Catalyst

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Saved from a cull?

Badgers, cattle and TB

SEP
Science Enhancement Programme

Catalyst

Volume 18 Number 1 September 2007

The front cover shows a young badger emerging from its sett (Colin Varndell/ naturepl.com)

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How do we know that?

Welcome to first issue of Volume 18 of CATALYST. A theme common to several articles in this issue is: how can scientists be sure of their knowledge? They may have some good ideas, but how can they be sure that they are right?

For example, on pages 6-8, you can read about badgers and bovine tuberculosis. Badgers can carry bovine TB, but are they responsible for spreading this disease among cattle in the UK? And if they are, would a cull of badgers solve the problem?

This is a complex question and an extensive study has taken place. We report some of its results here. The scientists involved have had to be unsentimental about their work, and they have had to put aside any prejudices they might have held. Their job was not to find a solution that was politically acceptable; rather, they had to discover the truth and present it as they found it. This has involved them in publishing data from their observations in scientific papers which have been through the process of peer review (see the article on pages 16-17). This means that their work has been checked by others in the scientific community to make sure that it comes up to the high standards required of all scientific publications.

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Wave Power

Joao Cruz

When thinking about renewable energy, wind and solar energy immediately come to mind. To tackle climate change and all the challenges imposed by the need to find alternative and reliable energy sources, there is one major resource that has remained untapped until now: wave power. In this article, Joao Cruz describes the size of this resource and presents the leading technological solution to the problem of harnessing it.

Key words
Wave energy
Kinetic energy
Gravitational potential energy
Energy resource

Ocean waves

Wave energy is a concentrated form of solar energy: the Sun produces temperature differences across the globe, causing winds that blow over the ocean surface. These cause ripples, which grow into swells. Such waves can then travel thousands of miles with virtually no loss of energy. Don't confuse these deep-water waves with the waves you see breaking on the beach. When a wave reaches shallow water (roughly when the depth of the water is less than half a wavelength), it slows down, its wavelength decreases and it grows in height, which leads to breaking. The major losses of energy are through breaking and through friction with the seabed, so only a fraction of the resource reaches the shore.

A wave carries both kinetic and gravitational potential energy. The total energy of a wave depends on two factors: its height H and its period T. The power carried by the wave is proportional to H^2 and to T, and is usually given in watt per metre of incident wave front. Figure 1 shows the worldwide distribution of wave power, in kW/m. From the map, you can see that the coastline of western Europe has an average 'wave climate' of about 50 kW of power for each metre width of wave front.

The overall resource is of the same order of magnitude as world electricity consumption (around 2 TW). A conservative estimate is that we might extract 10-30% of this, suggesting that wave power could make a significant contribution to the energy mix. On a typical day, about 1 TWh of wave energy enters the coastal waters of the British Isles. This corresponds to approximately 1/3 of the average daily energy needs in the UK, and is about the same amount of energy as that of the Indian Ocean tsunami of the 26th December 2004. These figures put into perspective the sort of demand that human beings put on available natural resources, and the urgent need to find sustainable solutions.

Pelamis installed at the European Marine Energy Centre, Orkney

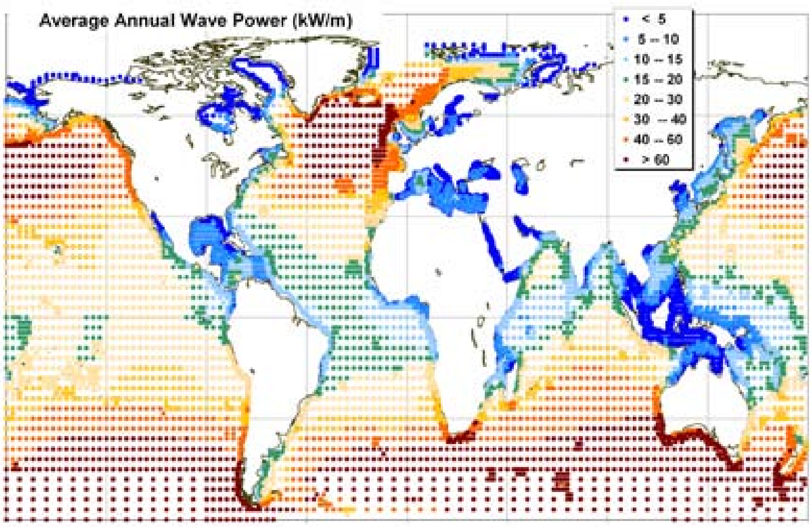


Figure 1 *World's distribution of wave power in kW/m (Courtesy of Oceanor)*

Why is the resource still untapped?

It was only in the 1960s that electricity from waves was first put into practice: the Japanese navy built a marker buoy which used waves to power its lamp. The turning point that spurred research in several countries was the publication in 1974 of an article in the widely-read scientific journal *Nature* by Prof Stephen Salter, of the University of Edinburgh. This came as a direct reply to the oil crisis of the 1970s, and its attraction was immediate. The concept, a cam-shaped floating body known as the Salter duck, is still renowned as one of the most efficient at absorbing waves.

Why didn't wave power take off after this? Around the early 1980s, the UK government made the bold decision to focus all funding on large generating systems rated at 2 GW, the capacity of a large coal-fired or nuclear station. Many scientists and researchers believed that this was not the way forward, and that it would be better to think in terms of arrays of smaller units, each producing a few MW. Experience suggests they were right - see 'How does it work?' below. Some supporters of alternative energy claim that the government's policy was designed to stop wave energy research and to justify the route to nuclear power. The lack of funding virtually halted the significant progress that was taking place.

Starting in the mid-1990s, there have been significant achievements in the development of offshore wave power systems, with several full-scale prototypes being tested and connected to national grids. As with wind energy fifteen years ago, there are still several competing approaches, and it is unclear which one (if any) will make the final leap towards commercial applications. An Edinburgh-based company, Ocean Power Delivery (OPD) has been developing a wave energy converter since 1998, and is in the front row of the technology

How does it work?

Ocean Power Delivery's solution is named Pelamis, after *Pelamis platurus*, a metre-long sea snake which lives in the Indian and Pacific Oceans. The Pelamis wave energy converter is 150 m long and has a diameter of 3.5 m. 74 members of staff work on current projects and are also developing future generations of machines.

The Pelamis is a semi-submerged, articulated floating structure composed of four long cylindrical sections linked by hinged joints. At each joint there is a power conversion module. Its mooring system ensures that the Pelamis machine aligns itself head-on with incoming waves. How does Pelamis make electricity?

- As waves travel down the length of the machine the structure bends around the joints.
- This motion pushes hydraulic rams that pump high-pressure oil through hydraulic motors.
- The hydraulic motors drive generators to produce electricity.
- Power from all the joints is fed down a single umbilical cable to a junction on the seabed.

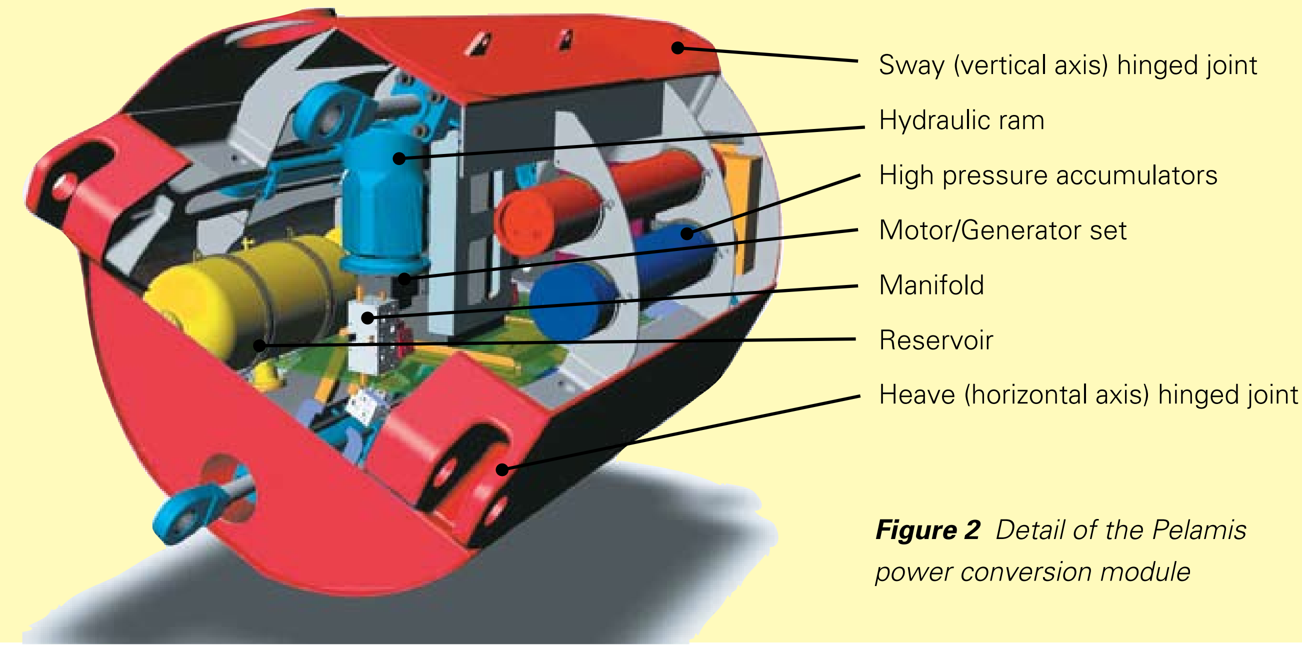


Figure 2 *Detail of the Pelamis power conversion module*

race. The world's first wave energy farm is about to be installed offshore near Póvoa de Varzim in the north of Portugal, in a project led by utility company Enersis, and the Scottish Executive recently announced support to build another wave energy farm in Orkney, in a project led by Scottish Power, and with OPD again supplying the technology. Portugal and Scotland have shown the political will and are leading the way to an environmentally-friendly solution to the energy problem.

