Catalyst

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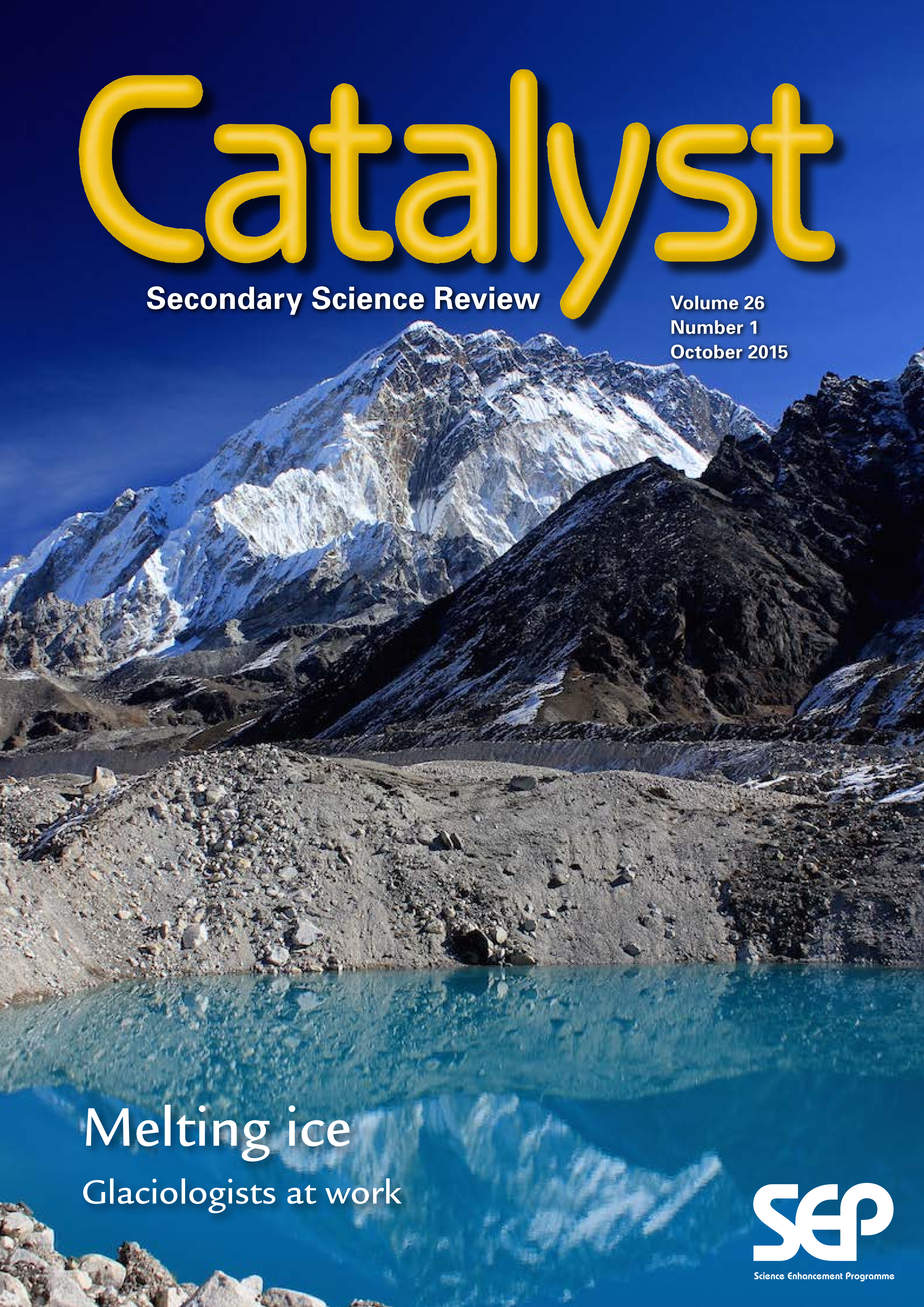

Melting ice

Glaciologists at work

Science Enhancement Programme

Catalyst

Volume 26 Number 1 October 2015

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Editorial contact:
01273 562139 or catalyst@sep.org.uk

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The cover image shows a 'supraglacial lake' – a lake on top of a glacier. The Earth's glaciers have expanded and retreated as the climate has changed. Today, teams of scientists monitor these changes as an indication of global warming. The disappearance of a glacier may not be of immediate significance in your life but, for some people, the annual release of meltwater from glaciers during the summer is of vital importance – it's their principal source of water for agriculture. See Duncan Quincey's article on pages 9-13.

Keeping up with Science

Antibiotics have saved many millions of lives. Since the discovery of penicillin, we have become used to the availability of antibiotics for the treatment of bacterial infections, problems that may seem minor now but which might have proved fatal in the past. Just imagine if, at any time that you cut yourself whilst playing, your parents feared that your cut might become infected and that you might die. That's not a pleasant thought.

So it's alarming that bacterial infections are evolving to have resistance to the commonly available antibiotics. In this issue of CATALYST, Stefania Hartley describes progress towards the development of a different type of antibiotic which might prevent us from reverting to the bad old days.

Antibiotics are an example of a science-based technology which has proved beneficial in our lives. But Science can't stand still. We need to develop our understanding of how infectious bacteria function if we are to keep ahead of their natural evolutionary changes.

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Andrew Hyam

Prioryman

Death of a king

Skeletal injuries of the last Plantagenet king

The discovery and analysis of King Richard III's skeleton is an amazing scientific detective story, told here by ***Andrew Hyam*** *of Leicester University.*

Richard III was killed at the Battle of Bosworth on 22 August 1485 and was the last English king to die in battle. After the battle he was brought back to Leicester and was buried in the Grey Friars church, where he was to remain for next 500 years.

At his death, Richard's enemy, Henry Tudor, became King Henry VII. Later, during the 16th century, the friary was closed and the land became a garden and, finally, a car park. In 2012 a team of archaeologists searching for the lost grave of King Richard found a skeleton which was eventually identified as that belonging to King Richard III.

Along with many other scientific and analytical techniques used during the identification process an osteologist, a forensic pathologist and a forensic engineer from the University of Leicester studied the wounds found on the skeleton. Their aim was to try to understand if these wounds were caused during battle and, if so, what sort of weapons could have caused them.

Specialists working together

An **osteologist** is a qualified archaeologist who specialises in the scientific study of bones, their diseases and injuries.

A **forensic pathologist** is someone who uses scientific techniques to study a body, or the remains of a body, in order to determine the cause of death.

A **forensic engineer** uses scientific and engineering methods and techniques to study materials, components or structures which fail or break.

In the case of Richard III, the pathologist and the engineer combined their methods to determine angles of attack, size and shape of weaponry etc.

An archaeologist at work on the Grey Friars site in Leicester

Key words

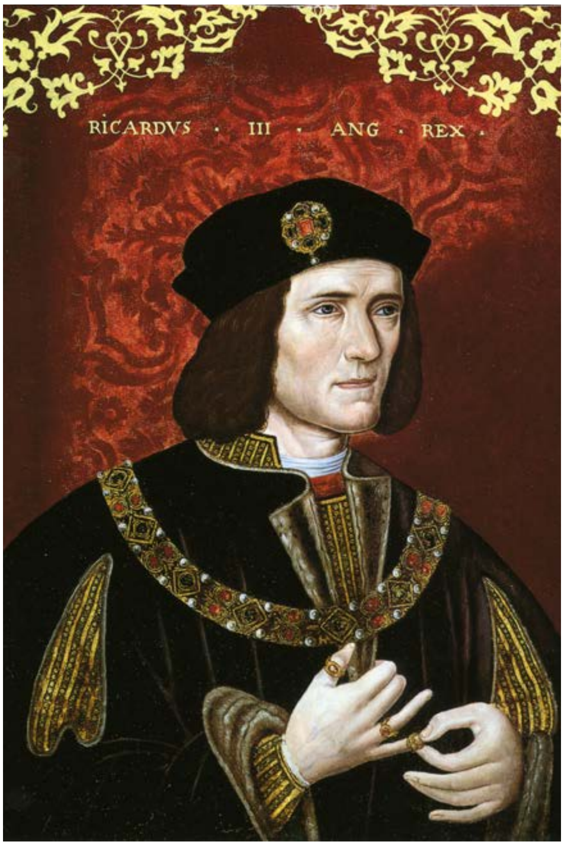
skeleton

archaeology

forensic science

A battle-hardened king

From contemporary accounts we know that Richard was experienced in battle and was regarded as a good commander. Medieval battles were face-to-face hard-fought affairs often leading to confused and localised fighting. Accounts also tell us that during the battle Richard saw an opportunity to win by leading a cavalry charge across the battlefield deep into the enemy's ranks. Richard got close enough to Henry Tudor to be able to kill the standard bearer who would have been at Henry's side.



Richard III towards the end of his life. The original of this portrait is in the National Portrait Gallery in London.

At this point the course of the battle, and the course of history, turned when Richard lost his horse. We don't know how this happened but we can assume he was in the thick of the fighting and surrounded by his enemies.

The clock is now turned forwards to 2012 to a car park in Leicester where the skeletal remains were discovered and were subsequently analysed and identified as those belonging to King Richard III. Amongst other things the investigation revealed a total of eleven injuries on Richard's bones, most of which were around the head. These wounds were caused at or around the time of death – 'peri-mortem'. It must be borne in mind that the injuries which were seen do not include any soft tissue damage which may have been inflicted. Unfortunately soft-tissue does not often survive for archaeologists to study. This is very much like a cold-case murder investigation where a lot of potential evidence is missing.

A life or death struggle

As a 15th century re-enactor with my own armour, I am in the fortunate position to help build up a possible sequence of events during Richard III's last moments in battle. As none of the injuries overlap each other it is difficult to state precisely in what order they occurred. However, from my knowledge and experience of using medieval armour and weapons, what follows is my interpretation of the events. Also, because we only have the skeletal evidence the following scenario is only one of a number of variations which can be postulated given the same evidence. What is important is that we must only use the available evidence for any interpretation. This is one of the many attractions of archaeology when trying to reconstruct the past.

Typical 15th century plate-armour giving all-round protection especially to the head area; King Richard III's armour would have been considerably more ornate.

Given that Richard's armour would have been fit for a king and offered the best protection during battle, especially around the head, why did he sustain so many head injuries? From wearing similar armour I know that it can be difficult to breathe and shout orders when my face visor is down. Perhaps, after losing his horse Richard lifted his visor and sustained his first injury which was a stab to the cheek by a small dagger.

To be attacked by a dagger shows just how close his enemy was. The wound, although painful, is not life threatening but the assailant appears to have then cut the chin strap holding his helmet on. This was such a hard cut that the blade not only cut the chinstrap but also cut into Richard's jawbone leaving a permanent record for us to analyse.

