Catalyst

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Stripes and spots

How animal patterns form

Science Enhancement Programme

Catalyst

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The cover image shows a Bengal tiger at Antwerp Zoo. Many animals have patterns of spots or stripes, but how do these develop as the animal grows? See the article on pages 1-3. (Image courtesy of Tiene Alles)

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

Talking science

When scientists carry out research, they are finding out something new, something that no-one ever knew before. It's not like at primary school where, if a pupil is asked to 'research' a topic, they look in encyclopedias or online. And, once a scientist has found something new, they have to communicate their findings. That's what scientific papers and journals are for.

Nowadays, scientists recognise that they have to communicate their findings to a wider audience, because science has an impact on all our lives. It is also the case that much of scientific research is paid for from public funds, so it is right that we hear about what we have funded.

On pages 4-5 of this issue of CATALYST, Emily Dawson describes the field of science communication, and on pages 6-8, six young science communicators describe their work.

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Photos Tiene Alles and Marja Flick-Buijs

Caroline Wood

How the leopard gets its spots
The origins of animal patterns

The animal kingdom contains an abundance of exquisite natural patterns from the stripes of an angelfish to the spots of a leopard. But how do these arise during early development? ***Caroline Wood*** *explores one theory.*

In 1952, Alan Turing proposed a mechanism to explain how animal patterns are produced. This became known as the 'Reaction-Diffusion Model' and is still the strongest theory for how patterning is controlled. Turing was a mathematician rather than a biologist, and is most famous for deciphering the Nazi Enigma Code during the Second World War. From this experience, he suggested that animal patterns were specified by another type of code, where diffusing molecules acted either as inhibitors or activators. A central idea is that the pattern is not pre-determined but arises spontaneously as a result of the interactions between these molecules.

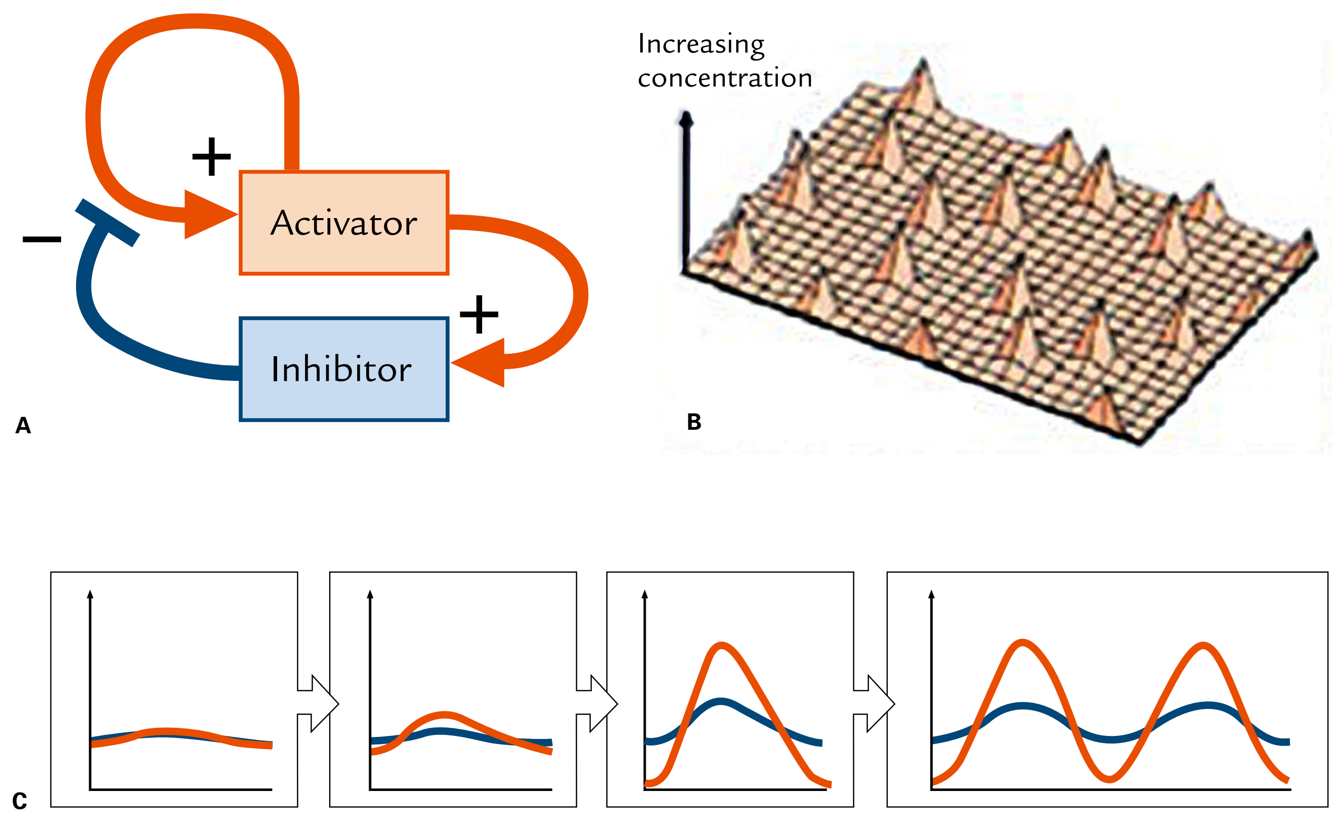
The central theory

Turing's theory is based on the concept that a process (e.g. spot or stripe formation) occurs when the concentration of an activator reaches a critical level. The concentration of the activator, however, is regulated by feedback mechanisms. The activator produces more of itself through an auto-catalytic mechanism (known as 'positive feedback') yet at the same time also stimulates the production of an inhibitor, which acts as an antagonist to the activator. Because the production of the inhibitor depends on the activator, the highest concentration of activator and inhibitor will occur in the same place, called the focus.

Both molecules diffuse away from the site of production, forming a concentration gradient around the central peak. A key concept of the theory is that the diffusion range of the activator is less than that of the inhibitor. The concentration of the activator is only strong enough to initiate a process at the focus; although this is also where the concentration of inhibitor is highest, sufficient quantities of activator are present here to overcome this negative effect. Because the inhibitor is a more powerful diffusing agent however, the concentration of the activator drops sharply outside the focus point, causing it to be suppressed by the inhibitor.

Key words
pattern formation
diffusion
feedback
Alan Turing

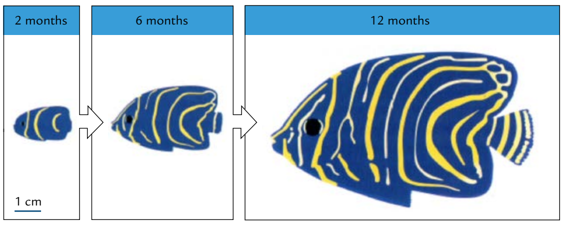
Antagonist: something (a gene, molecule, muscle) which counteracts the activity or effect of another entity (the agonist).



Theory of Turing mechanisms. ***A*** *The patterning process is governed by the activities of diffusible substances that act either as activators or inhibitors. The activator promotes the production of itself, but also increases the concentration of the inhibitor.* ***B*** *This produces distinct peaks of production where the concentrations of both the activator and inhibitor are highest.* ***C*** *These properties allow complex patterns to develop from initially small, random fluctuations in concentration.*

What Turing explains

Turing mechanisms have many attractions for explaining animal patterning. Firstly, they describe how patterns arise spontaneously from a group of cells that all have equal potential to form a patterning element. Because the activator and inhibitor substances are dependent on each other, random fluctuations in concentration resolve over time into sharply defined peaks. Reaction-Diffusion mechanisms also enable the pattern to be maintained as the animal grows. The stripes of the angelfish *Pomacanthus semicirculatus*, for instance, maintain a constant spacing even as the animal grows.



