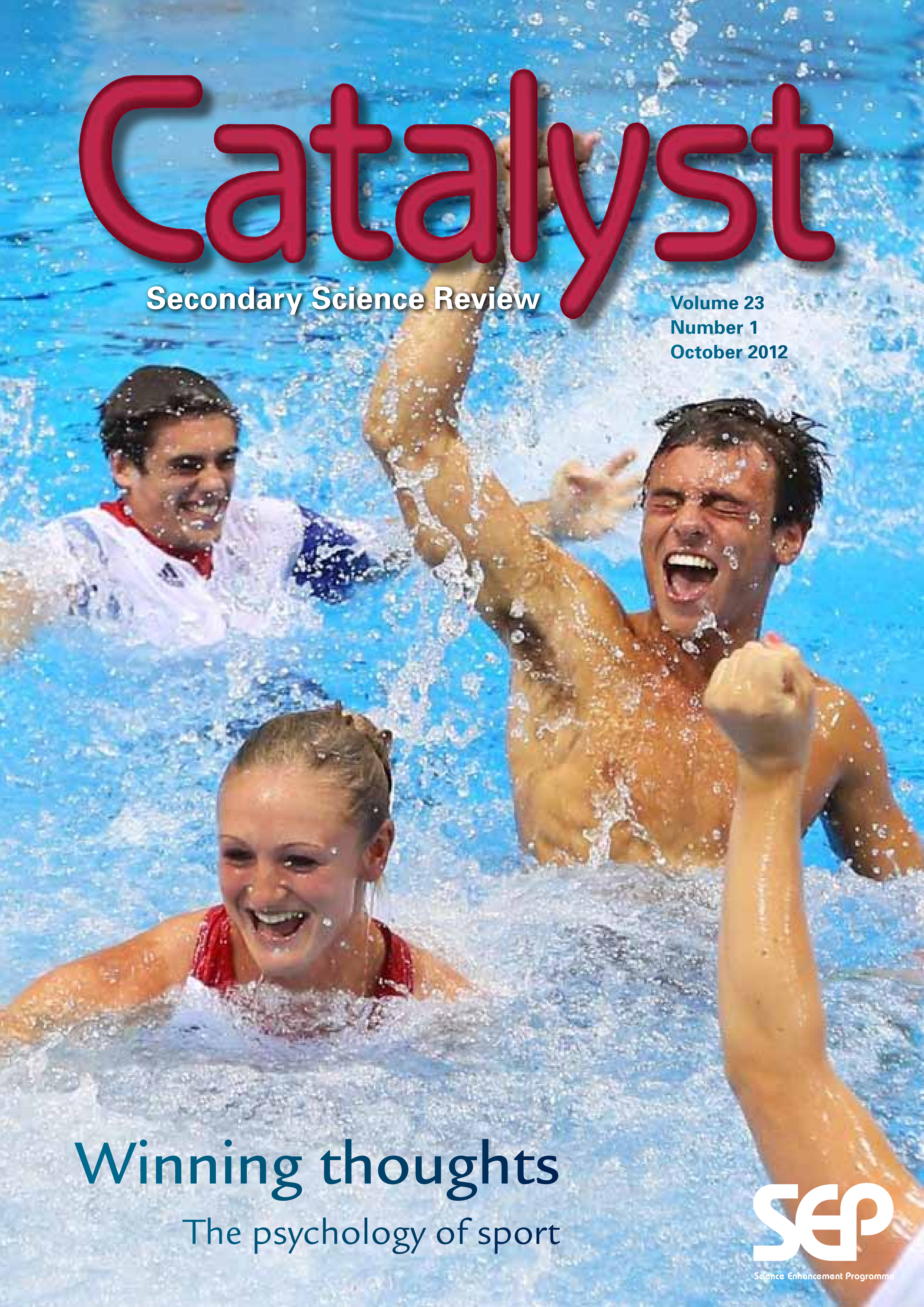

Catalyst

Secondary Science Review

Volume 23
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October 2012

Winning thoughts

The psychology of sport

SEP
Science Enhancement Programme

Catalyst

The cover image shows Tom Daley and other Team GB members celebrating his winning of a bronze medal in the diving competition at the London 2012 Olympic Games. See the article on pages 1-3. (Image courtesy of ODA.)

Volume 23 Number 1 October 2012

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Pushing the boundaries

NASA's Curiosity rover is now at work on Mars and is likely to greatly increase our knowledge of that planet. This is a formidable achievement, made possible by teams of scientists and engineers from several different countries. They have had to develop new instruments for chemical analysis to be carried out remotely, and they had to land the rover on a small target area after a journey of over half a billion kilometres. See the article on pages 4-5.

CERN, the European Centre for Nuclear Research, is also in the news. Again, large teams of scientists and engineers have been involved and as the articles on pages 19-22 show, their work is helping to reveal some fundamental properties of the matter which makes up the Universe.

Psychology is a relatively young science. It is still difficult to know what are the important factors which affect how our minds work, and how to measure them. The article on pages 1-3 describes some of the latest thinking on how athletes can develop ways of thinking which can help them to say, "I am the greatest!"

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Mark P. Otten

Ashley A. Samson

"I am the greatest"

How believing in yourself can influence performance

"If you believe it, you can achieve it." This is one of the most-used motivational quotes aimed at encouraging people to understand that they can be successful if they believe in their abilities. In this article, **Mark Otten** *and* **Ashley Samson** *discuss the science behind motivation in sport.*

Scientists have researched self-beliefs and success in a number of domains such as business, family, education, and life in general. In the sport domain, researchers have spent many years trying to understand how athletes who believe in themselves generally attain more success than those who are plagued with self-doubt.

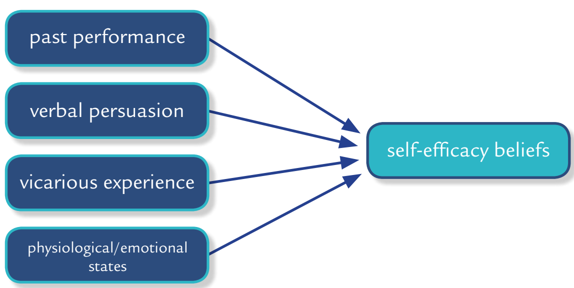
Self-efficacy

Self-efficacy can be defined as beliefs about your abilities to be successful in a given task. For example, if someone asks you to shoot a basketball, you will most likely make some sort of judgment about your probability for success in the task. That belief about whether or not you will be successful (am I going to make this or not?) is your self-efficacy.

Self-efficacy theory was developed by famous psychologist Alfred Bandura in 1986 and it says that people will be more likely to engage in behaviours that they believe they can successfully perform, and avoid behaviours in which they feel that they will be unsuccessful. People with high levels of self-efficacy are more likely to pursue challenging goals, cope with pain, and persevere through setbacks, thus leading to success on the field. On the other hand, those with low self-efficacy avoid challenges and tend to give up when confronted with obstacles, which can lead to impaired performance.

Sources of self-efficacy

Since self-efficacy has been shown to be a strong influence on performance in athletes, it is important to understand where those beliefs come from. According to researchers, self-efficacy perceptions are the product of four main sources of information: past performance accomplishments, verbal persuasion, vicarious experience/modelling, and physiological/emotional states.



When investigating a new idea, scientists must ask: what factors contribute to this? Here we have identified four factors which may contribute to self-efficacy.

The referee declares Nicola Adams the flyweight boxing winner at the London 2012 Olympic Games.

Key words

sports psychology

self-efficacy

motivation

coaching

"I believe strongly in my capabilities. There's a lot of confidence as well, with my record over the past few years. I've built up this feeling on big points that I can do it over and over again."

Roger Federer, 2004

Verbal persuasion

Verbal persuasion is a second influence on efficacy beliefs and can come in the form of feedback and speeches given by coaches or others, expectations of others, or even self-talk. Confidence in your abilities can be influenced by the encouragement, or discouragement, of other people, especially those whose opinions are greatly respected (i.e. peers, significant others, superiors).

In most sports, coaches rank pre-game speeches as the one of the most effective methods for raising the efficacy beliefs of their athletes. In the previously mentioned study on distance runners, one athlete commented on how encouragement influenced her beliefs in her abilities for running the marathon distance, "If it was just me and I didn't have any encouragement from others, I don't think I could stay confident in the marathon" and "knowing that my friend is there with me, telling me I can do it, that boosts my confidence....She's a big part of it."

Jessica Ennis, winner of the women's heptathlon at the London 2012 Olympic Games. She has a degreee in psychology from the University of Sheffield.

Women's basketball: Russia plays Australia for the bronze medal at the London 2012 Olympic Games.

Vicarious experience

Self-efficacy is also influenced by vicarious experience. Learning through vicarious experience, also known as modelling, is when you learn by watching someone else successfully perform the desired task. By watching someone like you experience a positive outcome in a desired behaviour, your confidence in your chances for success are enhanced, which leads to higher self-efficacy beliefs.

For example, a research study with Ironman triathletes found that athletes competing in their first race felt high self-efficacy for completing the race based on watching friends who finished the race previously: "I kind of compare myself to my friends, and if they have done it and survived, I can do it."

Team-talk from a coach is important at all ages.

Nan Zhang and Yunlei Zhao of China celebrate winning gold in the Mixed Doubles Badminton

Psychological information

The last source of efficacy information is physiological information, which is basically the physical feelings and processes happening in your body. Physiological information can include perceptions of strength, fitness, fatigue, or pain and can be measured by aerobic capacity, heart rate and perceived exertion levels (how hard you feel you are working). In sports, this is really important because of the physical nature of the activities and if you feel good physically, you will feel higher efficacy beliefs for being successful in the activity.

For example, if someone asks you to swim five hundred metres and you feel energetic and loose, the chances are that you will feel high efficacy beliefs towards swimming, while on the other hand if you feel tired and stiff, your efficacy beliefs will most likely be lowered. Going back to the distance runners from earlier, one athlete said, “When I feel strong, I know I can do something...if my body feels up to it, I know I can do it.”

Confidence and perceived control

Today, sport psychology researchers have taken Bandura’s theories one step further to study an athlete’s efficacy expectancies within a particular sport. That is, Michael Jordan might have been quite confident when he was playing basketball, but not so much when he was playing rugby. So when we as researchers ask an athlete how confident he or she is, we need to specify which sport or activity we are talking about (e.g. “How confident are you that you have the ability to improve and become more successful in basketball free throw shooting?”).

To be successful, especially when there is pressure in sports, it is important to be confident. If you expect success, then you are more likely to be “clutch” (see Box). In fact, some recent research has shown that there is a specific component of this kind of positive thinking that is especially important in the big moment: perceived control. Have you ever experienced a feeling of complete control when playing a sport, or when giving another type of performance? Maybe you play a musical instrument: have you ever given a good performance when there is pressure, like when a large audience is watching?

Who is a clutch player?

