may find in space. Astrobiologists choose to use the short NASA definition as a starting point: "Life is a self-sustained chemical system capable of undergoing Darwinian evolution." Working with this basic definition gives a broad scope for investigation of early life forms across the many light years of space.

The first step in such a mission is to understand how to get life in the first place. Tying intimately into studies of early life on Earth, palaeontologists, geologists and chemists work together to discover the timing, likely environment and mechanisms of the origin of life as well as postulating the various forms such life could take. Between inaugural organisms and complex beings, there are intermediate states of life that would seem very strange to an observer today, but were essential in the development of life as we know it. Cells with a fundamentally different metabolism to today were likely to be common sights on the early Earth. Understanding the development of life processes and complex organisms may be particularly important in identifying newly emergent life on other planets.

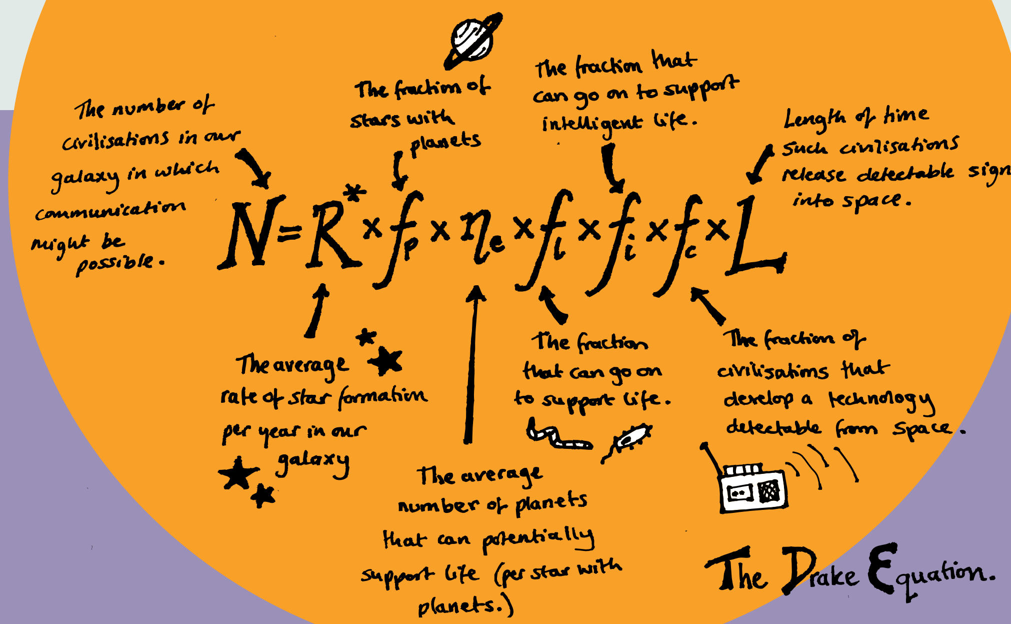
Secondly, once life is established, it is the job of microbiologists and earth scientists to understand the limits of that life. On Earth, living things were thought to only penetrate to about 10 cm deep in soils, 10 m deep in water, and to die out with increasing altitude. Now, however, we find life of one form or another pretty much everywhere we look. It can survive at temperatures from -20 °C to around 120 °C; pressures of up to 1060 MPa, equivalent to 50 km beneath the Earth's crust; and extremes of pH (both acid and alkali) and salinity. Such information is invaluable in the search for life elsewhere in the solar system and beyond, as it extends the range of so-called 'habitable zones', the area around a star where it is believed that life can exist. Depending on the size and age of a star, the nature of the planets surrounding it, and the range of conditions that life could tolerate, the size and position of habitable zones within other solar systems may be considerably different to that within our own.

"So what happens if we do find life? Whether it is close or far, simple or advanced, are humans as a race equipped to deal with the knowledge that we are not alone?"