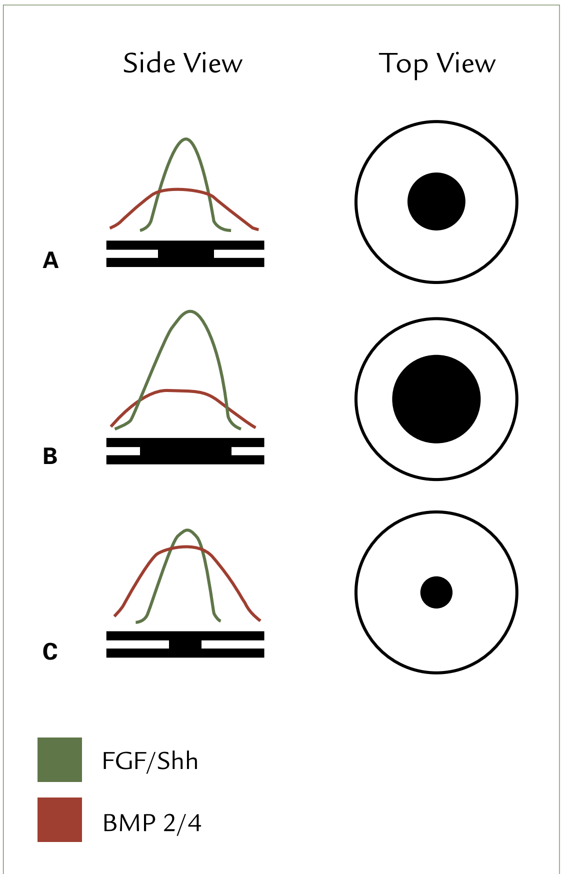
Angelfish stripe patterning. Angelfish stripes maintain a constant distance even as the animal increases in size. This is caused by the gaps between the peaks of inhibitor production widening, allowing new focus points to be established.

The angelfish Pomacanthus semicirculatus

This is the result of new stripes being produced as existing stripes move further apart. According to the Reaction-Diffusion Theory, the stripes represent the areas where the inhibitor substance is produced. As the gaps between the stripes widen, areas with low inhibitor concentrations form, allowing a new focus point to develop and initiate a new stripe. When the parameters of a Turing mechanism were entered into computer modelling software, the programme reproduced the natural pattern observed in angelfish, further supporting a Reaction-Diffusion mechanism.

Forming feathers

Another system that appears to use a Turing mechanism is feather patterning. Feathers develop where cells in the epidermis (the outer layer of the skin) multiply and condense to form an epidermal placode that develops into a feather primordium. Placodes and feather primordia develop in sequence, beginning from the midline and spreading across the flanks. This is promoted by the gene products Fibroblast Growth Factor (FGF) and Sonic Hedgehog (Shh), which have the role of activators. At the foci, Bone Morphogenic Proteins 2 and 4 are also produced, which act as inhibitors. Feather primordia form in the regions where the concentrations of FGF/Shh are high enough to overcome the effects of BMP2 and 4.



*Feather placode formation. **A** The formation of epidermal placodes is determined by the ratio of positive inducers (FGF and Shh) and inhibitory substances (BMP 2 and 4). Placodes form where the concentration of positive inducers overcomes the influence of the inhibitors. **B** If the activator concentration is artificially raised, the placodes will increase in size. **C** Increasing the level of inhibitors, meanwhile, will result in smaller epidermal placodes.*

Hence, the size of the feather primordia depends on the diffusion range of FGF/Shh and the threshold level at which BMP2 and 4 prevent epithelial condensation. Meanwhile, the spacing between the developing feather follicles is determined by the diffusion range of the inhibitor. In experiments where beads coated with FGF were placed next to chicken skin, the size of the feather placodes expanded so much that they fused together. On the other hand, injecting a synthetic virus coding for BMP2/4 expression caused the feather placodes to reduce in size. Normal feather patterns can form on isolated strips of skin, demonstrating that the pattern arises spontaneously without relying on signals from pre-existing placodes, providing additional evidence of a Turing mechanism.

The pattern and separation of feathers on a chicken's skin can be explained by a Turing mechanism.

Future patterns

The spontaneous production of patterns is an intriguing facet of the field of developmental biology and there is still much debate about the underlying causes. Turing mechanisms have been proposed to govern a large range of processes, including tiger stripes, lung branching, digit formation and even the patterning of mussel beds. Who knows what features they will be implicated with in the future? Although the great mathematician himself is no longer with us, Turing's theories continue to shape our understanding of the mysterious events that occur during early development.

Alan Turing, best known today for his work as a code-breaker during the Second World War, was celebrated in his centenary year 2012.

Caroline Wood is a postgraduate student at the University of Sheffield. She is currently investigating the interactions between parasitic plants and their hosts.

Emily Dawson

What is Science Communication?

What do the TV show 'Bang Goes the Theory', the Eden Project in Cornwall and the physicist Professor Brian Cox have in common? They are all involved in Science Communication. ***Emily Dawson*** *explains.*

On one level Science Communication does what it says on the tin: it is about communicating science and building bridges between the people involved in scientific research and different groups of the public. But Science Communication is much more than just communicating science. Science Communication is involved in developing government science policies, understanding relationships between 'the public' and 'scientists', and creating science stories in the mass media, as well as exploring how people learn about and engage with science.

Dara O Briain testing out the University of South Wales' mind control robotic arm on his BBC Science Club programme. Television is a main source of science ideas once you have left school.

The Eden Project in Cornwall aims to educate visitors about science. It includes these large biomes that house plants from all over the world.

Where did Science Communication come from?

Science Communication has grown enormously over the last 40 years. The expansion of Science Communication in the UK was driven by a number of factors. These included the growth of research in science, engineering, technology and similar subjects, the increasingly central role of science in our lives, and concerns about whether most people understood enough about science.

This growth was also, in part, a response to some huge public relations disasters from the perspective of the scientific community and policy makers. These include the debates about genetically modified (GM) food, public anxiety over the MMR vaccine and concerns about the use of animals in research, to mention but three.

The MMR scare led to fewer children having the MMR (Measles, Mumps and Rubella) vaccination. As a result, the numbers of children with measles has risen. Could better communication of the science help reduce the likelihood of such scares?

Because of these very public, very controversial arguments about how science was used and affected people's lives, Science Communication began to focus on asking people about their views on science. This change, from 'telling' to 'asking', meant the public could be more involved in political decisions about what kinds of scientific research to fund and what kinds of science were considered too unethical, too dangerous or too scary.

Why is Science Communication important?

Think about the places where you find science. For most people, science is something they learn most about in school; after that, most of the science people see or hear about is in the mass media. In other words, science is something you do at school when you are young and is something you see on TV or read about in newspapers or online when you are older. If your job involves science you will become a specialist in that area, but probably will know no more about other areas of science than anyone else. But science plays an important and complicated role in our lives, so being able to understand, learn about, question and critique science is an important part of modern life.

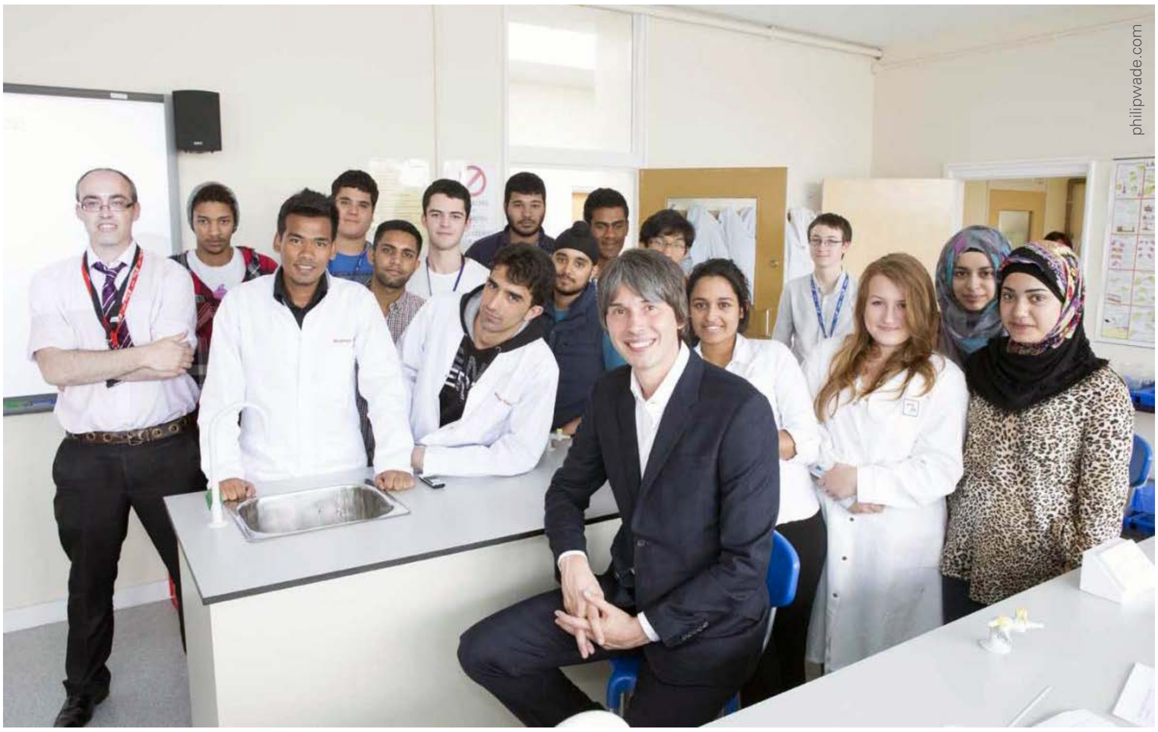
Most people only spend a small part of their lives at school. This means that the science you learn there will probably not be enough to help you understand and contribute to the scientific debates of your life. From personal decisions about health care, which car to buy or whether it's ok to eat the chicken that has been out of the fridge all day, to bigger, societal decisions about military technology, online privacy or stem cell research, helping people to understand the science involved is crucial. Science Communication has an important role to play in helping people to learn about science, to understand science issues when they hit the news and to have a voice in debates about the roles of science in our lives.