The concept of “clutch” is central to our understanding of sports. Simply put, a clutch player is one who performs better when the game is on the line. The usual criterion for recognizing “clutchness” is something along the lines of, “If your life depended on a jump shot/putt/hit being made, whom would you want to attempt it?” For most people, the answer would be Michael Jordan or Tiger Woods.

Could you be clutch?

What the recent research says is that these feelings of intuition or control are most important when there is pressure, like at the end of the game and/or when your parents are watching. Don’t think about it; just shoot the ball. Researchers in the past have termed this “explicit monitoring theory”. That is, if you consciously monitor what you are doing, or remind yourself to pay attention while playing, this is actually a bad thing when there is pressure. This will only increase your anxiety! Instead, be like Michael Jordan: feel confident, in control, and just rely on your intuition. Maybe you can be “clutch” too!

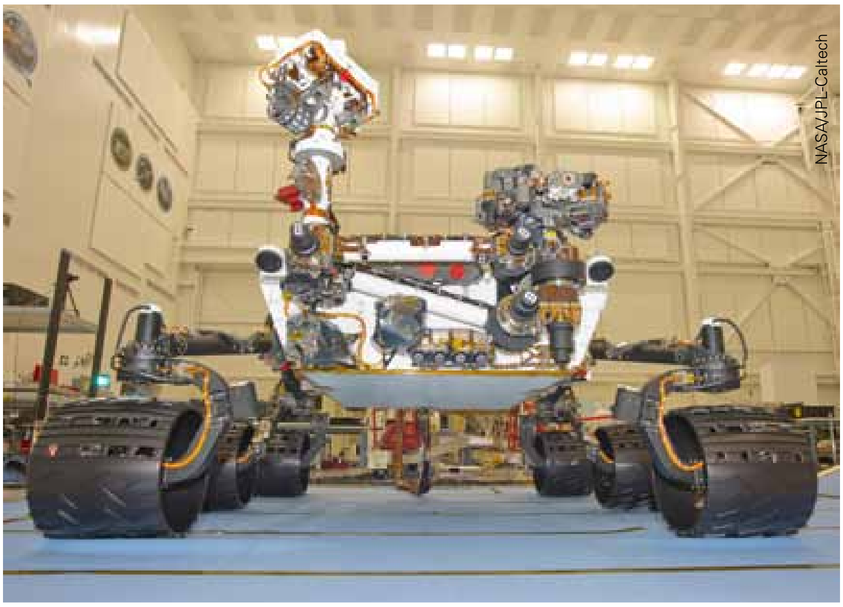
Dr Mark P. Otten and Dr Ashley A. Samson are assistant professors at California State University, Northridge, USA.

David Sang

Curious about

NASA's Mars Science Laboratory landed safely in Gale Crater on the night of 5th/6th August 2012. Ahead are two years of experiments as the Curiosity rover trundles around at an average speed of 30 metres per hour.

Previous rovers have photographed the surface, while orbiters have given us an initial impression of the planet's surface geology. The new rover will be able to select rocks and soil of interest and carry out chemical analyses of them.



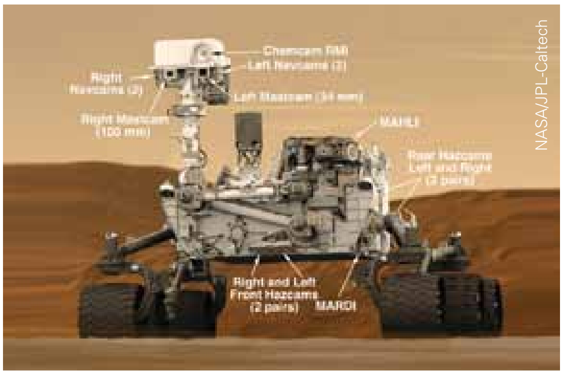
The NASA Mars Science Laboratory rover, Curiosity, seen during mobility testing in June 2011 at the Spacecraft Assembly Facility at NASA's Jet Propulsion Laboratory, Pasadena, California.

Landing on Mars

NASA developed the 'sky crane' used to drop Curiosity gently on the surface of Mars. Four rocket motors fired vertically downwards to slow the descent through Mars' thin atmosphere.

17 cameras

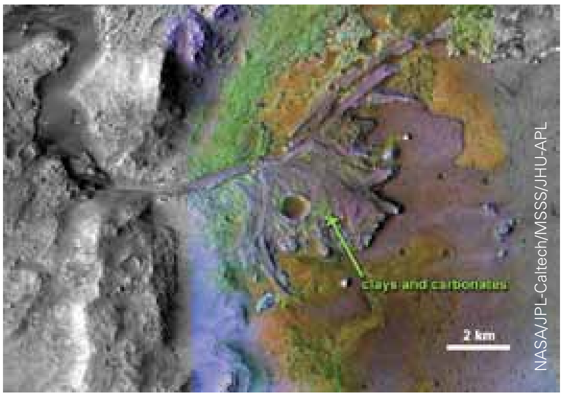
- Curiosity's two Mast Cameras take photographs of its surroundings. They have different focal lengths (34 mm and 100 mm).
- Also on the mast are four navigation cameras and the Remote Micro Imager, part of the Chemistry instrumentation.
- Eight hazard cameras ensure that Curiosity doesn't run into obstacles.
- MAHLI is the Hand Lens Imager, fitted to the end of a robotic arm.
- MARDI is the Descent Imager, used during the rover's landing.



Signs of life

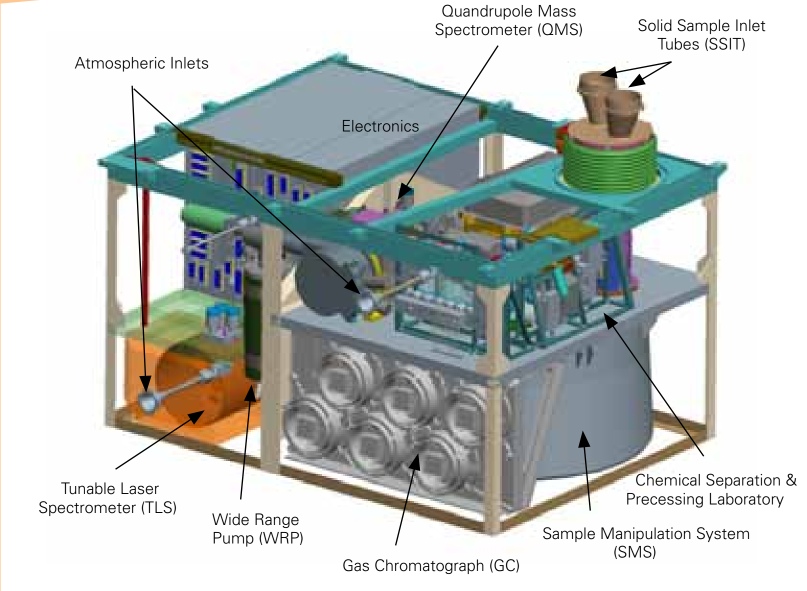
Curiosity is searching for chemical traces of life. We already know that, at some time in its past, water flowed on the surface of Mars. The Jezero Crater delta was formed when water flowed into a large lake.

A spectrometer on board NASA's Mars Reconnaissance Orbiter analysed reflected light from rocks in the delta and showed that they contain clays and carbonates, substances which form when water is present.



This image of Jezero Crater has been coloured to show the different minerals present.

Mars



The SAM chemistry lab will analyse martian rocks and atmospheric gases to find their chemical composition, together with the relative proportions of different isotopes.

Chemistry lab

The Sample Analysis at Mars instrument (SAM) is a miniature chemistry lab which will analyse martian gases.

- Curiosity's robotic arm drops a sample into the Inlet Tube.
- The solid samples are heated to release gases in the Chemical Laboratory.
- The Gas Chromatograph separates the different gases.
- They then pass into the Mass Spectrometer and the Tunable Laser Spectrometer, where each is identified and the relative proportions measured.

Rock formation

Curiosity's image of Mount Sharp shows the layered rock formations in this part of the planet. Although this looks similar to sedimentary rocks on Earth, geologists know of several ways in which such striations can form – they don't necessarily show that these rocks were formed underwater.

	Mars	Earth
distance from Sun	227 million km	150 million km
orbital period	687 days	365 days
day length	24h 40m (1 sol)	24h 00m
radius	3380 km	6371 km
mass	6.4×10^{23} kg	6.0×10^{24} kg
tilt of axis	25°	23°
mean surface temperature	-63°C	+14°C
atmosphere	95% CO_2, 3% N_2	78% N_2, 21% O_2
atmospheric pressure	0.6 kPa	100 kPa

Look here!

NASA's Curiosity website is constantly updated with the mission's latest news and images:

http://www.nasa.gov/mission_pages/msl/index.html

Paul Butler

Clam shells, climate change and ageing

The mollusc that had 500 birthdays

Key words
environment
mollusc
dating
ageing

In the summer of 2006, scientists collecting material from the seabed off the north coast of Iceland found some clam shells. Now, that doesn't sound all that exciting, but it turned out that they came from animals that were quite remarkably long-lived, several of them having lived for more than 300 years, and one that had lived for an amazing 507 years, making it the longest lived non-colonial animal whose age scientists have been able to measure accurately.

A live specimen of the mollusc Arctica islandica

The mollusc *Arctica islandica*

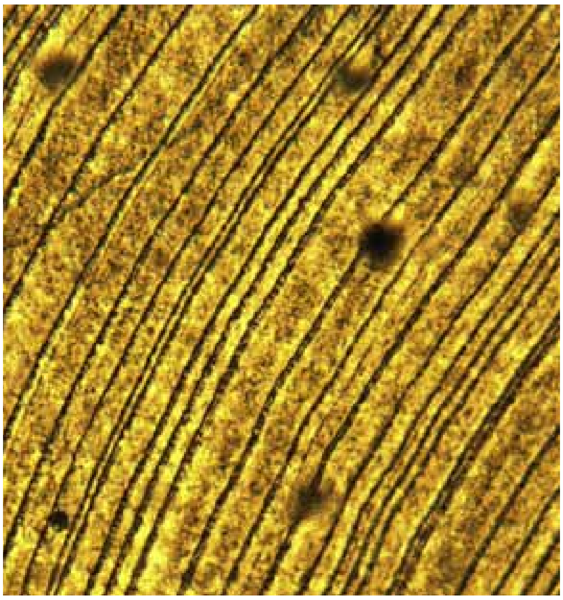
But why are these shells useful? Why do we spend money and time collecting them? Shells are what we call environmental proxies (see the box on page 8). That means that they are natural archives which record information about the environment within which they were formed. For example, by looking in detail at the chemistry of the calcium carbonate material that forms the shell, we can determine the seawater temperature when the shell was deposited. With extended records obtained from long-lived shells, we can get a useful picture of the recent history of global climate in the marine domain, one that goes back several centuries and includes the periodic cycles and long term trends that can help us to distinguish between the natural and human contributions to climate change.