Having established how and where life could exist outside Earth, the search can begin for likely habitable worlds. The most obvious place to start is our own solar system, and there are cases for potentially habitable environments either now or in the past on Mars, Venus, the Jovian moon Europa and the Saturnian moons Titan and Enceladus. These bodies, although almost certainly not harbouring intelligent, advanced life forms, are important short term destinations for astrobiological exploration, including investigation by remote or manned missions.

Astronomers and cosmologists are also occupied in finding habitable planets orbiting other stars. Extra-solar planet searches turned up the first results in 1996 and have, at the time of writing, located 452 bodies orbiting other stars in our galaxy. Most are the size of Jupiter or greater, because of resolution limitations, but a number of planets of little more than a few Earth-masses have been found. Furthermore, it is thought that the Earth-sized rocky planets, thought to be more habitable than larger bodies, greatly outnumber the larger planets in the galaxy.

So what happens if we do find life? Whether it is close or far, simple or advanced, are humans as a race equipped to deal with the knowledge that we are not alone? Needless to say, any astrobiological revolution will deeply affect our philosophical and social outlook, as well as transforming our scientific goals and our view of the universe.



Currently, despite the fact that we are yet to find conclusive evidence of life anywhere, there are reams of UN legislation and quarantine regulations to ensure planetary protection in the event of living sample return. Far from allowing a District 9-esque co-habitation, any alien life, whether microscopic or advanced and gigantic, will never leave a sealed container in quarantine at the landing site.

Clearly there are many theoretical and practical obstacles to be overcome in our continuing search for life in the universe. But the field of astrobiology is yet young. The first man-made object was launched into space only 53 years ago. Even in the short period of human history, this is just a blink of an eye, and technology is moving faster every day. In the words of the brilliant departed astronomer Carl Sagan: 'How lucky we are to live in this time, the first moment in human history when we are, in fact, visiting other worlds.' ■

Text: Leila Battison
Art: Anna Pouncey

Museum Piece

Reinventing the interface between science and society

Walking into Oxford University's Natural History Museum (OUMNH), it's difficult not to be impressed by the 12 metre long T-Rex staring back at you from between the Gothic arches. Such awe-inspiring grandeur and close-up encounters with the natural world have sparked the imaginations of both children and adults for the last 150 years at the museum.

So effective is this traditional museum format that photos on display show today's museum looking uncannily like it did back in the 1860s. Huge skeletons still dominate the hall and, while the contents of the grand wooden display cabinets have been modernised, the principles of presentation are essentially the same. Similarly, the adjacent Pitt Rivers Museum needed to do little more than dust off the shrunken heads in its recent renovation.

