Summer 2011 Issue 19

# SCIENCE in SCHOOL

In this issue:

## A planet from another galaxy

Also:

## Science teachers take to the stage

EIROforum

Highlighting the best in science teaching and research

# Editorial

Life in space – scientists and lay people alike are intrigued by this possibility. Recently, astronomers have found a planet orbiting a star that entered the Milky Way from another galaxy (see page 26). Does that whet your appetite for space travel? Why not discuss what we would need to live on another planetary body and get your students to design a space habitat (see page 43)?

One of the many considerations for this activity is cosmic radiation – high-energy particles that fall on Earth and other planets from space. One type of particle produced by cosmic rays is the neutrino; as Susana Cebrián explains, thousands of them pass through your body in the time it takes you to read these lines (see page 55).

Whereas huge detectors are necessary to find neutrinos, UK physics teacher Becky Parker and her students use tiny detectors to find other cosmic particles – doing real science at school, with help from CERN. Learn more about the project and how to join on page 69.

Another inspiring science teacher, Bernhard Sturm, introduced his students to the chemistry of amber (see page 36). This fossilised resin is also analysed by palaeontologists at the European Synchrotron Radiation Facility, where their chemist colleagues have recently revealed why the famously bright yellows of van Gogh's paintings are darkening over time (see page 19). The culprit is thought to be a chemical reaction initiated by light.

Reverse this process and, as Emma Welsh explains, the result is chemiluminescence: the production of light from a chemical reaction (see page 62). One of the applications of chemiluminescence is the detection of blood at crime scenes using luminol. Forensic scientists, however, perform not only chemical but also genetic analyses, such as DNA fingerprinting. Using this method, your students can solve a murder mystery in the Gene Jury team's DNA detective game (see page 30).

If that sounds too lurid, you may prefer the Moja Island role play, to determine the best sustainable energy solutions for fictitious island communities (see page 50).

Is background reading what you are looking for, rather than games? Then you may be interested in Laurence Reed and Jackie de Belleroche's report on the latest research into schizophrenia (see page 13), Andrew Wildes' description of his life as a neutron scientist at the Institut Laue-Langevin (see page 10), or one of the book or website reviews by our readers. You can find all these articles and more on the *Science in School* website (www.scienceinschool.org).

**Marlene Rau**

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**About *Science in School***

*Science in School* promotes inspiring science teaching by encouraging communication between teachers, scientists and everyone else involved in European science education.

The journal addresses science teaching both across Europe and across disciplines: highlighting the best in teaching and cutting-edge research.

It covers not only biology, physics and chemistry, but also earth sciences, engineering and medicine, focusing on interdisciplinary work.

The contents include teaching materials; cutting-edge science; interviews with young scientists and inspiring teachers; reviews of books and other resources; and European events for teachers and schools.

*Science in School* is published quarterly, both online and in print. The website is freely available, with articles in many European languages. The English-language print version is distributed free of charge within Europe.

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If you teach science in Europe and would like to review books or other resources for *Science in School*, please read the guidelines on our website.

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We offer articles online in many European languages. If you would like to volunteer to translate articles into your own language, please read the guidelines for translators on our website.

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## Additional online material



Forthcoming events for schools: **www.scienceinschool.org/events**

To read the whole issue, see: **www.scienceinschool.org/2011/issue19**

At the end of each article in this issue, you may notice a square black and white pattern. With the aid of a smart phone, this QR code will lead you straight to the online version of the article. All you need to do is download a free QR code reader app (such as BeeTagg or i-Nigma) for your smart phone and scan the code with your phone's camera. To find a suitable one for your phone, see: http://tinyurl.com/byk4wg

Hint: the apps works better in good light conditions, and with a steady hand. You may also want to try holding your camera at different distances from the code.

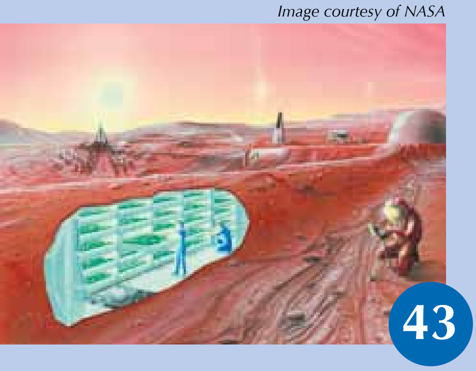
You can then use all the live links to the references and resources, download the PDF, send the article to your friends, leave comments, and much more. What do you think about this new feature? Does it work for you? Leave your feedback here: www.scienceinschool.org/QRfeedback

*Image courtesy of Vlue / iStockphoto*


*Image courtesy of the Van Gogh Museum, Amsterdam*


*Image courtesy of dtimiraos / iStockphoto*


*Image courtesy of NASA*



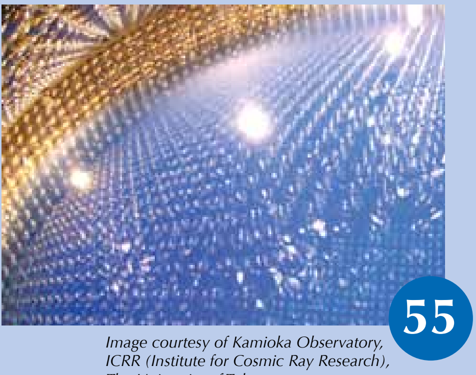
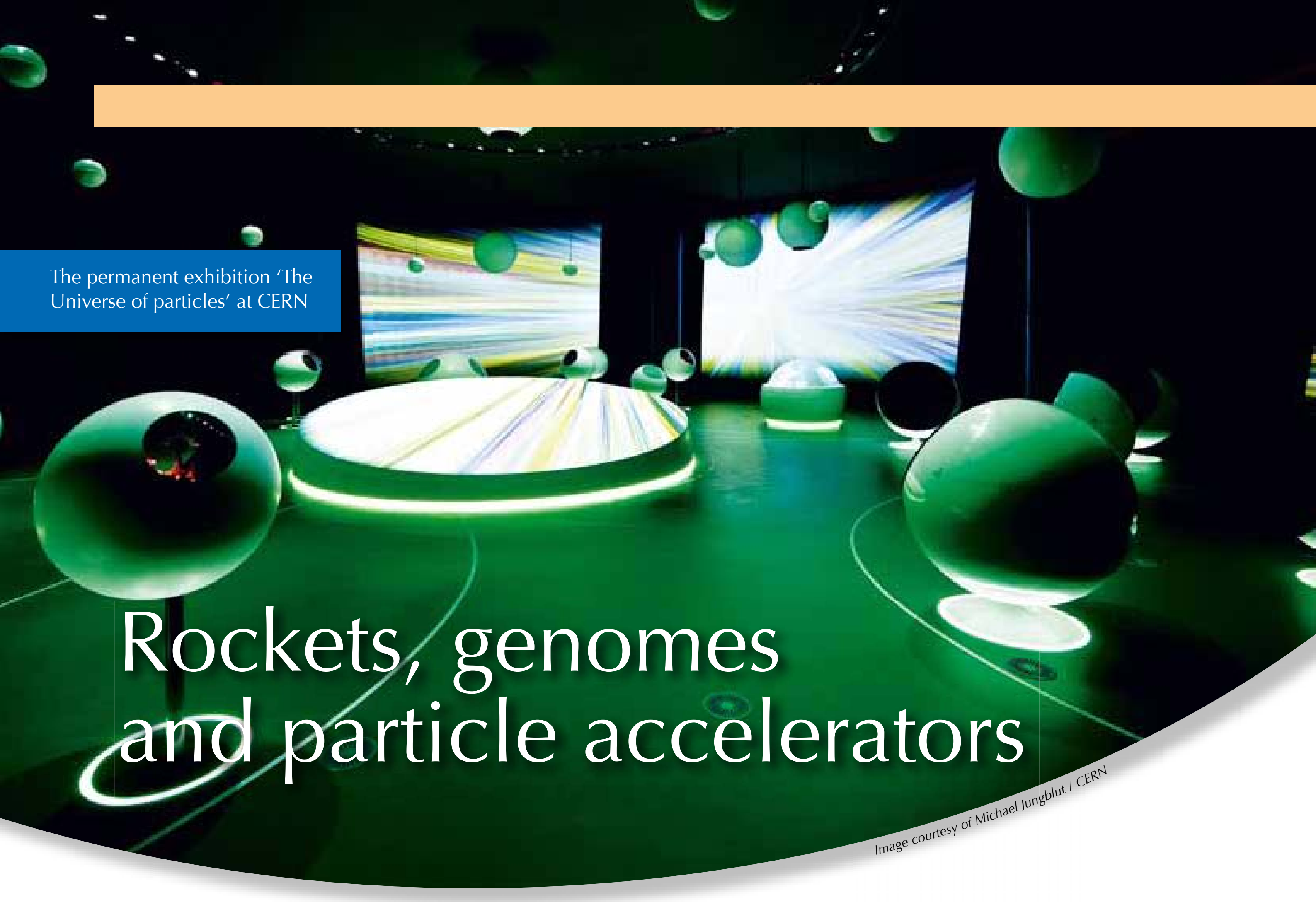




*Image courtesy of Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo*



The permanent exhibition 'The Universe of particles' at CERN

Image courtesy of Michael Jungblut / CERN

# Rockets, genomes and particle accelerators

*Science in School* is published by EIROforum, a collaboration of research organisations. **Eleanor Hayes**, Editor-in-Chief of *Science in School*, reviews some of the latest news from the EIROforum members.

## EIROforum

EIROforum, the publisher of *Science in School*, is a partnership of eight European inter-governmental scientific research organisations (EIROs). As regular readers of *Science in School* will know, the range of research done at these organisations varies widely – from molecular biology to astronomy, from fusion energy to space science. The equipment is also very disparate – including enormous particle accelerators, beams of neutrons or high-energy X-rays, large telescopes or the International Space Station.

Whether individually or as part of EIROforum, the EIROs are also involved in many outreach and education activities – for school students, teachers and the general public. *Science in School* is one example of a joint EIROforum activity; this article details other research and outreach activities at some of the EIROs.

For a list of EIROforum-related articles in *Science in School*, see: www.scienceinschool.org/eiroforum

To learn more about EIROforum, see: www.eiroforum.org

## CERN: visit the world's largest particle physics laboratory

In 2010, a stunning 58 000 people visited CERN in Geneva, Switzerland. The permanent exhibition entitled 'The Universe of particles' attracts many visitors, offering them an overview of CERN's research goals, tools and impact throughout the world. After that, many visitors go on to find out more about the research at CERN, visiting the control centre, the computer centre and SM18, a large hall housing cross-sections of the magnets used in the Large Hadron Collider (LHC), some superconducting cables and a life-size model of a section of the LHC tunnel.

By the end of 2012, CERN plans to make the experience yet more spectacular for its visitors, with an even more realistic model of the LHC tunnel, plus high-tech audiovisual tools to make the roles of the control centre and computer centre clearer.

Why not apply to visit CERN with your students (aged 12 and over)? For more details, see: http://outreach.web.cern.ch/outreach/visites/index.html

The CERN education website offers information about all the teacher programmes, as well as educational resources for schools. See: http://education.web.cern.ch/education/Welcome.html

To find out more about the world's largest and most powerful particle accelerator, the Large Hadron Collider at CERN, see:

Landua R, Rau M (2008) The LHC: a step closer to the Big Bang. *Science in School* **10**: 26-33. www.scienceinschool.org/2008/issue10/lhcwhy and

Landua R (2010) The LHC: a look inside. *Science in School* **10**: 34-45. www.scienceinschool.org/2008/issue10/lhchow

For a list of CERN-related articles in *Science in School*, see: www.scienceinschool.org/cern

To learn more about CERN, see: www.cern.ch

## EFDA-JET: powered by humans

The young fusion scientists working at EFDA-JET in Culham, UK, make every effort to get the message about their research out to you, the public. In addition to their 'day jobs' in the lab, many are keen and happy to undertake outreach and education work. A group of them recently gave up their Saturday to join the very popular opening event of the annual Oxfordshire Science Festival, explaining why fusion research is so important in the context of energy for the future of the world.

*Image courtesy of Mel Cunningham*


Chris Warrick from EFDA-JET faces the 'pedal power challenge'

This involved a 'pedal power challenge' to find out how hard you have to pedal a static bicycle to produce enough energy for lighting up even a single light bulb (15 Watt). There were plenty of volunteers who wanted to test their own energy and stamina at the fusion stand, as it is obviously easier to relate to explanations of the global energy challenge in terms of an individual's energy needs.

Why not visit EFDA-JET and its scientists yourself? The Culham Centre for Fusion Energy runs special tours of the facilities as well as offering Open Evenings and running a great outreach programme including the 'Sun Dome', an exciting science roadshow for school students aged 10-12.

For more information on the outreach programme and to visit EFDA-JET, see: www.ccfe.ac.uk

To find out more about the annual Oxfordshire Science Festival, see: www.oxfordshiresciencefestival.co.uk

To build your own human powered bicycle generator, see:

http://scienceshareware.com/bike_gen.htm
www.instructables.com/id/Bike-Generator
www.magnificentrevolution.org/diy/single-bike-generator
www.pedalpowergenerator.com

If you prefer an energy bike for hire to come to your school, try Global Action Plan UK. See: www.globalactionplan.org.uk/energy-bike

To learn more about EFDA-JET, see: www.jet.efda.org

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

## EMBL on air: ten years of the human genome

It was a global endeavour to rival the space race: billions of dollars invested, a massive international effort of singular scientific, medical, industrial and societal significance. The nail-bitingly close and bitterly fought battle culminated in the publication on 15 and 16 February 2001 of two scientific papers, one in *Nature* and the other in *Science*, of the first draft sequence of the human genome.

To celebrate ten years since the publication of the sequence, the European Molecular Biology Laboratory (EMBL)

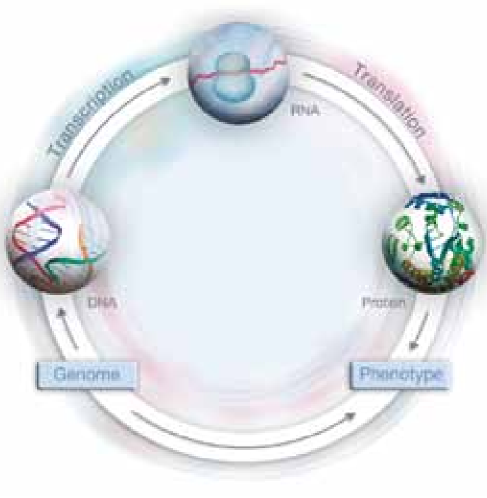



*Image courtesy of Petra Riedinger / EMBL*

Biologists are still striving to link genetic information to observable characteristics released a podcast describing what the breakthrough has meant for EMBL science and scientists. "The human genome sequence provided a blueprint of all the protein-coding genes in the human genome for the first time," explains one EMBL scientist, Jan Ellenberg. "This changed how we go about studying protein function."

The second in a new online series aimed at the general public, this podcast is complemented by a written article and visuals. To view the growing collection, see: www.embl.de/aboutus/communication_outreach/explore

See the original 2001 research papers:

International Human Genome Sequencing Consortium (2001) Human genome. *Nature* **409**: 860-921. doi:10.1038/35057062 Download the article free of charge from the *Science in School* website (www.scienceinschool.org/2011/issue19/eiroforum#resources), or subscribe to *Nature* today: www.nature.com/subscribe

Venter JC et al. (2001) The sequence of the human genome. *Science* **291**: 1304-1351. doi: 10.1126/science.1058040

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

To learn more about EMBL, see: www.embl.org

## ESA

When you think of the European Space Agency (ESA), do you fantasise about being an astronaut or consider ESA's wide range of research and technology development? Did you know that, with the help of partners in Belgium, Ireland, the Netherlands, Norway and the UK, ESA also offers training sessions and conferences for primary- and secondary-school teachers? Through the European Space Education Resource Offices (ESEROs) in these countries, ESA also provides teachers with free materials for teaching space science and astronomy, and develops resources to meet the needs of the national education communities.

Founded in 2006, ESERO Belgium is a collaboration between ESA and the Belgian Federal Science Policy Office, based in Brussels at the Planetarium of the Royal Observatory of Belgium. In cooperation with colleges in Flanders and Brussels, it offers weekly workshops for trainee teachers on how to teach children about space and astronomy. The young teachers work together to make and launch rockets fuelled by vinegar and baking powder, build a lunar landscape out of plaster or use paper to build a model of the Solar System. They use quizzes and games to help the children to learn and remember. Many of the participants are amazed at how much fun – and how easy – teaching about space can be.

Launching water rockets at a science day

How are impact craters formed? Let's find out!

*Images courtesy of Ellen Geerts, ESERO Belgium*

At public events like Greenlight for Girls days, the ESERO activities are popular with children, who enjoy launching water rockets or making comets out of dry ice, starch, soil, water and window cleaner. In the future, ESERO Belgium hopes to extend its workshops to secondary-school trainee teachers.

For information about all the ESEROs, see: www.esa.int/esero

Greenlight for Girls encourages girls of all ages to consider a future in maths, science, engineering and technology by introducing them to the world of science in fun and exciting ways. To find out more, see: www.greenlightforgirls.org

To learn more about the European Space Agency, see: www.esa.int

For a list of all ESA-related articles published in *Science in School*, see: www.scienceinschool.org/esa

## ESO: planet formation in action?

Planets form from the discs of material around young stars, but the transition from dust disc to planetary system is rapid, and few objects have been detected during this phase. One such object is T Chamaeleontis (T Cha), a faint star in the small southern constellation of Chamaeleon that is comparable to the Sun, but very near the beginning of its life (the Sun is about half-way through its life). T Cha lies about 350 light-years from Earth and is only about seven million years old.

After careful analysis with the Very Large Telescope of the European Southern Observatory (ESO), a group of astronomers found the clear signature of an object located within a gap in the dust disc, about one billion kilometres from the star – slightly further out than Jupiter is within our Solar System and close to the outer edge of the gap. This is the first detection of an object much smaller than a star within a gap in the planet-forming

Image courtesy of ESO / L Calçada

This artist's impression shows the disc around the young star T Cha. Using ESO's Very Large Telescope, this disc has been found to be in two parts, a narrow ring close to the star and the remainder of the disc material much further out. A companion object, seen in the foreground, has been detected in the gap in the disc; it may be either a brown dwarf or a large planet. The inner dust disc is lost in the glare of the star on this picture

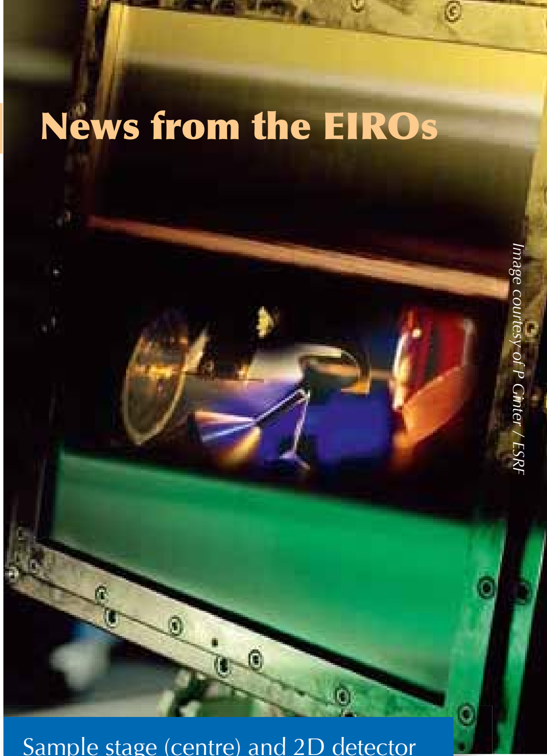


Image courtesy of P Ginter / ESRF

Sample stage (centre) and 2D detector (background) on ESRF beamline ID23, where the GPCR protein structures were determined

dust disc around a young star. The evidence suggests that the companion object cannot be a normal star, but it could be either a brown dwarf surrounded by dust or, most excitingly, a recently formed planet.

To learn more, see the press release (www.eso.org/public/news/eso1047) and the research papers:

Olofsson J et al. (2011) Warm dust resolved in the cold disk around T Chamaeleontis with VLTI / AMBER. *Astronomy & Astrophysics* **528**: L6. doi: 10.1051/0004-6361/201016074 www.eso.org/public/archives/releases/sciencepapers/eso1106/eso1106a.pdf

Huélamo N et al. (2011) A companion candidate in the gap of the T Chamaeleontis transitional disk. *Astronomy & Astrophysics* **528**: L7. doi: 10.1051/0004-6361/201016395 www.eso.org/public/archives/releases/sciencepapers/eso1106/eso1106b.pdf

To find out more about ESO's Very Large Telescope, see:

Pierce-Price (2006) Running one of the world's largest telescopes. *Science in School* **1**: 56-60. www.scienceinschool.org/2006/issue1/telescope

For more information about ESO, see: www.eso.org

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

## ESRF: I can sense your heartbeat

More than a quarter of all drugs work thanks to G-protein-coupled receptors (GPCRs). These proteins are embedded in the cell membrane and bind other molecules, relaying the signals conveyed by them through the membrane. This process often transmits sensory information or changes in the physiological state from one cell to another. The $\beta_1$-adrenergic receptor, for example, is the GPCR relaying a signal conveyed by the release of adrenalin or related agonists into cells in a number of organs including the heart, where it leads to an increase of the heart rate, one of the most important body functions.

Determining the structure and function of $\beta_1$-adrenergic receptor could therefore help pharmaceutical companies to develop more efficient drugs. However, good crystals of these proteins are extremely difficult to make. With the help of micro-focus X-ray beams at the European Synchrotron Radiation Facility (ESRF), however, Tony Warne and colleagues from the MRC Laboratory of Molecular Biology in Cambridge, UK, were able to solve four structures of this receptor, bound to four different agonists. These structures enabled the researchers to identify the interactions that appear to be crucial in signal transmission.

To learn more, see the news article on the ESRF website (www.esrf.eu/news/general/GPCR-structure) and the research paper:

Warne T et al. (2011) The structural basis for agonist and partial agonist action on a $\beta_1$-adrenergic receptor. *Nature* **469**: 241–244. doi: 10.1038/nature09746
Download the article free of charge from the *Science in School* website (www.scienceinschool.org/2011/issue19/eiroforum#resources), or subscribe to *Nature* today: www.nature.com/subscribe

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

To learn more about ESRF, see: www.esrf.eu

To learn how to use this code, see page 1.

Eye-catching stage shows are an integral part of Science on Stage

Image courtesy of Science on Stage Europe

# Science teachers take to the stage

Science recognises no national borders – and neither does Science on Stage, the network for European science teachers. **Eleanor Hayes** attended the international festival.

Both *Science in School* and the Science on Stage network for teachers were initiated by EIROforum, so as a representative of both EIROforum[w1] and *Science in School*, I was delighted to attend the Science on Stage[w2] international teaching festival in April 2011. Where better to find teaching activities to share with you, our readers, than at a festival of 350 science teachers, selected from across Europe for their inspiring ideas?

The European aspect is one of the things that make Science on Stage so special. As Jörg Gutschank from Germany explained, "Meeting people from so many different countries, you see so much more than you would see at teachers' meetings in your own country." Helle Houkjaer from Denmark agreed. "I most enjoyed exchanging ideas with colleagues from other countries, and discussing how they teach the same subject as I do, but in another way."

Appropriately enough, the festival was held at the Ørestad upper-secondary school in Copenhagen, Denmark. Opened in 2006, the school receives visitors from across the world, eager to learn about the school's philosophy of teaching in open spaces – and to see the architecture that supports such teaching.

During the festival, which took place during the school holidays, the fair occupied the open spaces on all five floors, with teachers from 22 European countries displaying and discussing 239 teaching projects, and swapping ideas and experience. With so many projects, there was inspiration for everyone to take home.

Christian Selchow from Germany looks forward to trying out what he learned from the Czech stand: Zdenek Polak's students put an infra-red filter in front of a normal digital camera, and were able to visualise infra-red radiation and investigate how different materials react to it[w3]. "It's inspiring because I've already got all the materials, and I can work together with my students on it – we'll be in the same experimental phase," Christian explains.

Siri Krogh from Norway is in her first year of teaching. "I will be going home with so many simple ideas I can try out straightaway. For example Katerina Lipertova's 'Playful physics' project[w2] from the Czech Republic, to build little moveable toys out of recycled materials – it was simple and not expensive."

There were also more than 30 workshops and masterclasses by teachers and other experts in science education[w3]. Paul Nugent, one of the organisers of Science on Stage Ireland, explained: "The masterclasses were outstanding – really useful, practical teaching ideas that could be used straightaway. I particularly liked the Spanish masterclass entitled 'Listening to gravity'."

Catherine Tattersall from Ireland, whose innovative project with aqua beads won a prize (see box on page 8), was fascinated by the European Space Agency's (ESA) workshop[w3] on developing experiments to run on the International Space Station. She and Shamim Hartevelt (ESA) plan to investigate whether these beads can be used to test how plants grow under conditions of microgravity. "I would be the coolest teacher on Earth if I could get a science project into space," she enthused.

The participants in Angela Köhler's masterclass about 'Chocolate science'[w2] learned a lot, but so did she. "Later, people asked me about the project and we discussed the situation in their countries and how the project could be used there."

There's no doubt that for the 350 participants, this all-expenses-paid festival was an inspiring experience that will enrich their teaching. But that is only the tip of the iceberg: each of these teachers was selected from among the most inspiring teachers in their own countries and all of them will be taking ideas back home to share with their colleagues.

Helle Houkjaer already has plans: "We have a network in our community with one or two teachers from each school, so at our next meeting, I can tell them about what I have learned here."

When I spoke to the Irish team, they were also planning to share some of the ideas from the festival – not only with their Irish colleagues but also with all enthusiastic teachers. As they have done after each Physics on Stage and Science on Stage festival, they will prepare a downloadable book of demonstrations and teaching ideas, including pictures and instructions, as well as videos of 50 of the experiments[w4]. The team are also planning workshops, to share the ideas with Irish teachers in a more hands-on way.

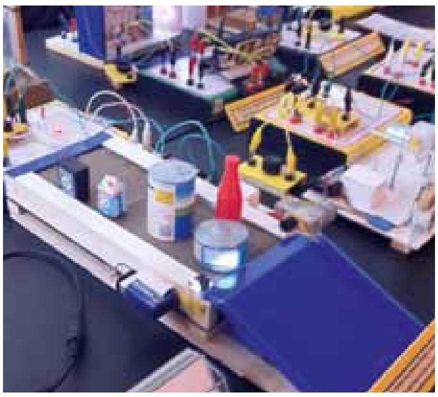
Think Ing, an initiative of the German Association of the Metal and Electrical Industry Employers (Gesamtmetall), aims to improve science teaching in Germany – and it supports not only the German event but also Science on Stage Europe. As Wolfgang Gollub from Think Ing explains, "To improve science teaching in Germany, you need to look around Europe, look over the fences and try to gather the best ideas for improving science teaching." With Thing Ing's support, the German team will also be publishing some of their favourite experiments and projects[w5].

Following a model established by Science on Stage Germany (see Hayes, 2010), Antonio Gandalfi from Italy also hopes to maintain some of the momentum of the international festival by inviting Science on Stage teachers from other countries to run a masterclass for Italian teachers.

And of course, in forthcoming issues of *Science in School*, we hope to share several of the activities from the Science on Stage international festival with you.

Momentum is an important element of Science on Stage. In 2013, the next international festival will be a cross-border event, hosted by the adjoining towns of Frankfurt an der Oder (Germany) and Słubice (Poland). In the run-up to that festival, there will be dozens of national festivals, competitions, workshops and other events in many countries to select the participants. If you would like to join the Science on Stage network, exchanging ideas and inspiration with colleagues from across Europe, contact your national organiser through the Science on Stage Europe website[w2]. You may even get to represent your country in 2013!

*Images courtesy of Eleanor Hayes*



Georgios Georgiou from Cyprus challenges his students to wire the circuits correctly. Can they get the car windscreen wipers to start automatically when it rains? Will the supermarket conveyor belt stop when the food passes the photoelectric barrier?

## Reference

Hayes E (2010) Science on Stage: sharing teaching ideas across Europe. *Science in School* **16**: 2-5. www.scienceinschool.org/2010/issue16/sons

## Web references

w1 - EIROforum is a partnership of eight of Europe's largest inter-governmental research organisations, and is also the publisher of *Science in School*. See: www.eiroforum.org

w2 – To learn more about Science on Stage Europe, see: www.scienceonstage.eu

To find your national contact, click on 'National activities', then 'Science on Stage countries'.

w3 – The abstracts of all projects, workshops and masterclasses at the festival are available in the festival programme, which can be downloaded here: www.scienceonstage.eu/?p=3_2

w4 – To download free books of demonstrations and teaching ideas, chosen by the Irish team at all the previous Science on Stage and Physics on Stage festivals, visit www.scienceonstage.ie

w5 – A publication with the German team's favourite experiments and projects will be freely available for download from the Science on Stage Germany website: www.scienceonstage.de

BACKGROUND

# The winning projects

All the participants at the Science on Stage international festival were winners: they had been selected from among thousands of teachers across Europe for their innovative ideas. But there were further prizes for some lucky participants.

EIROforum, as the initiator of Science on Stage, was happy to continue its support in the form of three prizes: reserved all-expenses-paid places in the EIROforum teacher school[w6] in October 2011, in a CERN teacher school[w7] and in an EMBL ELLS teacher workshop[w8]. Furthermore, Intel Corporation sponsored five generous prizes: one of US$2000 and four of US$1000 each.

As co-chairs of the award committee, Helle Houkjaer and I agreed on five criteria for a winning project:

- Is it innovative?
- Is it useable and relevant for science teaching?
- Is it educational?
- Is it easy for other teachers to repeat?
- Does it make good use of minimal resources?

Not all our winners had to meet all the criteria and, as always, it was very difficult to select eight from among so many outstanding projects. After much discussion, Helle, Jörg Gutschank (Germany), Fernand Wagner (Luxembourg), Michalis Hadjimarcou (Cyprus), Alison Alexander (UK), Anders Blomqvist (Sweden), Ulrich Johan Kudahl (Denmark) and I agreed on the eight winning projects.

Intel prize (US$2000): Michael Vollmer and Kalus-Peter Möllmann from Germany, for their 'High speed / low speed' project to understand the physics of phenomena as varied as breaking spaghetti and exploding balloons with the aid of inexpensive high-speed cameras.

Intel prize (US$1000): Catherine Tattersall from Ireland, for her 'Colourful science – introducing aqua beads' project, in which she grew algae on hydroponic gel beads for photosynthesis experiments, soaked the beads in universal indicator solution for pH tests and developed many other innovative uses for the beads. She even hopes to send an experiment into space, with help from the European Space Agency (see page 6).

Intel prize (US$1000): Imma Abad and Pere Compte from Spain for their 'Thermoelectric solar energy' project, in which the students investigated the technologies involved in generating solar energy, then designed, developed and built several prototypes and experiments to explain how we can exploit solar energy without using photovoltaic cells.

*Images courtesy of Eleanor Hayes*

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*Image courtesy of Eleanor Hayes*

Intel prize (US$1000): Ida Regl from Austria for 'Cosmi wants to know', a development of her 'Sunny side up project' which won an award at Science on Stage 2 in 2007. Since then, the project has expanded to cover all four years of primary education and – together with pupils, parents, the local council and scientists from the university – the school has built a planetary walk. Visitors can even borrow a rucksack filled with small experiments to help them on their trip through the Solar System. More information and instructions for carrying out the experiments are available on the project website[w9].

Intel prize (US$1000): Olaf Gutschker from Germany, for his 'Physics from the inside out' project, which shows how magnetic resonance imaging works, with the aid of some simple equipment.

Jan Pavelka and Ondrej Pribyla from the Czech Repub-

*Images courtesy of Eleanor Hayes*


**1** Small, portable experiments that fit into a rucksack and can be taken along the Austrian Lichtenberg primary school's planetary trail to demonstrate the science on the planets – and much more

**2** Prize-winner Ida Regl from Austria displays the solar-powered 'insects' that she uses with her primary-school pupils to explain science along the planetary trail that the school built


**3** Gianluca Farusi's Italian project involves studying chemistry with Pliny the Elder. You too can smell like Julius Caesar!

**4** Gabriele Sons, managing director of the German Association of the Metal and Electrical Industry Employers (Gesamtmetall), one of the sponsors of the festival, investigates audible light on stage

*Image courtesy of Science on Stage Europe*

lic received the EIROforum prize for their project 'See the sound, hear the light', which uses light to help us understand basic acoustic concepts in a dramatic and appealing way.

For his 'From rainbows to the chemistry of colours' project, which uses simple home-made apparatus to demonstrate why a rainbow has its characteristic curved form, Elias Kalogirou from Greece received the CERN prize.

In this, the International Year of Chemistry, chemistry teacher Gianluca Farusi from Italy was delighted to win the ELLS prize for his extensive and interdisciplinary project 'Studying chemistry with Pliny the Elder', one of the activities of which was the creation by his students of telinum, the perfume used by Julius Caesar.

To learn more about these and all other projects, workshops and masterclasses, see the abstracts in the festival programme[w3].

My EIROforum, CERN and EMBL colleagues look forward to welcoming the prize-winners at their teacher workshops, where they will have the chance to develop their ideas together with research scientists and other exceptional science teachers.

Congratulations to the prize-winners, but also to all 350 participants at the Science on Stage international festival. I hope to see some of you, our readers, at the next festival.


w6 – From 9-12 October 2011, EIROforum, the publisher of *Science in School*, will be offering a free, three-day course entitled 'Physics and chemistry of life' to European science teachers. To learn more, see: http://tinyurl.com/eiroschool

To read about the first EIROforum teacher school, see:

Hayes (2010) Teachers and scientists face to face: the first EIROforum teacher school. *Science in School* **14**: 6-9. www.scienceinschool.org/2010/issue14/eiroforumschool

w7 – CERN, the world's largest particle physics laboratory and a member of EIROforum, offers courses for physics teachers in English or in their mother tongue, lasting between 3 days and 3 weeks. To learn more, see: http://education.web.cern.ch/education/Welcome.html

and

CERN (2009) Particle physics close up: CERN high-school teachers programme. *Science in School* **13**: 4-5. www.scienceinschool.org/2009/issue13/cernlist

w8 – Based at the European Molecular Biology Laboratory (EMBL, a member of EIROforum), ELLS is a science education facility that brings secondary-school teachers in contact with EMBL's scientific environment, fostering mutual exchange between European high-school teachers and research scientists. For more details, see: www.embl.org/ells

w9 – To learn more about 'Cosmi wants to know' and download instructions for the planetary experiments, see: www.cosmi.at


## Resources

To read all previous articles about Science on Stage, see www.scienceinschool.org/sons

To learn how to use this code, see page 1.

NEUTRONS FOR SCIENCE

# Life in the line of fire

All major X-ray and neutron facilities employ instrument scientists, who are experimental experts, liaison officers and researchers rolled into one. **Andrew Wildes** from the Institut Laue-Langevin explains how he juggles his daily tasks.

Division of labour: as an instrument scientist, Andrew Wildes holds several diverse responsibilities

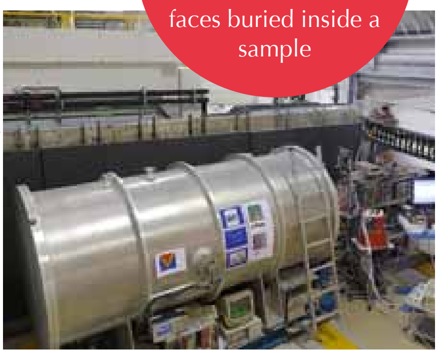
*Image courtesy of Andrew Wildes*

For the past 14 years I have been working as an instrument scientist at the Institut Laue-Langevin (ILL) in Grenoble, France. Life in the French Alps is certainly a far cry from my origins in the flatlands of Victoria in Australia, although the quality of the wine is comparable. I came to Europe after completing a physics degree at the University of Melbourne, and a doctorate in condensed-matter physics at Monash University, both in Victoria. Initially I worked in the UK at Oxford University on neutron and X-ray scattering experiments, but then, just before my contract ended, I was offered a job at the ILL. Although I have now spent more time working here than on both my degrees and my postdoc put together, it feels much shorter!

The ILL is a high-neutron-flux research facility and is arguably the most powerful source of neutrons in the world. More than 40 instruments for experimental science are attached to the nuclear reactor that produces the neutrons. Most of the instruments are used for neutron scattering, in addition to four for nuclear physics, one for radiography and one for interferometry. All the instruments are different, although there is some overlap between the science that can be studied with them. I like to think of the institute as a giant toolbox where scientists can choose the right tool to solve each problem that comes along.