The Natural History Museum in London is a very popular place to learn about the natural world.

Science Communication today

Today Science Communication is a broad field of activity and research, so people working in Science Communication do a huge range of different activities. Some work for the government and research councils, training scientists to communicate different aspects of their research. Others work for science centres and spend their days doing amazing experiments in front of crowds of visitors. Others still do social research to understand how the public think about scientific issues. So whether you want to be the next Brian Cox, wowing TV audiences with science, or you want to explore how science works in our society, Science Communication is an important subject.

Read six case studies of people who are making careers in Science Communication – see pages 6-8.



Prof. Brian Cox meets students at Redbridge College in Romford, Essex (www.redbridge-college.ac.uk).

Dr Emily Dawson is a Lecturer at King's College London, currently launching the first BSc course in Science Engagement and Communication in the UK

Look here!

For information on the new undergraduate degree in Science Communication see: *http://tinyurl.com/p5dwq29*

Your future

Working in science communication

Six people whose work can be described as 'communicating science' reveal the great variety of career paths in this area.

Alex Tate, Producer/Director, Windfall Films

I produce and direct science and natural history documentaries. For me it strikes the perfect balance between my interests in science, natural history, photography and storytelling. Plus I get paid to travel the world!

I studied zoology at university and then took a master's in Science Communication, with a focus on science media production. The course was invaluable for me. It opened my eyes to the filming-making process, taught me to write about science in an engaging way and helped me get a foot in the door with a production company. I'm at the same company 6 years later.

My job varies a lot. Making a documentary usually starts with a lot of research - so I'll be reading journals, speaking to scientists and trawling the internet for information to help me write a script and work out the details. If you're lucky, a few weeks later you could be filming in a far flung corner of the world. After filming I spend about 2 months with an editor, putting the film together. This involves more script writing, working with graphics, animation companies and music composers. Managing all the different parts of the process is hard, but worth it!

It is great when your film is recognised by others. A lot of TV gets made and not all of it is good! So I'm very pleased to have a BAFTA on my shelf at home as recognition of my work on 'Inside Nature's Giants' for Channel 4.

A *master's* is a higher university degree, often studied after completing a first or bachelor's degree.

Dr Sai Pathmanathan, Science education consultant

I am a science education consultant with a focus on entertainment media. I do all kinds of things, from running workshops at the BBC's 'Bang Goes the Theory' roadshow, to researching and creating new educational games and media.

While at university studying neuroscience I started doing science communication activities, which got me interested in working in this field so I did a master's in Science Education. I focused on studying how young people learnt about marine biology from films such as Finding Nemo.

Because of my research on children's media, I was invited to work at the National Science Foundation in Washington, D.C. in the United States. It was a truly memorable experience. I juggle a lot of different projects, but I'm never bored. I travel to fantastic places (Hawaii!) and meet amazing people, and all for work!

Alexis Mannion, Education and Outreach Manager, The Francis Crick Institute

I manage the Francis Crick Institute's education and outreach programme. Due to open in 2015, the Crick will be one of the largest biomedical research institutes in the world! My work involves creating science education opportunities for diverse audiences – from local schools and community groups, to internationally acclaimed scientists.

I studied Geology at University and found my first job as an Explainer at the Science Museum in London. The experience opened my eyes to the world of science communication and confirmed that I didn't want to work in a lab (or the field!) all day. While working, I studied for a Master's in Science Communication to understand the practice and theory of science communication in more depth. The course really helped me to develop the experiences I had gained while working and move forwards with my career.

At the moment I'm working on an exciting project with local community groups to create three graphic novels all about Francis Crick and the new institute – we've worked with an award winning children's writer and amazing illustrators to create the books – it's been a fantastic project!

Toby Shannon, British Science Association, Science in Society Officer

I am a Science in Society Officer at the British Science Association – I work on many different, exciting projects with scientists and engineers to get them engaged with the public. The Association aims to bring people and science together through our nation-wide programme of events and activities – we've been going since 1831!

I've always loved science and started off studying for a degree in Physics with Nuclear Astrophysics. I had the opportunity to go on a placement year to work in communications at the Rutherford Appleton Laboratory in Oxfordshire. I learnt so much about science communication that I was inspired to pursue it as a career. I went on to do a Science Communication master's course which gave me a really solid theoretical base and loads of new practical skills.

One of the things I love about my job is that it's so varied. You might find me preparing for conferences, running the x-change events at the British Science Festival or training scientists to better communicate their research to the public. It's tricky balancing lots of different projects at once but I love the challenge! It's great working on something that you believe in and that you're proud of!

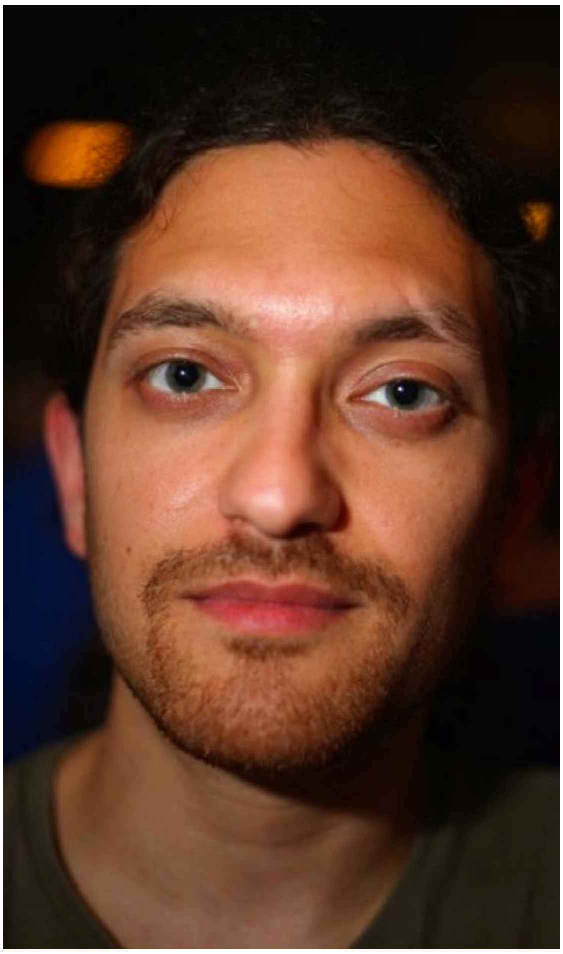
Kamini Plaha, Natural History Museum, Science Educator

My job is to engage, enthuse and inspire visitors of the Natural History Museum (NHM) through the use of the museum's collections. I deliver workshops and shows around the museum for families and schools. My favourite is a show called Animal Vision as we get to work with a professional animal handler and their amazing living animals.

After my degree in Biological Sciences, I wanted to experiment with different careers in Science Communication as I was unsure as to what it was and whether I would enjoy it. I became a Learning Volunteer at the NHM and was an intern at the Royal Society. I really enjoyed engaging with the visitors at the NHM and communicating the behind-the-scenes science to visitors and was delighted to get a full time job at the museum. Science communication has become a big part of my life and studying it has helped me to communicate science in an effective way and to understand how science actually works. I've never looked at a documentary, exhibition or magazine article in the same way again!