At this point without a helmet Richard would be in serious trouble as although his body was still protected by plate armour his head was now exposed and vulnerable. This would have been the signal for many other opponents to start a ferocious attack on him. At the same time Richard's men would be desperately fending them off and trying to get the king to safety.

Blows to the head

Shallow saucer-like cuts on the top and back of the skull show where one or more swords were trying to hack into his head. The press of people was possibly so dense that they could only achieve glancing blows which shaved off patches of scalp and thin slivers of bone. This shows how incredibly sharp a medieval sword could be – not the heavy blunt weapons often portrayed by Hollywood. Although extremely painful the injuries sustained so far would be survivable if medical attention was available; unfortunately for Richard this was not an option at Bosworth.

Typical medieval swords

The sword blows were likely to have stunned Richard who may have fallen or been dragged to his knees as the next wound is at the top of the skull. A small square-section hole has partially penetrated the skull and was possibly caused by a Rondel dagger. Rondel daggers are particularly unpleasant weapons designed to be placed on the top of a victim's skull and driven through into the brain by a sharp blow resulting in instantaneous death. In Richard's case this blow did not do this which again may indicate that the press of people around him prevented a clean killing blow.

Although he was probably still alive the number and severity of the blows to the head would probably have stunned him or even knocked him unconscious. Remember, we don't have any soft-tissue evidence so cannot be sure of any other additional injuries caused at the same time.

Rondel dagger showing square section blade and extremely sharp point

Once face down on the ground more assailants may have moved in. These included a person armed with a halberd (a lethal weapon with a multi-function blade, spike and hook on a long pole) and another with a sword. The sword was driven point-first into the base of the skull with such force that it passed through the brain and only stopped when it hit the opposite side of the skull. Around the same time a halberd was used to slice off a large section of skull near to the base which would have exposed brain tissue. If not already dead either of these blows would be capable of causing Richard's death.

A 15th century halberd of German design

A final injury caused either during the fighting, or as a post mortem injury, was a cut through the buttock which left a permanent mark on the pelvis. Either a sword, or more likely a halberd, was used for this. A number of possibilities exist as to how this may have occurred. One possibility is that it was done after death as a humiliation injury to show how much someone hated the former king.

Alternatively it may have been caused during battle as the only exposed spot on an armoured knight is where he sits on his horse. If laid face down on the ground the backside is exposed to such an attack. An injury which was definitely caused after death was a small dagger cut to a rib. This was possibly caused by another humiliation injury or by the action of cutting his armour and clothing off on the battlefield.

King Richard III's injuries show just how close up and frenzied his final battle was. The whole series of events would probably be over in a matter of minutes at most. Accounts credit a Welsh Lancastrian with killing Richard but the number of weapons used indicates that many people were involved.

Andrew Hyam is a full-time field archaeologist working for the University of Leicester Archaeological Services. He has been involved with the Grey Friars project as part of the outreach team demonstrating and interpreting the last moments of King Richard III's life. He is a 15th century re-enactor with his own full harness of armour and associated weaponry.

Look here!

The Grey Friars Project was a collaborative project between the University of Leicester, the Richard III Society and Leicester City Council.

See images of King Richard's damaged bones in this academic paper: *tinyurl.com/pgyd2cc*

Further information on the search for King Richard III and his injuries: *www.le.ac.uk/richardiii*

David Sang

What is Physics?

Key words
Physics
laws
matter
particles

1609 was a crucial year in the development of science. That was the year that Galileo first turned a telescope on the heavens. Without a telescope, what do you see if you look out at the night sky? There are specks of light – the stars – which cross the sky in the course of a night. There's also the occasional planet, looking little different from a star, and the Moon.

Before Galileo, people imagined that the heavens were somehow 'perfect'. The stars were the same from one night to the next, unchanging during a person's lifetime. Down here on Earth, things were different. Things changed; plants, animals and people grew and died. The orbit of the Moon represented the boundary between our world and the perfection beyond.

In Barcelona, a 'live statue' of Galileo invites a young observer to look through his telescope.

Galileo's telescope allowed him to be the first person to overturn these ideas. In particular, he saw that Jupiter had four moons whose positions changed with time – they were orbiting the planet. He began to develop the idea that the universe beyond the Moon was not so different from our own world. Today, we have detailed images of the planets and their moons. Although they are very varied in appearance, we have no doubt that they are all made of the same elements that we know of here on Earth, and that they move according to the same laws of motion as we experience.

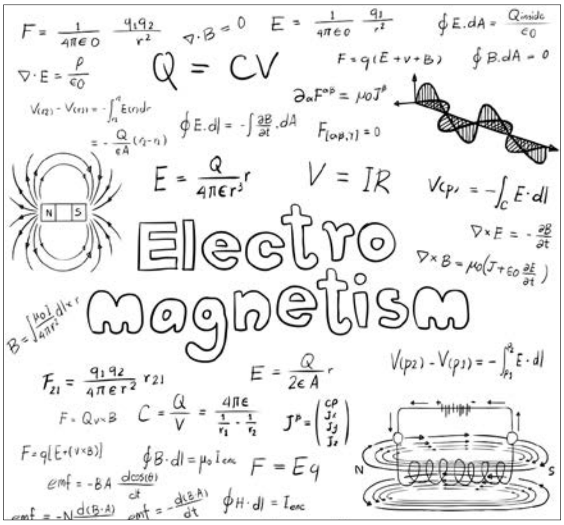
Universality: This is one thing that Physics tries to do. It tries to devise rules or laws that apply everywhere. As far as we know, the same laws apply in the most distant galaxies as apply here on Earth. They also applied in the distant past and will continue to apply in the future.

These are big claims. Periodically, physicists have suggested that things might have been different in the past – gravity might have been weaker, for example. If this could be proved true, we would of course have to accept it. But so far, the laws of Physics seem to be universal.

Self-consistency: This is a related idea. All of the laws of Physics must fit together. We can't have one set of laws that apply to atoms and a different, contradictory set that apply to planets.

One of the most beautiful aspects of Physics is the link between the very small and the very large. Particle physicists have built up a theory of the tiny particles that make up matter and the forces between them – the 'Standard Model' – which cosmologists have been able to use to explain the history of the universe, starting with the Big Bang.

Reductionism and unification: Who would want a book filled with hundreds of laws to describe the natural world? Physicists try to solve problems using a limited number of basic ideas (concepts and laws) which have been developed gradually over the last four centuries. They try to bring these laws together in order to show the underlying unity of nature. For example, in 1820, Hans Christian Oersted discovered the magnetic effect of an electric current. This led to the unifying of two separate fields of Physics in the laws of electromagnetism.



The theory of electromagnetism unifies ideas about electricity, magnetism, light waves and more.

Mathematics: Physicists make measurements. The things they are interested in are mostly quantities, and by measuring them they hope to find the laws that relate them. These laws take the form of mathematical equations or models which can then be used to describe what we observe and also to predict what will happen. Think of the mathematical models which are used by climate scientists to predict the weather and the future of Earth's climate.

Indeed, there is a symbiotic relationship between Maths and Physics. Many important ideas in Maths have been developed because they were useful in Physics – for example, calculus was developed by Newton and by Leibnitz in order to solve problems in mechanics.

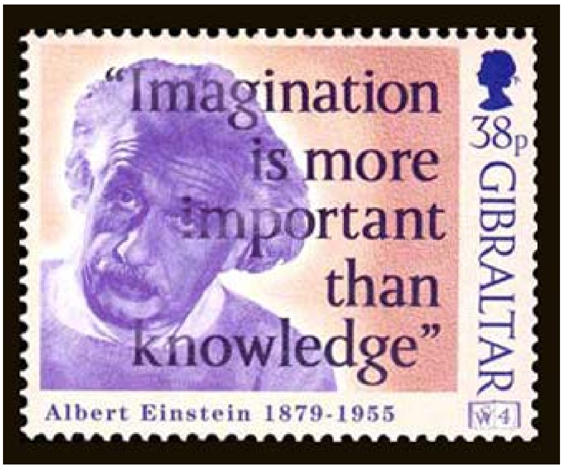
A statue of Isaac Newton, by the Scottish Sculptor Eduardo Paolozzi, outside the British Library in London. It highlights the role of measurement in Physics.

Technology: Physics is useful! Our developing understanding of Physics has allowed many useful inventions. And it can work the other way round: new inventions have allowed us to do new types of experiment. The laser is an interesting example. Physicists understood the principle of the laser and built the first one in 1960; it found many lab applications but it was decades before it became the basis of many everyday consumer products.

A red laser cutting machine

Is Physics complete?

Of course not. You can think of it like this: Picture Galileo at the centre of a vast, dark chamber. He shines his torch and illuminates an area around his feet – this represents his understanding of motion and the Solar System. The area of illumination was expanded by Newton, particularly in the fields of motion, astronomy and optics. In the nineteenth century, Physics expanded into electromagnetism. The twentieth century brought atomic and nuclear Physics, cosmology and so on. As the area of illumination expands, there is a longer boundary between the light and the dark. That's where physicists are working today.



Physics is one of the greatest constructions of the human imagination. There's lots more imagining to be done.

There are still many questions to be resolved. One example is how to unify Quantum Physics (the theory which explains how matter behaves at the level of atoms and nuclei) with the laws which govern the behaviour of matter on a larger scale. It's unacceptable to have two sets of laws which operate at different scales, but how to connect them up?

David Sang is Physics editor of Catalyst. Note: other sciences are available.

Meriame Berboucha

Tokamak power

Making progress with nuclear fusion

Key words
nuclear fusion
energy supply
electricity generation
tokamak

Energy is a necessity for life. Without it we wouldn't have food, warmth, clean clothes, light and all the electrical appliances we use in our everyday lives. Our major sources of energy are fossil fuels – oil, coal and natural gas. As the world population rises and demand for electricity increases, these energy sources are diminishing. If we continue to use fossil fuels at an increasing rate they will soon run out. Then what will we do to provide us all with electricity, heating, transport….?

We mustn't run out of energy, but we mustn't pollute either. We have to find alternative, cleaner ways to provide our energy. These include nuclear power and renewable energy sources, such as geothermal, hydroelectric, tidal, wind and solar. Although these energy sources are naturally replenished, they can take up a lot of space in order to provide enough power. For instance, large spans of land in the UK are wind farms, which provide only a small percentage of the UK's power. In addition to this, nature can be unpredictable. There will be peaks and troughs in energy generation due to varying wind speeds, thus making this energy source unreliable in times of demand. We need a better solution. Fusion energy could be the answer.