## Three jobs in one

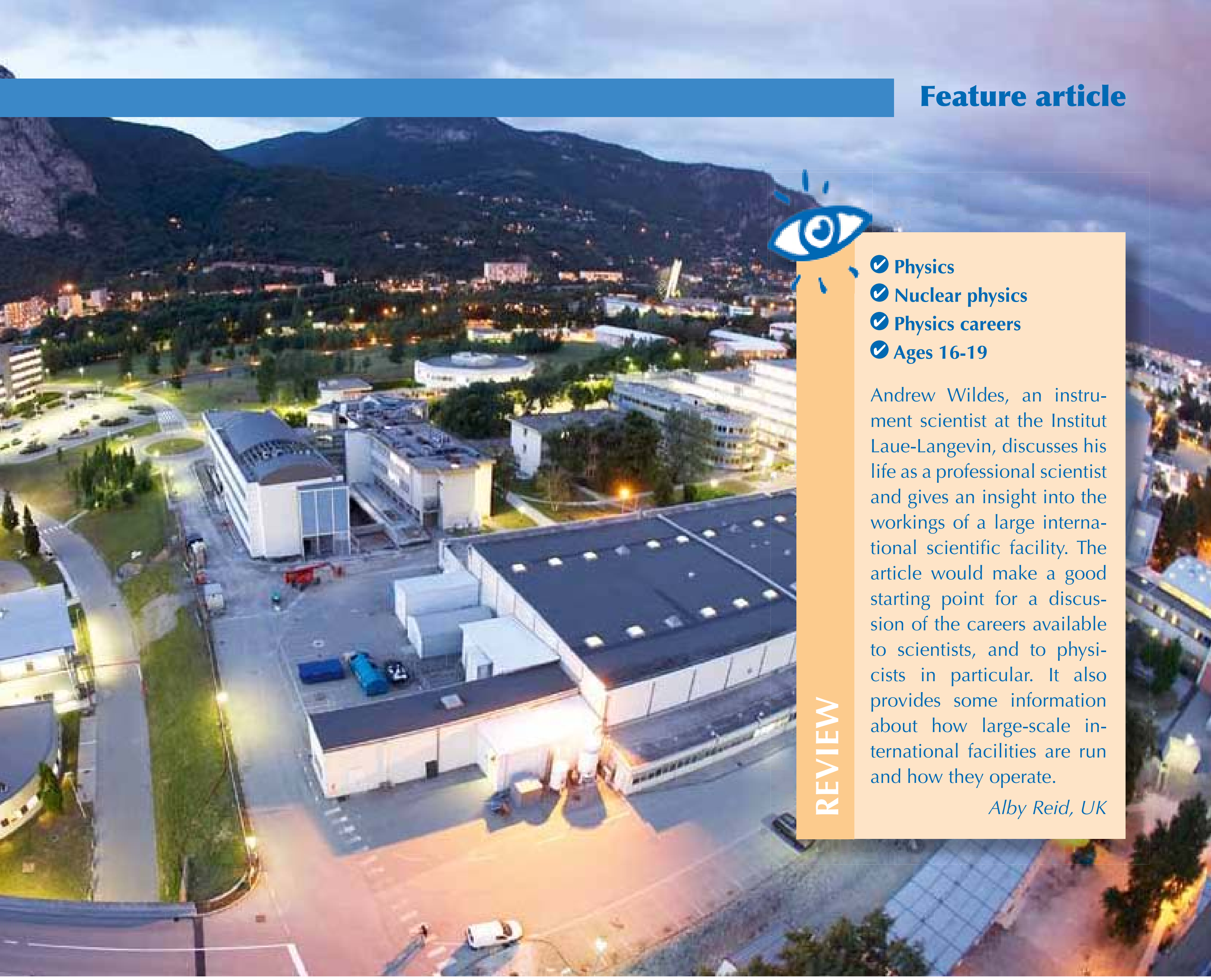
The ILL employs about 70 full-time scientists, and our work is roughly divided into three parts. First, we each have responsibility for maintaining and developing one of the instruments. I work on D17, which is a neutron reflectometer designed to measure the properties of surfaces and sub-surface interfaces buried inside a sample. The instrument is always changing as we think of ways to improve it – from boosting the neutron intensity to developing the software used to run it. The scientific experiments conducted with D17 are very broad in scope, ranging from studies of biological membranes to chemical catalysis and magnetism, so careful thought and lateral thinking are required to optimise each experiment.



D17, a neutron reflectometer designed to measure the properties of surfaces and sub-surface interfaces buried inside a sample

*Image courtesy of ILL / Briq*

Second, instrument scientists have local contact duties, which means helping visiting academics to carry out and interpret their experiments. The ILL welcomes about 2000 scientists each year who perform a total of about 750 experiments during that time. Anyone can propose an



- Physics
- Nuclear physics
- Physics careers
- Ages 16-19

REVIEW

Andrew Wildes, an instrument scientist at the Institut Laue-Langevin, discusses his life as a professional scientist and gives an insight into the workings of a large international scientific facility. The article would make a good starting point for a discussion of the careers available to scientists, and to physicists in particular. It also provides some information about how large-scale international facilities are run and how they operate.

*Alby Reid, UK*

*Image courtesy of ILL / P Ginter*

*Image courtesy of ILL /Artechnique*

VIVALDI, a typical neutron Laue diffractometer

experiment at the ILL, but they must be approved through competitive scientific evaluation. Once a proposal is accepted, the researchers are assigned *beam time* to carry out the experiment. Neutron-scattering experiments typically take between two days and two weeks, depending on the instrument and the type of experiment, and the visitors want to get the best use out of every available neutron.

This aspect of the work can be very rewarding, as my colleagues and I are exposed to new and exciting ideas, and get to meet many people. We can act as the local contact on any of the instruments at the ILL. As well as working on D17, I often act as the local contact for the three-axis spectrometers, which are instruments particularly suited for measuring structural and magnetic vibrations in crystals. Being able to work on other instruments means that I can collaborate closely with visitors as they move

*Image courtesy of ILL / Briq*

Neutron guides, down which the beams of neutrons pass

Image courtesy of ILL / Artechnique

The ILL reactor

around the facilities at the ILL – far more satisfying than being confined to one-off experiments on a single instrument.

Third, all instrument scientists have their own research programmes. Ultimately, the ILL is judged on the science that it produces, and we are encouraged to publish our work regularly. My research is in the measurement of magnetic structures and dynamics. A neutron has no electrical charge, but it does have a magnetic moment that will interact with any magnetic induction in a sample, which makes neutron scattering a sensitive probe for experiments in magnetism. One of my research programmes looks at the magnetic structures of iron-based metallic glasses, which are poorly understood, but are used widely in industry. Another programme looks at magnetic structures and vibrations in low-dimensional materials, such as thin magnetic films. Research is probably the most challenging and the most fun part of my work, as I am free to use my imagination and pursue the science that I find the most interesting.

## A career with neutrons

The division of time between the three parts of an instrument scientist's job can fluctuate enormously. You must fight to make time for all three, and sometimes it feels as though you do, in fact, have three jobs! In particular, when there are problems on the instrument or visitors needing help, it can be very difficult to find time for your own research. The reactor runs for four cycles of 50 days each year, and during these cycles it can be very busy indeed. Between cycles, there is more time to concentrate on analysing data, writing journal articles and attending conferences, although any major modifications to the instrument must also be made while the reactor is shut down. Finding time for holidays during all this can lead to friction, particularly when trying to negotiate with one's family.

Nevertheless, being an instrument scientist means having a great job, tremendous fun and plenty of career opportunities. A few years ago, neutron scattering was considered to be in decline, with many of the older neutron sources being closed down. However, there is a new wave of investment with the construction of many new and powerful neutron sources all over the world, and also with new instrumentation at established sources like the ILL. Instrument scientists are in great demand, so it is an excellent time to start a career with neutrons.

A good way to begin is to try neutron experiments during doctoral work. I used neutron scattering during my PhD for magnetic-structure determination, which taught me the basics and introduced me to many other people who use neutrons, some of whom I now work with on a regular basis. A background in physics is useful for an instrument scientist, as the techniques are all physics-based, but centres like the ILL have excellent opportunities for multidisciplinary science and also employ instrument scientists who are trained in chemistry or biology.

Am I still enjoying working at the ILL after 14 years? In Nick Hornby's novel *How To Be Good*, the main character compares science and the arts, saying one is "all empathy and imagination and exploration and the shock of the new, and the outcome is uncertain". That is how I feel about my job, every day. In fact, Hornby's character was actually talking about the arts, going on to say that science "presses this button, then that one, and bingo! Things happen. It's like operating a lift". Believe me, this is nothing like what we do, and just goes to show that Hornby should spend more time in a physics lab.

Image courtesy of ILL / Artechnique

FlatCone, one of ILL's three-axis spectrometers

## Acknowledgement

This is an updated version of an article published in *Physics World* (see Wildes, 2007) and is reproduced with kind permission of the publisher.

## Reference

Wildes A (2007) Life in the line of fire. *Physics World* **Sept 2007**: 52-53

## Resources

To learn more about neutron research, see: http://neutron.neutron-eu.net

To find out more about ILL, see www.ill.eu

To learn how to use this code, see page 1.

# Investigating the causes of schizophrenia

Image courtesy of Vlue / iStockphoto

**Laurence Reed** and **Jackie de Belleroche** discuss schizophrenia – and how functional genomics could help to identify its causes.

REVIEW

- Biology
- Medicine
- Genetic diseases
- Ages 17+

In many peoples' minds, schizophrenia is equivalent to madness. This image is at least partially caused by ignorance of the nature of the disease. This article provides basic information about schizophrenia and elaborates on the possible causes of this devastating disease.

After an unusual and clever prologue to introduce schizophrenia, the article concentrates on molecular genetic methods that have been used to investigate the causes of schizophrenia. Although the scientific detail and the terminology used might overwhelm a non-scientific audience, advanced high-school biology teachers will most likely find the information highly interesting and useful and could use it in their teaching.

For example, the article could be used in a lesson on diseases that are caused, at least in part, by genetic factors. Some knowledge of molecular genetics would be required. If the students want to investigate the subject further, the author provides references and suggests resources.

Example comprehension questions include:

1. What criteria can be used to recognise a person with schizophrenia?
2. What are the most common symptoms of schizophrenia? Which are classified as positive and which as negative?
3. Describe a method that can be used to find out if a disease is genetic or not, and if it is, to what degree.
4. Explain what you have learned about the molecular genetic basis of the causes of schizophrenia.

*Michalis Hadjimarcou, Cyprus*

Image courtesy of sandramo / iStockphoto

Japanese writing, including kanji characters

# The experience of schizophrenia 私

"Don't you think that Japanese letters – the kanji – are the most extraordinary things in the world? You can just write this symbol, 私 – which means 'I' – and it can communicate with people. It tells them where you have been and what you think; some kanji – the powerful ones – can tell them what to think and what to do.

I started to notice this at school – I saw that some kanji were much more beautiful and much more powerful than others. I took down my posters in my room and painted my favourite kanji on the walls – the good ones – not the ones that made me feel afraid. My mother became very upset by this – we argued a lot about this – and tried to paint over them.

I couldn't go home – my mother had got rid of the good kanji – everywhere I looked there were bad kanji – I even started to be able to hear them. I slept wherever I could – it had to be outside – inside, I felt so trapped. I lost lots of weight and felt very weak. Six months later, I was picked up by the police and they took me to the clinic…"

## Introduction to schizophrenia

Schizophrenia affects about 1 in 100 people and is recognised worldwide. In this article, we will discuss what schizophrenia is and what its potential causes are, and then introduce some of our recent research to investigate the combined genetic and environmental influences that can lead to this devastating condition.

The best introduction to schizophrenia is to listen to what the person with a diagnosis of schizophrenia *actually* says – and that is the introduction we have tried to give here. AB's account above is fictitious, but it is based upon a real case. The story of each person who suffers from schizophrenia is different, but there are some common and important features, which AB's case history shows.

The most striking features of schizophrenia are those of *psychosis* – meaning delusions or hallucinations. Like many words used to describe psychiatric disorders, these terms are often used quite loosely, although they have precise definitions. A *delusion* is when someone believes very odd ideas for reasons that do not justify the belief. A *hallucination* is the experience of sensations without any external physical cause for the sensation. For example, in psychosis, these hallucinations are often in the form of 'voices', which may tell the person what to do, or may talk about the person, commenting on their actions.

These features tend to appear in adolescence, and tend to be 'paranoid' – which simply means that the experiences that a person is having, refer in some way to themselves, as if they are in some way special. In AB's case, he experienced his mother's attempts to remove the kanji as threatening him directly, so he had to leave home.

Although these symptoms (known as positive symptoms) are striking, they are most often accompanied by negative symptoms – inactivity, inability to relate to people and inability to look after oneself. In AB's case, he has left school, left home and is walking the streets unable to look after himself. Negative symptoms tend to appear slowly and gradually, and tend to last the lifetime of the sufferer. Whereas current medical treatments work reasonably well with positive symptoms, negative symptoms are more difficult to treat.

## Possible causes of schizophrenia

The more we understand about a disorder, the more likely we are to be able to diagnose and treat it effectively. In particular, it is important to understand what causes the disease or contributes to it. How much do we know about the causes of schizophrenia?

Figure 1 (below) shows many of the factors that we know can influence a person's behaviour, whether or not they are mentally ill. These factors are shown in a hierarchy, or a ladder, starting from the most fundamental

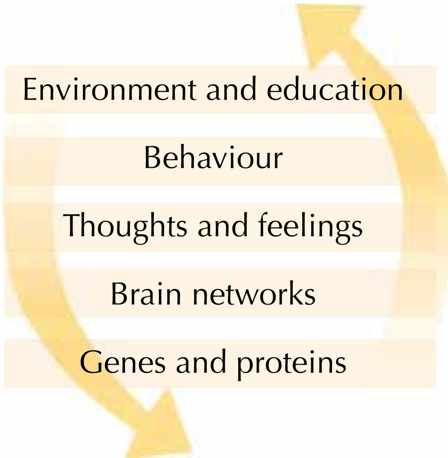



Image courtesy of Laurence Reed

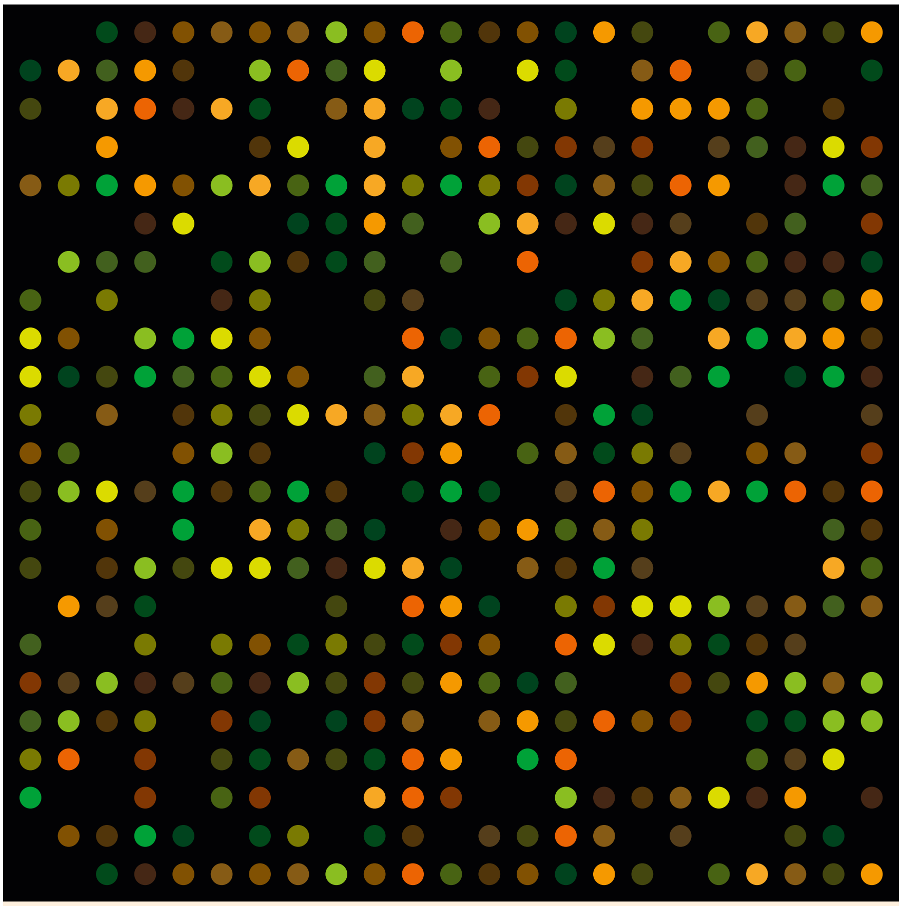
**Figure 1:** The hierarchy of causes of psychiatric disorders

individual characteristics of a person through to factors that affect many people.

At the base of this hierarchy are the genes that a person inherits from their parents. These genes make mRNA that makes proteins that make cells, including networks of nerve cells in our brains. These networks give rise to our thoughts and feelings, and hence to how we behave. The most important point is that this hierarchy doesn't just work in one direction: the environment can affect how we behave, think and feel, and can produce changes in the brain itself – that is why the arrows go in both directions – and it is not always possible to say which are the most important factors without studying the disorder carefully.

There are a number of clues about possible causes for schizophrenia. It tends to run in families, suggesting a genetic cause. However, it also tends to occur more often in conditions of overcrowding, suggesting that the environment has a role to play. Some drugs such as amphetamines cause symptoms of psychosis. All these different factors may also work together in a complicated way to cause schizophrenia – this is what we have tried to show in Figure 1.

Image courtesy of Wikimedia Commons / Guillaume Paumier



A DNA microarray. Thousands of sections of DNA (probes), each corresponding to a particular gene, are spotted onto a surface. A sample containing genes from an individual with schizophrenia is labelled a certain colour: red, for example. A second sample from a healthy person is labelled green. The two samples are introduced to the microarray, where they hybridise with the probe DNA, becoming fixed in place. Genes that are expressed in the schizophrenic individual appear as red spots, and in the healthy individual as green spots. If they are equally expressed in both, the result is a yellow spot. Microarrays allow researchers to pin-point the differences in gene expression levels between diseased and non-diseased individuals

## Evidence for a genetic contribution

One of the simplest ways of understanding how our genes contribute to any condition is to examine how that condition is shared between identical twins. If a condition is wholly genetic, then if either identical twin develops the condition, the other twin will develop the condition as well. This is called 100% concordance. If the concordance rate is less than 100% (i.e. the other twin does not always develop the condition), then other factors must contribute to the development of the condition as well. In schizophrenia, twin studies report that concordance rates amongst identical twins worldwide are 41-65%, suggesting that both genetic and non-genetic (environmental) factors play a significant part. Untangling the genetic and environmental factors is not simple, however. Furthermore, extensive DNA analysis suggests that there is no single gene involved in schizophrenia; instead, many genes seem to be linked to the condition, and their effect may be independent or cumulative.

## Genetic and environmental interactions

One way of investigating the combined effect of genes and the environment is to study which genes are active (*expressed*) in the brain regions affected in schizophrenia. Which of our genes are expressed depends, of course, on the genes encoded in our DNA but also on environmental factors. For example, smokers have a higher activity (expression) of genes that encode enzymes involved in metabolising tobacco smoke than non-smokers do. We wanted to see whether gene expression also differed between people with and without schizophrenia.

We can determine the level of gene expression by measuring the amount of mRNA and protein that are pro-

*Image courtesy of www.BrainHealthandPuzzles.com*

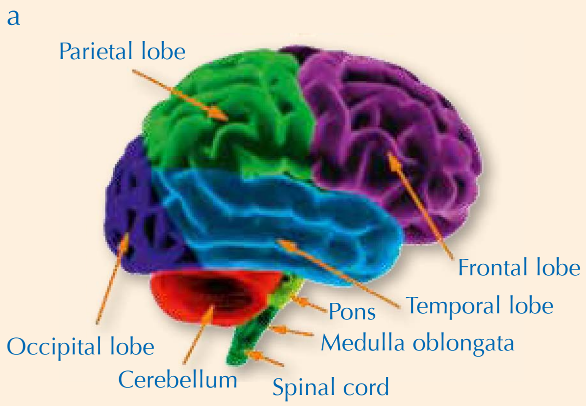



**Figure 2:** From brain to synapse: gene expression changes in schizophrenia are highly localised to the synapse

a) We analysed the prefrontal cortex in the frontal lobe (purple)

b) The cellular structure in these brain regions: a neuronal cell body with abundant tree-like branches known as dendrites, which receive numerous inputs from other neurons. The point of contact between neurons is known as the synapse (white box)

c) The synapse, including examples of genes that are expressed differently in schizophrenia. Red arrows indicate up-regulation; green ones indicate down-regulation

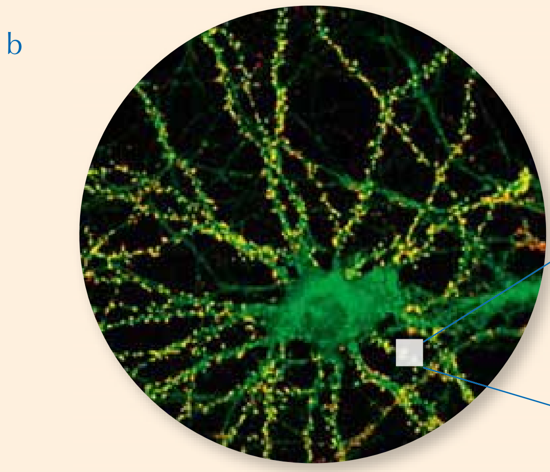



*Image courtesy of www.its.caltech.edu/~mbklab/*

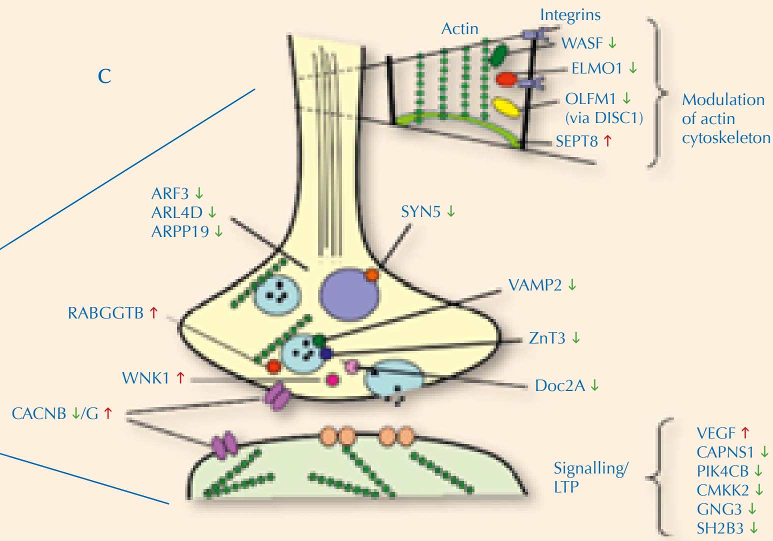



*Image courtesy of Maycox et al. (2009)*

duced from particular genes. If a gene is expressed more (or less) in people with schizophrenia than in unaffected people, then the gene may be involved in schizophrenia (either as a cause or a consequence of the disease).

Examining gene expression allows the combined influence of both the genetic effects (encoded in the DNA) and environmental effects (which may modify levels of the expression of some genes) to be investigated. Through recent technological advances, it is now possible to use microarrays, which allow the expression of more than 30 000 gene transcripts from a single individual to be analysed simultaneously (for a classroom activity to simulate microarrays, see Koutsos et al., 2009).

The genes that are expressed, of course, vary from tissue to tissue – this is one reason why different tissues *are* different. So how did we know in which regions of the brain to test the gene expression? Previous brain imaging and postmortem examinations have helped to define the main brain regions affected by schizophrenia, for example by comparing brain images of people with and without schizophrenia. One of these key brain regions is the frontal cortex, which is responsible for complex planning; damage to this region results in a loss of motivation, similar to the negative symptoms of schizophrenia.

Based on these previous analyses, therefore, we measured the changes in gene expression in the prefrontal cortex (which is part of the frontal cortex), using post-mortem samples from the brains of 28 patients with schizophrenia (the test group) and 23 healthy people (the control cases) in the UK, matched for age and gender. We also compared our results to those of a similar study using a US database (Glatt et al., 2005).

We found 49 genes that each showed a distinct difference in expression between the test and control groups, a difference of the same direction in the US and UK groups (Maycox et al., 2009). Of these 49 genes, 33 were less active (down-regulated) in patients with schizophrenia than in healthy people, and 16 were more active (up-regulated). Potential confounding factors such as exposure to drugs of abuse and alcohol, smoking or pharmacological treatment were examined, but there was no evidence that the expression of these genes was correlated with such factors.

## Which functional pathways are affected?

When we looked at the functions of the 49 genes that were expressed differently in healthy people and those with schizophrenia, we could see that they were involved in biochemical pathways that affected specific functions in the brain: synaptic neurotransmission, signal transduction, cytoskeletal dynamics (see Figure 2, page 16) and neurodevelopment.

To understand this, we need to take a closer look at brain cells: neurons. Typically, a neuron consists of a cell body, containing the nucleus; many extensions of the cell body, known as dendrites; and a single extension, called an axon, which may be as long as 1 m (see Figure 3).

Neurons are linked together via synapses, allowing electrical nerve impulses to be passed from one neuron to the next: this is known as synaptic transmission and can be initiated by the release of a specialised chemical, a neurotransmitter, into the synapse. The neurotransmitters released by one neuron interact with receptors on either the dendritic spines (swellings on the dendrites) or the cell body of the next neuron. In that second neuron, the chemical signal is converted back into an electrical signal in a process known as signal transduction. The structure of our neurons is, however, not static, but changes according to the signals we receive – our experiences. The structure of the synapse in particular can change in response to the signals it receives – this is how memories are formed, skills are learned and experiences are integrated. These changes reflect the cytoskeletal dynamics of the cell and contribute to the overall process known as synaptic plasticity.

The 49 genes that were expressed differently in people with schizophrenia, therefore, are involved in fundamental brain processes that determine how the cells in the brain respond to external signals and to nerve impulses elsewhere in the brain; these responses include a change in the density of dendritic spines at the synapse. This is consistent with the decreases in synapse density observed microscopically in post-mortem examinations of the brains of people with schizophrenia. Such changes at the synapse are known to be key to the adaptive changes that occur during learning and development – changes known as synaptic plasticity.

The unusual patterns of expression of the genes that we detected in patients with schizophrenia suggest that schizophrenia disrupts the synaptic plasticity in the prefrontal cortex, which we would expect to result in impaired learning and social interaction – features that are indeed associated with schizophrenia. Our results, therefore, suggest that schizophrenia

*Image courtesy of Animean / iStockphoto*

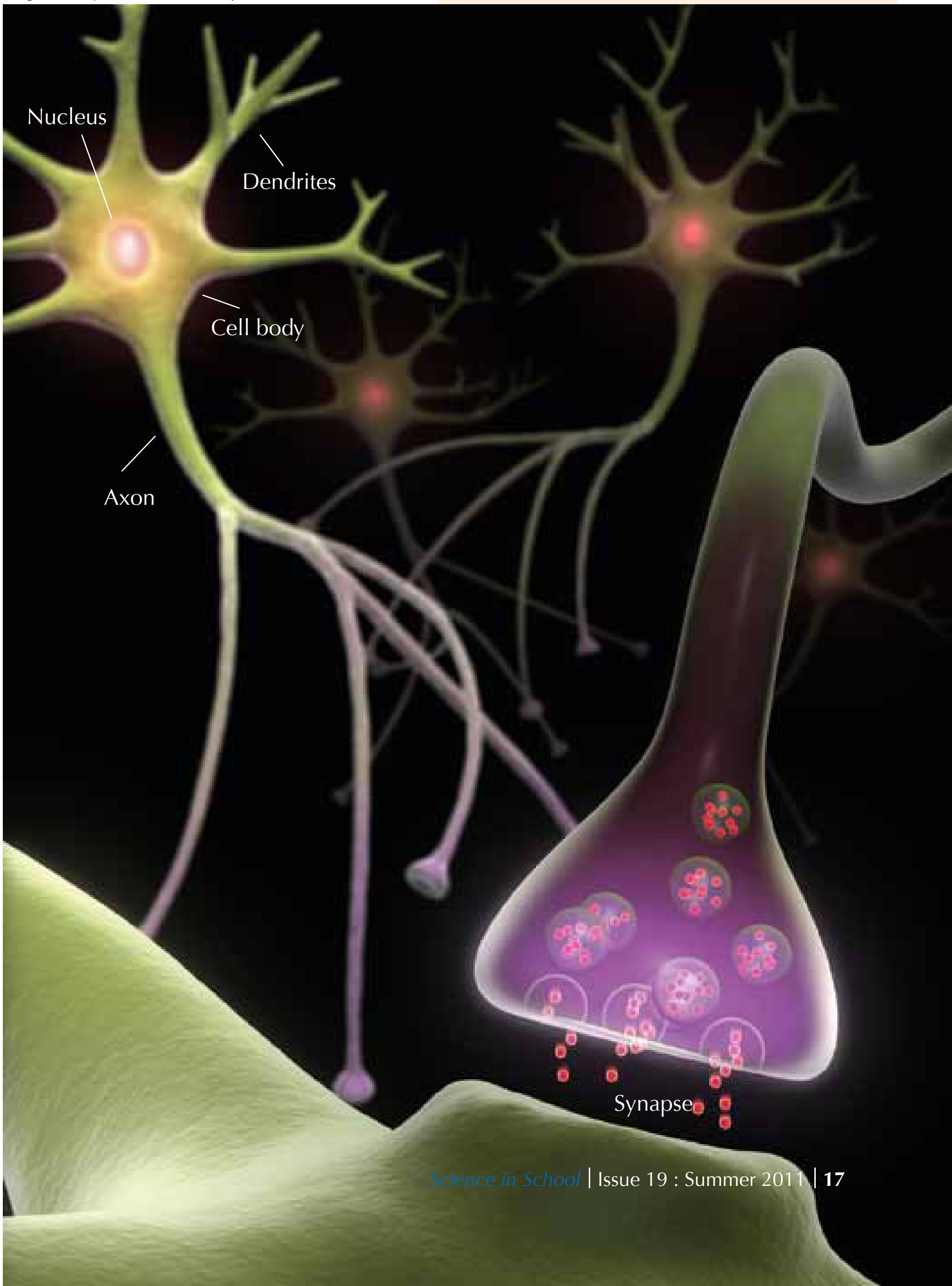



**Figure 3:** Artist's impression of a neuron, showing the release of a neurotransmitter chemical into the synaptic cleft. The neurotransmitter interacts with receptors on the adjacent cell membrane, propagating the nerve impulse

may result from a cumulative effect of multiple factors (genetic and environmental) targeting these functional pathways.

## Implications for patients

From these and similar studies, we hope to understand what changes occur at the molecular level in people with schizophrenia. Some of these molecular changes may be common to all patients with schizophrenia, whereas others may correspond to specific features such as cognitive changes that often lead to people with schizophrenia having difficulty concentrating and learning. Fundamentally, this knowledge will provide clues to the processes that take place as schizophrenia develops. If we can understand these processes, this knowledge may help us to diagnose the disease and to design better treatments for patients or for particular groups of patients. Overall, studies such as these provide 'puzzle pieces' which will help us to put together the picture of how our genes and environment contribute to the development of schizophrenia.

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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

Maycox et al. (2009) Analysis of gene expression in two large schizophrenia cohorts identifies multiple changes associated with nerve terminal function. *Molecular Psychiatry* **14**: 1083-1094. doi: 10.1038/mp.2009.18


## Resources

For more information about schizophrenia, its causes and treatment, see the website of the US National Institute of Mental Health (www.nimh.nih.gov) and the Psychological Information Online website: www.psychologyinfo.com/schizophrenia

When teaching about schizophrenia, it is important to bear in mind that it may affect one or more of your students. They may be sufferers themselves or they may have a family member who is. Schizophrenia is devastating for the whole family, so do emphasise that help is available. Support groups are available in many countries. For example, the UK organisation Rethink offers support for people with serious mental illnesses and also for their families. To find out more, see: www.rethink.org

The international, independent non-profit organisation Schizophrenia.com provides similar information and support. See: www.schizophrenia.com

Written by Christian Seeger, then a university student, the short story 'I can see things that you can't see' describes the effects of childhood schizophrenia. It can be downloaded from the *Science in School* website: www.scienceinschool.org/2011/issue19/schizophrenia#resources

Edwin H Rydberg's story 'Through the illusions', about the link between schizophrenia and smoking, won the EMBO Science Writing Prize in 2005 and can be downloaded here: www.embl.de/ExternalInfo/SciSoc/downloads/2005_embo_rydberg.pdf

If you found this article interesting, you may like to read the other medicine-related articles published in *Science in School*. See: www.scienceinschool.org/medicine

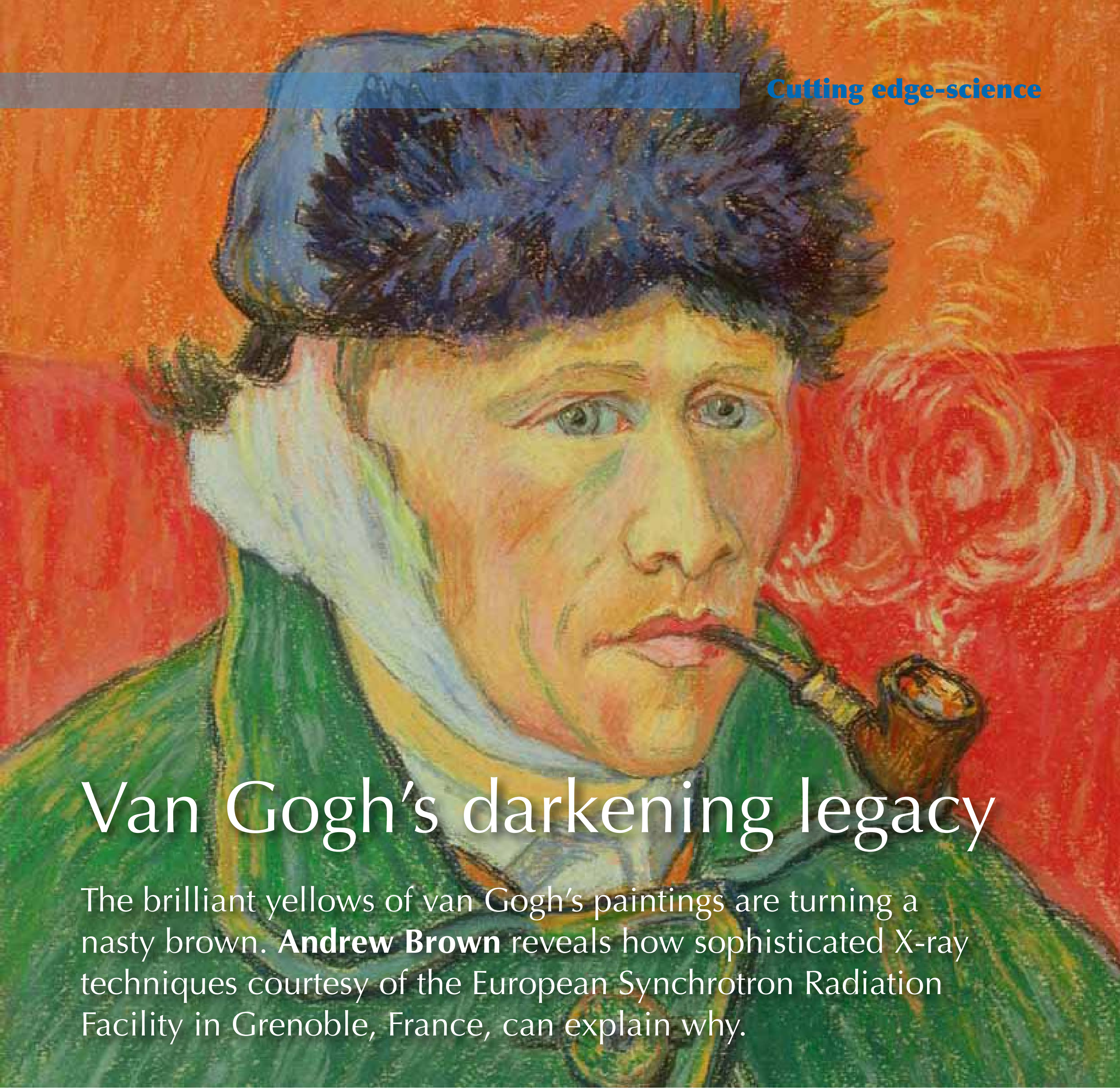

Laurence Reed is a psychiatrist working to innovate the treatment of psychiatric disorders. He has a background in neuroscience and uses brain imaging to understand how drugs affect brain function. He works at the Hammersmith Hospital in London, the foremost centre for brain imaging in the UK.

Jackie de Belleroche is a professor at the Centre for Neuroscience in the Faculty of Medicine at Imperial College London, based at the Hammersmith Hospital campus. She teaches on the undergraduate medical course and is director of the neuroscience and mental health BSc course. She leads the neurogenetics research group, which studies the molecular basis of neurological and psychiatric disorders and develops new strategies for treatment.