An artist's impression of a wave farm.

A number of devices can be connected together in an array, resulting in a wave farm. A 30 MW installation (40 Pelamis machines) would occupy a square kilometre of ocean and provide electricity to 20 000 homes. Working at sea is difficult and expensive, so the Pelamis is constructed, assembled and commissioned before it is moved out to sea. For maintenance operations, electrical and moorings connections can be rapidly detached, allowing the quick recovery of the machines, again minimising the cost of offshore operations. Pelamis can be installed in a variety of water depths and sea bed conditions, which increases flexibility.

Developing Pelamis

Two main requirements governed the design of the Pelamis machine: survivability and availability. A wave energy converter should be designed to resist any sea state, even the most extreme one, and then designed to maximise the power capture. In addition, Pelamis is designed to use readily-available components; it is innovative in its over-all design and assembly.

Ocean Power Delivery were very thorough in their development of Pelamis. They used several numerical (computer) models of different levels of complexity, and many scale models were built and tested in wave tanks to validate the numerical predictions.

In 2004 a full-scale prototype was tested in the North Sea and later installed in the European Marine Energy Centre. The success of the test programme led to the sale of three machines to a Portuguese consortium lead by Enersis. These machines have been assembled in a shipyard in Portugal and they are being installed about now (autumn 2007). A second stage with 27 more machines is already planned.

The next few years will determine if the new wave energy industry can emulate what has been created for wind energy in the recent past. The technology exists, conditions have never been better and the sea has been waiting for far too long.

Another approach to wave power: this land-based wave power station generates enough electricity for 300 homes on the Scottish island of Islay.

Alternative Applications

Is electricity the only product than we can extract from wave power? The answer is no, and the main alternative is easy to guess: fresh water. At the University of Edinburgh researchers are developing a version of the original Edinburgh duck, which aims to produce freshwater rather than electricity. Even in moderate wave conditions (say 12 kW/m) the output can be very significant, up to 1000 m^3 per day for each unit. This stand-alone concept has no moving parts, minimising maintenance. Because the water is heated to produce steam which is then condensed, the output is pure water even if the feed water is polluted. Several numerical models have been created and a 1:40 scale model has been tested in a wave tank, helping to validate the approach.
More details at www.easywaves.eu

***Joao Cruz** is a mechanical engineer at Ocean Power Delivery in Edinburgh, where he develops software and methods to better characterise and predict the state of the sea. He and his colleagues will be monitoring the world's first wave energy farm which will be installed later this year (2007) in Portugal. He has worked on the monitoring of other prototype wave power plants and on research institutes spread throughout Europe*

Science and Engineering **Apprenticeships**

If you want an interesting career in science you have to stay at school, do A-levels and go to university, right? Wrong. With an apprenticeship scheme you can start your career at 16, keep learning and getting qualifications – and get paid for it too. And the likelihood is that you will get a permanent job at the end of the apprenticeship. Many different companies up and down the country offer apprenticeships as an entry to a wide range of interesting careers in the sciences. These positions are usually provided in conjunction with a 'learning provider', usually a local college.

On the opposite page, one young apprentice describes his experiences.

There are a number of ways to find out more about apprenticeships in your area. A good place to start is the apprenticeship website (see the Further Information box.) If you know of a company in your area which offers apprenticeships then you can also contact them direct.

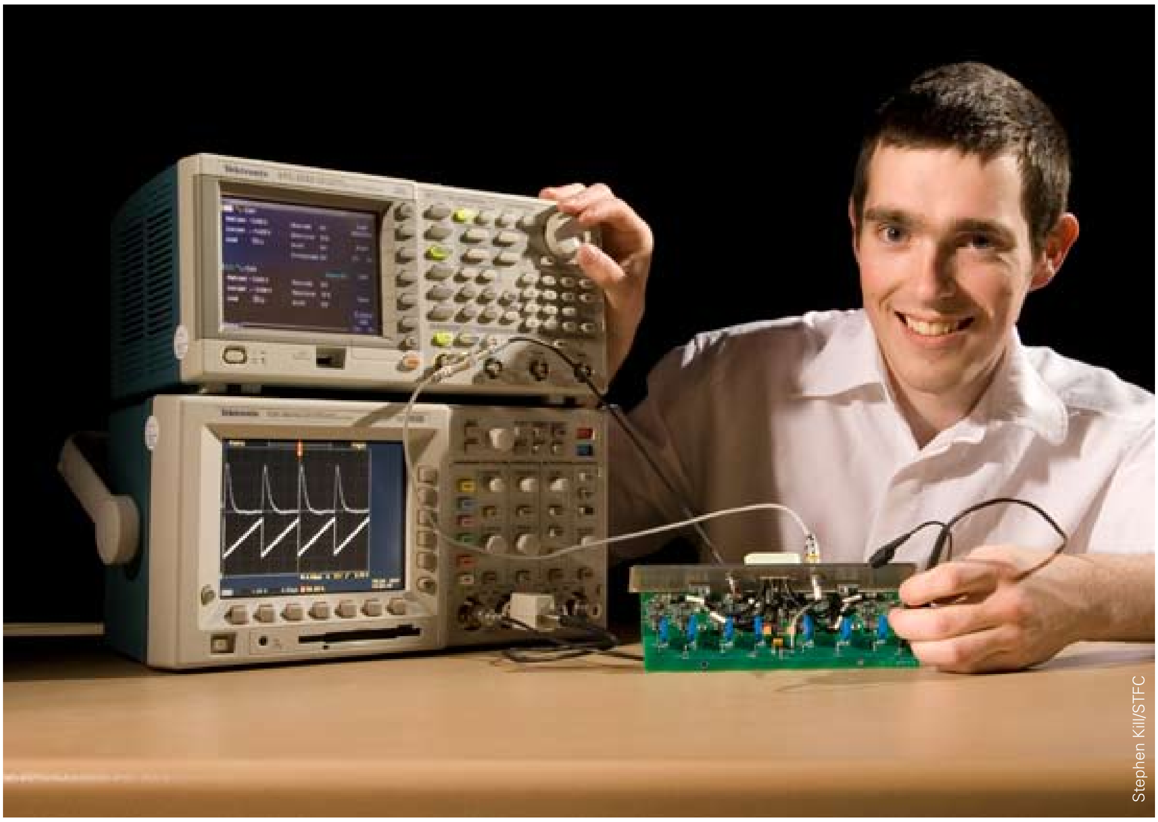
A place on an apprenticeship is not guaranteed and there are a limited number available each year. You will need to apply as you would for a job, fill in forms and have an interview. You may need to do this with both the learning provider (usually a college) and also the employer. It is important to make a good impression and convince the employer that you are interested in a career with them and prepared to work hard. You will have to sign up for between two and five years, so both you and the employer need to be convinced that you are the right person for them.

Further Information

The apprenticeship website **www.apprenticeships.org.uk** is a good place to start. This has more details about being an apprentice and can put you in touch with apprenticeships in your area.

The details of the apprenticeship that Simon is on are available on **www.apprentices.cclrc.ac.uk**

The BT website has some good general information about being an apprentice as well as details of how to apply for their scheme **www.bt.com/apprentice**



Left:
Simon Moorby, apprentice electrical engineer

Simon Moorby is an electrical engineer working as a technician at the Rutherford Appleton Laboratory in Oxfordshire. He helps to build and maintain equipment which is used for a wide range of science research. Here he describes his career so far:

I wanted to work in a science career but I didn't want to stay at school after GCSEs. I liked the idea that with an apprenticeship you could earn while you carried on learning and that you would have the chance to get work experience too. I needed at least 5 GCSEs grade A*-C and this had to include Maths, English and Science. The first year was spent at college learning mechanical, electrical and electronic engineering as well as academic subjects leading towards an ONC (Ordinary National Certificate) in electrical and electronic engineering. Although I was at college full time I was still getting paid.

For the next 3 years I spent one day a week in college and the rest of the time I worked. I did placements in different workshops to gain a wide range of experience. The last 6 months of the apprenticeship was in the workshop where I now work so that the transition from being an apprentice to working was gradual. By the final year of the apprenticeship I was earning £310 per week.

