



# SCIENCE in SCHOOL

The European journal for science teachers

In this issue:

The genetics of obesity:  
a lab activity

Also:

Life without  
the **Moon**:  
a scientific  
speculation





**A**s I write this editorial, the bare tree branches outside my office are outlined in snow and the ground is dangerously icy. However, by the time this issue of *Science in School* has been copy edited, laid out, proofread, printed and distributed, those bare branches will be sprouting young leaves and the first flowers will be blooming below.

We take these predictable seasonal changes – very noticeable towards the poles, almost negligible at the equator – for granted. Were you aware, though, that without the Moon, Earth would be a very different place: with less predictable seasons, smaller tides, higher winds and shorter days (page 50)? The Sun's influence is still more profound; for a stunning classroom demonstration, why not simulate solar wind and the aurorae (northern and southern lights; page 32)? Our star inspires not only classroom activities but also international research collaborations: in the search for a clean and sustainable source of energy, fusion scientists are recreating the processes taking place in the Sun's core. But how do you design a thermometer to withstand millions of degrees Celsius inside a fusion reactor (page 44)?

Moving from the sky to the ground beneath our feet, find out how plate tectonics may have started millions of years earlier than we used to think (page 14). Or discover how one engineer combated the effects of ground movements and helped to save the famous Leaning Tower of Pisa (page 9). On a more personal scale, damage to our own leaning tower – our spinal cord – can cause incontinence, loss of feeling or paralysis. Might stem cell treatment offer hope for sufferers (page 38)?

Staying at the level of our cells, did you know that most of our 'junk' DNA is very far from being junk – it is, in fact, alive with activity (page 20)? Elsewhere in our genomes, particular genes may even hold the key to obesity. Why not get your students to research the genetics of obesity and extract their own DNA in the lab (page 25)?

Finally, who could fail to be inspired by the participants in the European Union Contest for Young Scientists? Among the many winners were students, some as young as 16, who discovered how to simulate gravity, characterise a new steel alloy and improve light microscopy (page 6).

We hope you enjoy this issue – and we are always happy to have your feedback.

## Eleanor Hayes

Editor-in-Chief of *Science in School*

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[www.scienceinschool.org](http://www.scienceinschool.org)



To learn how to  
use this code, see  
page 57.



## About *Science in School*

### The European journal for science teachers

*Science in School* is the **only** teaching journal to cover all sciences and target the whole of Europe and beyond. Contents include cutting-edge science, teaching materials and much more.

### Brought to you by Europe's top scientific research institutes

*Science in School* is published and funded by EIROforum ([www.eiroforum.org](http://www.eiroforum.org)), a partnership between eight of Europe's largest intergovernmental scientific research organisations.

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69117 Heidelberg

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Image courtesy of John Burland



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Image courtesy of Reto Stöckli, Nazmi El Saleous  
and Marit Jentoft-Nilsen, NASA GSFC



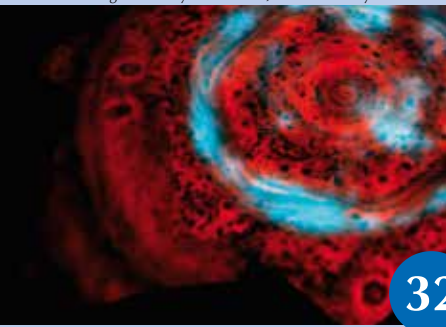
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Image courtesy of fr73 / iStockphoto



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Image courtesy of NASA / JPL / University of Arizona



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Image courtesy of Kubrak78 / iStockphoto



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Forthcoming events for schools: [www.scienceinschool.org/events](http://www.scienceinschool.org/events)

To read the whole issue, see: [www.scienceinschool.org/2013/issue26](http://www.scienceinschool.org/2013/issue26)



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# Science in space, society and synchrotrons

*Science in School* is published by EIROforum, a collaboration between eight of Europe's largest inter-governmental scientific research organisations (EIROs). This article reviews some of the latest news from EIROs.



EIROforum combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. To learn more, see: [www.eiroforum.org](http://www.eiroforum.org)  
For a list of EIROforum-related articles in *Science in School*, see: [www.scienceinschool.org/eiroforum](http://www.scienceinschool.org/eiroforum)

To browse the other EIRO news articles, see: [www.scienceinschool.org/eironews](http://www.scienceinschool.org/eironews)



Phil Dooley, presenter of EFDA-JET's new educational videos, gets hands-on with some electromagnetic theory.



Images courtesy of EFDA-JET



## EFDA-JET: Fusion videos and teacher resources

With the help of the European Fusion Development Agreement (EFDA), you can now bring fusion research right into your classroom, with a series of short videos complete with teacher resources. The videos are based on new hands-on exhibits built for EFDA's travelling exhibition, Fusion Expo. They feature not only the demonstrations themselves, but also visits to related facilities at the Joint European Torus (JET, currently Europe's largest fusion experiment), as well as interviews with scientists and engineers working in fusion research.

The topics will include:

- Fusion forces roller coaster
- Cyclotronic! Magnetic orbits
- Natural toruses – smoke rings
- Real-life avatar – remote handling technology
- Jacob's ladder – controlling lightning
- Superconductors for supermagnets.

The videos and teacher resources are available on the EFDA website ([www.efda.org/fusion/classroom](http://www.efda.org/fusion/classroom)). The videos can also be found on EFDA's Youtube channel ([www.youtube.com/efdajet](http://www.youtube.com/efdajet)) and Facebook page ([www.facebook.com/efda.jet.fusion](http://www.facebook.com/efda.jet.fusion)).

Learn more about the Fusion Expo and if it will be visiting your area soon: [www.fusion-expo.si](http://www.fusion-expo.si)

Situated in Culham, UK, JET is Europe's fusion device. Scientific exploitation of JET is undertaken through EFDA. To learn more, see: [www.efda.org](http://www.efda.org)

For a list of EFDA-JET-related articles in *Science in School*, see: [www.scienceinschool.org/efdajet](http://www.scienceinschool.org/efdajet)



Aquanaut teamwork  
during NEEMO

EMBL

**EMBL:****EMBL: Flu spreads in the  
café scientifique**

On 10 October 2012, nearly 50 people gathered in the centre of Grenoble, France, for a relaxed and interesting discussion on medical and research issues related to flu. The occasion? The first café scientifique co-organised by the European Molecular Biology Laboratory (EMBL) and the Café Sciences et Citoyens de l'Agglomération Grenobloise.

Three panellists – Rob Ruigrok, research director on influenza at the Université Joseph Fourier, Grenoble, and a member of the Flupharm project; Alain El-Sawy, general practitioner and member of GROG, the French national flu monitoring network; and Agathe Billette de Villemeur, public health expert – engaged in a lively discussion with the audience. From vaccination efficiency to research goals, through decision-making for public health policies and standard medical practice, the debate touched on all the important questions surrounding the influenza virus and helped place research projects such as Flupharm in a wider social context.

Flupharm (<http://flupharm.eu>) is an EU-funded project involving EMBL scientists that aims to develop effective drugs against influenza. It is a follow-up from the FLUPOL project, on which *Science in School* reported:

Ainsworth C (2009) Outmanoeuvring influenza's tricks. *Science in School* 11: 25-29. [www.scienceinschool.org/2009/issue11/influenza](http://www.scienceinschool.org/2009/issue11/influenza)

EMBL is Europe's leading laboratory for basic research in molecular biology, with its headquarters in Heidelberg, Germany. To learn more, see: [www.embl.org](http://www.embl.org)

For a list of EMBL-related articles in *Science in School*, see: [www.scienceinschool.org/embl](http://www.scienceinschool.org/embl)



Image courtesy of J-PH Vincent CSCAC

Panellists from left to right: Agathe Billette de Villemeur, Alain El-Sawy, Rob Ruigrok. Moderator: Benjamin Piton

**ESA:****Astronauts underground  
and underwater**

In small multicultural teams cut off from the rest of the world, astronauts have to perform physically and mentally demanding tasks. In 2012, two international teams went underground and underwater to train their skills.

One group of six became 'cavenauts' for the 6<sup>th</sup> CAVES mission led by the European Space Agency (ESA). In the extreme environment of a cave system 200 m below the surface, they spent six days in Sardinia, Italy, linked to the outside world only through the mission's ground control. In addition to mapping the partly unexplored caves, the astronauts catalogued all the life forms they found.

On Earth, diving is one of the best ways of simulating the weightlessness of space. For this reason, another team of six, including ESA's Timothy Peake, became 'aquanauts' on the NASA-led NEEMO 16 mission – investigating the best way for astronauts to explore asteroids. They spent twelve days 20 m under the sea at the world's only undersea research station, in Aquarius off the coast of Florida, USA. To make the mission more realistic, communication between the aquanauts and ground control was delayed by 50 seconds to simulate the time delay in transmitting messages across the Solar System.

In addition to the main mission, the astronauts performed educational experiments that were repeated on land, to study the effect of the high underwater pressure. Videos of these experiments are available on Youtube. See [www.youtube.com/playlist?list=PL50D3F281AF1788F3](http://www.youtube.com/playlist?list=PL50D3F281AF1788F3) or use the shorter link: <http://tinyurl.com/9wzgaeg>

The ESA website offers more information on the CAVES mission. See [www.esa.int](http://www.esa.int) (search for 'going underground') or use the direct link: <http://tinyurl.com/b3yecqg>

The ESA website also hosts further details of the NEEMO mission. See [www.esa.int](http://www.esa.int) or use the direct link: <http://tinyurl.com/b892e25>

ESA is Europe's gateway to space, with its headquarters in Paris, France. For more information, see: [www.esa.int](http://www.esa.int)

For a list of ESA-related articles in *Science in School*, see: [www.scienceinschool.org/esa](http://www.scienceinschool.org/esa)



## ESO:

### The star-spangled centre of the Milky Way

In October 2012, an international team of astronomers released a catalogue of more than 84 million stars in the centre of the Milky Way. Collected using the VISTA infrared survey telescope at the European Southern Observatory (ESO)'s Paranal Observatory in Chile, this gigantic nine-gigapixel image contains more than ten times as many stars as previous studies. It is a major step in understanding our home galaxy, giving viewers an incredible, zoom-able view. It is so large that, if printed with the resolution of a typical book, it would be 9 m long and 7 m tall. "By observing in detail the myriad of stars surrounding the centre of the Milky Way, we can learn a lot more about the formation and evolution of not only our galaxy, but also spiral galaxies in general," explains Roberto Saito, lead author of the study.

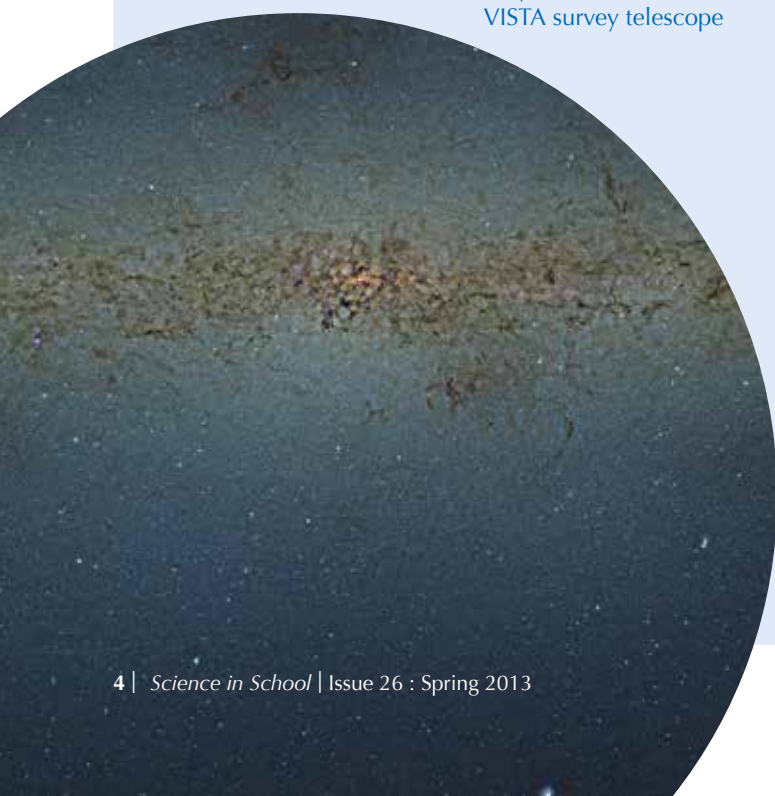
For more information, see the press release on the ESO website ([www.eso.org](http://www.eso.org)) or use the direct link: <http://tinyurl.com/ctb72f9>

Also available on the ESO website ([www.eso.org](http://www.eso.org)), the image is too large to be easily displayed at full resolution and is best appreciated in a zoom-able view. See: <http://tinyurl.com/bv6vqoc>

ESO is by far the world's most productive ground-based astronomical observatory, with its headquarters in Garching near Munich, Germany, and its telescopes in Chile. ESO is the European partner in the ALMA project, which is a collaboration between Europe, North America and East Asia, in co-operation with the Republic of Chile. For more information, see: [www.eso.org](http://www.eso.org)

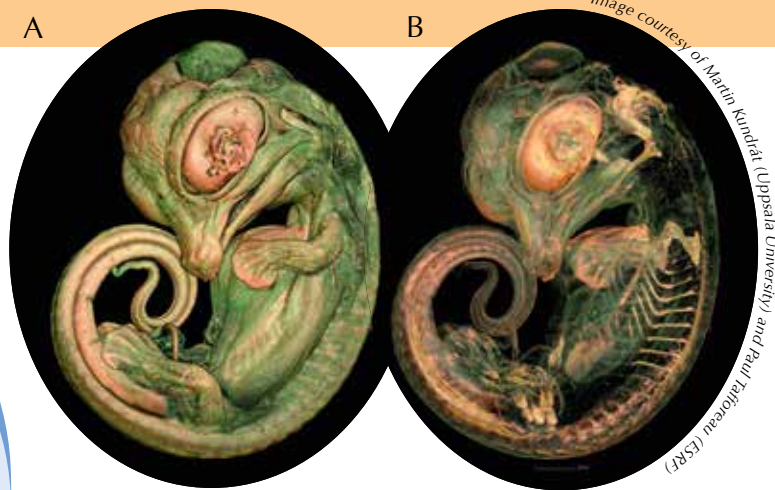
For a list of ESO-related articles in *Science in School*, see: [www.scienceinschool.org/eso](http://www.scienceinschool.org/eso)

The centre of the Milky Way, as observed with the VISTA survey telescope



A

B



A 31-day-old embryo of a Nile crocodile (*Crocodylus niloticus*), measuring 1.4 cm across. A: The external morphology of the animal. B: A semi-transparent view of its skeletal mineralisation.



ESRF

## ESRF:

### Investigating the embryonic development of the dinosaurs

We all know that the dinosaurs died out millions of years ago, don't we? Wrong! In fact, we see living dinosaurs every day; some of us even keep them as pets. Strictly speaking, the group Dinosauria comprises not only the extinct creatures we traditionally consider to be dinosaurs, but also birds. The dinosaurs themselves are part of a larger group – the Archosauria, which also include crocodiles and their relatives, and which were the dominant groups of vertebrates in the Mesozoic era (250-65 million years ago).

So how did the first heavy, scaly, cold-blooded, quadrupedal archosaurs evolve into modern birds – light, feathered and warm-blooded? Most of these evolutionary innovations resulted from changes in the molecular programming that determines how different tissues in the embryo develop. In an attempt to turn back the clock to study these changes, a research team led by Martin Kundrať from Uppsala University, Sweden, are comparing the two extant groups of archosaurs: birds and crocodiles. By studying the differences in the embryonic development, they hope to learn how those innovative characteristics originated and made birds such successful animals.

Very young crocodile and bird embryos look similar. To better understand when and where the developmental differences occur, the team are taking 3D images of the embryos as they develop inside their eggs, using brilliant X-ray beams at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. This will help them to understand the embryonic life not only of birds and crocodiles, but also of their ancient relatives.

Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. To learn more, see: [www.esrf.eu](http://www.esrf.eu)

For a list of ESRF-related articles in *Science in School*, see: [www.scienceinschool.org/esrf](http://www.scienceinschool.org/esrf)

Image courtesy of ESO / VVV Consortium

Image courtesy of Martin Kundrať (Uppsala University) and Paul Tafforeau (ESRF)



European  
XFEL

## European XFEL: Crystal-clear laser light

How do you make the world's brightest X-ray lasers even better? Led by Gianluca Geloni, scientists at European XFEL and DESY in Hamburg, Germany, have proposed using tiny diamond crystals to improve X-ray free-electron lasers (XFELs).

All lasers, be they the small ones in DVD players or the 3 km ones being constructed at European XFEL, amplify light: a small seed of light is transformed into a powerful laser beam. When X-ray laser light is generated, spontaneous emissions are used as seeds, which amplify into a spectrum of X-ray wavelengths. Unfortunately, this 'rainbow' can result in blurred pictures. Gianluca Geloni and his team, therefore, suggested sending the light created by spontaneous emissions through a diamond to select a narrow part of the spectrum. This seed of filtered light could then be further amplified and the resulting flashes used for taking extremely sharp images of biomolecules, materials or chemical reactions. Because the seed is not created by an external source but by the laser itself, the process is known as self-seeding.

Such flashes have now been created for the first time at the Linac Coherent Light Source X-ray laser facility in Stanford, California, USA, following the original suggestion of the Hamburg researchers (Amman et al., 2012). Researchers from all over the world are now waiting for the technology to be further developed.

Amman et al. (2012) Demonstration of self-seeding in a hard-X-ray free-electron laser. *Nature Photonics* 6: 693–698. doi: 10.1038/nphoton.2012.180

Geloni G et al. (2011) A novel self-seeding scheme for hard X-ray FELs. *Journal of Modern Optics* 58(16): 1391–1403. doi: 10.1080/09500340.2011.586473

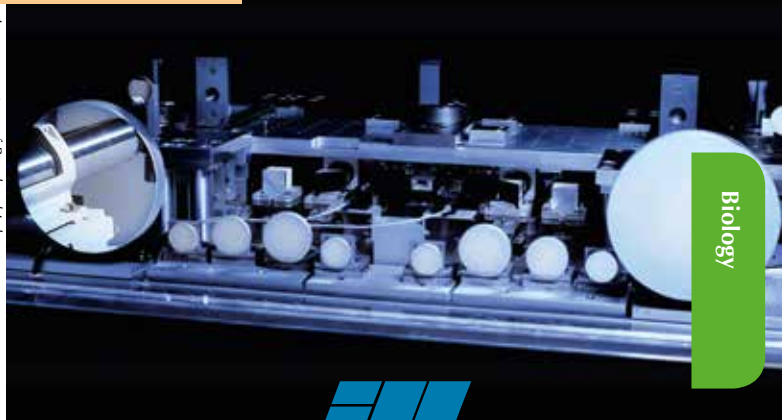
A freely available version of this article was published in 2010 in Arxiv. See: <http://arxiv.org/abs/1008.3036>

For more detailed information, see the press release on the European XFEL website ([www.xfel.eu/news](http://www.xfel.eu/news)) or use the direct link: <http://tinyurl.com/avg7rea>

The European X-ray Free Electron Layer (European XFEL) is a research facility currently under construction in the Hamburg area in Germany. Its extremely intense X-ray flashes will be used by researchers from all over the world. To learn more, see: [www.xfel.eu](http://www.xfel.eu)

For a list of European XFEL-related articles in *Science in School*, see: [www.scienceinschool.org/xfel](http://www.scienceinschool.org/xfel)

Image courtesy of Bernhard Lehn



Biology



NEUTRONS  
FOR SCIENCE

## ILL: Bending gamma rays – a door to a whole new field of science

According to decades of theoretical predictions, it should not be possible to create lenses for gamma rays. Until recently, it was thought that this highly energetic form of light, produced by the radioactive decay of atomic nuclei, was too energetic to be bent by the electrons in any lens material. Nonetheless, scientists at the Institut Laue-Langevin (ILL) decided to attempt the impossible – and succeeded. In a variation of the classical classroom experiment with glass prisms, first used by Newton in 1665, they used a silicon prism to successfully bend a beam of gamma rays, albeit by just a millionth of a degree.

This has opened the door to a whole new field of science, called nuclear photonics. Scientists can now study what is at the heart of this unexpected effect and work on refining the lenses. Focused gamma-ray beams would be scattered only by certain radioisotopes, streaming past others unimpeded; this could be used to characterise radioactive material remotely. Moreover, the beams could even make new isotopes, 'evaporating' protons or neutrons from existing samples. This could be used to turn harmful nuclear waste into a harmless, non-radioactive material, or to provide more targeted radioisotopes for cancer diagnostics and treatment.

To learn more, see the press release on the ILL website ([www.ill.eu](http://www.ill.eu)) or use the direct link: <http://tinyurl.com/illgamma>) or read the research paper:

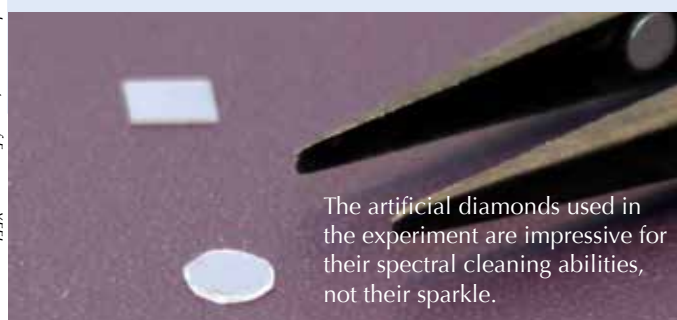
Habs D et al. (2012) Refractive index of silicon at  $\gamma$  ray energies. *Physical Review Letters* 108: 184802-1-4. doi: 10.1103/PhysRevLett.108.184802

ILL is an international research centre at the leading edge of neutron science and technology, based in Grenoble, France. To learn more, see: [www.ill.eu](http://www.ill.eu)

For a list of ILL-related articles in *Science in School*, see: [www.scienceinschool.org/ill](http://www.scienceinschool.org/ill)

Physics

Image courtesy of European XFEL



The artificial diamonds used in the experiment are impressive for their spectral cleaning abilities, not their sparkle.



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page 57.



# Meeting the next generation of scientists: the European Union Contest for Young Scientists

As young scientists from across Europe gathered in Bratislava to exhibit their projects, find out what impressed the jury most.

By Estelle Mossou, ILL

The 2012 European Union Contest for Young Scientists (EUCYS)<sup>w1</sup> took place in the beautiful Slovak capital of Bratislava. For three days, 117 contestants aged 16-21 from 37 countries gathered in the Incheba exposition centre, all eager to present their work. As a new jury member, I was overwhelmed by the quality of the science displayed.

Picking just a few winners from 83 amazing projects in disciplines as varied as engineering, biology, social science and mathematics, all of which had already won first prize in their national contests, was an extremely difficult task.

The three cash prizes offered by the European Commission were awarded

Eileen Clucas from ILL (on the right) awarded the EIROforum prizes.



Image courtesy of the European Commission

to 19-year-old Austrians Philip Hu-prich, Manuel Scheipner and Daniel Zindl for developing an engineering solution to protect cameras in extreme environments; Mark James Kelly (18) and Eric Doyle (19) from Ireland for mathematically simulating how objects respond to gravity in particular environments; and Jakub Nagrodzki (17) from Poland for synthesising a modified molecule that can allow drugs to enter the nucleus of a cell, which offers the potential to treat various genetic diseases.