To learn how to use this code, see page 1.


Image courtesy of Vlue / iStockphoto



# Van Gogh's darkening legacy

The brilliant yellows of van Gogh's paintings are turning a nasty brown. **Andrew Brown** reveals how sophisticated X-ray techniques courtesy of the European Synchrotron Radiation Facility in Grenoble, France, can explain why.

*Image courtesy of the Van Gogh Museum, Amsterdam*

Along with his expansive brush strokes, Vincent van Gogh's (1853-1890) choice of vibrant and often unrealistic colours to convey mood and emotion were central to his unique style, one which had a powerful influence on the development of modern painting. The new-generation pigments of the 19th century made it possible for van Gogh to create, for example, the rich yellows used in his celebrated *Sunflowers*. These striking shades, used in many of his works, contained one of these new pigments, called chrome yellow. Unfortunately, more than 100 years after it left van Gogh's brush, chrome yellow has in some cases darkened visibly to a less than striking brown, a phenomenon that recently caught the interest of a group of scientists.

## Vincent van Gogh

An international team led by Koen Janssens of the University of Antwerp, Belgium, believes that chemical changes to chrome yellow ($PbCrO_4 \cdot xPbO$), brought about by exposure to ultraviolet (UV) light, are responsible for its colour transformation (Monico et al., 2011). The darkening of the pigment in sunlight has been known since its invention. Studies in the 1950s demonstrated that it is caused by the reduction of chromium from Cr(VI) to Cr(III) (see Figure 1 on page 20).

Until now, however, the precise mechanism was unknown, and the degradation products were uncharacterised.

1853

Image courtesy of the Van Gogh Museum, Amsterdam

Van Gogh, aged 13. Vincent van Gogh was born in 1853 in the town of Zundert, the Netherlands. Although only active as an artist for 10 years, in this short period he produced more than 800 paintings and 1000 drawings, of which he sold only one in his lifetime

1888

Image courtesy of the Van Gogh Museum, Amsterdam

*Self-portrait with Bandaged Ear*. In October 1888, van Gogh was joined in France, where he was living, by French painter Paul Gaugin. Relations between the two men were fraught, and following an argument with Gaugin on Christmas Eve, van Gogh cut off half of his left ear; a graphic indicator of the fragility of his mental health

1889

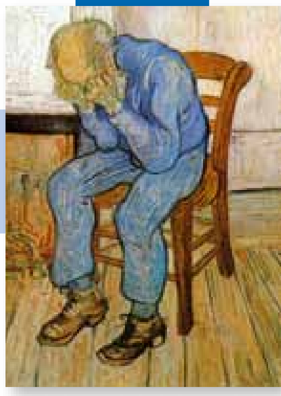


Image courtesy of Acacia217; image source: Wikimedia Commons

*Old Man in Sorrow (On the Threshold of Eternity)*. Van Gogh admitted himself voluntarily to a psychiatric hospital in Saint-Rémy, France. In the 12 months he was there, he produced many of his greatest masterpieces. This painting, completed in Spring 1890, of an old man in despair, provides a further insight into van Gogh's mental state

1890

*Image courtesy of the Van Gogh Museum, Amsterdam*

*Wheatfield with Crows*. In July 1890, only three months after leaving the hospital and in the middle of a period when his artistic vision was still developing, van Gogh walked into a wheat field and shot himself in the chest. Of all van Gogh's paintings, *Wheatfield with Crows* is probably subject to most speculation. Many believe it to be his last work, interpreting the dramatic sky filled with crows and the cut-off path as portents of his coming death

## Historic paint tubes

To address these unknowns, Janssens's team began by collecting samples from paint tubes belonging to van Gogh's contemporary, Flemish painter Rik Wouters (1882-1913). Some tubes contained unmixed chrome yellow paint, whereas others contained paint of a lighter shade of yellow, formed by mixing chrome yellow with a white substance. The researchers artificially aged the samples under UV light, expecting to observe a colour change after several months. To their surprise, in only three weeks, a thin surface layer of the lighter yellow paint had darkened significantly to a chocolate brown. The unmixed samples changed either comparatively little or not at all. "We were amazed," says Janssens.

Having identified the sample most likely to be undergoing the fatal chemical reaction, the team subjected it to sophisticated analyses based on X-rays. Much of the work was carried out at the European Synchrotron Radiation Facility (ESRF)[w1] in Grenoble, France, where two techniques, XRF and XANES, were used to detect, with extreme sensitivity, the spatial distribution and oxidation state of selected elements in the paint samples (see box on page 22).

Analyses revealed that the darkening of the thin surface layer of pigment was linked to a reduction of the chromium in chrome yellow from Cr(VI) to Cr(III); this fits with what has been observed for industrial paints based on lead chromate. In addition, the Cr(III)-containing degradation product was identified for the first time as $Cr_2O_3 \cdot 2H_2O$, better known as the pigment viridian green. But how can a green pigment's presence explain the brown colouration observed in the researcher's experiments? The scientists suspect that the reduced chromium in viridian green is formed during the oxidation of the oil component of the paint. It is this oxidised form of the oil, together with the mixture of green and any remain-

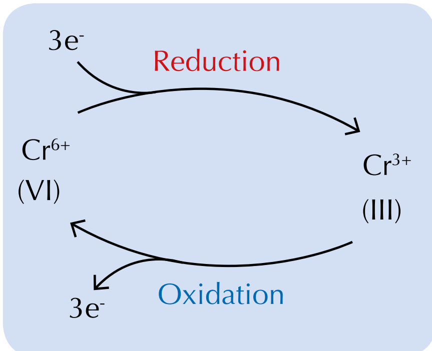



**Figure 1:** Oxidation state. In chemistry, for reactions that involve electron transfer, oxidation is defined as the loss of electrons, whereas reduction is defined as the gain of electrons. We can describe these oxidation-reduction (redox) processes in terms of the oxidation state of the reactants: oxidation is a reaction involving an increase in oxidation state, whereas reduction involves a decrease. For example, two of chromium's most common oxidation states are III and VI, corresponding to $Cr^{3+}$ and $Cr^{6+}$ species, respectively. We can say that $Cr^{6+}$ is reduced when it gains three electrons to form $Cr^{3+}$ because its oxidation state decreases from VI to III

- Chemistry
- Physics
- Science and conservation
- Deterioration by chemical processes
- Ages 15–18

This article nicely links science with art and conservation studies. The sophisticated techniques used by the scientists reveal chemical changes in the pigments, which occur many decades after van Gogh's paintings were finished.

The article is a useful way of demonstrating to students that there is always a scientific explanation for why artefacts change with time. It would be best used as a teaching aid in chemistry lessons and for students aged 16-18. The article could also be used to teach selected chemistry topics, such as oxidation and reduction.

To develop the students' understanding of the chemistry behind the research, you could ask the following questions:

1. The work of the scientists described in this article shows that sulphide ions may be the chemical species responsible for the reduction of chromium. Write down separate equations for the reduction of lead chromate ($PbCrO_4$) by the sulphide-ion-containing compounds $H_2S$ and PbS. Hint: Cr(VI) compounds are oxidising agents.
2. The scientists suggest that sulphate-containing compounds in the paint used by van Gogh may be a source of sulphide ions. Try to think of other ways in which paintings could be exposed to sulphide ions.
3. Silver jewellery darkens over time when in contact with air. Write down the equation for the reaction responsible for this. Note that this is not a simple displacement reaction.

To show that lead chromate darkens when exposed to sulphide ions, you can demonstrate the following experiment in class:

1. Synthesise lead chromate in a beaker by adding any water-soluble lead salt, such as lead(II) acetate, $Pb(CH_3COO)_2$, or lead(II) nitrate, $Pb(NO_3)_2$, to an equal volume of potassium chromate solution, $K_2CrO_4$. Dilute solutions (~ 0.03 M) will be sufficient.
2. A yellow precipitate of lead chromate will form instantly. Filter off the residual liquid using a funnel and filter paper. In a fume hood, gently dry the precipitate with a blow dryer, ensuring that it does not dry completely.
3. Prepare a dilute aqueous solution of hydrogen sulphide ($H_2S$), by dissolving 50 mg sodium sulphide ($Na_2S$), in 90 ml water. Add the resulting solution to 10 ml hydrochloric acid (HCl, 0.1 M). Stir the mixture.
4. Fill a rubber balloon with air and connect it to a small glass Drechsel's bottle containing a few millilitres of the dilute hydrogen sulphide solution (see image below). Aim the resulting stream of hydrogen-sulphide-gas-containing air onto the surface of the lead chromate precipitate.
5. The precipitate will instantly turn brown. You have simulated and accelerated the darkening process observed in van Gogh's paintings by many orders of magnitude.

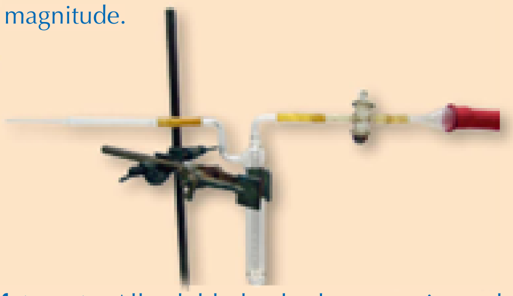


Image courtesy of Vladimir Petruševski

**Safety note**: All soluble lead salts are toxic, and soluble chromates are toxic (above 0.003 M) and suspected to be carcinogenic. Potassium chromate may cause sensitisation and / or ulcers after contact with the skin. There is limited evidence that lead chromate is carcinogenic. It may also cause harm to unborn children, so should not be used if the teacher or any of the students are, or may be, pregnant. Hydrogen sulphide is a toxic gas with a very unpleasant odour.

Perform the above experiment in a fume hood and wear safety goggles and gloves. Dispose of all chemicals according to your local safety regulations. See also the general safety note on the *Science in School* website (www.scienceinschool.org/safety) and on page 73. You may find it helpful to consult the CLEAPSS student safety sheets on chromium and lead[w5].

*Vladimir Petruševski, Republic of Macedonia*

REVIEW

ing yellow pigment, that may be the root of the brown colouration.

Using the X-ray techniques, the researchers were also able to show that the mixed, lighter-coloured paint contained sulphur compounds. They concluded that these compounds were somehow involved in the reduction of chromium, explaining why there was comparatively little darkening in the unmixed paint samples.

## Shining the X-ray beam on van Gogh

Having uncovered the chemistry of the reaction in isolated paint samples, the scientists sought to ask whether the darkening of the surface layer of

## Studying art with a synchrotron

The chemical characterisation of precious works of art can be problematic. It is only possible to take a few very small samples for analysis, and these often consist of a diverse mixture of complex compounds in heterogeneous states of matter. To overcome these challenges, scientists use techniques based on X-rays. The more powerful and precise the X-rays are, the better the quality of the analysis. The most potent X-rays available are produced by a synchrotron source[w2] (see Figure 2). In this study, two spectroscopic techniques at ESRF were used on the paint samples: XRF and XANES.

*Image courtesy of EPSIM 3D / JF Santarelli, Synchrotron Soleil; image source: Wikimedia Commons*

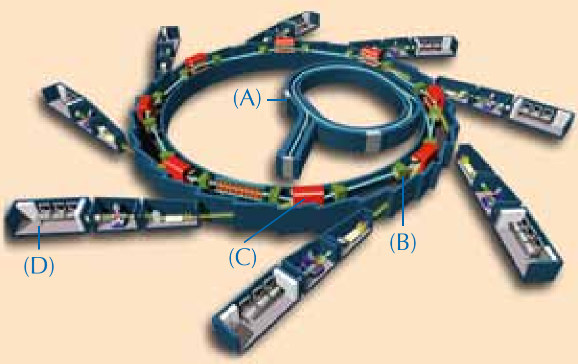



**Figure 2:** Synchrotrons. There are currently about 50 synchrotrons in the world, of which ESRF is the most powerful in Europe. The X-ray beams produced by ESRF are a thousand billion ($10^{12}$) times brighter than those produced by a hospital X-ray machine. Their high intensity and narrow diameter (100 µm to <1 µm) permit the detection of minute concentrations of elements at sub-micro-scale resolution and from the smallest of samples. The production of X-ray beams in a synchrotron begins with electrons (A), which are accelerated to a very high energy (six billion electron-volt, 6 GeV, at ESRF) before being injected into a storage ring (B) where they circulate in a vacuum at close to the speed of light. Strong magnetic fields (C) cause the electrons to change direction, resulting in the emission of the X-ray beams, which are directed towards the experimental stations (D) that surround the storage ring

### XANES

XANES spectroscopy relies on the physics of X-ray absorption. Atoms of a particular element absorb X-rays in a characteristic way. By looking at the X-ray absorption spectrum, which is the pattern of X-ray absorptions of a particular sample (Y axis) against the energy range of the X-rays (X axis), it is therefore possible to identify the sample's constituent elements. High-resolution X-ray absorption spectra are usually collected in particular energy regions (called XANES) that are close to an *absorption edge* of an element of interest (see Figures 3 and 4). Such detailed spectra can show what oxidation state the element of interest is in. This information was of great interest to the researchers.

**Figure 3: X-ray absorption**

(A) X-ray absorption spectrum. Let us take a pure sample of an element. If X-rays directed at the sample are scanned through a range of energies, at certain energies the rays will be strongly absorbed, giving rise to a series of *absorption edges*. Each edge corresponds to the specific energy required to eject an electron occupying a particular energy level in the element's atoms (see Figure 4). Thus, a 'pattern' of absorption edges emerges that is specific to atoms of that element, a sort of atomic hallmark. In a sample that consists of multiple unidentified elements, it is possible to deduce the identity of those elements by observing the pattern of absorption edges (the X-ray absorption spectrum). The purple, green and red arrows correspond to the ejection of electrons from the first (n=1), second (n=2) and third (n=3) energy levels, respectively

(B) An absorption edge in detail. When we zoom in on a seemingly smooth absorption edge, we can find that it is decorated with a number of smaller impressions relating to correspondingly smaller absorptions. The region at the leading edge of the absorption edge (shaded in blue) is referred to as an X-ray Absorption Near-Edge Structure (XANES, the dark blue box) and it corresponds to electrons making transitions to unoccupied energy levels close to those that they left. The XANES region was used by the scientists analysing the van Gogh paintings, because it can provide information on the oxidation state of the atoms in a sample: atoms that have different oxidation states contain different numbers of electrons (see Figure 1, on page 20). This alters the value of their energy levels and therefore their XANES spectra

BACKGROUND

*Image courtesy of the Van Gogh Museum, Amsterdam*

*Image courtesy of Nicola Graf*

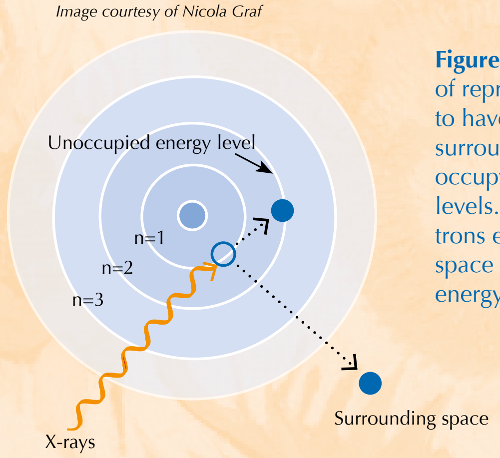



**Figure 4:** A common way of representing an atom is to have a central nucleus surrounded by electrons occupying distinct energy levels. X-rays can eject electrons either into surrounding space or into an unoccupied energy level

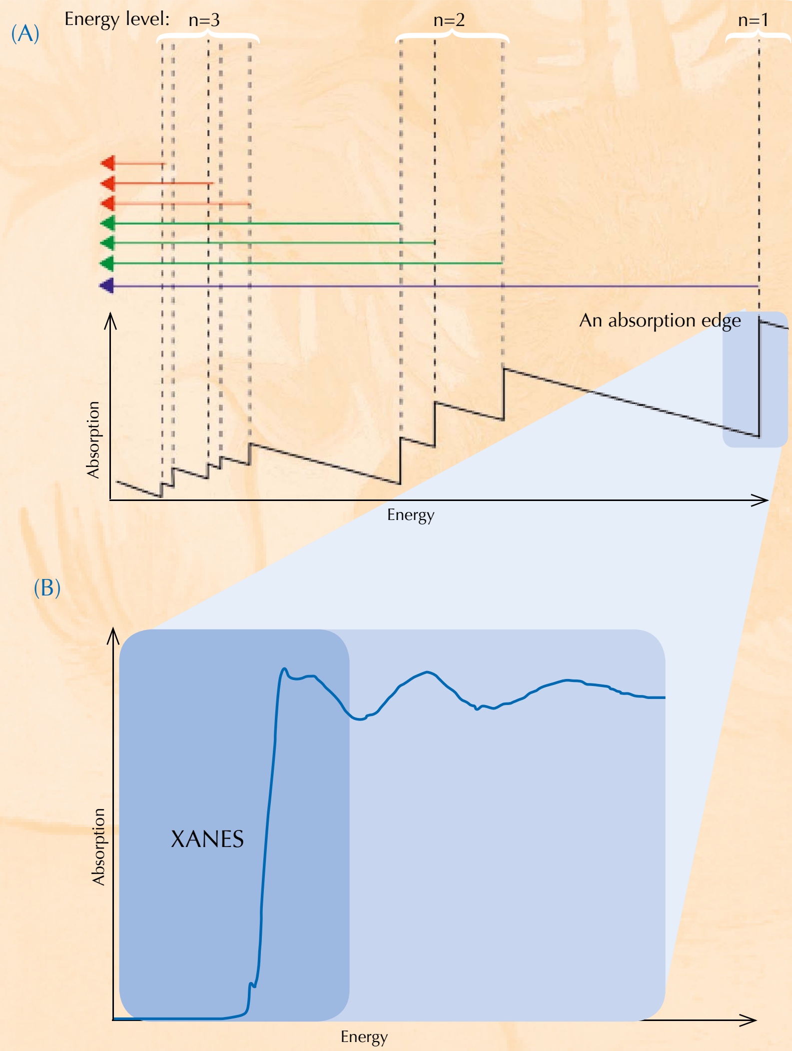



*Image courtesy of Atenderholt; Image source: Wikimedia Commons*

*Image courtesy of M Blank; Image source: Wikimedia Commons*

## XRF

When they absorb X-rays, atoms enter an unstable excited state. When they then return to a more stable state, they emit secondary X-rays in a process called X-ray fluorescence (see Figure 5). The pattern of X-ray fluorescence (XRF) produced by a particular sample, called the XRF spectrum, can be used to map the distribution of elements across a given area. In contrast, XANES can only be performed on an isolated point in the sample. By combining the information obtained with both XRF and XANES, the authors were able to form a detailed picture of the chemistry of the paint samples.

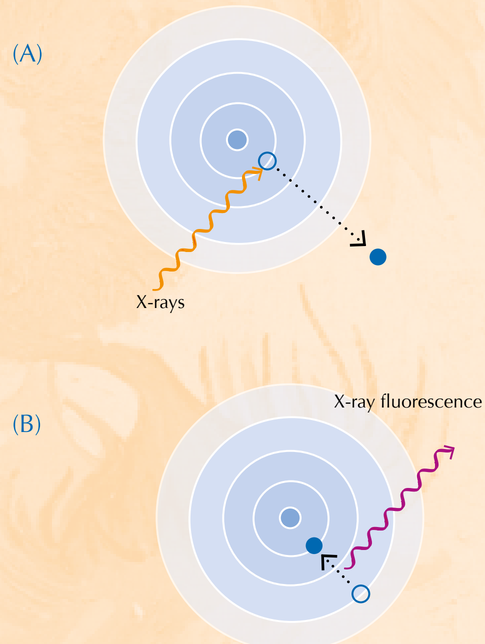



*Image courtesy of Nicola Graf*

**Figure 5:** X-ray fluorescence. The ejection of an electron following X-ray absorption leaves an atom in an unstable excited state (A). The most important way in which the atom relaxes back to a stable state (B) is by the emission of secondary X-rays, or XRF signals. This is a consequence of electrons filling the vacancy left behind by the ejected electron

Image courtesy of the Van Gogh Museum, Amsterdam

*View of Arles with Irises*

## CLASSROOM ACTIVITY

### Science in art

What do you and your students think? Should science be used to halt the degradation of important works of art, or even return them to their original state? Or should the ravages of time be accepted and even valued as historical evidence? Leave your comments in our online discussion forum: www.scienceinschool.org/forum/vangogh

yellow paint in samples taken from two of van Gogh's paintings, *View of Arles with Irises* (1888) and *Bank of the Seine* (1887), could be attributed to the same phenomenon.

XRF spectroscopy was used to map the chemistry of the region encompassing the interface between the dark surface layer and the underlying unaltered yellow layer of paint. XANES spectra were collected at specific points within these regions. The findings mirrored those of the previous experiment: the reduced form of chromium, Cr(III), was found in the darker surface layer, suggesting that its presence here was responsible for the brown colouration. Furthermore, Cr(III) was not distributed uniformly, but occurred in loci that also featured sulphate- and barium-containing compounds. Chemically, these regions resembled the lighter yellow paint samples from the previous experiment, further supporting the researchers' conclusion that sulphur compounds were involved in reducing chromium (see equation to the right). Because of their white colour, van Gogh blended powders containing such compounds with chrome yellow to create the lighter shades that were vital in creating the brightly lit scenes characteristic of a certain period of his life.

One important question remained: how does the supposed trigger for the reaction, UV light, actually work? Quite simply, it supplies the reactants with the energy needed to overcome the activation energy barrier, allowing the reaction to proceed (see Figure 6 on page 25).

### What can be done?

Janssens's team has exposed the chemistry that underlies the darkening of van Gogh's paintings. But can we use this knowledge to rescue the artist's work? Ella Hendriks of the Van Gogh Museum[w3] in Amsterdam, the Netherlands, has her doubts: "Ultraviolet light…is already filtered out in modern museums. We display the paintings in a controlled environment to maintain them in the best possible condition." Part of what constitutes a controlled environment is the maintenance of a low temperature in the museum. As a general rule, an increase of 10 °C increases the rate of a reaction by a factor of 2-4, and reduction of chromium is no exception to this.

Image courtesy of Nicola Graf

electrons

$$8CrO_4^{2-} + 20H^+ + 3S^{2-} \leftrightharpoons 8Cr^{3+} + 20OH^- + 3SO_4^{2-}$$

Cr(VI) Cr(III)

The role of sulphur. Janssens's team believe that sulphide ions ($S^{2-}$) may be the chemical species responsible for the reduction of chromium. Sulphide ions are an electron-rich form of sulphur, which can readily donate electrons to and thereby reduce Cr(VI) to Cr(III), by the above redox reaction.
Barium was also associated with areas containing reduced chromium, possibly because compounds containing this element were a source of sulphide ions

Image courtesy of Nicola Graf

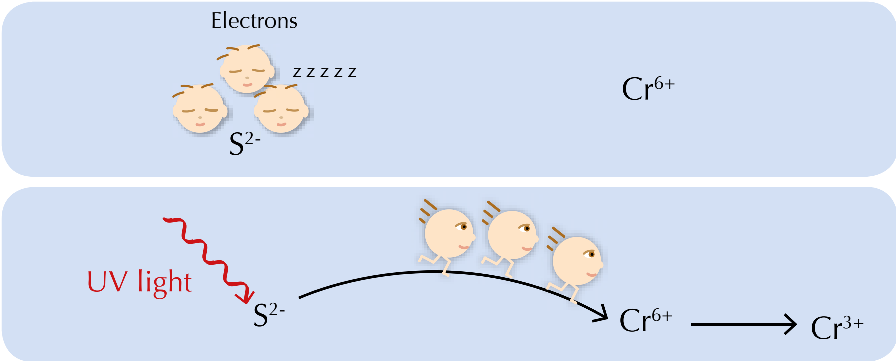



**Figure 6:** Electrons involved in a redox reaction cannot move spontaneously from one reactant to another. UV light supplies the electrons belonging to sulphide ions (the form of sulphur thought to be involved in the darkening reaction) with sufficient energy for them to become mobile enough to be transferred to Cr(VI)

So if both UV levels and temperature are already controlled, what more can be done for van Gogh's paintings? There is a more radical alternative: rather than slow the degradation process, attempt to reverse it altogether. "Our next experiments are already in the pipeline," says Janssens. "Obviously, we want to understand which conditions favour the reduction of chromium, and whether there is any hope of reverting pigments to their original state in paintings."[w4]

Although turning back the hands of time in this way would be the supreme solution, Janssens admits that the prospect of reverting the altered pigment to its original colour is at present rather unlikely. Nevertheless, the scientists' work offers us reassurance that we are doing everything we can to preserve van Gogh's paintings, and hope that future generations can appreciate what this great artist achieved.

## Reference

Monico L et al. (2011) Degradation process of lead chromate in paintings by Vincent van Gogh studied by means of synchrotron X-ray spectromicroscopy and related methods. 2. Original paint layer samples. *Analytical Chemistry* **83**: 1224-1231. doi: 10.1021/ac1025122

## Web references

w1 – The European Synchrotron Radiation Facility (ESRF) is an international research institute for cutting-edge science with photons. ESRF is a member of EIROforum, the publisher of *Science in School*. To learn more, visit: www.esrf.eu

w2 – For more details of how synchrotron radiation is used in research, see:

Capellas M, Cornuéjols D (2006) Shipwreck: science to the rescue! *Science in School* **1**: 26-29. www.scienceinschool.org/2006/issue1/maryrose

Capellas M (2007) Recovering Pompeii. *Science in School* **6**: 14-19. www.scienceinschool.org/2007/issue6/pompeii

w3 – To learn more about Vincent van Gogh and his art, visit the excellent website of the Van Gogh Museum: www.vangoghmuseum.nl

A section of the museum's website also contains primary- and secondary-school teaching resources: www.vangoghmuseum.nl/vgm/index.jsp?page=110&lang=en

w4 – To listen to an interview with Koen Janssens talking about his research on van Gogh's paintings, broadcast on BBC Radio 4, see: www.bbc.co.uk/programmes/b00yjs49

w5 – CLEAPSS is a UK advisory service providing support in science and technology teaching, on the subjects of health and safety; risk assessment; sources and use of chemicals; and living organisms and equipment. For more information, see: www.cleapss.org.uk

For safety advice on using lead, chromium and their compounds, see the student safety sheets, which can be downloaded for free here: www.cleapss.org.uk/free-publications

## Resources

Images and an animation of the investigation of the historic paint samples can be found at: www.vangogh.ua.ac.be

To learn more about the science of preserving art, see:

Leigh V (2009) The science of preserving art. *Science in School* **12**: 70-75. www.scienceinschool.org/2009/issue12/katylithgow

If you enjoyed reading this article, take a look at other cutting-edge research articles in *Science in School*. See: www.scienceinschool.org/cuttingedge

To read all other *Science in School* articles about research at ESRF, see: www.scienceinschool.org/esrf

Andrew Brown recently graduated from the University of Bath, UK, with a degree in molecular and cellular biology. During his course, he took a year out to work for the agrochemical company Syngenta where he specialised in light and electron microscopy. He now works as an intern for *Science in School*, based at the European Molecular Biology Laboratory in Heidelberg, Germany.

To learn how to use this code, see page 1.

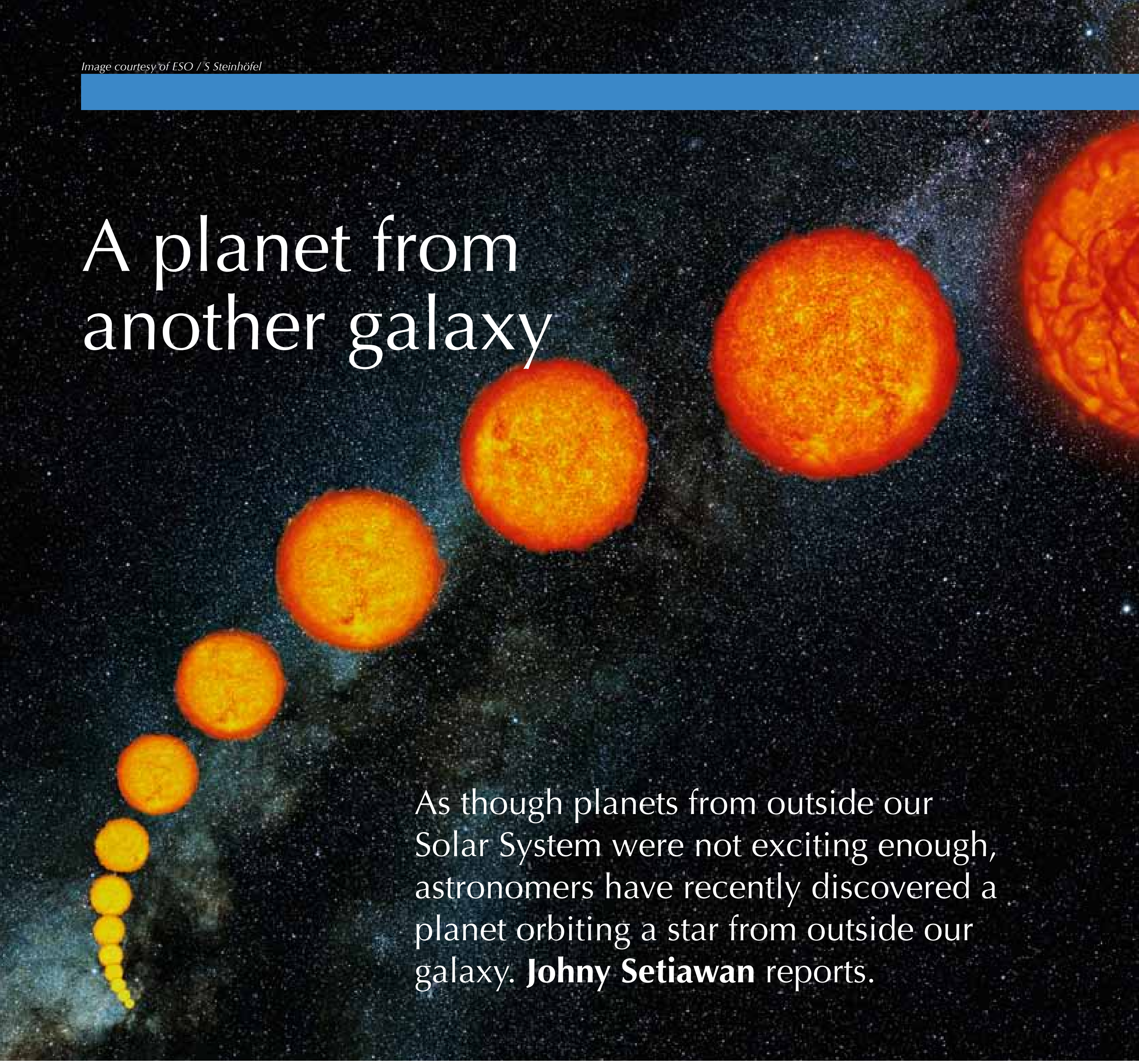


Image courtesy of ESO / S Steinhöfel

# A planet from another galaxy

As though planets from outside our Solar System were not exciting enough, astronomers have recently discovered a planet orbiting a star from outside our galaxy. **Johny Setiawan** reports.

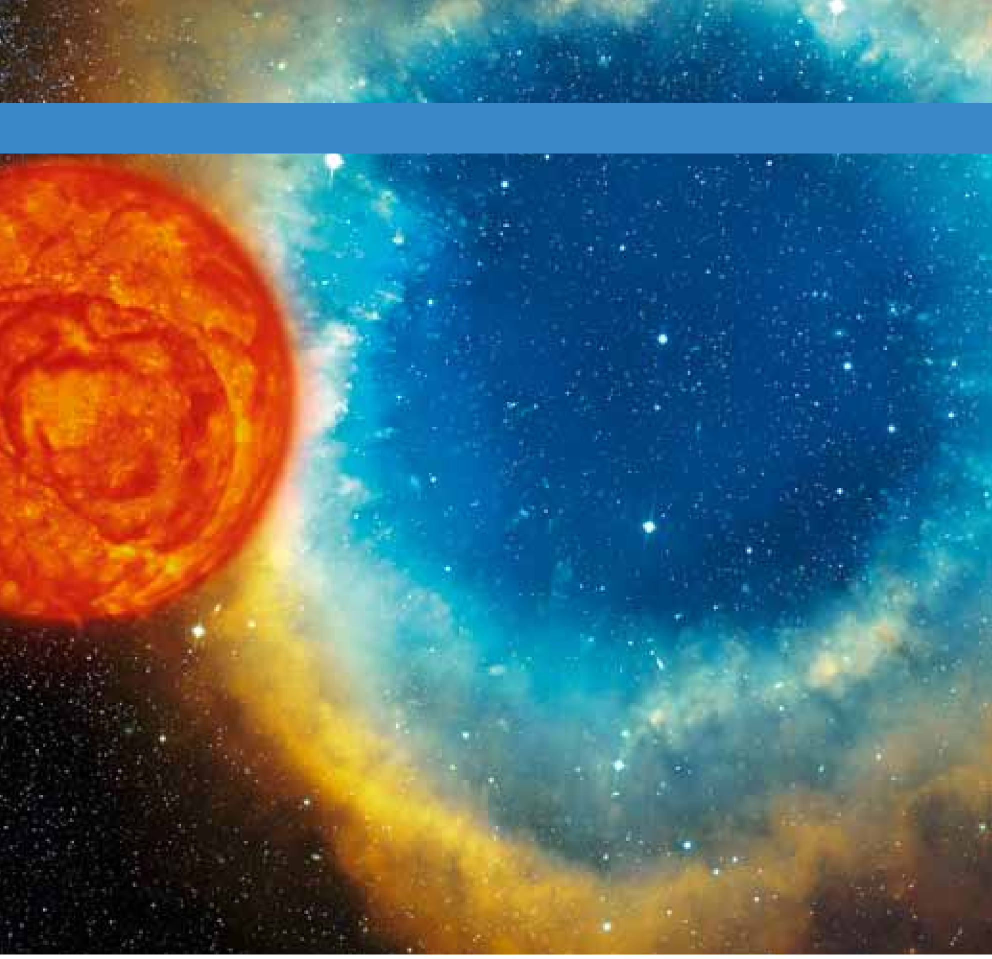
For two decades, astronomers have known that there are planets beyond our Solar System (Wolszczan & Frail, 1992). Orbiting other stars, they are known as extrasolar planets or exoplanets. So far, more than 500 exoplanets have been detected, the majority of which orbit stars with characteristics similar to those of the Sun (as described in Jørgensen, 2006). In particular, more than 90% of the stars hosting exoplanets are in the same evolutionary phase as the Sun – the *main-sequence* phase, during which stars burn hydrogen (see image above).

Our research group at the Max Planck Institute for Astronomy in Heidelberg, Germany, however, concentrates on the search for planetary companions around stars that are not in the main-sequence phase, but in later evolutionary stages. These include what is known as the *red giant* phase, during which the star expands to hundreds of times its original diameter. The detection of planets around such giant stars is important for the study of the evolution of planetary systems. In particular, it allows us to predict the future of our own Solar System.

Recently, our team have successfully detected a planet around the star HIP 13044, which has left the red giant phase.

## An extragalactic star

The star HIP 13044, which is about 2000 light years away from our Solar System in the southern constellation of Fornax ('the furnace'), is significantly different from other known stars with planets. In particular, it has a very low abundance of the metal iron – less than 1% of what the Sun has. High metal abundance (stellar metallicity) is important in the *core ac-*



Stars like our Sun spend most of their lifetime in the main sequence, slowly burning their primary nuclear fuel, hydrogen, into the heavier element helium. This is the stage our Sun is in.

After several billion years, their fuel is almost exhausted and they start swelling, pushing the outer layers away from what has turned into a small and very hot core. These 'middle-aged' stars become enormous, and thus cool and red, and are known as red giants.

After the red giant phase, the star enters the horizontal-branch phase, during which the energy source is helium fusion in the core, and hydrogen fusion in the shell surrounding the core. This is the stage in which the star HIP 13044 is now.

Unlike much more massive stars, these Sun-like stars do not end their existence in dramatic explosions, but die peacefully as planetary nebulae, blowing out everything but a tiny remnant, known as a white dwarf.

To learn more about the evolution of stars, see Boffin & Pierce-Price, 2007 (small stars), Székely & Benedekfi, 2007 (massive stars) and the Langton Star Centre website[w1]

*cretion* model of planet formation: the more metal there is in the star system, the higher the probability of forming a planet. Given these low iron levels, we had not expected to find a planet around HIP 13044.

What makes this star particularly interesting, however is, the fact that HIP 13044 is one of a group of stars crossing our galaxy, the Milky Way, and orbiting the centre of the galaxy on similar orbits; such a group is known as a stellar stream. The Helmi stream, to which HIP 13044 belongs, is known to have its origin outside our galaxy, (Helmi et al., 1999). It is assumed that the gravitational pull of the Milky Way drew these stars into our galaxy.