Now I am employed by the company where I did the apprenticeship, but I am still paid to carry on learning. I am working towards my HNC (Higher National Certificate) in Electronic engineering and am hoping to to an HND (Higher National Diploma) and then a degree after that. The cost of my courses is paid and I still have one day a week in college.

I now work in data acquisition electronics. I design, build, test and commission circuitry. There is new technology available all the time so I have to keep up-to-date and keep on learning, but I enjoy the challenge.

If anyone was thinking about doing an apprenticeship they should be aware that it is not an easy option – it is hard work but it is well worth it.

***Vicky Wong** teaches and writes about chemistry. She is an editor of* CATALYST.

Below and opposite:
Apprentices at work in the government labs.

Gary Skinner

TB or not TB?

Badgers, cattle and tuberculosis

Above: *Dairy cattle, the victims of bovine TB*

Inset: *This badger cub may have died of TB, or as a result of illegal badger digging.*

When cattle are found to be suffering from tuberculosis, a disease which can be passed on to humans, they are routinely slaughtered. It is known that badgers can transmit the disease to cattle, so many farmers would like to see badgers culled. But is this the solution to the problem? A recent scientific study suggests that it is not.

Box1 What is TB?

Tuberculosis (TB) refers to a range of diseases all caused by bacteria of the genus *Mycobacterium*. In humans a lung disease (pulmonary TB), commonly simply referred to as TB, is caused by *Mycobacterium tuberculosis*. In cattle the villain is *M. bovis*, causing bTB. Humans can get this from cattle, and it causes mainly a disease of the membranes of the brain, the meninges, called meningeal TB. In humans, cattle and badgers it can be vaccinated against, although with nothing like 100% success. It is also treatable with antibiotics, but again, not easily. The disease is very serious, causing many deaths in all species.

Mycobacterium bovis*, the bacteria responsible for bovine TB, seen with a transmission electron microscope.*

Badgers, cattle and TB

In 1971, a farmer in Gloucestershire found a dead badger on his land. The farm was in an area where cattle commonly suffered from bovine tuberculosis (bTB). On examination, the badger was shown to be infected with *Mycobacterium bovis,* the bacterium which causes bovine tuberculosis (see Box 1). Ironically, cattle make an area a better habitat for badgers by increasing earthworm numbers and giving rise to short grass, which badgers favour for foraging. Badgers also like to eat silage, a type of cattle feed.

It is not fully clear how the disease is passed from badger to cattle, although the eating of urine-contaminated grass seems to be the most likely way. Contagion (that is, spread by actual contact) is unlikely since badgers and cattle avoid each other.

Starting in the 1970s, badgers were culled in areas where cattle seemed to be under threat. This was first carried out by gassing with cyanide, but it was discontinued in 1981 when trapping and shooting became the favoured method.

Aside from the wish to keep a domestic animal disease free, why are people worried about TB in cattle? Firstly, there are forms of TB which humans can get from cattle. However, the major worry is economic. UK policy is that any cattle which test positive for TB (they are called reactors) are slaughtered. Farmers are paid compensation for this, but there is a human cost to a farmer in seeing his herd wiped out. There is also a cost to the government, and therefore the taxpayer. In the two years 2002-3 and 2003-4 the total cost to the UK taxpayer was over £160,000,000. Numbers of cattle involved can be seen in the graph in Figure 1.

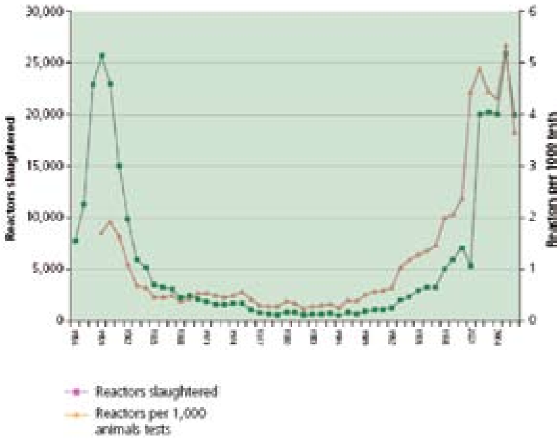


Figure 1 *Number and rate of tuberculin test reactors disclosed annually in Great Britain (from the Bourne Report, 2007).*

Calling culling into question

In some areas, culling was followed by a great reduction in cases of bovine TB. So, with this apparent success story, many farmers were shocked to read this in a recent report:

> After careful consideration of all the RBCT (Randomised Badger Culling Trial) and other data presented in this report, including an economic assessment, we conclude that badger culling cannot meaningfully contribute to the future control of cattle TB in Britain. **(The Bourne Report, 2007)**

What reasons can there be for not culling badgers? First of all, of course, the general public objected to the mass killing of badgers. However, this is not a scientific reason to reject the idea of culling. The Bourne Report was an attempt to give an answer to the scientific question:

· Can the culling of badgers reduce the transmission of bovine TB to cattle?

The Bourne Report

Here is how the Independent Study Group (ISG) of scientists went about answering this question. They first decided to have three sorts of trial area:

Reactive culling: Badgers culled in response to an outbreak of bovine TB.

Proactive culling: Badgers culled to try to prevent an outbreak.

Survey-only: A control area.

Each area was about 100 km^2, circular to reduce 'edge effects' (Figure 2). In addition, each had inner and outer buffer zones to minimise any likelihood of badger territories overlapping between the different treatments. These buffer zones were 1km wide, a figure based on the maximum 'ranging distance' of a badger which had been found out in earlier work. Each group of three treatments was called a triplet and ten such triplets were studied over the nearly seven years of the study. This makes 30 areas in all, the three treatments being assigned to each area randomly. The scale of this work can be appreciated by the fact the proactive culling programme involved 160 000 trapping nights and the reactive 25 000 trapping nights. Just over 10 000 badgers were killed.

All of them were located in the South-West of England, where the main difficulties with bovine TB have been for decades past (Figure 3).

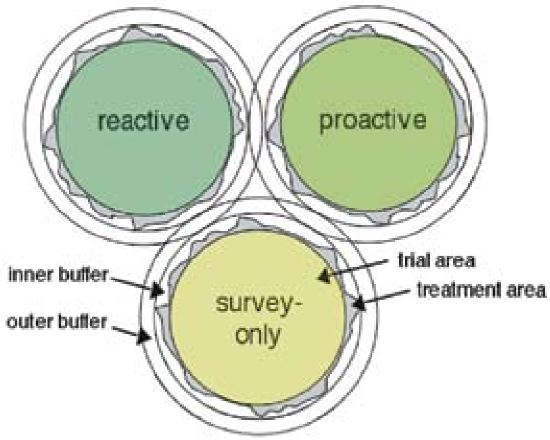


Figure 2 *A triplet of study areas*

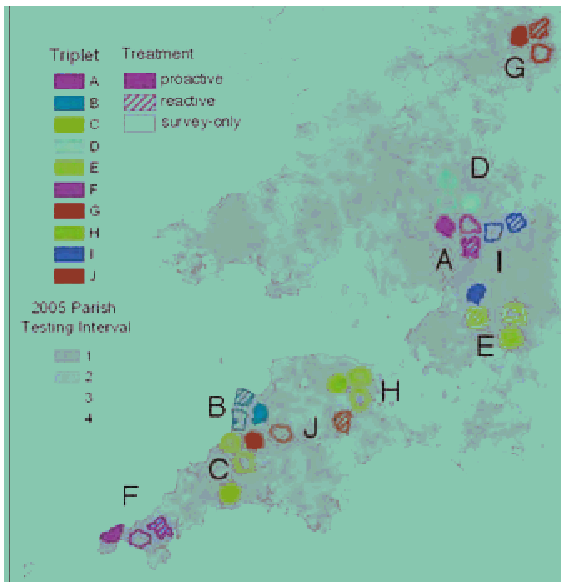


Figure 3 *Location of randomised badger culling trial study sites (from the Bourne Report)*

What they found out

- Culling had a large effect on badger populations, lowering them by about 75% in culled areas.
- Reactive culling had a detrimental effect, that is, it led to an increase in bTB in cattle.
- Proactive culling lead to a reduction in bTB cases in the culled areas, but it led to an increase in its incidence in nearby areas, an effect which seemed to cancel out any positive benefits more-or-less exactly.

Key words
Bacterium
Contagion
Transmission
Vaccine

The UK Government set up the Independent Study Group of seven scientists. Their final conclusions appeared as the Bourne Report.

Many country people were unhappy with the Bourne Report's findings, as these comments on the BBC's Farming Today website show:

"Why all this nonsensical language about 'wild-life reservoirs'? As to bovine TB, the answer is all too clear: Kill all the badgers; let not one survive. And all the lovers of 'The Wind in the Willows' can go and top themselves. What romantic nonsense! The welfare of our hard-working farmers surely comes first. Their cattle deserves to be disease-free."

"We have a very large population of badgers in North Devon. Bovine TB is a big problem round here, with most farms getting re-infected despite culling of infected cattle and testing of replacements. The State vets tell us that infected badgers are the cause, and it certainly can't be cattle to cattle transmission. I just hope that they introduce a badger cull round here."