In addition, there were 19 special prizes, among them visits to research sites, including the eight members of

EIROforum<sup>w2</sup>, the publisher of *Science in School*. Céline Lay, Fanny Risbourg and Ophélie Bolmin, three 18-year-old French engineers who designed an energy-efficient hexapedal robot, will visit the world's largest particle physics laboratory, CERN<sup>w3</sup>, in Geneva, Switzerland. EFDA-JET<sup>w4</sup>, the European fusion energy experiment in Culham, UK, will welcome Tim Piper (16) from Germany, a young microscope enthusiast who has found ways of improving light microscopy images.

Sweden's Nils Wilhelm Ygge's (19) project, to fly a balloon to an altitude of 30 000 m to take photographs, will enable him to attend one of the Euro-



In 2012, EUCYS was held in the Slovak capital Bratislava.



Estelle Mossou from ILL gave one of the EIROforum lectures at EUCYS in Bratislava.

Image courtesy of the European Commission

pean Space Agency (ESA)'s<sup>w5</sup> major five-day space science conferences in Europe. The main site of the European Molecular Biology Laboratory (EMBL)<sup>w6</sup> in Heidelberg, Germany, will open its doors to Tim Prezelj (18), a biologist from Slovenia who produced a chimeric receptor which could potentially be used to design a vaccine against malignant melanoma.

Thomas Glenn Myers (18) from the UK was awarded a visit to the European Southern Observatory (ESO)'s<sup>w7</sup> telescopes in Chile. In his search for gravitational lensing systems, this dedicated physicist scanned 10 000 images of galaxies by eye. The European X-ray free-electron laser facility (European XFEL)<sup>w8</sup> in Hamburg, Germany, will welcome the Israeli contestant Alfarook Abu Alhassan (18), who studied the kinetics of water crystallisation in porous media.

At the Institut Laue-Langevin (ILL)<sup>w9</sup> in Grenoble, France, where we host the world's most intense neutron source, we are lucky to host 19-year-old Austrians Lucas Noel Sulzberger and Robert Gautsch, who developed a faster way of detecting *Clostridium* spores in dairy products. Helen Mary Sheehan (18) from the UK will visit the European Synchrotron Radiation Facility (ESRF)<sup>w10</sup>, after she impressed the jury by processing and characterising a new steel alloy using selective laser melting.

To broaden the participants' horizons, daily lectures offered an insight into different areas of science. Jeremy Philpott from the European Patent Office gave a talk to raise patent awareness, and three lectures were given by members of EIROforum. German Carillo Montoya from CERN spoke about the Higgs boson, Jean Pierre

Guignard from ESA introduced students to Earth observation from space, and I represented ILL with a lecture about the impact of neutrons in the life sciences.

The EUCYS contestants are among Europe's brightest young scientists but they are also young people like any other. In between jury visits and lectures, they had the opportunity to relax, playing table football or board games, and the varied social and cultural programme encouraged them not only to swap their ideas about science but also to make new friends.

I felt very privileged to meet the next generation of scientists. Their enthusiasm for their projects and curiosity about science was extremely refreshing. This was undoubtedly one of the highlights of my year.

Why not encourage your students to take part in your national contest

EUCYS contestants in 2012 came from 37 countries.







In between jury visits and lectures, contestants got to relax and play.

synchrotron radiation source in Europe. See: [www.esrf.eu](http://www.esrf.eu)

w11 – The EUCYS website lists the national organisers of contests for young scientists, the winners of which take part in EUCYS. See [www.eucys2012.eu](http://www.eucys2012.eu) or use the direct link: <http://tinyurl.com/bfkmmfa>

Morten Lennholm, EUCYS jury member from EDFA-JET, proudly presenting *Science in School* at the EIROforum stand.



Image courtesy of Marlene Rau

for young scientists<sup>w11</sup>? We may even meet them at EUCYS 2013 in Prague, capital of the Czech Republic!

## Web references

w1 – Find out all about EUCYS 2012, including all projects and winners: [www.eucys2012.eu](http://www.eucys2012.eu)

w2 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combine their resources, facilities and expertise to support European science in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. See: [www.eiroforum.org](http://www.eiroforum.org)

w3 – Based in Geneva, Switzerland, CERN is the world's largest particle physics laboratory. See: [www.cern.ch](http://www.cern.ch)

w4 – Situated in Culham, UK, JET is Europe's largest fusion device. Scientific exploitation of JET is undertaken through the European Fusion Development Agreement (EFDA). See: [www.jet.efda.org](http://www.jet.efda.org)

w5 – EMBL is Europe's leading laboratory for basic research in molecular biology, with its headquarters in Heidelberg, Germany. See: [www.embl.org](http://www.embl.org)

w6 – ESA is Europe's gateway to space, with its headquarters in Paris, France. See: [www.esa.int](http://www.esa.int)

w7 – ESO is by far the world's most productive ground-based astronomical observatory, with its headquarters in Garching near Munich, Germany, and its telescopes in Chile. See: [www.eso.org](http://www.eso.org)

w8 – European XFEL is a research facility currently under construction in the Hamburg area, Germany. It will generate extremely intense X-ray flashes for use by researchers from all over the world. See: [www.xfel.eu](http://www.xfel.eu)

w9 – ILL is an international research centre at the leading edge of neutron science and technology, based in Grenoble, France. See: [www.ill.eu](http://www.ill.eu)

w10 – Situated in Grenoble, France, ESRF operates the most powerful

## Resources

If you enjoyed reading this article, why not browse the full list of event reports published in *Science in School*? See: [www.scienceinschool.org/eventreports](http://www.scienceinschool.org/eventreports)

Originally trained as a physicist, Estelle Mossou developed an interest in self-assembling systems during her PhD. She now works in the deuteration laboratory at the Institut Laue-Langevin (ILL)<sup>w9</sup> on an EU-funded project to develop a common interface for neutron and X-ray structural studies of biological samples.



To learn how to use this code, see page 57.





# Propping up the wall: how to rescue a leaning tower

Civil engineer  
John Burland talks  
about the perils  
and practicalities  
of supporting some  
of the world's most  
iconic buildings.

John Burland in  
front of the tower  
he helped to save,  
in Pisa

Image courtesy of John Burland



By Susan Watt

One of the joys of being a civil engineer, believes John Burland, is that “every single project is unique; no buildings are alike”. There is, however, one feature shared by most of the buildings on which John has worked: they seem to have been in danger of falling down.

Most famously, John was one of the engineering experts called on in 1990 to help rescue the Leaning Tower of Pisa, Italy, but the Big Ben clock tower in London, UK, and even the Metropolitan Cathedral in Mexico City have also benefitted from his expertise.

## Rescuing the Big Ben clock tower

The Big Ben project was not so much a rescue as damage limitation. As a soil mechanics engineer, John was already involved in deep excavation projects in London when the decision was taken in the early 1970s to build a multi-storey car park underneath the Houses of Parliament

- ✓ Physics
- ✓ Earth science
- ✓ History
- ✓ General science
- ✓ Engineering
- ✓ Ages 10+

This article offers an insight into the life and work of an engineer: his decision to study engineering, how science and engineering methods are combined, and his small and large projects. The Leaning Tower of Pisa and its problems are well known, but it is especially exciting to be told the story of how it was saved by the man who did it.

The topic is interdisciplinary, can be easily understood without much knowledge of physics, and, because the article is written like an adventure, can be used in many ways and to enhance the teaching of several subjects. Teachers can find their own ways of using the article, for example in geography, general science, history, physics or engineering lessons, but also in language lessons, to read and translate the article. For students aged 10-15, I would recommend the article for general reading, while older students can benefit from it in the context of lessons on engineering.

The article is also suitable for comprehension questions such as:

- What problems may occur if massive buildings are built on unstable ground? Describe these problems in detail.
- Which methods can be used to stabilise unsafe ground and how do they work?

*Gerd Vogt, Higher Secondary School for Environment  
and Economics, Yspertal*

REVIEW

Physics

and the Big Ben tower. John was approached to help with the design and construction, to ensure that the state buildings would not be damaged by the work on the 20 m-deep car park beneath. The fear was that another famous leaning tower might be created, this time in London.

Constant monitoring was crucial to the project, as John recalls: "My team was involved in taking measurements as the car park was constructed, and we discovered all sorts of unexpected things – as you do when you take measurements. For example, we predicted that the Big Ben clock tower would move towards the east, and it actually moved westwards. We got the amount right, but we got the direction wrong, and we had to explain to Black Rod [the House of Lords official] why, even though we were out by 180°, it wasn't a serious mistake!"

Mistake or not, John's expertise was again called on years later when, in the early 1990s, an even deeper excavation was needed for an underground train line being run beneath the Houses of Parliament. Again John's team managed both to measure and to control the movement – by pumping cement into the ground before the excavation started – but not without a lot of attention from the media. "The press got very excited about it, and we still get questions occasionally, and see headlines such as 'The Palace of Westminster is about to subside into the River Thames'," John says.

John has had a lot of practice at dealing with the international press, as well as in tackling technical issues. So how does he approach this? "My line is to tell it as it is – say what the technical challenges are and how

you're trying to meet them. I don't believe you can do anything else," he says.

### How it all began

As an engineering student, John initially disliked the discipline of soil mechanics, in which he is now regarded as such a prominent expert, but warmed to it while studying for his PhD at the University of Cambridge. After Cambridge, he joined the Building Research Establishment (BRE) in London, a UK government research organisation that had pioneered the study of soil mechanics. "I wanted to go there and work on real buildings, and find out how they really behaved," he says.

At BRE John worked on his first high-profile project – the Sydney Opera House – and honed his skills in foundations and excavations. "I had a wonderful 16 years at BRE working on all sorts of projects, but one in particular required digging deep excavations in urban areas," he says. "So I began to get involved with some of the deep excavations that were taking place in London – the Barbican Arts Centre, for example, which was a huge excavation in the City of London. And because of this work, I was asked to become involved with the Houses of Parliament car park. That became a seminal project that was published in the engineering journals. And I guess it was because of my involvement with that that I got involved with Pisa."

### The Leaning Tower of Pisa in danger

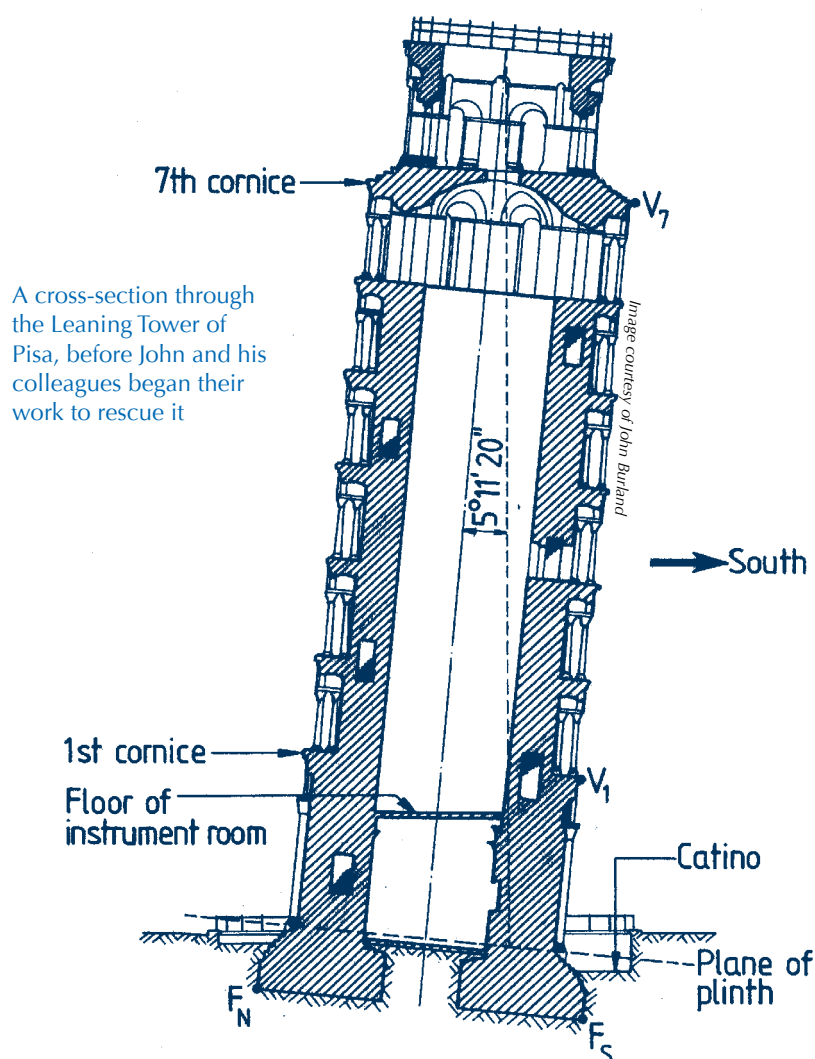
This was in 1990, when the famous Leaning Tower of Pisa was leaning rather too far for comfort. Not only that, but a medieval tower in the northern Italian town of Pavia had collapsed the previous year, killing four people. So the Italian government set up a multidisciplinary commission of international experts to prevent the Pisa tower meeting the same fate, and John was asked to join it.

The new underground train station under construction at Westminster



Image courtesy of John Burland





A cross-section through the Leaning Tower of Pisa, before John and his colleagues began their work to rescue it

of ground it was built on, as John explains: "The ground there is so soft that it's like foam rubber, and in this situation there's a critical height for a building of a given weight and diameter before it starts to lean and fall over. And the Pisa tower is exactly at that critical height: amazing."

So the tower was hovering between stability and collapse. "It was going to fall over, but it was impossible to say when – a storm or an earthquake could have finished it off. So we had to do some very urgent work if we were to stabilise it," John says.

The problem is that once a tower starts leaning, it becomes increasingly unstable. "As the inclination increases, the centre of gravity moves, producing an additional overturning force," he explains. "So it gets worse and worse, and then it collapses." At the time, the tower was moving at about 1.5 mm a year, but the movement was accelerating – which was terrifying, John says.

Of course, working on such iconic buildings involves more than just engineering. "The problem was incredibly complex, because we had to obey the laws of conservation of

In the beginning, not everyone agreed that the tower needed saving. "There was this huge mythology about the tower. People were saying 'Don't touch it, it's quite safe as it is; if you do anything to it, it'll fall over'," says John. "There was a quote from the mayor saying 'It's in the Piazza dei Miracoli [the Square of Miracles],

Image courtesy of tiseb / Flickr



The Leaning Tower of Pisa, after John's work, is still leaning, but more stable.

so it'll never fall down'. So our job was to bring some science to bear."

The first step was to investigate how the tower had been built originally, to understand why it was leaning. The team discovered that the tower had probably begun to lean from day one. "You can see tapered layers of masonry, showing that the builders were trying to correct the slant even as they were building it," says John.

He and other technical experts spent two years trying to understand why the tower was leaning and what was controlling its movements, which was absolutely fundamental to solving the problem, John believes. "Up until then, people had just proposed solutions at random, but until you really understand things, you're likely to get it wrong."

They discovered that the leaning was caused by a combination of the tower's dimensions and the type



The Leaning Tower of Pisa, pictured before John's work on it began, is surrounded by mythology.

ancient monuments, which forbid you to change the character of the monument. So you couldn't go and stick a great big prop on one side," John says. "And it had to continue leaning: the Italians didn't want a vertical Leaning Tower."

### Stabilising the Leaning Tower

The team's solution was inspired by the tunnelling work that John had already carried out in London. "When you drill a tunnel in the ground, you always cause the ground to settle a little bit. And I thought that if we could magically induce the ground to settle a little bit on the high side of the foundations, we could perhaps reduce the inclination of the tower enough to make it stable," he says. "So we came up with this idea of extracting small amounts of soil, rather like mini-tunnels."

"There were all sorts of ideas about what you could do to stabilise the tower, and all of them would work if you could implement them, but implementing them would cause the tower to fall over."

*Image courtesy of John Burland*



Drainage was part of the solution to stabilising the Leaning Tower of Pisa

*Image courtesy of John Burland*



The Metropolitan Cathedral of Mexico City, the oldest and largest cathedral in Latin America, photographed during John's work on it

But there was a risk that putting any idea into practice could itself make the tower topple. "There were all sorts of ideas about what you could do to stabilise the tower, and all of them would work if you could implement them, but implementing them would cause the tower to fall over," says John. So the team did a huge amount of computer analysis and precise monitoring to test the tunnelling approach before going ahead. "In the end we extracted about 70 cubic metres [of soil], a couple of lorries full, so it was really quite small," he says.

But the monitoring and historical investigations had also revealed another factor: the tower leaned further to the south in winter than in summer. "Originally I thought this was something to do with the sun going round the tower, but then we began to measure the way the water table changes seasonally. Whenever there is a rainstorm – and in Tuscany they get incredibly heavy rain storms in the winter – the water table comes up a little bit more on the north [high] side than on the south [low] side, so it lifts the north side and pushes the tower further to the south. So in addition to reducing the inclination, we had to

stabilise the water table," says John.

The solution to this problem was engineering of a much more standard type, as John explains: "We put in some drains on the north side, which ran the water into wells that are kept at a constant level by discharging into a conduit. That's all been in operation since about 2006, and it really has stabilised the water table. And that's one of the major reasons why the movement has stopped."

So is the tower now permanently secure and stable? "We've continued our measurements for the past three or four years and for all practical purposes it's not moving," he says.

### Saving Latin America's oldest cathedral

Remarkably, at the same time as he was in the international spotlight for the Pisa project, John was also working on another endangered historical building, this time in Mexico City. As in Pisa, the problem was that one side of the Metropolitan Cathedral – the oldest and largest cathedral in Latin America – was subsiding more than the other. Once again, changes in the water table were found to be the underlying cause, as John explains.



the ground and made it much firmer. But the other half was built on undisturbed ground, so the cathedral underwent these vast differential settlements of 1.5 metres and more."

The result is that, over the 300 or so years of the cathedral's existence, it has cracked badly, and in the 1990s the movement was still continuing. Coincidentally, the experts in Mexico were considering soil extraction to stabilise the cathedral at the same time as John was proposing this approach for the Pisa tower. "They were doing it in a very different way, but the principle was the same," he says. "Three of us on the Pisa commission got involved with the Mexican cathedral because of that link." The soil extraction successfully evened out the rate of sinking across the cathedral's foundations, greatly reducing the risk of further cracking.

So is a building ever in such a bad state that John would advise just giving up? "The decision is probably economic in the end, but it's also a question of how important the building is historically," he says.

And buildings don't get any more important historically than the Leaning Tower of Pisa. To enhance the success of the engineering work, the tower has now been cleaned – as John had the pleasure of seeing on a recent visit. "It's now absolutely mind-blowing, this beautiful white marble tower, dramatically leaning, with the most beautiful inlays and patterns in the marble. It absolutely takes your breath away," he says.

Image courtesy of Moyan Brenn / Flickr



When a multi-storey car park was built underneath the Houses of Parliament in 1979, John was called in to make sure that the Big Ben clock tower (on the right) did not become another leaning tower.

### Engineering in the classroom

John is understandably passionate about this unique building, regarding the Pisa project as perhaps his most satisfying achievement in a lifetime of daring projects. But he is also passionate about teaching, and believes that a truly hands-on approach is the right way to engage the next generation of scientists and engineers.

"My experience with children is that they long to get their hands on things," he says. "And in some senses I'm quite dismayed at how the virtual world, through the computer, is replacing that. You can computerise models, but it's not the same as giving children something to handle and to push and prod, because that's the way you really cultivate curiosity and the intrinsic understanding of how things work."

This philosophy seems to have become a hallmark of the Burland approach to teaching, as John says: "I'm well known for bringing physical models into class, and I bump into

former students all over the place who say, 'Oh, Professor Burland, I'll never forget the model you showed us of such and such'. Because they remember models; they don't remember equations."

### Acknowledgement

This article is based on an interview given by Professor John Burland to the editor-in-chief of *Science in School*, Dr Eleanor Hayes.

### Resources

Published by the UK's Royal Academy of Engineering, *Ingenia* magazine offers articles about engineering written for the non-specialist. See: [www.ingenia.org.uk](http://www.ingenia.org.uk)

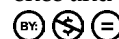
In 2005, *Ingenia* published an interview with John Burland. See the magazine's website ([www.ingenia.org.uk](http://www.ingenia.org.uk)) or use the direct link: <http://tinyurl.com/bou227h>

For a further interview with John Burland, see:

Smith D (2009) Engineering beats Pisa's problem. *Physics Education* **44**(3): 311-313. doi: 10.1088/0031-9120/44/3/M02

If you enjoyed reading this article, you might like to browse the full collection of feature articles published in *Science in School*. See: [www.scienceinschool.org/features](http://www.scienceinschool.org/features)

Susan Watt is a freelance science writer and editor. She studied natural sciences at the University of Cambridge, UK, and has worked for the Science Museum, London, and the British Council. Her special interests are the history and philosophy of science and science education.



To learn how to use this code, see page 57.



John's first high-profile project was on the Sydney Opera House, Australia.

Image courtesy of jimmyharis / Flickr



# Cracking the mystery of how our planet formed

Studying the chemical composition of some of the planet's oldest rocks has revolutionised our understanding of how our continents formed.

By Jérôme Ganne and  
Vincent de Andrade

Sometimes even the tiniest of rock fragments can hide big secrets. Our recent chemical analysis of African rocks has revealed that the continents we know today may have started to form more than a billion years earlier than was previously thought.

## Our globe has changed over time

Earth formed about 4.6 billion years ago, from material in a giant molecular cloud called the solar nebula. Gravity caused this material to assemble into a sphere – Earth, with the densest forming the core, and the least dense forming the mantle. The crust and the upper part of the mantle – which together comprise the lithosphere – formed rigid plates which move horizontally on top of the more malleable lower part of the mantle – the asthenosphere (figure 1).

The organisation of these plates has changed dramatically over time (figure 2). About 2.5 to 4 billion years ago – during what is known as the Archaean eon – the lithosphere was partitioned into plates much smaller

than the continents we know today. Later, during the Proterozoic eon, the plates joined together, forming one large supercontinent called Pangaea. Traditionally, this is believed to have been the situation 1 billion years ago. Subsequently, the continents started to drift away from these masses, progressively forming the globe we now recognise. This final drift is referred to as modern-style plate tectonics and is

traditionally thought to have started around 900 million years ago.

As this process occurs, plates collide. When one plate moves under the other and sinks into the mantle, it is called subduction (figure 2). Subduction is a slow process that happens at high pressure (about 10 kilobar) and a temperature of less than 500 °C, and with a thermal gradient of less than 15 °C per kilometre.



The appearance of Earth has changed considerably over time, as the rigid plates on the lithosphere have moved.