This is the first time that astronomers have detected a planetary system in a stellar stream of extragalactic origin. Because of the great distances involved, there are no confirmed detections of planets in other galaxies. But this cosmic merger has brought an extragalactic planet within our reach.

## Detecting exoplanets

Although the star HIP 13044 and its attendant planet HIP 13044 b are now within the Milky Way, they are still

REVIEW

- Physics
- Chemistry
- Astronomy
- Earth science
- Ages 17-19

Before reading this article, I had not known that our galaxy, the Milky Way, hosts streams of stars from other galaxies. I was fascinated by the story of these alien visitors and an exoplanet on a galactic trip.

For teaching purposes, I thought first of gravity – how powerful it can be, how universal and over what long distances it works. The article could also be easily applied to other topics in physics, chemistry, astronomy and earth science: mass, the Doppler effect, spectroscopy (absorption and emission lines), metal abundance in the Universe, the mutual attraction of celestial bodies and planetary accretion. It could be used as the basis of a discussion on cosmology, the history of the Solar System and the search for Earth-like planets and extraterrestrial life.

It could also be used for a discussion of how science works: how hypotheses and theories begin with new observations and discoveries, and are based on previous scientific achievements and established techniques, by scientists who are open to possibilities that had never before been considered.

*Marco Nicolini, Italy*

2000 light years from Earth; whereas the star can be seen with a telescope, the planet itself is far too small to observe directly. How, then, did we detect it?

Using a technique known as radial velocity, we looked for tiny telltale wobbles of the star caused by the gravitational tug of its orbiting companion. By examining the stellar spectral lines at intervals, we detected changes to those lines (see diagram below). These indicate changes in the velocity of the star along the line of sight and can reveal the presence of an unseen low-mass companion, such as a planet. Although there are other techniques for detecting exoplanets (for example microlensing, as described in Jørgensen, 2006), the radial velocity method has proved the most successful. For these precise observations, we used the high-resolution spectrograph FEROS attached to the 2.2 m MPG / ESO telescope at the European Southern Observatory's La Silla facility in Chile[w2]. This observatory is equipped with world-class instruments for detecting extrasolar planets.

## Looking into our future?

HIP 13044 b is one of the few exoplanets known to have survived the red giant phase of its host star, during which the star expands massively after exhausting the hydrogen fuel supply in its core. The host star HIP 13044 has now contracted again and entered the *horizontal branch*, burning helium in its core. This is the first exoplanet detected around a horizontal-branch star. The discovery of HIP 13044 b, therefore, is particularly intriguing when we consider the distant future of our own planetary system; the Sun is already halfway through its life and is expected to become a red giant in about five billion years.

Not only the existence of the newly discovered planet is interesting; its characteristics are also unusual. HIP 13044 b has a mass at least 1.3 times that of Jupiter, the biggest planet in our Solar System, and orbits at a distance 0.12 that of the distance between the Sun and Earth (0.12 astronomical unit). Because it is so much closer to its host star than we are to the Sun, HIP 13044 b orbits its host star in only 16.2 days rather than the year it takes Earth. Such a small planetary orbit is common for stars in the main sequence, like the Sun, but is unusual for stars in late evolutionary phase like giant stars.

Our team hypothesises that the planet's orbit might initially have been much larger, but that it moved inwards during the red giant phase. If the planet had been closer to the star, it may not have been so lucky: the star is rotating relatively quickly for a horizontal branch star, and one explanation is that HIP 13044 swallowed its inner planets during the red giant phase, which would make the star spin more quickly (for an explanation of why this is, see Carlberg et al., 2009).

Although HIP 13044 b has so far escaped the fate of these inner planets, the star will expand again in the next stage of its evolution. HIP 13044 b, having survived this long, may nonetheless be about to be engulfed by its star. This could also foretell the demise of even our outer planets – such as Jupiter – when the Sun approaches the end of its life.

Radial velocity technique for detecting exoplanets. If a star is sufficiently close to Earth, we can detect its light. The light contains information about the elements in the star's atmosphere, which can be in the form of spectral lines (black lines on the coloured spectrum, right); these can be detected with, for example, a high-resolution spectrograph.
In a star without a companion, the position of these lines in the spectrum shows no periodic change. However, the presence of an orbiting companion, such as a planet (blue ball) causes the star (orange ball) to wobble; the star's movement is shown as a yellow line. As the star (not the planet!) moves towards us (towards the right of the diagram), the change in its radial velocity is negative (as shown in the graph, below); as it moves away from us (to the left), the change in its radial velocity is positive. This is reflected by a change in the position of the spectral lines: a positive change in radial velocity corresponds to a shift towards red wavelengths in the spectrum; a negative change corresponds to a shift towards the blue end. These changes are used to detect the presence of a companion orbiting the star

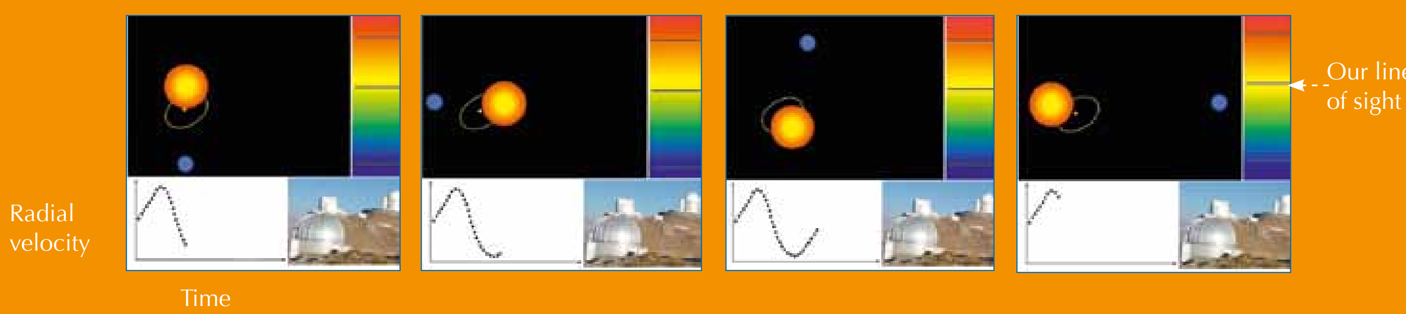



*Image courtesy of Johny Setiawan*

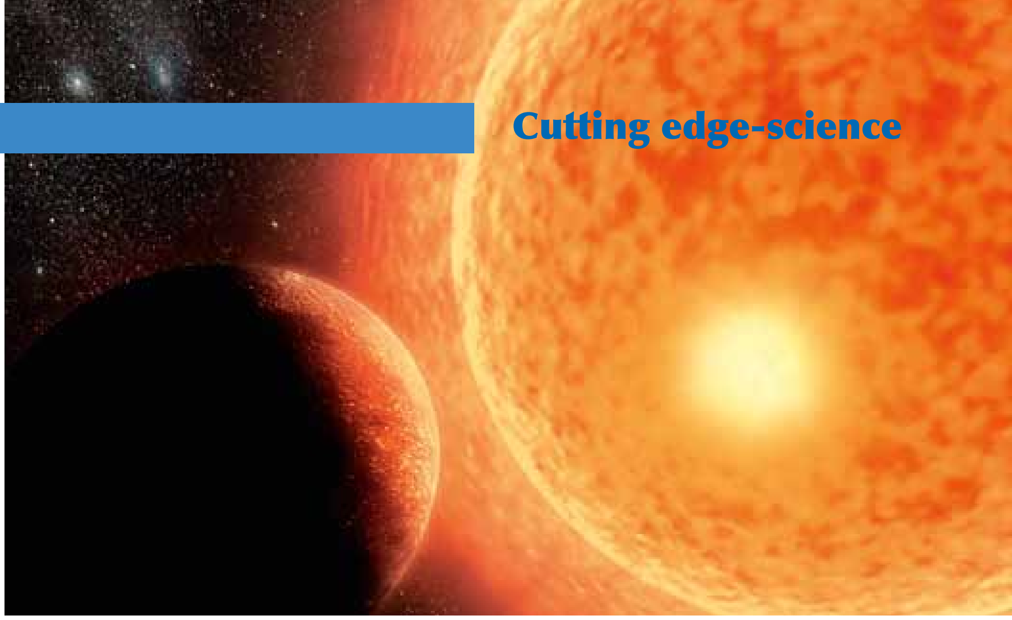


Image courtesy of ESO / H H Heyer

An artist's impression of the exoplanet around the star HIP 13044

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Download the article free of charge from the *Science in School* website (www.scienceinschool.org/2011/issue19/exoplanet#resources), or subscribe to *Nature* today: www.nature.com/subscribe

Jørgensen UG (2006) Are there Earth-like planets around other stars? *Science in School* **2**: 11-16. www.scienceinschool.org/2006/issue2/exoplanet

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Wolszczan A, Frail DA (1992) A planetary system around the millisecond pulsar PSR1257 + 12. *Nature* **355**: 145-147. doi:10.1038/355145a0

Download the article free of charge from the *Science in School* website (www.scienceinschool.org/2011/issue19/exoplanet#resources), or subscribe to *Nature* today: www.nature.com/subscribe


## Web reference


w1 – The Langton Star Centre supports research groups of school students who are involved in cutting-edge scientific research. To learn more about the life cycle of a star, see the resources on the website: www.thelangtonstarcentre.org

To find out how physics teacher Becky Parker established The Langton Star Centre, see:

Stanley S (2011) Schoolhouse scientists. *Science in School* **19**: 69-72. www.scienceinschool.org/2011/issue19/parker

w2 – The European Southern Observatory (ESO) builds and operates a suite of the world's most advanced ground based telescopes. ESO is a member of EIROforum, the publisher of *Science in School*. To learn more about ESO, see: www.eso.org

To see all *Science in School* articles about ESO, see: www.scienceinschool.org/eso


## Resources

To find out more about the research described in this article, see:

Setiawan J et al. (2010) A giant planet around a metal-poor star of extragalactic origin. *Science* **330(6011)**: 1642-1644. doi: 10.1126/science.1193342

To learn about the European Space Agency's search for exoplanets, see:

Fridlund M (2009) The CoRoT satellite: the search for Earth-like planets. *Science in School* **13**: 15-18. www.scienceinschool.org/2009/issue13/corot

To learn more about exoplanets, see the press kits (in English and Spanish) on the ESO website: www.eso.org/public/products/presskits

To find out how to build your own spectrometer and examine the spectral lines of the Sun, see:

Westra MT (2007) A fresh look at light: build your own spectrometer. *Science in School* **4**: 30-34. www.scienceinschool.org/2007/issue4/spectrometer

If you enjoyed this article, you may find the complete series of *Science in School* articles about fusion in the Universe interesting. See: www.scienceinschool.org/fusion

To browse all astronomy-related articles published in *Science in School*, see: www.scienceinschool.org/astronomy

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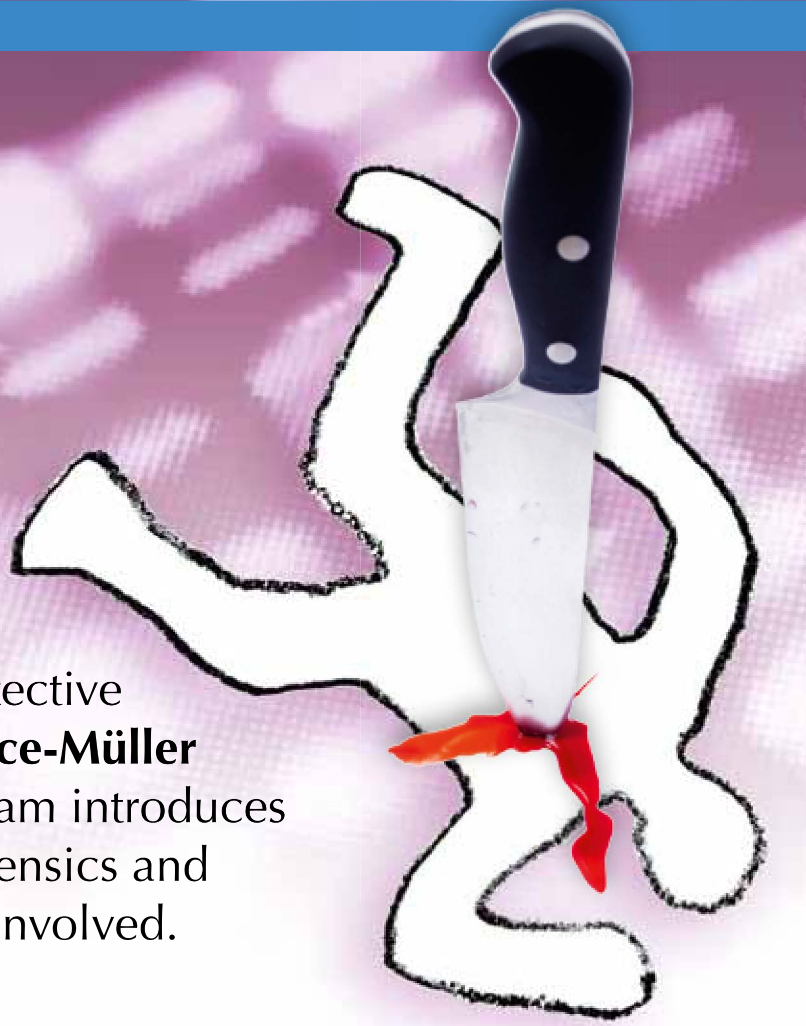
Johny Setiawan studied physics at the Albert Ludwig University in Freiburg im Breisgau, Germany, before obtaining a PhD in astronomy and astrophysics in 2003. He then moved to the Max Planck Institute for Astronomy in Heidelberg, Germany, where his research focuses on extrasolar planets of both evolved and young stars. In particular, he is working on spectroscopic data of the optical spectrographs dedicated to planet search programmes.


To learn how to use this code, see page 1.



*Images courtesy of udokant, Paul Cowan and blackred / iStockphoto*

# The DNA detective game

With the help of a detective game, **Kenneth Wallace-Müller** from the Gene Jury team introduces the use of DNA in forensics and the ethical questions involved.

Peter has been found dead in his hotel room. Who could have killed him? What DNA evidence can you find at the crime scene and how can you analyse it? Can you find the murderer?

The game is most suitable for students aged 10-15 [note that the reviewer suggested using the activity with older students]. You will need time to print, cut and laminate the resources, 30 minutes to play the game, and additional time for discussion.

Before introducing the game, explain how DNA fingerprinting works. Do not forget to point out the differences between DNA fingerprinting (profiling) and sequencing the complete genome. You may find Hodge & Wegener (2006) and the resources on the Gene Jury website[w1] helpful.

## Materials

To run the game, you will need the following materials, all of which can be downloaded from the Gene Jury[w1] website.

- Worksheets (one per student or group)
- One set of DNA evidence cards to be laid out around the crime scene; see Figure 1.
- One set of suspects' statements (green) and the pathologist's report (purple); see Figure 2.
- Several sets (one per group) of suspect (blue) and victim (purple) DNA profile cards; see Figure 3.
- Several sets (one per group) of cards showing the DNA profiles found around the crime scene and of the people in the DNA database; see Figure 4. Do not give these materials to the students until later.

Ideally, all the materials except the worksheets should be printed in colour and laminated.

## Preparing the game

Six students take the roles of the suspects: Alex, Eric, Lisa, Olivia, Melinda and Dave. Give each of the students the statement card and DNA

**Figure 1:** The DNA evidence cards


Blood found on windowsill

Skin cells found on knife handle

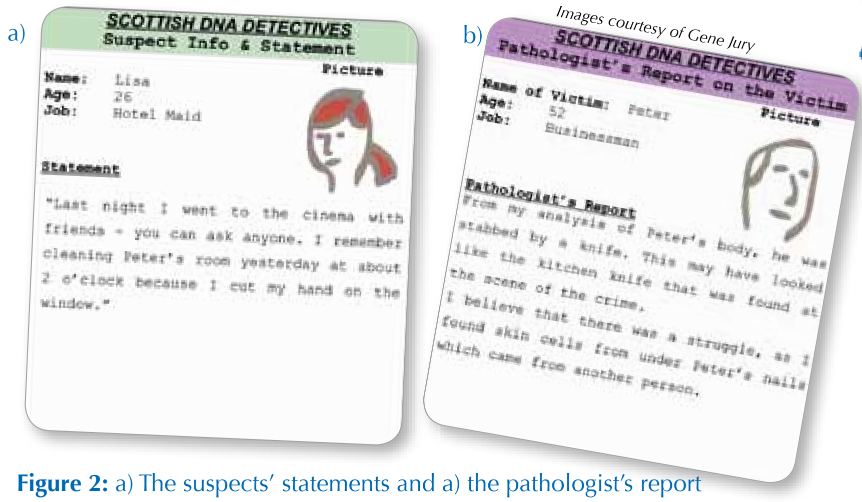



**Figure 2:** a) The suspects' statements and a) the pathologist's report

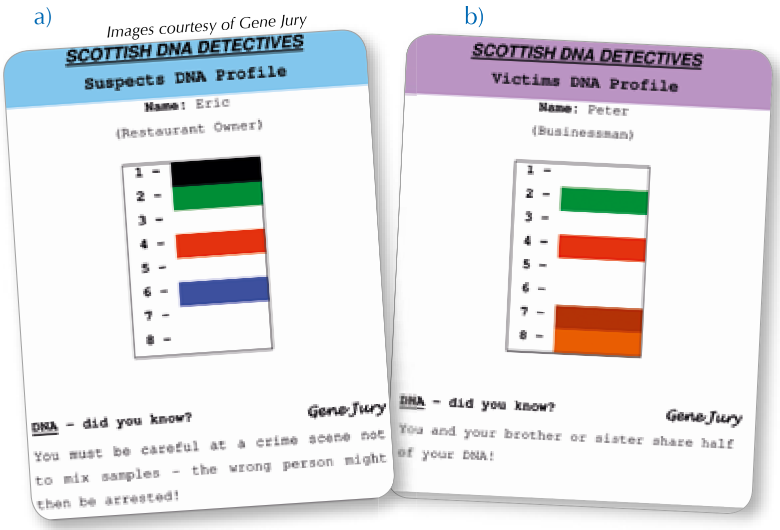



**Figure 3:** The DNA profile cards of a) the suspects and b) the victim

REVIEW

✔ Biology
✔ DNA structure
✔ Ages 16+

This article offers a brilliant idea for teaching about the DNA molecule, and should motivate quite a number of students. It would be feasible in any standard school classroom, so long as the teacher allocates enough time for preparation.

*Andrew Galea, Malta*

* Note that the author uses the activity with younger students.

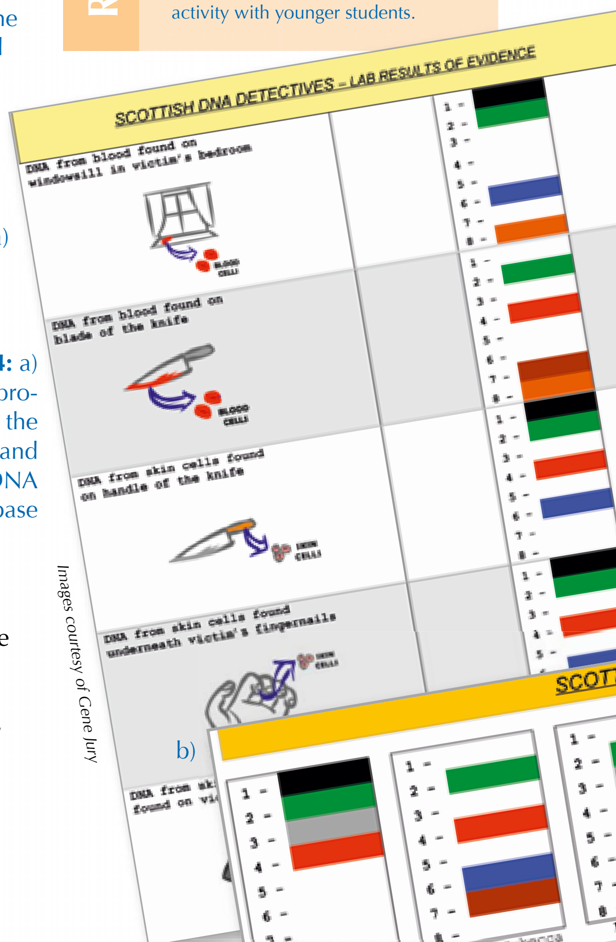



**Figure 4:** a) DNA profiles from the evidence and b) the DNA database

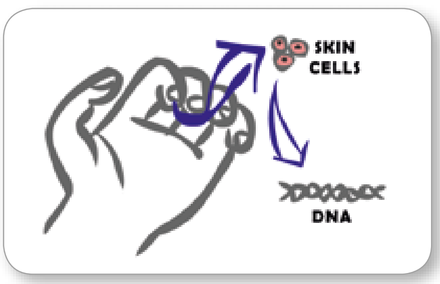
profile card for their character.

One student is the police pathologist; give him or her the pathologist's report card and the DNA profile card of the victim.

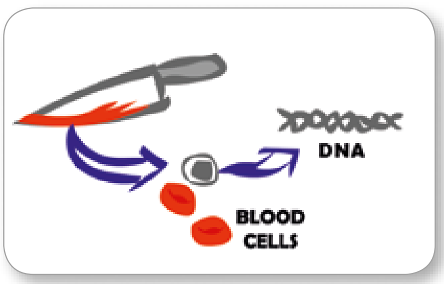
Optionally, one student represents the victim: lying on the floor with a knife (or substitute) nearby. Even if you choose to imagine the victim and weapon, place the five DNA evidence cards (the knife blade, the knife handle, the victim's fingernails, the victim's jacket, and the blood on the window) around the 'crime scene'.

The rest of the class are the investigators, working in groups of about four. Give these students the worksheets.

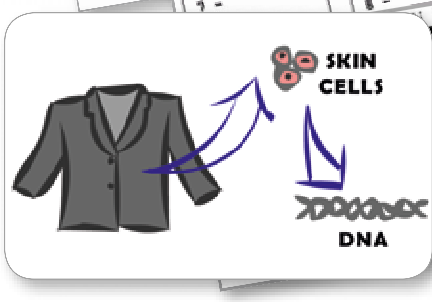
The teacher plays the role of the chief inspector and the forensics




Skin cells found under victim's fingernails




Blood found on knife blade




Skin cells found on victim's jacket

laboratory. He or she needs the sheets with the DNA profiles from the evidence and the DNA database.

## Playing the game

The flow diagram (Figure 5) illustrates the game sequence.

1. Chief inspector (teacher): read out the introduction to the class.

*Last night in the local hotel, a terrible crime was discovered. Peter, a well-known businessman, was found dead in his hotel room by two guests, Alex and Olivia, at 11pm. They immediately telephoned the police, who arrived soon afterwards. The pathologist examined the body, and estimated the time of death at 9pm, not long after Peter had finished dinner.*

*Peter had held a dinner party that evening with some friends to celebrate finishing writing, by hand, a book about his life. The party had taken place in the hotel dining room with his five friends, who had all stayed that night in the hotel. After the police arrived, the five guests and the hotel maid were woken, and assembled downstairs to be questioned.*

2. Investigators: look around the crime scene and use Table 1 to record any evidence (the DNA evidence cards in Figure 1; one example has already been entered in the table below).
3. Investigators: take your evidence to the forensics laboratory (the teacher) for analysis.
4. Police pathologist: read out the report on your analysis of the victim's body.
   Investigators: make notes about the pathologist's report.
5. Suspects: read out your statement of who you are and what you know about the crime (Figure 2).
   Investigators: using Table 2, make notes on the suspects' statements. Who do you think could be the murderer? All of them have given you their permission to sample their DNA but the police chief inspector has allowed you to take samples from only three of the suspects. Decide which three to sample.
6. Investigators: take a sample from each of your three chosen suspects (the samples have already been analysed by the laboratory, to make things easy for you).
   Suspects: give your DNA profile card (Figure 3a) to the investigators who ask for it.
7. Forensics laboratory: give the investigators the results of the DNA analysis from the crime scene (the victim's DNA profile, Figure 3b) and the DNA profiles found on the evidence, (Figure 4a).
   Investigators: does the DNA profile of any of your three suspects match the DNA profiles on any of the evidence found at the crime scene?
8. Investigators: using Table 3, what can you conclude from your comparison? Do you know who the murderer is? Remember what the suspects said in their statements, and do not forget that not all the DNA found at the crime scene necessarily has anything to do with the murder.
9. Chief inspector: did any of the groups identify the murderer? If not, announce that the investigators can compare the samples taken from the crime scene against a national DNA database (Figure 4b). You may choose to let the investigators compare their samples against the database, even if they have identified a murder suspect.
   Investigators: can you find a match between the evidence collected at the crime scene and the profiles in the DNA database (Figure 4b)? Who do you think is the murderer?
10. Chief inspector: once all the groups have decided who they think the murderer is, reveal the murderer's identity as Eric and read out his confession.

*After his arrest, Eric decided to confess to the police what happened that night.*

*In his former life, Eric had been arrested several times for carrying and taking drugs. He had decided to forget his old life, and he now owned*

**Table 1:** Collecting the evidence at the crime scene

| Type of sample (e.g. blood or skin) | Where was it found? |
|---|---|
| Skin | On the victim's jacket |
| | |

**Table 2:** Evidence from the suspects

| Name | Notes from suspect's statement | Do you suspect him / her? | Ask for sample? (Select only three) |
|---|---|---|---|
| Alex | | | |
| Eric | | | |
| Lisa | | | |
| Olivia | | | |
| Melinda | | | |
| Dave | | | |

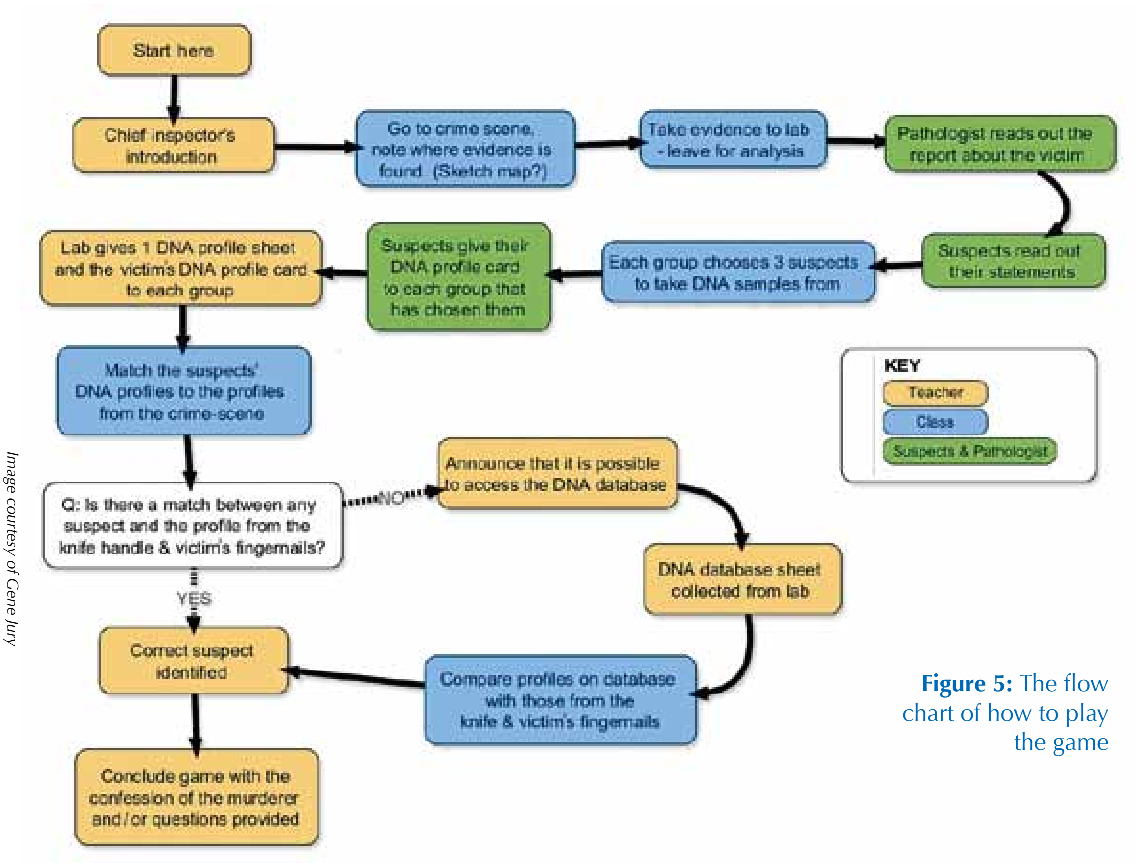



**Figure 5:** The flow chart of how to play the game

*Image courtesy of Gene Jury*

*Image courtesy of dimiraos / iStockphoto*

*his own restaurant. Only a handful of people knew about his past, including Peter. Peter also had a dark past, and had known Eric very well. He decided to write about Eric and include details of his criminal activities in the book of his life story.*

*On the evening of the murder, Peter was celebrating the completion of his book by having dinner in the hotel with some friends, including Eric. During the conversation over the meal, Eric realised what Peter had written about him in his book, and how it could damage his reputation.*

*After dinner, all the guests stayed in the restaurant for coffee. Eric finished and went for a walk in the gardens to plan a way to silence Peter and steal his book. He crept into the kitchen and stole a knife, concealing it in his trouser pocket. Eric hatched a plan to meet Peter in his hotel bedroom for a chat, and – when Peter was least expecting it – to kill him using the knife.*

*Everything went according to his plan, but while Peter lay dying on the floor covered in blood, Eric heard footsteps walking past the room, and as he grabbed the book, he panicked, accidentally dropping the knife.*

*After quickly walking back to his room, he hid the book in his suitcase in order to destroy it later. He planned to use the excuse of an early business meeting to leave first thing the next morning.*

## Ethical questions

The game raises several ethical questions about the forensic uses of a DNA database. Below are some questions, together with possible answers, which can be used in a discussion. Remember that there are no correct answers here: governments, doctors, scientists and the general public may all have different opinions.

**Table 3:** The investigators' conclusions

| Sample from the crime scene | Does this profile match any of your suspects? If so, which? | Do you think this sample is from the murderer? |
|---|---|---|
| Blood on the windowsill | | |
| Blood on the knife blade | | |
| Skin cells on the knife handle | | |
| Skin cells under the victim's fingernails | | |
| Skin cells on the victim's jacket | | |

BACKGROUND

## How well does the game reflect reality?

The DNA profiles used in the DNA detective game are loosely based on band patterns from real profiles. Profiling involves forensic scientists looking for *markers* (small sequences) within DNA, the sizes of which vary between people. By including multiple markers, all with size variations between individuals, it is possible to create an almost unique profile for each person. In early profiles, these marker sizes were shown as bands of different sizes (rather like barcodes), but these days, profiles are now often represented as graphs.

In the UK, 10 pairs of markers plus a sex chromosome marker are analysed to ensure that two given people can effectively be differentiated. This would give a match probability (the chance of finding two people with the same profile) of less than one in a billion (1 000 000 000). The chance of finding a match is higher between family members, whose DNA is shared, and identical twins, who have identical (or nearly identical) DNA profiles. Profiles generated in England and Wales are currently stored in the UK National DNA Database.

The DNA detective game reflects reality in that profiles, loosely represented here as the original 'barcodes', are generated for every individual as well as from crime scene stains (such as blood, skin cells or hair). The eight markers used in the game are more than enough to differentiate the six suspects from one another. As in reality, each profile in the game is compared with those of other suspects of a crime being investigated and other profiles found at the crime scene. It can also be compared to a profile database of suspects and criminals and of samples from previous crimes.

The main problems that forensic scientists face in generating real-life profiles are crime scene stains containing DNA from several people, stains containing very small amounts of DNA, or stains containing degraded DNA. These problems can be overcome to an extent by profiling all of the suspects and those who may have visited the crime scene, by developing newer profiling techniques and by using larger numbers of DNA markers.

DNA profiling technology is used as a complement to other investigative techniques and, in court, DNA-based evidence should be backed up with other non-DNA-based evidence, such as video or witness statements.

*Image courtesy of PaulCowan / iStockphoto*

1. Why do you think the murderer's DNA was in the DNA database? How might you have found the murderer if his DNA had not been in the database?

*The murderer had been convicted on several occasions for drug possession, and each time, his DNA was put onto the DNA database. If the murderer had not been in the database, DNA samples would have to be taken from all of the suspects (rather than just three). More 'traditional' evidence would also have been useful, such as fingerprints, closed-circuit television if available, and deduction from the suspect and witness statements.*

2. What do you think should happen to the DNA profiles taken from suspects who turn out to be innocent? Should their DNA profiles be put into the DNA database or should they be destroyed? What is the situation in your country?

*In Scotland, a suspect's DNA must normally be destroyed immediately if they are not found guilty. For serious crimes such as murder, an innocent suspect's DNA may be kept in the database for three years. DNA from convicted criminals is kept permanently in the database.*

*Until recently, in England, DNA was taken from everybody who was arrested and put into the database – even the DNA from people who were later proven innocent was kept permanently. Following a decision in 2008 by the European Court of Human Rights, the situation in England will be changed to one similar to the Scottish system.*

3. What do you think should happen to the DNA profile of a 12-year-old shoplifter? Should children's DNA be in the DNA database – and does it depend on how serious the crime is? What about a 12-year-old convicted of murder?

*In Scotland, the minimum age at which someone is considered to be* *responsible for a crime that they commit is eight. Some people believe that children should not be treated and labelled as criminals, because they should be given a chance to learn from their mistakes. Other people believe, however, that young offenders are more likely to re-offend, and that putting their DNA in the database will help to catch them if they do commit a crime in the future.*

4. After playing this game, what do you think about using DNA databases for solving crimes? Can you think of any reasons why you might not want your DNA on a database?

*Although a DNA database is very useful in catching criminals and identifying dead bodies, there are several reasons why people wouldn't want their DNA on a database. For example:*

- *Some people are concerned about the chances of mix-ups in the database, or that someone may hack into the database and change information.*
- *Criminals themselves might be concerned, as if they re-offend, they might be caught more easily.*
- *Many people are worried about privacy, as DNA can reveal personal information. Although the DNA profile itself is fairly uninformative, the original cell sample or DNA may also be stored; although unlikely, it is possible that the DNA could be sequenced from that sample.*
- *An answer which might not be raised by the class is proportionality – this is the term used to ask the question: is putting everybody's DNA onto a criminal DNA database going to solve or cause more problems? These may be financial or administrative, as well as ethical and moral.*
- *A balance must be found between valid personal concerns such as these, and the benefits of using a criminal DNA database. These are identified by discussion and enforced by law.*

## Acknowledgements

This game was developed as a collaborative effort by the Gene Jury team – Heather McQueen, Fiona Stewart, Sarah Keer-Keer and Kenneth Wallace-Müller – at the University of Edinburgh, UK. For more details, see the Gene Jury website[w1].

Thanks to Sandra Couperwhite, forensic scientist with Lothian and Borders Police, for her help with the box 'How well does the game reflect reality?'

## Reference

Hodge R, Wegener AL (2006) Alec Jeffreys interview: a pioneer on the frontier of human diversity. *Science in School* **3**: 16-19. www.scienceinschool.org/2006/issue3/jeffreys

## Web reference

w1 – The Gene Jury project located in Edinburgh, UK, aims to engage children aged 7-14 with bioethical issues surrounding the use of modern genetic technology, via interactive workshops and teaching activities.

For more information and to download materials visit the Gene Jury website: www.biology.ed.ac.uk/projects/GeneJury

To download the materials for the detective game, visit: www.biology.ed.ac.uk/projects/GeneJury/databaseDNAdetectives.html

For more details of DNA profiling, see: www.biology.ed.ac.uk/projects/GeneJury/databaseTeachersResources.html

For a list of more materials about DNA on the Gene Jury website, see: www.biology.ed.ac.uk/projects/GeneJury/learningzone_whoseDNA.html

## Resources

The University of Edinburgh has also developed a discussion activity on the use of DNA databases in criminal investigations and for medical research. To download the instructions, visit: http://sibe.bio.ed.ac.uk/resources

For more detective mysteries in the science classroom, see:

Gardner G (2006) The detective mystery: an interdisciplinary foray into basic forensic science. *Science in School* **3**: 35-38. www.scienceinschool.org/2006/issue3/detective

For a forensic activity based on chromatography, see: www.csiro.au/resources/colour-forensics-activity.html

Kenneth Wallace-Müller is a graduate in biological sciences from the University of Edinburgh where, as a member of the Gene Jury team, he compiled a variety of DNA database and forensic teaching resources. Kenneth is currently studying law and economics in Vienna, Austria.


To learn how to use this code, see page 1.

# Amber: an introduction to organic chemistry

Did you know that the electron and electricity are named after amber, the ‘gold’ of the Baltic Sea? **Bernhard Sturm’s** teaching unit based on this fossilised resin introduces not only conductivity but also many other characteristics of solid organic compounds.