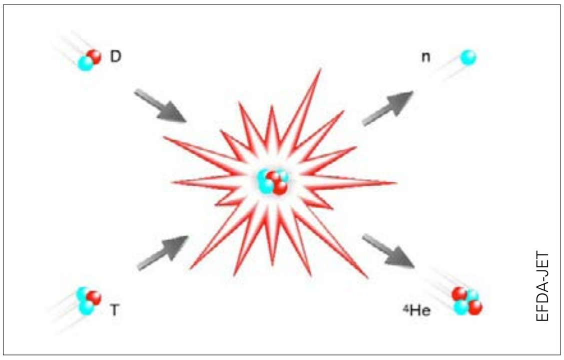


Figure 1 The fusion reaction: where deuterium (D) and tritium (T), isotopes of hydrogen, fuse to make helium (He). A neutron and some energy are by-products of this reaction.

What is fusion?

Fusion is the process that powers the stars, including our very own Sun. Within the core of a star, small atomic nuclei are joined together to make larger nuclei (**Figure 1**). Heavier elements such as helium are made in this process. This is where the saying 'we are all stardust' comes from. All the elements you see in our Universe came from the stars: the element factories.

The Sun produces a lot of energy. Remember those times where you have been out on a sunny day and felt a burning sensation on your skin because of the Sun. This is from 150 million km away! Now just imagine if you were stood next to it! If only we could harness this process on Earth and use it to generate power.

Scientists are coming up with innovative ways of achieving fusion on Earth. The world requires a power source that is abundant, safe and carbon dioxide-free; and fusion offers this. But how can we harness the power of the stars? Scientists have been trying for decades. Now businesses are getting involved. Tokamak Energy, a private company based at Milton Park in Oxfordshire UK, aims to accelerate the development of fusion energy using new technologies and smaller machines.

Fusion can only happen at extremely high temperatures, approximately a few hundred million degrees. Nuclei are positively charged and when they come close together they repel each other, because like charges repel. Therefore, trying to get nuclei close together is a huge challenge. Having high temperatures (and pressures) causes the nuclei to gain a large amount of kinetic energy so that they can overcome this repulsion and fuse.

At such high temperatures, atoms no longer exist. Instead the electrons break away from the nuclei forming a plasma. Plasma is the fourth state of matter and can be thought of as a soup of very fast-moving charged particles (ions and electrons). In this environment fusion can occur (**Figure 2**), but we must somehow be able to hold this very hot plasma in a container. To do this, we can either use magnetic cages (magnetic fusion) or lasers to heat and confine the fuel (laser or inertial fusion). Tokamak Energy's research is in the field of magnetic fusion, and they use machines known as tokamaks.

What is a tokamak?

Tokamak is a Russian acronym for 'toroidal chamber – magnetic coils'. That is, a tokamak is a doughnut-shaped (toroidal) vessel surrounded by rings of magnets. The charged particles within the plasma are influenced by magnetic fields, so the tokamak acts as a magnetic cage trapping the plasma. By varying the shape of the magnetic fields we can stabilise the plasma to make sure it doesn't hit the walls. (This is not dangerous, since if we lose control the plasma simply cools, but we do not want to slowly melt our apparatus, atomic layer by atomic layer). The plasma is heated using microwaves or powerful particle injectors – a bit like steam heating up the milk in a cappuccino.

Tokamak Energy combines two emerging technologies in their fusion experiments: spherical tokamaks and high temperature superconductors. A spherical tokamak is a squashed tokamak that resembles a cored apple rather than a doughnut (**Figures 3**).

Figure 2 *A tokamak with new, high temperature superconducting magnets used by Tokamak Energy. Plasma can be seen in the chamber.*

Containing super-hot plasma is just one challenge of fusion power. A second is to extract energy so that electricity can be generated.

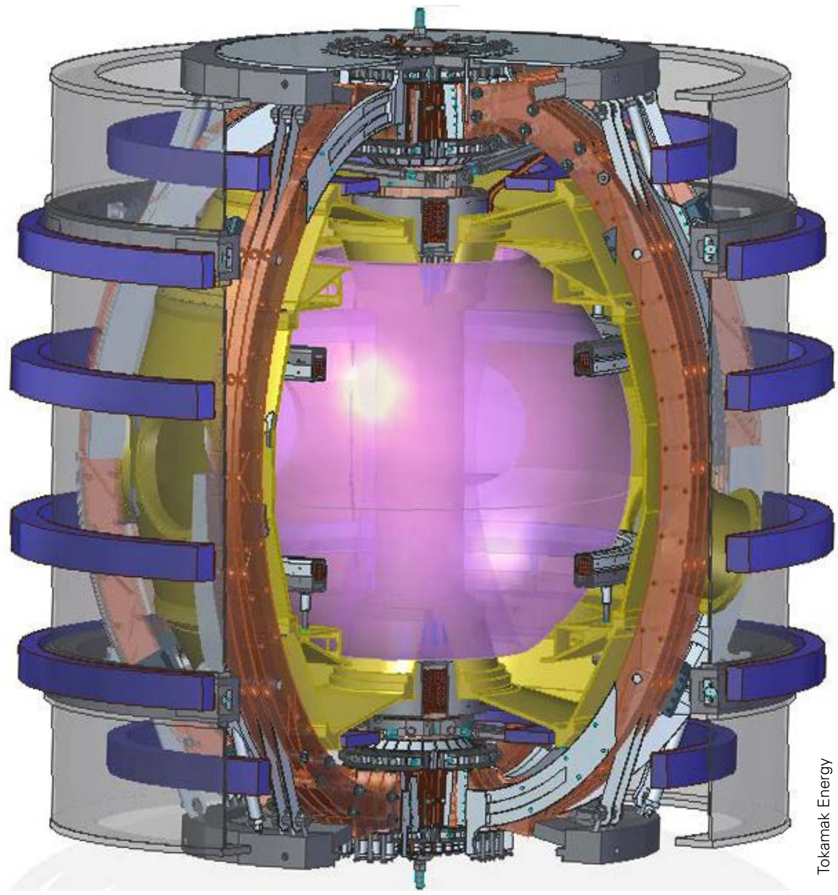


Figure 3 *Inner workings of a spherical tokamak. The plasma would sit in the purple region and the magnets are shown in copper and blue.*

What are high temperature superconductors?

A superconductor is material that has zero electrical resistance when a current is passed through it. Normally this special characteristic is only seen when the material is extremely cold. Conventional superconductors are cooled down to -269°C with liquid helium. A high temperature superconductor, on the other hand, can exhibit this property at a higher temperature of -196°C, about the boiling point of liquid nitrogen. Because of this lower temperature there is a large saving in the energy and costs required to cool the superconductors (**Figure 4**).

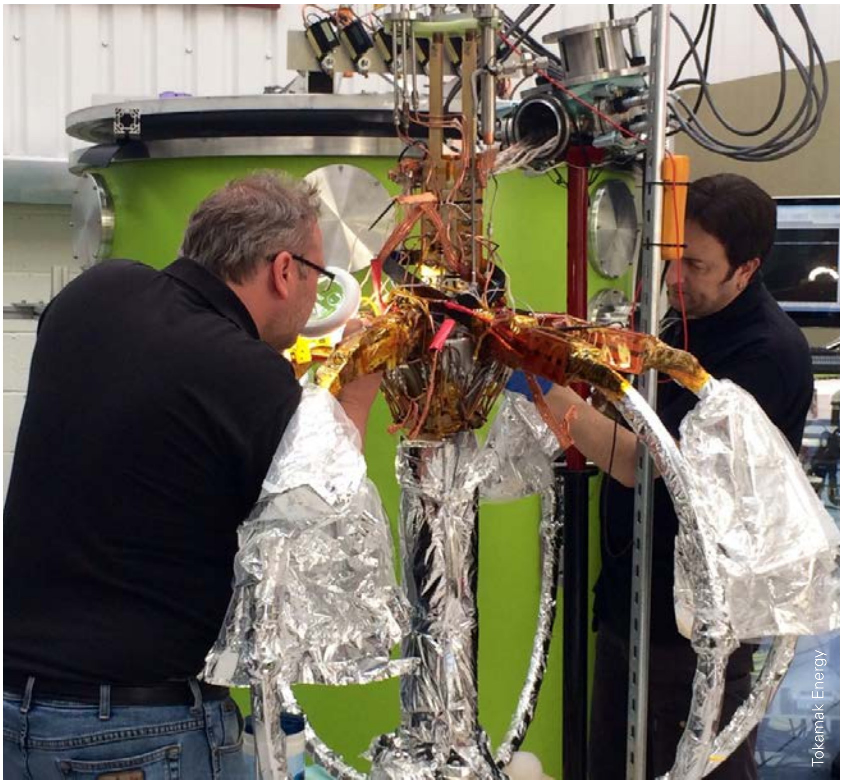


Figure 4 *Assembling the high temperature superconducting magnets.*

A spherical shape and high temperature superconductors – how do these help fusion? Spherical tokamaks offer higher efficiency than conventional tokamaks as they naturally provide a higher plasma pressure for a given magnetic field. This means that the magnetic trap is better than in a regular tokamak. High temperature superconductors generate higher magnetic fields than conventional superconductors, and higher magnetic field equals a better trap.

An added advantage to using high temperature superconductors is that they can be made into narrow tapes that can be wound into magnets that take up considerably less space than magnets made from ordinary superconductors or copper. This works well with the squished design of a spherical tokamak and means we can make smaller machines.

Using these new technologies, Tokamak Energy can build smaller, cheaper machines and therefore make progress faster.

When will we be using fusion power?

If you ask a scientist this question they would probably laugh first and remind you of the big joke, that fusion is 30 years away and always will be. Research into fusion began in the 1950s. Since then we've gained a lot of knowledge about plasmas and fusion, but have yet to get more energy out of our machines than we put in. The current world record for fusion power was achieved by JET (Joint European Torus), the world's largest and most powerful tokamak, based at Culham. In 1997, JET got out 65% of the energy it put in. Tokamak Energy aims to demonstrate fusion energy gain (more energy out of the system than put in) in a compact tokamak in five years, and the first electricity from fusion in ten years (**Figure 5**). In your lifetime, you may be able to see the world powered by tokamaks!