Interpreting the results

So, what is going on? Culling seems to have an effect on the complex ecology of the badgers and this leads to an increased likelihood of transmission of the disease to cattle, rather than the hoped for decrease. In culled areas, badgers move around more with some coming from outside the area to re colonise it and those in the area simply ranging further afield. As the report summarises:

> These pieces of evidence strongly suggest that pro-active culling provoked increased immigration, greater contact rates among badgers and, as a consequence, increased transmission of *M. bovis* infection among badgers.

The report predicts that culling would give a reduction in outbreaks of 116 in culled areas, but, because of the effect on badger behaviour, lead to 104 more cases outside. The difference is very small, and not in fact significant. The report's authors concluded that they could not be confident of any improvement at all, and this is in the light of the huge effort described above.

The ISG's cost benefit analysis suggests that the culling of badgers is simply not a cost effective means of controlling bovine TB.

So, for the moment, the much-loved Brock the Badger seems to be safe. But what other solutions are there? Bourne is only cautiously optimistic about a vaccine for TB. He stresses the importance of even more careful control of cattle movements and thus the reduction of cattle-to-cattle spread. This, along with immediate eradication of reactors, is the most efficient means of control, even though it is costs a lot of money.

Gary Skinner teaches and writes about Biology. He is an editor of CATALYST.

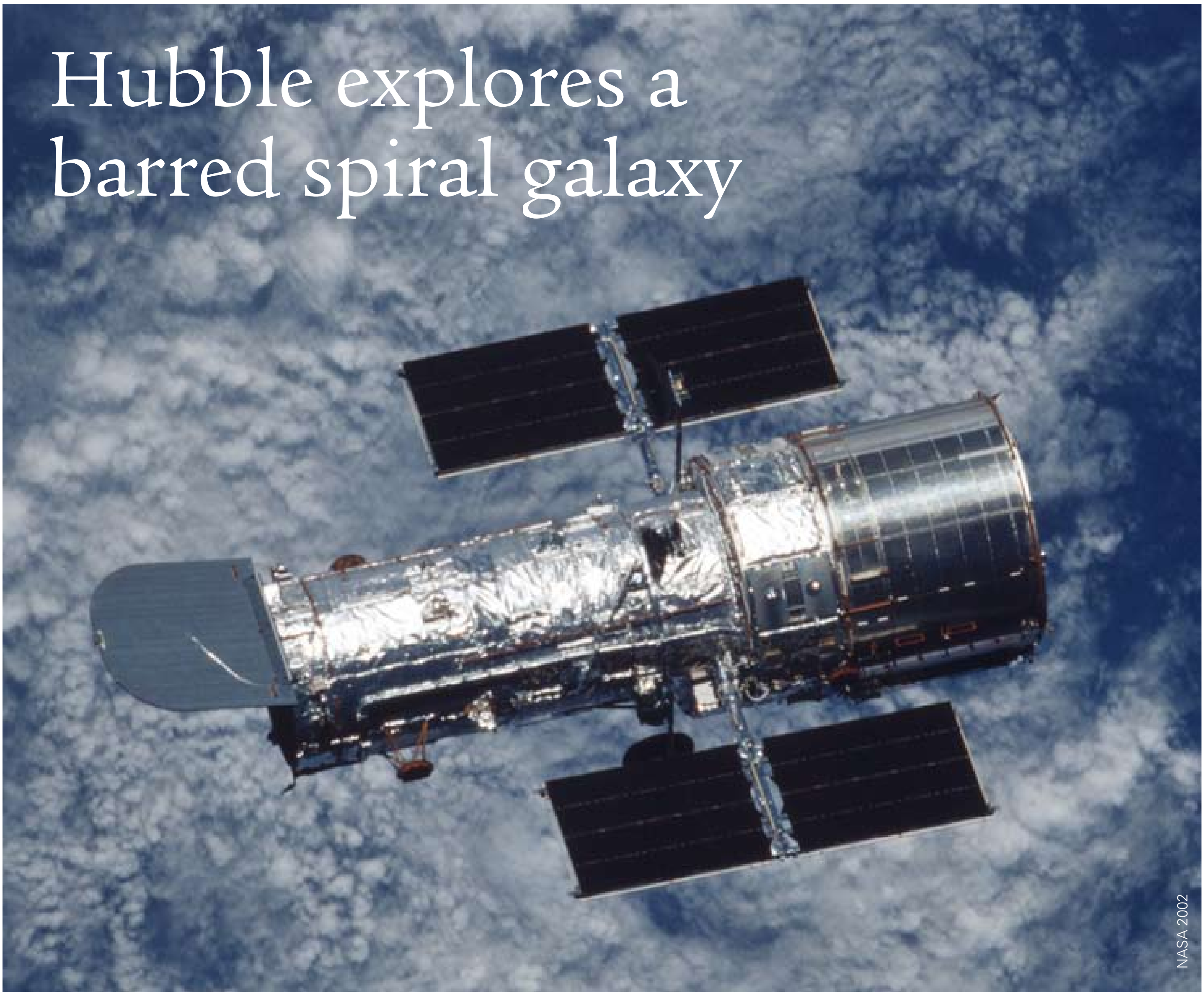
SPL

Testing a cow for TB: *a vet injects tuberculin into the cow's neck and then looks for an allergic reaction.*

Box 2 Testing for Tuberculosis

In both humans and cattle, where it is important to find out if they have encountered TB, a simple allergy test is done. A small amount of TB protein is introduced under the skin. Inflammation, showing up as a swelling, shows that an immune response is possible, and that immunity to TB exists (in humans). In this case a BCG injection would not be offered. In cattle, a positive reaction (the animal is said to be a *reactor*) would signal bovine TB and, in the UK, the animal would need to be slaughtered as part of the policy to prevent spread.

Hubble explores a barred spiral galaxy



The photograph on pages 10-11 shows a barred spiral galaxy, NGC 1672 in the astronomers' New General Catalogue. The image was made by the Hubble Space Telescope (HST), and was released in April 2007.
NGC 1672 is situated 60 million light years away, in the constellation of Dorado. The image is just 75 000 light years wide.

Dr Andrew Levan of Warwick University is part of the team studying this galaxy. He explains why this image was made:

> This was part of a programme to understand how star formation works in spiral galaxies. The bright red regions in the spiral arms are where the star formation is happening. Using this data, and some taken in tandem by the Chandra X-ray Observatory (which uses X-rays which can penetrate through dense gas and dust around stars, in the same way they can penetrate our bodies), we can investigate in detail the properties of these regions and how they affect the galaxy as a whole.

How the image was made

To make the image, light from the distant galaxy was recorded four times, through four different filters. Three of these let through blue, green and infrared light, while the fourth transmitted a narrow band of wavelengths around 658 nanometres, corresponding to red light coming from ionised hydrogen gas. (Stars consist largely of hydrogen.)

Total exposure time was 2.7 hours, after which the four images were combined.

The HST is in orbit at an average height of 600 km above the Earth, where it can get a clear view of objects in space, free from the effects of the Earth's atmosphere.

What to look for:

- spiral arms leading out from a central bar with dust lanes following their inner edges
- clusters of hot, young blue stars which are forming along the spiral arms
- the bright central nucleus glowing brightly; this energy comes from material being dragged into a supermassive black hole at the centre of the galaxy
- other, distant galaxies shining through NGC 1672's dust clouds
- a few bright stars from our own galaxy

Dust, gas and stars make up the barred spiral galaxy NGC 1672 in this image from the Hubble Space Telescope.

NASA, ESA, and The Hubble Heritage Team

The word galaxy comes from the Greek word *gala*, meaning milk.

We all live in a barred spiral galaxy

Our galaxy is the Milky Way. On a clear night, it appears as a band of stars, straggling across the sky. For a long time, the Milky Way has been recognised to be a spiral galaxy; now we know that it is a barred spiral galaxy, somewhat similar to NGC 1672 (pages 10-11).

How do we know?

We cannot possible hope to see our galaxy from outside – it is 100 000 light years across. So how did astronomers work out its shape?

It is clear from the fact that stars are clustered in a band across the night sky that our galaxy must be two-dimensional, roughly speaking a flat disc. There is a prominent split in the band, in the constellation of Scorpius.

In 1785, William Herschel, the discoverer of Uranus, counted stars in different directions. He guessed that the galaxy extended furthest in directions where the stars were most numerous. His diagram (figure 1) has the Sun close to the centre of the galaxy, and the Scorpius division on the right.

Building the picture

In the second half of the 19th century, astronomers used large telescopes to scan the night sky. They spotted many thousands of 'spiral nebulae' (a nebula is a cloud). Some thought that these were simply clouds of glowing dust and gas; others that they were giant star systems, perhaps even 'island universes'. Today we know that these nebulae are other galaxies, comparable to the Milky Way.

It wasn't until the 1930s that sufficient measurements had been made of stars in the Milky Way to confirm that our galaxy is spiral in form, roughly 100 000 light years across, with a central bulge about 16 000 light years thick.