Blue Dominican amber, 25-40 million years old

Public domain image; image source: Wikimedia Commons

An amber inclusion

Image courtesy of Steev Selby; image source: Wikimedia Commons

## Introduction

Amber has been used as jewellery, as an ingredient in perfumes and in folk medicine for thousands of years – but it also has its place in science. It was the first substance on which electrostatic phenomena were observed, by the Greek philosopher Thales of Miletus, 600 BC, and it gave electricity its name: in 1601, the English physicist William Gilbert, the first to distinguish between magnetic and electrical attraction, coined the term ‘electricus’ for the property of attracting small objects after being rubbed, derived from amber’s Greek name elektron (meaning shiny).

Amber is plant resin that fossilised either inside the plant, or after oozing out from it. Pieces of amber can be 20 to 320 million years old, but it is difficult to be certain: radiocarbon dating can only be used for specimens up to 50 000 years of age. So you have to determine the age of the surrounding sediment, which can be misleading because the amber may have originated far from the location in which it was discovered. Although amber is found all over the world, including in the Dominican Republic where rare blue amber is mined, possibly its most famous deposits in Europe are in the Baltic Sea, where large quantities are found. Yet amber is also found in eastern Europe, the North Sea, the Alps, northern Spain and Sicily. Pieces of amber torn from the sea floor are cast up by the waves and collected by hand, dredging or diving. Elsewhere, amber is mined, both in open works and in underground galleries.

The heterogeneous yellow to red organic macromolecule fossilises from two types of soft, sticky plant resin: terpenoid resins or phenolic resins. Terpenoid resins, produced by both conifers and angiosperms (flowering plants), consist of ring structures formed from isoprene ($C_5H_8$) units. Phenolic resins are found only in angiosperms, and include lignins, flavonoids and certain pigments.

Resins protect injured plants from further damage, oozing out and hardening to form a defence against invading fungi and insects. The volatile fractions of resins are scented (think of the typical scent of pine


Image courtesy of Johannes Richter; image source: Wikimedia Commons

Amber sources in Europe. Amber discovery locations in red, historical amber routes in black and red, rivers in blue

Image courtesy of Bernhard Sturm

Amber 'baby chains' like this one are very useful for the experiments

resin), but it is the sticky, non-volatile, di- ($C_{20}$) and tri-terpenoid ($C_{30}$) fractions that fossilise into amber via free-radical polymerisation. During this maturation process, which takes place over millions of years, polymerisation, isomerisation, cross-linking and cyclisation may occur, forming a mixture of substances with the general formula $C_{10}H_{16}O$. A small amount of sulphur (up to 1%) may also be included.

Since amber has many classical properties of solid organic compounds, such as being combustible, not conducting electricity and being electrostatically chargeable, it is a good model substance to introduce these compounds in general, despite its varied and complex composition. It offers the added value of putting

REVIEW

- Chemistry
- Organic chemistry
- Physics
- Biology
- Earth science
- Environmental science
- Arts and crafts
- Ages 16+

Bernhard Sturm, who has already published another enjoyable article in *Science in School* (Sturm, 2009), is a model of creativity in the field of science teaching.

Those who think that chemistry and physics are boring subjects should try the activities based on amber proposed by the author. Starting from this ancient material and following the suggested links, a science teacher can explore many different topics related to amber and discover unexpected relationships with arts and humanities.

The different core activities, in fact, provide the opportunity to address organic chemistry (natural and man-made polymers), earth science (sedimentary rocks, fossils, fossil fuels), physics (density, separation methods, conductivity and charge separation), environmental science (combustion, pollution) and biology (plant resins, amber inclusions).

For those interested in interdisciplinary links, the choice is also wide: arts and crafts (making jewellery), history (the Amber Road, the Amber Room) or economy (amber mining and commerce), just to mention some.

Finally, a teacher only needs to get some pieces of the 'gold of the Baltic Sea' (which is – luckily – much cheaper than true gold) to follow Bernhard Sturm in the footsteps of Thales of Miletus, William Gilbert and others.

The article might provide valuable background reading for a visit to a natural history or science museum and can also be used as a comprehension exercise. Possible questions include:

1. To assess the age of a piece of amber:
   a) radiocarbon can normally be used
   b) it is necessary to date the surrounding sediments
   c) different methods are used depending on the circumstances.
2. Which of the following materials is most different in density compared to amber?
   a) polyethylene
   b) polyvinylchloride
   c) oak wood
   d) colophony.

*Giulia Realdon, Italy*

chemistry into a broader context, thus appealing to students who are not normally interested in the subject, because there are links to arts, biology, earth science and physics.

This five-lesson teaching unit is suitable for students aged 16+ who already know about density, conductivity and the electric circuit. You may want to provide textbooks from earlier grades for the students to refresh their knowledge. The teaching unit consists of six core activities: over four lessons of 45 minutes each, groups of students rotate through the stations, so that each group performs all the activities. Each activity will take about 20 minutes. In a large class, it may be useful to provide two of each station. In the final lesson, the students present their results in class.

It is possible to extend the teaching unit with additional optional activities (see below), which may involve colleagues from other subjects. Alternatively, you may perform all or part of the activities as demonstration experiments or by the entire class simultaneously. The methods used in the different activities are quite varied, and the results tend to be easily remembered by the students.

The amber required for these activities can easily be obtained through online shops. One 30-35cm-long 'baby chain' for teething babies to chew on, available for about €8-20, will suffice to perform all core activities with about 30 students. Often, students are also keen to take family jewellery into class. The only experiment that will actually use up or damage the amber is combustion.

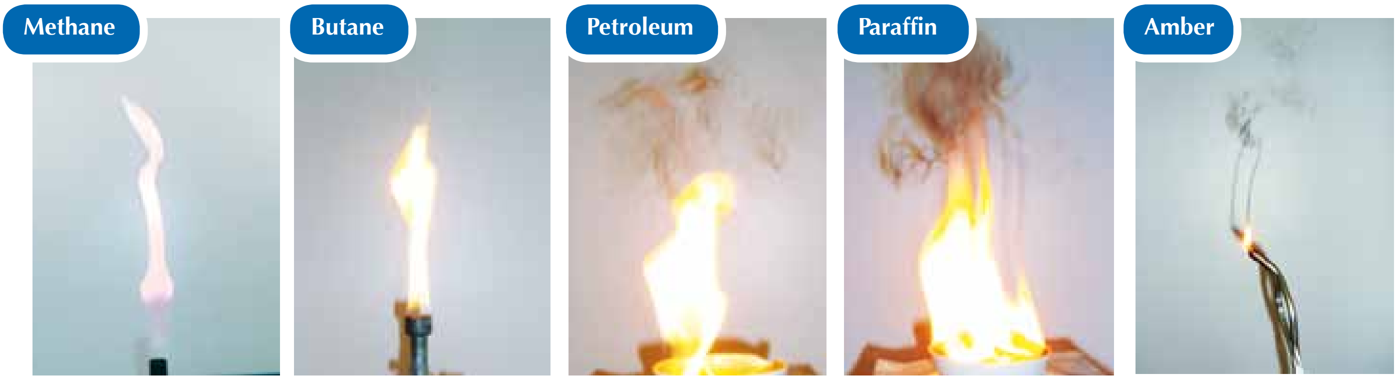
## Core activities

For those students who are especially fast, you may want to provide further organic compounds on which they can perform the same experiments and compare to amber. These can be: for Experiment 2, other non-

**Table 1:** Geological origin of crude oil, coal and amber

| Source | Crude oil | | Coal | | Amber | |
|---|---|---|---|---|---|---|
| | Time of origin | Formation | Time of origin | Formation | Time of origin | Formation |
| dtv-Lexikon, Munich, 1966 | Cretaceous, 145-65 million years ago | Small organisms sank to the bottom of the sea, forming sapropel (organic sludge); they were digested in the sediment under anaerobic conditions and high pressure | Carboniferous, 360-300 million years ago | Dead tropical plants sank into the mud where they were covered by sand and clay; high pressure and anaerobic conditions led to carbonisation | Devonian to Triassic, 400-40 million years ago | Resin oozed from trees to the ground, sank below the sea level after the climate changed, and polymerised under anaerobic conditions |
| http://en.wikipedia.org accessed on 31/03/2011 | Millions of years ago | Large quantities of prehistoric zooplankton and algae settled on the bottom of a water body under anoxic conditions; the organic matter mixed with mud and was buried under sediment; heat and pressure led to formation of crude oil | Carboniferous (359-299 million years ago) | Layers of plant matter accumulated at the bottom of a body of water; mud or acidic water protected them from biodegradation and oxidisation; they were covered by sediment and metamorphosed into coal | Upper Carboniferous (320 million years ago) and earlier | Resin that was either still in the plant or had oozed out and dropped to the ground, often acquiring impurities; high temperatures and pressures due to overlying sediments first led to formation of copal (an intermediate stage of polymerisation and hardening, between 'gummier' resins and amber); sustained heat and pressure drove off terpenes, resulting in amber formation |

*Images courtesy of Bernhard Sturm*




Comparing the flames of burning organic compounds

saturated organic compounds such as alkanes, e.g. in the form of a gas burner (with a yellow flame) and a lighter; for Experiments 3 to 6, plastics such as polyvinylchloride and polyethylene, as well as different types of wood (for example pine and oak, e.g. from a set of density cubes) and colophony (violin rosin, used to rub the hairs of the bow).

## 1) Geological origin

The students should compare the date and process of formation for natural deposits of amber, crude oil and coal by performing Internet and literature searches. They should critically evaluate the reliability of different sources of information and note down the dates and processes given in the different sources. For websites, they should note down the date at which they were accessed. See Table 1 for an example of what they may find.

## 2) Combustion

Remind your students that high levels of carbon in a burning organic substance will lead to a sooty flame. The students should then hold a piece of amber (German *Bernstein* = Börnsteen = burning stone) with a pair of crucible tongs below a glass test tube, then burn the amber with a match and watch the soot collecting on the test tube.

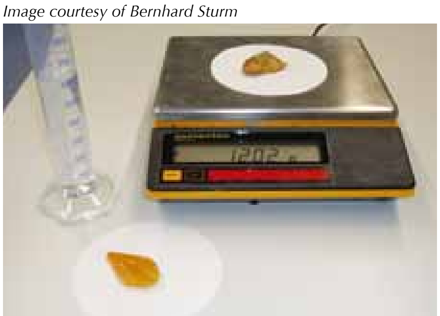
To link the activity to the topic of particulate matter pollution by combustion engines, the students can vary the combustion conditions of a Bunsen burner by opening and closing the draft, and discuss how to avoid soot production.

**Safety note**: wear safety goggles and do not overheat the glass, as it may explode. Do not burn polyvinylchloride (available as optional material for Experiments 3 to 6), which would result in the production of harmful dioxins. See also the general safety note on the *Science in School* website (www.scienceinschool.org/safety) and on page 73.

## 3) Density

The students should determine the density of amber (1.050–1.096 g / ml), which is only slightly higher than that of water (about 0.998 g / ml at room temperature). For this experiment, more accurate results will be achieved using a larger piece of amber with no hole in it. I own a large piece of amber and a piece of flint of comparable size and like to give both to the students, asking them to determine which is which by measuring their densities.

*Image courtesy of Bernhard Sturm*



Amber (in front) and flint (on the balance) can be distinguished by determining their density

You will need a piece of amber, a measuring cylinder, water (containing a small drop of washing-up liquid to reduce the surface tension and improve the accuracy of measurements) and a balance.

Weigh the piece of amber. Partly fill the cylinder with water and note down the volume of water. Add the amber and note the difference in volume. Calculate the density of amber as:

Density of amber [g / ml] = weight of amber [g] / (volume with amber [ml] – volume without amber [ml])

Many organic compounds have densities similar to water (0.8–1.2 g / ml). Polyvinylchloride is atypical, with a density of 1.4 g / ml, due to its heavier chloride atoms.

## 4) Separating amber from a mixture of organic and inorganic compounds

The students will learn how to separate amber from rocks and sand, an experiment with practical relevance for amber mining.

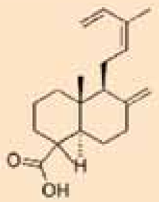
1. Weigh an empty beaker.
2. Add a defined volume of water and weigh it again to determine the mass of the water.
3. Next add a mixture of sand, rocks and amber, and weigh the beaker again. Also note down the volume contained.
4. Gradually add salt and mix until the amber floats. Weigh the full beaker again and note down the volume contained.

## Classification of amber

Plant resins are so diverse that their distinct chemical composition is used to identify from which plant species a piece of amber formed. This does not mean that similar resins must originate from similar plants, however: recent research has revealed that resins of extremely similar molecular composition can be produced by entirely unrelated plants (Bray & Anderson, 2009) – the distinctions can be quite small. On the basis of their chemical constituents, five classes of amber are roughly defined:

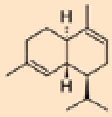
- **Class I:** by far the most abundant, comprising labdatriene carboxylic acids; three subclasses

  8(17),12,14-Labdatriene-19-oic acid, also known as communic acid



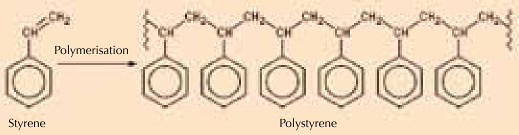

- **Class II:** formed from resins with a sesquiterpenoid base, such as cadinene

  Cadinenes, such as +-(α)- cadinene, are found in a variety of essential-oil-producing plants including the Cade juniper *(Juniperus oxycedrus)*



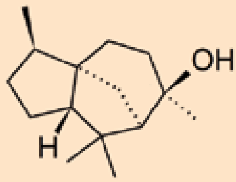

- **Class III:** natural polystyrenes

  Polystyrene forms by polymerisation of styrene units



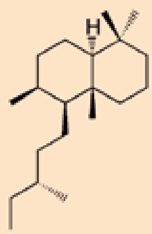

- **Class IV:** a collection of non-polymerised ambers which consist mainly of cedrane-based sesquiterpenoids

  Cedrol, a common cedrane found in cedar oil




- **Class V:** considered to be produced by a pine or pine relative; a mixture of diterpenoid resins and n-alkyl compounds (R-NH-CH3)

  Labdane, a diterpene originally obtained from labdanum, a resin derived from rockroses *(Cistaceae)*




What is the density of the salt water? Calculate it as:

Density of salt water [g/l] = [(mass of beaker at the end (step 4) – mass of beaker before salt is added (step 3)) + (mass of beaker with water (step 2) – mass of empty beaker (step 1))] / [volume of water + (volume of beaker at the end (step 4) – volume of beaker wihout salt (step 3))]

This should of course be higher (>1.1 g/ml) than the density of amber determined in Experiment 3, otherwise the amber would not float.

The students should illustrate their ideas of how this technique could be developed into a technology for continuously mining amber (see image on page 41).

### 5) Conductivity

The students will learn that solid organic compounds do not conduct electricity, by building an electric circuit using a power supply, three cables and a light bulb to test the conductivity of amber. If they are not familiar with the experimental setup, you could supply a physics textbook for them to look it up.

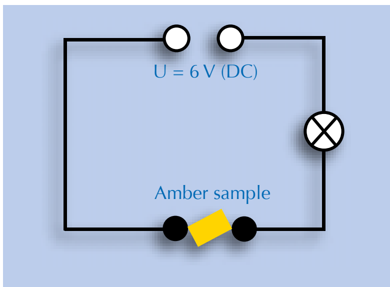
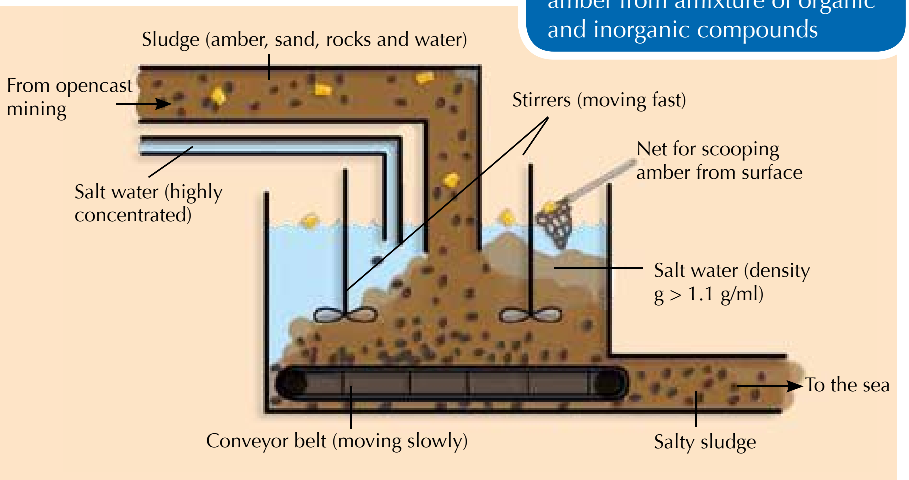



*Image courtesy of Bernhard Sturm*

### 6) Charge separation

The students will learn about electrostatic induction and charge separation, performing Gilbert's electrostatic experiment: they rub a piece of amber with wool and see that it attracts small pieces of paper or, for example, the dried pith from the centre of an elder (*Sambucus* spp.) twig. This also works well with the small pieces of amber from a baby chain.

The experiment will not work well if the air is humid, because water in the




A possible solution for seperating amber from amixture of organic and inorganic compounds

*Image courtesy of Bernhard Sturm and Nicola Graf*

air will conduct electricity and reduce the electrostatic charge on the amber. Damp fingers will do the same; for better results, the students could use insulated (plastic) tweezers to hold the amber.

## Optional activities

### Making jewellery

To link art and chemistry and foster your students' technical skills, you could get them to produce their own amber jewellery. You will need raw amber pieces of at least 15 mm in diameter. Sand the piece of amber with wet fine sandpaper (Coated Abrasive Manufacturers Institute grit size 120–1000), then polish it with toothpaste. Rinse with water and dry with kitchen roll, then rub in some cooking oil using a cloth. Pierce the amber with a hot needle (this should be done by the teacher) or drill a small 1-2 mm hole. Thread the amber onto a nylon or leather string to make a necklace or bracelet.

### Links to biology

For a link to biology, the students can look at inclusions in amber and discuss tree resins in depth – what is their composition, where do they occur, what is their function and what is the structure of wood?

BACKGROUND

## Amber research at ESRF

Pieces of amber are a rich source of fossil evidence. At the European Synchrotron Radiation Faciliy (ESRF)[w1] in Grenoble, France, powerful X-rays are used to study inclusions in amber. This is especially useful for opaque amber pieces, which are inaccessible to palaeontologists with classical microscopy techniques. Several hundred animal inclusions from the mid-Cretaceous, 100 million years ago, have been identified.

In another study at ESRF, researchers used the same technique to obtain detailed three-dimensional images of feathers enclosed in translucent amber, which may have belonged to a feathered dinosaur – an intermediate in the evolution to modern birds.

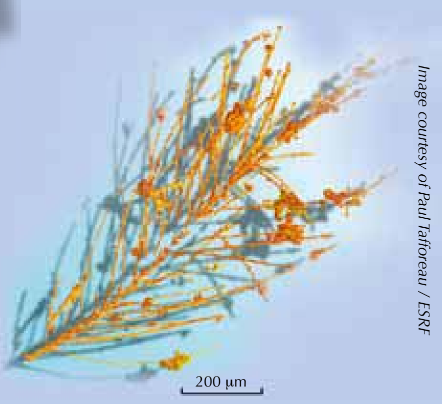
For more information, read the online report[w2] from ESRF, one of the members of EIROforum, the publisher of *Science in School*.

*Image courtesy of V Girard / D Néraudeau, UMR CNRS 6118*

Opaque amber

*Image courtesy of M Lak, P Tafforeau, D Néraudeau (ESRF Grenoble and UMR CNRS 6188 Rennes)*

3D reconstruction of a hymenopteran insect of the *Falciformicidae* family, embedded in 100-million-year-old opaque amber




3D reconstruction of a feather intermediate between dinosaurs and modern birds, enclosed in amber

*Image courtesy of Paul Tafforeau / ESRF*

## References

Bray PS, Anderson KB (2009) Identification of carboniferous (320 million years old) class Ic amber. *Science* **326(5949)**: 132-134. doi: 10.1126/science.1177539

The free full-text article is available online.

For drama activities in the chemistry and physics classroom, including one about the radical polymerisation of ethene to polyethylene in class, see:

Sturm B (2009) The drama of science. *Science in School* **13**: 29-33. www.scienceinschool.org/2009/issue13/drama

## Web references

w1 – For more information on ESRF, see: www.esrf.eu

w2 – Scientists at ESRF used powerful X-rays to study amber inclusions. See: www.esrf.eu/news/general/amber


## Resources

To download charts of Earth's history, see: www.stratigraphy.org/upload/ISChart2009.pdf or www.chronos.org/downloads/timetowerparis_highres.png

To learn about research into biodegradable plastics, see:

Bradley D (2007) Plastics, naturally. *Science in School* **5**: 66-69. www.scienceinschool.org/2007/issue5/plastics

If you enjoyed reading this article, why not take a look at the full collection of articles on chemistry published in *Science in School*? See: www.scienceinschool.org/chemistry


Bernhard Sturm obtained his PhD in chemistry at the GKSS Research Centre Geesthacht, Germany. He teaches chemistry and physics at the Neues Gymnasium, a secondary school in Oldenburg, Germany. His main interest is interdisciplinary work linking science and humanities. His students have won a number of science competitions on geoscientific and climate topics. This led to Bernhard winning the Lower Saxony Teacher's Award for STEM subjects in 2010.



To learn how to use this code, see page 1.

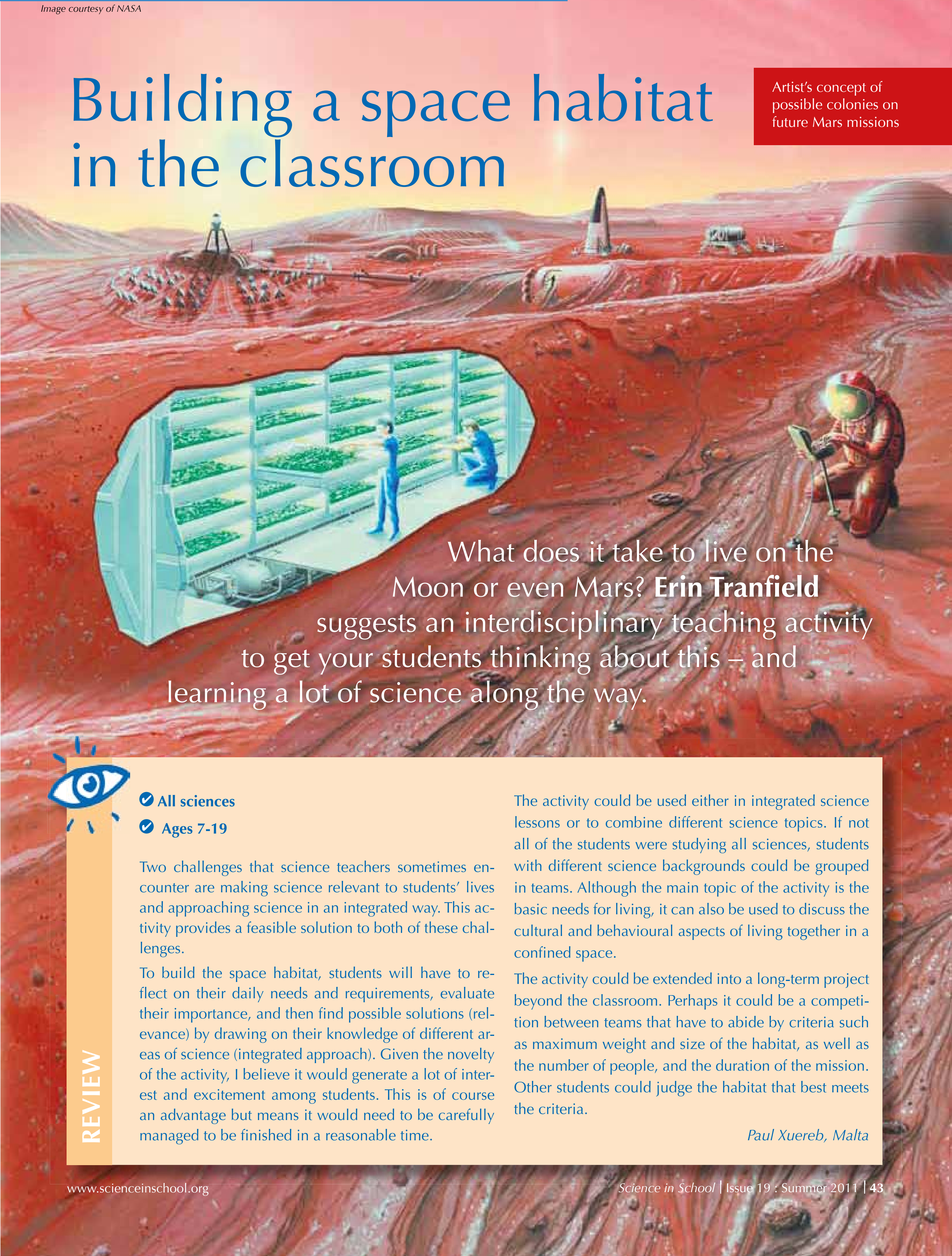


Image courtesy of NASA

Artist's concept of possible colonies on future Mars missions

# Building a space habitat in the classroom

What does it take to live on the Moon or even Mars? **Erin Tranfield** suggests an interdisciplinary teaching activity to get your students thinking about this – and learning a lot of science along the way.

REVIEW

- **All sciences**
- **Ages 7-19**

Two challenges that science teachers sometimes encounter are making science relevant to students' lives and approaching science in an integrated way. This activity provides a feasible solution to both of these challenges.

To build the space habitat, students will have to reflect on their daily needs and requirements, evaluate their importance, and then find possible solutions (relevance) by drawing on their knowledge of different areas of science (integrated approach). Given the novelty of the activity, I believe it would generate a lot of interest and excitement among students. This is of course an advantage but means it would need to be carefully managed to be finished in a reasonable time.

The activity could be used either in integrated science lessons or to combine different science topics. If not all of the students were studying all sciences, students with different science backgrounds could be grouped in teams. Although the main topic of the activity is the basic needs for living, it can also be used to discuss the cultural and behavioural aspects of living together in a confined space.

The activity could be extended into a long-term project beyond the classroom. Perhaps it could be a competition between teams that have to abide by criteria such as maximum weight and size of the habitat, as well as the number of people, and the duration of the mission. Other students could judge the habitat that best meets the criteria.

*Paul Xuereb, Malta*

Planet Earth is able to meet the basic living requirements for trillions of organisms, including humans. The oxygen we need is in the air around us, the atmosphere protects us from radiation, drinking water can be found in rivers and lakes, and food can be readily found in most places. On Earth, cycles exist where one species' waste products are used by another species, so that the waste products do not build up to high levels: an example of this is the complex carbon cycle[w1] in which oxygen and carbon dioxide are alternately produced and used by plant species and animal species.

However, in space, none of these requirements for human survival are met. Therefore, to live and work in space, we have to take with us everything we need, and we need to devise ways to recycle or dispose of the waste we produce. We must do this while limiting the weight of material taken to space and building in backup safety equipment (redundancy).

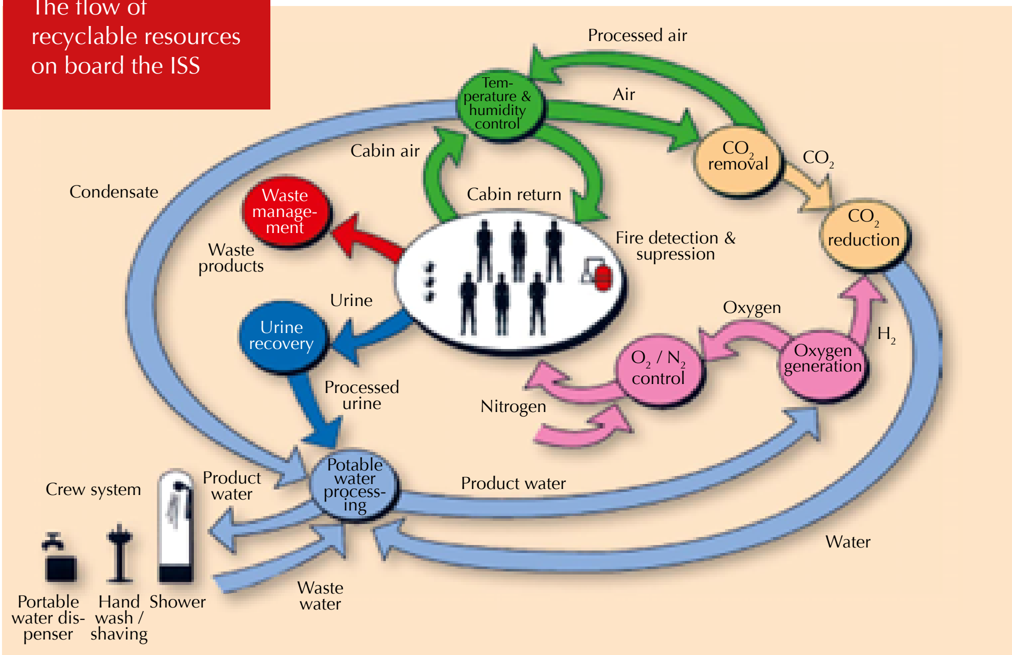
Weight must be minimised as transport into space is extremely expensive. It currently costs about 17 000 USD to lift 1 kg to the International Space Station (ISS) (based on an average launch cost of 450 million USD and shuttles carrying an average of 26 000 kg of cargo plus astronauts). It will cost much more to take 1 kg to the Moon or to Mars. At such a great expense and with the inherent difficulty of each mission to space, every kilogram needs to be justified. Furthermore, backup equipment is required for every life-support system in space. Currently, on the ISS, there are three levels of this redundancy, just in case the primary system fails and a backup system is needed.

Getting your students thinking about habitat design on the Moon or Mars can be a good way to consider the challenges of living and working in space as well as illustrating the critical role that the cycles on Earth play in the survival of all organisms. It is an activity suitable for students of all ages (see the suggestions for different age groups, below).

The introduction to the activity will take about 2 hours, with at least a further 2 hours to design the habitat, depending on its complexity. To build the habitat could take 5-15 hours, depending on how many students are involved and how complex a habitat they are building. If the students are really enthusiastic about the idea, they might want to invest even more time.

When you have finished, send a photo of your completed space habitat to editor@scienceinschool.org and we will publish a selection of the photos on the *Science in School* website.

Image courtesy of NASA




The flow of recyclable resources on board the ISS

Image courtesy of ESA

A photo of the Earth taken by ESA astronaut André Kuipers out of the window of the Soyuz capsule

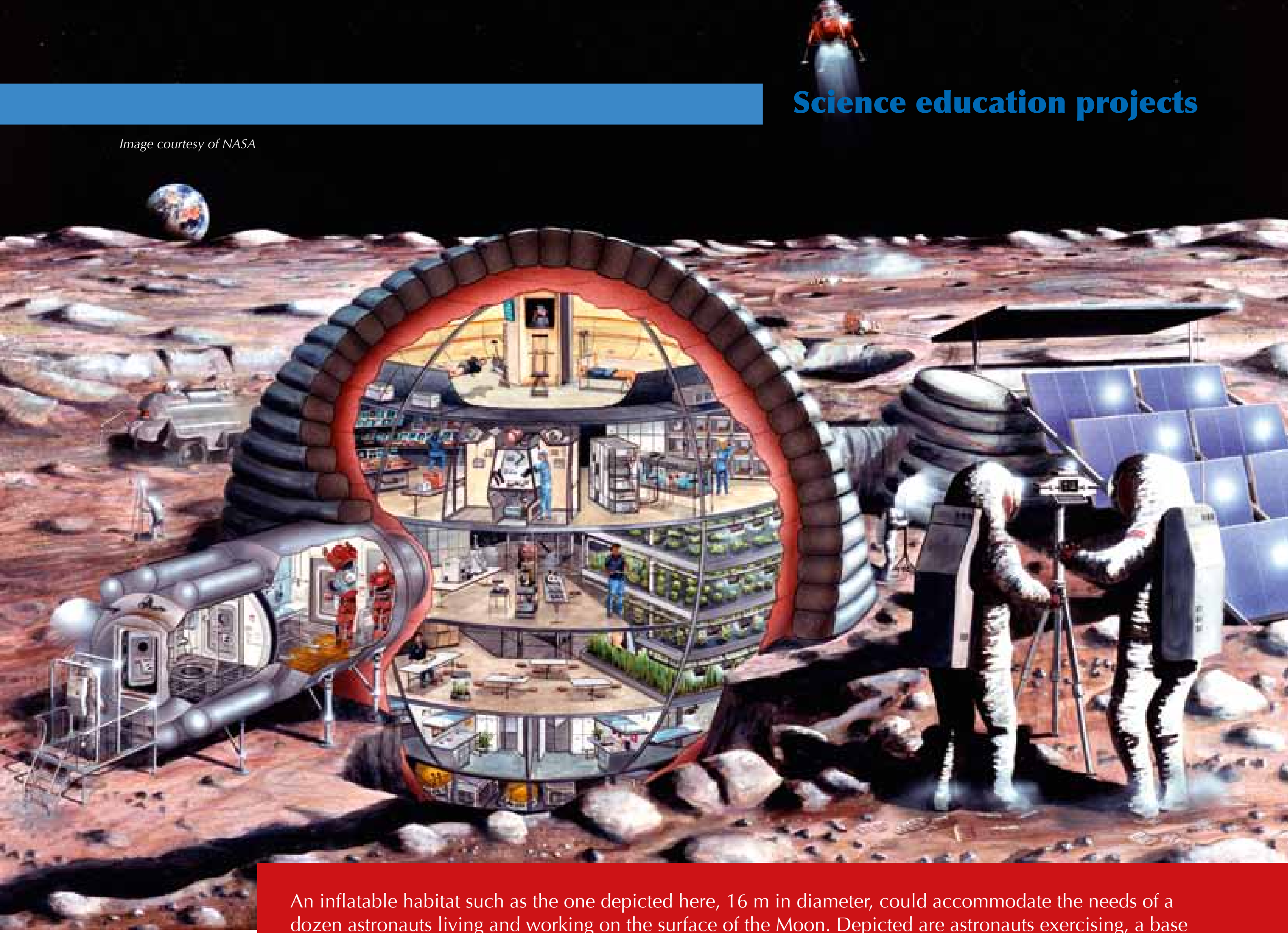


Image courtesy of NASA

An inflatable habitat such as the one depicted here, 16 m in diameter, could accommodate the needs of a dozen astronauts living and working on the surface of the Moon. Depicted are astronauts exercising, a base operations centre, a pressurised lunar rover, a small clean room, a fully equipped life sciences lab, a lunar lander, selenological (lunar geology) work, hydroponic gardens, a wardroom, private crew quarters, dust-removing devices for lunar surface work and an airlock

## Designing a space habitat

Begin by asking your students to consider what humans need to stay alive and work efficiently on Earth. How could we meet these needs in space? And how can we build space facilities with the highest efficiency, lightest weight and longest durability? See the box on page 46 for many ideas, together with links to more resources, including many from the European Space Agency[w2]. Further background information can be downloaded from the *Science in School* website[w3].

Now the students can begin to design and even build their own space habitat. First, they will need to decide whether to build their habitat on Mars or the Moon, because the design requirements will differ[w4]. They should bear in mind that the Moon has greater temperature changes and no atmosphere for protection but is closer to Earth. Mars has more moderate temperature changes and an atmosphere, but it is much further away from Earth, thus a Mars habitat will need to be much more independent.

### Activity for students aged 7-10

1. Begin by discussing what humans need to survive on Earth and then extrapolate the list to what humans need in space. What is essential for survival in space and what can be removed to save weight and money?
2. Discuss how the requirements are important during the design and construction process. Pick two of the requirements that a habitat needs to provide (listed in the box on page 46) and include them in the design of a planetary habitat for at least two people.
3. Build a model habitat out of cardboard and strong sticky tape. The habitat can be room-sized or tabletop-sized. You may find the Worldflower Garden Dome[w5] and Geo-Dome[w6] websites helpful for your design. Decorate the habitat to make it a liveable place, for example by adding colour or windows.
4. Discuss with the group what each student would take with them if they could only choose one personal item (e.g. a family photo, music recording or book).

Image courtesy of janrysavy / iStockphoto

# Considerations for designing a space habitat

### Earth requirements

What do we expect for our everyday life on Earth?

- Shelter from weather – a home and clothing
- Clean drinking water and a sanitary living environment
- Breathable air
- Nutritious food
- Medical care
- Adequate sleep and leisure time
- Physical well-being.

### Requirements for a planetary space habitat

Many of our requirements in a space habitat would be similar to those on Earth, but some would be specific to the new environment.