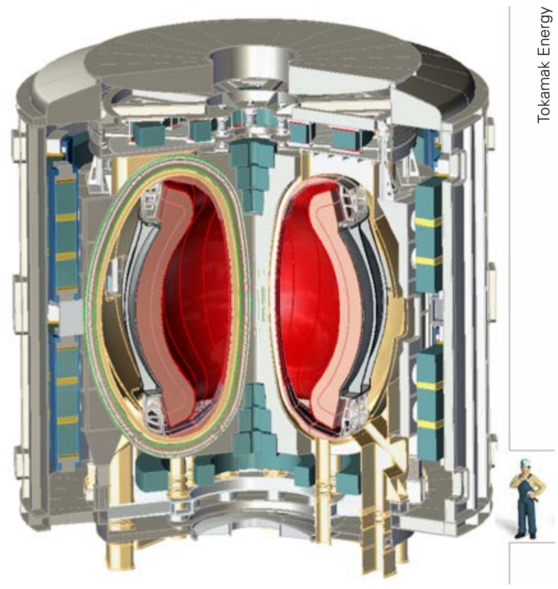


Figure 5 *Tokamak Energy's concept for the first fusion power module.*

However, we must remind ourselves that science can be unpredictable and that we may encounter new challenges in the future, so it is hard to say for certain when we might be using fusion power. The future will hold opportunities to learn new things and – who knows – you could be the next scientist to help turn this dream into a reality.

Meriame Berboucha is a physics student at Imperial College and a keen science communicator; http://meriameberboucha.weebly.com

Look here!

Tokamak Energy hold the world record for holding a plasma in one of their machines for 29 hours! (The previous record was only 5 hours.): *www.tokamakenergy.co.uk*

Twitter: *@TokamakEnergy #fasterfusion*

YouTube: *bit.ly/1QadDVz*

Glaciology in the Himalaya

Duncan Quincey

The Himalaya is the highest mountain range in the world and is home to Mount Everest (8848 metres above sea level). Because of the extreme topography, and an abundant snowfall associated with the Indian Monsoon, many of the world's longest glaciers can also be found here. They represent one of the most stunning natural environments you can see today. Here, a group of glaciologists explain why they are interested in these glaciers, and how they rely on teamwork to be able to better understand how these glaciers are responding to climatic changes.

What is a glacier? A glacier forms when snow accumulates over many years and compresses into glacier ice. What makes them unique is their ability to move. They flow like very slow rivers, mostly downhill and under the force of gravity. There are an estimated 198 000 glaciers in the world, covering around 726 000 km^2.

Working on glaciers is all about teamwork. Glaciologists travel as a team, eat as a team, often they even sleep as a team. During the day they divide tasks among the group, and never work individually. They are in constant contact by walkie-talkie and often collect small amounts of data each that they then collate in the evening into one large dataset to answer their research question.

Dr Phil Porter, University of Hertfordshire

"I supply my hydrology data to glacier modellers so that they can forecast how water supplies may change in the future."

I am a glacier hydrologist and study how meltwater is generated and drains from glacial environments. As glaciers continue to shrink, it's important to understand how this will impact water supplies. Predicting how much meltwater glaciers will produce is not easy though! We need to know how much ice is melted at the glacier surface, but this is complex because thin layers of dark-coloured debris accelerate melt by absorbing solar energy and transmitting it to the ice below, whereas thick debris layers may slow melt, because the debris insulates the ice.

The inside of the glacier is also made up of a complex network of tunnels through which meltwater travels on its way out of the glacier and we can't easily see inside the glacier to understand how this impacts meltwater transport and storage. However, by undertaking fieldwork to measure surface melt rates and flow from the glacier, we are able to build mathematical models to forecast meltwater production.

Himalayan snow and ice melt is a vital water resource for approximately one fifth of the world's population.

This article continues on page 12.

Key words
glacier
glaciologist
water resource
imaging

The picture on pages 10-11 shows Dr Ann Rowan, University of Sheffield, at work.

Measuring discharge from a glacier is much the same as gauging a lowland river anywhere else in the world. Here, Dr Ann Rowan is measuring the concentration of fluorescein dye that has just been injected upstream which, with a bit of calibration, gives the discharge rate at that moment. Photo by Morgan Gibson, Aberystwyth University.

Morgan Gibson

Catalyst

www.catalyststudent.org.uk

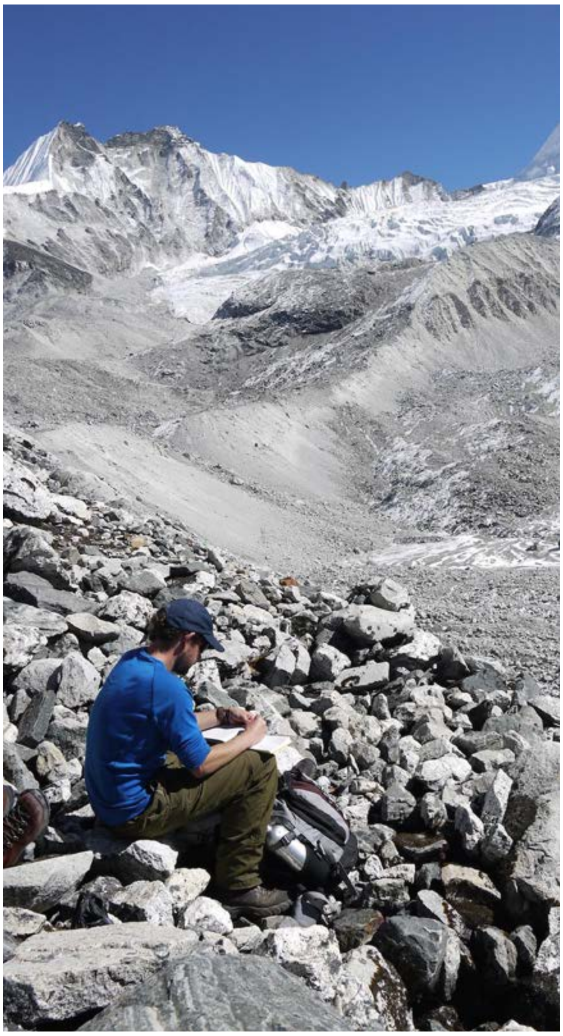
Some glaciologists spend their time abseiling into the glacier and mapping the internal hydrological network – this is known as glacio-speleology.

Glaciers contribute approximately 29% to the current rate of sea-level-rise – that's around 260 000 000 000 tonnes of water melting every year.

At 15 km long and descending from Mount Everest, the Khumbu Glacier is the highest glacier in the world.

Glaciers store about 75% of all the world's freshwater.

Some glaciers are so remote it can take several weeks of hiking just to reach them.



Dr Matt Westoby, University of Northumbria

"I need satellite images from remote sensing scientists to be able to measure how fast lakes are growing and when they might burst."

My main area of interest is glacial hazards and the risks posed by glacial lakes. These lakes form through the growth and merging of numerous small melt ponds on a glacier surface, or when water collects at the edge of the glacier. Glacial lakes can contain a staggering amount of water – for example, the largest lake in the Mt. Everest region, Imja Tsho, contains over 60 million cubic metres of water, which is enough to fill over 25 000 Olympic-sized swimming pools! A large rockfall or avalanche into a lake can release the stored water and produce a devastating glacial lake outburst flood.

My research uses case studies of past flood events to simulate the full range of possible outburst scenarios for glacial lakes. This information is useful for hazard managers, who can then inform local communities of the potential risk posed by upstream glacial lakes.

Dr Tristram Irvine-Fynn, Aberystwyth University

"I need information from glacier hydrologists to be able to understand how my tiny bugs may adapt to changes in water supply."

My scientific research demands I spend lots of time 'in the field', actually walking all over glaciers and the surrounding landscape, making measurements, taking samples and recording any observations I think are interesting or important. Some of these measurements are of microscopic organisms that live on glacier surfaces and are moved around by the meltwater. Amazingly, it turns out there are over one hundred trillion trillion of these micro-organisms living just on the surface of Earth's glaciers and ice sheets!

These tiny life forms have important roles to play in global nutrient cycles and can influence the ecology of streams or ponds that are fed by glacial meltwater. These micro-organisms can also contribute to meltwater production because they contain pigments (to protect them from the Sun's UV rays) or chlorophyll (to photosynthesize, like plants), which makes them darker-coloured compared to the white glacier ice, so that they warm up in the sunlight and help melt the ice. As you might guess then, I work very closely with hydrologists to tackle questions about how glaciers melt.

Becoming a glaciologist

The UK has many hundreds of glaciologists working in research centres and universities. If you enjoy travelling and a bit of adventure this could be a good career to choose – consider taking a science subject (including Physical Geography or Geology) at university and you may end up getting paid to visit some amazing locations!

Dr Ann Rowan, University of Sheffield

"I need field data from all of my colleagues to feed into my glacier models. This way we can make accurate simulations of how fast the glaciers are melting."

I'm a glaciologist and studied Geology and Earth Science at University. I use computer models to describe how glaciers respond to climate change, and to quantify the impact of glacier change on water supplies. Glaciers flow in a similar way to treacle (because ice deforms under its own weight) and we can describe the physics of ice flow mathematically using differential equations.

The changes that we see over time in the shape and volume of glaciers occur because the glacier's mass balance changes either by increasing as more snow is added than ice is melted each year, or decreasing because more ice melts each year than is replaced by snowfall. By making a calculation for the change in glacier mass balance over time and combining this with what we know about the physics of ice flow, we are able to make computer models that can predict how glaciers will change in the future and what this means for the water supply in countries such as Nepal and India.

Dr Duncan Quincey, University of Leeds

"I supply my satellite images to glacier modellers so they can predict how long it is before glaciers disappear."

I am a remote sensing scientist, which means I am interested in any images of the Earth's surface acquired by aircraft or by satellite. The development in this field has been extremely rapid in recent years. We can now routinely collect images from satellites that are more than 400 km above the Earth with a spatial resolution (i.e. the size of each pixel in the image) less than 50 cm. That means we can almost resolve people walking in the street using images acquired from space.

For the glaciers of the Himalaya, this exciting technology means we can do two main things. The first is to quantify rates of glacier surface lowering, which tells us how quickly the glaciers have melted in the past. The second is to detect how fast the glaciers are flowing, which is an important consideration in predicting how quickly they will melt in the future. Although we have such amazing images to work with these days, I never miss an opportunity for fieldwork – it is far more exciting than working in the office!

Working at such high-elevations requires a lot of support from Nepalese porters and Sherpas who are already well-acclimatised. Sherpa people are a particular ethnic group who originate from the mountain regions and so are well-qualified to guide visitors who often have little knowledge of the terrain. Porters are generally not Sherpa people, originating often from the lowlands. They are strong however, carrying loads of 30-50 kg each, in baskets that they wear around their foreheads. Yaks can carry heavier loads (50-100 kg per yak) and often travel in 'yak trains', negotiating precarious looking suspension bridges along the way. The Sherpas, porters and yaks are all critical members of the scientists' expedition team.

Duncan Quincey is a glaciologist in the Department of Geography at the University of Leeds.

Look here!