It can be hard to keep a high level of energy, enthusiasm and attention for each workshop and show, but I love the reaction from the visitors when they engage with me and an animal. We are the ones that bring the specimens and science at the museum to life!

Rohan Mehra, Exhibition Content Developer, Science Museum (Contemporary Science)



I produce exhibitions, displays and lots of events for the Science Museum. I'm always on the lookout for the most amazing things I can find, that affect people and get them talking!

Before working at the Science Museum I was a documentary film maker, which is a lot like being a journalist, which really helped me communicate contemporary science. But my road to this job started when I did a master's course in Science Communication. I learned all about turning complex ideas in science into something fun and engaging, that everyone can explore.

I spend a lot of time researching science news and issues, which is important because without research it is impossible to delve deeply into a science story. I interview scientists and read all about strange and wonderful things. If I'm working on an exhibition then everyone I talk to will be researching a different part of a large story, such as the environment, physics, robotics, or anything!

I really get a buzz from the creative parts of this job. We've run spy-games to talk about online-security, used ice-cocktails to discuss climate change and even had some live spiders in for an event on pain relief. My absolute highlight was when I wrote a short piece with Professor Stephen Hawking!

These six case studies were collected by Emily Dawson.

Balloons in space

The Big Picture

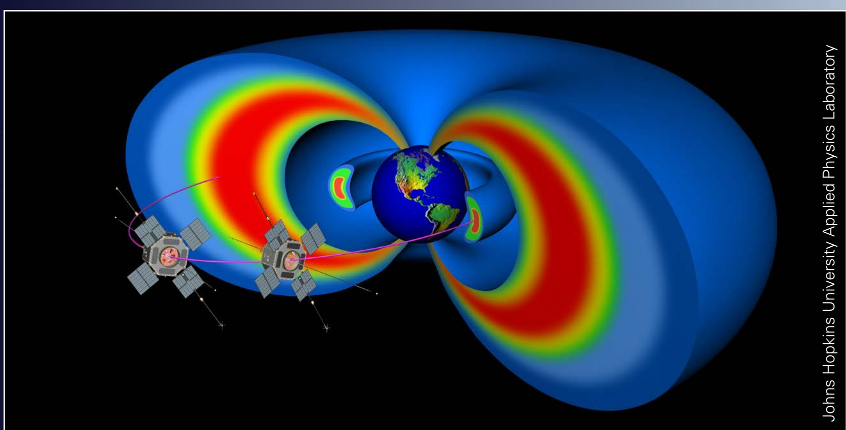
The Big Picture on pages 10-11 of this issue of Catalyst shows scientists in Antarctica launching a balloon which will travel up through the atmosphere to a height of 34 km above the Earth's surface. This balloon is part of NASA's BARREL mission, probing the radiation belts which surround the Earth.

The Van Allen Belts consist of fast-moving charged particles, mostly electrons and protons, held in place by the Earth's magnetic field. The particles spiral down, following the magnetic field lines, before bouncing back when they approach the poles. Because the belts are closest to the Earth's surface at the poles, this makes Antarctica a good place to investigate them.

NASA already has two satellites, the Radiation Belt Space Probes, in orbits which take them through the radiation belts. Balloons are being used to gather extra information.

Robyn Millan is the chief scientist on the BARREL project. She explains that, as the charged particles slow down, they emit X-rays. These are detected using instruments hanging below the balloon. It is important to understand the radiation belts because they represent a hazard to astronauts passing through them and to the on-board instruments of spacecraft.

Launching a balloon is like flying a kite. Here, NASA scientists run across the Antarctic ice below the balloon payload of instruments.



The Van Allen radiation belts are under investigation by two NASA spacecraft.

Robyn Millan, principal investigator for the BARREL project.

Why 'BARREL'?

BARREL stands for Balloon Array for Radiation-belt Relativistic Electron Losses. The electrons in the radiation belts are described as relativistic – they move at speeds close to the speed of light. The detectors on the array of balloons detect the energy they lose in the form of X-rays.

In Antarctica, NASA scientists launch a balloon with a payload of instruments to investigate radiation belts high in the atmosphere.

Catalyst

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NASA

Sylvia Knight

Launching a balloon to the edge of space

This photo of the Earth was taken from 21 000 m up, just before the weather balloon burst.

Key words
atmosphere
weather
pressure
gas laws

On 22nd May 2013, a weather balloon was launched from a school playing field in Chorley, Lancashire. The balloon travelled almost 21 km up and landed near Loughborough, 138 km away, carried by the wind. **Sylvia Knight** *explains what happens when a weather balloon is sent up.*

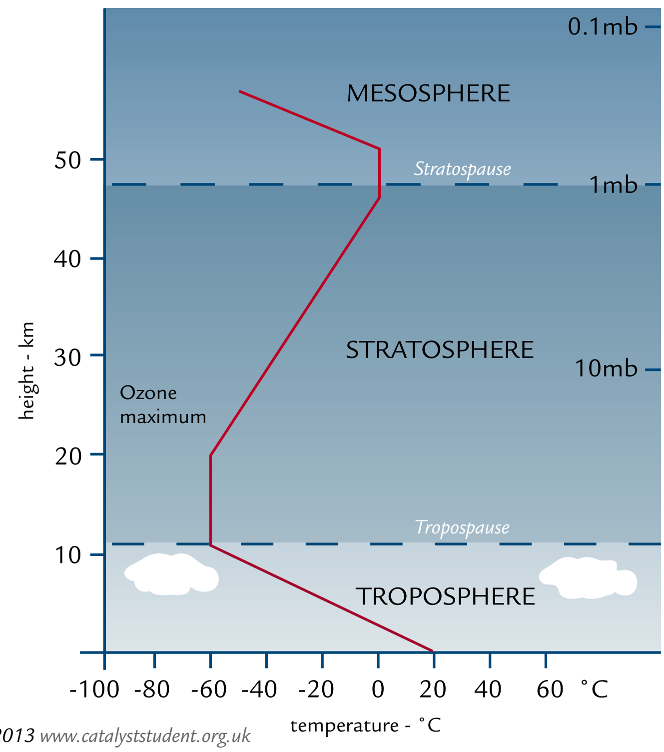
What is the edge of space? It is technically defined as being at the Karman Line, 100 km up. Weather balloons don't get anywhere near that high, but at an altitude of 21 km, which is much higher than aeroplanes normally fly, you can get a good view of the curvature of the Earth and the thinness of the atmosphere.

So what happens to a balloon as it rises through the atmosphere? Air pressure is simply a measure of how much air there is above you. As the balloon goes up through the atmosphere, the amount of air above it reduces, and so the pressure falls.

As the pressure falls, the balloon expands. Eventually it gets so big that it bursts, and falls back to the ground. Our balloon had a parachute attached so that the instruments didn't fall too fast, potentially damaging them and anything they might land on.

As the pressure falls, the temperature falls too. So, in the troposphere (the lower atmosphere, which contains all our weather), it gets colder as you go up. However, there is ozone in the stratosphere, which is the next layer up. Ozone absorbs the Sun's ultraviolet rays and re-emits them as heat, warming the stratosphere up. So it actually gets warmer again.

Have you ever thought about what it sounds like when a balloon bursts in space? Sound is a pressure wave that needs molecules to be transmitted. This means that there is no sound in Space. In the stratosphere, there are still air molecules but they are much further apart than they are near the ground. This means that sounds are a lot quieter. Also, because it is colder, the speed of sound is slower than it is near the ground.



Balloons and Boyle's law

As the balloon rises, the pressure p outside it decreases. If the temperature is constant, Boyle's law applies:

$p \times V$ = constant

where V is the volume of the balloon. So, if the pressure falls from 1000 mb to 100 mb, the volume of the balloon must increase by a factor of 10 – or, if you assume the balloon stays roughly spherical, the radius approximately doubles.

In fact, the graph on page 15 shows that the temperature drops as the balloon rises. The relatively warm air inside the balloon loses heat to the air outside the balloon. A decrease from 20 °C to -60 °C (293 K to 213 K) is a decrease of about 20%, so the balloon will expand less than predicted by Boyle's law.