- Shelter from radiation, micro-meteorites, dust, the surrounding vacuum and the extreme temperature environments
- Significant reduction in standard water use, increased water recovery and recycling[w10]. This includes hygiene facilities that use very little water – for the astronauts to wash their clothes and bodies, and a toilet
- Breathable air – a way to either recycle old air (oxygen provision, carbon dioxide and contaminant removal) or supply new air[w11]
- Nutritious food – to be either brought and stored or produced in the habitat
- Medical facilities for minor problems such as cuts, rashes, infections, toothache and motion sickness, and for more serious problems such as broken bones, kidney stones and heart attacks
- Sleeping quarters
- Exercise facilities addressing cardiovascular, muscle and skeleton maintenance
- Temperature regulation systems to compensate for the temperature extremes. Surface temperatures on the Moon can be as low as -270 °C in permanently shadowed craters at the poles, and higher than 121 °C in the full sun at the lunar equator[w12]
- Communication systems (contact with mission control as well as family and friends on Earth)
- Recycling or disposal of liquid waste (urine) and solid waste (general garbage, faeces)[w10, w11, w13]. This needs to be done under the guidelines of planetary protection[w14]
- Monitoring systems for the life-support systems (air- and water-quality monitoring, radiation dose measurements)
- A food preparation and eating area
- Work areas for exploration experiments (geology, biology, chemistry, etc.). This is a requirement to justify long-duration space exploration.

Many of these considerations were also important in the design of the ISS. For more details, see Hartevelt-Velani & Walker (2008).

### Activity for students aged 10-14

1. As for the previous group, but pick four to six of the requirements of a space habitat (see box above) and include them in a design for at least four people.
2. Give more consideration to the weight of the habitat and the associated costs.

### Activity for students aged 14-19

1. As for the first group, but instead of building a cardboard model, small groups of students should use computer modelling software[w7] to create their vision of a habitat. Take into consideration at least eight of the requirements for a space habitat (see box above) for four people.
2. Include a description of the different technologies needed for the habitat, e.g. an electrolyser to produce oxygen from water, or a Sabatier reactor to split carbon dioxide into methane and water[w8], technology that is being tested on the ISS[w9].
3. In the design, incorporate features to support a sense of well-being such as windows, paint colour or leisure areas.
4. Compare what the teams did and see if everyone likes the designs. There will probably be differences in what individuals consider appealing. Discuss how to design one habitat for many cultures.

### References

Hartevelt-Velani S, Walker C (2008) The International Space Station: a

## Possible extension: psychology

Any crew on a long mission, for example to Mars, will be isolated from their loved ones and confined in a small space with other crew members. Training in conflict management is crucial, as is enhancing our understanding of how humans respond under stress, in a confined space over long durations[w15].

The mental state of each individual is extremely important, as it will affect the group mental state and ultimately even the overall mission success. It is therefore important to ensure good mental support for the crew.

On Earth, humans need a sense of mental well-being including interactions between people to be happy and productive. To achieve this, in addition to the points listed above, a space habitat needs to provide:

- Privacy for each crew member, even if the space is small
- A common area for interaction and leisure
- Colour in the habitat, selected by each crew prior to launch
- Living things, e.g. plants or fish. Might there be ethical issues?
- Windows. Being able to look outside is a very important psychological factor. From Mars, this will be harder than from the Moon, since Earth will look like just another small star in the sky.

To learn about life on board the ISS, for which these considerations are important, see also Hartevelt-Velani et al. (2008).

## Design constraints

When a space habitat is designed, it is important that it should be:

- Safe – this is the most important consideration
- Robust – strong, reliable, durable, requiring minimal maintenance
- Lightweight – the average fridge weighs 100 kg and is clearly not an option in a space habitat
- Launchable – the different elements have to fit an available rocket in terms of weight, shape and power requirements
- Effective – it must do what it was designed to do
- Affordable – space exploration is expensive, so all steps to reduce costs without compromising performance and safety must be taken.

## Designing an effective habitat

How can we meet the requirements of a space habitat under the constraints that are imposed? This is done by:

- Using a modular construction system, beginning with the essential features and adding 'rooms' as needed for particular purposes (e.g. research or space for more crew)
- Developing technology to utilise the resources on the Moon or Mars, e.g. making lunar bricks or lunar cement, or using the underground caves on Mars for habitats
- Recycling (air, water, waste, parts of the landing spacecraft for construction, the oxygen and hydrogen in extra rocket fuel for water production)
- Miniaturising as many things as possible, standardising all tools, power connections, etc.
- Making areas multipurpose, e.g. a dining table that folds away so that the space can also be used for other purposes.

*Image courtesy of Luc Viatour; image source: Wikimedia Commons*

foothold in space. *Science in School* **9**: 62-65. www.scienceinschool.org/2008/issue9/iss

Hartevelt-Velani S, Walker C, Elmann-Larsen B (2008) The International Space Station: life in space. *Science in School* **10**: 76-81. www.scienceinschool.org/2008/issue10/iss

## Web references

w1 – Learn more about the carbon cycle on the Windows to the Universe website: www.windows2universe.org/earth/Water/co2_cycle.html

w2 - The European Space Agency (ESA) is Europe's gateway to space. It is a member of EIROforum, the publisher of *Science in School.* For more information, see: www.esa.int

w3 – Background information to support teachers in this activity can be downloaded from the *Science in School* website: www.scienceinschool.org/2011/issue19/habitat#resources

w4 – For detailed information about our Solar System, see: http://solarsystem.nasa.gov

w5 – The Worldflower Garden Domes website offers instructions for building a paper dome based on a buckyball. See: www.gardendome.com/GD1.htm

w6 – Further instructions for building a geodesic dome are available on the Geo-Dome website: www.geo-dome.co.uk/article.asp?uname=modelbuild

w7 – For a list of free computer-aided design (CAD) software, see www.freebyte.com/cad/cad.htm

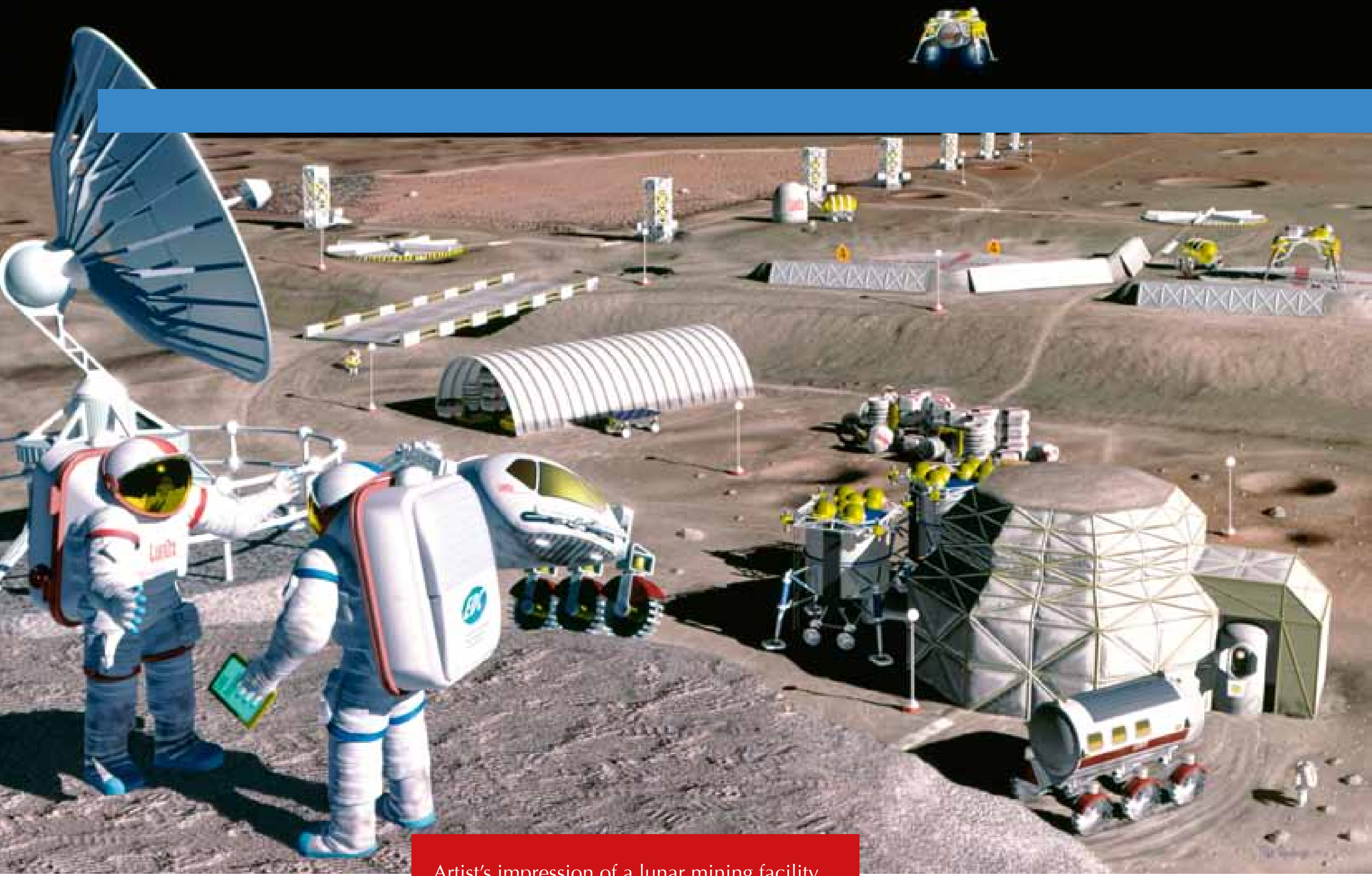


Image courtesy of NASA / Pat Rawlings (SAIC)

Artist's impression of a lunar mining facility harvesting oxygen from the resource-rich volcanic soil of the eastern Mare Serenitatis (Sea of Serenity) on the Moon

w8 – To learn more about the Sabatier reaction for use on Mars missions, see:
Richardson JT (2000) Improved Sabatier reactors for in situ resource utilization on Mars. In Institute for Space Systems Operations - *1999-2000 Annual Report.* pp 84-86. Houston, Texas, USA: University of Houston. www.isso.uh.edu/publications/A9900/mini-richardson.htm

w9 – In 2010, a Sabatier system was delivered to the ISS for testing. See the NASA press release on www.nasaspaceflight.com or use the direct link: http://tinyurl.com/3su8p26

w10 – For an interactive online model of the water recycling circuit on board the ISS, see: http://esamultimedia.esa.int/docs/issedukit/en/html/t030505t1.html

w11 – To find out more about the flow of recyclable resources on board the ISS, especially air, see: http://science.nasa.gov/science-news/science-at-nasa/2000/ast13nov_1

w12 – For fact sheets on the planets and their satellites, see: http://nssdc.gsfc.nasa.gov/planetary/planetfact.html

w13 – For more information on ESA's life support and recycling systems for space, including French educational materials on the MELISSA project, see: http://ecls.esa.int/ecls

w14 – For more information on how NASA, the US National Aeronautics and Space Administration, reduces the risk of biological cross-contamination, see http://planetaryprotection.nasa.gov

w15 – For information about Mars500, a study done to understand key physiology and psychology effects of long duration isolation and crew dynamics, see: www.esa.int/esaMI/Mars500

w16 – The report *Luna Gaia – a closed loop habitat for the moon* can be downloaded from www.isunet.edu[w17] or using the direct link: http://tinyurl.com/69bjugb

w17 – To find out more about the International Space University, see: www.isunet.edu

## Resources

NASA has developed a problem-based learning module on space habitats. Starting from a 'sealed room' introductory activity, four content areas are offered, on 'life in a sealed container', 'healthy choices', 'air and water', and 'trash or treasure', exploring ecosystems, human nutrition and fitness, recycling of air and water, and waste removal. See: www.nasa.gov/audience/foreducators/son/habitat

The EU-funded CoReflect project has developed a teaching unit on designing a Moon habitat for 10- to 12-year-olds, available in English and Dutch. See: www.coreflect.org/nqcontent.cfm?a_id=15089

To learn more about a potential manned mission to Mars, see:

Image courtesy of NASA / JPL-Caltech

http://nssdc.gsfc.nasa.gov/planetary/mars/mars_crew.html

ESA's ISS education kits are freely available for primary- or lower-secondary-school students (ages 8-10 and 12-15) in all ESA member state languages. They offer teaching activities, background notes for teachers and students, and much more.

The primary-school ISS education kit includes activities such as building a model of the ISS from recycled household materials, planning the amount of water and weight of other materials to be taken onto a space mission, or creating an astronaut menu. See: www.esa.int/SPECIALS/Education/SEMN3A5KXMF_0.html

An outpost on the Moon could produce lunar oxygen, conduct long-term surface operations, and reveal issues before humans begin the journey to explore Mars. The Moon's proximity, only several days from Earth, allows the testing of systems that will enable months-long round trips to Mars

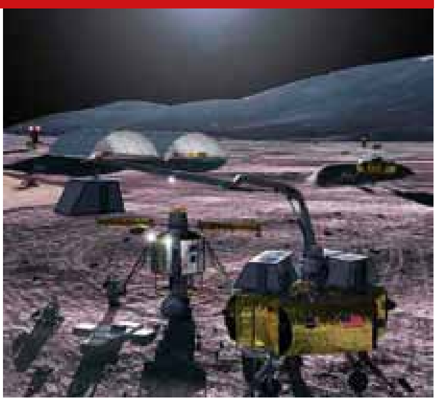


Image courtesy of Pat Rawlings and Faisal Ali / SAIC

The lower-secondary-school ISS education kit offers videos, background reading and interactive online materials about building the ISS, life and work on board, as well as classroom activities such as investigating and filtering your local fresh water, designing a space station bathroom, studying how the environment affects materials, or designing and constructing a glove box like the one used for experiments on board the ISS. See: www.esa.int/SPECIALS/Education/SEMTBS4KXMF_0.html

Educational DVDs about the ISS for students aged 12-18, explaining basic concepts such as the effects of weightlessness on the human body with simple demonstrations, were produced with the help of European astronauts during their missions on board the ISS. The free materials can be downloaded online or ordered on DVD. See: www.esa.int/esaHS/SEMZTFYO4HD_education_0.html

ESA's teaching materials on the ISS also include the 3D teaching tool 'Spaceflight challenge I' for secondary-school students, which can be used either as a role-playing adventure game or as a set of interactive exercises. It features science topics from across the European curricula, with scientific explanations and background information. To download the software or order your free copy, see: www.esa.int/esaHS/SEM3TFYO4HD_education_0.html

ESA's 'lessons online' for primary- and secondary-school students and their teachers include text, short videos and graphics. Topics covered include 'life in space', 'radiation', 'gravitation and weightlessness' and 'bugs in space'. See: www.esa.int/SPECIALS/Lessons_online

Simulate flying over the surface of Mars with Google Mars: www.google.com/mars

Here is a selection of space-related articles previously published in *Science in School*:

Warmbein B (2007) Down to Earth: interview with Thomas Reiter. *Science in School* **5**: 19-23. www.scienceinschool.org/2007/issue5/thomasreiter

Wegener A-L (2008) Laboratory in space: interview with Bernardo Patti. *Science in School* **8**: 8-12. www.scienceinschool.org/2008/issue8/bernardopatti

Williams A (2008) The Automated Transfer Vehicle – supporting Europe in space. *Science in School* **8**: 14-20. www.scienceinschool.org/2008/issue8/atv

For a complete list of ESA-related articles, see: www.scienceinschool.org/esa

To browse all space-related articles in *Science in School*, see: www.scienceinschool.org/space

## Acknowledgement

The author would like to thank Scott Hovland from the European Space Agency for valuable comments and advice.

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 currently at the European Molecular Biology Laboratory in Heidelberg, Germany, working on the three-dimensional reconstruction of the mitotic spindle using high-resolution electron tomography.

Erin was an author of *Luna Gaia – a closed loop habitat for the moon*[w16], a student research report of the International Space University (ISU)[w17] in 2006. She is now adjunct faculty at the ISU and will be the chair of the space life science department at the ISU two-month space studies programme in summer 2011 in Graz, Austria.

To learn how to use this code, see page 1.

# Moja Island: learning about renewable energy sources

Renewable energy is not only important in the developed world; in developing countries, it may be a prerequisite to overcoming poverty. **Marlene Rau** introduces a teaching activity from Practical Action.

In Sri Lanka – these children are looking forward to having light in their home generated by a small wind turbine

*Image courtesy of Practical Action / Zul Mukhida*

Electricity is an important factor in overcoming poverty, as the United Nations Development Programme[w1] states. In communities without electricity, children are often unable to attend school because they are needed to help collect biomass for fuel – but education is a crucial contributor to escaping poverty. In addition, without access to radios, computers or the Internet, communities have no access to vital information about farming techniques, or to flood warnings or local news. Lack of energy also means that people struggle to start a simple business that could help them out of poverty.

Practical Action (previously known as the Intermediate Technology Development Group) is a UK-based development charity that has been working with the world's poorest communities for more than four decades, focusing on energy and technology as a catalyst for change. The education section of the charity's website[w2] provides a range of educational resources and teaching materials on sustainable engineering, climate change and renewable energy.

This article presents one of the classroom activities: Moja Island, in which students consider the options available to the four communities living on a fictitious island and select the most appropriate technologies to meet their

REVIEW

- Biology
- Physics
- Chemistry
- Earth science
- Interdisciplinary
- Ages 11-16

The article and teaching activity can be used in any science classroom anywhere in the world, in any subject that includes renewable energy sources in its curriculum. In fact, since the topic requires knowledge from many disciplines, including biology, physics, chemistry, geography, geology, meteorology, and even economics and mathematics, this teaching activity could be an ideal case for studying and learning through interdisciplinary projects.

The materials for the teaching activity can be freely downloaded. The students assume the role of scientific experts and in small groups decide which kind of renewable energy sources would be most appropriate to use in a specific fictitious environment.

The article could trigger discussions on whether any renewable energy source is suitable to be used in particular environment. As the answer would most likely be negative, discussions could then focus on specifying which criteria a specific environment would have to fulfil to be a good candidate for a given renewable energy source.

Teachers may also use the method presented to study different topics.

*Michalis Hadjimarcou, Cyprus*

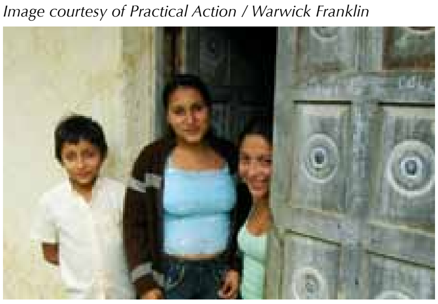
needs. Aimed at students aged 11-16, this 1-2 hour activity reinforces their understanding of renewable energy sources.

## The Moja Island activity

Did you know that one fifth of all people in the world have no access to electricity? Of these, 85% live in rural areas (International Energy Agency, 2010). Furthermore, most people who do have access in remote areas – especially in developing countries – are not connected to a national grid, but have to find other ways to generate power. The main reason is that grid extension is often not cost-effective: the cost per MWh delivered through an established grid is lower than through off-grid systems, but the cost of extending the grid to only a few people in remote regions can be very high. Long-distance transmission systems also lose more energy, for instance due to long wires. Therefore, governments are often reluctant to invest in extending their national grids to these remote areas. Small-scale renewable energy technologies are often a viable alternative, and are cheaper than diesel-based power generators.

A successful example is a small-scale wind power project run by Practical Action in Sri Lanka. You can find background information and watch a video about the project online[w3]. Small-scale renewable energy technologies are now reasonably well developed, but access to the technology and funding is often difficult. In Practical Action's experience, the most successful small-scale renewable energy projects are those that involve the people who are affected: in the planning and decision making, and by providing them with training so that they can carry out installation and maintenance.

*Image courtesy of Practical Action / Warwick Franklin*



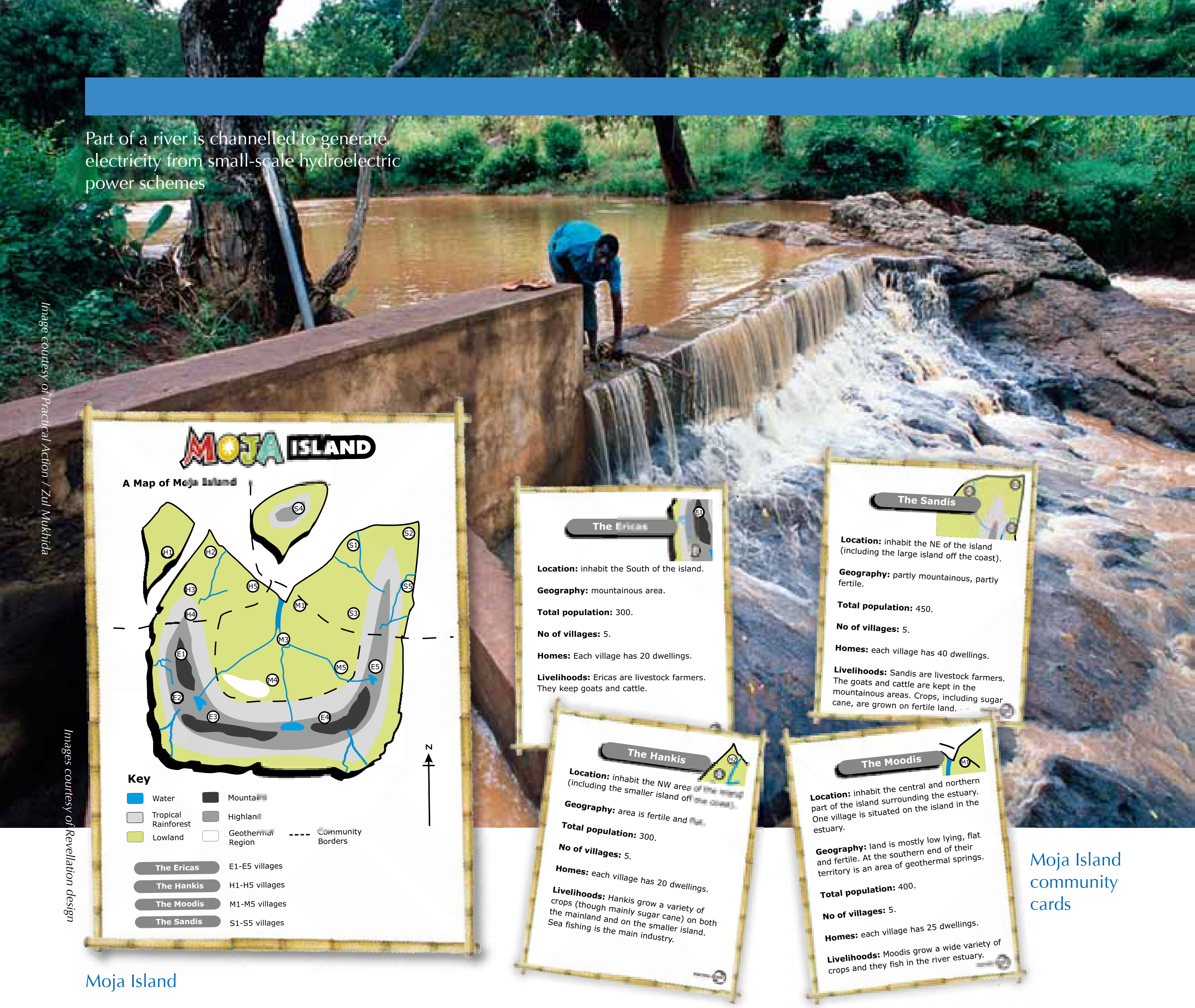
Here in Peru, this family home is connected to a micro-hydro scheme that generates electricity to enable the family to listen to the radio, watch TV and have lighting

*Image courtesy of Catsenko Alexander / iStockphoto.com*

In the developed world we tend to take for granted the availability of electricity

## An example of Practical Action in Kenya

In Kenya, 96% of people have no access to grid electricity[w4]. A community from Mbuiri, a village north of Nairobi, has channelled part of a river to generate electricity in small-scale hydroelectric power schemes. A video about micro-hydro energy in Kenya and other background material about this Practical Action project can be found online[w5].



Part of a river is channelled to generate electricity from small-scale hydroelectric power schemes

Image courtesy of Practical Action / Zul Mukhida



Moja Island



Moja Island community cards

Images courtesy of Revellation design

This sets the scene for the Moja Island activity.

## Materials

All materials required to run the activity can be for the downloaded from the Practical Action website[w6], including video clips showing renewable energy in action. You will need the file entitled 'Powerpoint presentation introducing activity'.

The activity is designed for four groups of up to four students each. A large class could be split into eight groups, with two groups working on each of the Moja communities. For each group of students, you will need:

- A map of Moja Island (the original map on the Practical Action website will work in colour. A black and white version is available via the *Science in School* website[w7])
- A set of renewable energy fact cards that provide background information, including the advantages and disadvantages of eight renewable energy sources
- One of the four Moja Island community cards that give background information on the communities living on Moja Island
- A renewable energy choices worksheet.

## Introduction to the activity

Introduce Moja Island, using the downloadable PowerPoint® presentation to explain the main issues of meeting energy requirements in rural communities, and set the scene for the classroom activity. Discuss why there is little chance of the majority of people without access to mains electricity being connected in the near future.

- Moja Island is a small country situated off the east African coast in the Indian Ocean.
- It has no mains electricity.
- The 1450 islanders mainly use kerosene lamps and candles for light and wood for cooking food.

## The task

1. The Moja Island government has decided to invest money in generating electricity through small-scale renewable energy technologies. As scientists, your students have been asked to identify the most appropriate renewable energy options for the village communities on the island.

**Table 1:** Renewable energy facts

| | Generation | Advantages | Disadvantages | Environmental impact | Energy provided |
|---|---|---|---|---|---|
| **Geothermal energy** | Underground water is heated by hot rocks below Earth's surface. The resulting steam can be used to turn turbines that then power generators to produce electricity. | It is free and available day and night. | Only available in certain parts of the world. Sometimes poisonous gases are given off. | Some impact from the installation of the equipment that is needed to direct steam to turbines. For example, infrastructure such as roads will be needed to transport the building materials to the site, and the equipment itself takes up a lot of space. | One geothermal power plant provides enough electricity for 20 dwellings. |
| **Solar energy** | Uses the Sun's energy in two main ways:<br>1) To heat solar panels which can be used to heat water<br>2) In solar cells which can transform light energy into electricity. | The Sun's energy is freely available whenever the Sun is shining. | Solar panels require continuous sunshine, unless the energy can be stored in batteries. Solar cells are expensive to buy. | Some minor impact as a large area may be needed for solar cells (about 2 $m^2$ per cell). | A single photovoltaic cell provides enough electricity for 5 dwellings. |
| **Wind energy** | The wind turns blades, which drive a turbine; this in turn drives the generator to produce electricity. | Whenever the wind blows electricity is generated. | Large numbers of turbines are needed to produce a large amount of energy. Only works well in windy places (hills or offshore). | Some impact from installing wind turbines, such as noise and danger to birds. Bats are particularly affected by the changes in pressure caused by the turbines. | Two wind turbines provide enough electricity for 15 dwellings. |
| **Hydroelectric energy** | Running water is diverted from a river to turn a waterwheel or turbine, which in turn drives the generator to produce electricity. | If there is a good supply of rain, there will always be water to produce electricity. | Only suitable for hilly areas with rivers. | Some impact from diverting rivers. This may upset the ecology of the area or the fertility of surrounding land. | A single hydroelectric plant provides enough electricity for 40 dwellings. |
| **Tidal energy** | A barrage is placed across the mouth of an estuary. Tidal water passes through holes in the barrage, driving a turbine which in turn drives the generator to produce electricity. | Wherever there are tides, electricity is generated. | Barrages are expensive to build. | Some impact through barrier installation, which can disrupt the tidal flow to shore and hence the movement of nutrients and organisms, including migrating fish. | A single barrage provides enough electricity for 25 dwellings. |
| **Wave energy** | Buoys (floats) are placed in the sea, and convert wave movement into vertical movement inside the buoy. This drives a turbine which in turn drives the generator to produce electricity. | Whenever there are waves, electricity is generated. | A large number of buoys are needed to generate enough electricity for a town. The technology only works where there are big waves. | Minimal impact is caused, and only when there are many floats in the water. | Ten buoys provide enough electricity for 10 dwellings. |
| **Biomass** | Solid organic materials (wood, dung, sugar cane) are combusted and the heat released is used to produce steam, which drives a generator to produce electricity. | Plants are renewable; they can be grown continuously. | Combustion produces carbon dioxide and other pollutants. | Pollution caused by combustion. | A single generating plant provides enough electricity for 25 dwellings. |
| **Biogas** | Plants and animal manure are decomposed (allowed to rot) in a tank. The resultant methane gas is combusted and the heat released is used to produce steam, which in turn drives a generator to produce electricity. | Uses natural waste products. | Combustion produces carbon dioxide and other pollutants. | Pollution caused by combustion. | A single generating plant provides enough electricity for 20 dwellings. |

2. Can the students think of some renewable energy options that might be suitable for Moja Island? Discuss briefly in class. Students may suggest options that they are already aware of, such as wind and solar power.
3. Discuss the location of the island, providing the relevant background information: what is the climate (sunshine, wind and rain)? Are there tides? Are there waves?
4. Split the class into four groups and distribute the materials. Each group will represent one of the four communities on Moja Island – the Ericas, Hankis, Moodis and Sandis, with five villages each.
5. Allow approximately 40 minutes for each group to read through the cards with information on their community and the renewable energy sources, and to decide on the most appropriate energy solutions for the five villages within their community. They are given a choice of geothermal, solar, wind, hydroelectric, tidal or wave energy, biomass or biogas (see Table 1 on page 53). From the cards, the students may, for example, decide that some communities may be more confident sourcing their energy either on land or at sea. Although cost is certainly an important factor, this is a separate issue and not part of this activity. Each group should record their results in the worksheet provided.
6. Ask the students to present their decisions to the whole class – at this stage, without giving reasons.
7. Summarise the activity by counting the number of groups that chose to use each renewable energy source using Table 2. Which were the most popular renewable energy options for Moja Island?
8. Finally, ask the students to explain their energy choices. There are no right or wrong answers – the most important point is that students are able to justify their decisions.

## Acknowledgement

The Moja Island activity was developed by the Practical Action[w2] team (Bren Hellier, education officer, and Peter Crowther, freelance education consultant).

## Reference

International Energy Agency (2010) World Energy Outlook 2010. Paris, France: OECD / IEA. ISBN: 9789264086241

## Web references

w1 – The United Nations Development Programme works with 166 countries to improve their inhabitants' lives. See: www.undp.org

w2 – For more information on Practical Action, see: www.practicalaction.org

w3 – Read more about Practical Action's small-scale wind power project in Sri Lanka and watch a video about it here: http://practicalaction.org/energy-advocacy/access-wind-sri-lanka

w4 – To read the United Nations Development Programme 2003 report on the Mbuiri hydropower project, see: http://sgp.undp.org/download/SGP_Kenya1.pdf

w5 – To find out more about Practical Action's micro-hydro power project in Kenya, including a video, see: http://practicalaction.org/our-work/ourwork_energy?id=microhydro

w6 – You will find all materials required for the activity here: www.practicalaction.org/moja-island-1

w7 – You can download the black and white version of the Moja Island map from www.scienceinschool.org/2011/issue19/moja#resources

**Table 2:** The most popular energy choices

| Energy sources | Number of groups |
|---|---|
| Wind | |
| Solar | |
| Water (hydroelectric, wave, tidal) | |
| Geothermal | |
| Biological (biomass, biogas) | |

## Resources

For further activities and free downloadable material on renewable energy, visit: www.practicalaction.org/education/renewable-energy-resources

If you enjoyed reading this article, have a look at the full collection of earth science articles published in *Science in School*. See: www.scienceinschool.org/earthscience

Dr Marlene Rau was born in Germany and grew up in Spain. After obtaining a PhD in developmental biology at the European Molecular Biology Laboratory in Heidelberg, Germany, she studied journalism and went into science communication. Since 2008, she has been one of the editors of *Science in School*.

To learn how to use this code, see page 1.

# Neutrinos: an introduction

What do continental drift, nuclear power stations and supernovae have in common? Neutrinos, as **Susana Cebrián** explains.

## What are neutrinos?

Neutrinos, meaning 'little neutral ones', are everywhere, all around us. These tiny elementary particles travel through space at close to the speed of light and have no charge. They were once thought to have no mass either, but scientists now suggest that they *do* have a mass; it is estimated to be less than a billionth of the mass of a hydrogen atom, but the research continues[w1].

The existence of neutrinos, among the most abundant particles in the Universe, was first postulated by Austrian physicist Wolfgang Pauli in 1930 to explain observations of radioactive beta decay. It was not until the first nuclear power stations were built, though, that a sufficiently high flux of neutrinos (actually their antiparticles, antineutrinos; see Landua & Rau, 2008, for more information on antiparticles) from decaying fission fragments was available to confirm their existence. In 1956, Clyde Cowan and Frederick Reines built two large water-filled tanks underground, mere metres away from the nuclear power plant at Savannah River near Aiken,

- Physics
- Earth science
- Particle physics
- Astrophysics
- Ages 14+

REVIEW

Neutrinos are strange particles – small but fascinating. This article describes their origin, properties and detection in an accessible way and with sound facts. It makes good background reading for physics teachers, but can also be a starting point for students doing a presentation project on the topic or to stimulate further discussions, e.g. about particle physics in general, the standard model, detector physics, CERN, astrophysics or radiation.

The article is mainly useful for physics lessons, but it contains links to earth science. To make the topic accessible to younger students (about the age of 14) as well, I would suggest the teacher selects parts of the article to discuss.

*Gerd Vogt, Austria*

The Super-Kamiokande detector tank is filled with water

*Image courtesy of Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo*

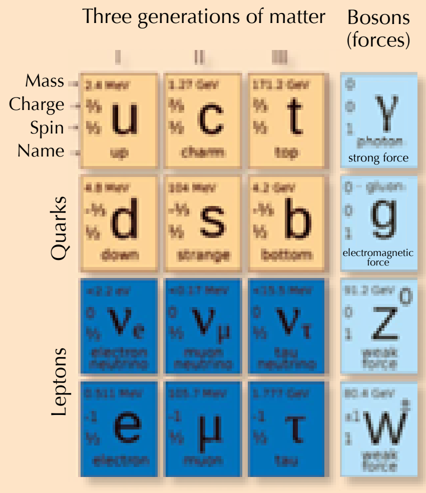
South Carolina, USA, in which the antineutrinos interacted with the water's protons (see diagram below). Frederick Reines was awarded the Nobel Prize in Physics in 1995[w2] for this experiment. Clyde Cowan could not share the prize, because he had passed away in 1974.

Neutrinos come in three types or *flavours*, according to the standard model of particle physics (see image, right): the *electron neutrino*, *muon neutrino*, and *tau neutrino*, which have all been confirmed experimentally. For the detection of the muon neutrino, Leon M Lederman, Melvin Schwartz and Jack Steinberger were awarded the Nobel Prize in Physics in 1988[w2].

A fourth, 'sterile' type has been proposed, which is immune to the weak force of the standard model, and recent data including a refined calculation of measurements performed at the Institut Laue-Langevin[w3] in Grenoble, France, in the 1980s support this idea (Hand, 2010; Reich, 2011). Were sterile neutrinos to be found, a new realm of physics beyond the standard model would open up.

Even the three confirmed types of neutrinos are special: they oscillate from one flavour to another – electron, muon and tau neutrinos change from one to another. This phenomenon was first observed in 1998 by the Japanese Super-Kamiokande experiment[w4], in which muon neutrinos generated in the atmosphere were found to 'disappear', presumably into tau neutrinos. A recent experiment has now successfully observed such an event from the other perspective – as an appearing tau neutrino rather than a disappearing muon neutrino: after three years in which a beam of muon neutrinos was released at CERN[w5] in Geneva, Switzerland, a tau neutrino was detected in 2010 by the OPERA detector at the Gran Sasso National Laboratory[w6] in Italy, 730 km away (see images on page 57). The detectioin of the oscillations also solved a 40-year-old mystery: scientists had always found many fewer electron neutrinos arriving from the Sun than expected. In 2001, the Solar Neutrino Observatory[w7] in Canada demonstrated that they changed into neutrinos of other flavours on their way to Earth (Bahcall, 2004). Further experiments to analyse neutrino oscillations are underway, for example in France and Japan, where accelerators and nuclear power stations provide large numbers of antineutrinos for observation[w8].