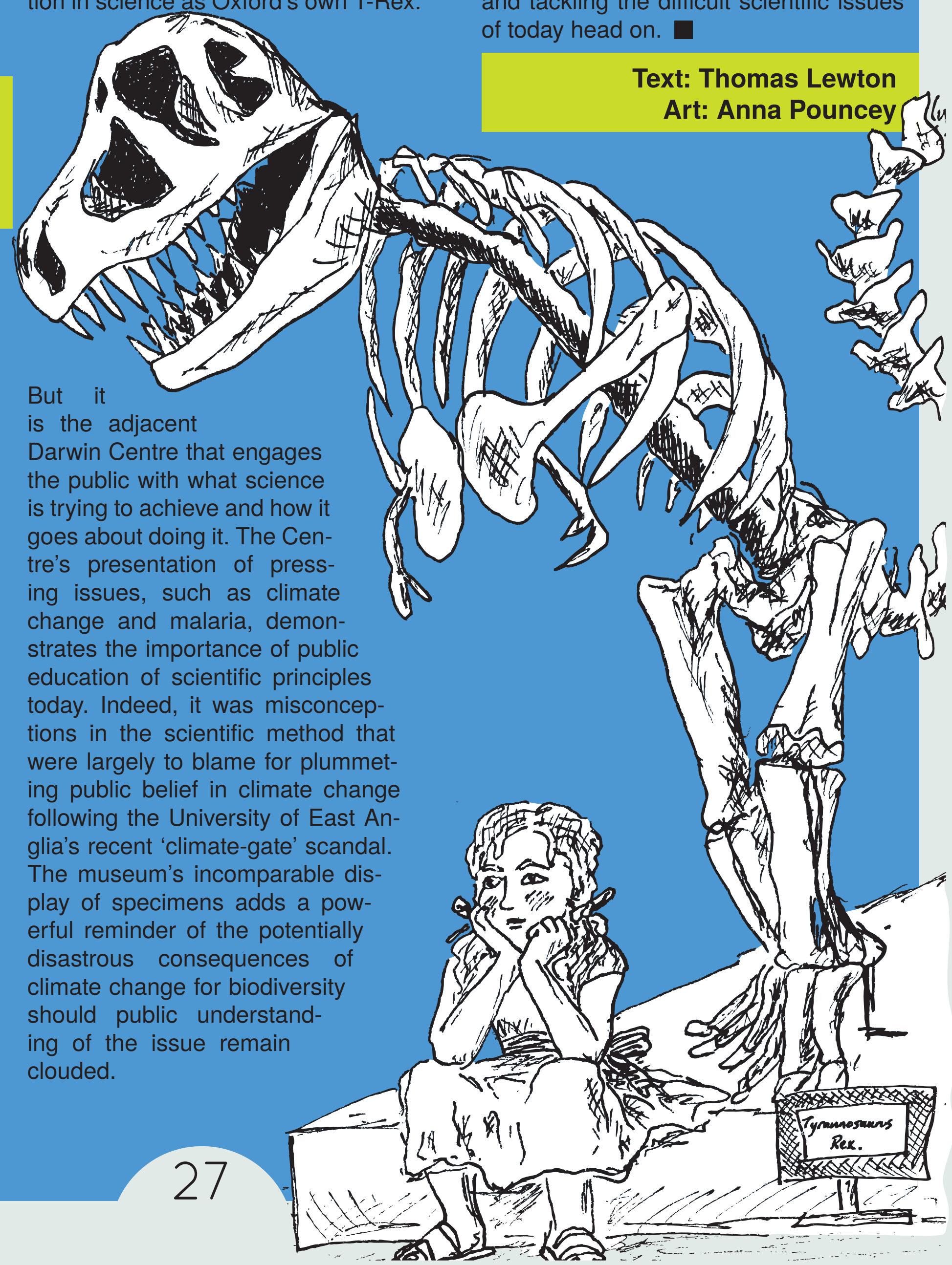
"...it was misconceptions in the scientific method that were largely to blame for plummeting public belief in climate change..."

OUNHM was designed as a home for the sciences in Oxford, collecting together the breadth of research scattered about the colleges to balance the increasing dominance of the arts within the University. But while today's internationally renowned research laboratories have grown and flourished around this grand centrepiece, the museum's position at the forefront of science has sadly been lost.

This year OUNHM celebrates its 150th anniversary, remembering the infamous Huxley-Wilberforce debate, a turning point in the public acceptance of evolution, and key alumni scientists, such as Nobel Laureate Dorothy Hodgkin. But while it is important to remember the museum's rich history through memorial plaques and busts, the museum must also take this opportunity to question how best to maintain its relevancy today. It could do worse than to look to its younger, yet bigger, brother in London whose innovative, newly-opened Darwin Centre leads the way in 21st century science communication.

At the heart of the Centre, a vast white 'cocoon' houses 20 million specimens – not least a nine metre long pickled giant squid. But moving beyond the 'wow' factor, the Centre also aims not only to explain the process of museum curation, but the very scientific method itself – addressing contemporary issues such as the relative merits of peer review. Furthermore, visitors are given the rare opportunity to talk to and see scientists going about their everyday work. While appearing a little like animals in a cage ('Scientists at Work – No Flash Photography!'), the attempt to create a more realistic, more human, perception of scientists, together with both the excitement of discovery and the often difficult and arduous nature of scientific work, must be applauded.

'Dippy' the diplodocus still stands tall in the entrance of the London Natural History Museum, instilling the same fascination in science as Oxford's own T-Rex.