More information and some amazing images of glaciologists at work:

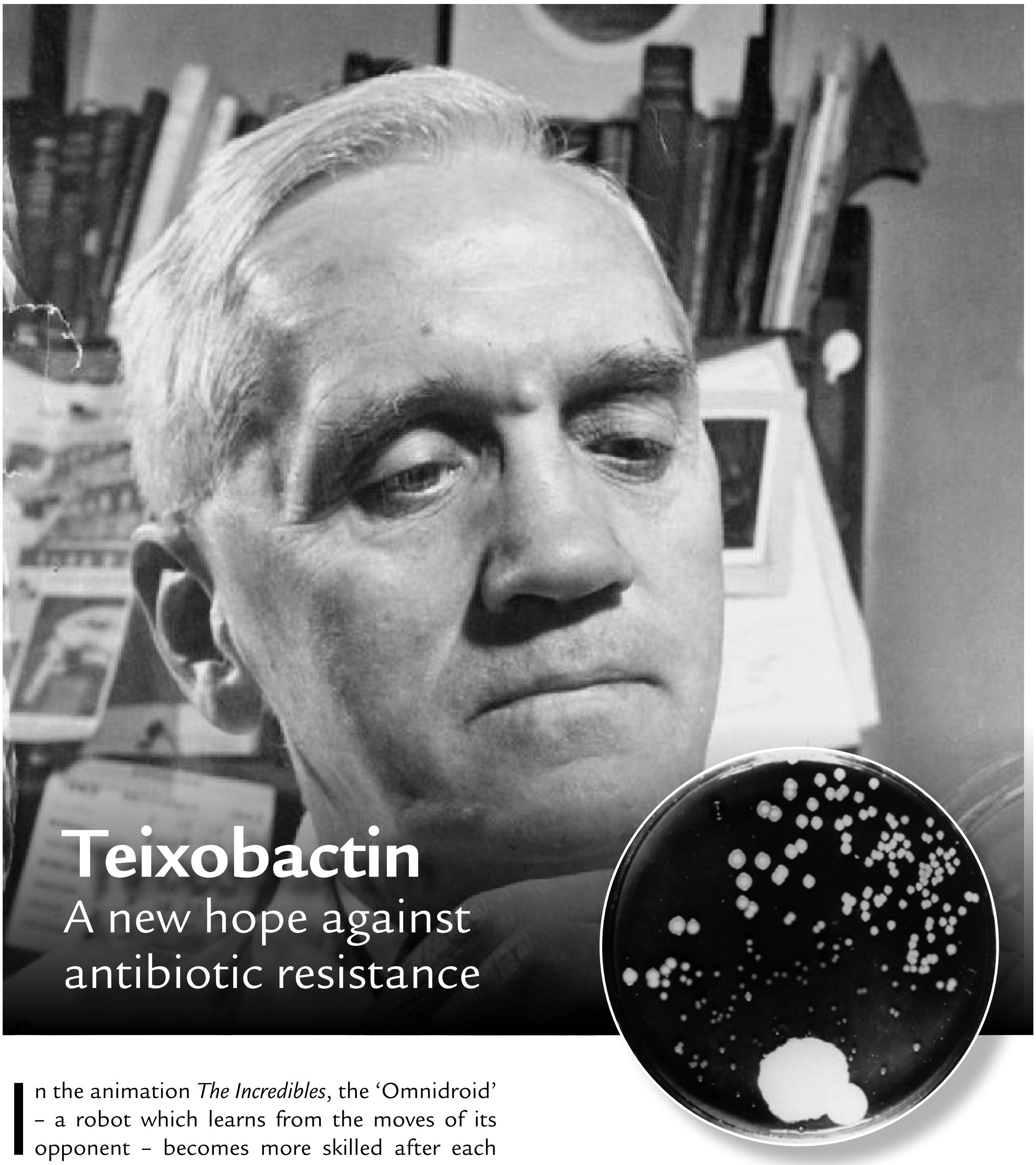
www.swisseduc.ch/glaciers/

www.rockyglaciers.co.uk

Stefania Hartley

Key words
antibiotics
drug resistance
penicillin
bacteria

Teixobactin
A new hope against antibiotic resistance



Alexander Fleming, discoverer of penicillin, at work in St Mary's Hospital in in 1942, together with the plate which he found in his lab on 3rd September 1928. Colonies of Staphyolococcus *are growing normally at the top but in the centre they are severely affected by penicillin spreading out from the* Penicillium *mould at the bottom.*

In the animation *The Incredibles*, the 'Omnidroid' – a robot which learns from the moves of its opponent – becomes more skilled after each fight. Imagine that your adversary is not an artificial intelligence but millions of unicellular organisms, and that they look set to win.

Now you've got the picture of the war between humans and pathogenic bacteria. Thankfully, things might have just started to turn in our favour.

The first antibiotic

On the morning of 3 September 1928, biologist Alexander Fleming returned to his lab from his summer holiday. He wasn't a particularly tidy person so it was no wonder that some of his bacterial cultures were contaminated with a mould. What was wonderful was that the bacteria did not grow around the mould. The mould was *Penicillium notatum*, from which Fleming isolated the first antibiotic, penicillin. Humanity now had a sure-fire weapon against bacterial diseases which, until then, had cost millions of lives and huge suffering.

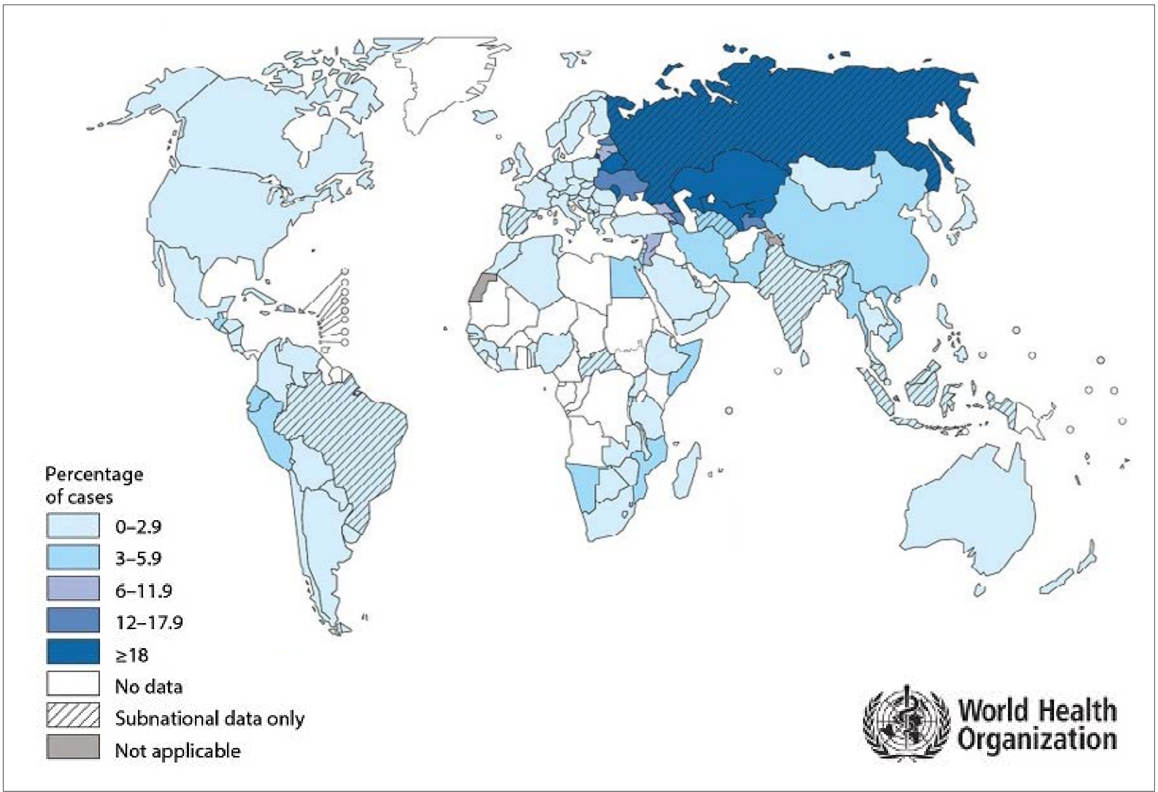
The major problem, at the beginning, was that of getting enough penicillin: it took 2000 litres of *Penicillium notatum* 'juice' to extract enough penicillin to treat one person.

The 'spreading scourge' of antibiotic resistance

Far from being in limited supply, antibiotics are now widely available. Today's issue is a much more pernicious one. Already in 1945, in his Nobel Prize acceptance speech, Fleming had warned against the dangers of bacteria developing resistance to the penicillin. Now – seventy years later – the World Health Organisation (WHO) describes antibiotic resistance as a 'spreading scourge'.

On 30 April 2014, WHO released the first ever global report on antimicrobial resistance, including data from 114 countries. With high levels of bacterial resistance in all regions of the world and a patchy system of monitoring, the report warns of the danger of entering a post-antibiotic era, where microbial infections can again kill.

The situation is made worse by the fact that the speed with which we are discovering new antibiotics is no match for that at which bacterial resistance is spreading. No new classes of antibiotics have entered the market in the last thirty years.



Map showing the percentage of new cases of tuberculosis which are multiple-drug resistant (WHO 2014)

Soil bacteria

For drug companies, antibiotic development is a risky business: bacterial resistance gives antibiotics a limited and unpredictable shelf life. For the same reason, new antibiotics are not widely prescribed. Instead, they are treated as 'drugs of last resort' and used only for cases which are resistant to 'first line' drugs. In addition, the bacterial cell wall makes it difficult for antibiotics to penetrate into the bacterial cell. Synthetic antibiotics have proven much less successful in doing this than natural ones. However, only about 1% of the bacteria that live in soil (the source of most antibiotics) can be cultivated in a lab. By the 1960s, all the cultivable soil bacteria had been fully utilised. The challenge, until now, has been to unlock the secrets of the remaining 99%.

This is what scientists have just achieved, thanks to the diffusion chamber and the iChip, a new device that has made it possible to isolate 10 000 soil bacterial strains and grow them in their own environment.

The diffusion chamber sandwiches bacterial samples between sheets of a material with pores. These pores allow nutrients in and waste out, but trap the bacteria. The chamber is placed in a sample of the natural environment in the lab. This approach allowed thousands more bacteria to be cultured than had ever been achieved in the past.