*Image courtesy of PBS NOVA; image source: Wikimedia Commons*




The standard model of particle physics. Matter particles come in two different types, leptons and quarks, forming a set of 12 particles, divided into three generations, each consisting of two leptons (one of which is a neutrino) and two quarks. Matter particles can 'communicate' with each other in different ways by exchanging different types of messenger particles named bosons (a different boson for each of the fundamental interactions), which can be imagined as little packets of energy with specific properties. The masses of certain particles are still being investigated by the scientific community; these are values from 2008

## Where do neutrinos come from?

Neutrinos first originated some 14 billion years ago, $10^{-43}$ seconds after the Big Bang. A mere second later, they were already rapidly moving

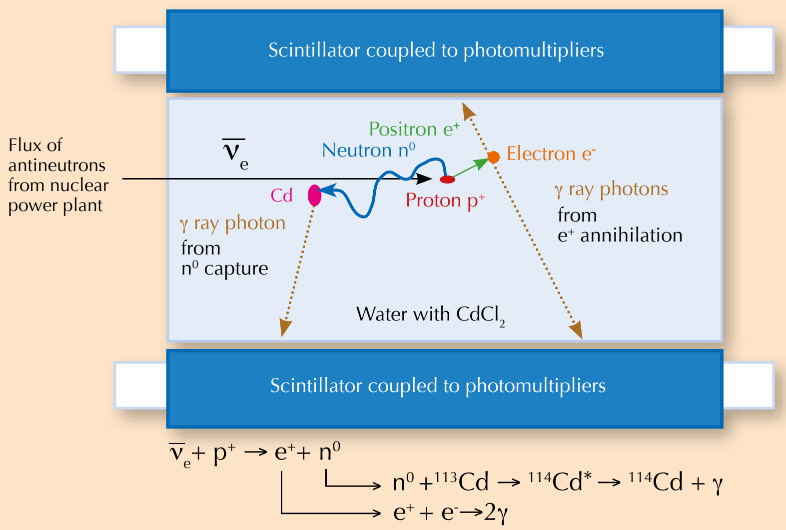


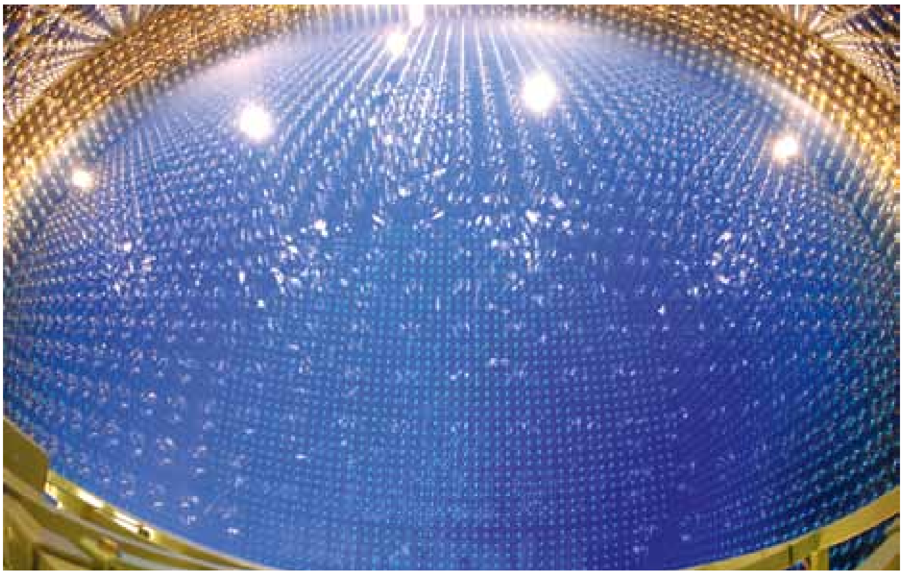

*Image courtesy of Susana Cebrián*

The Reines and Cowan experiment: electron antineutrinos ($\bar{\nu}_e$) interact with the water's protons ($p^+$) in a big tank filled with water and cadmium chloride ($CdCl_2$); as a result, positrons ($e^+$, the antiparticles of electrons) and neutrons ($n^0$) are produced. Positrons are annihilated when they encounter electrons from the medium ($e^-$) and neutrons are absorbed by the cadmium (Cd) nuclei. Both these reactions result in the release of gamma ray photons ($\gamma$) which are detected by means of scintillators. These transform the signal into flashes of visible light, which can then be detected and processed by photomultiplier tubes

Image courtesy of CERN

The OPERA detector at the Gran Sasso National Laboratory in Italy

Image courtesy of Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo

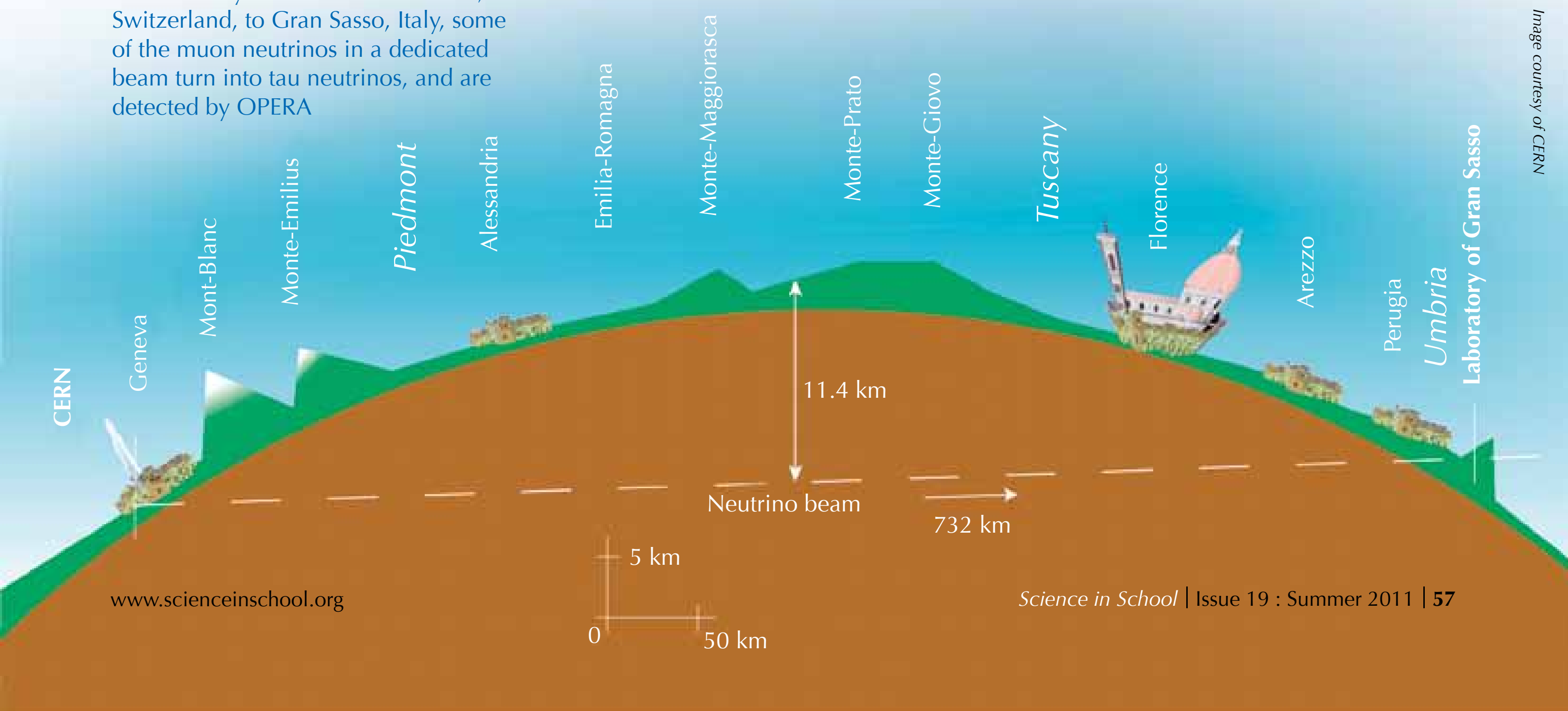


The Super-Kamiokande tank, nearly full of water, seen from above

away from the rest of the hot and dense primary particle soup; scientists are still seeking to detect neutrinos that survive from the Big Bang.

It is neutrinos' weak interaction with matter that makes them almost impossible to detect, but it is also what makes them of interest to scientists. Unlike most other particles, neutrinos are able to escape from dense regions such as the core of the Sun or the Milky Way, and they can travel long distances from far-away galaxies without being absorbed, carrying information about these areas. In this sense, neutrinos are cosmic messengers, and neutrino astronomy is becoming increasingly important.

So far, only two sources of extraterrestrial neutrinos have been observed: the Sun and supernovae. Raymond Davis Jr and Masatoshi Koshiba won the third neutrino Nobel Prize in Physics in 2002[w2] for their detection of solar and supernova neutrinos. Like other stars, the Sun emits electron neutrinos at several steps of the process by which light nuclei fuse into heavier ones (see image on page 58, and to learn more, see Westra, 2006, and Boffin & Pierce-Price, 2007); more than $10^{10}$ solar neutrinos hit a square centimetre of Earth every second. Unlike photons, which take about 100 000 years to travel from the core of the Sun to its outer photosphere before speedily travelling to Earth, neutrinos released in the same fusion process do the entire trip in a mere 8 minutes. This is why solar neutrinos are useful messengers carrying information about the current fusion




On their way from CERN in Geneva, Switzerland, to Gran Sasso, Italy, some of the muon neutrinos in a dedicated beam turn into tau neutrinos, and are detected by OPERA

Image courtesy of CERN

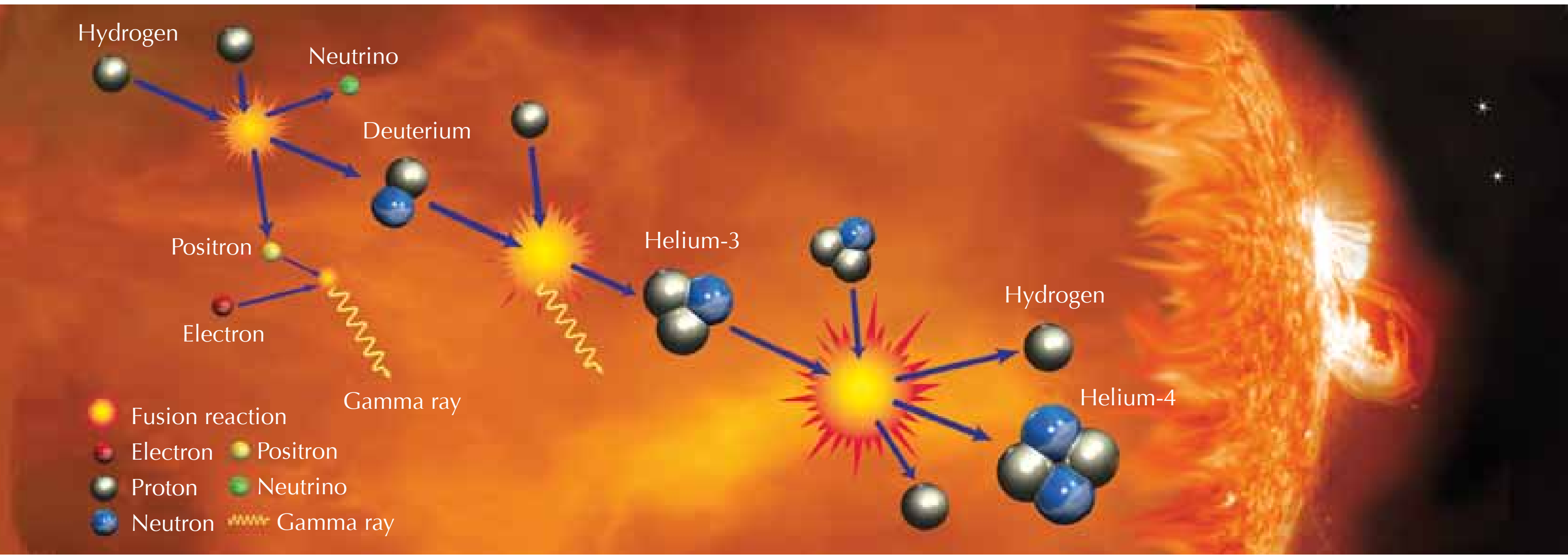



*Image courtesy of Mark Tiele Westra*

processes inside the Sun, such as the chemical composition of its core[w9].

Supernova neutrinos are the result of the violent end of some stars, which explode and produce even more neutrinos than photons (see Székely & Benedekfi, 2007): in 1987, several detectors registered an unusually strong signal (several events within a few seconds, as opposed to the usual frequency of about one per day), attributed to neutrinos from supernova SN1987A in the Large Magellanic Cloud. To allow astronomers to prepare to observe these events, several neutrino detectors are now linked together as the Supernova Early Warning System[w10], because during these stellar explosions, the neutrinos are released before the photons that the astronomers seek to detect.

Astronomers, however, are not the only scientists interested in neutrino detectors. On Earth, both natural and artificial neutrino sources exist: radioactive materials from inside Earth can undergo beta decay, producing geo-neutrinos. In addition, nuclear fission reactors produce neutrinos, and dedicated particle accelerators are being used as neutrino sources for research. These are interesting to particle physicists, of course, to further characterise neutrinos, but also to earth scientists and maybe even politicians (see 'Neutrinos as nuclear police' and 'Powering Earth').

Finally, when cosmic rays hit Earth's atmosphere, atmospheric neutrinos are emitted as decay products of pions and muons. This most abundant source of naturally occurring neutrinos on Earth is a nuisance to neutrino astronomers (see 'How to detect neutrinos'), who are interested in neutrinos that originate in outer space, but it provides neutrino physicists with another means of studying their favourite particles.

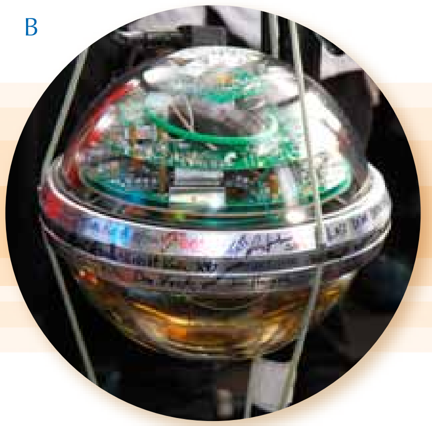
## How to detect neutrinos

Neutrinos are very useful for studying astronomical and cosmological phenomena, and neutrino detectors are being built worldwide, deep underground to filter out the 'noise' of other particles. The recently finished IceCube[w11] is the largest detector yet: a cubic kilometre of ice at the South Pole, acting as a telescope to search for neutrinos from astrophysical sources (see images below). When a neutrino hits a proton of Antarctic ice, a muon is released. Like any charged particle travelling at more than the speed of light in a specific medium

The IceCube neutrino telescope array is located at the South Pole (A; South Pole Station to the left of the runway, IceCube to the right). It consists of thousands of autonomous digital optical modules (B), which record the arrival time of each neutrino. They are deployed in deep holes in the ice, drilled with hot water (C). When a neutrino hits a proton of Antarctic ice, a Cherenkov cone of blue light is generated (D), and the path of light is reconstructed from the times of neutrino detection

A

B



*Images courtesy of NSF*

Fusion 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

(though less than the speed of light in vacuum), the muon will generate a conical trail of blue light – Cherenkov radiation, the photonic equivalent of a supersonic boom, which can also be seen in some nuclear reactors.

Thousands of optical sensors, in a three-dimensional grid 1.5-2.5 km deep in the ice, detect this light; combined, the data can be used to determine the energy of the neutrino and the direction it came from. To distinguish muons that are generated from cosmic neutrinos from the millions more muons that are produced by cosmic rays in the atmosphere above the detector, IceCube uses Earth as a filter, only looking at muons that come from underground. Neutrinos are the only particles able to penetrate the Earth unhindered, so any muon coming from that direction must have been newly generated in the detector from a cosmic neutrino.

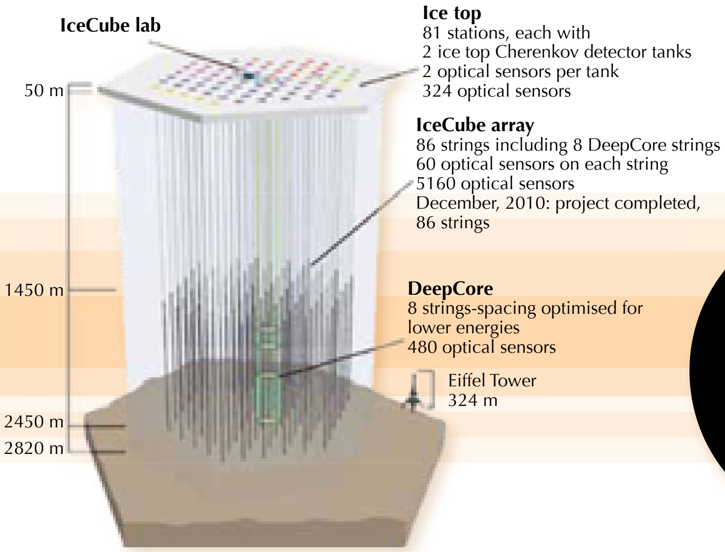
Other detectors use different materials and strategies – but all put as much material in the neutrinos' way as possible, trying to make them interact and reveal themselves.

## Neutrinos as nuclear police

Detection of nuclear weapons and material is important for many reasons, including the prevention of nuclear proliferation and terrorism. Scientists now propose that cubic-metre antineutrino detectors could be used to non-intrusively monitor and safeguard nuclear reactors[w12].

At present, reactors are monitored indirectly (for example using satellites, gas and dust emissions, and seismic and infrasound signatures for weapons testing), which can result in misleading data. Neutrino detectors would provide real-time information about the reactor core power and possibly even its isotopic composition. An array of about 500 such detectors worldwide would be able to calculate the power output of individual reactors, allowing the detection of clandestine nuclear weapons testing.

C

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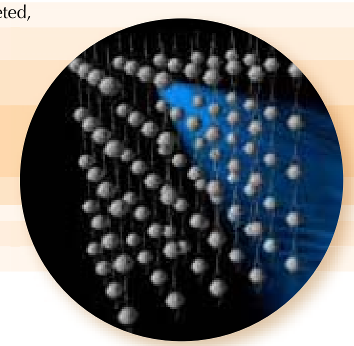

An artist's impression of the material around supernova SN1987A: two outer rings, one inner ring and the deformed, innermost expelled material

*Image courtesy of ESO / L Calçada*

Image courtesy of Karlsruhe Institute of Technology (KIT)

The KATRIN spectrometer in Karlsruhe, Germany, is one of the experiments aims to 'weigh' neutrinos

## Powering Earth

Neutrinos are also detected in geophysics. Natural radioactive decay of uranium, thorium and potassium in Earth's crust and mantle sustains the flow of molten material in convective currents, which drive continental drift, seafloor spreading, volcano eruptions and earthquakes.

There are several models for this decay, depending on the composition of Earth's crust. Geo-neutrinos produced during decay may help answer the question of crust composition. Geo-neutrinos were first detected in 2005 by the KamLAND[w13] experiment in Japan, although an abundance of nuclear power stations limited the studies, because the antineutrinos they release have similar energetic signatures to those of geo-neutrinos. In 2009, an international team from the Borexino project[w6, w14] was more successful because there are fewer nuclear power stations nearby, so eventually, statistically significant numbers of geo-neutrinos should be collected to determine the relative amounts of uranium, thorium and potassium.

In the time that you have been reading this article, about 10 000 000 000 000 000 neutrinos have passed through you without your noticing. Tiny, yet with the power to confirm or overthrow a number of scientific theories.

## Acknowledgement

The editors would like to thank Dr Christian Buck, neutrino physicist from the *Max-Planck-Institut für Kernphysik* (Max Planck Institute for Nuclear Physics), Heidelberg, Germany, for advice in developing the article.

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Download the article free of charge from the *Science in School* website (www.scienceinschool.org/2011/issue19/neutrinos#resources), or subscribe to *Nature* today: www.nature.com/subscribe

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## Web references

w1 – Scientists from the University College of London have estimated the mass of the neutrino: www.ucl.ac.uk/news/news-articles/1006/10062204

Hopes for the most accurate measurements yet lie with the KATRIN experiment, which is in Karlsruhe, Germany: www-ik.fzk.de/~katrin

w2 – Read about the Cowan and Reines experiments here: http://library.lanl.gov/cgi-bin/getfile?00326606.pdf

To find out more about the Nobel Prizes in Physics 1988, 1995 and 2002, see: http://nobelprize.org/nobel_prizes/physics/laureates

w3 – The Institut Laue-Langevin operates one of the most intense neutron sources in the world. It is a member of EIROforum, the publisher of *Science in School*. See: www.ill.eu

w4 – For more information on the Japanese Super-Kamiokande experiment, see: www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html

w5 – To find out more about CERN, the world's largest particle physics laboratory and one of the eight members of EIROforum, see: www.cern.ch

To read more about the successful detection of a muon neutrino turned into a tau neutrino in CERN's press release, see http://public.web.cern.ch/press or use the direct link: http://tinyurl.com/64crhr5
Or watch a video on the topic: www.youtube.com/watch?v=M3aB_zUZ1c8

w6 – The Gran Sasso National Laboratory in Abruzzo near L'Aquila, Italy, is the largest underground laboratory in the world for experiments in particle physics, particle astrophysics and nuclear astrophysics, including the OPERA and Borexino experiments. To learn more, see: www.lngs.infn.it

w7 – For more information about the Canadian Solar Neutrino Observatory experiment, see: www.sno.phy.queensu.ca

w8 – In France and Japan, detectors have been installed to further analyse neutrino oscillations. See: http://doublechooz.in2p3.fr and http://jnusrv01.kek.jp

w9 – To find out more about current solar neutrino research, see: http://arxiv.org/pdf/0811.2424

For more information about fusion in the Sun and elsewhere in the Universe, see the *Science in School* article series: www.scienceinschool.org/fusion

w10 – The Supernova Early Warning System website can be found here: http://snews.bnl.gov

w11 – For more information about ongoing research projects at IceCube, see: http://icecube.wisc.edu

Olivier Hainaut from the European Southern Observatory (ESO), the world's most productive astronomical observatory, which is a member of EIROforum, talked to the IceCube scientists during the 24-h live webcast 'Around the world in 80 telescopes' during the International Year of Astronomy 2009. Start watching the online video from minute 1:27: www.eso.org/public/videos/10msouthpole

For the ESO website, see: www.eso.org

For further astronomy resources, see:

Starr C, Harwood R (2009) Education resources for the International Year of Astronomy. *Science in School* **13**. www.scienceinschool.org/2009/issue13/iya

w12 – To learn more about the idea of detecting secret fission reactors using neutrinos, see: http://physicsworld.com/cws/article/news/44411

w13 – If you would like to find out more about the KamLAND experiment in Japan, see: http://kamland.lbl.gov

w14 – Find out the latest about the Borexino experiment: http://borex.lngs.infn.it

## Resources

The Booster Neutrino Experiment and Interactions.org have produced good overview brochures on neutrinos, freely available online. See: www-boone.fnal.gov/about/nusmatter (Neutrinos Matter) and www.interactions.org/pdf/neutrino_pamphlet.pdf (Neutrino Odyssey)

The IceCube project website hosts a wonderful teaching activity on 'popcorn neutrinos', in which students can investigate the concepts behind beta decay. See: www.icecube.wisc.edu or use the direct link: http:// tinyurl.com/45ytuq7

For slides of three talks on neutrino research for school students, available in German, see: www.mpi-hd.mpg.de/hfm/wh/pams/PamS0708.htm

Particle Adventure is a fun interactive online tour of particle physics: http://particleadventure.org

The Contemporary Physics Education Project offers student and teacher worksheets in English and Spanish for classroom activities on particle physics, including one on conservation laws, following Pauli's footsteps in postulating the neutrino (Activity 5). See: www.cpepweb.org/Class_act.html

The UK Science and Technology Council has compiled a resource guide for teaching particle physics. See: www.stfc.ac.uk/Public and Schools/2563.aspx

Susana Cebrián is a professor at the University of Zaragoza, Spain, working on several experiments in the field of astroparticle physics at the Spanish Canfranc Underground Laboratory.

To learn how to use this code, see page 1.

Chemiluminescence of luminol in the laboratory

Image courtesy of David Muehlheimer; image source: Wikimedia Commons

A firefly glowing

Image courtesy of Terry Priest; image source: Flickr

# What is chemiluminescence?

Glowing jellyfish, flickering fireflies, fun glow sticks; **Emma Welsh** introduces the beautiful and mysterious world of chemiluminescence.

Glow sticks

Image courtesy of Erik Solheim; image source: Wikimedia Commons

Fireflies, jellyfish and glow sticks – one flies, one lives deep in the ocean and one provides entertainment in night clubs. What is the link? The answer is some intriguing chemical reactions that produce light.

Chemiluminescence is the production of light from a chemical reaction. Two chemicals react to form an excited (high-energy) intermediate, which breaks down releasing some of its energy as **photons** of light (see glossary for all terms in bold) to reach its ground state (see Figure 1 on page 64).

A + B –> AB* –> Products + Light

(AB*: Excited intermediate)

Chemiluminescent reactions do not usually release much heat, because energy is released as light instead. Luminol produces a light when it reacts with an oxidising agent; the chemistry of this reaction is shown in Box 1 (page 66).

Image courtesy of How Stuff Works

Using luminol at the scene of a crime

## Chemiluminescence in forensics

Forensic scientists use the reaction of luminol to detect blood at crime scenes. A mixture of luminol in a dilute solution of hydrogen peroxide is sprayed onto the area where the forensic scientists suspect that there is blood. The iron present in the haem unit of haemoglobin (Figure 3, page 66) in the blood acts as a **catalyst** in the reaction described in Box 1. The room must be dark and if blood is present, a blue glow, lasting for about 30 seconds, will be observed. The forensic investigators can record this glow by using photographic film, which can be used as evidence in court for the presence of blood at the scene. (For a teaching activity about forensic science, see Wallace-Müller, 2011.)

Because the iron acts as a catalyst, it is only required in trace amounts, therefore only a tiny amount of blood is required to produce a positive result. This means that blood can be detected even when it is not visible to the naked eye.

One of the drawbacks of using luminol is that the reaction can be catalysed by other chemicals that may be present at the crime scene, for example, copper-containing alloys, some cleaning fluids such as bleach, and even horseradish. Clever criminals can clean up the blood with bleach, which destroys the evidence of the blood, but bleaching the carpet may alert people to the crime sooner. Urine also contains small amounts of blood, which can be enough to catalyse the reaction of luminol. Once luminol has been applied to the area, it may prevent other tests from being performed there. However, despite these drawbacks, luminol is still used by forensic scientists as a tool to solve crime.

REVIEW

- Chemistry
- Biology
- Physics
- Interdisciplinary
- Chemical bonds
- Chemical reactions
- Atomic structure
- Electromagnetic spectrum
- Light
- Energy
- Genetics
- Ages 14-18

This article offers a way to motivate students to understand chemical reactions. Even if they are not keen to know why a glow stick glows in the dark, they will surely be eager to find out how fireflies or jellyfish produce light, or to discover how blood is detected at crime scenes. The article can serve either as an introduction to chemical reactions or to give attractive examples of redox reactions and also to illustrate the levels of energy in the shell of an atom.

The article can be adapted for different age ranges and for different subjects and topics. For students aged 14-15, it could be used to teach chemistry (atomic structure and movement of electrons between shells, introduction to chemical reactions) or biology (bioluminescence). For this age group, the teacher would need to simplify the information in the article and omit the details of the reactions. For students aged 16-18, the article could be used to teach chemistry (redox reactions, catalysts, the influence of temperature on reaction speed, the effect of pH on a reaction, and covalent bonds), physics (the electromagnetic spectrum and photons) or genetics (genetic engineering). Suitable comprehension questions include:

- What is chemiluminescence?
- What do forensic scientists use chemiluminescence for?
- Explain some biological functions of bioluminescence.
- Why should you keep your glow stick in the freezer when you are not using it?
- How could you make a self-illuminated Christmas tree?

*Ana Gil, Spain*

*Image courtesy of* Chemistry Review

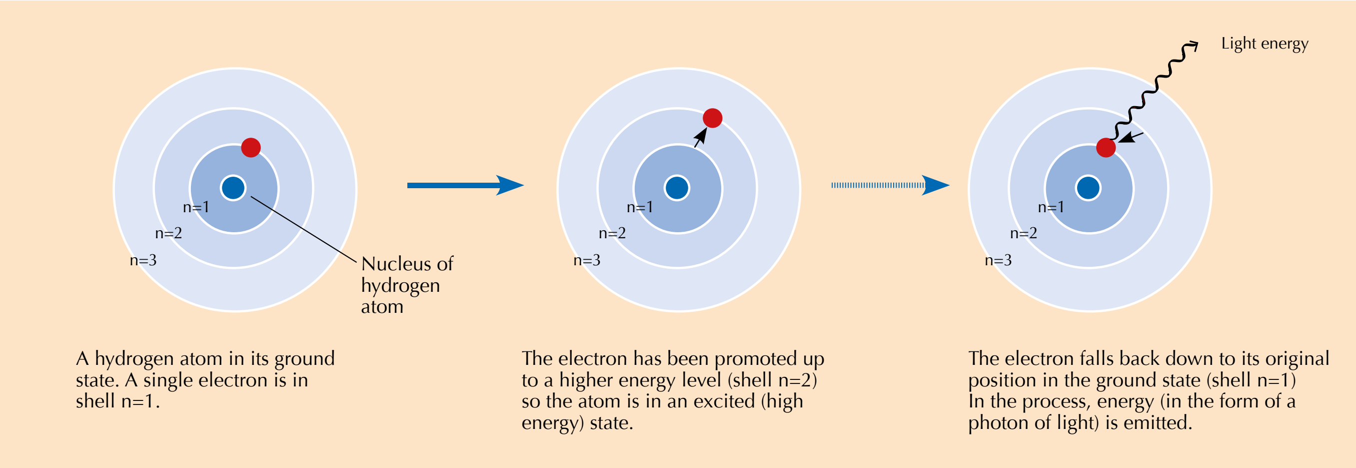



**Figure 1: Movement between electron shells**
A hydrogen atom in its ground state. A single electron is in shell $n = 1$. Each shell has its own energy level.

When the hydrogen atom absorbs a quantum (defined amount) of energy, it is promoted to a higher energy level (shell $n = 2$) and is now in an excited (high-energy) state. We draw an asterisk (*) next to the molecule to indicate this.

The electron falls back down to its original position in the ground state (shell $n = 1$). In the process, a packet of energy (a **photon**) is released in the form of electromagnetic radiation. The wavelength depends on the amount of energy. If the wavelength is within the range of visible light, the electron transition will be perceived as light of a particular colour. The wavelength determines the colour (see Figure 2 below)

*Image courtesy of NASA*

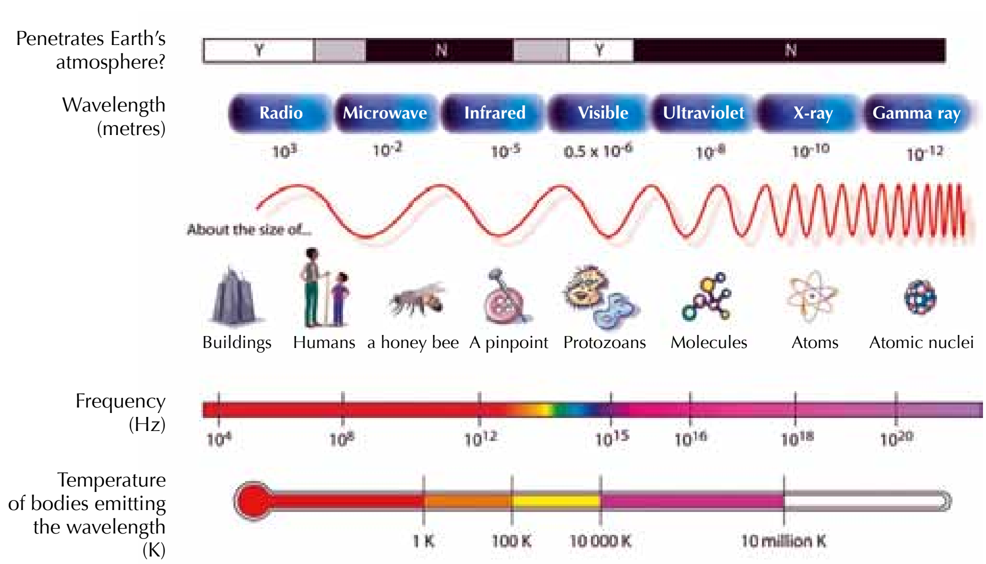



**Figure 2: The electromagnetic spectrum**

## In the nightclub

When you snap a glow stick and it begins to glow, the light produced is an example of chemiluminescence (Figure 4, page 67). Glow sticks comprise a plastic tube containing a mixture including diphenyl oxalate and a dye (which gives the glow stick its colour). Inside the plastic tube is a smaller glass tube containing hydrogen peroxide. When the outer plastic tube is bent, the inner glass tube snaps, releasing the hydrogen peroxide and starting a chemical reaction that produces light (see Box 2, page 67). The colour of light that a glow stick produces is determined by the dye used (see Box 3, page 68).

Chemiluminescence reactions, such as those in glow sticks, are temperature-dependent. The reaction speeds up as the temperature rises – snapping your glow stick in hot water will produce a fantastic glow, but it will not last as long as it would at room temperature. Conversely, the reaction rate slows down at low temperature; this is why keeping your glow stick in the freezer for several hours can allow the stick to glow brightly again when

BACKGROUND

# Glossary

**Anion:** an atom (or group of atoms) that bears a negative charge.

**ATP:** adenosine triphosphate occurs in all known life forms. It is the primary *energy currency* in cells. ATP is formed from ADP (adenosine diphosphate) and phosphate during energy-yielding reactions (such as the oxidation of glucose), and is broken down (to ADP and phosphate) to release this energy in order to drive unfavourable reactions.

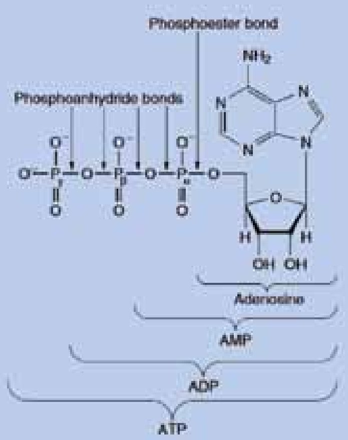



*Image courtesy of* Chemistry Review

**Bioluminescence:** The production of light by living organisms. Bioluminescence may result from the absorption of light (**fluorescence** or **phosphorescence**, e.g. in many deep-sea fish) or from a chemical reaction (**chemiluminescence**, e.g. in fireflies).

**Catalyst:** A substance that makes a reaction occur faster, but that does not undergo a permanent chemical change during the reaction (i.e. is not used up in the reaction). Catalysts work by providing an alternative route for the reaction that is lower in energy.

**Chemiluminescence**: A type of luminescence in which the electrons are excited by a chemical reaction, for example the reaction of luminol described in Box 1.

**Conjugated:** Conjugated systems mainly arise in chemistry when there are double bonds next to each other. The atoms in a conjugated system are held together by **covalent bonds** and have alternating single and multiple bonds (mainly double bonds, but triple bonds are also capable of being in conjugation). Alkenes are flat; conjugated systems must always be planar to allow **delocalisation** of the electrons throughout the system. The dye molecules in Box 3 are all examples of conjugated compounds.

**Covalent bonds:** Bonds between two atoms where a pair of electrons are shared between them.

**Delocalised:** When molecules have conjugated bonds, the electrons are free to move around throughout the entire conjugated system. These are referred to as delocalised electrons. The electrons in a benzene ring are delocalised, and this is why all the carbon-carbon bonds are the same length.

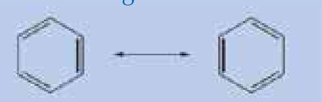


*Image courtesy of* Chemistry Review

The electrons in benzene are delocalised in a conjugated system.

**Fluorescence:** A type of **luminescence** in which the electrons are excited by light, e.g. in the security markings on banknotes.

**Luminescence:** The production of light, usually at low temperatures, for example by chemical reactions or electrical energy. Incandescence, in contrast, is light generated by high temperatures.

**Phosphorescence:** As **fluorescence**, but the glow lasts for longer (according to some definitions, over 10 nanoseconds), for example glow-in-the-dark stickers.

**Photon:** A quantum (packet) of light energy.

it is removed and warmed up, long after it would otherwise have stopped glowing. The reaction does not stop completely in the freezer, but it does slow down so that the glow is barely detectable.

## Living glow sticks

Have you ever walked along a beach at night and seen sparks of light around your feet? Or been in the countryside at night and seen fireflies flitting about? These are examples of bioluminescence and around 90% of deep-sea life also exhibits this strange phenomenon. These organisms have evolved to produce light because it has many useful functions. Glowing can be used as a lure to catch prey, as camouflage, or to attract potential mates. Some bacteria even use bioluminescence to communicate. The term 'glow worm' describes the larvae of several species of insect, including fireflies; some of them glow to scare off predators, whereas other species use their glow to attract prey. There are species of squid and crustacean that can release clouds of bioluminescent liquid to confuse predators while

BACKGROUND

# Box 1: Luminol, a glow-in-the-dark chemical

The release of a photon of light from a molecule of luminol is a fairly complex, multi-stage process. In a basic (alkaline) solution, luminol exists in equilibrium with its **anion**, which bears a charge of -2. The anion can exist in two forms (or **tautomers**), with the two negative charges **delocalised** on either the oxygens (the enol-form) or on the nitrogens (the ketol-form; see Figure 5, below).

