Summer 2009 Issue 12

SCIENCE in SCHOOL

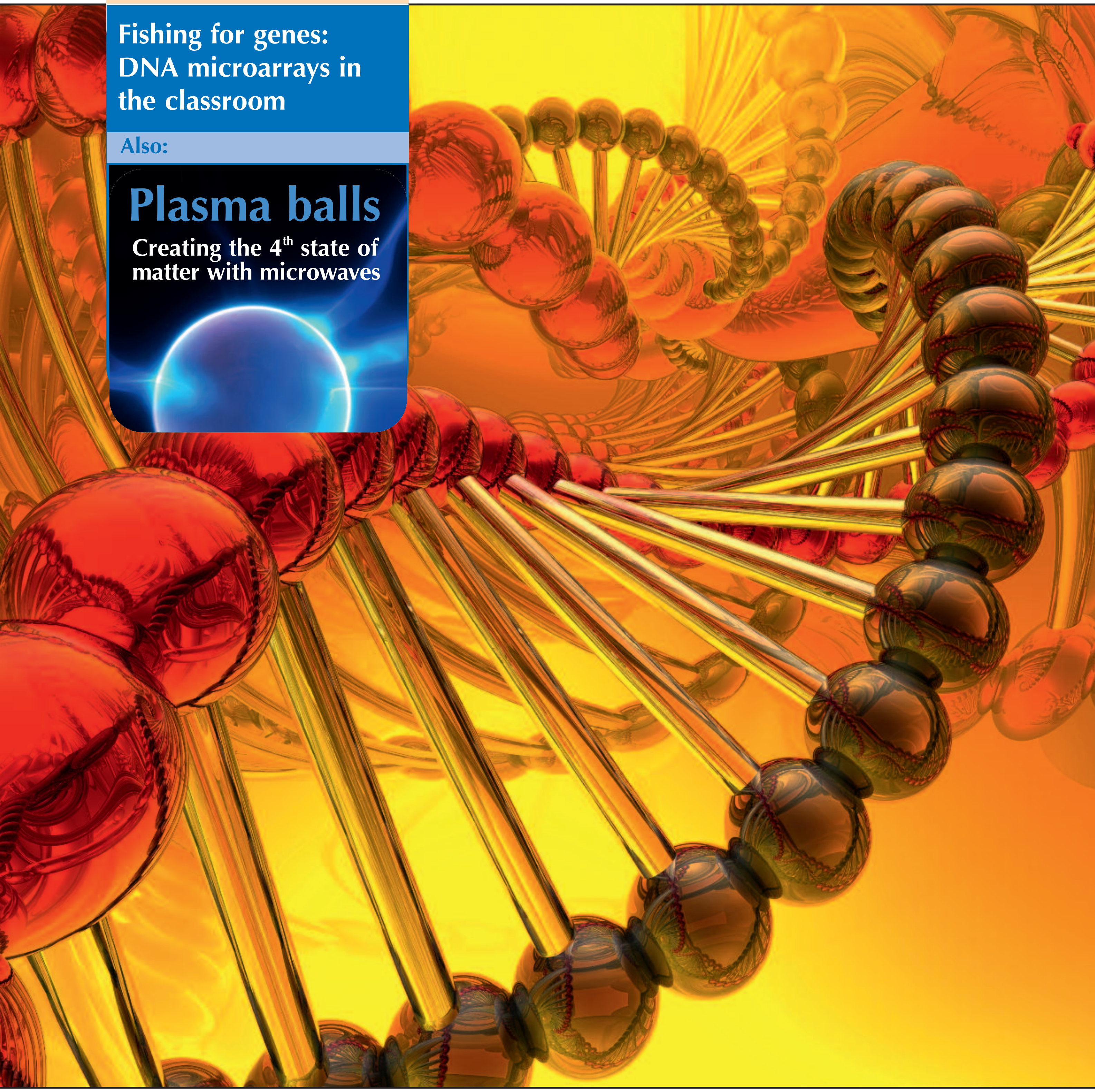
In this Issue:

Fishing for genes: DNA microarrays in the classroom

Also:

Plasma balls

Creating the 4th state of matter with microwaves



Highlighting the best in science teaching and research

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.**

Science in School **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 maths, earth sciences, engineering and medicine, focusing on interdisciplinary work.**

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

Science in School **is published quarterly and is available free online; free print copies are distributed across Europe. Online articles are published in many European languages; the print version is in English.**

Safety note

For all of the activities published in *Science in School*, we have tried to check that all recognised hazards have been identified and that suitable precautions are suggested. Users should be aware, however, that errors and omissions can be made, and safety standards vary across Europe and even within individual countries.