Today's view

This picture has recently been further refined. Following in Herschel's footsteps, a team of astronomers have measured the distances of 30 million stars. They looked at infrared radiation coming from these stars, as this long-wavelength radiation can pass right through the thickness of the galaxy. To their surprise, their data showed that the Milky Way is more than a simple spiral galaxy; it has an extensive central bar.

The Sun is a star in one of the spiral arms of the galaxy, about one-third of the way in from the edge. The image shown below is an artist's impression of what you would see if you could travel out from the galactic disc and look at it face-on.

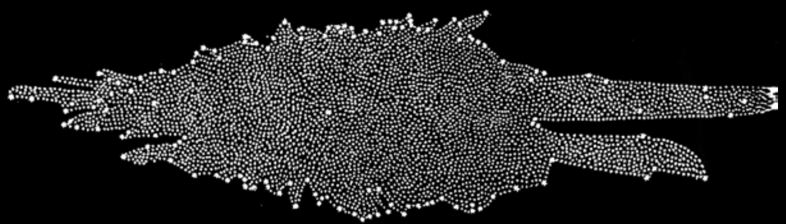
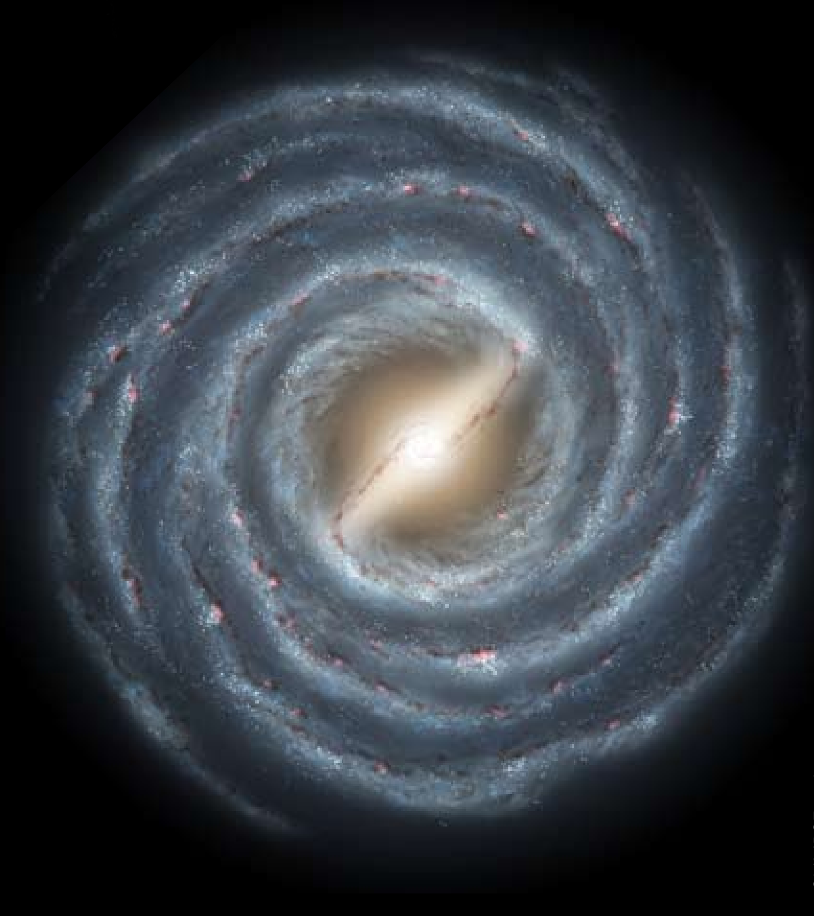


Figure1: *William Herschel's diagram of a cross-section through the Milky Way*



GLIMPSE project team

QTC making the most of a novel material

David Bloor

QTC is Quantum Tunnelling Composite, a remarkable new material discovered by David Lussey in 1997. Since then, the material has been carefully characterised (to understand its composition and how it works), and its first applications have emerged.
In this article, David Bloor of Durham University describes how QTC was discovered, and how his team set about exploring this strange new material.

Pressure-sensitive gloves for an astronaut and iPod controls built into the fabric of your jacket – two uses for QTC.

How QTC was found

QTC is a **composite material** made from particles of a metal (nickel) embedded in a polymer. Its resistance changes dramatically when it is compressed. Uncompressed, it is an almost perfect electrical insulator. When a force is applied, it conducts as well as a metal.

When David Lussey discovered QTC, he was trying to make a conductive adhesive for use in a security system. Computers would be attached by a wire to an alarm; the glue joining the wire to the computer would be conducting, so that if the wire was detached, the alarm would sound.

David describes himself and what he was trying to achieve:

> I'm not a scientist but I am a practical person with a technical background from the military. When I needed a conductive adhesive and found there wasn't one available, I decided to make one.

To make a conducting adhesive, David mixed metal powders with adhesives in different combinations. One turned out to be very special. When two metal plates were glued together, they did not conduct – the glue between them acted as an insulator. However, when he tried to pull the plates apart, they started to conduct.

> This was very strange and not what I was looking for. So I put that on one side (in fact I threw it on one side!) and it wasn't until some little while later that I thought, 'Well, that was a strange reaction.' I went back and measured it with a meter and found I got something very unusual.

It was not obvious at this stage that the material had commercial possibilities; nor did David understand how the material worked to produce this strange behaviour. So he approached my research group here at the University of Durham to help him make sense of his discovery.

Exploring QTC

When David Lussey first showed me a sample of QTC it was immediately apparent that it was an unusual material for two reasons. First, new materials are usually the product of targeted projects carried out in research and development laboratories. The unexpected discovery of a new material, particularly by someone working on their own, is rare.

Secondly, QTC behaved differently from other metal-polymer composites. Such materials usually conduct better when compressed, but their resistance rises when they are stretched – see Box 1. QTC becomes conducting when stretched, bent and twisted as well as when compressed!

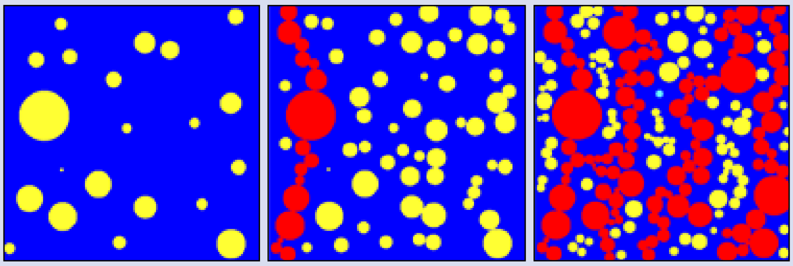
We set out to understand why QTC is different in two ways:

- by measuring its electrical properties;
- by determining its microstructure.

Key words
Composite
Electrons
Resistance
Quantum mechanics

The microstructure of a material is its structure as seen with microscopes, including very powerful electron microscopes.

Box 1



a b c

How does a normal metal-polymer composite conduct electricity?
a When the concentration of conductive particles (yellow) in the composite is low, the particles are far apart and the resistance is high, close to that of the binder (blue).
b At a critical concentration, particles begin to come into contact and form conducting chains (red) that extend throughout the material. Electrical current can then flow along these chains between the electrodes (green). **c** The resistance falls rapidly as the particle concentration and the number of conductive chains increase. Compression forces more particles into contact giving more conductive chains and the resistance falls. However, when the composite is stretched the particles are pulled apart and the resistance rises. QTC is different – stretching also causes the resistance to fall.

Electrical properties

A simple measurement shows that the resistance of a small 'pill' of QTC decreases by a factor of 10^6 as the pressure is increased by a factor of 4 *(figure 1)*.

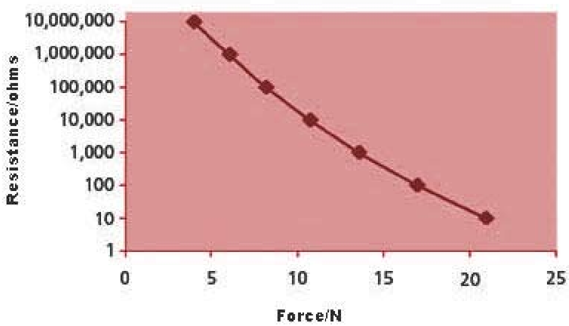


Figure 1 *Small increases in force produces enormous changes in the resistance of QTC.*

However, we discovered that when a sheet of QTC was stretched, its resistance fell by a factor of about 10^{10}, and an even larger effect was observed for compression where the resistance fell by $>10^{14}$, both truly remarkable results.

Measuring such big changes needed special instruments. The resistance of un-deformed samples is very high and requires the measurement of very small currents. We used an electrometer capable of measuring currents down to pico-amperes (1 pA = 10^{-12} A). At the other extreme we needed a digital meter capable of accurately measuring milli-ohm resistances.

Measuring the resistance of un-deformed QTC was not straightforward. Tiny forces can alter its resistance, so simply putting wires into contact with QTC can affect the measured resistance. To overcome this problem a layer of QTC was cast between aluminium foils, which did not produce any strain in the sample.