The moment the balloon burst

The team from Manchester University and the Royal Meteorological Society launch the balloon with the school STEM club watching. You can see the balloon, the red parachute and the box containing the camera and GPS tracker underneath.

The balloon travelled from Chorley to Loughborough in 90 minutes, an average speed of almost 100 km/h.

Hugo Ricketts with the parachute and the box containing the camera and GPS tracker, before the launch

Sylvia Knight asked Dr Hugo Ricketts, Research Scientist at Manchester University, to describe what we can learn using weather balloons.

Weather balloons can give us detailed information about the structure of the atmosphere and how its temperature, pressure and humidity change as you go up. We need this information to feed into the computer models which we use to make weather forecasts, and to improve our understanding of how the atmosphere works. We also get information about the atmosphere from weather instruments on the ground, on ships, on buoys and aircraft, and from radar and satellites.

What is a radiosonde?

A radiosonde is a collection of instruments which is usually attached to a weather balloon. It includes a thermometer, a humidity and pressure sensor, and a GPS antenna which transmits the data back to a receiving station on the ground, as long as there is a line of sight between the radiosonde and the receiving station. As soon as a hill or building gets in the way, we lose contact with the balloon. You can work out the wind speed from the GPS too. The radiosonde transmits data once every second. We don't normally find the radiosondes once they come back to Earth, although they are quite valuable, so they have a note on them asking anyone who finds one to post them back.

How well did the radiosonde work on this launch?

We didn't get data back from the radiosonde all the time, but we got enough to show how the temperature, pressure and humidity changed through the atmosphere.

You can see the data from the radiosonde on page 15.

Teacher Sean Hardeley collects the parachute and camera box where the balloon landed in a field near Loughborough, Leicestershire.

Sylvia Knight asked Sean Hardley, science teacher, to explain why the project was organised.

This was a joint project between the STEM club from Holy Cross School in Chorley and the North West Local Centre of the Royal Meteorological Society. The balloon was carrying a camera, a GPS transmitter and a radiosonde, an instrument which transmits measurements by radio waves back to Earth.

Why did you want to launch a balloon?

We have a very active school STEM club, and we wanted to do something completely different from anything that the students were already likely to cover in class.

What did the STEM club do prior to the launch?

The students took part in a range of activities in the after-school STEM club. These included demonstrations with different gases, experiments on the effects of pressure and learning about how pressure changes with altitude. We looked at trajectories with PE equipment and learnt how to calculate landing sites, taking wind speed and direction into account.

What weather were you hoping for?

We were hoping for clear skies, so that the camera would get good pictures of the Earth. However, more importantly, we had to have the right wind conditions. To be able to launch a balloon, you have to have permission from the Civil Aviation Authority. Our permission said that the balloon couldn't go anywhere near Manchester Airport, so that was one concern. Also, we didn't want it to land too far away, in the sea or anywhere else we couldn't retrieve it, so we used trajectory forecasts. These combine the wind forecast with information about how fast the balloon rises and what altitude it bursts at, to predict roughly where the balloon will go. The forecast we had was very accurate, which helped us find the balloon.

What were the risks?

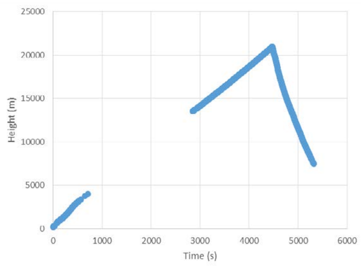
Not being able to find the balloon and the camera! Although we would still have the data which the radiosonde had transmitted, what we really wanted were the images the camera had captured.

Was it worth doing?

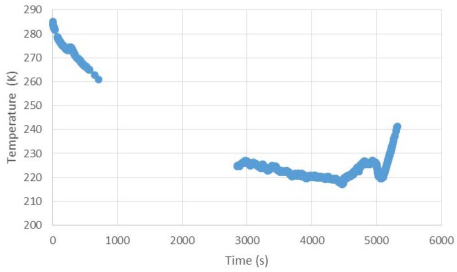
Yes, it was so exciting to watch the balloon's progress, and then use the GPS tracker to find it – its location was less than 5m from where the tracker said it was. We couldn't believe it when we downloaded the photos and they were so good.

Data from the radiosonde

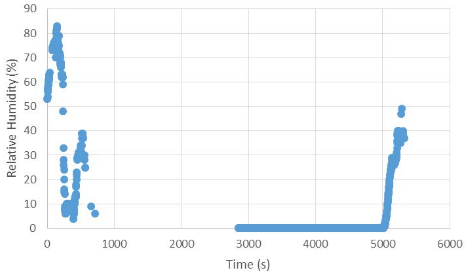
Instruments attached to the balloon gather data during the flight. The radiosonde transmits this data back to the ground station. In these graphs you will see that there were periods of time when the radiosonde lost contact with the receiving station.



The balloon rises at a pretty constant velocity (the line is straight) before bursting at about 21 000 m, then falling much faster. Notice how the balloon slows down as it falls and the atmosphere becomes denser.



The temperature falls as the balloon rises through the troposphere. In the lower stratosphere, the temperature is pretty constant at 220 K (-53 °C). The temperature rises again once the balloon starts falling.



The relative humidity is a measure of how much water is in the air. Cloud droplets can form when the relative humidity is close to 100%, so here you can see that the balloon reached the cloud base at about 150 s into the flight, or 1km up. There is virtually no water vapour in the stratosphere.

Look here!

You can see some video highlights from the launch, and find out how to arrange your own, on MetLink *http://www.metlink.org*

Sylvia Knight is Head of Education Services at the Royal Meteorological Society. She has a PhD in meteorology from the University of Reading and has worked in climate science. You can read Sylvia's article about cloud formation in Catalyst Vol 21 no 4.

Make your own aneroid barometer

A barometer is any device that measures atmospheric pressure. Weather forecasters use changes in pressure to help predict the weather.

What to do

Find a large, open-mouthed jar or tin – avoid sharp edges.

Cut a sheet of rubber from a balloon, stretch it over the mouth of the jar or tin and fix it in place with a rubber band.

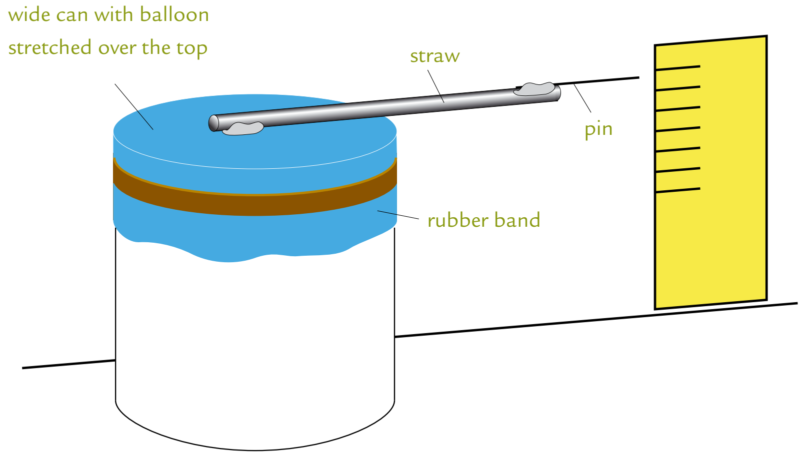
Glue one end of a drinking straw to the centre of the rubber. Cut the other end (which will stick out beyond the rim) to form a point.

What happens

As the atmospheric pressure changes, it presses down more or less strongly on the rubber sheet, causing the free end of the pointer to move up or down.

Arrange a ruler next to the pointer to act as a scale. Look at predicted pressures in a local weather forecast – can you see changes in the position of the pointer as the pressure changes?

Aneroid means without fluid – many barometers use a liquid, usually mercury, but this one uses a trapped volume of air and no liquid.