Therefore, before undertaking any activity, users should always carry out their own risk assessment. In particular, any local rules issued by employers or education authorities MUST be obeyed, whatever is suggested in the *Science in School* articles.

Unless the context dictates otherwise, it is assumed that:

- Practical work is carried out in a properly equipped and maintained science laboratory
- Any electrical equipment is properly maintained
- Care is taken with normal laboratory operations such as heating substances
- Good laboratory practice is observed when chemicals or living organisms are used
- Eye protection is worn whenever there is any recognised risk to the eyes
- Pupils and/or students are taught safe techniques for activities such as handling living organisms, hazardous materials and equipment.

Credits

Science in School is published by EIROforum (a collaboration between seven European inter-governmental scientific research organisations: www.eiroforum.org) and is based at the European Molecular Biology Laboratory (EMBL: www.embl.org) in Heidelberg, Germany.

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Submissions

We welcome articles submitted by scientists, teachers and others interested in European science education. Please see the author guidelines on our website for details.

Referee panel

If you are interested in reviewing articles for their suitability for publication, please read the guidelines for referees on our website.

Book reviewers

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

Translators

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

Advertising in *Science in School*

Contents

Welcome to the twelfth issue of *Science in School*

In this issue's feature article, Leroy Hood, the 'father of systems biology' describes his commitment to encouraging concept-driven, hands-on science teaching. He explains how he introduced this approach across schools in Seattle – and why his achievements in science may be due to his small-town upbringing.

Hands-on science is also the key to Greek science teacher Theodoros Pierratos's success: he and his students entered – and won – a competition to send an experiment into space. This and the resulting contact with the European Space Agency have changed the way his students view science.

Games are one way to grab the attention of your students. The virtual microarray activity introduces the colourful and sophisticated technique of the DNA microarray into the classroom. And as if that wasn't enough colour, Sonia Furtado investigates how glow-in-the-dark jellyfish led to a Nobel Prize in Chemistry in 2008 – for the discovery and development of green fluorescent protein.

From green jellyfish to black boxes: Ľudmila Onderová describes how to build and use black boxes in the classroom – inspiring your students to think scientifically by hiding electric circuits inside them.

Inspiring a school full of students can be a daunting task, but how would you go about motivating a different group of students every few months? Substitute teacher Jeanne Keweloh encounters exactly this challenge: new students, new colleagues, new topics – she's always on the move.

The challenge of Katy Lithgow's job is very different: using science to preserve paintings, textiles, furniture and other contents of historic houses. One of the problems she faces these days is climate change, which can cause flooding and increased damage by insect pests, for example. Why not combine our profile of Katy with Dudley Shallcross's teaching activities? In the latest article in our climate-change series, he and his colleagues propose an experiment involving solar power as a source of energy.

The most common sources of energy are still hydrocarbons. Continuing

our energy series, Menno van Dijk explains why we need to use this stored energy from the Sun carefully. Of course, solar radiation is not the only type of natural radiation around us. The Portuguese 'Environmental radiation' project developed school activities to safely introduce radioactivity into the classroom. Luis Peralta and Carmen Oliveira offer one experiment for you to try: growing irradiated seeds.

Staying with the topic of radiation, Halina Stanley shows how scientists developing a microwave drill discovered how to modify it to produce nanoparticles – and impressive balls of plasma. To create your own plasma balls and have more fun with microwaves in the classroom, why not try her accompanying teaching activities?

In her articles, Halina has used *Science in School* to share her teaching ideas with teachers across Europe and beyond. You too can contact your international colleagues through the journal by using our online discussion forum. If you want to share your ideas, find answers to scientific questions or start collaborations with teachers in other countries, the *Science in School* forum could be the place to start. See: www.scienceinschool.org/forum.