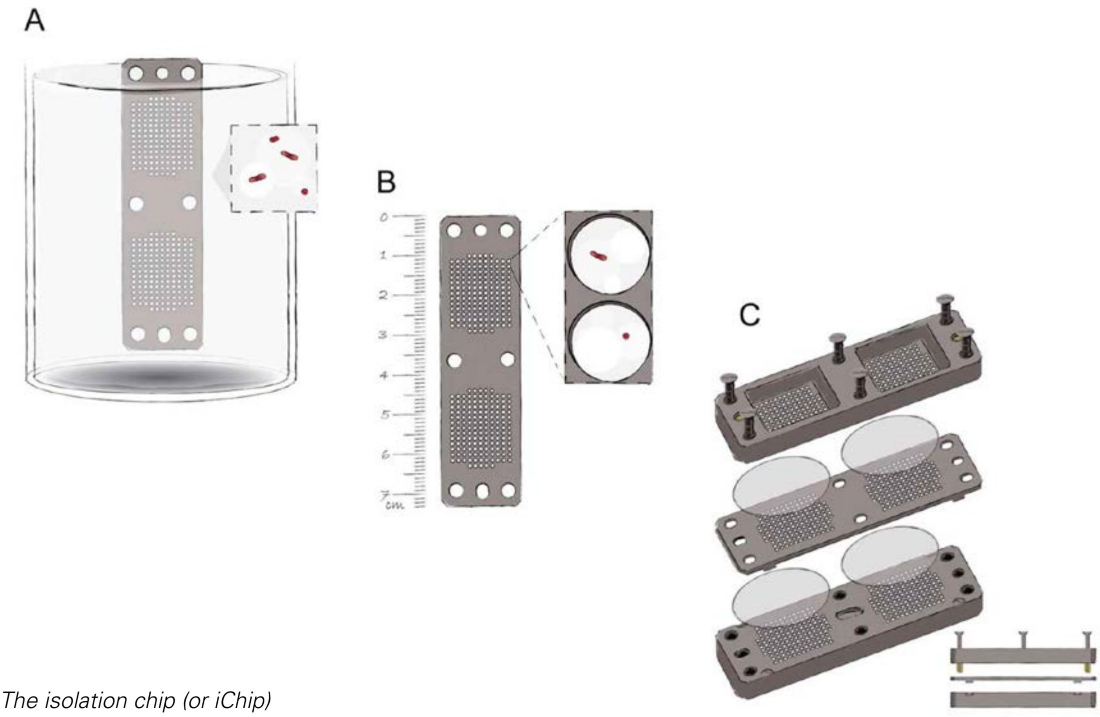
Then came the iChip, a piece of hard plastic with 192 wells in each of two arrays. A scientist just dips it into a sample of the mixed bacteria, thus

Antibiotic resistance

Because of their quick life cycle and their high numbers, bacteria undergo evolution by natural selection very quickly. Thus, resistance against an antibiotic can spread quickly within a population:

- By chance, a mutation occurs in the DNA of a bacterium. The mutation allows it to survive and multiply, even in the presence of the antibiotic.
- The rest of the bacteria – without the favourable mutation – are decimated by the antibiotic.
- The mutated bacterium does not need to compete for resources and can multiply undisturbed.
- In the end, most of the bacteria in that population will be carrying the mutated DNA.

Bacteria are able to transfer their genes vertically (to their clones) and also horizontally to other bacteria of the same species or of other species, in a process called conjugation, during which one bacterium transfers a copy of a ring of DNA called a plasmid to another bacterium.



The isolation chip (or iChip)

trapping (on average) a single cell in each well. The whole is sealed in diffusion membranes and placed in a larger sample of the natural environment. This has allowed isolation of many species of bacteria new to science.


An iChip used for picking up marine sediment in the search for new antibiotics

Teixobactin

The bacterial extracts have been screened for the ability to inhibit the growth of *Staphylococcus aureus*. This has led to the discovery of a new compound with a chemical scaffold unlike that of any of the existing antibiotics. 'Teixobactin' (this is the name given to the new compound, from the Greek: *teixos* = wall) has not only proven successful against a number of pathogens (like *Mycobacterium tuberculosis, Clostridium difficile, Bacillus anthracis*), including those which are resistant to other antibiotics, but it has done so in a completely new way. It binds to two lipids which are the precursors of the bacterial cell wall's peptidoglycan and teichoic acid.

This is great news on the bacterial resistance front: whereas proteins are coded for by stretches of DNA – which may mutate – lipids are synthesized by the cell from organic precursors, which are unlikely to change.

The chances of bacterial resistance are reduced also by the fact that teixobactin affects Gram-positive bacteria but is produced by a Gram-negative bacterium, provisionally named *Eleftheria terrae*. Surrounded by an impermeable outer membrane and lacking teichoic acid, *Eleftheria terrae* is unaffected by teixobactin, and does not possess any specific mechanism to inactivate teixobactin (which could potentially be passed horizontally to other bacteria – see Box *Antibiotic resistance* below). It is not surprising, then, that lab trials did not show the development of strains of *Staphylococcus aureus* or *Mycobacterium tuberculosis* resistant to teixobactin, even when a low dose of the antibiotic was used.

There are good reasons to be optimistic about the future. Still, we'll need to make a tactical and disciplined use of our new weapon if we want to win against our own 'omnidroid'.

Stefania Hartley is a science teacher living in Singapore.

What you can do

As recommended by the World Health Organisation:

- Use antibiotics only when prescribed.
- Complete the full treatment course, even if you feel better.
- Never share antibiotics or use leftovers.

Find out more about microbial resistance: *www.who.int/mediacentre/factsheets/fs194/en/*

Mike Follows

Going into reverse?

How Earth's magnetic field is changing

The Earth's magnetic field helps us navigate over its surface. It also protects us from the solar wind – a stream of high energy particles pouring out from the Sun. Now scientists have shown that the strength of the Earth's field is decreasing. So are we heading for one of the periodic reversals of the field which we know have happened in the past? And what might this mean for life on Earth?

Key words
magnetic field
dynamo
electric current
plate tectonics

What generates the geomagnet?

Figure 1a shows the structure of the Earth. Both the solid inner core and the liquid outer core are made of metal, mainly iron with some nickel. Diagrams in textbooks often suggest that the Earth's magnetic field behaves as if the Earth is skewered by a giant bar magnet, aligned about 11° from its spin axis – see **Figure 1b.**

The real explanation is more complicated. As the molten outer core freezes to become part of the solid inner core, latent heat is released. This heat drives convection currents in the outer core. Because the core is metallic it contains de-localised electrons. The convection currents and the spin of the Earth cause these electrons to move and so to form electrical currents. This generates a magnetic field whose direction is given by the right-hand grip rule.

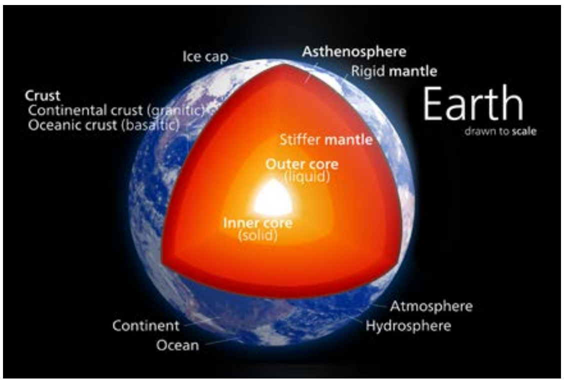


Figure 1 *The structure of the Earth – the magnetic field is thought to arise from electric currents in the metallic outer core.*

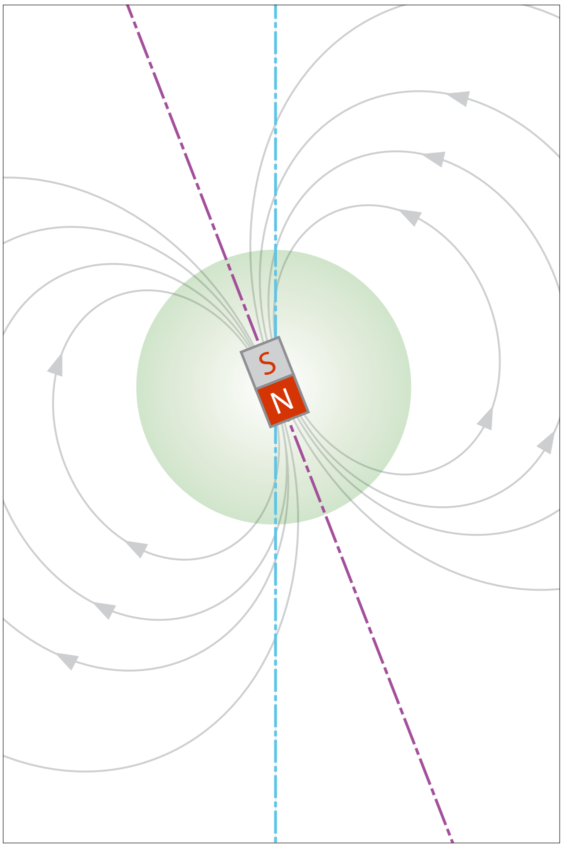


Figure 2 *The axis of the Earth's magnetic field (blue) is tilted relative to its axis of rotation (purple).*

Bar codes and how we discovered flipping fields

In the late 1950s, the USA and USSR had developed military submarines to help them wage the Cold War. This motivated the US Navy to secretly map the ocean floor as a potential battlefield, leading to the discovery of mid-ocean ridges in the Pacific. When molten rocks intrude between the diverging plates at mid-ocean ridges, grains of magnetite act like little compasses. At high temperatures they are free to change direction because thermal vibrations prevent any alignment. However, as the rock cools below its Curie temperature, the preferred direction of the magnetite becomes fixed – and aligned with the direction of the Earth's magnetic field prevailing at that moment.

By towing a magnetometer behind a ship, scientists can measure variations in the magnetic field on the seabed. Where the rocks beneath the magnetometer have reversed polarity the total magnetic signal is relatively weak, coloured white in **Figure 3**. In contrast, when the magnetic field of the rocks is in the same direction as the Earth's field, a stronger magnetic signal is detected (coloured black).