Molecular oxygen ($O_2$) combines with the enol-form of the luminol anion, oxidising it to a cyclic peroxide. The required oxygen is produced in a *redox reaction* (i.e. one in which both reduction and oxidation occur) involving hydrogen peroxide ($H_2O_2$), potassium hydroxide and (for example) potassium hexacyanoferrate(III) ($K_3[Fe(CN)_6]$, also known as potassium ferricyanide). The hexacyanoferrate(III) ion ($[Fe(CN)_6]^{3-}$) is reduced to the hexacyanoferrate(II) ion ($[Fe(CN)_6]^{4-}$, giving potassium ferrocyanide, $K_4[Fe(CN)_6]$), while the two oxygen atoms from the hydrogen peroxide are oxidised from oxidation state -1 to 0:

reduction; oxidation

$$2K_3[Fe(CN)_6] + 2KOH + H_2O_2 \rightarrow 2K_4[Fe(CN)_6] + 2H_2O + O_2$$

The cyclic peroxide then decomposes to give 3-aminophthalate (3-amino-1,2-benzenedicarboxylic acid) in an excited state, along with a molecule of nitrogen ($N_2$) – see Figure 5, below. This decomposition reaction is favoured because the cyclic peroxide molecule is highly unstable, and the reaction involves breaking some weak bonds. It is also favoured because of the increase in *entropy* (disorder) due to the liberation of a gas molecule. When the excited 3-aminophthalate drops down to the ground state, a photon of blue light is released.

*Image courtesy of* Chemistry Review

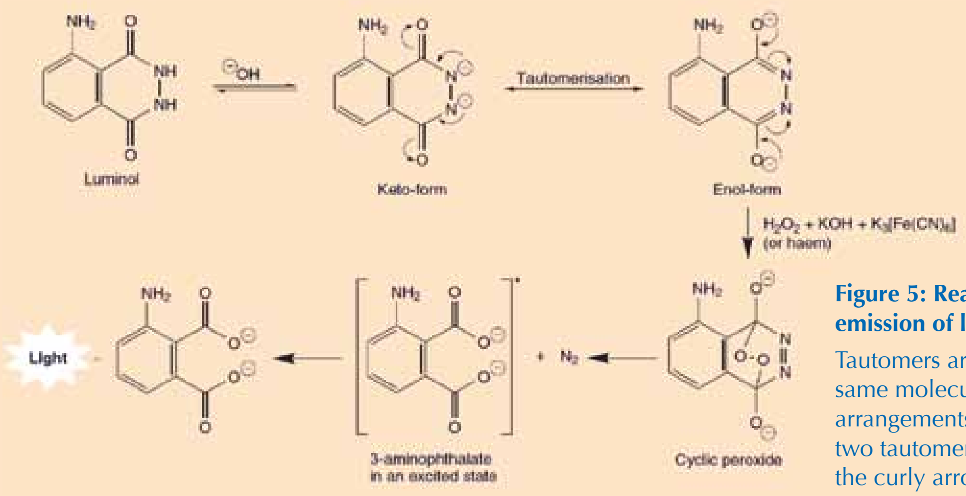


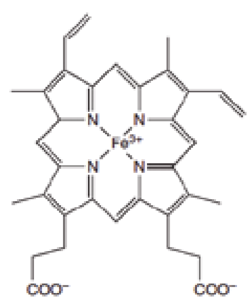

**Figure 5: Reactions leading to the emission of light from luminol**

Tautomers are molecules with the same molecular formula, but different arrangements of atoms or bonds. The two tautomers can be interconverted; the curly arrows show the movement of electrons that brings about the change between the two forms

*Image courtesy of* Chemistry Review

**Figure 3: Haem group in haemoglobin**

The iron atom (Fe) in the centre of the porphyrin ring catalyses the reaction of luminol




they make their escape. Creatures living deep in the ocean have evolved to produce mainly blue or green light because it transmits well through seawater. This is because blue light has a shorter wavelength than red light, which means it is absorbed less readily by particles in the water.

Bioluminescent reactions use **ATP** (adenosine triphosphate) as a source of energy. The structure of the light-producing molecules varies from species to species, but they are all given the generic name *luciferin*. The structure

Aequorin was first discovered in the jellyfish *Aequorea victoria*

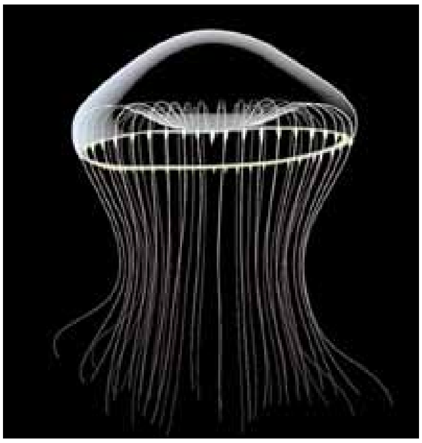


Image courtesy of Typoform / the Royal Swedish Academy of Sciences (RSAS)

of firefly luciferin is shown in Figure 6, to the right. When fireflies glow, the luciferin is oxidised to produce an excited complex, which falls back down to the ground state, releasing a photon of light, just like the chemiluminescent reaction of luminol described in Box 1. However, fireflies do not use hydrogen peroxide and potassium hexacyanoferrate(III) to oxidise luciferin; instead they use molecular oxygen and an enzyme called luciferase (this is also a generic name – luciferases vary from species to species).

Luciferin + $O_2$ —Luciferase—> Oxyluciferin + Light

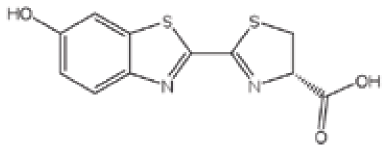



**Figure 6: The structure of firefly luciferin**

Image courtesy of Chemistry Review

There have been a number of experiments investigating aequorin, a protein found in certain jellyfish, which produces blue light in the presence of calcium (see Shaw, 2002, and

BACKGROUND

## Box 2: Chemistry of glow sticks

When diphenyl oxalate reacts with hydrogen peroxide ($H_2O_2$), it is oxidised to give phenol and a cyclic peroxide. The peroxide reacts with a molecule of dye to give two molecules of carbon dioxide ($CO_2$) and in the process, an electron in the dye molecule is promoted to an excited state. When the excited (high-energy) dye molecule returns to its ground state, a photon of light is released. The reaction is pH-dependent. When the solution is slightly alkaline, the reaction produces a brighter light.

**Safety note**: phenol is toxic, so if your glow stick leaks, take care not to get the liquid on your hands; if you do, wash them with soapy water straight away.

See also the general safety note on page 73 and on the *Science in School* website: www.scienceinschool.org/safety

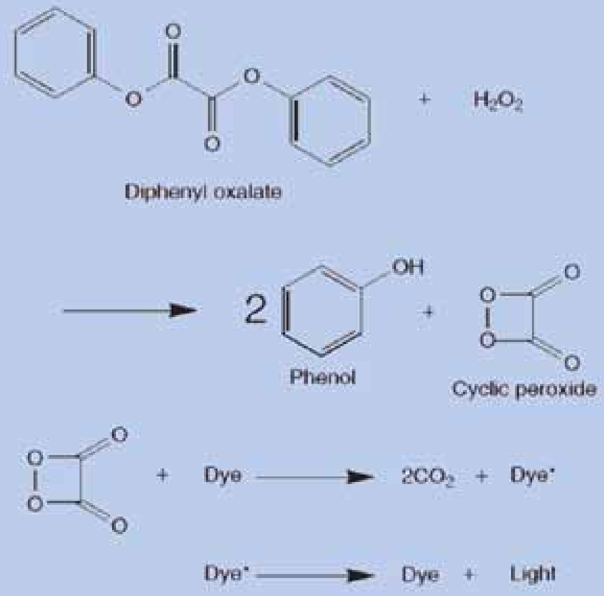



Image courtesy of Chemistry Review

**Figure 4: How a glow stick works**

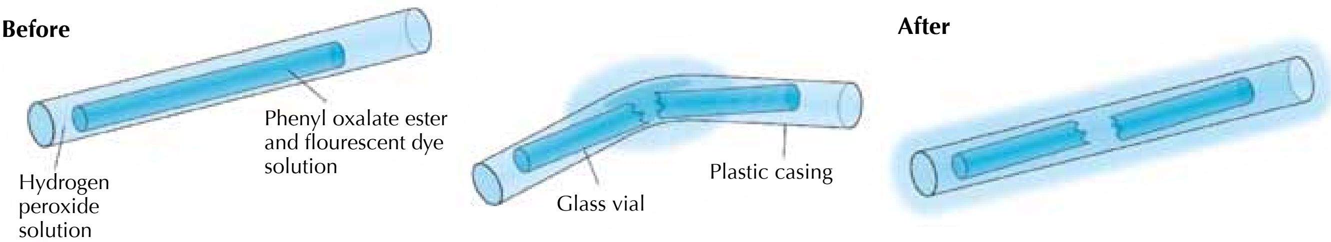


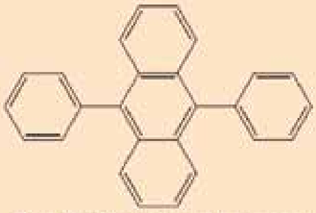

Image courtesy of Chemistry Review

BACKGROUND

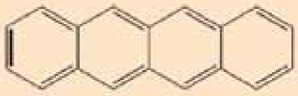
*Image courtesy of* Chemistry Review

## Box 3: What makes glow sticks different colours?

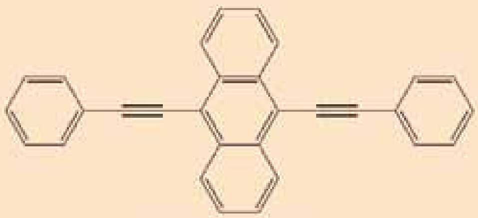
The dyes used in glow sticks are **conjugated** aromatic compounds (arenes). The degree of conjugation is reflected in the different colour of the light emitted when an electron drops down from the excited state to the ground state.



Blue light (9,10-diphenyl anthracene)



Yellow-green light (tetracene)



Green light (9,10-bis(phenylethynyl)anthracene

*Image courtesy of James Jordan; image source: Flickr*

A firefly glowing

Furtado, 2009) and can thus be used in molecular biology to measure calcium levels in cells. Some scientists have come up with other ideas for utilising bioluminescence in the future, for example self-illuminated Christmas trees. Can you think of any other exciting potential uses for this amazing natural phenomenon?


## Acknowledgement

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Wallace-Müller K (2011) The DNA detective game. *Science in School* **19**: 30-35. www.scienceinschool.org/2011/issue19/detective


## Resources

For some experiments with luminol, see Declan Fleming's website for older school students, all about the chemiluminescence of luminol: www.chm.bris.ac.uk/webprojects2002/fleming/experimental.htm

To learn about other types of light in chemistry, see:

Douglas P, Garley M (2010) Chemistry and light. *Science in School* **14**: 63-68. www.scienceinschool.org/2010/issue14/chemlight


Emma Welsh is a freelance science communicator with a PhD in synthetic organic chemistry and postdoctoral experience of medicinal chemistry, making drugs that inhibit enzymes which are involved in cancer biology.



To learn how to use this code, see page 1.

CERN@school students

*Image courtesy of the Langton Star Centre*

# Schoolhouse scientists

**Sarah Stanley** explains how Becky Parker gets her students involved in particle physics at CERN. Why not get your students to join in too?

Although we are all curious about the world we live in, research is a pursuit usually reserved for full-time scientists and university students. Laboratory space and equipment are costly, and experiments take lots of time and patience. But, every so often, a lucky school student is given a unique chance to step into the shoes – or lab coat – of a scientist. Such opportunities are now becoming more accessible, thanks to teachers like Becky Parker.

In 2007, Becky, who teaches physics in the UK, travelled 10 hours by coach with 50 of her students on an annual school visit to CERN[w1], the world's largest particle physics laboratory, in Geneva, Switzerland. That trip would prove to be a pivotal point in her career.

"When we returned from our visit to CERN, we heard about the Space Experiment Competition, run by the British National Space Centre – now UK Space Agency[w2] – and Surrey Satellite Technology Limited," Becky says. "My students thought it would be a good idea to use particle detectors we had seen at CERN to measure cosmic radiation."

The particle detectors, known as TimePix chips, were developed by the international, multi-institutional MediPix collaboration[w3]. Each MediPix and TimePix chip consists of a grid of pixels. The Medipix chip counts each light particle (photon); its important advantage compared to conventional techniques is that no signal whatsoever is measured if no photon enters. This means that there is no noise irrespective of the period

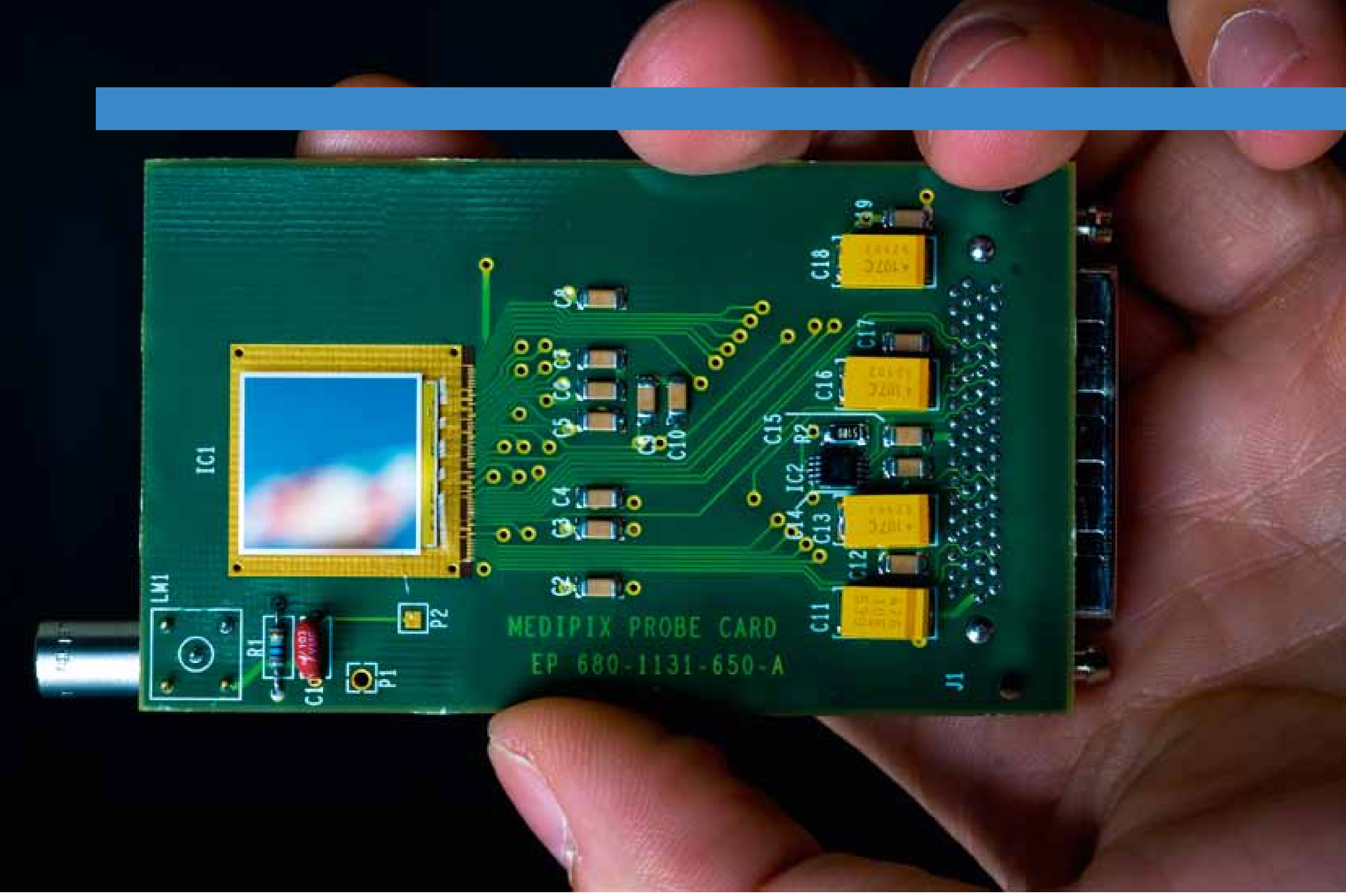


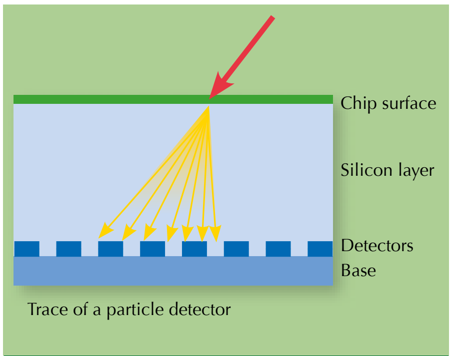

Image courtesy of Maximilien Brice, CERN

of exposure. Unlike a MediPix chip, which just detects incoming particles, a TimePix chip uses an external clock with a frequency of up to 100 MHz as a time reference.

"Michael Campbell, the spokesperson for the MediPix collaboration, had already thought the TimePix chips could be used in schools," Becky says. "For the competition, my students designed the Langton Ultimate Cosmic ray Intensity Detector (LUCID), which uses four TimePix chips around the sides of a cube and one in its bottom to collect cosmic ray data."

Cosmic rays are subatomic particles produced by a variety of events in outer space. They originate in the Sun, other stars, and in unidentified sources at the edge of the visible Universe. Cosmic rays travel unimpeded through vast stretches of empty space, and scientists can detect those that cross paths with Earth, revealing a wealth of information about the Universe. Becky's students hoped to make their own contribution to cosmic ray detection.

Image courtesy of the Medipix collaborations




How Medipix functions

"We entered LUCID into the competition and ended up in second place! We were awarded with the opportunity to fly LUCID on board the TechDemoSat satellite, planned to launch in 2012," Becky says. "The initial LUCID team was three boys and three girls, but now we have 30 to 40 students involved at any given time. The students are working on protocols for sending commands when the experiment is in space – effectively setting up a mission control. The results from LUCID will yield valuable insights about the cosmic ray environment."

Wishing to share the excitement of LUCID, Becky has founded the CERN@school programme, in which smaller versions of LUCID are distributed to other schools. Students gather cosmic ray data, which is collected and made available to all the schools through the CERN@school website[w4]. Ten UK schools are currently involved in the programme, which will soon expand to other schools in Europe and the USA.

"CERN@school students experience the excitement of being involved in real scientific research," Becky says. "They collaborate with an international body of students and are encouraged to consider careers in physics and engineering. The project also allows teachers to act as practicing scientists, and researchers are given opportunities to work in school settings."

Enthusiasm about scientific research is nothing new for Becky. After enjoying science and maths at school, she

The MediPix card

completed a physics degree at the University of Sussex, UK, and a master's degree in conceptual foundations of science at the University of Chicago, USA. She returned to the University of Sussex for a teaching degree, choosing to teach physics because she "loved the subject and wanted people to be excited and inspired by physics".

Becky Parker has now been a teacher for 18 years and has long taught at the Simon Langton Grammar School for Boys, which also enrolls girls in their last two years before university. She first visited CERN in 1993 and began an annual school trip to the institution in 1995, leading ultimately to the fateful 2007 trip that inspired LUCID.

Driven by the successes of LUCID and CERN@school, Becky recently founded the Langton Star Centre[w5], which encourages students to perform research beyond the realm of particle physics. The centre offers students from many schools a chance to work with experts in plasma physics, astronomy and molecular biology. One of the centre's plasma physics students has even published his work in a peer-reviewed journal (Hatfield, 2010).

"Students love getting involved in experimental work when the answers cannot be looked up on the next page," Becky says. "They work with the very best scientists and engineers, and are treated as responsible scientists themselves. They work hard, yet have fantastic experiences, and they are far more likely to continue in science and engineering."

Indeed, since the initiation of the LUCID project, Simon Langton Grammar School has come to contribute 0.05% to 1% of all physics students at UK universities, more than doubling its previous numbers. The school also produces more engineers these days, and a high proportion of its female students continue in physics and engineering.

So what will Becky Parker do next? "We hope to expand the CERN@school project," she says. "With detectors in schools across Europe, we have the potential to do really exciting new physics. We are working out a way to store more data from LUCID and CERN@school by linking the schools together with the help of GridPP, which is a collaboration of particle

A cosmic ray shower

*Image courtesy of CERN*

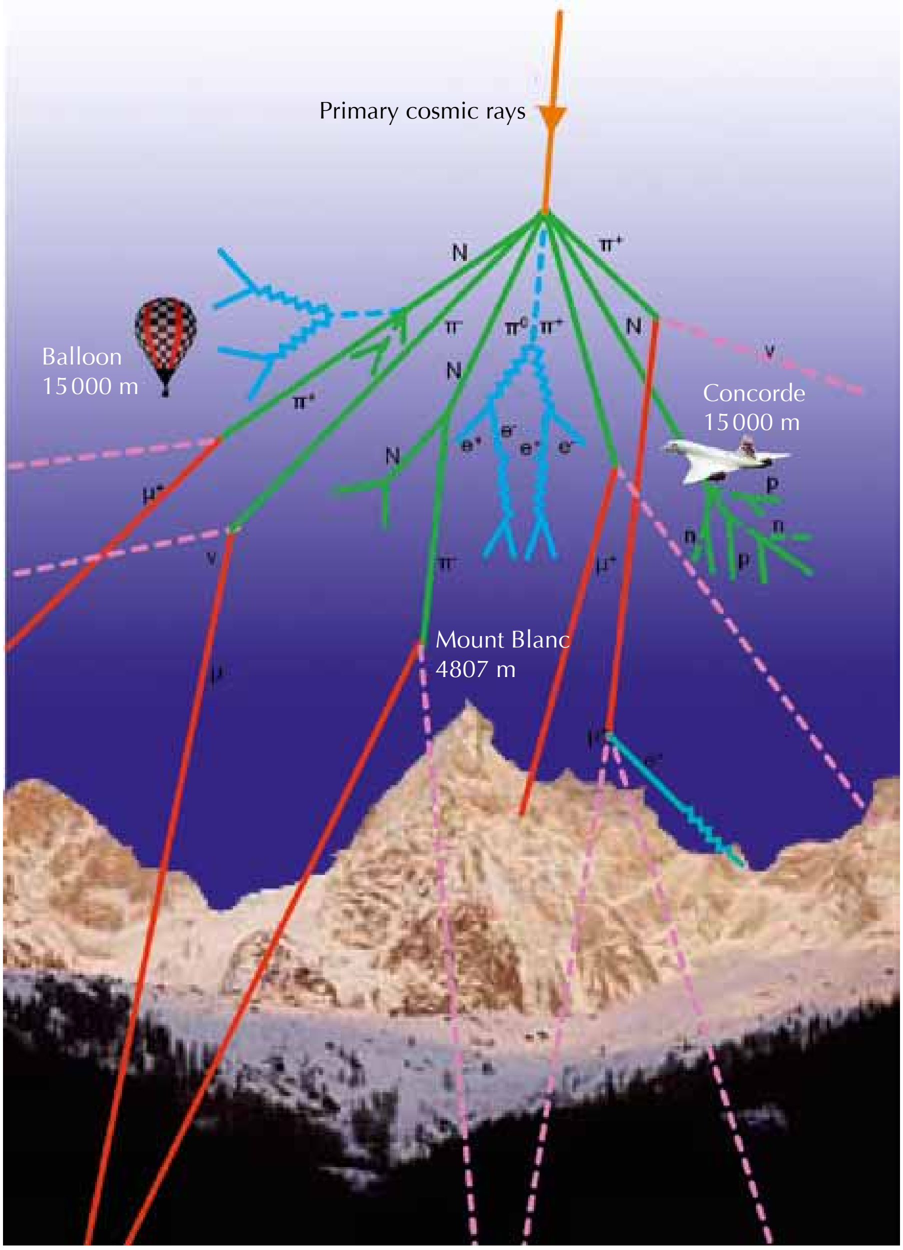
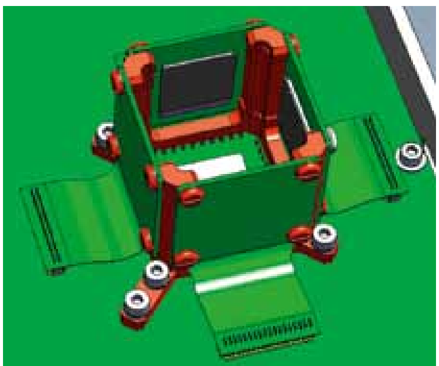



*Image courtesy of Surrey Satellite Technology Limited*



The LUCID detector designed by the Langton school

Image courtesy of the Langton Star Centre

Becky's students visiting CERN

Image courtesy of the Langton Star Centre

The CERN@school kit

physicists and computer scientists from the UK and CERN, forming the UK distributed computing network that is part of the wider CERN Grid. This grid will provide superior data analysis, taking the project to a new level of sophistication and potential."

Teachers interested in getting their students involved in the CERN@school programme or the Langton Star Centre are encouraged to email Becky Parker at bparker@thelangton.kent.sch.uk

## Reference


Hatfield P (2010) Using line intensity ratios to determine the geometry of plasma in stars via their apparent areas. *High Energy Density Physics* **6(3)**: 301-304. doi: 10.1016/j.hedp.2009.10.001


## Web references


w1 – CERN is the world's largest particle physics laboratory, based in Geneva, Switzerland. It is a member of EIROforum, the collaboration of inter-governmental scientific research organisations that publish *Science in School*. To learn more about CERN, see: www.cern.ch

w2 – To find out more about the educational support by the UK Space Agency, visit www.bis.gov.uk/ukspaceagency and click on the 'Discover and learn' tab.

w3 – More details of the MediPix collaboration can be found here: http://medipix.web.cern.ch/medipix

w4 – To learn more about the CERN@school project, or even get involved, see: http://194.81.239.119

w5 – For more information on the Langton Star Centre, see: www.thelangtonstarcentre.org


## Resources

Becky Parker is one of the teachers who participated in the 'Why is science important?' online project. See her video response to this question here: http://whyscience.co.uk/contributors/becky-parker

For a review of the project website, see:

Rüth C (2009) Review of the Why is science important? website. *Science in School* **13**. www.scienceinschool.org/2009/issue13/whyscience

If you enjoyed reading this article, why not take a look at the full list of teacher profiles published in *Science in School*? See: www.scienceinschool.org/teachers


Sarah Stanley graduated in biology from the University of California, Santa Barbara, USA. At the time of writing this article, she was a science-writing intern at the European Molecular Biology Laboratory. She is currently an intern at *Discover Magazine*.



To learn how to use this code, see page 73.

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# *Exploring the Mystery of Matter: The ATLAS Experiment*

**By Kerry-Jane Lowery, Kenway Smith and Claudia Marcelloni**

**Reviewed by Eric Demoncheaux, Battle Abbey School, UK**

*Exploring the Mystery of Matter: The ATLAS Experiment* is an engaging and beautifully presented photo book that provides a captivating tour of the marvels of the large-scale particle detector experiments of the Large Hadron Collider (LHC) at CERN, the world's largest particle physics laboratory. The book focuses on just one of the LHC experiments: ATLAS, an experiment of epic proportions, involving an international collaboration of more than 2000 individuals from 170 institutions.

The book traces the history and key moments of the construction of the LHC. The authors balance technical details with an account of the people at CERN: the physicists, engineers and others who built the detector.

The first chapter puts the work done at ATLAS into perspective and explains its goals. The second chapter is about the human and capital resources invested in the project, while the next four chapters cover the designs, simulations, and inventions that were required to get it off the ground. The authors also comment on the project's personal, transportational and logistical challenges, and describe the piecing together of the finished ATLAS detector from its separate components.

*Exploring the Mystery of Matter* goes on to explain how other groundbreaking inventions at CERN have changed our world and the global impact of any resulting technological spin-offs, such as the World Wide Web and the use of anti-matter in medical imaging. The final chapters describe the installation of the detectors, in a tunnel 23 km long and 100 m underground. Also covered is the work involved in designing the grid of computers that process and analyse the data from the LHC experiments. The book ends with extracts of interviews with CERN's leading physicists, including Lisa Randall, John Ellis and Peter Higgs.

*Exploring the Mystery of Matter* lays bare this extraordinary feat of engineering in a highly readable and visually appealing way. The book is written in concise and coherent language, which will be accessible to non-native English speakers and to readers from various scientific backgrounds. The carefully chosen images help to explain the text and add interest to the book.

Physics is not always popular at school, because it can be hard for students to relate to. However, this book might just capture their imagination and show them what an exciting subject physics can be.

## Details

Publisher: Papadakis, UK
Publication year: 2008
ISBN: 9781901092950

## Resources

A preview of *Exploring the Mystery of Matter: The ATLAS Experiment* can be found at www.atlasbook.ch

To find out about the LHC, see:

Landua R, Rau M (2008) The LHC: a step closer to the Big Bang. *Science in School* **10**: 26-33. www.scienceinschool.org/2008/issue10/lhcwhy

Landua R (2010) The LHC: a look inside. *Science in School* **10**: 34-45. www.scienceinschool.org/2008/issue10/lhchow

To browse all the other reviews of resources published in *Science in School*, see: www.scienceinschool.org/reviews

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# Ask a Biologist website

**Reviewed by Tim Harrison, University of Bristol, UK**

The Ask a Biologist website is dedicated to answering questions on all aspects of biology. Although aimed primarily at school students of all ages, questions are accepted from anyone, whatever their age, including teachers. The site can be used free of charge and is devoted to providing the highest-quality scientific information. It is staffed by academics and scientific experts from a variety of organisations from around the world.

The site is divided into 13 categories, which cover all aspects of biology: mammals; birds; reptiles and amphibians; fishes; invertebrates; plants and fungi; micro-organisms; fossils; genes, genetics and DNA; human biology and evolution; ecology, biodiversity and behaviour; evolution; and general biology. There is also a special category dedicated to careers and training in biology.

Ask a Biologist has been operating for four years and has provided more than 10 000 answers to around 3700 questions from the general public. Contributions have come from more than 80 researchers, the majority of whom are from Europe and the USA.

Visitors to the site post questions, which are answered by one or more of the registered academic experts. The answers are then available for everyone to see and can be browsed by category. The system is simple and is an excellent way of enabling direct contact between the public and scientists.

Teachers should make their students aware that Ask a Biologist does not answer homework questions. However, the site should prove a great occasional resource to teachers and students alike. The site has attracted an estimated half a million visitors from across the world and so appears to be becoming very successful indeed.

## Details

URL: www.askabiologist.org.uk

## Resources

To learn about many more 'ask a scientist' websites that you could use at school, see:

Stanley H (2007) 'Ask a scientist' websites. *Science in School* **6**: 88-90. www.scienceinschool.org/2007/issue6/web

To learn how to use this code, see www.scienceinschool.org/help#QR

# *2010-2011 State of the Wild: A Global Portrait*

## By the Wildlife Conservation Society

**Reviewed by Michalis Hadjimarcou, Cyprus**

2010-2011 *State of the Wild: A Global Portrait* describes the present state of wildlife and wild places, detailing developments in conservation and examining environmental issues around the world. As experts in the field, the authors provide a reliable account of what has happened in the past, what is happening now and what should happen in the future to conserve precious places, from the wild oceans to urban green spaces. One section of the book is devoted to the challenges facing wildlife conservation, such as those that occur at times of conflict. Another section highlights both new species and new populations of known species that have been discovered recently.

Some of the information about efforts to conserve wildlife, in both terrestrial and aquatic ecosystems, is rather predictable and disheartening. By contrast, there are also some surprising success stories, giving us reason to be more optimistic.

The book discusses how the increased pressure on land and natural resources, mostly due to the growth of human populations and changing global economic forces, threatens wildlife conservation. The effects of climate change and the degradation of ecosystems are also discussed.

The authors highlight two important issues that have implications for the future conservation of the wild. First, the planet is changing rapidly and we have to consider this as we plan, develop and execute conservation programmes. Second, we need to consider our planet as an interconnected system: damage to one part can have cascading effects in distant areas.

With such a variety of issues covered, everyone can find something of interest in *State of the Wild* and it would be a valuable addition to a school library. If they have a good standard of English, teachers from any science discipline and from any level of secondary education will find the book extremely useful. It would be suitable for teaching, discussions, debates and comprehension exercises. The book would also be an excellent source of information for case studies and class projects. Some issues that students could investigate, either individually or in groups, include:

1. How do oil spills affect aquatic ecosystems?
2. In conflict zones, how can wildlife conservation organisations help local people make a living in environmentally stressed areas, while at the same time protecting the environment?
3. How does human conflict affect wildlife; do all species suffer or can some use it as an opportunity to thrive?

### Details

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ISBN: 9781597266789

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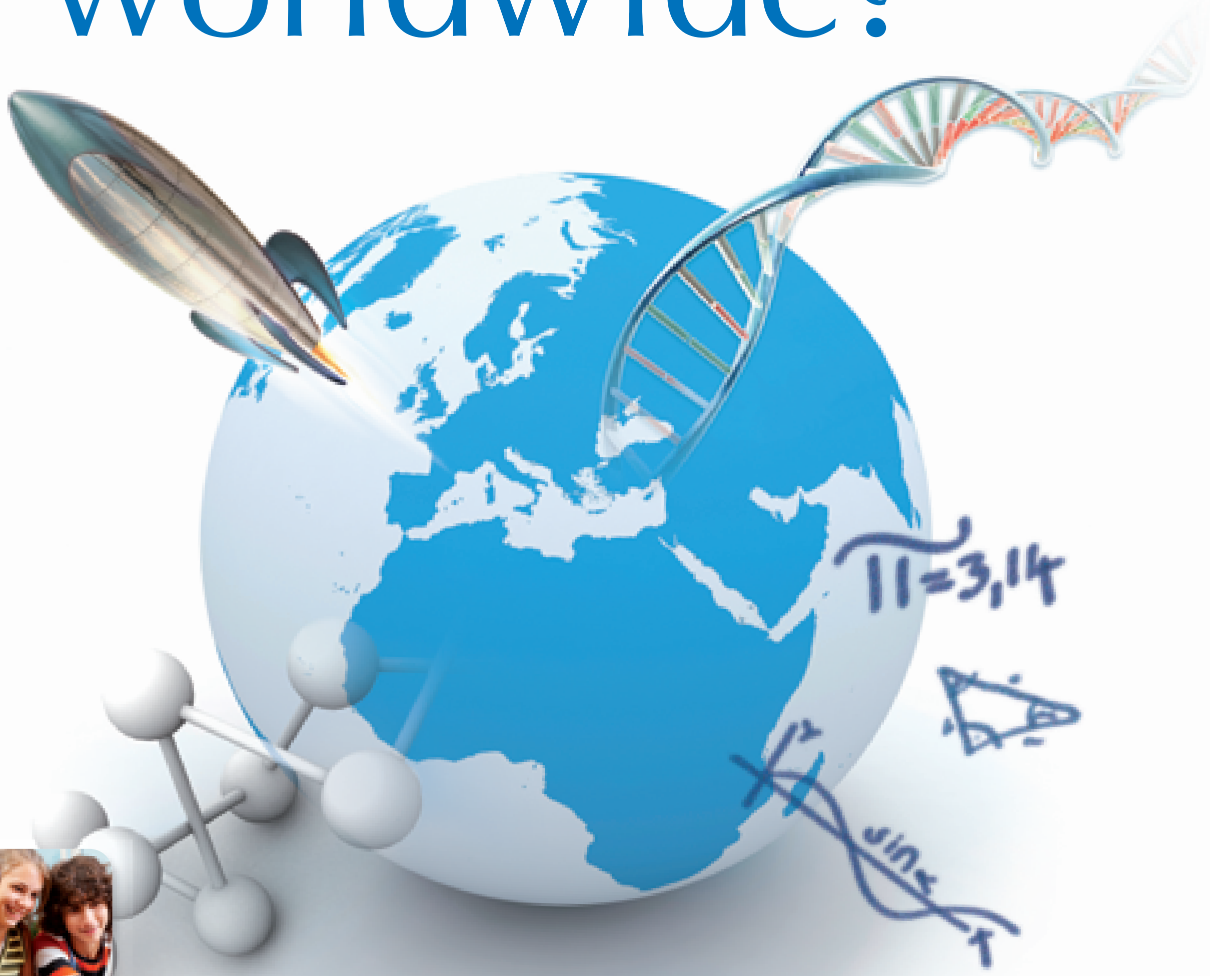

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