Johanna Galloway

Magnificent magnetic bacteria

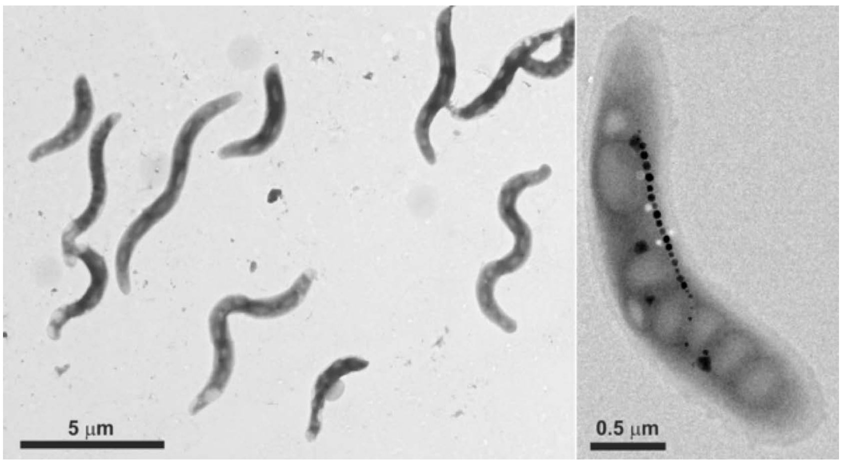
The magnetic disc of a computer hard drive

Key words
magnet
bacteria
biomineral
computer memory

It takes a lot of rare natural resources and energy to make a mobile phone, laptop or computer, the modern technology we use every day. That is why many scientists would like to take inspiration from Mother Nature to help us to make more environmentally-friendly machines in the future. ***Johanna Galloway*** *is one of them.*

We've all heard of viruses in computing, but few people know that real microbes (specifically magnetic bacteria) may actually be useful in computers.

The storage of data in smartphones, laptops or computers uses magnets to record the information in binary code. Making the magnetic materials that are used to store this code usually needs expensive specialised equipment, high-temperature processing and scarce (often poisonous) minerals, which is not very environmentally-friendly. That is why we want to use magnetic bacteria to help us make magnets for computer memories.



Electron microscope images of magnetic bacteria; we can see magnetic particles that are too small to see with a light microscope (5 µm = 5 × 10^{-6} m). Images from Dr Sarah Staniland (University of Leeds) and Dr Masayoshi Tanaka (Tokyo University of Agriculture and Technology, Japan.)

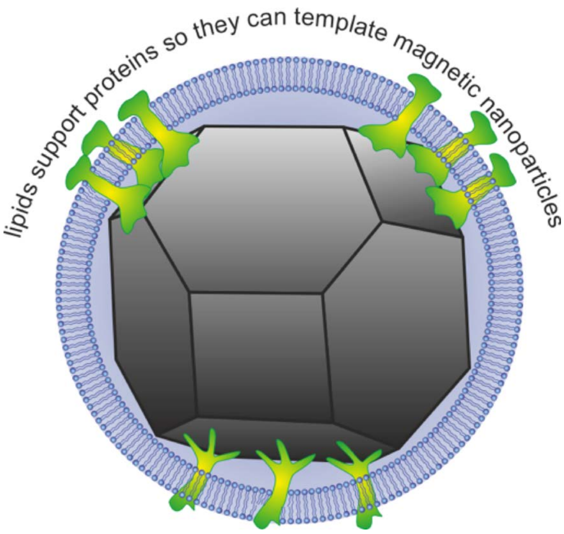
Magnetic bacteria are able to make their uniform magnets whilst happily swimming around in their natural habitat, so they could be a much greener way of making high quality magnetic components for modern technology. In my work, I study how magnetic bacteria make such good magnets, and think about how we can use them for inspiration to make computer memories of the future.

An electron microscope image of a magnetic bacterium shows magnetic field lines within the bacterium.

[From R. E. Dunin-Borkowski, M. R. McCartney, R. B. Frankel, D. A. Bazylinski, M. Pósfai, P. R. Buseck (1998). Science, vol. 282, page 1868. Reprinted with permission from AAAS.]

Why do some bacteria make magnets?

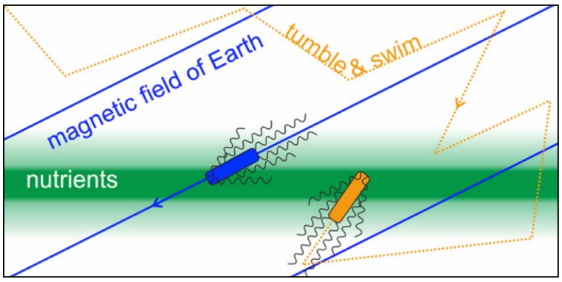
Magnetic bacteria are anaerobic – they inhabit areas that do not contain oxygen, like in deep ocean waters or in water-logged soils, because oxygen is poisonous to them. In these areas, different nutrients become concentrated at different levels, and bacteria must move around to find their optimal living conditions. Normal, non-magnetic bacteria are able to sense the presence of chemicals in their surrounding environment, a bit like our sense of smell. They move along the concentration gradients around them by randomly tumbling and swimming to try to find high concentrations of nutrients; this is called chemotaxis.



Structure of a magnetosome, showing the lipid membrane supporting proteins that template the magnetic nanoparticle inside the compartment

However, some bacteria have evolved a trick to help them navigate the layers of nutrients to find their niche – they synthesise tiny magnets so they can line up with the Earth's magnetic field. This is an example of biomineralisation. Magnetic bacteria biomineralise magnetic particles within compartments called magnetosomes that are usually about 50 nm (50×10^{-9} m) across. A magnetosome compartment consists of a layer of lipid fat molecules and proteins. The proteins have evolved to form a template on which the magnetic nanoparticles form; these are usually made of the magnetic mineral magnetite (Fe_3O_4). The particles are large enough to maintain their magnetism at room temperature and above, so are permanent magnets.

The size, shape and material of a magnet are all important for determining its properties. The proteins in the magnetosome work together so that the nanomagnets inside are all the made from the correct mineral (e.g. magnetite, rather than other non-magnetic iron oxides) and that they are of the same size and shape. This means they have very uniform magnetic properties.



Non-magnetic bacteria (orange) tumble and swim to find nutrients, but magnetic bacteria (blue) can align with the magnetic field of the Earth so their search is more efficient.

Other proteins organise the magnetosomes into a chain inside the bacterium so that the poles of the permanent nanomagnets are aligned. This helps the magnetic bacteria to align with the magnetic field of the Earth, just as a compass needle points north. Magnetic bacteria combine chemotaxis with this magnetic alignment to follow a concentration gradient of nutrients along the Earth's magnetic field lines which they use like paths, speeding up the process of finding nutrients. This is far more efficient than the 'tumble and swim' method used by most other bacteria, as it reduces a three dimensional search to just one dimension, a straight line.

Using magnetosomes in technology

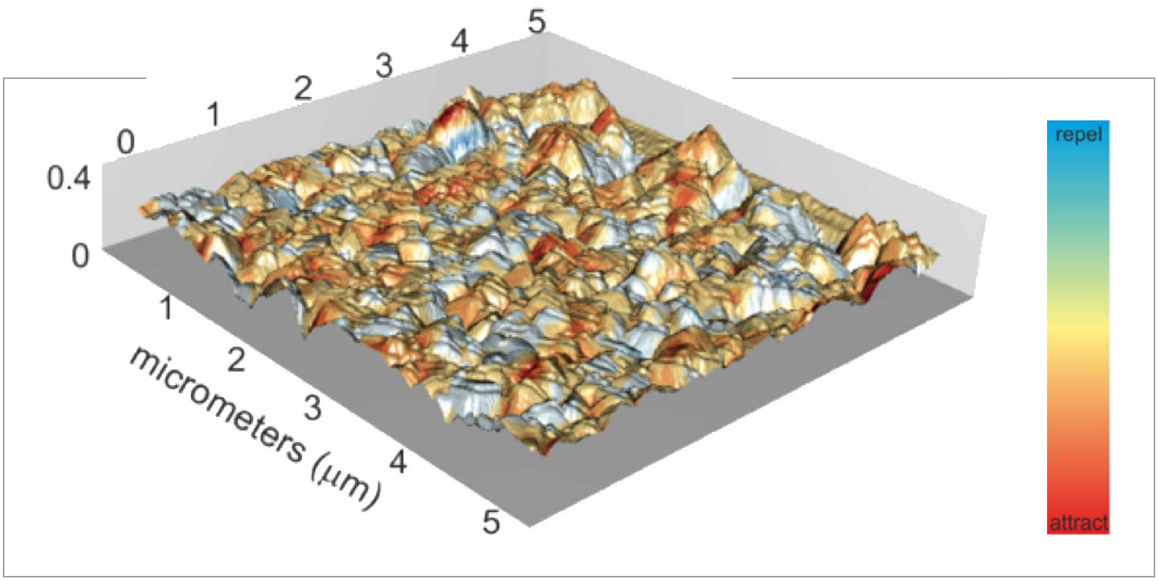
Magnetic nanoparticles are really important for many modern gadgets and technologies. For example, they can be used in medicine to treat cancer and they are used to store data in devices like computers. By studying magnetic bacteria, we hope to find greener methods of making magnetic nanoparticles for use in modern technology.