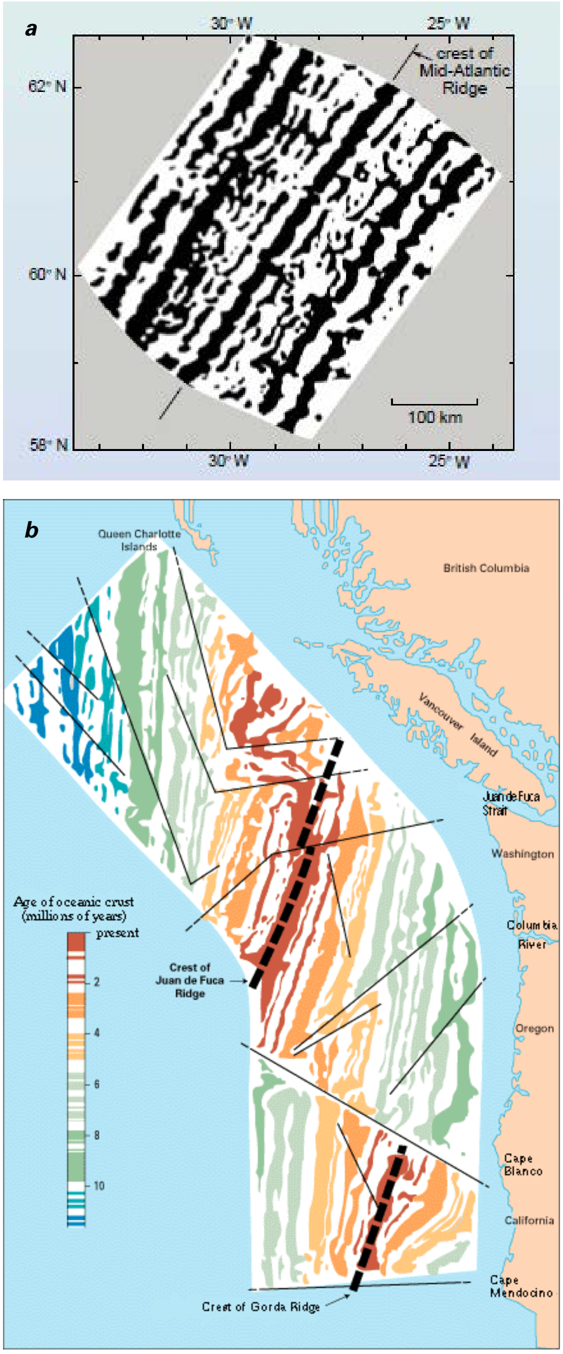


Figure 3 a *Stripes of opposite magnetisation on either side of the mid-ocean ridge in the North Atlantic, near Iceland. The symmetry of the pattern shows that the seabed formed from material gradually pushing outwards from the ridge in both directions.* ***b*** *In this more recent data from the north-east Pacific, white stripes represent reversed magnetisation. Colouring shows the age of the crustal rocks. The pattern of alternating stripes is clear, but it is broken up by fault lines caused by the movement of tectonic plates.*

Scientists had unwittingly discovered the mechanism for plate tectonics, and provided support for the continental drift hypothesis championed by Alfred Wegener, which he used to explain the near-perfect jigsaw fit of Latin America with Africa. Driven by convection currents in the mantle, ocean-floors move tens of millimetres per year, the same speed as fingernails grow.

It quickly became clear from the marine magnetic anomalies that the Earth's field has collapsed and reversed more than 60 times in the last 20 million years, about once every 300 000 years on average. Because reversals are random, the date of the next one cannot be predicted but we know that the last reversal took place 778 000 years ago so perhaps the next one is overdue – and evidence is mounting that our magnetic field is getting weaker.

Using ships logs

Until recently, scientists were only able to trace the magnetic field's behaviour back to 1832, when Carl Friedrich Gauss invented the magnetometer, the first device to measure both the strength and direction of the field directly. But ships' logs have now been studied allowing scientists to look further back in time.

We can navigate by the Sun and stars but a compass has the advantage that it can be used even when clouds obscure the heavens. Early ocean-going explorers like Captain Cook measured the declination and sometimes the inclination of the Earth's field (see **Figure 4**). Professor David Gubbins and his team of researchers at Leeds University believe that these measurements were very accurate given that 'their lives depended on it'. Using the locations of the ships at the time measurements were taken by Captain Cook and other explorers has allowed the Gubbins team to construct a map of the relative strength of Earth's magnetic field since 1590.

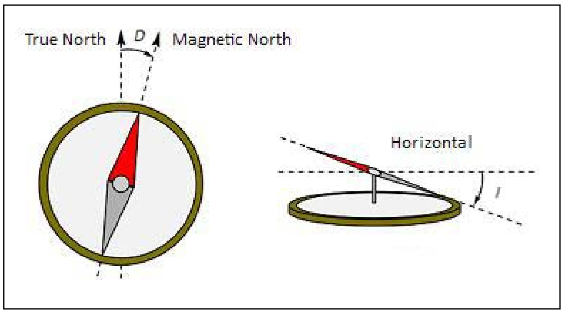


Figure 4 *Two important angles:* ***declination****, the angle D between geographic and magnetic North, and* ***inclination****, the angle I that a freely suspended magnet makes with the horizontal.*

They have discovered that the Earth's magnetic field has been weakening at a rate of 5% per century since 1860 and we might be heading for a reversal. However, Gubbins says that the decline is almost entirely due to the South Atlantic Anomaly (SAA), an area where the Earth's field strength has fallen dramatically (**Figure 5**).

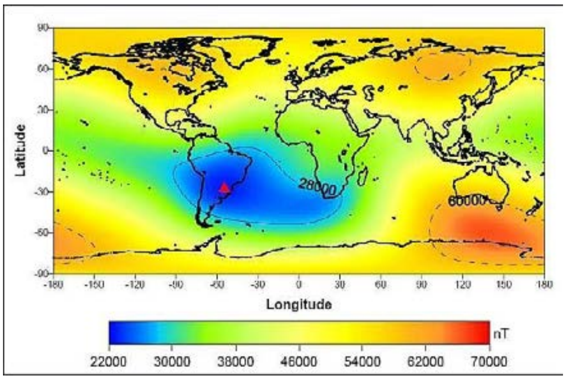


Figure 5 *The Earth's magnetic field is weakest at the South Atlantic Anomaly, an area which shows up clearly on this map. Field strength is shown in units of nanoteslas (nT).*

Different approaches

The appearance of the SAA might be further evidence of a reversal because computer modelling suggests that reversals get complicated. As **Figure 6** shows, several new poles may appear in odd places before the geomagnet returns to the familiar dipole pattern (i.e. a north and south pole) but with the poles swapped over.

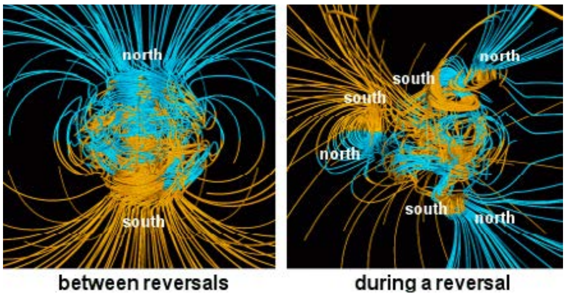


Figure 6 *Computer modelling shows how the familiar pattern of the Earth's magnetic field (left) can become entangled in the course of a magnetic reversal.*

Gauss started a network of observatories based on the magnetometer he developed in 1832 but, because this network was patchy, NASA launched the MAGSAT satellite in November 1979, which collected data for about six months. This has led to a greater understanding of the Earth's magnetic field. To enhance our understanding still further, at the end of 2013 the European Space Agency launched three identical Swarm satellites to monitor the Earth's field from different orbits.

Getting experimental

In a further bid to understand what is going on, Daniel Lathrop and his colleagues at the University of Maryland have set up a spinning sphere of molten sodium to act as a model of the Earth's core (**Figure 7**). They are hoping to show that the spinning sphere acts as a dynamo, generating its own magnetic field. Sodium is the best liquid metal conductor available and melts at the relatively low temperature of 100°C. The downside is that sodium is highly reactive and, if the spinning sphere were to rupture, it would probably explode.

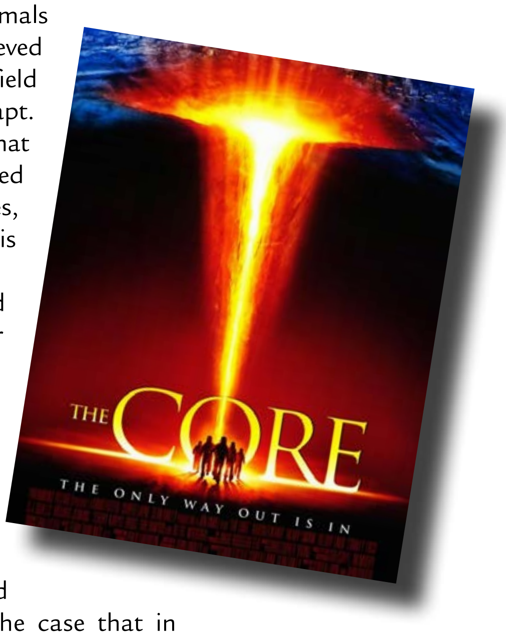
Figure 7 *This 3 m diameter sphere contains molten sodium, a metal. When set spinning, electric currents may be produced, resulting in a magnetic field. But will it be similar to the Earth's?*

The 3-metre dynamo experiment continues a tradition started by William Gilbert, who published *De Magnete* in 1600. In it he describes many experiments with his *terrella*, the model Earth he had constructed out of lodestone (**Figure 8**). He correctly concluded that the Earth is magnetic and dispelled the myth that the North Star (Polaris) or a large magnetic island at the North Pole was attracting compass needles. Given that nothing surpassed his work on magnetism for more than two centuries, it is surprising that his contribution is largely forgotten, particularly as a pioneer of experimental science, whose approach greatly influenced Galileo and those who followed.

Assessing the future

Unlike dramatic portrayals of geomagnetic phenomena in Hollywood films such as The Core, it would probably take thousands of years for the Earth's north and south poles to actually swap. This might allow migratory animals such as birds, which are believed to rely on the geomagnetic field for navigation, time to adapt. A few scientists believe that past reversals have caused mass extinctions of species, though the evidence for this is weak.

However, the solar wind would penetrate further into our atmosphere so there may be an increase in the amount of ionising radiation reaching the ground. Evolution might proceed at a slightly faster pace with the increase in background radiation. It is certainly the case that in the last 10 million years humans have survived 30 reversals and will undoubtedly survive the next.



The Earth's core has stopped spinning – scientists rush to set it in motion once more.

Mike Follows teaches Physics. In a future article, he will describe how a declining magnetic field might prove hazardous for many of our everyday technologies.

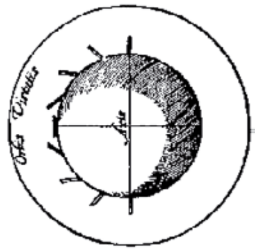


Figure 8 *William Gilbert invented this 'terrella' to explain the Earth's magnetic field. It is made of magnetic lodestone and shows how compass needles align at different points on the Earth's surface.*

Gary Skinner

The Ebola outbreak
Tackling a new disease

Workers at the Red Cross Ebola treatment centre in Kenema, Sierra Leone.