The shells we found on that Icelandic trip come from a bivalve mollusc that lives buried in a wide range of sandy sediments and feeds by filtering food particles falling through the water. As its Latin name (*Arctica islandica*) suggests, it is very common around Iceland, but it is also found in most of the other shelf seas surrounding the North Atlantic Ocean. This makes it an especially promising archive for the study of marine climate, since the North Atlantic is the site of some of the key processes in the global ocean circulation, in particular the heat- and salinity-driven overturning that plays a crucial role in the global distribution of heat energy.

The distribution of Arctica islandica *around the North Atlantic ocean*

How old is that bivalve?

How do we know that these animals lived for hundreds of years? Shell growth in *A. islandica* is characterized by a short period every year (probably in late summer or autumn) when deposition of shell material becomes very slow or ceases altogether. When we take a cross section through the shell and look at the growth patterns internally under a microscope, this period shows up as a darker line, while a wider band of lighter material indicates the main growing season. We can record the amount of growth during each year by measuring the distance between the darker lines. When we do this with many shells from the same population, we find that that they grow synchronously. This shows, usefully, that they are all responding to the same environmental factors, and it also allows us to work out the dates of any dead shell we happen to find on the sea bed because we can compare its growth patterns with the patterns in shells from live caught animals whose date of death is known. (This technique, called 'crossdating', is derived from tree-ring research.) As a result, we can extend the period we can study back in time, potentially for many thousands of years.



Bands in the shell of Arctica islandica *allow us to age it just like we can with trees using tree-rings*

Shell interpretation

What information can we get from the shells? Having created an archive of precisely-dated shell material, the next challenge is to tease out some useful information about the environment.

First, we can investigate the width of the growth increments. This is just an indication of how much shell material the animal was able to produce in a single year. The most direct relationship is probably with food supply, but it may also record other factors, such as seawater temperature or the presence of ice at the sea surface, especially in regions where the animal is stressed by one of those factors.

A specimen from a recent dredging exercise near Iceland

Another approach is to look at the composition of the shell material itself. The different isotopes of oxygen and carbon can be measured with great precision and these analyses can tell us about seawater temperature, salinity and nutrients at the time of shell deposition. They can also help us investigate more complex aspects, such as changes through time in the original source of local water masses or in the uptake of fossil fuel carbon from the atmosphere into the marine environment.

Finally, the concentrations of other elements in the shell (calcium, strontium, magnesium, boron, zinc and many others) can be measured and compared, and these analyses can be used to investigate, for example, marine pollution and ocean acidification.

What have we found out?

We have been able to use radiocarbon measurements in the shell to show how the source of ocean water north of Iceland has changed over the past thousand years from a predominantly Atlantic origin to a predominantly Arctic origin, and that there are indications that this trend may have reversed in recent decades, possibly linked to modern global warming. We have also been able to use carbon isotopes in the shell to show how the uptake of fossil fuel carbon from the atmosphere into the ocean has changed during the past few hundred years. Up until now the ocean has been a major sink for anthropogenic ('man-made') carbon, and long term records such as that provided by *A. islandica* will help us to detect any signs that the oceanic sink is becoming saturated.

Clams are also dredged for food.

Looking back

Our Iceland chronology goes back 1350 years, and we have also created one for the Irish Sea which goes back nearly 500 years. The potential to extend them depends on the availability of shell material further back in time, which in turn depends on the persistence of the population and the fate of the dead shells. *A. islandica* has been common in the shelf seas surrounding the North Atlantic ocean at least since the last glaciation (about 18 000 years), but it will be difficult to find shells from any single population to cover that whole period. More likely, a network of so-called 'floating chronologies' (shells with growth patterns which match each other but which cannot be linked to any live-collected shells) will be built up with the potential to be connected and correctly dated as more material comes to light.

Look here!

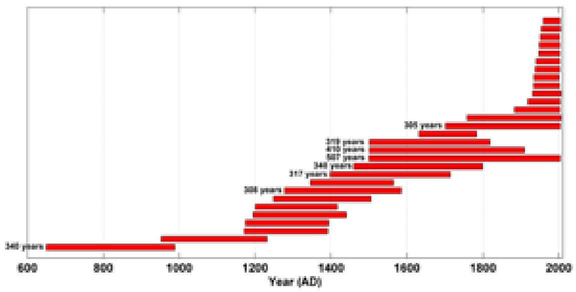
You can keep up to date with what we're doing at our website *http://www.sos.bangor.ac.uk/sclero.*

Environmental proxies

Instrumental observations of climate variables are now very precise and increasingly global in their coverage, but that hasn't always been the case. Even the most basic measurements of air temperatures only provide wide coverage for 100 years or so back in time. To find out about the climate before there were instrumental observations, scientists use proxies. These are natural archives that record something about the surrounding conditions under which they were formed. They include tree-rings, ice cores, corals and sediments in lakes and oceans. They can't always be dated accurately (for example, in a marine sediment core, we can only get a very rough approximation of the rate of sedimentation) but if they can be well-dated, we can get very useful information about when changes happened and the rate at which they happened.

Research into ageing

How long is *A. islandica* capable of living? We have found one animal that lived for more than 500 years, and several others that were more than 300 years old when they died. But the true answer to the question is that we just don't know. They appear to be able to switch off some of the usual processes of ageing (such as deterioration in muscle tissue and susceptibility to tumours) and it has been suggested that if they weren't eaten by predators they could in principle live forever. You won't be at all surprised to hear that *A. islandica* is now the focus of research aimed at finding out just how they manage to resist the ageing process.



Matching up shell bands allows us to tell when a clam lived and died. Each red band represents the lifespan of a single specimen.

Researchers are trying to understand the main determinants of the exceptional longevity of *A. islandica*; why does this species live so long? Identification of the mechanisms that delay or halt the ageing process in *A. islandica* would then enable research into the traditional model species to be directed towards the most productive areas.

Dr Paul Butler is a Research Officer at School of Ocean Sciences, Bangor University, specializing in sclerochronology and scleroclimatology.

Seeing the atoms that will shape our future

Philipp Studer

Steven Schofield

Cyrus Hirjibehedin

Neil Curson

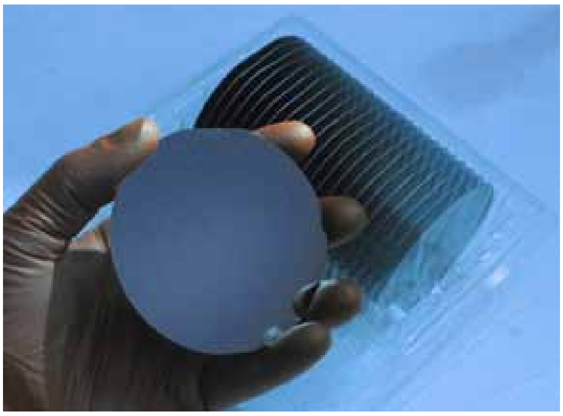
The last few decades are often described as the Information Age. In this time, the way people use and share knowledge has changed faster than at any other time in history. This has been driven largely by the constant improvement of integrated circuits, brought about by shrinking circuit components and packing more of them onto a single silicon chip.

Technologies created in this way have brought us a wide variety of innovations including programmable household appliances that improve our energy efficiency, cars that automatically find the quickest route to any destination to help us save time, and smart phones and the internet to allow us to stay connected to each other.

However, we are reaching a point where components on silicon chips have become so small that soon even a single misplaced atom might change the way a chip behaves. Researchers in the London Centre for Nanotechnology at University College London (UCL) are at the forefront of efforts to study how different arrangements of only a few atoms in silicon could be used to make radically new types of computers.

Silicon, dopants and transistors

One of the most fundamental breakthroughs that enabled the creation of highly scaled integrated circuits was the discovery of how mono-crystalline silicon (see photo) can be produced with unprecedented purity. Silicon is one of the most abundant materials in the universe and is found in common materials such as sand. A crystal made out of silicon atoms is semiconducting: its properties lie between an insulator and a conductor and can easily be tuned into one or the other using electric fields (gating) or impurities (doping).



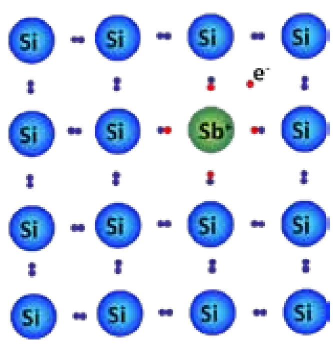
A thin slice cut from a single crystal of high-purity silicon. A wafer like this is used to make hundreds of individual integrated circuits.

The concept of doping is explained in Box 1. It relies on the introduction of non-silicon atoms, called dopants, into the crystal. These dopants either introduce or remove electrons, enabling the engineering of the local charge and conduction characteristics in silicon. Carefully controlling the size and layout of doped areas then allows the fabrication of the fundamental building block of integrated circuits, the transistor.

However, since the next generation of transistors will be less than 100 atoms wide, it will become necessary not only to restrict the area in which the dopants are present but also to control exactly the position of each individual dopant atom. This is a huge challenge, as ways have to be found that allow placing single dopants with atomic scale precision.

Box 1 Doping semiconductors

Silicon has four electrons in its outermost shell. In a crystal, every silicon atom is bonded to four neighbouring atoms. This means that every electron is involved in a covalent bond, leaving no free charges to conduct electrical current.



By introducing impurities with either five or only three electrons in their outermost shell, electrons or holes (i.e. the absence of electrons, which leaves a positive charge) can be introduced into the crystal, enabling the engineering of the electrical properties of the silicon.

Studying dopants

Studying individual dopant atoms and controlling their location is difficult, as the lengths involved are even smaller than the wavelength of light. This means that single donor atoms cannot be looked at, even with the most advanced optical microscope. To overcome this fundamental problem, researchers at UCL use a Scanning Tunnelling Microscope (STM), which is described in Box 2.