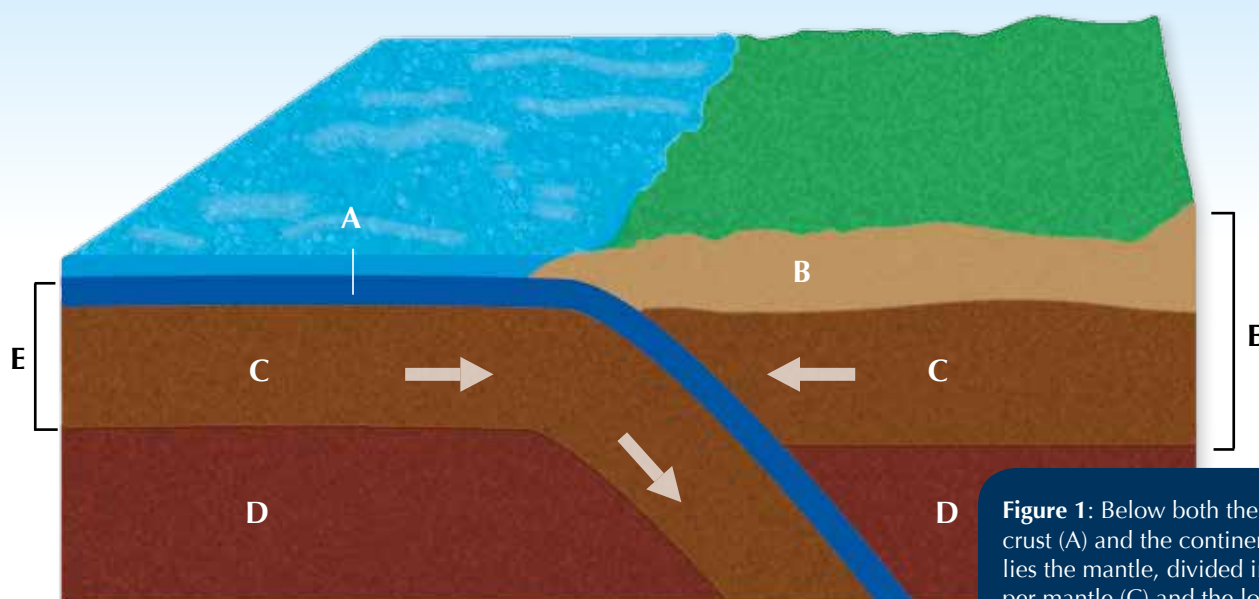


Image courtesy of Nicola Graf

**Figure 1:** Below both the oceanic crust (A) and the continental crust (B) lies the mantle, divided into the upper mantle (C) and the lower mantle (D), also known as the asthenosphere. Together, the crust and the upper mantle form the lithosphere (E).

Plate tectonic movements can create subduction zones, where part of the lithosphere (E) descends into the asthenosphere (D). Subduction is a slow process that happens at high pressure (about 10 kilobar) and a temperature of less than 500 °C, and with a thermal gradient of less than 15 °C per kilometre.

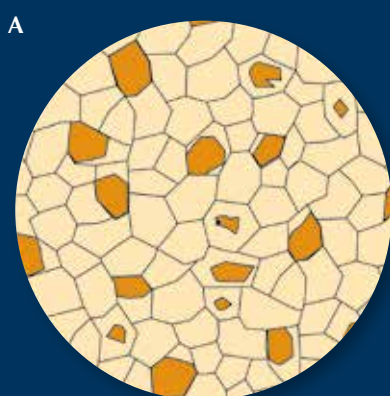
### Testing the age of African rocks

We didn't set out to investigate plate tectonics, however. Instead, the purpose of our study was to use a new technique to learn more about the formation of metamorphic rocks about 2 billion years ago. We had not expected our work to have any

implications for plate tectonics, which was generally thought to have started nearly 1 billion years later.

For the first stage of our study we visited several hundred geological sites around Africa (figures 3 and 4) and collected samples of greenstones. These rocks are known to have un-

Images courtesy of Hervé Martin (A and C), Kieff / Wikimedia Commons (B)



**Figure 2:** The evolution of the lithosphere from the Archaean eon to modern times:

A) During the Archaean eon (4 to 2.5 billion years ago), the lithosphere was divided into many small plates.



B) About 1 billion years ago, during the Proterozoic eon, the plates are thought to have joined together, forming one large continental mass: Pangaea.

1: Eurasia; 2: North America; 3: South America; 4: Africa; 5: India; 6: Antarctica; 7: Australia



C) As the continents started to drift apart, they progressively formed the globe we know today. This is traditionally thought to have started later in the Proterozoic eon, around 900 million years ago.



- ✓ Earth science
- ✓ Chemistry
- ✓ Physics
- ✓ Plate tectonics
- ✓ Ages 11+

This article about two scientists' discoveries about plate tectonics offers a taste of cutting-edge research. In a clear and concise style, the authors guide their readers from the basics of plate tectonics theory to the object of their research, focusing on its implications for Earth's history and on the new questions raised by this breakthrough.

As an earth science teacher I find the article interesting for different reasons:

- It focuses on a period of Earth's history that is rarely addressed in school textbooks.
- It gives an interesting view on early plate tectonics.
- It provides details of the methodology and equipment used in the research.
- It is a vivid example of the scientific method.

I recommend this article to secondary-school teachers keen to interest their students in earth science and scientific research in general. It could provide valuable background reading to raise students' interest before addressing some topics usually considered tedious, such as minerals and plate tectonics.

The text offers multiple links not only to earth science topics (Earth's history, plate tectonics, mineralogy, the rock cycle, geochemistry, investigative techniques, Africa, greenstone belts and gold mining), but also to chemistry (iron oxides and redox reactions) and physics (X-rays and synchrotron radiation machines, scanning electron microscope, pressure, temperature and phase transitions). In addition, it is a good case history for discussing the scientific method.

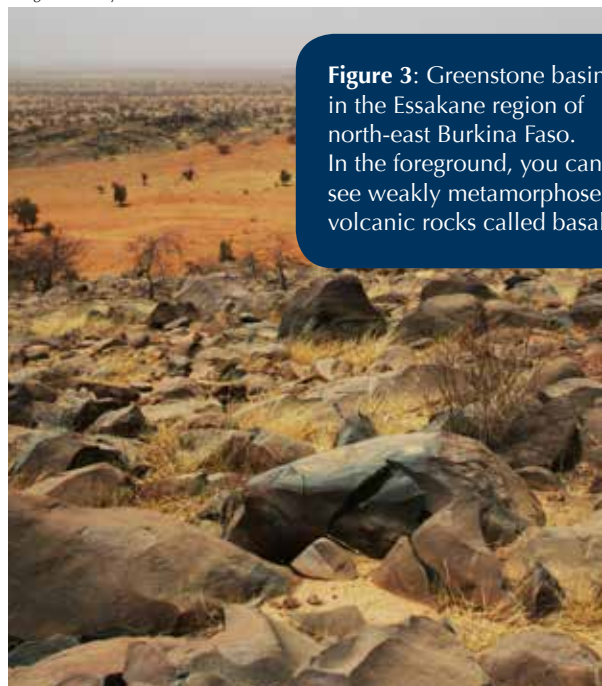
Given the language in which it is written, the article could easily be used for comprehension exercises, such as:

1. The minerals studied formed under conditions of:
  - a) High pressure (10 kbar) and low temperature (less than 500 °C)
  - b) Low pressure (5 kbar) and high temperature (more than 700 °C)
  - c) Low pressure (5 kbar) and temperatures ranging from 200 to 700 °C
  - d) High pressure (10 kbar) and temperatures ranging from 200 to 700 °C.
2. The composition of the different types of chlorite and phengite depends on:
  - a) The ratio of  $H_2O$  to  $CO_2$
  - b) The ratio of  $Fe^{2+}$  to  $Fe^{3+}$
  - c) The temperature and pressure of formation
  - d) All of the above.

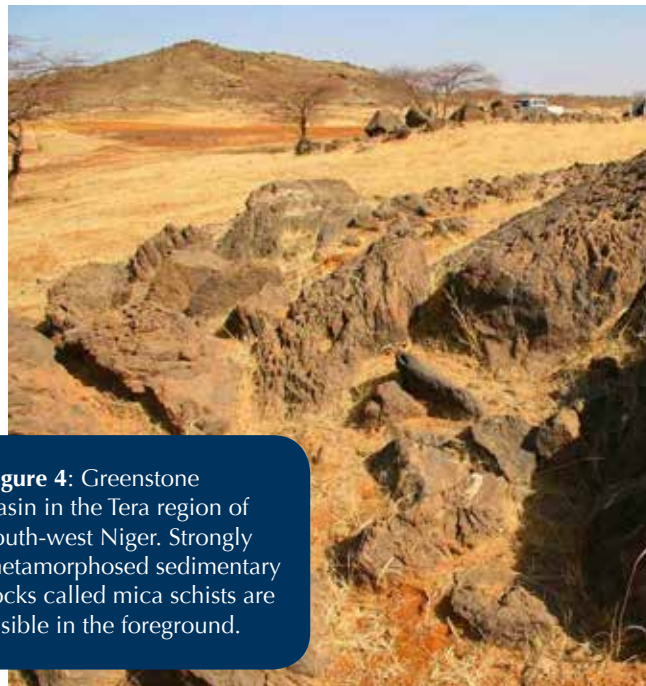
*Giulia Realdon, Italy*

## REVIEW

Images courtesy of Lenka Baratoux



**Figure 3:** Greenstone basin in the Essakane region of north-east Burkina Faso. In the foreground, you can see weakly metamorphosed volcanic rocks called basalts.

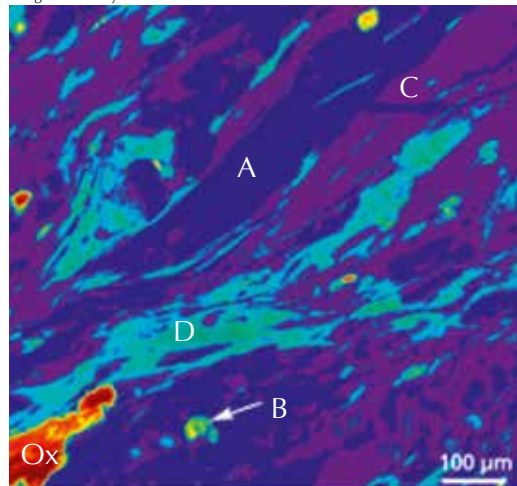


**Figure 4:** Greenstone basin in the Tera region of south-west Niger. Strongly metamorphosed sedimentary rocks called mica schists are visible in the foreground.



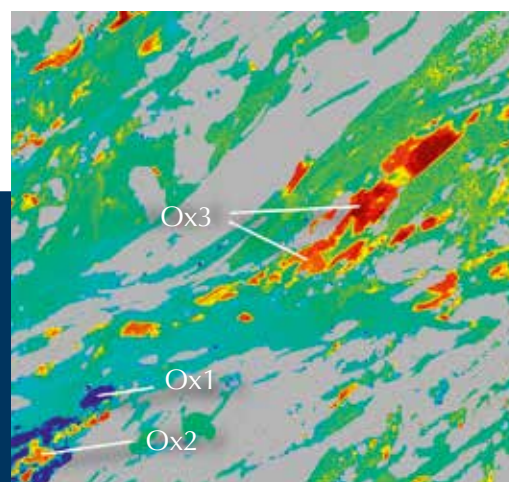
**Figure 5:** Images of one of our rock samples, obtained at ESRF using very intense X-ray beams.

Images courtesy of Vincent de Andrade



a) Chemical mapping of a complex metamorphic rock containing quartz (A), garnet (B), phengite (C), chlorite (D) and iron oxides (Ox).

b) Fine qualitative chemical mapping showing three types of iron oxides: Ox1, which is low in  $\text{Fe}^{3+}$ ; Ox3, which is rich in  $\text{Fe}^{3+}$ ; and Ox2, which has intermediate levels of  $\text{Fe}^{3+}$ .



Chemistry

Earth science

Physics

dergone metamorphism – a change from one rock type to another – about 2 billion years ago. Based on previous knowledge about the metamorphism of rocks during this period, it was thought that they must have formed under conditions of low pressure (no more than 5 kbar) and temperatures ranging from 200 to 700 °C.

Next, we investigated the composition of minerals in these rock samples using microprobe analysis. This is a range of techniques that includes microscopy and back-scattered electron imaging, which distinguishes heavy elements, which scatter electrons well, from light elements, which do not. We also performed chemical mapping, which shows where particular minerals are found in the samples.

Furthermore, we carried out experiments at the European Synchrotron Radiation Facility (ESRF; see box on page 18) to decipher the very fine chemical structure of some of our

Image courtesy of Ginter / ESRF



Lying at the foot of the French Alps, the European Synchrotron Radiation Facility uses brilliant beams of X-rays to resolve the structure of matter. A synchrotron is a type of cyclic particle accelerator: at ESRF, the synchrotron light travels at great velocity around the giant grey ring.

samples. Synchrotron X-ray beams are billions of times brighter than the beams produced by a hospital X-ray machine, allowing them to resolve the structure of matter at a level of detail impossible to reach with standard X-rays.

Using very thin slices of rock, we were able to map their chemical composition. We found that they contained quartz, garnet, phengite, chlorite and iron oxides (figure 5). But what did this tell us about how the rocks formed and under what conditions?

To interpret our results, we used computer calculations based on different chemical parameters that we measured. For example, we analysed the ratio of  $\text{H}_2\text{O}$  to  $\text{CO}_2$  in the fluids trapped within the quartz, and measured the ratio of  $\text{Fe}^{3+}$  to  $\text{Fe}^{2+}$  present in the rocks (figure 5b). There are many different chlorites (e.g. magnesium chlorite, iron chlorite) and several different forms of phengite (which may contain, for example, magnesium or iron). The precise chlorites and phengites that we observe in the metamorphic rocks depend on the conditions at the time of rock formation. These are the  $\text{H}_2\text{O}:\text{CO}_2$  to  $\text{Fe}^{3+}:\text{Fe}^{2+}$  ratios as well as the pressure and temperature. Measuring the ratios of these different chemicals in our rock samples therefore allows us to work backwards to calculate exactly the temperature and pressure conditions under which the rocks formed.

## More about ESRF



The European Synchrotron Radiation Facility (ESRF<sup>w1</sup>) is one of the most intense sources of X-rays in the world. Thousands of scientists come every year to ESRF to carry out experiments in materials science, biology, medicine, physics, chemistry, palaeontology and cultural heritage. ESRF is a member of EIROforum<sup>w2</sup>, the publisher of *Science in School*.

To view all ESRF-related articles in *Science in School*, see: [www.scienceinschool.org/esrf](http://www.scienceinschool.org/esrf)



## Revolutionising our understanding of plate tectonics

Using these calculations, we demonstrated that the chlorite and phengite composition in the rocks of western Africa was obtained under high pressure (about 10 kbar) and a low temperature of less than 500 °C. This was surprising, because these pressure and temperature conditions are found only in subduction zones. Since the rocks we studied date back more than 2 billion years, our results imply that modern-style plate tectonics existed 2 billion years ago, far earlier than the 900 million years ago that scientists had previously thought.

Our discovery has changed the scientific understanding of the geodynamics of Earth. So when, then, did modern-style plate tectonics actually begin? And how widespread were these gigantic land movements? To address these questions, our next step

will be to study other rocks of the same age and older. In particular, we plan to visit Yilgarn Craton in Australia and the Barberton area in South Africa, to examine their chlorite- and phengite-containing metamorphic rocks.

## Acknowledgement

The authors would like to acknowledge the help of Dominique Cornuéjols, from ESRF's communications department, in preparing and translating material for this article.

## Web references

w1 – Learn more about ESRF. See: [www.esrf.eu](http://www.esrf.eu)

w2 – EIROforum is a collaboration of eight of Europe's largest international governmental scientific research organisations, which combine their resources, facilities and expertise to support European sci-



ence in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. To learn more, see: [www.eiroforum.org](http://www.eiroforum.org)

### Resources

The Exploring Earth website offers a useful interactive animation of the rock cycle. See [www.classzone.com/books/earth\\_science/terc](http://www.classzone.com/books/earth_science/terc) (search for 'ES0602') or use the direct link: <http://tinyurl.com/eye52>

If you found this article useful, why not browse the other earth science articles in *Science in School*? See: [www.scienceinschool.org/earthscience](http://www.scienceinschool.org/earthscience)

Dr Jérôme Ganne is in charge of a research programme at the Research Institute for Development (IRD) in the GET Lab at the University of Toulouse III, France, where his research focuses on tectonic processes that control the formation and demolition of mountain ranges. In association with the IRD, he has assembled a team of young researchers at the University Cheikh Anta Diop in Dakar, Senegal. He also teaches on several higher education programmes in west African universities.

After receiving a PhD in Earth Sciences, Vincent de Andrade became a beamline scientist at the European Synchrotron Radiation Facility. In 2010, he joined the National Synchro-

tron Light Source-II at the Brookhaven National Laboratory as an associate scientist to build SRX, a spectroscopy beamline comprising very intense micro- and nanoprobe. Vincent specialises in the chemical imaging of complex heterogeneous geomaterials to better understand their genesis and transformations.



To learn how to use this code, see page 57.



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Earth science

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### MINI DATALOGGERS



### AIR ROCKETS



### ROBOTS



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# Laying bare our genetic blueprint

What does the majority of our DNA do? Hundreds of scientists have spent years examining these 'junk' sequences, which may hold the key to serious diseases – and much more.

By Louisa Wood, European Bioinformatics Institute

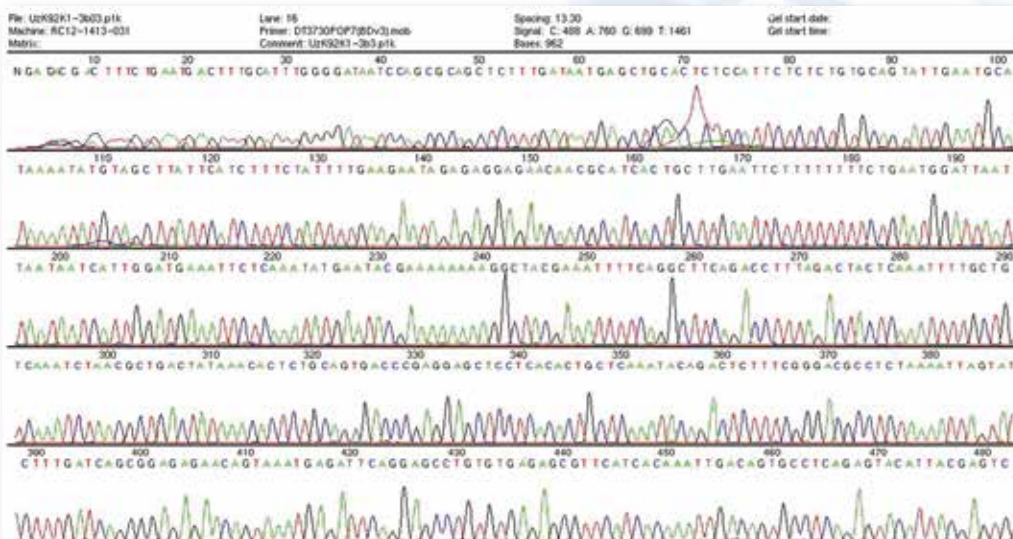
The Human Genome Project – the sequencing of the human genome – was a major achievement of the past decade: it laid bare the human genetic blueprint, all three billion bases, but the story doesn't stop there. Deciphering how this sequence is interpreted by our cells is essential to understanding how the genome works. Then, perhaps, we can apply this knowledge to biomedical research and healthcare.

One of the big surprises of the human genome was that only 2% of the genome contains genes, the instructions to make proteins. After accounting for additional bits of the genome such as non-coding RNAs, parts involved in controlling the activity of genes and introns (the sections of a gene's sequence that are removed before the messenger RNA molecule is translated), a common view was that the rest of the genome had no biological

function. As a result, it was often referred to as 'junk' DNA.

## Going beyond the sequence

Once the human genome was sequenced, it was time to find out whether these sequences really were junk. In 2003, the ENCODE consortium was formed to characterise the non-coding but functional elements of the human genome. The consortium was supported by the National



**Figure 1:** The output from an automated DNA sequencing machine used by the Human Genome Project to determine the complete human DNA sequence. Each peak shows the presence of a particular base. The Human Genome Project identified the 3 billion letters making up our genome. ENCODE now provides details of how the genome works.



Human Genome Research Institute in the USA and led by the European Bioinformatics Institute (EBI; see box on page 23) in the UK. The ENCODE pilot phase ran from 2003 to 2007 and allowed a global network of researchers to test, compare and optimise experimental and computational methods for identifying the active parts in a 1% portion of the genome – essentially sifting through some of the genomic ‘junk’.

Their initial results, published in June 2007 (The ENCODE Project Consortium, 2007), gave a tantalising insight into what the genome is doing. For example, the combined data from microarray (see Koutsos et al., 2009) and sequencing experiments showed that the majority of the genome is transcribed, including regions that had been thought to be transcriptionally silent (figure 2). Although the biological roles of most of the transcripts were still unknown, some were shown to be important regulators of gene expression. Overall, this genome snapshot showed that the interplay between genes, regions involved in regulating the activity of genes, and other types of DNA sequences was much more complex than anyone had



- ✓ Biology
- ✓ Genetics
- ✓ Human Genome Project
- ✓ Bioinformatics
- ✓ Ages 14+

## REVIEW

This article throws light on one of the latest advances in human genetics: the ENCODE project and how its research was carried out.

When students are introduced to the genetic code, they are often dumbfounded by the fact that only 2% of human DNA actually encodes proteins while the rest is supposedly junk. The ENCODE project has now investigated the function of some of this non-coding DNA, and found that it is not really junk after all.

While discussing the Human Genome Project with students, you can also introduce ENCODE. Providing students with background information on gene regulation, genetic diseases and their treatments, and techniques used in genetics research may be helpful. The article can trigger an interest in bioinformatics among students, and you could encourage them to perform a literature survey on the ENCODE project.

*Namrata Garware, India*

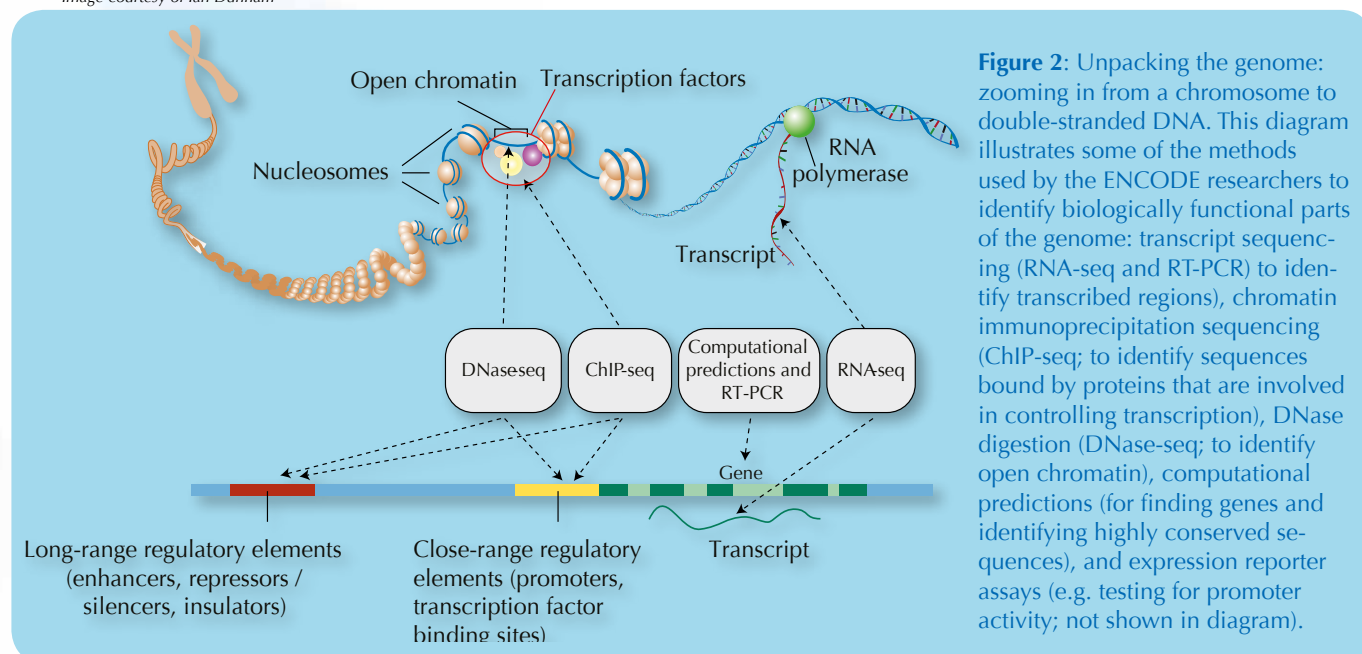
thought. The data had already started to indicate that the genome contained many forms of active elements and consequently less unused sequence than had been believed.