Key words
- Ebola
- virus
- antibodies
- vaccine

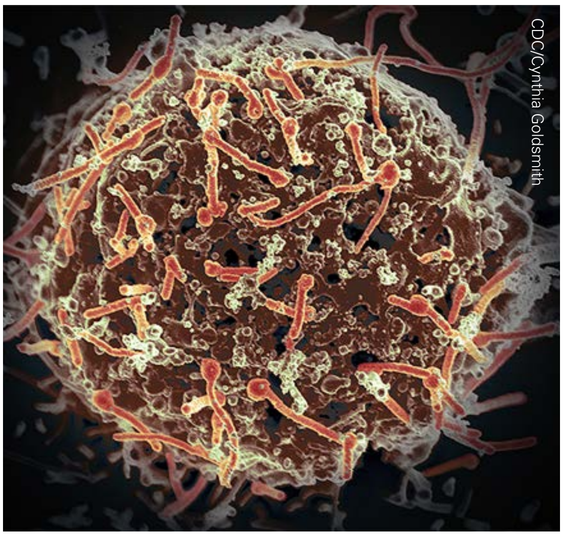
In 1976 a new and deadly disease, Ebola, appeared in Africa. In Sudan, 284 people were infected, 151 of whom died. In northern Zaire there were 318 cases with 280 deaths. In 1995, 254 died in Zaire. Through the early 2000s sporadic outbreaks occurred in Uganda and the Republic of Congo, claiming hundreds more lives.

Then, in March 2014, a new outbreak of the disease began in West Africa. The disease seems have begun in a two year old child called Emile Ouamouno or, in the epidemiological literature, 'patient zero'. Emile died in December 2013 in the village of Meliandou, Guinea. Very soon after, members of his family also died, as did a nurse, a doctor and other health workers. The disease quickly spread to Conakry, the capital of Guinea with a population over 1 million. From there it quickly spread into neighbouring Liberia and then on into Sierra Leone, Nigeria and, by the summer of 2014, Senegal.

By the end of the summer of 2015 the World Health Organisation (WHO) reported 28 256 cases with11 306 deaths, a mortality rate of 40%. They went on to say that this might be under reported by as much as 70%. They also stated that 10% of the dead were health workers.

Cause and origin

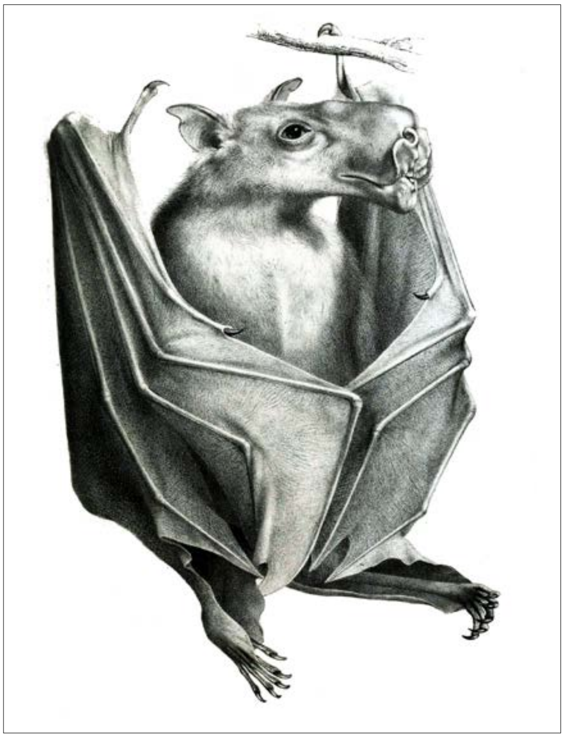
Ebola is caused by the Ebola virus. The symptoms include fever, headache, joint and muscle pain, vomiting and diarrhoea. It has a 50–90% death rate, occurring just one to two weeks after symptoms start.



The Ebola virus (red 'worms') attacking a single human cell.

Although no one is yet sure, the natural reservoir may be in fruit bats of the family Pteropodidae. The only species in this family that has yielded Ebola RNA is the hammer-headed bat (*Hypsignathus monstrosus*). No one knows how bats infect humans, even if they are the reservoir. Simple contact is assumed to be the mechanism. The range of this species certainly fits with the occurrence of the disease.

Once a human is infected, Ebola is spread via body fluids containing the virus, such as blood, diarrhoea, sweat, vomit, urine, semen or breast milk which can enter the mouth, nose, or eyes. The virus may also enter in these fluids through a cut.



The hammer-headed bat

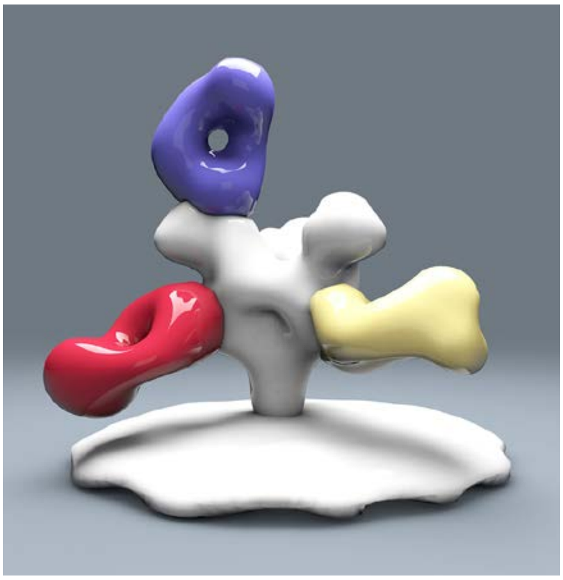
What can be done?

The key for the containment of viral diseases such as Ebola, against which antibiotics do not work, is very strict hygiene surrounding treatment and burial of victims. In addition, contact tracing and quarantine are vital.

The severity of the recent West African outbreak of Ebola coupled with the high mortality rate has led to some unprecedented actions. Drugs against Ebola, in the early stage of development, have been fast tracked and tried on patients at a stage in the development earlier than would normally be allowed.

One of these is ZMapp™, a cocktail of three monoclonal antibodies, requiring three separate manufacturing processes. Each is manufactured in tobacco plants and the process is very slow, so availability is currently low. So far, ZMapp™ has been used on seven sufferers, two of whom subsequently died.

The three antibodies are designed to join to glycoprotein spikes on the outer coat of the virus. These spikes are essential for virus entry into cells and the idea is that the antibodies will prevent this from happening.



A model showing the ZMapp antibodies (coloured) which attach to the glycoprotein which Ebola uses to recognise host cells, thereby blocking it

Ebola, contagious and dangerous, has given rise not only to tens of thousands of cases and many deaths, but a change in the way we look at epidemic diseases, their containment and treatment.

Gary Skinner is Biology editor of Catalyst

A vaccine against Ebola

Scientists are developing a vaccine to protect people from Ebola. They started trials in March 2015. It's tricky work as the vaccine must be kept cold, at −80°C.

Mohamed Soumah, 27 years old, was the first person to receive the Ebola vaccine. "It wasn't easy. People in the village said that the injection was to kill me. I was afraid. I was the first one to be injected, the very first, here in my village. I've been monitored for 3 months and I've had no problems."

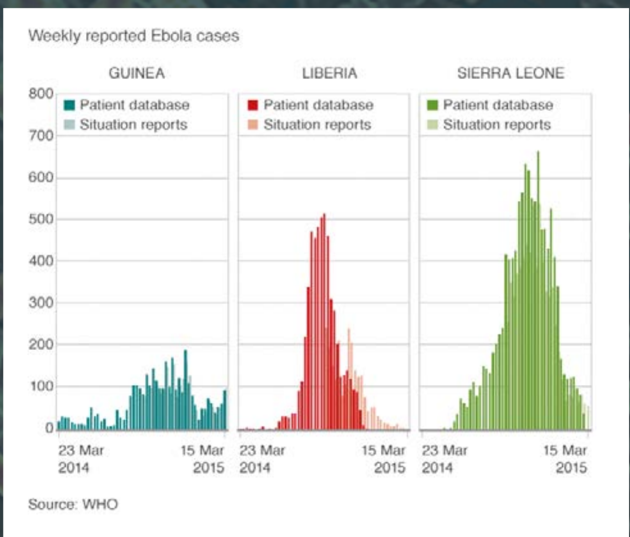
Turn to the next page to learn more about how the Ebola outbreak of 2014-15 was brought under control.

Responding to Ebola

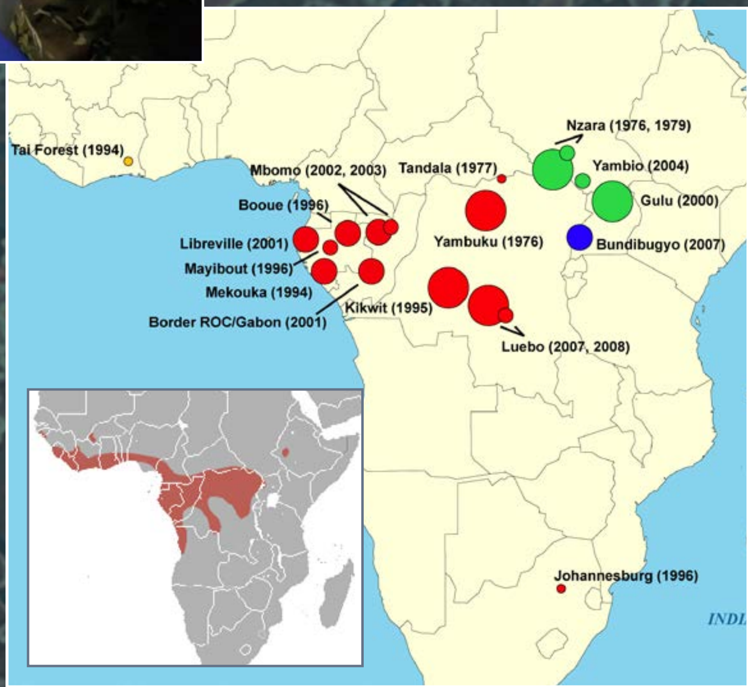
The Ebola outbreak of 2014-15 was brought under control by the application of strict hygiene measures. A parallel effort focused on development and trials of a vaccine.

A medical team from the UK's National Health service is trained at York before travelling to West Africa.

One of several World Health Organisation teams prepares for vaccine trials in Guinea.



In Liberia, the spread of the disease was brought under control within six months; it took longer in other countries.



Is Ebola transmitted by fruit bats? These maps show the distribution of the hammer-headed bat (inset) and outbreaks of Ebola in Africa.

A poster in Monrovia, Liberia, gives advice on how to avoid becoming infected.

An over-reaction? CNN compares Ebola to the threat from the ISIS terrorist group.