This highly advanced microscope was invented by G. Binning and H. Rohrer in 1981, for which they were awarded the Physics Nobel Prize five years later. To create an image of the surface, an STM uses an atomically sharp tip that is computer controlled and "feels" the surface corrugation. This

Key words

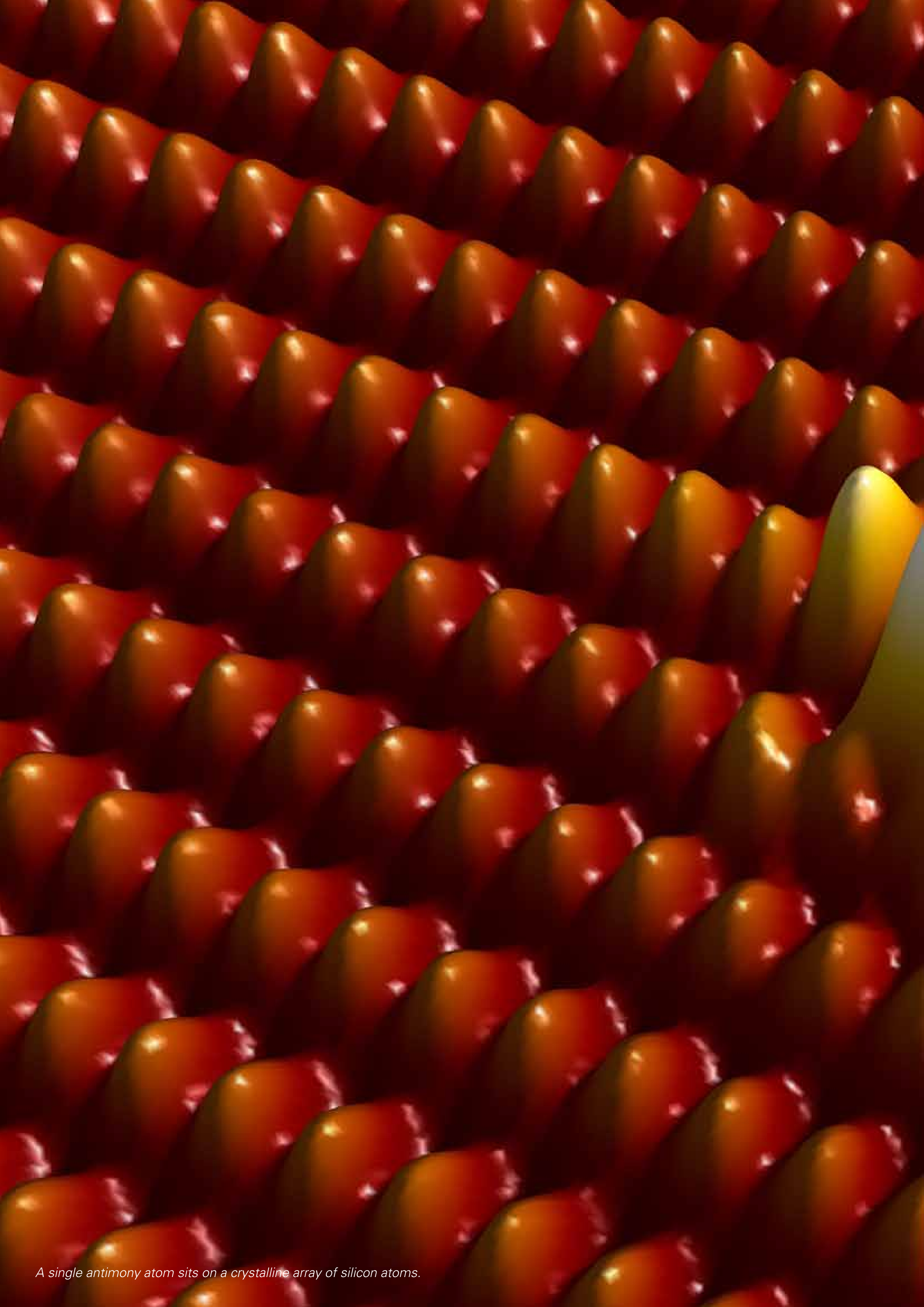
atoms

microscopy

semiconductors

electronics

Continued on page 12



A single antimony atom sits on a crystalline array of silicon atoms.

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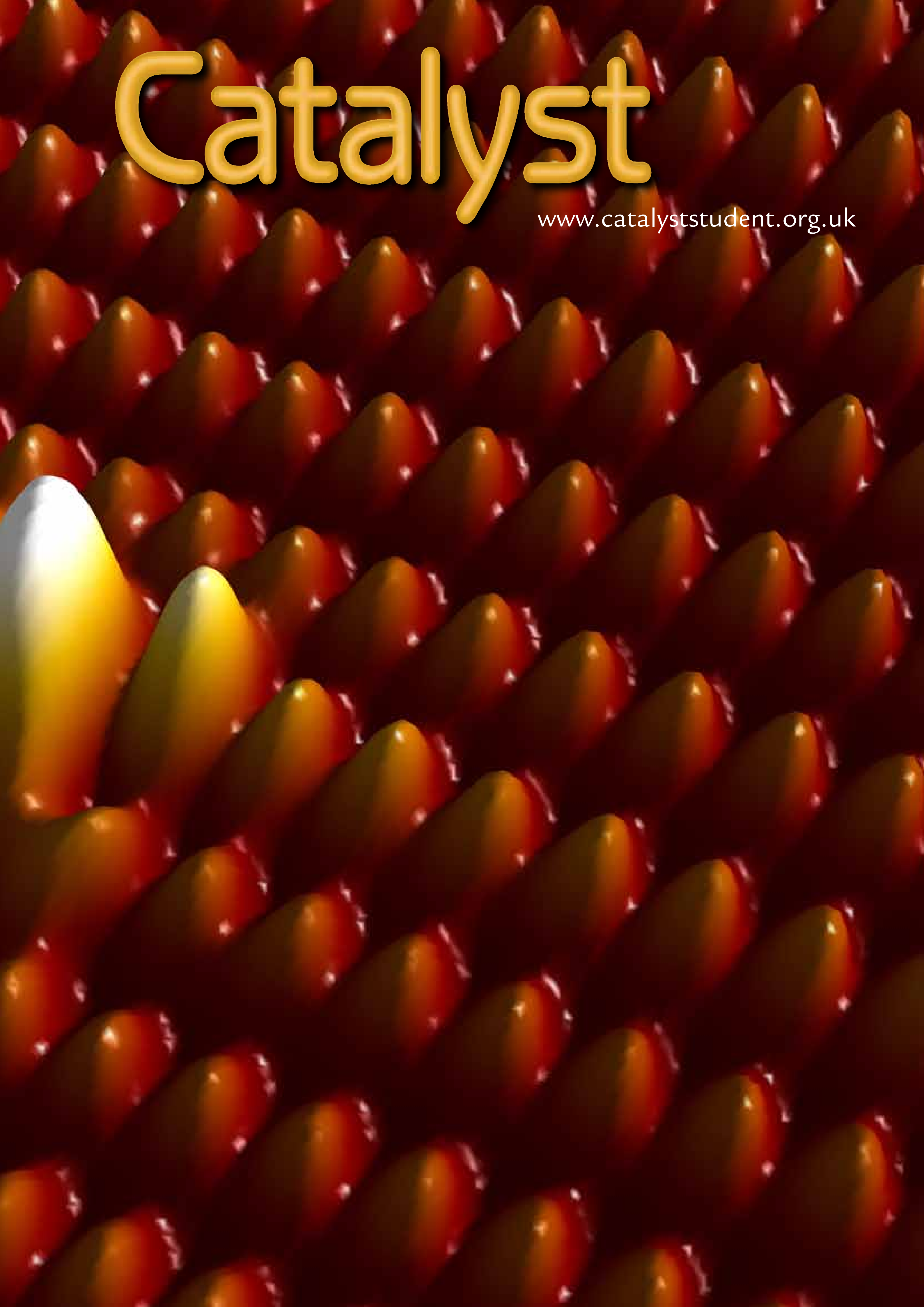
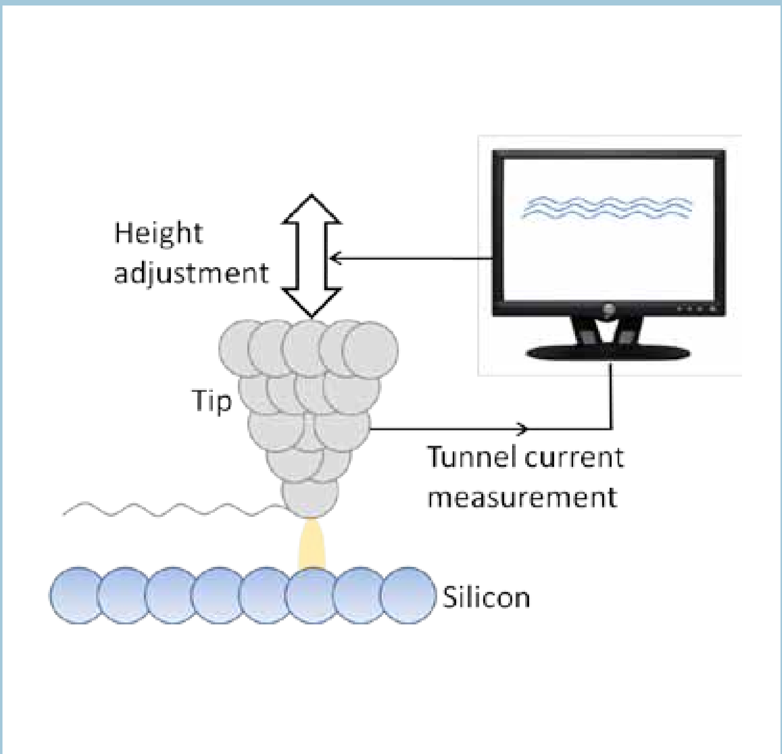


avoids the use of light and enables the visualization of individual atoms, as shown on pages 10-11.

The image shows a silicon crystal surface where every protrusion represents a single silicon atom. The central disturbance is caused by a single antimony (Sb) dopant and it can be seen how it has a huge influence on its surroundings. Using images such as this, researchers can investigate structural and electronic properties of individual donor atoms and furthermore determine the dopant position with atomic scale precision.

Box 2 Scanning tunnelling microscopy



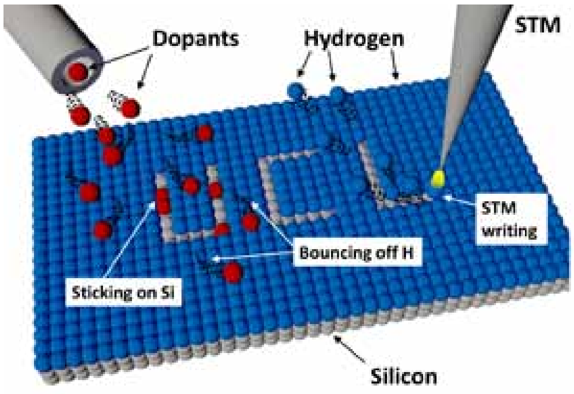
Scanning tunnelling microscopes use a sharp metal tip that is brought very close to the surface. A voltage is applied between the tip and the sample and the quantum mechanical tunnel effect allows electrons to cross the gap between tip and sample. The current created by these tunnelling electrons is so incredibly sensitive to the distance between the tip and the sample that it allows the microscope to "feel" whether the tip is on top of or in between two atoms. By recording the height profile of a complete area, a topography image of the surface is made.

Manipulating atoms

The truly amazing advantage of an STM is however not just the visualization of dopant atoms, but the fact that it also has the unique capability to manipulate individual atoms, one at a time. This is achieved by using the tip of the microscope to influence individual atomic bonds on the surface, enabling the creation of electronic devices with unprecedented length scales and accuracy.

The process for making such atomic scale devices is shown in the diagram (above right). In a first step, the silicon crystal surface is covered with a one atom thick layer of hydrogen, changing the chemical reactivity of the surface and preventing any other atoms from sticking. As shown in the image, electrons with a high energy, ejected from the STM tip, can then be used to selectively remove individual hydrogen atoms. This allows the creation of precisely controlled holes in the hydrogen layer, exposing the underlying silicon atoms.