Also, when a force is applied, it takes some time for the resistance to change to a stable value. This is because the material undergoes 'creep' – the applied force causes the individual polymer chains to slowly disentangle.

Inside QTC

We used two types of electron microscope to study the microstructure of QTC, a scanning electron microscope (SEM) and a transmission electron microscope (TEM).

The TEM images showed that the nickel (Ni) particles were covered in sharp edges and spikes. The SEM images showed a large number of particles all covered in a closely adhering coat of silicone rubber (Figure 2). How can these observations account for the strange properties of QTC?

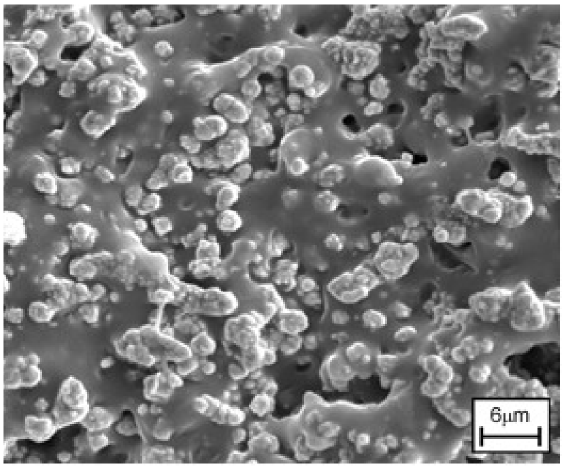


Figure 2 A scanning electron microscope image of QTC shows the sharply-pointed nickel particles embedded in rubber.

The polymer coating on the Ni particles prevents them coming into direct physical contact, preventing electrons from hopping from one metal particle to the next. This explains why the initial resistance of QTC is high, despite the high concentration of metal powder.

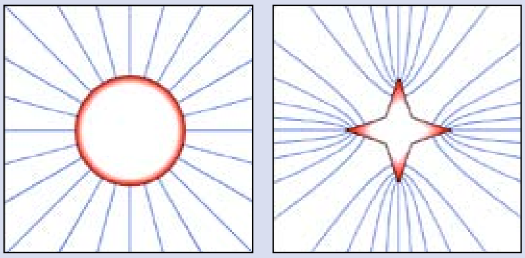
The sharp projections on the Ni particles are vital. Electrons collect at such sharp points, producing a strong electric field (see Box 2). This has an effect because electrons are quantum particles; their behaviour was not understood until the invention of quantum mechanics. An electron can 'tunnel' through a high-resistance barrier provided the barrier is very thin – of the order of nanometers. The thinner the barrier and the more energetic the electrons, the easier it is for them to tunnel through.

The strong electric field at the sharp tips makes the barrier appear thinner to the electrons, and it also gives the electrons more energy. When QTC is deformed, points on neighbouring particles come closer together. Energetic electrons emitted from the tips can 'tunnel' through the relatively thick polymer barriers between the particles, and this explains the low resistance values we found for deformed QTC.

To establish the importance of the sharp features on the Ni particles, we made samples with more rounded particles. The smoother the particles, the less the material's resistance changed when deformed.

Above: *QTC is used in the keys of this roll-up keyboard; to increase the speed of the drill, grip the body more tightly.*

Box 2



a **b**

How do electrons spread themselves over the surface of a metal particle?

a For a spherical particle, the charge (shown in red) is distributed uniformly over the surface giving rise to a uniform electric field, shown by the blue lines, outside the particle.

b For a non-spherical particle, most charge is on the extremities. The external electric field is strongest at the tips of the sharpest features – perhaps 10,000 times as large as on the surface of a sphere. Such large fields can cause electrons to be emitted from tips, an effect that is utilised in plasma TVs and lightning conductors.

Other possible uses for QTC:

as a sensor in tactile gloves, for disabled people, or for robots

as a sensor in a dance mat, linked to a computer

in pressure sensitive bandages, to avoid squashing the patient

Left: *This jacket has built-in QTC controls for an MP3 player*

The future

As QTC is a new material the study of its properties is still in its infancy. The measurements described here were the first steps taken in a programme of research and development that will continue into the future.

David Bloor is professor of Physics at Durham University.

Look here!

Peratech – the company set up to manufacture QTC: www.peratech.co.uk

David Bloor's research group has a website to explain its work: www.dur.ac.uk/psm.group/qtc.html

David Sang

It must be true – I read it in the paper!

***Right:** a selection of headlines which appeared in the **Daily Mail** during just one week in June 2007*

Our newspapers, magazines and TV programmes are full of stories based on science and technology. But can we trust what the papers say? This article looks at the way in which scientists try to ensure that their own publications are reliable. It makes use of a system called **peer review.**

How can you read articles like these and assess whether the report is to be trusted? What should you look for?

Start by scanning the article to find the source of the journalist's information. It might say, for example:

'Work by Cambridge University biologists published in this week's issue of *Nature*...'

This gives you an idea of who did the work and where it is to be published (*Nature* is a prestigious scientific journal). In principle, you could search out a copy of *Nature* and read the original article for yourself.

On the other hand, an article might say:

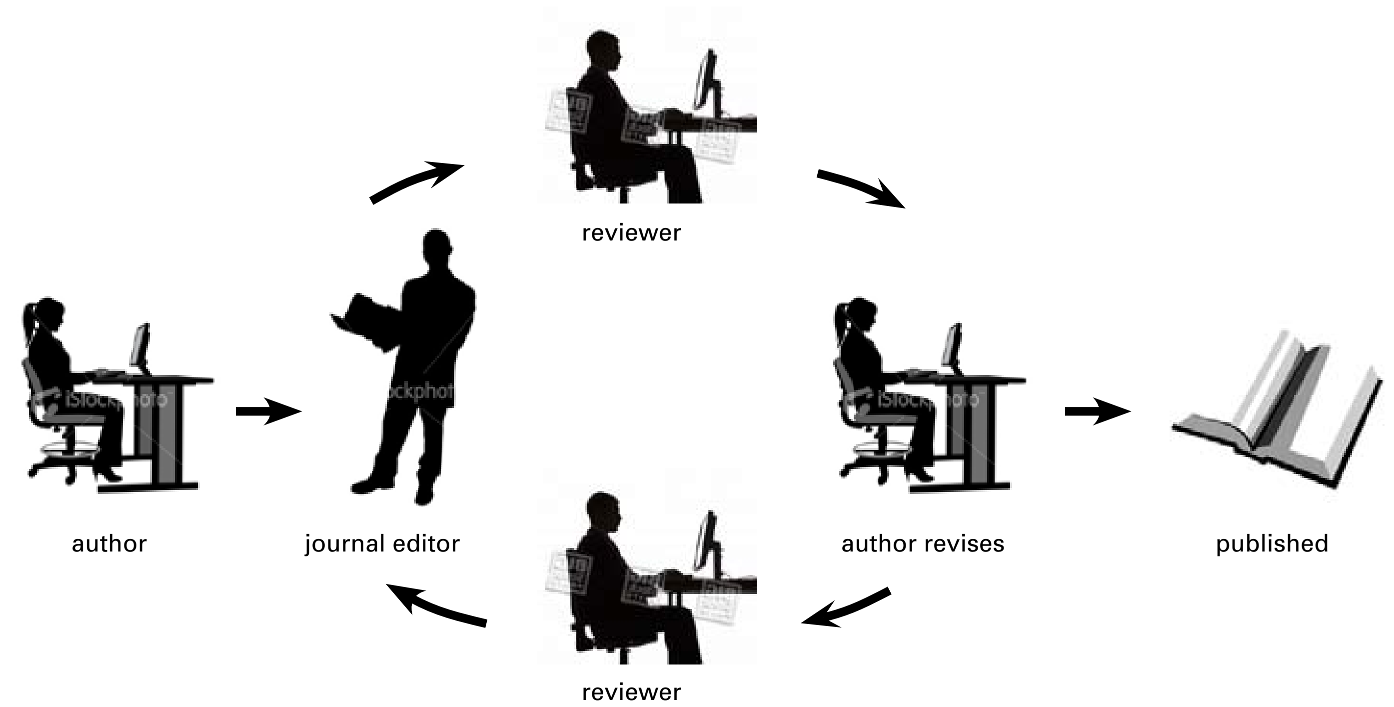
'Scientists working for a Japanese electronics firm predict that they will soon ...'

There is not enough information here to track down a specific group of scientists or to find their published work. It is more likely that the article is based on a press-release from a commercial firm, eager to suggest that they will soon have new products to sell.

Box 1 Scientific journals

There are thousands of peer-reviewed journals, not all of them scientific.
About one million scientific papers are published each year worldwide.
Some journals never appear in print; they are only available electronically, on the internet.

***Nature** is one of the leading scientific journals.*



Quality control

A **scientific paper**, published in a scientific journal, is the standard way in which scientists communicate their findings. Without a published paper, a piece of research is almost worthless because it is not available to the rest of the scientific community.

When a piece of work is finished, members of the team draft a paper describing what they have done and what they have found out. They then submit their draft to the editor of a journal. Now the process of **peer review** can begin.