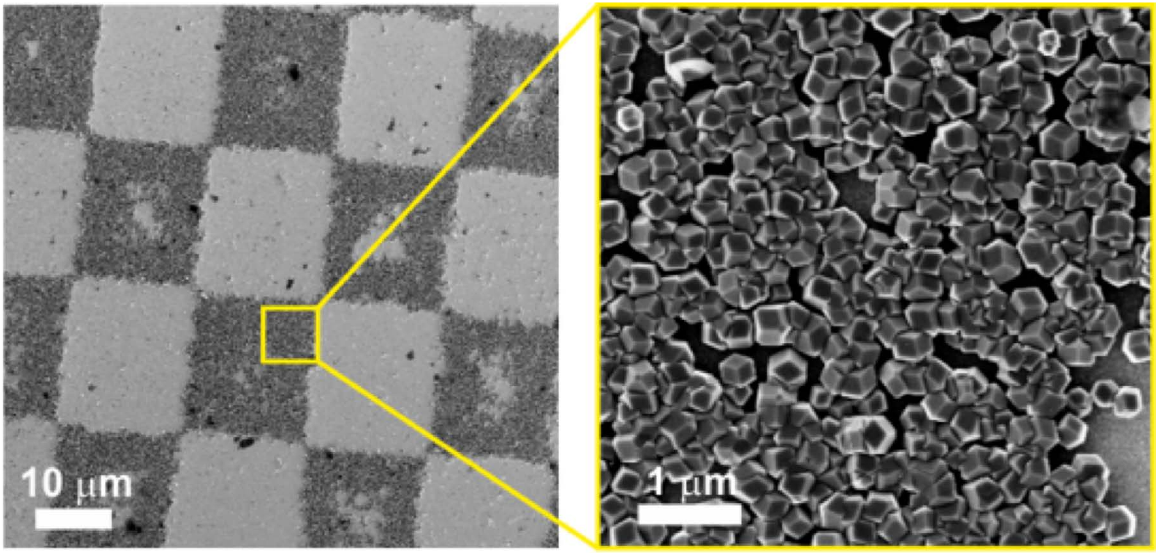
Researchers at the Université Pierre et Marie Curie in Paris, France, have shown that the magnetosomes from magnetic bacteria can be used to heat cancer cells when an alternating magnetic field is applied. The magnetosome chains were extracted from lab-grown magnetic bacteria and injected into tumours. A rapidly alternating magnetic field causes the magnetic particles in the magnetosomes to flip back and forth, so that they heat up. The heat generated can kill tumours more effectively than 'normal' synthetic magnetic nanoparticles without being toxic to the other non-cancerous cells.

Unfortunately, magnetic bacteria can be quite difficult to keep happy and grow in the laboratory because of the low oxygen levels that they like to live in. This is why our research group in the School of Physics and Astronomy at the University of Leeds is very interested in studying the biomineralisation proteins from the magnetosomes of magnetic bacteria. We are trying to find out how they work, so that we can use them to make uniform magnets; it is much easier to make a protein than to grow lots of magnetic bacteria.

Can we just use the proteins to make magnets?

In 2003, a group at the Tokyo University of Agriculture and Technology in Japan isolated proteins from the magnetosome of a magnetic bacterium. One of these proteins, called Mms6, was added to a test-tube of iron salts and alkali at room temperature. The protein controlled the size and shape of magnetic nanoparticles formed from the solution, without the need of the magnetic bacteria.





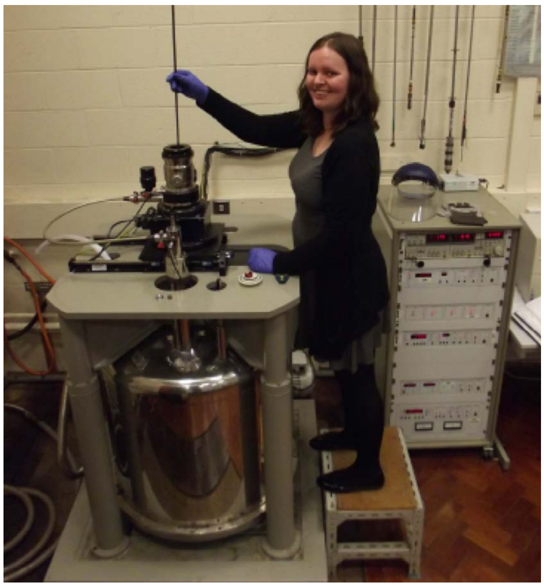
The Mms6 protein is attached to a chessboard pattern where it forms magnetic nanoparticles from a solution of iron and alkali (1 µm = 1 x 10 $^{-6}$ m). A very sharp magnetic probe was used to map the surface using magnetic force microscopy (MFM). This technique is able to image the height of features on the surface as well as any magnetic attraction (red) and repulsion (blue) of the particles.

Unfortunately, the magnetite nanomagnets templated by the Mms6 protein are magnetically soft – it is really easy to reverse their magnetism with an external magnetic field. The magnetic materials used in data storage must be magnetically hard to make sure that saved information stays on the magnetic recording layer. Therefore, we are working on making magnetically hard biotemplated nanomagnets on surfaces that are more suited for use in data storage.

We have shown that Mms6 can make uniform magnetic particles with increased magnetic hardness by adding elements like cobalt to the solution it is incubated with. We have also patterned the Mms6 protein on to a surface where it was able to biotemplate patterns of nanomagnets. Images of these patterned magnets show that the magnetic nanoparticles interact with each other on the surface in a similar way to magnetic particles used for recording data.

We are now trying to combine these techniques to increase the magnetic hardness of our biotemplated magnetic patterns for use in technology. One great advantage of using biomolecules like proteins to make materials is that they can assemble and heal themselves. This is very exciting, because these biomolecules could be designed to assemble themselves into the patterns we need to make the components for our future products. This means that instead of being broken by viruses or worms, green computers of the future could be able to build and fix themselves, all thanks to inspiration from these magnificent magnetic bacteria.

Johanna Galloway is in the Department of Physics and Astronomy at Leeds University.



Johanna loads a sample into a magnetometer to measure its magnetic properties.

Birth of an orchid

Creating *Vanda* William Catherine

Stefania Hartley

Key words
orchids
plant breeding
hybrid
pollination

Orchids are beautiful plants and they have great commercial value. So how are new varieties developed? ***Stefania Hartley*** *explains.*

Just imagine. After spending many months in the tropical forest, where you have managed to avoid deadly diseases and cannibalistic tribes, you are setting off home. But your ship catches fire and all its precious cargo is lost. Luckily, you have survived. All you wish for is to reach home. You send a telegram to your employer to inform him of the disaster and then you wait for instructions. His reply is sharp and cruel: "Turn back – collect more." Obediently you oblige and start all over again.

This is what happened to Wilhelm Micholitz, one of the many orchid hunters working for Frederick Sander, Queen Victoria's 'royal orchid grower'. These men defied hunger, disease and dangers of all kinds, in order to collect rare orchids and ship them back to their wealthy clients.

What is so special about orchids?

The family of Orchidaceae is one of the largest plant families, with about 900 genera and 25 000 species. Orchids are amongst the oldest flowering plants. After a long evolution, they have developed a very intimate connection with the insects that pollinate them: for example, some orchids mimic the appearance and odour of female insects in order to attract the males (pseudocopulation); other orchids, instead, resemble male bees so that real male bees, to defend their territory, attack them. In doing so, they end up with pollinia stuck to their forehead, which they then transfer to other flowers (pseudoantagonism).

A flower of the bee orchid, Ophrys apifera. *In warmer regions of its range bees of the genus* Eucera *are attracted to this flower because of its scent and its labellum, which looks like a female bee.*

Orchids that are pollinated by flies and midges release a scent of algae, yeast, crustaceans or rotting meat. Flies land on the orchid, slip and slide off into a large bag formed by the lower petal. The fly can only escape by squeezing through a narrow tunnel, rubbing off any pollen received from other flowers and receiving a new load.