To fabricate devices, dopants are then filled into these holes by evaporating them onto the whole area. The dopants only stick to the exposed silicon atoms where the hydrogen layer was removed; they simply bounce off the rest of the surface. This enables the placement of dopants with atomic scale precision and can be used to make prototype devices for the next generation of integrated circuits.



Using a scanning tunnelling microscope to write with individual atoms on a silicon surface

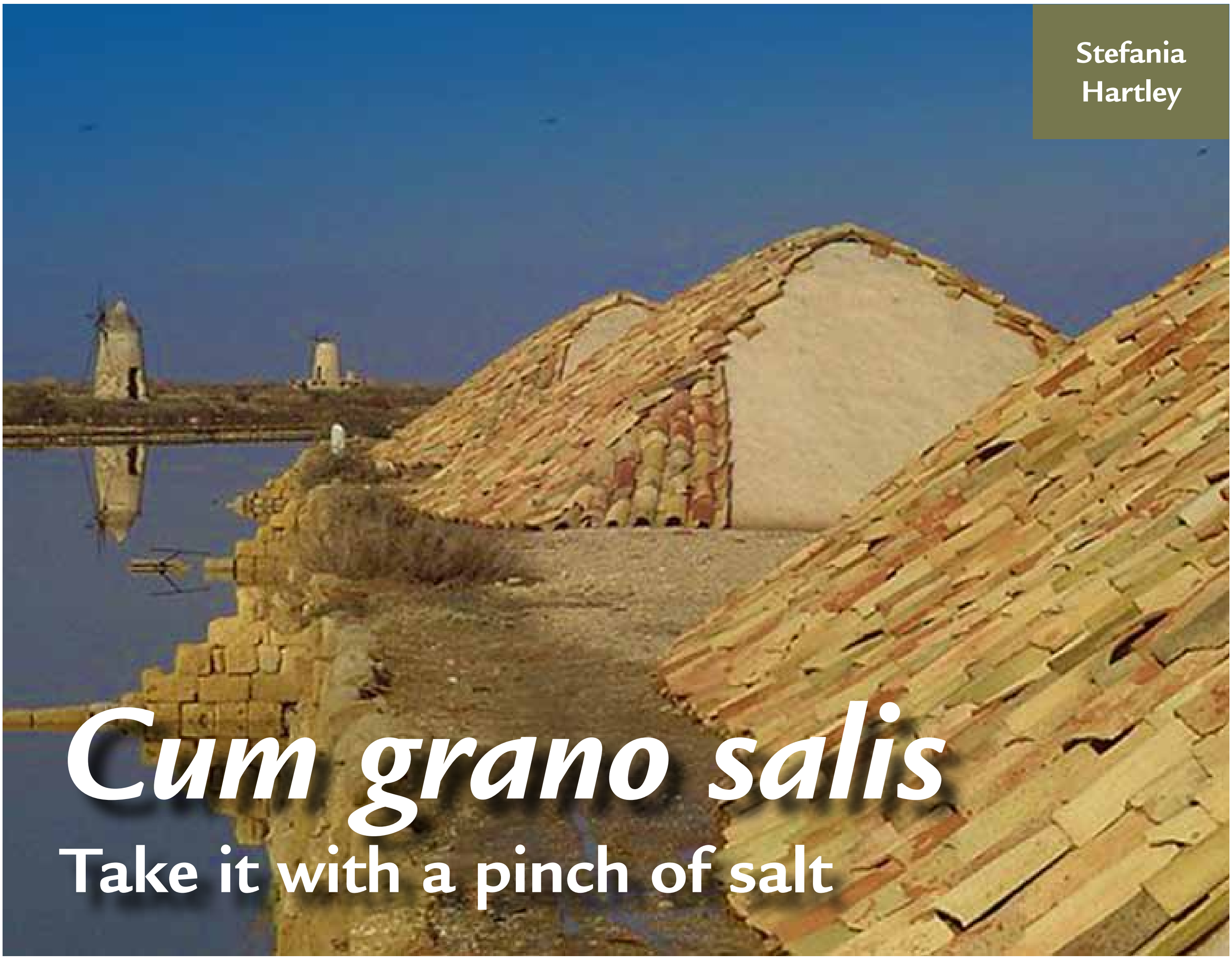
Future devices

Besides pushing conventional circuit components to their smallest possible size, this fabrication process can also be used to create more exotic devices. The current rate of miniaturization will reach a level where a device consists of only a few atoms in less than a decade, so it seems the trend in miniaturization cannot continue forever. Researchers are therefore already trying to find alternative ways to implement more powerful computing concepts.

By using dopant atoms to fabricate quantum bits (qubits), exotic quantum properties such as entanglement and superposition could be harnessed to solve complicated calculations significantly faster than with conventional computers. The ability to place and characterize dopants at the atomic scale offers the exciting opportunity to build prototypes of such devices and study their characteristics, hopefully enabling the breakthrough for the next generation of computational concepts such as spintronics or quantum information processing.

Philipp Studer, Steven Schofield, Cyrus Hirjibehedin and Neil Curson all work in the Scanning Tunnelling Microscopy Laboratory at the London Centre for Nanotechnology. They are Swiss, Australian, American and British, respectively.

Stefania Hartley



Cum grano salis

Take it with a pinch of salt

WWF Italia

Ever wondered where you would like to have your wedding photo shoot? A popular choice among Italian newlyweds is the salt factories of Trapani in Sicily. Located on the west coast of the island, the saline (salt ponds) were probably started by the Phoenicians about 3000 years ago. Why in Trapani? Because of Trapani's strong sunshine, constant winds and scarce rain, and the Mediterranean Sea's high salinity.

Sicily lies off the toe of mainland Italy.

A (very) brief history of salt

If you were a Roman soldier you would probably pray to Jupiter, god of the sky, that he wouldn't send any rain on pay day. According to the Roman historian Pliny the Elder, soldiers' wages were paid in salt ('salary' derives from the Latin *salarium*). Salt was a very precious chemical as it allowed people to preserve food well before the advent of the refrigerator. Salt trading made populations wealthy and salt routes gave their names to roads (Via Salaria, from Rome to the Adriatic sea) and towns (Salzburg, Austria).

This aerial view of the saltpans at Trapani shows areas at different stages of drying out.

Salt under terracotta tiles awaiting transport out of the salt pans at Trapani

Key words

salt extraction

sodium chloride

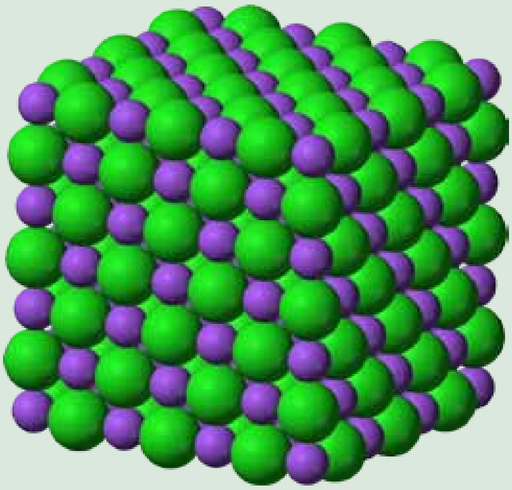
ionic solid

lattice

The Italian word *saline*, meaning salt ponds, is pronounced as three syllables, sa-lee-nay.

Sodium chloride

Sodium chloride is an ionic compound. It contains positive sodium ions and negative chloride ions which are held together in a lattice.



The sodium chloride lattice. The sodium ions are shown in purple, chloride ions in green.

There isn't a covalent bond holding the sodium to the chloride – each ion is attracted to all the oppositely charged ions in the lattice. The ions join together in a consistent pattern which results in crystals which are cubic. You can see this if you look closely at grains of salt. When the salt dissolves in water the ions no longer form a large crystal but instead are each surrounded by water molecules and act independently of each other.

This is what a saline (salt) solution is: water with sodium and chloride ions dissolved in it. Sodium chloride is very soluble – more than 350g can dissolve in one litre of water. As the water evaporates in the salt ponds, the sodium and chloride ions join together to form salt crystals which have the lattice structure shown here. This salt is collected, stored and sold.

Conditions which speed up the evaporation of the water will obviously speed up the collection of the salt. Salt could not be easily collected in the way shown here in the UK, but conditions in Sicily are ideal.

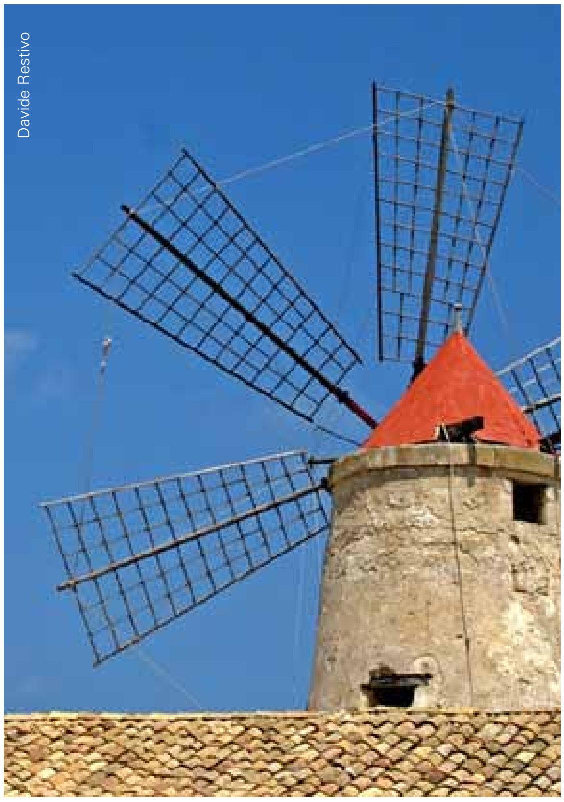
Crystals of sicilian sea salt

Extracting salt from the sea

As you would expect, the process of extracting salt from the sea in Trapani's saline is a seasonal one: it starts in March and finishes in September, with harvesting in June, August and September. The idea behind it is very simple: the sea water is trapped in square shallow ponds; the Sun's heat with the help of the wind causes the water to evaporate and crystals of NaCl are formed at the bottom of the pond.

There are several ponds that the seawater passes through. The first pond, also called 'cold', is the closest to the sea. There the water from the sea comes in through a narrow entrance and the water starts to evaporate. This pond is the biggest because it contains all the seawater that will be used during that season. A system of canals connects the different ponds, where the concentration of sodium chloride increases steadily. The last ponds are called *vasche salanti* where the salt is collected into heaps by teams of twenty men. The heaps containing 200 to 400 tonnes of salt are then covered with terracotta tiles and await the boat which will come to collect it through the canals. This work is still carried out today by 27 different saline in the area of Trapani.