The editor is likely to know many scientists working in the field. These people are the peers (or equals) of the paper's authors. The editor selects two or three with relevant experience and sends them the draft paper for review. The reviewers are unpaid, and they remain anonymous. They judge the paper, and send back suggestions to the editor.

- Is the paper ***valid***? (Are the conclusions based on good methods and is the data reliable?)
- Is the paper ***significant***? (The paper must make a useful addition to the existing body of scientific knowledge.)
- Is the paper ***original***? (Or has someone else already done the same work?)

It is rare for a draft paper to be accepted exactly as it was submitted. Usually, reviewers suggest alterations, or even some extra work, to be done before the paper can be accepted for publication. Occasionally, a paper is flatly rejected.

It may seem alarming to have to go through the process of peer review each time a paper is to be published, but most scientists value it because it confirms the value of their work. For scientists reading the published paper, it gives confidence that the work has been properly scrutinised.

Box 2 Go-it-alone scientists

Occasionally, scientists prefer to present their findings in a different way. In 1989, two scientists, Stanley Pons and Martin Fleischmann, announced that they had discovered a new technique for releasing energy from hydrogen. They called it 'cold fusion', and suggested that it might become a cheap, clean way of generating electricity. However, they didn't publish their results in a refereed journal; instead, they held a press conference in front of TV cameras.
Most scientists working in the field reject Pons and Fleischmann's work. However, there are still people developing the work, and cold fusion may yet turn out to be a genuine phenomenon, accepted by the rest of the scientific community.

Philippe Plailly / Eurelios / Science Photo Library

Pons (right) and Fleischmann, at work in their lab in 1993.

www.scirus.com
This specialist science search engine allows scientists to search existing published journals on-line. Go to the site and put in search words related to the article on wave power (pages 1-3): *Joao Cruz wave power* – you will find a link to one of Joao Cruz's published papers.

Vicky Wong

Hydrogels

water-absorbing polymers

Key words
Polymer
Bonding
Biocompatibility
Smart materials

What is the connection between soft contact lenses, disposable nappies, hair gel and plant water crystals? The answer is that they all make use of substances called hydrogels. These are polymers which have the unusual property of being able to absorb huge quantities of water.

Scientists still do not fully understand how hydrogels manage to absorb so much water, and there is still plenty of ongoing research into their properties and uses. Understanding the structure and bonding of these advanced materials helps to explain these properties; this in turn helps chemists to design new hydrogels which can perform different functions.

Structure and bonding

Many hydrogels are **polymers** of carboxylic acids. The acid groups stick off the main chain of the polymer (Figure 1). When these polymers are put into water, the hydrogen atoms react and come off as positive ions. This leaves negative ions along the length of the polymer chain.

When polymer chains are in solution, they tend to coil up (Figure 2). However, the hydrogel now has lots of negative charges down its length (Figure 3).

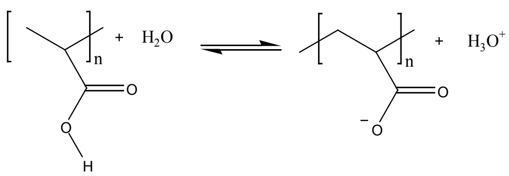


Figure 1 *The polymer chain of a hydrogel. Note: H_3O^+ is another way of writing H^+ and shows an acid.*

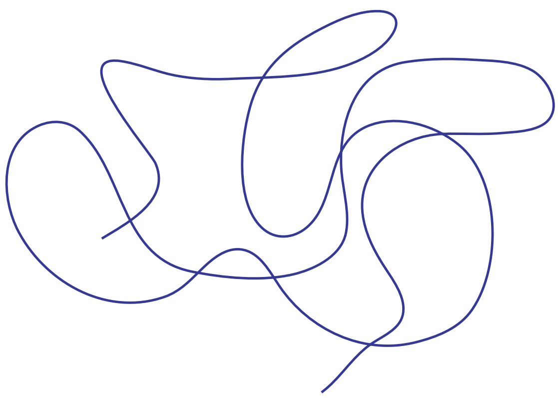


Figure 2 *A polymer chain coiled up in solution*

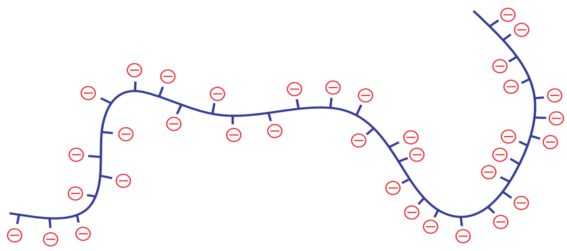


Figure 3 *A hydrogel polymer chain with lots of negative charges along its length*

These negative charges do two things:

- They repel each other. This forces the polymer chain to unwind and open up.
- They attract water molecules.

A water molecule is H_2O; it has two hydrogen atoms attached to a central oxygen atom. It is a covalent molecule and not ionic, and overall has no electric charge. However, the oxygen atom is better at pulling electrons towards itself than the tiny hydrogen atoms. This causes the oxygen atom to be very slightly negative and leaves the hydrogen atoms very slightly positive (Figure 4). The charges are tiny – far smaller than the negative and positive charges in something like sodium chloride – but they are big enough for the negative charges on the hydrogel polymer to attract them. The water molecules stick to the hydrogel polymer and force it to open up even further.

The combination of the polymer opening up and the water molecules sticking to it make a solution of the hydrogel get thicker and more viscous (sticky).

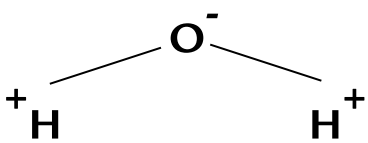
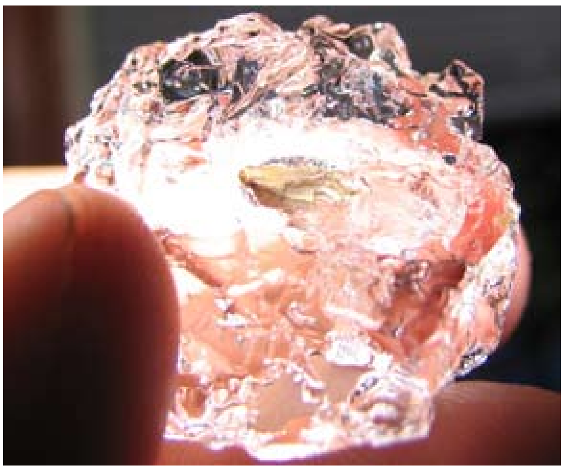


Figure 4 *A water molecule showing the very small negative and positive charges on the atoms.*

Drier babies, wetter plants

Disposable nappies make use of the ability of hydrogels to take up and retain water, even under pressure. They contain small crystals (about 1 mm in diameter) of hydrogel in the fluff at the core of the nappy (see Box 1). They absorb the urine and swell up. Because they do not easily give the water back, the child stays dry.

Plant water storage crystals are similar. They absorb water and swell up. If they are put in with plants in tubs or hanging baskets, they will slowly release the water as the soil dries up and extend the amount of time required between waterings, for example when you go on holiday.

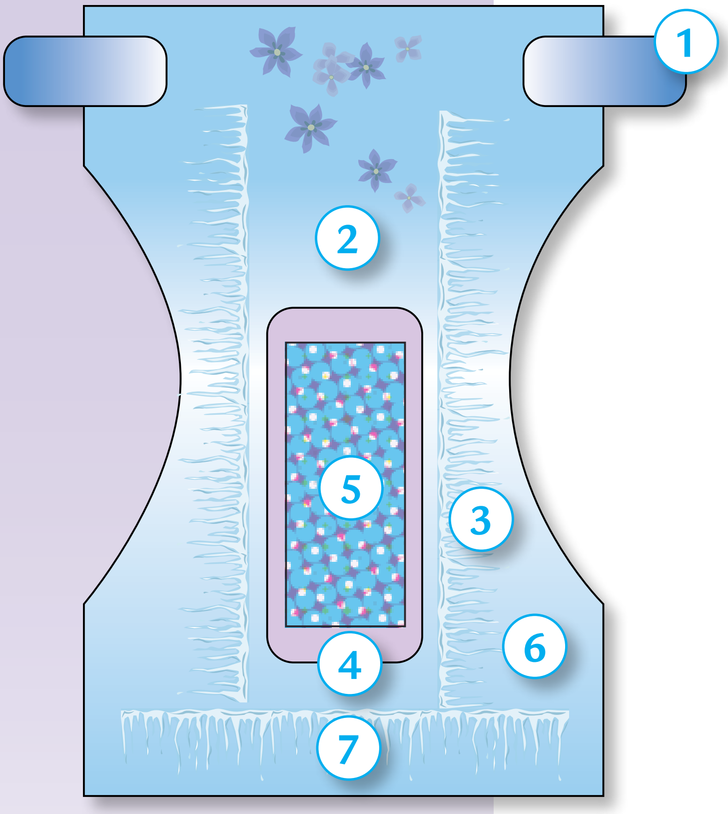


Plant gel crystal

Box 1 What's in a nappy?