After successfully testing their approach, the ENCODE researchers then

began to examine the entire human genome. This was made easier by advances in DNA sequencing technology and the availability of more precise biochemical assays.

Their analysis systematically mapped features of the genome, just

Image courtesy of Ian Dunham



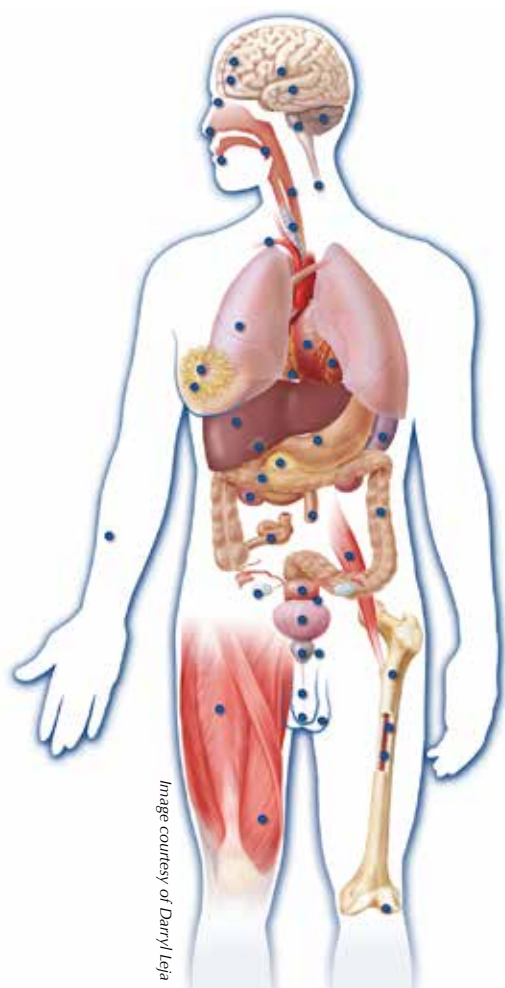


Image courtesy of Darryl Leja

**Figure 3:** The ENCODE project analysed 147 different cell types to understand differences in genome regulation in different tissue types. This diagram pinpoints 47 of the 147 different cell types included in the study. Multiple cell types were used because although cells share the same genome, the way they use this information differs between cell types.

as a map describes a physical landscape and geographical features such as forests, rivers and mountains. In the genome, the ENCODE researchers were looking for features such as regions of the genome flagged with 'shhhh' signs (specific types of methyl groups) indicating gene silencing, 'bind here' signposts for transcription factors, booster regions to enhance transcription, and DNA modifications that control how the DNA is packaged (figure 3).

## Data deluge

In September 2012, after 5 years of experiments and analysis by 442 researchers from 32 research institutes in the UK, US, Spain, Singapore and Japan, the ENCODE project announced the results of the most detailed analysis of the whole genome to date. The study used about 300 years of computer time to analyse 15 terabytes of data ( $15 \times 10^{12}$  bytes), all of which is publicly available. If the data were printed out at a density of 1000 base pairs per  $\text{cm}^2$ , the tower of paper would be 16 m high and more than 30 m long: the equivalent of 12 double-decker buses in volume.

The ENCODE project is an example of what can be achieved by large-scale projects building on the individual contributions of hundreds of researchers, each adding a piece of the jigsaw to produce a complete picture of the genome that could not be achieved by any single organisation.

## Bringing the sequence to life

One of the most exciting things that the ENCODE experiments showed is that rather than being predominantly

non-functional sequence, our genome is alive with activity: 80% of the genome is actively doing something. Exactly what it is doing remains to be discovered, but certainly 9% of it (and probably much more) is involved in regulating gene expression, controlling when and where proteins are made. The active 80% of the genome contains more than 70 000 promoter regions – the 'bind here' sites for transcription factors – and nearly 40 000 enhancer regions – the boosters that control the expression of distant genes.

## A massive, 3D control panel

Overall, ENCODE identified more than 4 million gene switches dispersed throughout the genome. You could picture the genome as a massive control panel, like a sound engineer's mixing desk, with lots of switches that turn genes on and off. This information deepens our understanding of gene expression and opens up new opportunities for treating disease. For example, a small change in a gene switch called CARD9 is linked to a 20% increased risk of developing

If the results of the ENCODE project were printed out, the paper would fill 12 buses.



Images courtesy of marcus\_jb1973 / benjamin247 / Andrew Farquhar / Flickr



Crohn syndrome, an inflammatory bowel disease. What if you could reset gene switches back to normal, effectively turning off the causes of a disease?

The ENCODE results also shed light on how the genome is organised and the physical interactions occurring within it. The researchers found that these gene switches were in physical contact with the genes they controlled, even though they might be separated linearly by hundreds of kilobases. We tend to imagine the genome as a long, straight line of sequence but in reality it's all tightly packed in the cell's nucleus, bringing different parts of the genome in close contact with each other.

### Building on the data

ENCODE provides a detailed map of the genome and opens up whole new areas of science to explore. As Ian Dunham from EBI and lead author on the ENCODE paper explains, "In many cases you may have a good idea of which genes are involved in a disease, but you might not know which switches are involved. Sometimes these switches are very surprising – their location might seem more logically connected to a completely different disease. ENCODE gives us a set of valuable leads to follow to discover key mechanisms at play in health and

disease. Those can be exploited to create entirely new medicines, or to repurpose existing treatments."

As well as knowing which genes are involved in a disease, researchers now know some of the switches involved in regulating how these genes are turned on and off. This will

Just like the mixing desk of a sound engineer, the expression of genes is under complex control, with the human genome containing over 4 million gene switches.

Image courtesy of Stuart Dallas Photography / Flickr



## More about EBI

EMBL



The European Molecular Biology Laboratory (EMBL)<sup>w1</sup> is one of the world's top research institutions, dedicated to basic research in the life sciences. EMBL is international, innovative and interdisciplinary. Its employees from 60 nations have backgrounds including biology, physics, chemistry and computer science, and collaborate on research that covers the full spectrum of molecular biology.

EBI<sup>w2</sup>, based near Cambridge, UK, is part of EMBL. It provides data from life science experiments free to the global scientific community, and performs basic research in computational biology. EBI is committed to training researchers in academia and industry to make the most of the incredible amount of data being produced every day in life science experiments.

EMBL is a member of EIROforum<sup>w3</sup>, the publisher of *Science in School*.

See the list of all EMBL-related articles in *Science in School*: [www.scienceinschool.org/embl](http://www.scienceinschool.org/embl)



be especially valuable for interpreting the results of population-based studies that identify links between a gene and a disease. By combining ENCODE's functional analysis of the genome with data from genome-wide association studies, researchers can map the genetic variations that have been linked to disease to the areas of regulatory function, including gene switches, identified by ENCODE. The ENCODE data will enable a better understanding of the genetic basis of disease and support the work of scientists for many years to come.

### References

The ENCODE Project Consortium (2007) Identification and analysis of functional elements in 1% of the human genome by the ENCODE pilot project. *Nature* **447**: 799-816. doi: 10.1038/nature05874

Download the article free of charge on the *Science in School* website ([www.scienceinschool.org/2013/issue26/encode#resources](http://www.scienceinschool.org/2013/issue26/encode#resources)), or subscribe to *Nature* today: [www.nature.com/subscribe](http://www.nature.com/subscribe)

The ENCODE Project Consortium

(2012) An integrated encyclopedia of elements in the human genome. *Nature* **489**: 57–74. doi: 10.1038/nature11247

Download the article free of charge on the *Science in School* website ([www.scienceinschool.org/2013/issue26/encode#resources](http://www.scienceinschool.org/2013/issue26/encode#resources)), or subscribe to *Nature* today: [www.nature.com/subscribe](http://www.nature.com/subscribe)

Koutsos A, Manaia A, Willingale-Theune J (2009) Fishing for genes: DNA microarrays in the classroom. *Science in School* **12**: 44–49. [www.scienceinschool.org/2009/issue12/microarray](http://www.scienceinschool.org/2009/issue12/microarray)

## Web references

w1 – Learn more about EMBL. See: [www.embl.org](http://www.embl.org)

w2 – Learn more about EBI. See: [www.ebi.ac.uk](http://www.ebi.ac.uk)

w3 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combine their resources, facilities and expertise to support European science in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. See: [www.eiroforum.org](http://www.eiroforum.org)

## Resources

Hosted on the *Nature* website, the ENCODE Explorer enables you to navigate the ENCODE data in its 13 threads. See: [www.nature.com/encode](http://www.nature.com/encode)

There, you can also download a free poster (20 MB) showing a subset of the ENCODE data. See [www.nature.com/encode](http://www.nature.com/encode) or use the direct link: <http://tinyurl.com/bloyd3k>

In an online video, *Nature* editor Magdalena Skipper and EBI's Ewan Birney discuss the ENCODE project. See: <http://youtu.be/Y3V2thsJ1Wc>  
*The Story of You: ENCODE and the Human Genome* presents ENCODE in cartoon format. See: <http://youtu.be/TwXXgEz9o4w>



Image courtesy of AlexRathis / iStockphoto

The ENCODE data will enable a better understanding of the genetic basis of disease.

Ewan Birney from EBI, Tim Hubbard of the Wellcome Trust Sanger Institute and Roderic Guigo of CRG present ENCODE in a video (subtitles in Spanish). See: <http://youtu.be/KiwXtHRfBC8>

To introduce bioinformatics into your lessons, why not try one of these activities?

Kozlowski C (2010) Bioinformatics with pen and paper: building a phylogenetic tree. *Science in School* **17**: 28–33. [www.scienceinschool.org/2010/issue17/bioinformatics](http://www.scienceinschool.org/2010/issue17/bioinformatics)  
Communication and Public Engagement team (2010) Can you spot a cancer mutation? *Science in School* **16**: 39–44. [www.scienceinschool.org/2010/issue16/cancer](http://www.scienceinschool.org/2010/issue16/cancer)

To learn more about bioinformatics, see:

Hayes E (2011) An archaeologist of the genome: Svante Pääbo. *Science in School* **20**: 6–12. [www.scienceinschool.org/2011/issue20/paabo](http://www.scienceinschool.org/2011/issue20/paabo)

Pathmanathan S, Hayes E (2007) Nicky Mulder, bioinformatician.

*Science in School* **6**: 75–77. [www.scienceinschool.org/2007/issue6/nickymulder](http://www.scienceinschool.org/2007/issue6/nickymulder)

If you found this article useful, you might also enjoy the other cutting-edge science articles in *Science in School*. See: [www.scienceinschool.org/cuttingedge](http://www.scienceinschool.org/cuttingedge)

Dr Louisa Wood works at EBI, where she is responsible for the institute's outreach to schools and the general public. She has a scientific background in plant molecular biology and undertook her PhD at the John Innes Centre, Norwich, UK, and at the Max-Planck Institute for Plant Breeding in Cologne, Germany. After this, she began a career in science communication and outreach. She has worked at EBI since 2007.



To learn how to use this code, see page 57.





# The genetics of obesity: a lab activity

Around 1.5 billion people worldwide are overweight or obese. Are we just eating too much or can we blame our genes? Here's how to investigate the genetics of obesity in the classroom.

By Sarah McLusky, Rosina Malagrida and Lorena Valverde

Obesity is a big problem, in more ways than one. More than 10% of the world's adult population is obese; in some countries this rises to 40%. Heart disease, type 2 diabetes, some cancers, pregnancy complications, joint problems, depression and anxiety have all been linked to obesity<sup>w1</sup>.

Readily available calorie-rich foods and a more sedentary lifestyle are usually blamed for the startling rise in obesity, but might our genes be part of the problem? This article introduces some of the current research into the genetics of obesity along with a method developed by the European Xplore Health project for extracting DNA, the first step for researchers looking to identify possible 'fat genes'.

The DNA extraction would be suitable for intermediate (aged 14-16) or

advanced (aged 16+) students and could be completed in one lesson. If this method is not appropriate for your students or lab, try one of two alternative methods (based on the same principles, but using more readily available materials), using frozen peas (Madden, 2006) or kiwi fruit<sup>w2</sup>.

The topic of obesity also provides a useful way of introducing current genetic research and ethical issues within a context that students are likely to have some personal experi-

An obese, leptin-deficient mouse (left) next to a normal mouse (right)



Image courtesy of US Department of Energy, Oak Ridge National Laboratory



- ✓ Biology
- ✓ Health education
- ✓ Genetics
- ✓ Nutrition
- ✓ Pharmacogenomics
- ✓ Statistics
- ✓ Ages 15+

The incidence of obesity is increasing worldwide. Growing awareness of the problem, changing our eating habits and investigating a genetic predisposition could all contribute to its reduction.

This article, which explores recent research into the genetics of obesity and details a practical activity on the topic, could be used for biology lessons on many different topics, including health education, genetics, nutrition, pharmacogenomics, individualised therapy correlated with the presence of specific genes, statistics on obesity in different countries and their link to the diet of the corresponding population.

In addition to providing the starting point for a discussion of obesity, the article could be used for a project on nutrition, starting by recording students' BMI and relating it to their daily diet (e.g. Krotscheck, 2010). In this way, the teacher could propose healthier eating habits, contributing to changing the attitude of students.

Suitable comprehension and extension questions include:

1. Is there a relationship between genetics and obesity? If so, what is it?
2. What are phenotype and genotype? How do these correlate with each other and with the environment?
3. How are epigenetic phenomena associated with phenotype? Are these epigenetic changes inherited?
4. Could the knowledge of our genetic composition help us prevent obesity?
5. Good nutrition is important for health. If your BMI is beyond the normal range, how could you change your eating habits to reduce it?

*Panagiotis Stasinakis, 4<sup>th</sup> Lyceum of Zografou, Greece*

## REVIEW

ence of and opinions about. After all, how many teenagers don't like fast food and lazing about in front of the TV? Other resources, including a debate pack for exploring the issues further, are available on the Xplore Health website<sup>w3</sup>.

### What have genes got to do with it?

Obesity runs in families. Does that mean obesity is genetic or does it just mean that families share unhealthy eating habits? Perhaps surprisingly, twin studies have shown that obesity

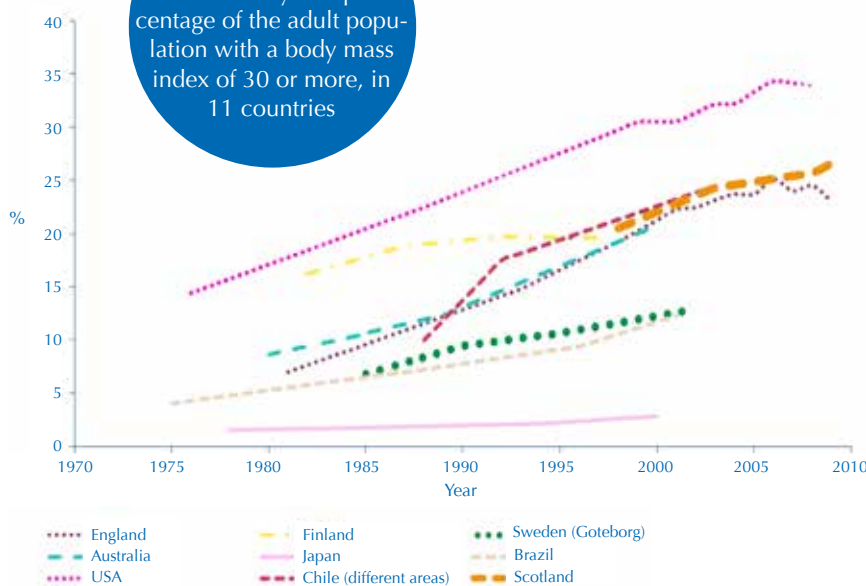
could be as much as 70% genetic, as siblings who share the same genes (identical twins) are much more likely to share the same body shape than non-identical twins (O'Rahilly & Farooqi, 2006).

Researchers have discovered a number of gene variants (alleles) that seem to be associated with obesity. Some of these are rare and affect a very small number of people, while others are fairly common and increase the risk of weight gain among large parts of the population (table 1).

The *Ob* gene is a single-variant cause of obesity. It controls appetite by producing a hormone called leptin. People who carry two defective copies of this gene cannot produce leptin and have a constant desire for food. Obese, leptin-deficient people treated with leptin injections have returned to a normal weight. Another gene found to act in a similar way is the *Mc4r* gene, which is part of a signalling pathway that controls eating behaviour (O'Rahilly & Farooqi, 2006).

However, these single-gene mutations are quite rare. Some other,

Changes in the prevalence of adult obesity: the percentage of the adult population with a body mass index of 30 or more, in 11 countries





**Table 1:**  
Different types  
of obesity-linked  
genes identified by  
researchers

	Rare single gene variants	Multiple common gene variants
<b>Effect on body weight</b>	Account for a lot of extra weight in very few people	Account for a little bit of extra weight in a lot of people
<b>Examples</b>	<i>Ob</i> gene, <i>Mc4r</i> gene	<i>Fto</i> gene, <i>Tmem18</i> gene
<b>Association with other clinical conditions</b>	Can be associated with rare diseases, e.g. congenital leptin deficiency, MC4R deficiency	One of many 'normal' varied human characteristics, but can also associate with other common diseases, e.g. type 2 diabetes
<b>How are these found?</b>	Candidate gene studies, animal studies, exome sequencing	Genome-wide association studies
<b>Potential relevance</b>	Prenatal genetic testing and gene therapy	Understanding risk of disease and tailoring disease prevention strategies

much more common gene variants have been identified that, although not a direct cause of obesity, do make carriers more likely to put on weight. Examples include variants of the *Fto* gene and the *Tmem18* gene. Studies have found that people with one copy of the 'at risk' *Fto* variant weigh, on average, 1.2 kg more than people with other variants, whereas those with two copies of the 'at risk' variant

weigh, on average, 3 kg more.

So are people who carry these more common 'fat genes' destined to be obese or can they escape their fate? These gene variants simply predispose people to gain weight, but with a healthy diet and lifestyle there is no reason why carriers shouldn't be able to maintain a healthy weight.

Obesity researchers are also exploring epigenetics (the interactions

between genes and environment) and how signalling pathways (e.g. hormones and the nervous system) in the body affect metabolism and behaviour. They hope that through a better understanding of the complex nature of appetite, metabolism and fat storage, it will be possible to develop better treatments or strategies for controlling food intake in people who are genetically predisposed to obesity.



## Defining obesity

Someone is considered obese if they have a body mass index (BMI) of 30 or more. The healthy range is 18.5-25. BMI is calculated by dividing a person's weight in kilograms by the square of their height in metres.

$$\text{BMI} = \frac{\text{weight (kg)}}{(\text{height (m)})^2}$$

Although BMI provides a useful guide, it doesn't allow for variation in build and body composition. For example, athletes who carry a lot of muscle mass would often be considered overweight if judged on BMI alone.



## Why are there so many different DNA extraction methods?

This is just one of many published methods for extracting DNA from cells (e.g. Madden, 2006, and the Naked Scientists website<sup>w2</sup>). They range from the very simple (using washing-up liquid and table salt) to methods that use chemicals more familiar to molecular biologists. The principles of the extraction are the same in all cases: a detergent is used to break up the cell membranes, an enzyme is added to digest the proteins that keep DNA tightly coiled up, and salt and cold alcohol are then added to create conditions where DNA is insoluble.

The main difference is that the more advanced the method, the purer the resulting DNA will be. For example, in the simplest method, a lot of pectin is mixed in with the DNA. Clearly, obesity researchers and other molecular biologists need their samples to be as pure as possible.

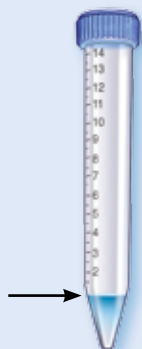
## Student activity: Extracting your own DNA

### Materials

- Micropipettes or graduated transfer pipettes  
If you don't have micropipettes, you can use calibrated / graduated disposable plastic transfer pipettes. On these pipettes the 'stalk' is graduated, allowing volumes of less than 1 ml to be transferred with sufficient accuracy for this experiment.
- Disposable culture loops or buccal swabs
- Small Falcon tube or a test tube with a bung or cap  
Falcon tubes are calibrated test tubes with screw caps. If you don't have them, just use normal test tubes.
- Water bath at 40°C (optional)
- Disinfectant solution
- Lysis solution
- Proteinase K solution
- Sodium acetate solution
- Cold ethanol or isopropyl (rubbing) alcohol (keep in the freezer until required)

### Procedure

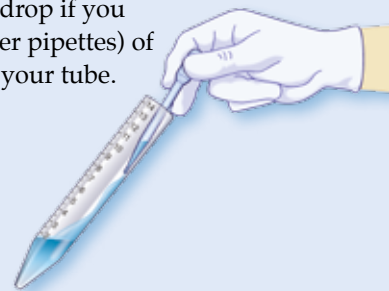
1. Place 1 ml lysis solution in your Falcon tube or test tube.



2. Vigorously scrape a loop or swab around the inside of your cheeks and across your tongue.
3. Place the loop or swab in the lysis buffer and mix it around to dislodge your cells.



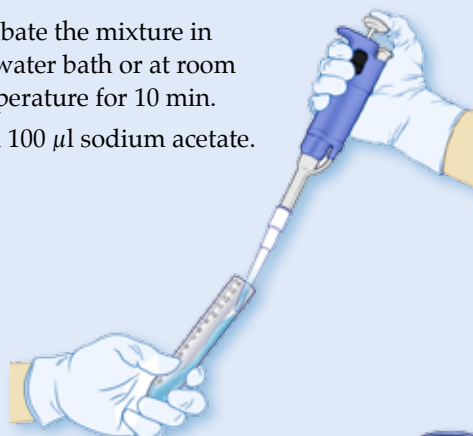
4. Put your loop or swab in the disinfectant.
5. Repeat steps 2-4 twice more to ensure you get plenty of cells. **Use a new loop or swab each time.**
6. Add 20  $\mu$ l (or 1 drop if you are using transfer pipettes) of proteinase K to your tube.