Instead of the old baskets carried by men and mules, now a conveyor belt is used; instead of windmills, diesel pumps push the water from one pond to another. The windmills were used both to lift the water from the sea (using an Archimedes' screw) and to mill the salt. Some windmills have been restored and are still active. With full wind, a windmill can produce as much as 100 times the power of a horse.



A windmill used for pumping seawater at Trapani

Nature reserve

A nature reserve under WWF's management since 1995, the saline are a unique place where history and traditions live together with nature. As well as their beautiful landscapes (used by some people for their wedding photos!) and their architecture, the saline host a number of birds, fish, arthropods and vegetation which are well-adapted to the various levels of salinity of the different ponds. The saline are also a convenient stopover in autumn and spring for many migratory birds on their way to and from Africa. 208 different species of birds have been counted.

Growing in the corridors between the ponds we find many plants of the family Chenopodiaceae. These are halophytes (they tolerate high salinity) which can live in this extreme environment thanks to their ability to either expel the excess salt (*Limonium* species) or to accumulate it inside vacuoles. On the 7th of February 2011 the saline with all the area surrounding them were declared a Ramsar (protected) site, under the Ramsar Convention on Wetlands.

All in all, I think we can say that the saline of Trapani are 'worth their salt'!

Stefania Hartley grew up in Sicily. She teaches science at Westonbirt School, Tetbury, UK.

The saline attract migrant birds (including flamingos and egrets) and are home to halophyte plants.

Salt cod is a popular food in southern Europe.

Salt and food

Salt has been traditionally used as a food preservative. Salt cod from North Atlantic fisheries was the main source of protein for slaves working on the sugar plantations of the southern United States.

Salt added to food can enhance its flavour. Sodium and chloride ions dissolve in saliva and increase its electrical conductivity, stimulating the nerve cells of the taste buds.

While we need some salt in our diet, processed foods may contain large amounts. Excess salt contributes to high blood pressure and heart disease.

Jeremy Lakey

Seeing into bacteria

Colonies of the bacteria Yersinia pestis, *which causes bubonic plague, grown on an agar plate.*

Key words

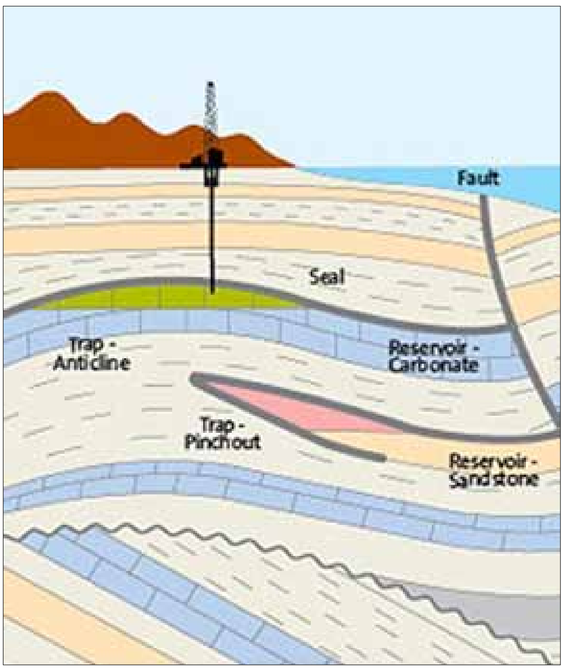
bacteria

cell wall

membrane

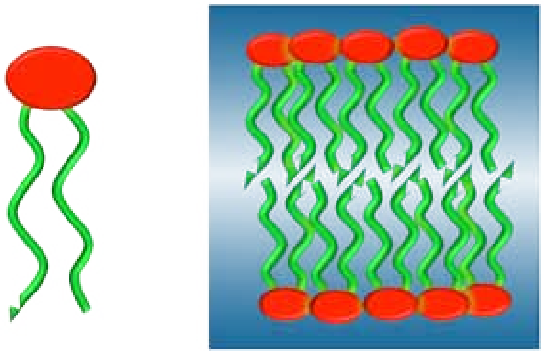
lipid

In science, we are used to diagrams that reveal cross sections of structures. The best examples are the colourful representations of geological strata which give us views which we would never normally see. In most cases these diagrams are based upon drilling or mining records since. Unless you are at the Grand Canyon or similar cliff faces, such views are not visible directly.



A typical geological diagram shows a cross-section through rock strata.

In biology, individual cells are separated from their environment by a series of layers. The layers are composed of molecules called **lipids**. Lipids are unusual molecules since one end is water soluble and the other end prefers oily environments. This behaviour enables them to form stable double-layered **membranes** which are like the skin of a soap bubble. Proteins are inserted into these double layers, adding extra functions to the membrane such as importing food, exporting waste, binding to surfaces and sensing signals about the environment.

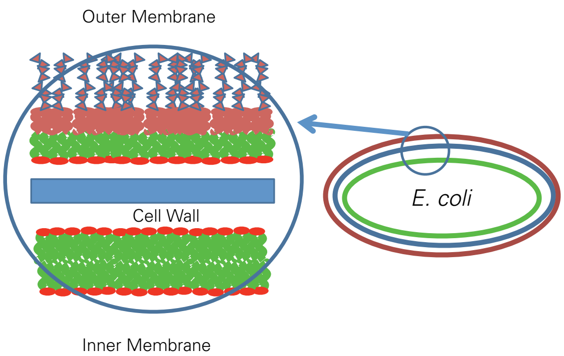


(left) A single lipid molecule; the red end is water soluble. (right) A cross-section of a membrane formed from two layers of lipid molecules. In water, the lipids arrange themselves with the oil soluble ends pointing inwards and the water soluble ends pointing out, forming a stable double-layered structure.

In our research group we are especially interested in how the membranes of disease-causing bacteria work. Bacteria are largely divided into two groups termed Gram-positive and Gram-negative because of the different colours they display under the microscope after being treated with a stain developed by Christian Gram in the 19th century. The Gram-negative cells owe their staining behaviour to the presence of an extra 'outer' membrane which they uniquely possess. The cells thus resemble a medieval castle with an outer wall, a courtyard and an inner keep, whereas most cells are more like a house with just an outer wall. In spite of this, bacterial cells are far smaller than animal cells.

A medieval castle acts as a model of a bacterium. Its outer and inner walls are equivalent to the outer and inner membranes of the bacterium. Its courtyard is the bacterial cell wall.

Unlike the bacterial inner membrane, which is similar to those of our own cells, the outer membrane is very robust and its two layers are quite different. The inner layer is similar to the inner membrane but interacts strongly with a rigid cell wall molecule called peptidoglycan which controls the cell shape. The outer layer is composed of a lipid unique to bacterial outer membranes, lipopolysaccharide, which as its name suggests consists of a lipid connected to a long sugar chain. This protects the outer surface of the lipid bilayer and makes the Gram-negative bacterial cell a very impregnable fortress.



A Gram-negative bacterium like E. Coli *has an inner and outer membrane separated by a cell wall. The surface structure of the outer membrane makes it difficult to penetrate.*

Bacterial diseases

Gram-negative bacteria cause some very serious diseases, including *E coli* food poisoning, cholera, Legionnaires' disease and even bubonic plague. We have been lucky for the past 50 years to be able to fight them with antibiotics but the bacteria are fighting back and developing resistance to our favourite medicines. One possible source of new antibiotics is the array of molecules that bacteria use to kill off competitors, called bacteriocidal proteins or 'bacteriocins'. We are studying proteins that kill *E coli* which are called colicins. These are very effective but also much bigger than antibiotics such as penicillins and this means that they cannot easily cross the defensive outer membrane. However they are very efficient at evading these defences and show an amazing ability to penetrate the layers of defensive molecules.

Streptococcus pyogenes*, the bacterium that causes scarlet fever.*

Peeling skin, one symptom of scarlet fever.

If we create bacteria lacking certain proteins these cells become resistant to the colicins. This allows us to work out which proteins are needed for the colicins to cross the outer membrane. To make new antibiotics which exploit the same pathway into the bacterium we need more information particularly about the structure of the colicin when it is crossing the membrane layers. Thus we need a bacterial equivalent version of the geological cross section which shows the drill making its way into the oil reserves hidden below many layers of rock. However the outer membrane is only about 5 nm thick (20 000 times thinner than A4 paper) so some special methods needed to be developed.

X-ray imaging

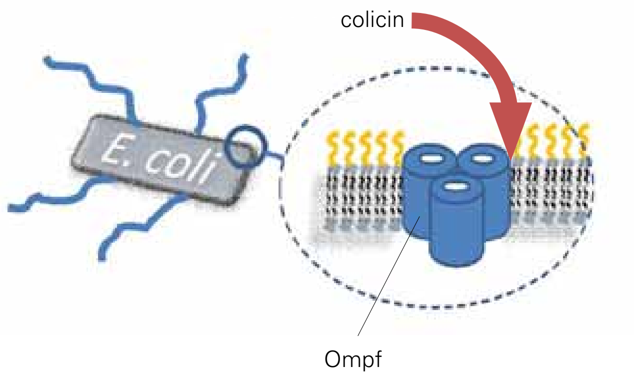
One way of looking at very thin structures is to reflect light off them and measure the ways in which different wavelengths (colours) interact as they pass through the different strata. You can see this when oil is spread on a puddle and the rainbow colours are produced by the different thicknesses of the film. To see layers as thin as membranes we can replace light with shorter wavelength beams such as X-rays but the complexity of the layers makes interpretation of the results difficult and seeing exactly where the antibiotic protein is becomes impossible.

To get a side view of colicin insertion into complex membranes we have used neutrons. When moving as a beam these sub-atomic particles display properties similar to X-rays but with one very important advantage. Neutrons are sensitive to the nucleus of the atoms they interact with and can tell the difference between different elements and even isotopes of the same element.

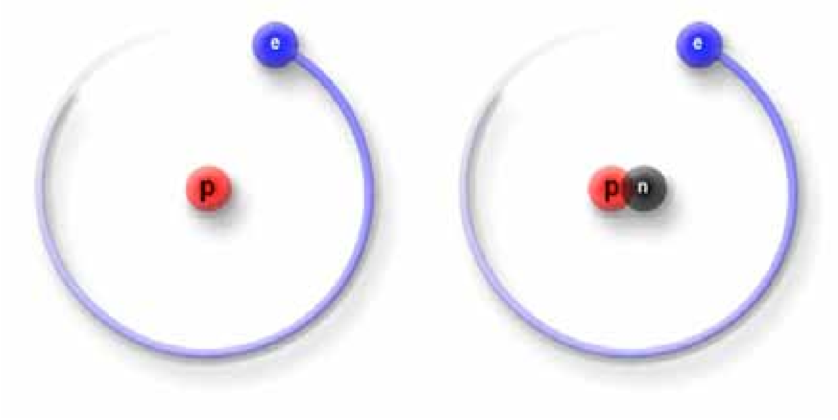
In biology everything is full of hydrogen and neutrons reflect very differently from hydrogen (nucleus = one proton) and its stable isotope deuterium (one proton and one neutron). We can make lipids and proteins containing deuterium and these 'labelled' molecules stand out from the background as if they were painted in dayglow yellow! Neutrons thus allow us to take a complex bacterial membrane system of lipids and proteins and look at just one component at a time. This unique selectivity is allowing structural biologists to solve the structures of very complex biological machines made up of lipids, DNA, sugars or proteins.