But it is the adjacent Darwin Centre that engages the public with what science is trying to achieve and how it goes about doing it. The Centre's presentation of pressing issues, such as climate change and malaria, demonstrates the importance of public education of scientific principles today. Indeed, it was misconceptions in the scientific method that were largely to blame for plummeting public belief in climate change following the University of East Anglia's recent 'climate-gate' scandal. The museum's incomparable display of specimens adds a powerful reminder of the potentially disastrous consequences of climate change for biodiversity should public understanding of the issue remain clouded.

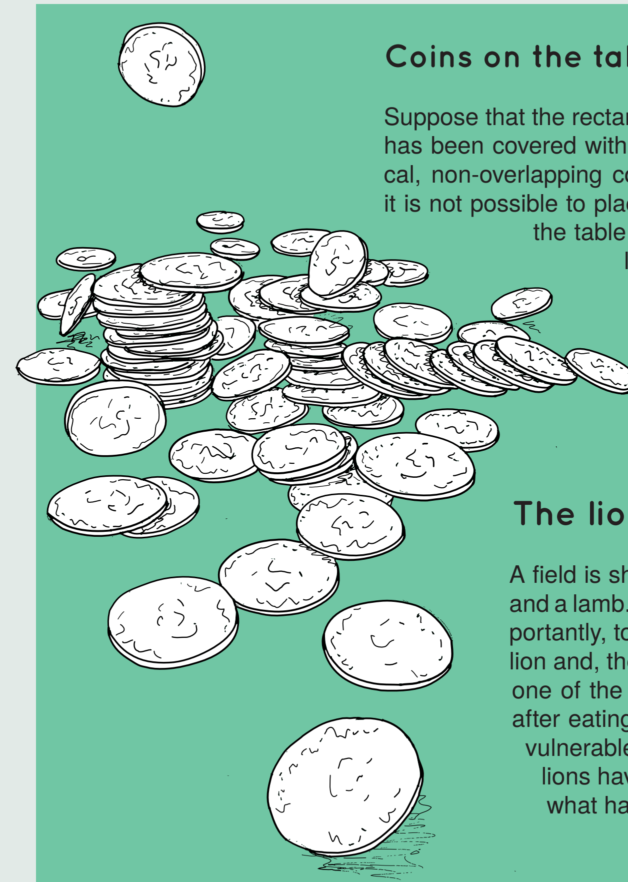
Not everyone has the Darwin Centre's £80 million budget to play around with, but attempts to engage the public in science need not cost the Earth (and may even save it). Last term's Steampunk exhibition, at Oxford's Museum of the History of Science, explored the role of aesthetics in modern science and that of science in consumerist society, bringing in record numbers of visitors. Exhibitions like this which seek to explore interdisciplinary links make science relevant to new audiences and question the changing purpose of science in modern society.

To continue to be a home for the sciences on its 150th anniversary Oxford's Natural History Museum must find novel, innovative ways to use its extraordinary collections, appealing to new audiences and tackling the difficult scientific issues of today head on. ■

Text: Thomas Lewton
Art: Anna Pouncey

Riddlers Digest

Cerebral amusement for the modern scientist



Coins on the table

Suppose that the rectangular surface of a table has been covered with a number, 'n', of identical, non-overlapping coins in such a way that it is not possible to place another such coin on the table without it overlapping at least one of the previous ones. Is it always possible to cover the entire surface of the table using 4n coins if they are allowed to overlap?

The lions and the lamb

A field is shared by a number, 'N' of lions and a lamb. A lion's priorities are, most importantly, to avoid being eaten by another lion and, then, to avoid being hungry. Any one of the N lions can eat the lamb, but after eating, a lion will fall asleep and be vulnerable to the attacks of others. If the lions have thought carefully about this, what happens for each value of N?

Chess tournament

A chess tournament with the usual scoring system (1 for the winner of any game, 0 for the loser, 0.5 for each in case of a draw) is played among some number of players. If half of each player's total points are obtained in games against the three lowest scoring players, then how many players are there in the tournament?

Text: David Seifert
Art: Leila Battison

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