7. Cap the tube and invert it a couple of times to mix.



8. Incubate the mixture in the water bath or at room temperature for 10 min.
9. Add 100  $\mu$ l sodium acetate.



10. Cap your tube and shake well to mix.
11. Add 3 ml cold ethanol.
12. Cap the tube and invert it very slowly to mix.
13. Your DNA should appear as a whitish stringy precipitate.





**Safety note:**

The solutions can irritate eyes and skin, so wear a lab coat, safety glasses and gloves. Saliva can carry diseases; only handle your own loops or swabs and put used items in the disinfectant.

Disposal: liquids can be poured down the sink with plenty of water. Used loops or swabs can be placed in normal waste after disinfecting for 15 minutes.

**Questions for discussion**

- What does 'lysis' mean? How does this help extract the DNA?
- The lysis buffer contains a detergent called SDS. Using your knowledge of cell structure, what do you think the detergent does?
- Inside cells, DNA is found tightly coiled up and bound to a variety of proteins. Which step helps to release the DNA from the proteins?
- What does the last step tell you about the solubility of DNA in both salty water and ethanol?
- How could you confirm that the white precipitate really is DNA?

**Extension activities**

- Compare this method of extracting DNA with the simpler methods using frozen peas (Madden, 2006) or kiwi fruit<sup>w2</sup>. How do they differ? Which one works best? Can you explain why? Can you find out which method is closest to the method that professional geneticists use?
- Simply extracting someone's DNA is not enough to tell if they have a predisposition for obesity. What other tests would have to be done? Find out more about the techniques used in genetic research.
- In many countries, parents who carry serious genetic conditions like cystic fibrosis or haemophilia can opt for pre-implantation genetic diagnostics to avoid having children that carry the disease. Do you think this procedure should be available for parents who have a genetic predisposition for obesity? Do your classmates agree with you?



## Sourcing and preparing the reagents

**Lysis solution (50 ml)**

1. Prepare tris-buffered saline (TBS) according to manufacturer's instructions or standard recipe.

TBS can be purchased as a ready-made solution, in tablet form or made up from scratch<sup>w4</sup>.

**Safety note:** a ready-made sodium dodecyl sulphate (SDS) solution is recommended as powdered SDS is harmful if inhaled. If powdered SDS is used, the teacher should prepare the solution, wearing a mask and using the fume hood.

See also the general *Science in School* safety note on page 57.

2. If using ready-made 10 % SDS solution, add 5 ml SDS to 45 ml TBS.

If using powdered SDS, dissolve 0.5 g in 50 ml TBS.

3. Store in the fridge until required.

**3 M Sodium acetate solution (for 50 ml)**

1. Dissolve 12.3 g anhydrous sodium acetate in 50 ml distilled water.
2. Add dilute HCl to adjust to pH 5.2.
3. Store in the fridge until required.

**Proteinase K (100 µg / ml)**

1. Dissolve 1 mg proteinase K in 10 ml tris-buffered saline.
2. Only a very small amount of the enzyme is required, so you might want to make up a smaller volume if you have a sufficiently accurate balance. Simply adjust the quantities accordingly.
3. Store in the freezer until required.

**Disinfectant solution**

Suitable disinfectants include 0.015 M sodium hypochlorite solution, 1 % Virkon® solution or 5 % domestic bleach. After soaking for at least 15 min, the loops can be transferred to a plastic bag (wear gloves) and disposed of with normal waste. To help you find the necessary reagents, a list of product numbers for Sigma-Aldrich is given in table 2. However, you will also be able to source them from other suppliers.

Reagent	Sigma-Aldrich product number
Tris buffered saline (TBS)	Tablets: TS030 or 94158
Sodium dodecyl sulphate (SDS)	Powdered: L3771 10% solution: 71736
Sodium acetate	S2889
Proteinase K	P6556

**Table 2:** Sigma-Aldrich product numbers for the reagents used in this protocol



Heart disease, type 2 diabetes, some cancers, pregnancy complications, joint problems, depression and anxiety have all been linked to obesity.

## References

- Krotscheck F (2010) Using cutting-edge science within the curriculum: balancing body weight. *Science in School* **16**: 19-26. [www.scienceinschool.org/2010/issue16/obesity](http://www.scienceinschool.org/2010/issue16/obesity)
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- O'Rahilly S, Farooqi IS (2006) Genetics of obesity. *Philosophical Transactions of the Royal Society of London Biological Science* **361(1471)**: 1095-1105. doi: 10.1098/rstb.2006.1850

## Web references

- w1 – The World Health Organization's factsheet number 311 *Obesity and Overweight* is available on the WHO website ([www.who.int](http://www.who.int)) or via the direct link: <http://tinyurl.com/62hyt96>

w2 – A simple DNA extraction method that uses kiwi fruit and does not require any specialist chemicals or equipment can be found on the Naked Scientists website ([www.thenakedscientists.com](http://www.thenakedscientists.com)) or via the direct link: <http://tinyurl.com/8aqhkhj>

w3 – You can download the DNA extraction method detailed in this article, as well as lesson ideas, games and videos related to obesity and other health science topics on the Xplore Health website ([www.xplorehealth.eu](http://www.xplorehealth.eu)). The website and most resources are available in English, Spanish, French, Polish and Catalan. Xplore Health is a European education project by scientists, educators, science centres and museums. It offers young people innovative multimedia and hands-on experiences about cutting-edge health science, to bridge the gap between research and education.

To learn more about obesity, its causes, consequences and treatment, as well as the ethical, legal and social aspects associated with obesity, download the background information for educators, *A Crisis of Fat?* (available in English, French, Polish and Spanish), from the Xplore Health website ([www.xplorehealth.eu](http://www.xplorehealth.eu)) or use the direct link: <http://tinyurl.com/cpq7esd>

w4 – A recipe for making tris-buffered saline from scratch is available on the Protocols Online website ([www.protocolsonline.com](http://www.protocolsonline.com)) or via the direct link: <http://tinyurl.com/br4or3t>

## Resources

The experiment was developed for the Xplore Health project with the help of scientists from the Institute for Research in Biomedicine in Barcelona, Spain. To learn more about the research, see the web page of the molecular pathology and therapy in heterogenic and polygenic diseases research group ([www.irbbbarcelona.org](http://www.irbbbarcelona.org)) or use the direct link: <http://tinyurl.com/bt93a7o>

org or use the direct link:

<http://tinyurl.com/bt93a7o> or read one of the original research articles:

Argyropoulos G, et al. (1998) Effects of mutations in the human uncoupling protein 3 gene on the respiratory quotient and fat oxidation in severe obesity and type 2 diabetes. *Journal of Clinical Investigation* **102(7)**: 1345-1351. doi: 10.1172/JCI4115

An animation of the DNA extraction process is available on the University of Utah's Learn Genetics website (<http://learn.genetics.utah.edu>) or via the direct link: <http://tinyurl.com/cuf8rzf>

The *Genetics and Obesity* factsheet can be downloaded from the website of the UK's National Genetics Education and Development Centre ([www.geneticseducation.nhs.uk](http://www.geneticseducation.nhs.uk)) or via the direct link: <http://tinyurl.com/cjezjxb>

If you found this article useful, why not browse all biology-related articles in *Science in School*? See: [www.scienceinschool.org/biology](http://www.scienceinschool.org/biology)

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Image courtesy of Tobyotter / Flickr



More than 10% of the world's adult population is obese; in some countries this rises to 40%.

Lorena Valverde holds a degree on biology from the University of Barcelona, Spain and a master's in immunology from the University of Barcelona and the Autonomous University of Barcelona. Lorena is currently doing a PhD in biomedicine and working as a teacher of the University of Barcelona. She has collaborated with Xplore Health, offering experimental workshops for students and the general public at the Barcelona Science Park.



To learn how to use this code, see page 57.



# CASTING LIGHT ON DARKNESS

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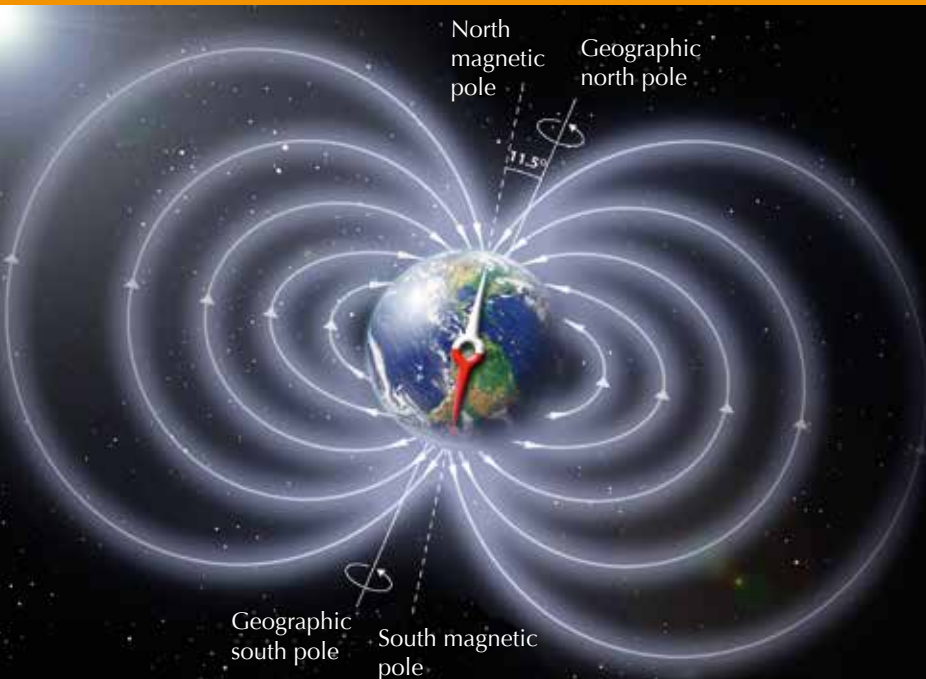
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# Casting light on solar wind: simulating aurorae at school

The aurorae are one of the wonders of the natural world. Using some simple apparatus, they and related phenomena can easily be reproduced in the classroom.



**Figure 1:** Earth's magnetic field. Solar wind particles are trapped by Earth's magnetic field and directed toward one of the magnetic poles, forming the Van Allen belt. It is only at the poles that the Van Allen belt is close enough to Earth to enter its atmosphere, where the collisions between the charged particles and atoms in the atmosphere cause the aurorae.

*Image courtesy of Peter Reid / University of Edinburgh*

**By Philippe Jeanjacquot and Jean Lilensten**

The aurorae are a striking phenomenon seen in polar regions, in which the thin air of the upper atmosphere glows and shimmers at night. They are also known as the northern and southern (or polar) lights. In this article, we explain how the aurorae are formed, and describe four activities, suitable for students aged 14-16, in which the aurorae and related phenomena can be simulated.

Perhaps unexpectedly, the ultimate

cause of the aurorae lies not in Earth's atmosphere, but in the Sun. The Sun – our star – releases its energy into space in two ways: as radiation, of which we see the visible part every day; and as solar wind, which is invisible, but which powers the aurorae when it interacts with the upper atmosphere. The solar wind is made up of charged particles – electrons and ions, primarily hydrogen ions (protons) – and has variable properties. Its velocity ranges from a few tens of kilometres per second to several thousand, and its density is in the range of a few (typically five) electrons and

protons per cubic centimetre at Earth's distance from the Sun.

Being electrically charged, the solar wind is sensitive to magnetic fields. One consequence of this is that a large proportion of the solar wind particles that pass by our planet are trapped by Earth's magnetic field (figure 1) and eventually directed toward one of Earth's magnetic poles; these trapped particles form what is known as the Van Allen belt. For the most part, it lies far above Earth's surface (about 45 000 km at the equator). At the poles, however, the Van Allen belt enters the atmosphere: its charged





Image courtesy of Earth Observations Laboratory, Johnson Space Center



The aurora as seen from the International Space Station



- ✓ Physics
- ✓ Earth science
- ✓ Electricity
- ✓ Ionisation
- ✓ Astrophysics
- ✓ Particle physics
- ✓ Ages 16+

The article provides an introduction to the aurorae and the solar wind, and describes a very interesting way to simulate them at school. The teaching activity would be useful mainly for teaching physics or perhaps geography to students aged 16-19. Younger students would also enjoy the colourful and dramatic experiments even if they didn't understand exactly what was being simulated.

The topic and the activity could be used as the basis of classroom discussions, because astrophysics is of huge interest to students. It would be an opportunity to link classic physics topics (e.g. electricity and ionisation) to modern physics (e.g. astrophysics and particle physics) or to have an interdisciplinary lesson linked to earth science (e.g. the Solar System).

Suitable comprehension questions include:

- What are aurorae and what do they look like?
- Where are the best regions to observe them, and why?
- What is the solar wind?
- Describe the interaction between the solar wind and Earth's atmosphere.
- What is ionisation of gas?
- What causes the colours of the aurorae?

*Gerd Vogt, Higher Secondary School for Environment and Economics, Yspertal, Austria*

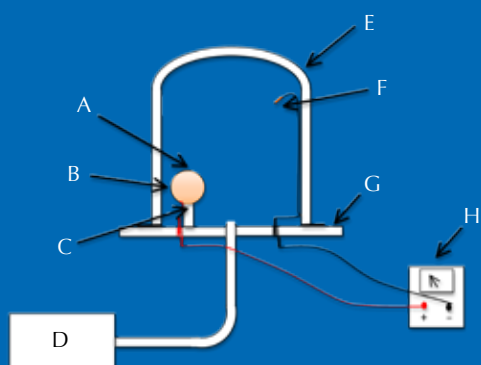
particles collide with the atmosphere at an altitude of 80-500 km, where the air is very thin (with a pressure of less than a few tenths of a pascal).

How does this cause the aurorae? During the collisions, the atoms in the atmosphere become ionised (when one or more electrons are ejected) or excited (when the collision increases the energy level of an electron, but stops short of ejecting it), and therefore unstable. To return to their normal state, they must either undergo chemical reactions or release the energy they have just absorbed as light. When this process emits visible light, we call it an aurora. Seen from space, the northern and southern aurorae each form a ring known as an auroral oval, demarcating the region where the Van Allen belt plunges into Earth's atmosphere (see images above).

Although we are most familiar with the aurorae on Earth, they are not restricted to our own planet: astronomers have observed aurorae on other planets in the Solar System, particularly Jupiter and Saturn, and even Mars, above magnetic anomalies.

### The basic experiment

The Norwegian scientist Kristian Olav Birkeland (1867-1917) was the first to use a small magnetised sphere



**Figure 2:** The experimental setup for activity 1. Inside the vacuum chamber, the sphere lies on an aluminium support. A magnet is placed inside the sphere, forming one electrode, and the second electrode is suspended from the top of the vacuum chamber.

- |                             |                              |
|-----------------------------|------------------------------|
| A: North pole of the magnet | D: Vacuum pump               |
| B: Magnetic sphere (anode)  | E: Vacuum chamber            |
| C: South pole of the magnet | F: Cathode                   |
|                             | G: Vacuum plate              |
|                             | H: High-voltage power supply |

Image courtesy of Philippe Jeanjacquot

known as a terrella ('small Earth') to demonstrate the mechanisms of the aurorae. In a vacuum chamber, a cathode, representing the Sun, produces a stream of electrons (the solar wind, although in reality, electrons are only one component of the solar wind), while the terrella (the anode) is subjected to this wind and behaves like a planet or other body in the Solar System. The setup can be varied, as described below, to demonstrate a range of other physical phenomena.

The equipment can be easily built using materials commonly found in high schools, and takes about 1-10 hours to construct. The general setup is shown in figure 2; details of the materials and construction can be downloaded from the *Science in School* website<sup>w1</sup>.

**Safety note:** care should be taken when working with high voltages. See also the general *Science in School* safety note on page 57.

### Activity 1: Simulating the aurorae and the Van Allen belt

In this experiment, similar to Birkeland's, we simulate the aurorae and the Van Allen belt. The equipment should be set up so that the electrode suspended from the top of the vacuum chamber is the cathode, representing the Sun and generating a stream of electrons (figure 2). The magnetic sphere is the anode, representing Earth, and its magnetic axis should be perpendicular to the stream of electrons.

The electrons ('solar wind') are attracted to and envelop the sphere ('Earth', the anode). As they do this, they collide with gas atoms because the chamber is not a perfect vacuum, and we see this as a glow around the sphere. The electrons then move towards the poles of the sphere and loop under, following the magnetic field lines; we see this as a bright ring surrounding each pole (figure 3).

Earth is not the only planet to experience aurorae. This ultraviolet image of Jupiter was taken with the Hubble Space Telescope Imaging Spectrograph on 26 November 1998.

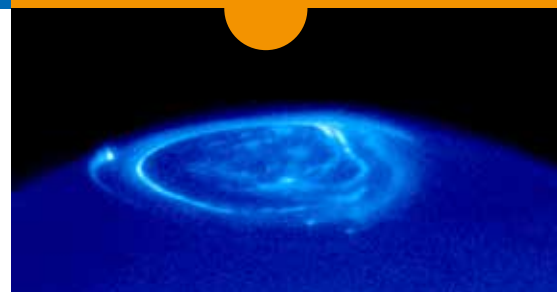


Image courtesy of NASA, ESA and John T. Clarke (University of Michigan)

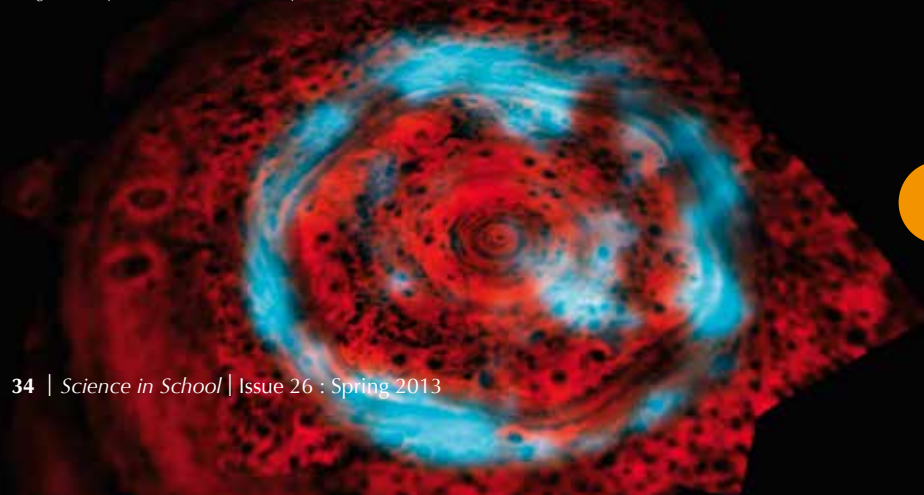
Saturn's aurorae (blue in this image) have been imaged by the Hubble Space Telescope.



Image courtesy of NASA, ESA, J. Clarke (Boston University, USA) and Z. Levay (STScI)

The aurora over the northern polar region of Saturn has a similar ring shape to the aurorae close to Earth's poles. The image was captured from NASA's Cassini spacecraft.

Image courtesy of NASA / JPL / University of Arizona





## Science education project



**Figure 3:** Our simulated auroral oval. See activity 1.

**Figure 4:** A simulation of a stellar ring current: electrons circle the magnetic equator under the influence of the Lorentz force (see activity 2).



Image courtesy of Philippe Jeanjacquot

How does the simulation relate to reality? The generalised glow around the magnetic sphere represents the Van Allen belt, which in reality is only visible at the poles, where it enters Earth's atmosphere. In our simulation, because there are small amounts of gas throughout the chamber, our 'Van Allen belt' visualises the entire magnetic field of 'Earth'.

The bright rings around each pole in our simulation represent the auroral ovals. As in reality, they are caused by large numbers of electrons (remember that the magnetic field lines are closer together at the poles) striking gas atoms.

The colours in the simulation, however, differ from those most commonly seen in the northern and southern

lights. The brightest colours in Earth's aurorae (green and red) are caused by atomic oxygen, which is only present in the upper atmosphere. The colours in our simulation (purple, red, pink and white) are found in aurorae only at lower altitudes, where molecular oxygen and nitrogen are abundant. These colours are only visible a few times per decade when the solar wind enters the atmosphere at particularly high speeds.

### Activity 2: Demonstrating the Lorentz force

In the previous experiment, the sphere was the anode and represented Earth, while the other electrode represented a star (the Sun). In this experiment we swap the two, setting up the sphere as the cathode, to see the effect of the solar wind around a star. When we do this, we see a bright ring around the equator of the 'star' (figure 4).

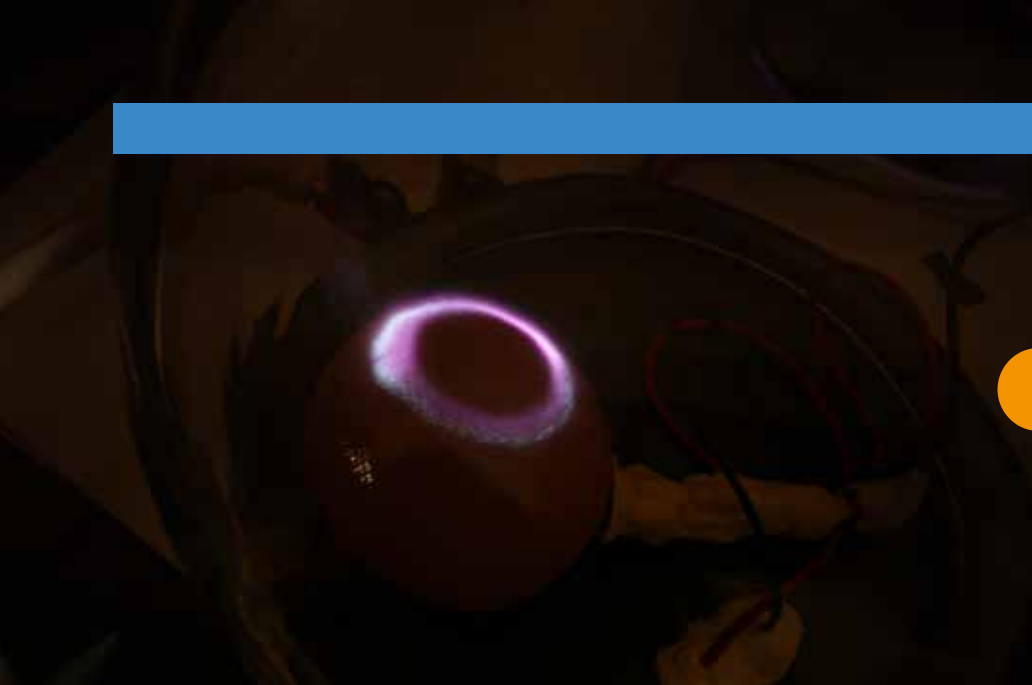
What is happening? The electrons are circling the magnetic equator of the sphere under the influence of the Lorentz force (also known as Laplace force), which is created when a charged particle moves in a magnetic field. The force is perpendicular to both the particle's direction of travel and the magnetic field, and therefore causes the particle to rotate around the magnetic field line. This creates a stellar ring current.

How does our simulation relate to reality? There is no ring current around the Sun because its magnetic field is not strong enough. It is possible, however, that ring currents may exist around other stars with stronger magnetic fields, but they cannot be observed with existing telescope technology because the stars themselves are much brighter than the ring current would be.