In the UK, a neutron beam is available at the ISIS facility at the Rutherford Appleton Laboratory near Didcot and in France these experiments are possible in Grenoble. We used both sources to get data on our system. In the UK we made a model outer membrane from proteins and lipids and then reflected neutrons from this surface.

Using lipids and proteins labelled with deuterium we were able to show that adding a single protein called 'outer membrane protein F' (OmpF) enables the colicin to penetrate into the membrane. This is important because bacteria which don't have OmpF are not killed by the colicin. The colicin only penetrates 3 nm but this is enough to get past the protective barrier. Interestingly, the colicin appears to stretch as it binds to OmpF and we wished to get more information on this event. Using OmpF made with deuterium and normal colicin at the Grenoble neutron source we were able to solve the structure of the colicin-OmpF complex. This shows that the colicin unfolds into a longer protein and binds to the outside of the OmpF protein where it finds a route across the membrane layer into the cell.



The cells of E. coli bacteria are surrounded by a protective membrane (black). In this membrane are OmpF proteins (blue) which allow food into the cell. The antibacterial toxin colicin (red) uses OmpF to penetrate into the cell and kill it. Neutron science has given us a picture of how this happens.



Two isotopes of hydrogen, ^1H (known as protium) and ^2H (deuterium). Each has a single electron orbiting the nucleus.

These measurements have shown that the junction between protein and lipid in the bacterial membrane is where the protective barrier is at its weakest. The colicins slip between the cracks in the castle walls. We are currently trying to design other antibiotic molecules to exploit this route. The answer to how the big molecules evade the defences is thus rather simple but without the selective vision of neutrons we would never have seen this taking place.

Look here!

Find out more about the ISIS accelerator: see Catalyst Vol 19 Issue 2 pp 9-12 (2008)

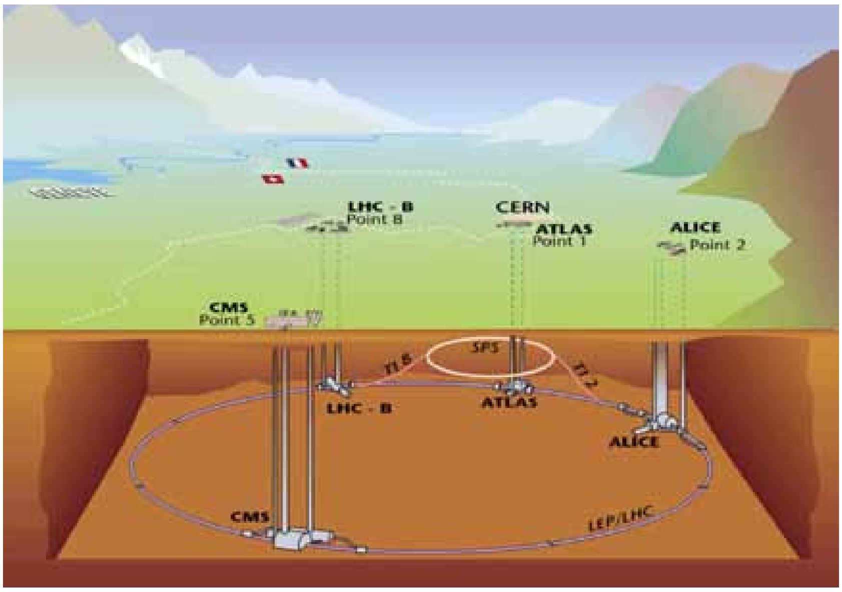
Prof Jeremy Lakey originally studied Zoology at University but his career has moved towards smaller and smaller things until he is now using biophysics to study novel antibiotic proteins at the Centre for Bacterial Cell Biology at Newcastle University.

Zoe Matthews

ALICE: Extraordinary nuclear adventures underground

The Large Hadron Collider at the CERN laboratory, Geneva, is now famous for the discovery of the Higgs boson. However, as, ***Zoe Matthews*** *of Liverpool University explains, scientists hope to learn much more from this hot-spot of physics research.*

ALICE, short for A Large Ion Collider Experiment, is an experiment at the Large Hadron Collider (LHC). It breaks down nuclear matter into its smallest components, melting it into a state that it hasn't been in since the dawn of time. The experiment measures collisions of lead nuclei at close to the speed of light. Why? So that a collaboration of over a thousand scientists can study the peculiar soup that the universe existed in just fractions of a second after the Big Bang.



The LHC ring sits 50-100 m below the Franco-Swiss border, and four major experiments (ATLAS, CMS, LHC-B and ALICE) observe its particle collisions.

LHC: Super Collider

The LHC is a 27 km circumference particle accelerator crossing the border of France and Switzerland. It is the most powerful accelerator in the world to date. Since 2010, protons have been travelling in its tunnels at 99.999 996% of the speed of light before being smashed together. It also accelerates lead nuclei to close to this speed.

The LHC is a synchrotron; it uses electric fields to accelerate charged particles as they travel round its ring, and the fields are synchronised to the increasing speeds of the particles. It uses strong magnetic fields to deflect the particles sideways so that they follow a circular path. The ring is an evacuated tube – any molecules of air remaining in the tube would collide with the fast-moving particles, reducing their energy.

Mass and energy

When a particle is made to accelerate, its speed and hence its energy increases. Einstein's equation $E = mc^2$ tells us that energy E and mass m are equivalent so that, as the particle goes faster, its kinetic energy increases and so its mass also increases. This makes it harder to accelerate – that's why we can never make a particle travel at the speed of light – its mass would become infinite.

When high-speed particles collide, they generally lose energy. The energy they lose appears as new particles whose mass has come from the lost energy.

Key words

particles

fundamental forces

collisions

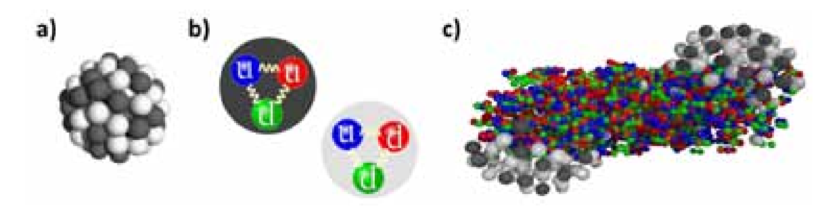
momentum

Protons in the LHC travel at just 12 m/s below the speed of light. Lead nuclei have more mass so they don't travel quite as fast.

A journey to the heart of matter

Back in 1910, Rutherford's gold foil experiment shone a light on the heart of the atom itself – a tiny positively charged nucleus. We now know that the nucleus is made up of protons and neutrons. Let us consider the lead (Pb) nucleus, which contains 82 protons, and around 126 neutrons (depending on the isotope). As an atom, the lead nucleus is surrounded by 82 electrons.

However, protons and neutrons (collectively known as nucleons) are not fundamental like electrons – they have structure. Scientists have found that protons and neutrons are made of smaller particles called quarks, bound together by the strongest force in the universe – the nuclear strong force. Massless particles called gluons are responsible for the force. They travel between quarks, gluing them together.



a) A lead nucleus, with protons (black) and neutrons (white). b) A proton and a neutron each consist of three quarks (u = up, d = down) held together by gluons. c) At the LHC, the collision of two lead nuclei produces quark-gluon plasma. Note the many coloured quarks!

As well as having an electric charge, quarks have another kind of charge that scientists call colour, and the strong force is felt between them in the same way that electric force is felt between electric charges (or magnetic force between magnetic poles). The colour charges prefer to be neutral, in the same way that positive and negative electric charges attract each other and cancel each other out in a neutral atom.

You might expect all of the protons in a nucleus to repel each other because of their positive charges, so that the nucleus would fly apart. However, the strong force is 100 times stronger than the electric force, and this is why the nucleons are bound so tightly at the centre of the atom, and why we never see isolated quarks in nature. In fact, if you try to pull a proton apart with lots of energy, the energy is used to make new particles and keep colour conserved. Remember, Einstein's equation $E = mc^2$ tells us that energy can be used to make matter (and vice versa).

	electromagnetic force	strong nuclear force	gravity
strength (relative to gravity)	10^{36}	10^{38}	1
carrier	photon	gluon	'graviton' – not yet found
charge	electric (positive, negative)	colour (red, green, blue)	0?

Comparing three of the fundamental forces of nature

The table compares three of the four fundamental forces of nature. Each force is carried between particles by a different carrier particle. (The fourth force is the weak nuclear force.)

However, there is a way to free quarks from the clutches of the strong force. By colliding lead nuclei at high speeds, a blob of extremely hot, dense nuclear matter can undergo a phase transition (it 'melts'), so that the strong force is effectively weakened and quarks are no longer bound together to form colourless particles such as protons.

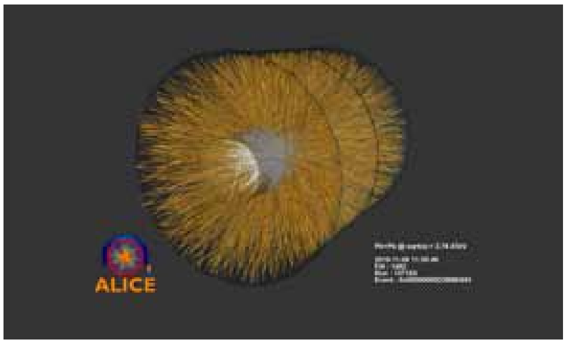
At the ALICE Experiment, temperatures exceed one million million million degrees (100 000 times hotter than the heart of the Sun). This molten nuclear matter is known as quark-gluon plasma, and is thought to have existed for the first few millionths of a second after the Big Bang. At ALICE it will last for less than 10^{-30} seconds before expanding and cooling into many particles.