Most orchids grow in tropical regions but they also occur in temperate regions and are present in every continent except Antarctica. Some orchids grow on trees (without being parasitic, using the tree for support) and they are called epiphytic (from Greek: epi = on; phytos = plant). They have thick roots surrounded by a layer of dead cells called velamen which absorbs water. Geophytic orchids live on the ground (geos = Earth). Lithophytic orchids live on stones (lithos = rock), sometimes making use of a thin layer of detritus that may have accumulated (like geophytes) and sometimes just using the bare rocks for support (like epiphytes). Tropical orchids are mostly epiphytic while those living in temperate climates are mostly terrestrial.

The characteristics which distinguish orchids from other flowering plants:

The column: a structure which incorporates stamen and stigmas.
Pollinia (sing: pollinium): waxy structures which contain the pollen.
The labellum: orchids have three petals and three sepals; one of the three petals has evolved into a highly complex structure called the labellum (Latin for 'lip').

The major parts of the orchid flower

But perhaps the characteristic that has most delighted orchids' fans is their remarkable ability to cross-pollinate each other giving the opportunity for many intergeneric crosses (between different genera) and intrageneric crosses (within the same genus).

Orchid hybrids

New hybrids are produced commercially by crossing two different species. The pollinia of the 'mother' plant are removed to prevent self-pollination and the pollinia of the 'father' plant are gently placed onto the stigma of the mother. The resulting plants show a mixture of characteristics from both parents and sometimes completely new ones, each plant showing wide differences from the others. Notwithstanding their differences, all the offspring of one particular cross still carry the same name, which is registered with the Royal Horticultural Society (RHS) in *Sander's Complete List of Orchid Hybrids* (yes, the Frederick Sander we mentioned before). Most hybrids are man-made but some do appear in the wild, especially for those species which share the same insects as pollinators. This is how we indicate a cross:

name of mother plant (pollen receiver)
x
name of father plant (pollen donor)

This is a hybrid if the mother and father have different specific names.

Example: *Vanda* Miss Joaquim 'Agnes' = *Vanda hookeriana* x *Vanda teres*

Vanda Miss Joaquim is a well-known orchid hybrid created by Miss Agnes Joaquim, a Singaporean of Armenian origin, in 1893. It triumphed at the 1899 Flower Show but the poor lady died of cancer and pneumonia only a few months later. Little did she know that her glory would live on as *Vanda* Miss Joaquim, selected as national flower of Singapore in 1981.

What's in a name?

What can you tell from these orchid names?

Vanda sumatrana

Vanda Miss Joaquim 'Douglas'

(Answers at foot of page 21.)

Vanda *Miss Joaquim growing in the Botanic Gardens in Singapore*

How to name an orchid

Why is *Vanda* Miss Joaquim 'Agnes' such a long name and partly written in italics? You can tell a lot just from the name. You can tell that it is a man-made hybrid not a wild species or hybrid and that it is a variety called 'Agnes'. Let's see how.

For a wild species, the first name is the genus. The second name is the species. If there is a third name that is the variety (e.g., white instead of red flowers).

Example: *Vanda teres* 'alba' or *Vanda teres* var. alba

For hybrids things are different: the names of the genus and the species begin with a capital letter. The genus is written in italics but the species is not, for example: *Vanda* Miss Joaquim.

Hybrids also can have different varieties, for example: *Vanda* Miss Joaquim 'Agnes'.

Growing orchids

After crossing you need to wait for the seed to mature inside their pods, taking from one month to a year. Orchids' seeds are dust-like and contain no food reserves for the developing embryo. In the wild they depends on an association with a fungus. But growers, instead, have to sow the seed on a sterile nutrient agar. Then the healthiest seedlings are transferred to bigger containers. It will take one to four years from the first transplant to the first flowering.

Orchids growing in nutrient agar

At first flowering, the plants displaying the best of the varied flowers are selected and monitored for one year. After that, the most suitable plants will be mass-produced. Pieces of growing tissue (meristems) are taken from young shoots to be grown in flasks on a sterile nutrient medium containing hormones. Each meristem produces many small plantlets which are all clones.

Vanda William Catherine

Walking in the Botanic Garden of Singapore the sounds of tropical insects and birds mean you soon forget you are in the centre of town. In the VIP section of the National Orchid Centre, you are treading in the footsteps of princes and heads of state. The names of hybrids created in their honour celebrate their visits. A year after the Duke and Duchess of Cambridge visited, the hybrid dedicated to them, *Vanda* William Catherine, is still there. It is surrounded by *Dendrobium* Elizabeth, *Dendrobium* Memoria Princess Diana, *Renantanda* Kofi Annan, *Paravanda* Nelson Mandela, and many others.

William and Kate with their orchid, Vanda *William Catherine*

Did you know?

- In 1890 one orchid was bought for £1 500, equivalent to around £96 500 in today's money.
- Orchids only flower every 2-3 years.
- *Grammatophyllum speciosum* (Tiger orchid) is the largest orchid in the world. A specimen weighing over a ton was collected in 1890 in Selangor. Because of its size it had to be divided and half was donated to the Singaporean Botanic Gardens, where it is still growing and flowering, as seen below.

- 'Vanda' is the Sanskrit word for 'flower'.
- Vanilla is a flavouring that comes from the seedpods of an orchid of the genus *Vanilla*.

Look here?

Kew Gardens' website explains how orchids are cultivated and conserved: *http://www.kew.org/plants/orchids/orchiddiscovery.html*

Singapore's National Orchid Garden: *http://www.sbg.org.sg/centralcore/nog.asp*

Stefania Hartley *studied Biological Sciences in Italy and taught Science in the UK. She now works in Singapore.*

Answers to What's in a name on page 20.

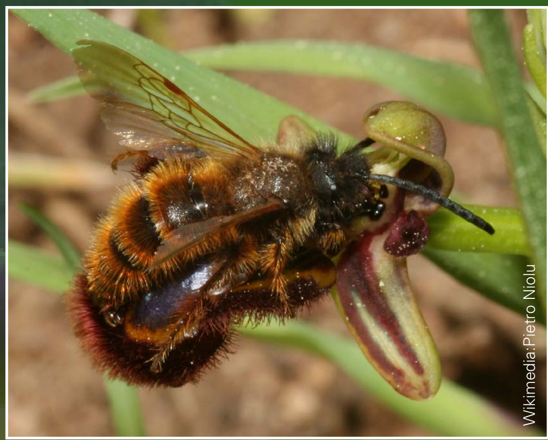
Vanda sumatrana is a species.

Vanda Miss Joaquim 'Douglas' is a man-made hybrid obtained by crossing two different species of the *Vanda* genus. 'Douglas' is the variety.

Orchids and insects

Like many plants, orchids rely on insects to carry pollen from one flower to another in order to reproduce. Many plants offer a reward to pollinators, and so do some orchids. However, a good many do not and in these cases they simply deceive the insect. In the most extreme cases, the orchid mimics a female wasp, even down to the scents it makes, to attract a male. The male tries to mate with the pretend female and in the process, picks up pollen which is transferred to another flower when it is fooled again!

This blue-banded bee has pollinia of the Cooktown orchid stuck to its thorax. The bee may transfer these to another orchid flower, thereby fertilising it.



The flower of the mirror orchid closely resembles the female wasp of the species Dasyscolia ciliata. *A male wasp is seduced into 'mating' with the flower. The top of the flower comes down due to the wasp's weight and sticks pollen onto its back (thorax). See how it works here: http://youtu.be/-h8l3cqpgnA*

An orchid's name can be a guide to the insect which pollinates it. The bee orchid is an example. However, other names reflect the flower's appearance – this is the Australian flying duck orchid Caleana major, *drawn by Ferdinand Bauer in 1803. It is pollinated by sawflies.*

▲ *The Australian hammer orchids have an elaborate flower matched by an elaborate pollination mechanism which you can see at http://youtu.be/wmgKABRCZpo*

Evolution of a relationship

In 2007, biologists from Harvard University, USA, reported finding a fossilized bee, trapped in amber dating from 15-20 million years ago. On its back were perfectly preserved orchid pollinia, showing that the association between orchids and insects evolved a long time ago.

The green fringed orchid of North America is pollinated by butterflies. ▶