### Activity 3: Creating an aurora on the Sun

In this experiment too, we go beyond what has been observed in nature, creating an aurora on the Sun itself. Once again, we set up the sphere as the cathode, this time increasing the strength of the magnetic field using a stronger magnet and a sphere with a thinner wall (we used a Christmas tree bauble). When we do this, we see that the electrons are blown from the 'Sun' but a proportion of this 'solar wind' then falls back onto the Sun along its magnetic field lines, forming a dramatic circle of light at the pole closest to the anode, as seen in figure 5 on page 36.

Does this reflect reality? Based on our understanding of the Sun and the solar wind, scientists predict that an aurora should exist around the Sun, but that we cannot observe it because the Sun is both too bright and too far away.



**Figure 5:** A simulated stellar aurora: as electrons from the simulated solar wind fall back onto the 'Sun' along its magnetic field lines, they form a dramatic circle of light at the pole. See activity 3.

Taken by the Hinode solar observatory, this image shows the structure of the solar magnetic field rising vertically from a sunspot (an area of strong magnetic field), out into the solar atmosphere.

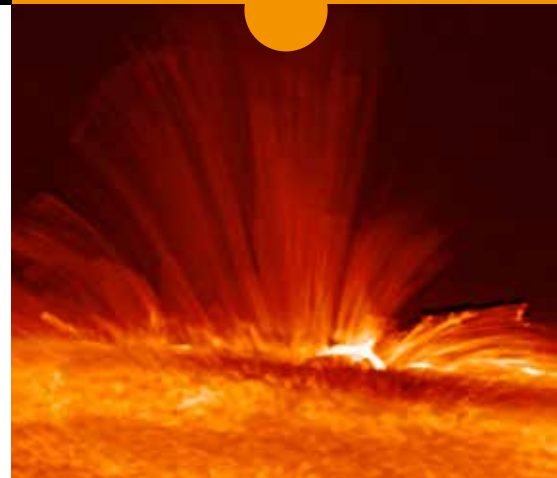


Image courtesy of Hinode JAXA / NASA / PPARC

We can also see bright plumes of light on the auroral ovals (figure 7D, E and F). These plumes also exist in reality, and are known as the polar cusps. In our simulation, they are the result of the magnetic fields of the two spheres being directly linked: the electrons travel along the interconnecting magnetic field lines. In reality, the explanation is a little more complex: the Sun and Earth's magnetic field lines are not directly connected to one another, but are linked through the interplanetary magnetic field, which is embedded in the solar wind.

In reality, unlike in our simulation, the auroral ovals are brighter than the polar cusps. This is because the acceleration of the charged particles that cause the auroral ovals increases as they enter Earth's magnetic field, which increases the particles' energy and velocity, brightening the aurora. In our simulation, the electrons travel at constant speed.

Image courtesy of Philippe Jeanjacquot

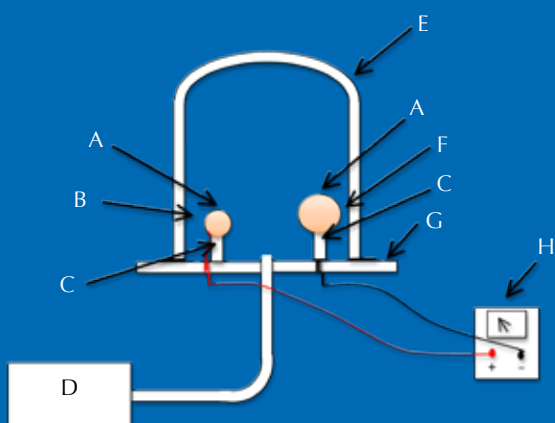
#### Activity 4: Modelling the Sun and Earth simultaneously

So far, our experiments have modelled either the Sun or Earth individually, representing the other with a simple electrode. However it is also possible to represent both bodies with spheres at the same time. In this activity, we dispense with the simple electrode and instead place two magnetic spheres in the vacuum chamber (figure 6), to demonstrate several phenomena related to the interaction between the Sun and Earth. For the Sun, we use the sphere from activity 3 (e.g. a Christmas tree bauble with a magnet inside it) as the cathode, and to represent Earth, a smaller spherical magnet as the anode. We see a glow all around the 'Sun' (figure 7A), similar to the generalised glow around 'Earth' in activity 1. This time, how-

ever, the glow represents the Sun's corona. The solar corona is the expansion of the solar wind leaving the star, and is only visible from Earth during solar eclipses; the rest of the time it is outshone by the Sun's surface. In reality, the formation of the solar corona depends not only on the solar wind but also on the temperature and the magnetic configuration of the Sun, so our 'corona' is more an analogy than a simulation.

The simulated solar wind travels from the Sun (figure 7A) through interplanetary space to Earth (B). There, as in activity 1, it causes a glowing envelope around the planet (the Van Allen belt), as well as bright rings around the poles (the auroral ovals). In figure 7, the northern auroral oval (C) is clearly visible and the southern one is hidden by part of our apparatus.

**Figure 6:** In activity 4, we place two magnetic spheres in the vacuum chamber, to demonstrate interactions between the Sun and Earth.



- A: North pole of the magnet
- B: Magnetic sphere (anode)
- C: South pole of the magnet
- D: Vacuum pump
- E: Vacuum chamber
- F: Cathode
- G: Vacuum plate
- H: High-voltage power supply

Image courtesy of Philippe Jeanjacquot





**Figure 7:** In activity 4, the larger sphere (A) represents the Sun, the smaller one (B) represents Earth. As well as the northern auroral oval (C), Earth's polar cusps (D, E, F) can clearly be seen.

The solar corona, as seen during the total eclipse of the Sun on 7 March 1970. The corona is visible to the naked eye only during an eclipse.



Image courtesy of Philippe Jeanjacquot

Jean Lilensten is a researcher at the Institut de Planétologie et d'Astrophysique de Grenoble, France, and winner of the 2010 Europlanet prize for excellence in public engagement with planetary science.

### Web reference

w1 – Detailed instructions for building the terrella can be downloaded from the *Science in School* website. See: [www.scienceinschool.org/2013/issue26/aurorae#resources](http://www.scienceinschool.org/2013/issue26/aurorae#resources)

### Resources

A more complex experiment, called the planetterella, allows still more processes to be simulated. The Planetterella website has detailed information (in English and French) on how to build and use this experiment. See: <http://planetterella.obs.ujf-grenoble.fr>

Lilensten J et al. (2008) La Planetterella, une expérience pédagogique en planétologie et physique des plasmas. *Bulletin de l'union des professeurs de sciences physiques, chimiques et appliquées*. **102**: 799-816

Lilensten J et al. (2009) The planetterella, a pedagogic experiment in planetology and plasma physics. *Acta Geophysica*, vol. **57(1)**: 220-235. doi: 10.2478/s11600-008-0079-x

Lilensten J et al. (submitted) The planetterella experiment: from individual initiative to networking. *Journal of Space Weather and Space Climate*

Messerotti M et al. (2009) A terrella device for simulating aurora-like phenomena in a box. *Earth, Moon, and Planets* **104(1-4)**: 55-58. doi: 10.1007/s11038-008-9262-y

On the NASA website, watch or download a spectacular video of an unusual aurora crossing the southern Indian Ocean, filmed from the International Space Station. See [www.nasa.gov](http://www.nasa.gov) (search for 'aurora from ISS orbit') or use the direct link: <http://tinyurl.com/3kzm6ou>

Download and print NASA's wonderfully illustrated International Space Station calendar for 2013. For pictures of the aurorae, see the June or November pages. See [www.nasa.gov](http://www.nasa.gov) or use the direct link: <http://tinyurl.com/a7tvr56>

If you found this article interesting, you might also like the following articles from *Science in School*:

Green L (2008) Research into the Sun's atmosphere. *Science in School* **8**: 52-55. [www.scienceinschool.org/2008/issue8/solarresearch](http://www.scienceinschool.org/2008/issue8/solarresearch)

Tranfield E (2011) Building a space habitat in the classroom. *Science in School* **19**: 43-49. [www.scienceinschool.org/2011/issue19/habitat](http://www.scienceinschool.org/2011/issue19/habitat)

*Science in School* has many more articles about space and astronomy. See [www.scienceinschool.org/space](http://www.scienceinschool.org/space) and [www.scienceinschool.org/astronomy](http://www.scienceinschool.org/astronomy)



To learn how to use this code, see page 57.



Philippe Jeanjacquot is a physics teacher at the Lycée Charlie Chaplin in Decines, near Lyon, France. He is also a senior research associate with the outreach department (Team ACCES) at the Ecole Normale supérieure de Lyon and the Institut Français de l'Éducation.

[www.scienceinschool.org](http://www.scienceinschool.org)

# Spinal cord injury: do stem cells have the answer?

Spinal cord injury typically causes permanent paralysis and is currently a condition without a cure. Could stem cell therapy provide hope?

By Andrew Brown

American actor and activist Christopher Reeve will be remembered for his leading role in the 1978 blockbuster movie *Superman*. Sadly, he will also be remembered as a man whose tremendously active life, both on and off screen, was shattered by a catastrophic injury that left him paralysed from the neck downwards – a state in which he remained until he died in 2004.

In May 1995, during an equestrian competition, Reeve was thrown headfirst off his horse. The weight of his body was thrust through his spine, breaking two of the vertebrae in his neck and causing extensive damage to his spinal cord<sup>w1</sup>.

What happened during his accident – at the level of blood, bones, cells and molecules – to cause his life-long paralysis? And how might research into new treatments based on stem cells offer hope for people paralysed by spinal cord injury? Could it help them to regain some control over their bodies and their lives?

## What is spinal cord injury?

Your spinal cord is an information highway connecting your brain to the rest of your body (figure 1). Injuries to

it are usually caused by sudden trauma, such as that sustained in sports or car accidents, and result in dislocation and / or breakage of vertebrae, which rip into the spinal cord tissue, damag-

ing or severing axons. Sensation and motor control are lost below the level of the injury (figure 2).

Multiple cell types die at or near the site of the spinal cord injury, due to

Image courtesy of Mike Lin / Wikimedia Commons

Christopher Reeve discusses potential benefits of stem cell research at a neuroscience conference at the Massachusetts Institute of Technology, USA, in 2003.

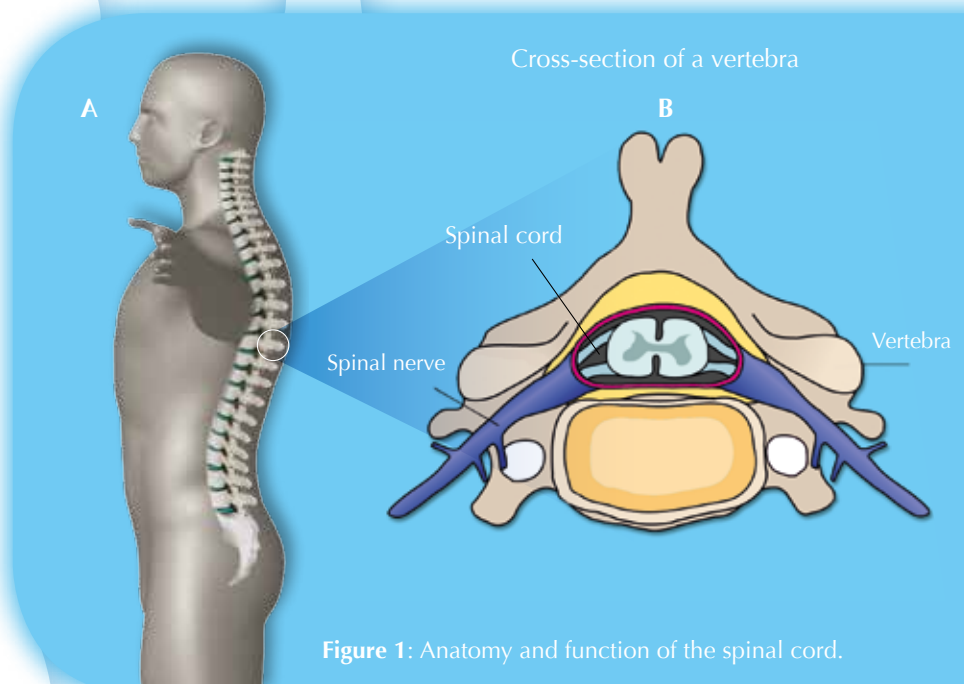
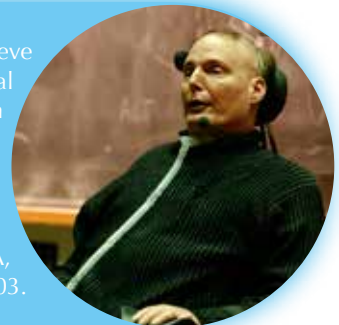


Figure 1: Anatomy and function of the spinal cord.





- ✓ Biology
- ✓ Physics
- ✓ Chemistry
- ✓ Medicine
- ✓ Nervous system
- ✓ Stem cells
- ✓ Cell proliferation and differentiation
- ✓ Immune system
- ✓ Biochemistry
- ✓ Ages 11+

This article focuses on the diverse consequences of spinal cord injury in humans, presenting cutting-edge science and considering potential future treatments based on stem cells.

Younger students (aged 11-14) could be motivated by the case of *Superman* actor Christopher Reeve to study the nervous system (e.g. the arc reflex). However, simplification of the text would be necessary.

The article would be particularly appropriate for upper secondary-school students (15-18 years old) due to the level of detail provided. It could be linked to topics including anatomy and physiology of the nervous system, physiology of the immune system, cell proliferation and cell differentiation. The list of suggested resources complements the article well.

The article could also be used as a starting point for interdisciplinary research projects linked to physics and chemistry. Topics for such projects could be: why do injured cells release free radicals, and why are they

harmful to cells? What molecules do free radicals react with primarily? Why does an oedema reduce the efficiency with which nutrients and molecules are exchanged between the blood and spinal cord cells? Which type of molecules might promote spinal cord repair?

The article could be used as the basis of comprehension and extension tasks including:

1. Distinguish pluripotent stem cells from non-neural adult stem cells and neural stem cells (from either adults or embryos), considering their potential to generate specialised neural cells. Relate this to the mechanism of gene regulation.
2. "Pluripotent stem cells can be either extracted from embryos (embryonic stem cells) or generated in the lab (induced pluripotent stem cells) from specialised cells, such as skin cells." "Transplantation of pluripotent stem cells into animals has led to severe side effects, such as tumour formation". Relate these sentences to the process of cell differentiation and genetic regulation.
3. "Transplanting stem cells is risky: it requires a delicate surgical procedure, and (in the case of embryonic stem cells and neural stem cells) the immune system may reject the newly introduced cells." Explain the biological mechanism that is responsible for this risk.

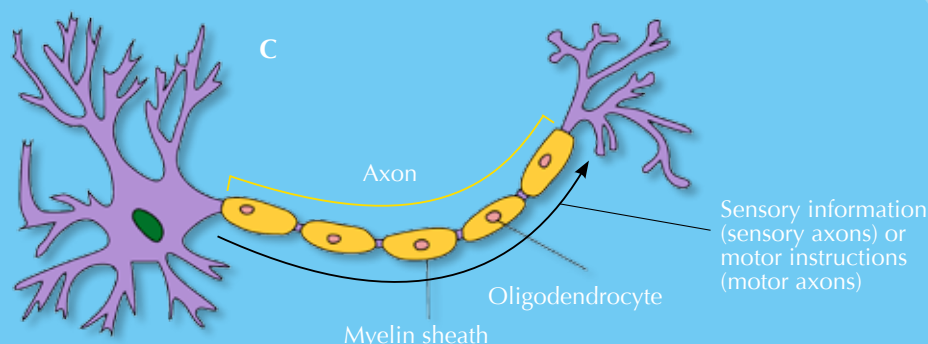
Betina da Silva Lopes, Portugal

## REVIEW

Images courtesy of Debiort / Wikimedia Commons (vertebra); Faigl.ladislav / Wikimedia Commons (neuron); Barnabé-Heider & Frisé (2008), with permission from Elsevier (grey man)

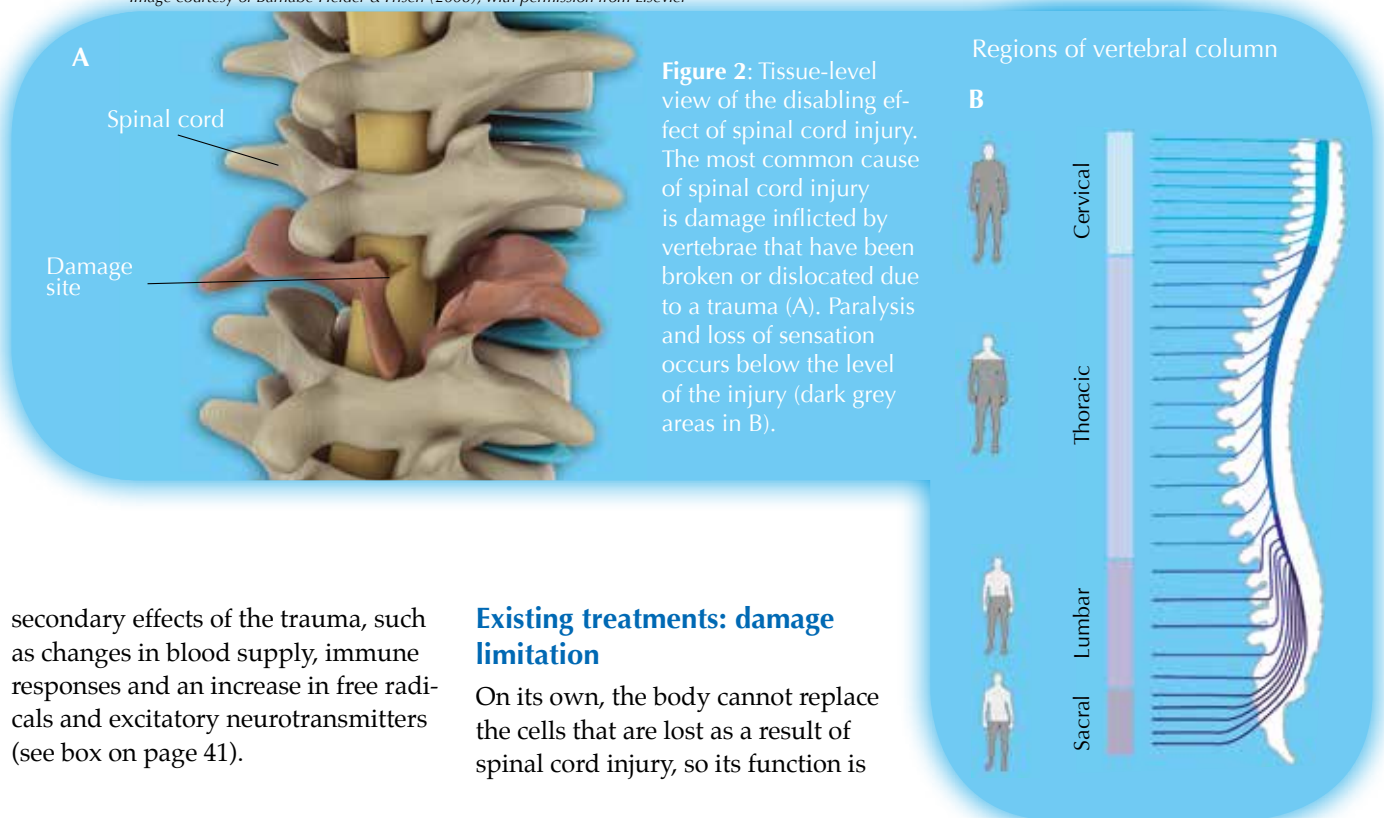
The spinal cord is a soft, jelly-like structure that extends from the base of the brain to the lower back (A). It is 38 to 43 cm long and, at its maximum width, is about as wide as a thumb. It sits in a hollow channel that runs through the spinal column's 33 stacked vertebrae (B).

Spinal nerves (part of the *peripheral nervous system*) are connected to the cord at various intervals along its length and run to and from specific regions of the body. Together, the spinal cord and the brain make up the *central nervous system*.



The spinal cord consists of *sensory* and *motor neurons* (C). Sensory axons carry sensory information to the brain from the rest of the body, whereas motor axons carry motor instructions (both voluntary and involuntary) in the opposite direction. The cord's neurons are supported by various glial cells, such as oligodendrocytes – which wrap myelin around axons, insulating them and enabling the quick and effective transmission of axon potentials – and astrocytes – which have multiple functions, such as providing nutrients and releasing growth factors for the benefit of other neural cells.

Image courtesy of Barnabé-Heider & Frisé (2008), with permission from Elsevier



secondary effects of the trauma, such as changes in blood supply, immune responses and an increase in free radicals and excitatory neurotransmitters (see box on page 41).

### Existing treatments: damage limitation

On its own, the body cannot replace the cells that are lost as a result of spinal cord injury, so its function is

permanently impaired. Current short-term treatments consist merely of damage limitation: surgery to relieve the pressure on the spinal cord and to stabilise the spinal column, and immobilisation (by bracing) to prevent further damage. In the long term, patients are given physiotherapy and treatment to relieve injury-related symptoms, such as pain, as well as counselling to help them cope with their new disability (figure 3). There is currently no cure for spinal cord injury, which causes such immense physical and emotional suffering. Several groups of scientists, however, are investigating the potential of stem cells to provide a cure.

### Stem cell therapies

Stem cells are cells that can both *differentiate* into specialised cell types and *self-renew* to produce more stem cells. Broadly, there are two types: pluripotent stem cells, which can differentiate into any of the body's cells,

**Figure 3:** Potential symptoms of spinal cord injury

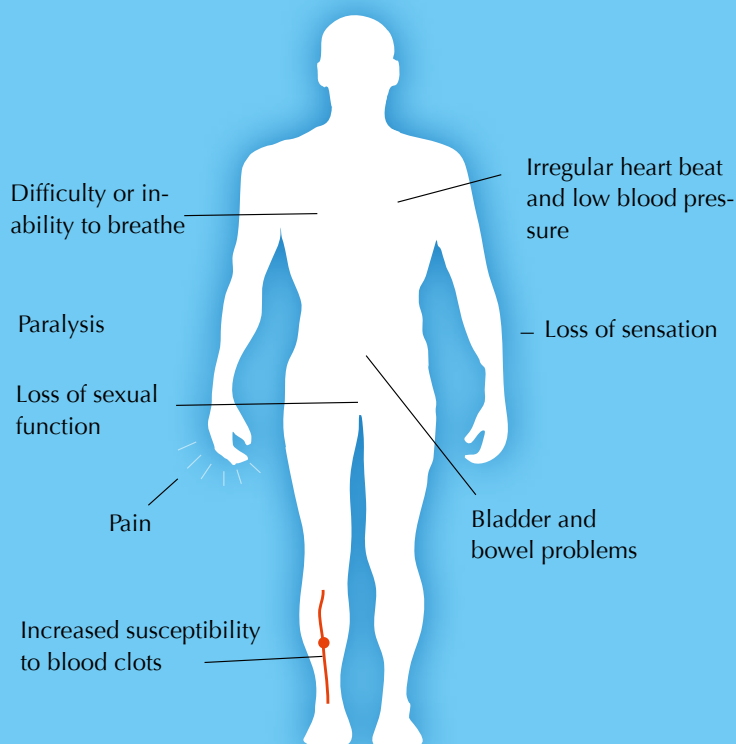


Image courtesy of Nicola Graf





## Secondary effects of spinal cord injury

Secondary effects that take place during spinal cord injury lead to death of multiple cell types, including neurons and oligodendrocytes.