How to spot quark-gluon plasma

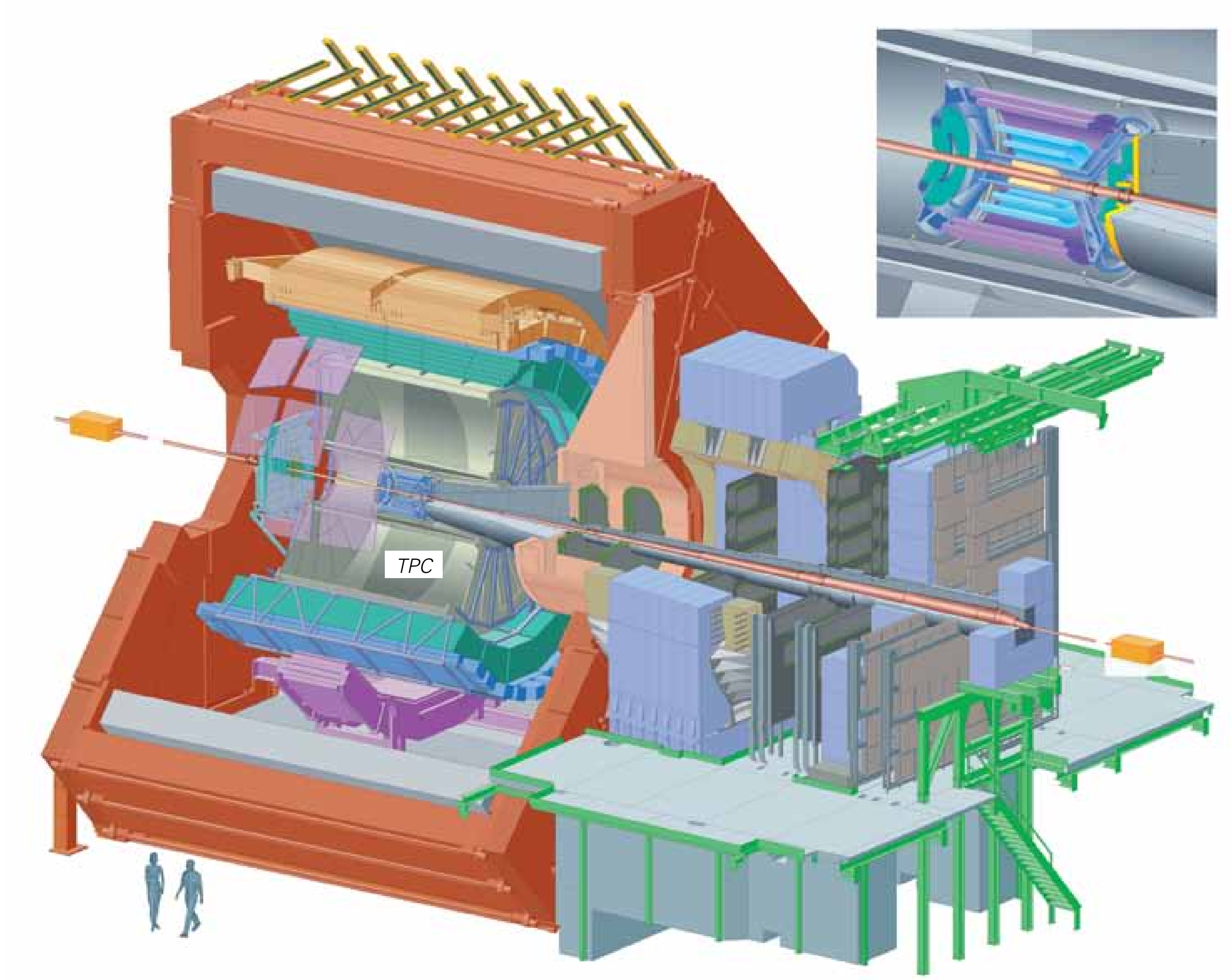
When lead ions collide with high energy in the detector, up to six thousand particles are produced. The detector needs to measure and identify these particles to understand what is happening in the initial collision, a little like piecing together the debris of an explosion to understand what caused it.

The image showing a spray of yellow particle tracks is a simulation of what we see when two lead ions collide. Each track represents the path of a single newly-created particle. By measuring the tracks, we can determine what each particle is.

Here is how the detector works. The time projection chamber (TPC) is a large cylinder filled with a gas mixture (90% neon, 10% carbon dioxide). It is positioned inside a large solenoid magnet which creates a magnetic field to bend the trajectory of charged particles. A high voltage (potential difference) is put across the gas (1000 kV) and, as charged particles travel through it, they ionise the gas. This means that they knock electrons out of the atoms in the gas. These electrons drift in the electric field to the end plates of the TPC. The position of its impact gives a 2-dimensional map of a particle's path (X and Y co-ordinates), and the time the electrons take to reach the end gives the third dimension (Z co-ordinate) of the track. The momentum of the particles can be determined from the curvature of their paths and they can then be identified.



A simulation of what is observed when two lead ions collide



The ALICE detector; the Time Projection Chamber (TPC) surrounds the point where ions collide as they travel along the central beam line.

Jet quenching: the mark of quark-gluon plasma

Jet quenching is one way scientists can spot the formation of quark-gluon plasma. When two protons collide at high energy, it is really the quarks and gluons inside that are colliding. When two quarks hit each other head on, their momentum changes. Imagine two sumo wrestlers crashing into each other – they start out with a large momentum in opposite directions and when they collide they share that momentum and rebound from each other. Similarly, when two quarks collide, they bounce off each other in opposite directions, forming two distinct showers of particles called 'jets' that can be spotted in the detector.

Most of the lead ion collisions at ALICE happen quite differently. Once the quarks have collided with high momentum, they rebound away but find themselves within the dense soup of the quark-gluon plasma. Imagine now the sumo wrestlers falling back into a pool of treacle. A wrestler close to the edge of the pool may escape, but the other one will have too much treacle to travel through, all the while losing momentum, so that he eventually stops, having given his kinetic energy to the treacle. This is what happens to the quarks in quark-gluon plasma; we see one high-momentum particle jet but the other one is missing, having lost energy in the plasma.

ALICE scientists made an interesting discovery recently – they found that if the quarks collide with extremely high momentum, both of them are able to escape the plasma to form jets.

After completing a PhD at the University of Birmingham, **Zoe Matthews** *worked at the University of Liverpool as a research scientist in Nuclear Physics.*

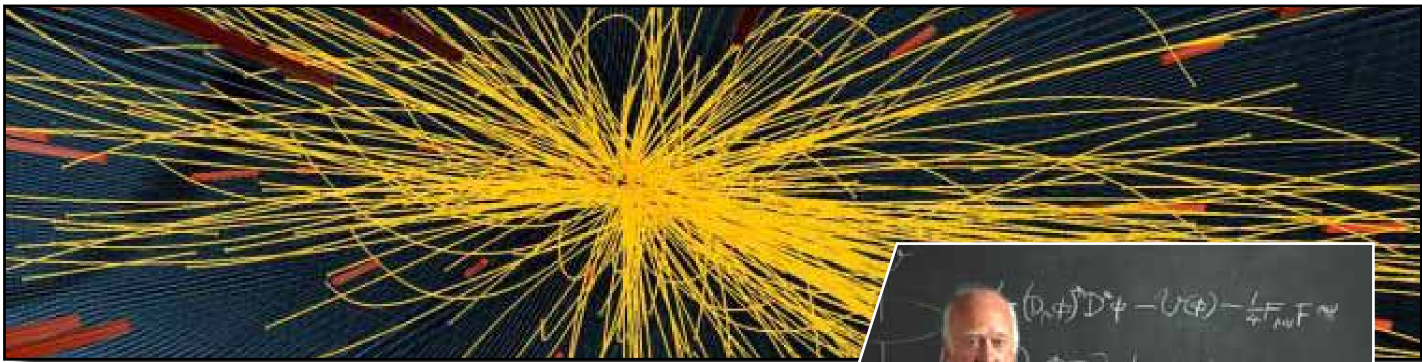
Look here!

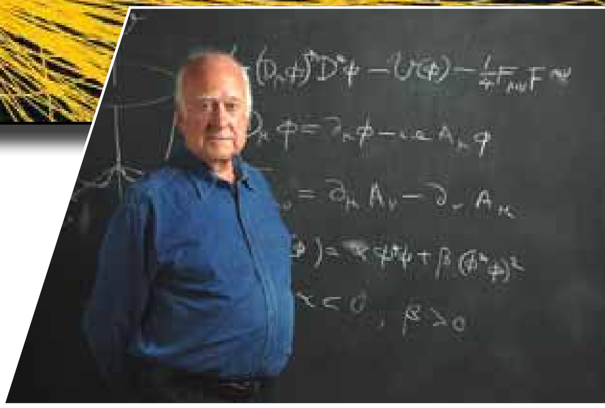
More about UK scientists and the LHC:
http://www.lhc.ac.uk/

Panoramic images of ALICE and the LHC by Peter McCready:
http://petermccready.com/

Higgs boson

On July 4th 2012, scientists from CERN announced the discovery of the Higgs boson, a fundamental particle first predicted almost 50 years earlier.

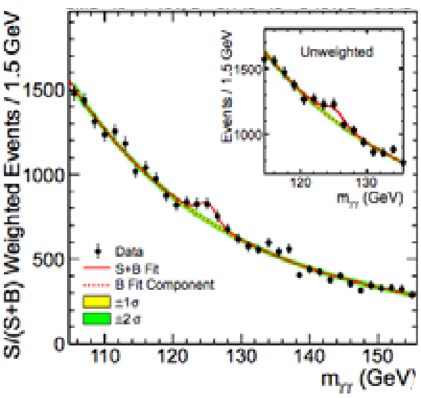




A particle collision recorded by CMS, one of two experiments at CERN, the European Centre for Nuclear Research.

A short life

When a Higgs boson appears, it decays rapidly into a host of other particles – within about 10^{-22} s. It is these particles which scientists detect and measure, and which have provided the evidence which confirms the existence of the Higgs.



The small bump in the line of data points is the evidence for the existence of the Higgs boson, from the CMS experiment.

Making predictions

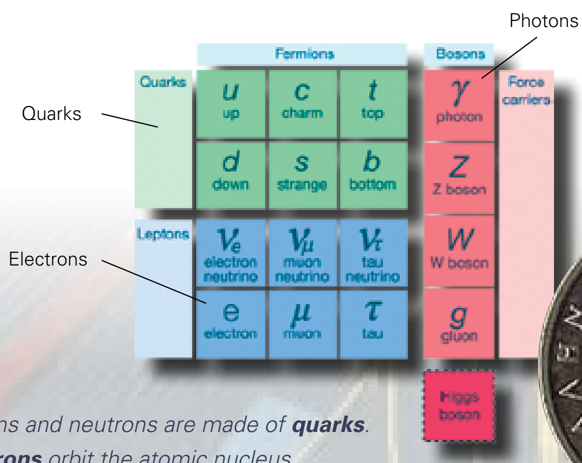
Professor Peter Higgs of Edinburgh University was one of six theoretical physicists whose work led to the prediction of the Higgs boson in 1964.

Higgs and mass

The idea is that the Universe is permeated by the Higgs field. Particles interact with the field as they moive through it, and this slows them down, giving them mass. It's a bit like wading through snow. The particles which interact most strongly with the field have the most mass.

One of a family

The Higgs boson is the last particle to be discovered in the 'Standard Model' – the set of fundamental particles which physicists believe can explain how matter behaves.



Protons and neutrons are made of ***quarks****.*
Electrons *orbit the atomic nucleus.*
Electromagnetic radiation is made up of ***photons****.*

How certain?

If you tossed a coin three times and each time it came down heads, you wouldn't claim that it was a double-header. Get heads 21 times in a row and you would be almost certain – that's how sure the CERN scientists are that they have found the Higgs boson.