Over 17 billion disposable nappies are sold in Europe each year. They have replaced traditional cotton nappies: 97% of babies use disposables.

A nappy may seem a mundane, everyday product, but there is a lot of technology in its design. For each part, a material is chosen with the correct properties – smooth, waterproof, sticky etc. And at the heart is the water-absorbent hydrogel which can retain urine even under pressure.



1 *tape/loop & hook closure system*
2 *absorbent hydrogel core*
3 *leg elastic*
4 *transport layer*
5 *acquisition layer*
6 *plastic film backsheet*
7 *elastic waist band*

Some medical applications of hydrogels

- breast implants
- wound dressings
- pressure sensors
- drug delivery systems
- lens replacements

Medical benefits

Hydrogels also have several major medical uses and you are likely to know someone who is benefiting from them as they are used in ‘soft’ contact lenses. However, scientists are discovering that hydrogels can be used for several other medical applications. There are many reasons for this including their amazing ability to absorb water. As they can hold so much of it they can have a similar water content to body tissue and can transport nutrients and waste.

They are also biocompatible. This means that they do not harm the body or stimulate an immune reaction.

As the hydrogels are known to work quite happily in the eyes of millions of contact lens wearers, it makes sense for scientists to look at ways in which they can be used to treat physical damage to the eyeball. In the USA, a hydrogel has been developed which it is hoped will be used to replace diseased and ageing lenses. As we age the lens of the eye gradually loses its ability to adjust its focus. The hydrogel has similar mechanical properties to the lens in the eye and the scientists hope that it will possible to inject the hydrogel into the eye to help restore sight.

Smart materials

An Italian company is testing hydrogel tablets as a slimming aid. A single tablet, less than 1 cm across, swells in the patient’s stomach to hundreds of times its original size. This causes the patient to feel full and suppresses their appetite. However, some doctors warn that this is no substitute for a reduction in calorie intake.

On top of these benefits, hydrogels are also smart materials. A smart material is one which changes its shape (or some other property) in response to changes in its environment. Different hydrogels can be made to change shape in response to changes in pH, temperature, salt concentration and many other factors.

Look again at Figure 1. The polymer changes when water is added and there is a $\rightleftharpoons$ sign in the equation. This sign shows that the reaction is reversible. If water is added, the equation moves to the right. If water is removed, it moves to the left. On the right hand side, H_3O^+ is acidic. If more acid is added the equation will move to the left; if acid is removed (for example by adding some alkali) the equation will move to the right. As the polymer on the left hand side is the collapsed form and the one on the right is large and viscous there is a considerable change in the properties as the pH changes. It is this shape change which makes the hydrogels ‘smart’.

Many scientists are researching ways in which hydrogels can be used as drug delivery systems. When you take a medicine or drug by mouth it is dispersed throughout your body. This means that if you take a paracetamol for a headache, the drug reaches not just your head but also your arms, legs, stomach and the rest of you. In the case of paracetamol, this is not usually a problem but some drugs have unpleasant side effects. What a drug delivery system aims to do is to deliver the drug to the site where it is needed, but to keep it tied up and unavailable to cause problems when it is in the rest of the body. So scientists hope to load the drug onto a hydrogel and have it released at the place where it is needed. The diseased site may have different chemical properties which the hydrogel could recognise and therefore release the drug it is holding only at that point.

Growing new body parts

The technology is still a long way off, but scientists are hopeful that some time in the future it will be possible to grow replacement body parts in hydrogels. Cells of the required tissue will be added to the hydrogel and injected into the body where they are needed. The hydrogel will take the place of the damaged tissue and also allow nutrients to pass through it to the cells inside. Over time, the cells will grow and the hydrogel be degraded by the body until new tissue is in place to repair the damage.

Hydrogels are still a long way from being used in hospitals and whole organs grown on hydrogels are even further away, but researchers in the USA recently managed to grow lung tissue in a hydrogel which demonstrated that this idea has potential.

Hydrogels, then, are both readily available in such everyday items as nappies and hair gel and the focus of cutting edge research around the world.

Vicky Wong teaches and writes about chemistry. She is an editor of CATALYST.

Cleaning up with hydrogels

Dr Nicholas Crowther and Dr Donald Eagland of Bradford University have invented a ‘supergel’ for use in combating environmental pollution. This hydrogel is much stronger than other hydrogels, and is capable of absorbing large amounts of oil. A sheet of the polymer can be thrown over an oil slick; when the oil has been absorbed, the gel is rolled up and removed.

Testing hydrogels

Try This

Hydrogels are polymers with a great capacity for absorbing water - see the article on pages 18-20. Here are some experiments to try on a couple of domestic products that make use of hydrogels: hair gel (cheap and cheerful is fine, from any supermarket or chemist), and plant water storage crystals (also known as water-retaining gel, from garden centres).

Experiment 1: Hair gel

Put a large blob of hair gel into each of two old yoghurt pots. To one add some salt, to the other some sugar.

You should be able to see a clear difference with the salt (an ionic compound) and the sugar (a covalent compound). The ions in the salt cause the hydrogel to collapse and quickly turn into a liquid (see the Hydrogels article on pages 18-20 for more about this). As the sugar does not contain any ions it does not cause the hydrogel to collapse.

Why do you think this hair gel contains hydrogel? What would happen if you went swimming in the sea while using this gel?

Experiment 2: Plant water storage crystals

Put a teaspoonful of the crystals into a yoghurt pot. Add a measured amount of purified water to the crystals. Try to work out how much water the crystals will absorb (they will take several minutes to finish absorbing the water). How much larger are the crystals when they are soaked in water than they were at the start?

Repeat with tap water in a second pot. Is there a difference? Can you explain it? There is likely to be a greater difference in hard rather than soft water areas. Why?

Some hydrogels can absorb as much as 600 times their original volume of water. They will absorb more purified water as it contains fewer ions. Tap water contains ions, so the hydrogel will not absorb as much tap water as purified water.

Put the remains of these experiments into the bin and not down the sink.

The hydrogel can look like colourless jelly, but it is not edible so don't eat it!

If you know someone who wears diposable contact lenses you may be able to persuade them to give you a pair. You can try Experiment 1 on a much smaller scale with the contact lenses – but do check first that they have definitely finished with the lenses and don't want them back!

100 years after Mendeleev

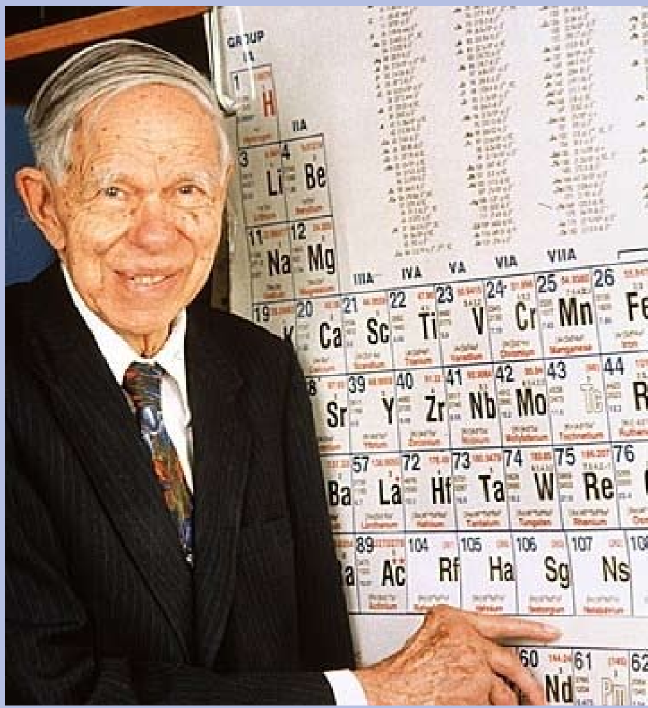
The Russian chemist Dmitri Mendeleev died 100 years ago, in 1907. He created the Periodic Table in the mid 1800s. Like other chemists, he put the known elements into some sort of order, but his great achievement was to realise that some elements had not yet been discovered and to leave spaces for them. He used the periodic table to predict the properties of several undiscovered elements, using those of the elements nearby as a guide. Within 15 years, three of these elements had been identified and their properties shown to match those he had predicted.

Celebratory stamp

This Spanish stamp has just been issued to mark the centenary of Mendeleev's death in 1907. The four gaps in the table show the elements which he predicted and which were subsequently discovered. Can you name them?

Beyond uranium

Elements beyond number 92 (uranium) have been made in nuclear reactors. Element number 106 is seaborgium (Sg), first made in the 1970s. At the time its properties were predicted, but it was only in the late 1990s that researchers had enough atoms and sensitive enough equipment to test and confirm the predictions.



Glenn Seaborg pointing to the element named after him on the Periodic Table. He is the only person to have an element named after them while still alive.

Could you do what Mendeleev did?

Mendeleev wrote the properties of all the known elements on pieces of card and re-arranged them to try to produce an order which made sense. Try the Mendeleev game and see if you can produce a periodic table.
www.chemsoc.org/networks/learnnet/ptdata/games/mendeleev.htm