These secondary effects include:

1. Ischemia: lack of proper blood supply (due to rupture of blood vessels). This reduces the supply of oxygen and nutrients to cells.
2. Oedema: an accumulation of tissue fluid. This causes swelling and reduces the efficiency with which nutrients and molecules are exchanged between the blood and spinal cord cells.
3. Immune invasion: injury triggers an inflammatory response that leads to an influx of immune cells (neutrophils, T-cells, macrophages and monocytes) to the spinal cord at and around the injury site. This response may be both protective (e.g. through the release of molecules that promote spinal cord repair, and the scavenging of damaged tissue) and detrimental (e.g. through inflammation that affects healthy tissue).
4. Neurotransmitter release: damaged neurons release an excess of the excitatory neurotransmitter glutamate, which overexcites neural cells, killing them or stopping them from functioning.
5. Free-radical release: cell damage and the inflammatory response increase the levels of free radicals, which further damage neural cells by reacting with molecules crucial for proper cellular function.

### BACKGROUND

and adult stem cells, which can differentiate into only certain cell types. Pluripotent stem cells can be either extracted from embryos (embryonic stem cells) or generated in the lab (induced pluripotent stem cells) from specialised cells, such as skin cells<sup>w2</sup>. Adult stem cells are found in various tissues, such as bone marrow.

There are two potential approaches to the use of stem cells in spinal cord injury:

1. Transplantation of stem cells to the injury site.
2. Recruitment of the injured spinal cord's resident neural stem cells.

In both approaches, the intention is for stem cells either to replace lost or damaged spinal cord cells, or to promote recovery indirectly. This indirect benefit may come from the stem cells themselves, or from the cells into which they differentiate.

### 1) Transplanting stem cells

Studies of spinal cord injury performed on animal models (mainly rodents) have shown that transplantation therapy can help recovery, although it is often difficult to know which mechanisms are responsible.

In these studies, three types of stem cell have been used: pluripotent stem cells, non-neural adult stem cells and neural stem cells (from either adults or embryos).

#### Pluripotent stem cells

Transplantation of pluripotent stem cells into animals has led to severe side effects, such as tumour formation. Before they are used to effectively treat spinal cord injury, therefore, these cells are treated to make them differentiate into *neural progenitor cells* – cells that have the potential to differentiate into particular types of specialised neural cells. One study showed that seven days after transplantation of oligodendrocyte progenitor cells into rats with spinal cord injury, axons were remyelinated and the rats were better able to move their legs (Keirstead et al., 2005).

#### Non-neural adult stem cells

Non-neural adult stem cells are extracted from various tissues, such as bone marrow, adipose tissue and the placenta. It is thought that these stem cells help repair the injured spinal cord indirectly. Many studies show

that animals are able to better move and feel after transplantation of these cells (Parr et al., 2007).

#### Neural stem cells

Neural stem cells are extracted from certain parts of the nervous systems of embryos or adults. Many studies have shown that the transplanted cells differentiate into astrocytes that help new neural cells to grow (Enzmann et al., 2006; Pfeifer et al., 2006). Research published last year suggests that neural stem cells can re-programme the local inflammatory response to injury, reducing the proportion of harmful immune cells (such as macrophages), while promoting healing of the injured spinal cord (Cusimano et al., 2012). In most studies that have looked at recovery after neural stem cell transplantation, the animals were better able to move their legs.

### 2) Recruiting resident stem cells

Transplanting stem cells is risky: it requires a delicate surgical procedure, and (in the case of embryonic stem cells and neural stem cells) the immune system may reject the newly introduced cells. These risks could po-

tentially be avoided using an alternative approach in which drugs instruct the injured spinal cord's *resident* neural stem cells to promote recovery (Barnabé-Heider & Frisé, 2008).

Even if these risks can be overcome, research into this potential treatment, known as stem cell recruitment therapy, is still at an early stage and it remains to be seen whether it can aid recovery from spinal cord injury in animals.

### Small changes can make a big difference

Understanding the mechanisms involved, testing the effectiveness in animals, running clinical trials in humans – the development of a treatment is a slow and complicated process. For now at least, transplantation therapy holds the greatest promise for the treatment of spinal cord injury with stem cells. In 2010, the Californian company Geron started a clinical trial based on this approach, although it was halted at an early stage for financial reasons<sup>w3</sup>. Currently, Balgrist University Hospital in Zurich, Switzerland, is running a trial using cells derived from human brain tissue. The hope is that when transplanted into the injured spinal cord, these cells may re-establish some of the circuitry important for the network of nerves that carry information around the body<sup>w4</sup>.

Given the multifaceted nature of spinal cord injury, it is unlikely that any one treatment will provide a cure, but even small improvements would make a big difference to patients' lives. Imagine if, like Christopher Reeve, you were paralysed from the neck downwards: being able to move your arms and grip with your hands could make the difference between living a dependent or independent life.

### Acknowledgements

This article was based on a fact sheet created for the Eurostemcell

website<sup>w5</sup>, and on the review paper Barnabé-Heider & Frisé (2008).

The author would like to thank Kate Doherty from Eurostemcell for her help in planning and writing the article. Thanks also go to Dr Stefano Pluchino of the Department of Clinical Neurosciences, University of Cambridge, UK, for his expert advice.

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- Pfeifer K et al. (2006). Autologous adult rodent neural progenitor cell transplantation represents a feasible strategy to promote structural repair in the chronically injured spinal cord. *Regenerative Medicine* **1**: 255-266. doi: 10.2217/17460751.1.2.255

### Web references

- w1 – The Christopher and Dana Reeve Foundation is dedicated to curing spinal cord injury by funding

research, and improving the quality of life of those with paralysis. See: [www.christopherreeve.org](http://www.christopherreeve.org).

The website includes videos of people with paralysis talking about their lives. Use the direct link <http://tinyurl.com/parastory>

w2 – In 2012, the Nobel Prize in Physiology or Medicine was awarded to John Gurdon and Shinya Yamanaka for their discovery that mature cells can be re-programmed to become pluripotent. See: [http://www.nobelprize.org/nobel\\_prizes/medicine/laureates/2012](http://www.nobelprize.org/nobel_prizes/medicine/laureates/2012)

Read more about embryonic and induced pluripotent stem cells on Nature Education's Scitable website. See: [www.nature.com/scitable](http://www.nature.com/scitable) or use the direct link <http://tinyurl.com/ipsccell>

In the online video 'Stem cells – the future: an introduction to iPS cells', leading scientists tell the story of induced pluripotent stem cells. See the Eurostemcell website ([www.eurostemcell.org](http://www.eurostemcell.org)) or use the direct link: <http://ow.ly/fGrTE>

w3 – Read about the Geron clinical trial in the *New York Times*. See [www.nytimes.com](http://www.nytimes.com) or use the direct link <http://tinyurl.com/gerontrial>

w4 – Read more about the clinical trial at Balgrist University Hospital on the Clinical Trials website ([www.clinicaltrials.gov](http://www.clinicaltrials.gov)) or use the direct link: <http://tinyurl.com/acz5hun>

w5 – Download the fact sheet *Spinal cord injuries: how could stem cells help?* from the Eurostemcell website ([www.eurostemcell.org](http://www.eurostemcell.org)) or use the direct link: <http://tinyurl.com/aqkj6s6>

Eurostemcell's stem cell toolkit ([www.eurostemcell.org/stem-cell-toolkit](http://www.eurostemcell.org/stem-cell-toolkit)) is a set of downloadable, Creative Commons-licensed resources and activities suitable for a variety of educational settings. For example:

The *Embryonic stem cell research: an*



*ethical dilemma* fact sheet. See [www.eurostemcell.org](http://www.eurostemcell.org) or use the direct link <http://tinyurl.com/stemethic>

*Hope Beyond Hype* is a story about stem cell therapies, from discovery to therapy, in the form of an interactive comic book. See: [www.eurostemcell.org/hopebeyondhype](http://www.eurostemcell.org/hopebeyondhype)

*Ready or not?* is a role play about spinal cord injuries, designed for classroom use. See [www.eurostemcell.org](http://www.eurostemcell.org) or use the direct link: <http://tinyurl.com/b7jrs78>

## Resources

For a review of one of Eurostemcell's DVDs for schools, see:

Gebhardt P (2006) Review of *A Stem Cell Story*. *Science in School* 3: 88. [www.scienceinschool.org/2006/issue3/stemcell](http://www.scienceinschool.org/2006/issue3/stemcell)

*Spinal cord injury: progress and promise in stem cell research* is a short video featuring spinal cord injury patient advocate (and former footballer) Roman Reed. See: <http://youtu.be/zGcjlZzMq3Q>

The website of the National Institute of Neurological Disorders and Stroke has detailed information on spinal cord injury. See: [www.ninds.nih.gov/disorders/sci/detail\\_sci.htm](http://www.ninds.nih.gov/disorders/sci/detail_sci.htm)

The International Campaign for Cures of Spinal Cord Injury Paralysis has statistics and other information on spinal cord injuries. See: [www.campaignforcure.org/iccp](http://www.campaignforcure.org/iccp)

If you found this article interesting, you might like to browse the full collection of articles on medical

topics published in *Science in School*. See: [www.scienceinschool.org/medicine](http://www.scienceinschool.org/medicine)

Andrew Brown is a molecular and cellular biology graduate of the University of Bath, UK. After working for *Science in School*, he joined the communications and publications team of the British Society for Immunology.



To learn how to use this code, see page 57.



# A thermometer that goes to 200 million degrees

Measuring the temperature inside a fusion reactor is no easy task. Find out how it's done – and even simulate it in the classroom.

By Phil Dooley, EFDA-JET

The Joint European Torus (JET) is the world's largest fusion energy experiment, pioneering methods for producing plentiful, clean power with the same method used by the Sun: fusing light atoms such as hydrogen together to form the heavier atom helium. In fact JET, in the UK – and its larger successor ITER, being built in the south of France – aims to operate thousands of times more effi-

ciently than the Sun, even though this requires creating temperatures in the heart of the fusion vessel that are ten times hotter than the core of the Sun.

Amazingly enough, scientists and engineers have devised ways of heating hydrogen fuels to these temperatures, and then preventing them from melting the vessel by controlling them with very strong magnetic fields (as described in R  th, 2012). Fundamental to these experiments are methods not only for monitoring the reactions (see Dooley, 2012) but also for measur-

ing the temperature profile of the fuel, from its scorching core to the cooler edges, so that researchers can create the optimum environment for fusion to occur.

At these temperatures the hydrogen fuel becomes the fourth state of matter, plasma. Measuring the temperature of a plasma that is ten times hotter than the Sun presents some challenges – you can't simply insert a conventional thermometer: it would be melted in microseconds. Things are further complicated because plasma is

The temperatures in a fusion vessel are ten times higher than at the core of the Sun.



**Figure 1:** A stripped-back model of the JET experiment, showing only the temperature-measuring systems. Electron cyclotron emission (pale purple), LIDAR / Thomson scattering (red), charge exchange (bright green), and X-ray spectroscopy (pale green).

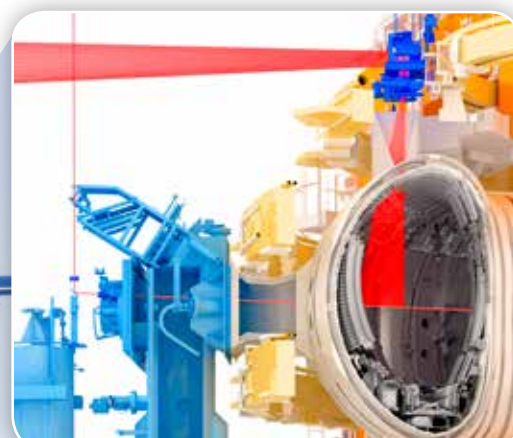


Image courtesy of EFDA

The path of the LIDAR signal through the plasma: the laser enters horizontally from left. A detector at the top of the vessel picks up light from this laser, which is scattered by electrons.

Image courtesy of EFDA



## REVIEW

- ✓ Physics
- ✓ Chemistry
- ✓ Optics
- ✓ Electromagnetism
- ✓ Energy
- ✓ Mechanics
- ✓ Atomic structure
- ✓ Ages 17+

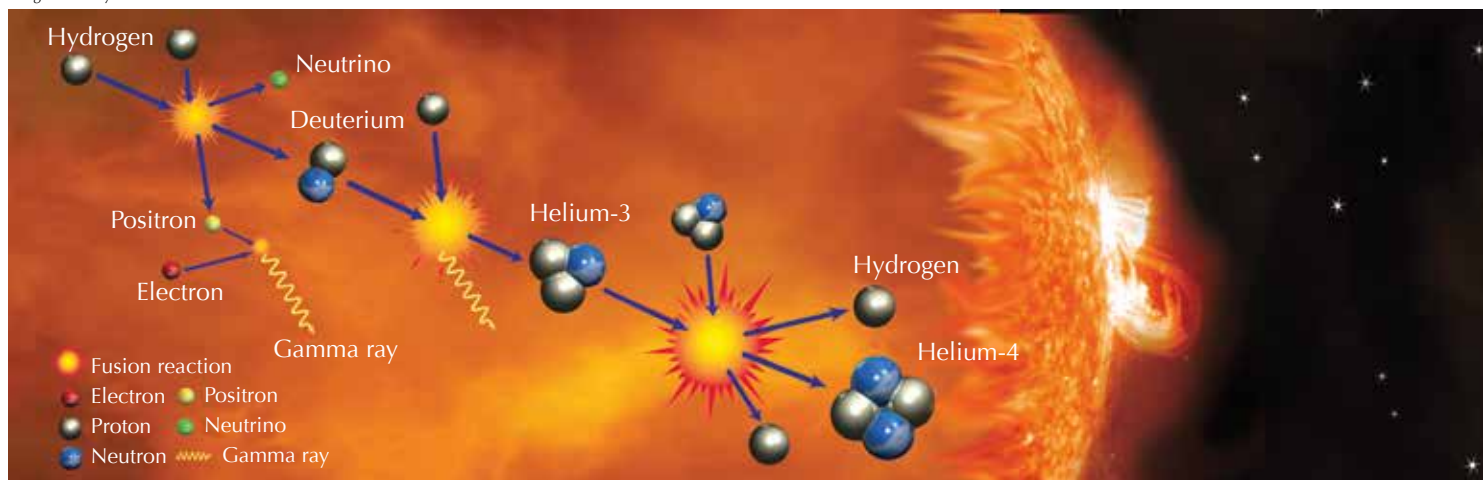
This article describes four methods that are used by the world's largest fusion energy experiment to deduce the temperature inside the fusion vessel. Due to the high temperatures involved, any thermometer would melt instantly.

The four methods involve concepts from several areas of physics and chemistry, including optics, electromagnetism, mechanics, energy and atomic structure. In addition, a classroom activity based on the demonstration of the Doppler effect is presented, which partially explains some of the four methods.

The *Science in School* series of fusion articles, of which this is one (see the resources list), has great interdisciplinary potential for upper secondary-school students, as the articles could be used to discuss fusion energy: as a source of future sustainable energy, how it works, and its advantages and disadvantages.

*Mariana Martinho, Portugal*

Image courtesy of Mark Tiele Westra



made up of two very different charged particles: electrons that have been stripped from atoms, and the heavier positive ions formed by the removal of the electrons. The key to fusion is to create hot ions that will fuse, but electrons can respond to the heating systems differently to ions – and can end up at a different temperature! The

complex interactions between electrons and ions can affect the success of a fusion experiment significantly.

Despite these challenges, plasma physicists have developed multiple methods for deducing the temperature (figure 1 on page 45) – cross-checking the results of different methods increases the reliability of

your measurements – so that they can be confident that they are in control of what goes on inside one of the hottest places in the Solar System.

### Electron temperature

#### Loop-the-loop: electron cyclotron emission

The first ‘thermometer’ relies on the effect that magnetic fields have on charged particles. Because they are charged, electrons are forced to spiral along the magnetic field lines, which creates microwaves called cyclotron emission (figure 2). The hotter – and therefore faster-moving – the electrons are, the more intense are the microwaves that they emit.

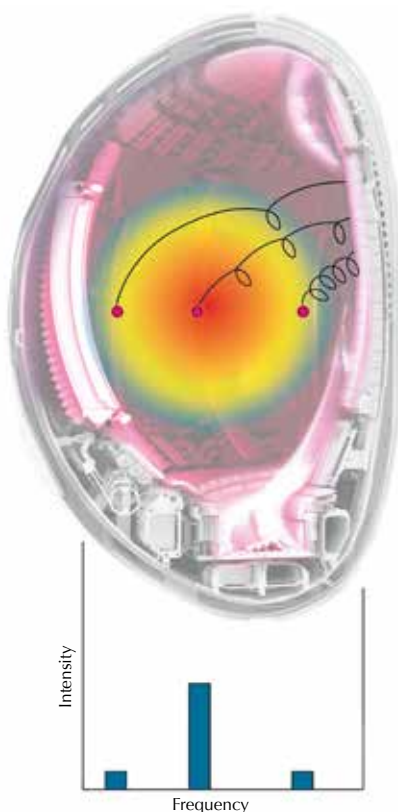
The microwaves also yield a profile of the electron temperature, due to the varied magnetic field in the vessel: the stronger the field, the higher the spiralling frequency. A scan of intensity against frequency tells us the temperature for each magnetic field strength. Combining this with a spatial map of the magnetic field strength, created by other systems, gives us a profile of the electron temperature.

#### Speed trap! LIDAR

JET’s second ‘thermometer’ uses a system similar to a police speed camera to measure the speed of particles, except that it uses laser light (LIDAR) instead of radio waves. Light from the

Image courtesy of EFDA

**Figure 2:** The magnetic field in the torus makes the electrons follow helical paths, emitting radiation at the frequency of their oscillation. The stronger the magnetic field (i.e. towards the pole of the torus – the hole in the doughnut), the tighter the helix, which results in a tighter spiral and therefore a higher frequency emission. The intensity of the radiation is determined by the speed at which the electrons are travelling – that is, their temperature. The hotter the plasma, the stronger the signal. The magnetic field strength is already known from other measurements not discussed here, and so the distribution of the plasma temperature can be calculated by correlating frequency against intensity.







Energy production in the Sun: two hydrogen nuclei fuse to form a deuterium nucleus, a positron and a neutrino. The positron quickly encounters an electron, they annihilate each other, and only energy remains. The deuterium nucleus goes on to fuse with another hydrogen nucleus to form helium-3. In the final step, two helium-3 nuclei fuse to form helium-4 and two hydrogen nuclei.

different angles through the plasma. This is similar to the creation of 2D computed tomography images from multiple individual X-rays.

### Ion temperature

Unfortunately LIDAR is not an effective way of measuring ions. This is because the process of Thomson scattering relies on the induced oscillations of a charged particle. The heavier ions oscillate less – they are not tossed about by the laser light waves as much as the lighter electrons.

The greater mass of the ions also means that their cyclotron frequency is too low to be useful – the waves are too long to give a precise measurement and they happen to coincide with the plasma's natural absorption frequency so they do not escape the plasma cleanly.

In addition, the hydrogen ions in a plasma effectively become invisible, because all their electrons are stripped off, disabling the common mechanism of radiation creation – electrons jumping between orbits.

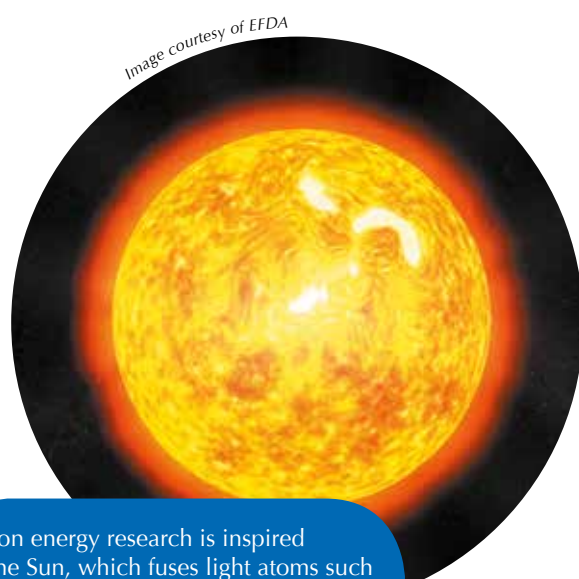
However, a route to working out the temperature has been found via impu-

laser is scattered by the electrons in a process known as Thomson scattering; if the electrons are moving, then the scattered light will be Doppler shifted (figure 3). We are more familiar with Doppler shifts of sound: the sound from passing cars has a slightly higher pitch as they move towards us than when moving away. Similarly, if light is scattered by moving electrons, its frequency (colour) will be Doppler shifted to higher frequencies for the electrons moving towards the detector and to lower frequencies for those

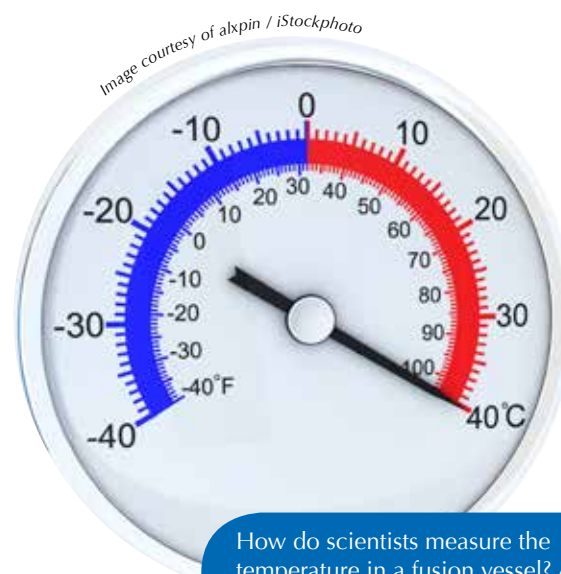
moving away. The faster the electron moves, the bigger the frequency shift.

The cumulative effect of the many electrons in the plasma – some moving towards and others away from the detector – is that the original narrow frequency band of the laser light is broadened (see inset in figure 1). The extent of broadening tells us the speed of the electrons, and hence their temperature.

A two-dimensional profile of the temperature is created by combining data from a number of beams fired at

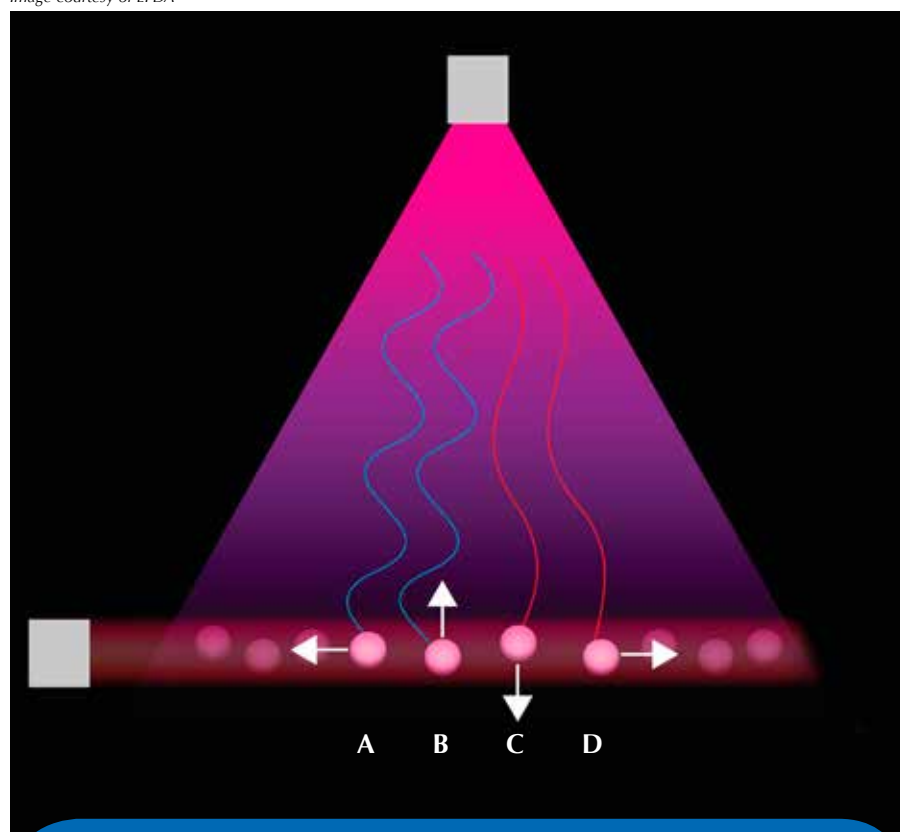


Fusion energy research is inspired by the Sun, which fuses light atoms such as hydrogen into heavier atoms, releasing energy in the process.



How do scientists measure the temperature in a fusion vessel? A conventional thermometer would melt in microseconds.

Image courtesy of EFDA



**Figure 3:** The Doppler effect in Thomson scattering. The laser light, entering from the left, is absorbed and then re-emitted by electrons, and a detector above the beam picks up the fraction of light emitted upwards. The motion of the electrons relative to both the laser beam and the detector causes the scattered light to be Doppler shifted from the original laser frequency either to higher or to lower frequencies, depending on the direction of motion.

Electron A is moving towards the laser and therefore absorbs blue-shifted radiation, while electron D is moving the opposite way, and absorbs red-shifted light, which is then scattered at the absorbed wavelength. Electrons B and C are not moving relative to the laser, so the light they absorb is at the original frequency. However, because of their motion towards and away from the detector, respectively, the re-emitted light is Doppler shifted to the blue or to the red, as shown.

urities in the plasma; while undesirable in large quantities, traces of impurities can be useful for this purpose.

### Partner swapping: charge exchange

One of the most common contaminants in plasma is carbon, which was JET's wall lining until 2010. Although the carbon tiles have been replaced with beryllium and tungsten, there are still traces of carbon in the plasma. Usually the carbon is invisible, like the hydrogen, but it can be made visible

in a process called charge exchange. This involves shooting a beam of neutral hydrogen atoms into the plasma at high speed. When these atoms encounter a carbon ion, sometimes an electron jumps from a hydrogen atom across to the carbon, which then emits a nice sharp spectrum that is easy to measure. Because of the high temperature, the carbon atoms are moving very fast in all directions, so the sharp frequencies of the spectrum are then spread out in the same way as the scattered LIDAR signal is (figure 3).

### X-Ray eyes: tungsten impurities

A second method for measuring the temperature of the ions – again based on impurities – has recently been commissioned at JET: a new X-ray detector. Tungsten inevitably gets knocked off the new tiles in the wall and contaminates the plasma in small amounts. Unlike the light atoms, hot tungsten typically retains about half of its 74 electrons even in the extreme heat of the core of the plasma, and so does not become invisible – these electrons jump between electron shells and emit X-rays. Doppler broadening of this X-ray spectrum caused by the movement of the ions allows the temperature to be calculated (as in figure 3).

The temperature profiles from these four systems are essential for analysing the effectiveness of the heating systems in use at JET – some of which heat electrons, while others work on the ions. The measurements also give vital information about how energy in the plasma behaves in different circumstances, including how the electrons and ions interact with each other. Using this knowledge, JET's scientists and engineers can manipulate the plasma to maximise the energy confinement, thereby creating and maintaining optimal conditions for fusion.

### References

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- Rüth C (2012) Harnessing the power of the Sun: fusion reactors. *Science in School* **22**: 42-48. [www.scienceinschool.org/2012/issue22/fusion](http://www.scienceinschool.org/2012/issue22/fusion)

### Web references

- w1 – Learn more about EFDA-JET. See: [www.efda.org/jet](http://www.efda.org/jet)



w2 – EIROforum is a collaboration between eight of Europe's largest inter-governmental scientific research organisations, which combine their resources, facilities and expertise to support European science in reaching its full potential. As part of its education and outreach activities, EIROforum publishes *Science in School*. To learn more, see: [www.eiroforum.org](http://www.eiroforum.org)

### Resources

Warrick C (2006) Fusion – ace in the energy pack? *Science in School* 1: 52-55. [www.scienceinschool.org/2006/issue1/fusion](http://www.scienceinschool.org/2006/issue1/fusion).

This article is part of a series of articles about fusion published in *Science in School*. [www.scienceinschool.org/fusion](http://www.scienceinschool.org/fusion)

For an introduction to the electromagnetic spectrum – and how it is used in astronomy – see:

Mignone C, Barnes R (2011) More than meets the eye: the electromagnetic spectrum. *Science in School* 20: 51-59. [www.scienceinschool.org/2011/issue20/em](http://www.scienceinschool.org/2011/issue20/em)



### CLASSROOM ACTIVITY

## Demonstrating the Doppler effect

To create your own Doppler shift, you will need a small battery-powered sound source that can emit a long tone or set of tones of a constant pitch. A small alarm clock or a mobile phone with a single-tone ring or alert will do nicely. Then you need a long sock or stocking – the longer the better – and lastly, plenty of space!

Standing in the middle of your space, start the alarm clock ringing, then drop it into the stocking and swing it around your head as fast as possible. Other people will hear the pitch varying as the sound source moves towards and then away from them. If you are doing the swinging, you will notice no difference, as the sound source is moving neither towards nor away from you, but at right angles to you.

If you enjoyed this article, why not browse the other cutting-edge science articles in *Science in School*? See: [www.scienceinschool.org/cuttingedge](http://www.scienceinschool.org/cuttingedge)

Dr Phil Dooley is the news and education officer at EFDA-JET. He was born in Canberra, Australia, and completed a PhD in laser physics at the Australian National University. To escape academia he took a job in IT in Rarotonga, Cook Islands, for 18 months, before returning to Australia and working in software training. His love of science drew him back to physics, this time as a communicator, running the school outreach programme at the University of Sydney. In October 2011 Phil joined the EFDA-JET team in Oxfordshire, UK.



To learn how to use this code, see page 57.



## More about EFDA-JET



The Joint European Torus (JET)<sup>w1</sup> investigates the potential of fusion as a safe, clean and virtually limitless energy source for future generations. It can create the conditions (100-200 million °C) in the plasma sufficient for fusion of deuterium and tritium nuclei to occur, and it has achieved a maximum fusion power output of 16 MW. As a joint venture, JET is collectively used by more than 40 European fusion laboratories. The European Fusion Development Agreement (EFDA) provides the platform to exploit JET, with more than 350 scientists and engineers from all over Europe currently contributing to the JET programme.

EFDA-JET is a member of EIROforum<sup>w2</sup>, the publisher of *Science in School*. To see all EFDA-JET-related articles in *Science in School*, see: [www.scienceinschool.org/efdajet](http://www.scienceinschool.org/efdajet)



# Life without the Moon: a scientific speculation

Soaring temperatures, a flooded landscape, violent winds.... What would our planet be like without the Moon?

By Erin Tranfield

The Moon, *der Mond*, *la lune*. Its name and even its gender vary from language to language but there is no question that it is key to our image of Earth. Can you imagine Earth without a moon? No beauti-

ful, bright object traversing the night sky, hovering on the horizon, peeking through the trees on a cold winter's night? No romantic moonlight, no *Blue Moon*, and no lunar landings. Not only would we miss it – without the Moon, we might not even exist.

Let us imagine two scenarios: (i) if Earth had never had a moon and (ii) if our moon suddenly vanished. But first, let's remind ourselves of the Moon's effects on Earth.



- ✓ Physics
- ✓ Earth science
- ✓ Biology
- ✓ Gravitation
- ✓ Evolution
- ✓ Ages 12+

The Moon has always been present in our lives and most of us are not aware of its importance. Before reading this article, students could think about and discuss the Moon's influence on Earth. The discussion could be carried out in small groups where all members have the opportunity to express their opinions.

Because the article provides information about the role of the Moon in the origin and evolution of life, it could also be used as an introduction to how evolution

works. Students could then talk about the effect that human beings have on their environment.

Finally, the article also provides a context for teaching physical concepts, particularly the study of gravitational fields, thus helping to raise students' interest in the topic.

The article could be used as a comprehension exercise, including questions such as:

- What is the origin of the Moon?
- What is the effect of the Moon on Earth?
- What was the role of the Moon in the origin and evolution of life on Earth?
- What would happen if the Moon suddenly vanished?

Mireia Guell Serra, Spain



Image courtesy of Erin Tranfield

Image courtesy of Colverez / iStockphoto



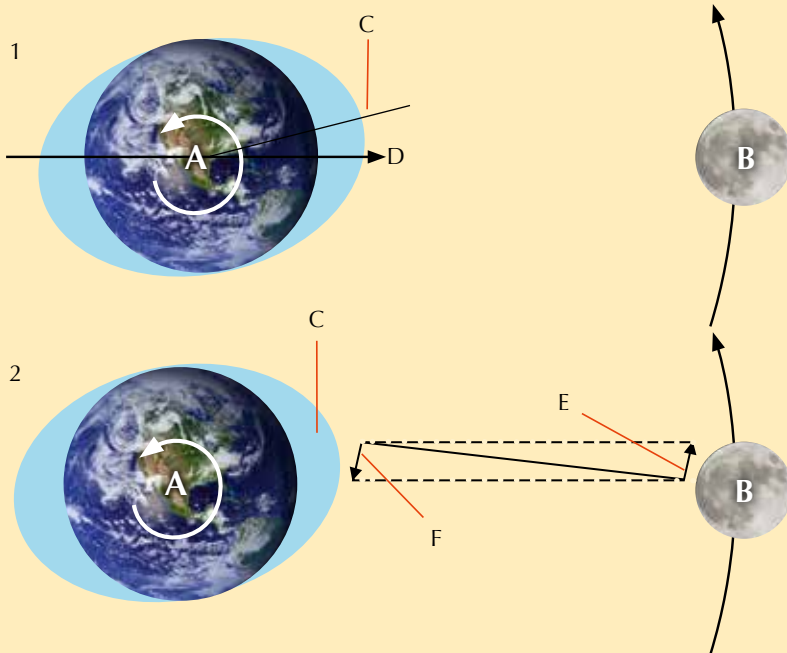
**Figure 2:** The gravitational attraction between Earth and the Moon stabilises the tilt of Earth's axis, giving Earth its predictable, fairly constant climate and its seasons. Because the Moon orbits Earth and is closer to it than any of the planets, its gravitational pull is both stronger than theirs and almost constant. Without the Moon, Earth would be subjected to the pull of the other planets as they orbited the Sun: when Jupiter was close, it would pull Earth in one direction, when Mars was close, it would pull in another direction. Earth would therefore be pulled by various forces over time and its axis would wobble. (Image not to scale.)

### Time and tides: the Moon's influence on Earth

Earth did not always have a moon, so where did it come from? The leading scientific theory is that an object about the size of Mars, called Theia, collided with Earth about 4.5 billion years ago. Striking at an oblique angle, it raised a cloud of debris that then coalesced to form the Moon. This had profound effects on Earth.

Earth and its newly formed moon exerted a gravitational force on each other, slowing the rotation of Earth and lengthening the Earth day from 5 hours to 24 (Touma & Wisdom, 1998). In fact, to this day, the Moon continues to slow down the rotation of Earth, although only by 0.002 seconds per century (figure 1).

The gravitational attraction between Earth and the Moon also stabilised the tilt of Earth's axis, and it is today's constant tilt of  $23.5^\circ$  that gives Earth



**Figure 1:** Earth (A) rotates, orbited by the Moon (B). The gravitational attraction of the Moon causes a tidal bulge (C): the water on Earth is pulled towards the Moon.

1) Earth rotates faster than the Moon orbits Earth, causing friction as the land rotates under the tidal bulge. The friction between land and the tidal bulge pulls the tidal bulge forward (C) so that it is ahead of the line of attraction between Earth and the Moon (D).

2) The friction force (F) between Earth and the ocean acts as a brake. This force is called tidal braking and it 'pulls' Earth backwards in its orbit, effectively slowing the rotation of Earth. Tidal braking also affects the Moon through force (E), which 'pulls' the Moon forward in its orbit, effectively speeding up the rotation of the Moon. This is what causes the orbit of the Moon to slowly increase, causing it to slowly move further from Earth.



The Moon is thought to have formed in a high-speed impact, when a body the size of Mars slammed into the young Earth about 4.5 billion years ago. The resulting molten rock, vapour and shattered debris mixed with debris from Earth to form a ring around our planet. Over time, this debris coalesced to make the Moon.

its predictable, fairly constant climate and its seasons (figure 2). Without the Moon, however, the axis would have continued to wobble, as does that of the moonless planet Mars.

Another feature of our planet is its oceans: more than 70% of Earth's surface is covered by salt water, rising

and falling on a 12.5 h tidal cycle. The forces that create tides are complex, involving not only the centrifugal forces of Earth's rotation but also the gravitational pull of both the Moon and the Sun (figure 3). The effect of the Moon, however, is twice that of the Sun; this is because the gravita-

tional force that one object exerts on another depends on both its mass and its distance.

We do not know how close the Moon was to Earth when it first formed, but we do know that it was farther than 12 000 km and closer than it is today (about 384 400 km). This

Without the Moon, the tides would be much smaller – affecting many organisms.





**Figure 3:** Both the Moon and the Sun are involved in the tides, as they exert their gravitational pull on Earth. The gravitational attraction of the Moon causes the oceans to bulge towards the Moon. Another bulge occurs on the opposite side, since Earth is also being pulled toward the Moon (and away from the water on the far side). Because Earth spins, these bulges (high tides, A) occur twice daily at any one spot.

The tides also show a pattern linked to the lunar cycle. 1) When the Moon and the Sun are aligned (at new moon, B, or full moon, C), their combined gravitation pull is strongest and the tides are highest (spring tides). 2) When the Moon is in its first quarter (D) or third quarter (E), the tides are lowest (neap tides).

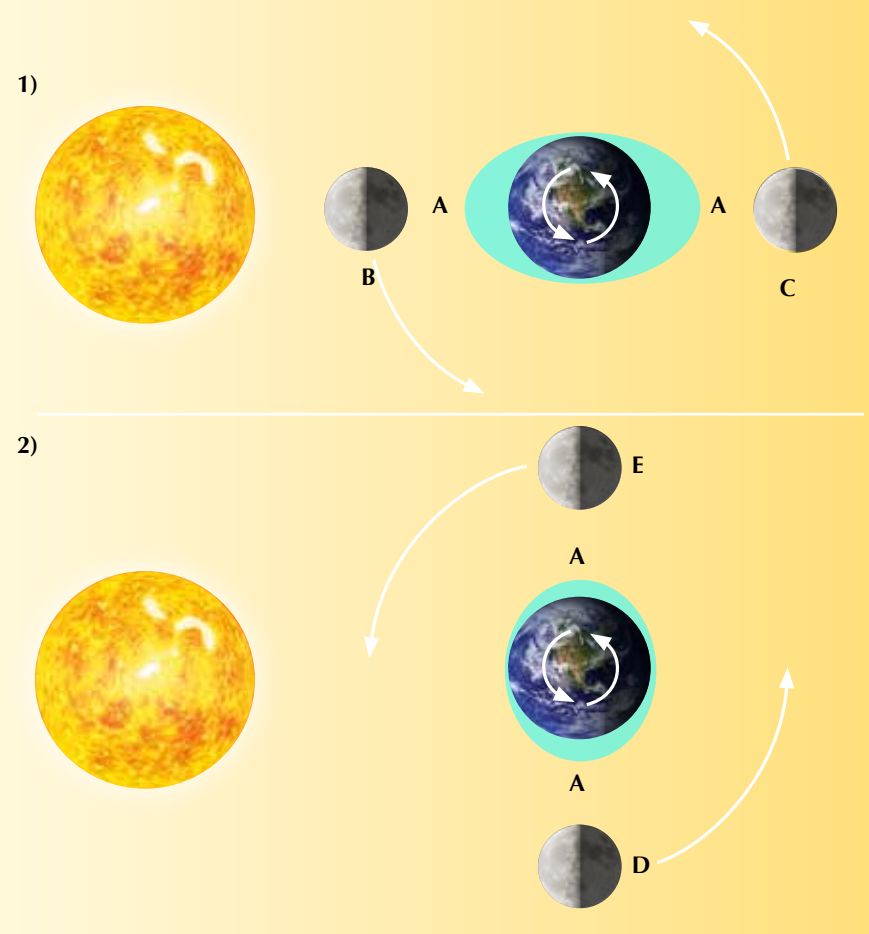


Image courtesy of Nicola Graf

means that it initially caused much larger tides than we experience today – tides that are thought to have been important in mixing the oceans and in the early evolution of life, some 3.8 billion years ago (Comins, 1996).

Interestingly, the tides and the rotation of Earth have an effect on the Moon. Together, they pull on the Moon, making it spin just a little faster, and as it spins faster and faster, it moves further away from Earth – albeit at a rate of only 3.82 cm per year (figure 1).

### Scenario 1: what if we had never had a moon?

What would have happened on Earth if, about 4.5 billion years ago, Theia had passed peacefully on its way without striking Earth and forming a moon?

Well, life of some sort would probably exist on Earth, but humans almost certainly wouldn't. Think of the very long course of evolution, the small changes, the minute

Biology

Physics

Marine turtles (Chelonioidae) tend to lay their eggs at spring tides, when the highest high tides occur. These tides allow the female turtles to swim up the beach to lay their eggs above the high-water mark (where they hatch best).



adaptations that organisms make to their environment. It would only have taken small changes to Earth's environment to have dramatically altered the course of evolution. I wouldn't be writing this article – and you wouldn't be reading it.

And if the Moon had never formed, Earth would be a very, very different place. An Earth day would be only 8-10 h long, with no moon to slow it down. The faster rotation would cause winds of 160-200 km to sweep Earth's surface. The tilt axis of Earth would wobble, resulting in dramatic changes in temperature over thousands to millions of years. And although our seas would still be tidal, the tides would be much smaller – caused only by the Sun.

You might like to ask your students to speculate about what kinds of life might have evolved on moonless Earth, capable of withstanding extreme temperatures, high winds, small tides and short days.

## Scenario 2: what if our Moon suddenly vanished?

Supposing the Moon just vanished tomorrow? We and all other organisms on Earth would be in serious trouble: we have evolved to live under a particular set of conditions and would then be faced with an entirely different environment. These changes would happen over the course of thousands to millions of years, which

*Image courtesy of Plbmak / Flickr*



How might the loss of seasons affect animals that hibernate, such as this hedgehog?

may sound like a long time, but the changes would be dramatic.

Without the Moon, the stability of Earth's axis would be lost again, and with it, our predictable temperatures. Let us consider two cities: Rome, Italy, and Stockholm, Sweden. In summer the average high temperature in Rome is 29 °C, and in the winter the average high temperature is 13 °C. In Stockholm, the high in summer is 20 °C and in winter it is 0 °C<sup>w1</sup>. If Earth's tilt axis changed, the temperatures in these

two cities would change dramatically. Imagine if the temperatures were swapped: the infrastructure (e.g. air conditioning or snow ploughs) would simply not be in place in those cities for humans to live, work and eat comfortably. The Italians, Swedes and all other life on Earth would need to adapt or face extinction.

Moving might be one option, but not for all organisms. Coral reefs, for example, are sensitive and complex ecosystems that might not be able to

*Image courtesy of Alex Groundwater / Flickr*

Many organisms, such as deer, mate at specific times of year. What effect might the loss of the Moon – and of our seasons – have on these organisms?







Image courtesy of midlander1231 / Flickr

adapt fast enough to the changing water temperature and would probably die (Saxby et al., 2003).

Furthermore, as the temperatures changed, Earth would lose its reliably cold regions: the poles, which contain huge amounts of ice. This ice would melt and the oceans would rise, changing the coastlines all around the world. Countries like the Netherlands would be covered in water.

With the lack of stability in Earth's tilt, we would also lose our regular seasons, with far-reaching consequences. Think how many organisms grow, mate, migrate or hibernate at particular times of year. And drastic changes in temperature would affect the growing season and climate for plants, making food production for the billions of people on Earth more complex.

### Nothing but lunacy?

You might not expect to find so much overt speculation in a science article. However, encouraging students to imagine a world without a moon is a fun exercise to illustrate

all the interesting ways that the Moon makes Earth the wonderful planet we know. Such an exercise not only introduces some complex physics in a simple context, but also gives students an opportunity to think about the course of evolution, and the way in which every aspect of our lives is affected by our environment.

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If we lost our Moon, and thus our regular seasons, how would this affect deciduous trees – which provide this beautiful autumn colour in the UK's Lake District?

### Web references

- w1 – The World Weather and Climate Information website offers information about the weather and climate for almost every country around the world. See: [www.weather-and-climate.com](http://www.weather-and-climate.com)
- w2 – The International Space University provides graduate-level training to the future leaders of the space community. See: [www.isunet.edu](http://www.isunet.edu)

### Resources

- Canup RM (2012) Forming a moon with an Earth-like composition via a giant impact. *Science*. doi: 10.1126/science.1226073
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Image courtesy of Nicolas Horzay / Flickr

Jellyfish (Cnidaria) and many other groups of marine and freshwater zooplankton move up and down the water column according to a daily rhythm. If the Moon were to disappear, Earth days would become shorter and the animals would need to adapt to the shorter daily rhythm.

Erin Tranfield completed her PhD in May 2007 in the Department of Pathology and Laboratory Medicine at the University of British Columbia, in Vancouver, Canada. She then spent two years at NASA Ames Research Center in Moffett Field, California, USA, investigating the effects of lunar dust on human physiology and pathology. Erin is now at the European Molecular Biology Laboratory in Heidelberg, Germany, working on the three-dimensional reconstruction of the meiotic spindle using high-resolution electron tomography.

Erin is currently adjunct faculty at the International Space University<sup>w2</sup> and a member of the European Space Agency's topical team for the toxicity of lunar dust.



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*What if the Moon did not exist?* podcast by Patrick McQuillan, on the 365 Days of Astronomy website. See: [www.365daysofastronomy.org](http://www.365daysofastronomy.org) or use the direct link: <http://tinyurl.com/ae3rgnm>

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The article raises questions about the evolution of the life forms that exist on Earth today. To support a lesson on evolution, why not browse the rest of the articles in the *Science in School* evolution series? [www.scienceinschool.org/evolution](http://www.scienceinschool.org/evolution)

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Image courtesy of Auntie P / Flickr

Without the Moon, winds of 160-200 km would sweep Earth's surface. How many of today's plants and animals would survive that?



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