You may notice another, more recent addition to our website: small advertisements. We hope that income from advertising will help ensure the future of *Science in School* – particularly of the print version – and enable us to continue to offer the journal to you free of charge. To support us, please tell potential advertisers (such as your school laboratory suppliers or textbook publishers) about the opportunity to advertise in both the print and online versions of *Science in School*. For more information, see: www.scienceinschool.org/advertising.

Marlene Rau
Editor of *Science in School*
editor@scienceinschool.org
www.scienceinschool.org

Forthcoming events

For a more extensive list, including events that run all year round, see www.scienceinschool.org/events

5-7 September 2009

Orkney Islands, Scotland, UK

Orkney International Science Festival 2009

A science festival has a radical role in developing a creative climate for a region, especially a remote region such as the Orkneys. This year's festival will take part during the Scottish Homecoming. Saturday 5 September will have various events built around the theme of Robert Burns – his love of nature and of his fellow beings. Burns said it then, and the Earth Charter says it today: we must respect all living beings on Earth.

With a programme of lectures, social events and more, this annual festival is aimed at the general public and most activities are free.

More information: www.oisf.org

5-10 September 2009

Guildford, UK

British Science Festival 2009: Creativity, Innovation & Evolution

The British Science Festival (formerly the BA Festival of Science) is one of Europe's largest science festivals, taking place each September. The festival is in a different location in the UK each year, bringing you the latest in science, technology and engineering. This year's festival is hosted by the University of Surrey in Guildford with events taking place across Surrey.

With loads of events, talks, plays, debates, hands-on activities and more, this year the festival will join the celebrations of Darwin Year and the International Year of Astronomy.

Throughout the festival week, a series of special events for school groups of Key Stage 2 and above is provided. Among other things, students can explore Earth's atmosphere, discuss important issues with eminent scientists and investigate the best material to make a successful catapult.

Most festival events can be booked through the website.

More information: www.britishscienceassociation.org/web/BritishScienceFestival

11 September 2009

University of Kassel, Germany

Workshop: Englischsprachiger Biologie- und Chemieunterricht an deutschen Schulen (English-language biology and chemistry lessons in German schools)

Biology and chemistry teachers who teach in English are invited to a free workshop organised by the Verband Biologie, Biowissenschaften & Biomedizin in Deutschland, the Vereinigung der Schulen mit deutsch-englisch bilingualem Zug in Hessen and the Förderverein MNU. English-language teaching materials will be developed in small working groups and presented to all participants. Teachers from outside Germany are warmly welcome.

More information: www.vdbiol.de

Contact: info@vbio.de

18-27 September 2009

Norway

National science week: Research Days (Forskningsdagene)

This is a nationwide event held every year to make science and research available to the public. Research and knowledge institutions throughout Norway participate and provide the general public with new insights into what they do. Events range from science fairs, demonstrations, lectures, 'stand-up scientist' performances, exhibits and discussions, to tours, information stands, and cultural and hands-on activities. Nearly all Forskningsdagene events are available to the public free of charge. This year's events focus on the Darwin anniversary, the International Year of Astronomy and the 150th birthday of Norwegian author Knut Hamsun.

Among others aspects of the event, each year there is a research campaign on a particular theme in which all schools are invited to participate. Participating schools and classes can submit their results online, for evaluation by scientists at the end of the campaign.

More information: www.forskningsdagene.no

Contact: Emmy Gram Lauvanger (egl@forskningsradet.no) or Sidsel Flock Bachmann (sfb@forskningsradet.no)

18 September – 16 October 2009

Lower Silesia, Poland

Science festival: XII Lower Silesian Science Festival 2009

This festival wants to promote science and its achievements, and outline the problems it can solve. This year's topic is 'Imagination and thought to go back further than the stars'. The festival will take place in five cities: Wrocław (18-23 September), Legnica (24-25 September), Wałbrzych and Ząbkowice Śląskie (8-9 October), and Jelenia Góra (15-16 October). Among the several hundred events covering all aspects and areas of science, there will be special 'science for kids' activities, as well as scientific marathons and contents for talented students.

More information: www.festiwal.wroc.pl

Contact: festiwal@uni.wroc.pl

19-28 September 2009

Warsaw, Poland

Science festival: XIII festiwal Nauki Warszawa

The goal of this festival is to make people realise that a country's future depends on its ability to use achievements of science as well as their practical applications in everyday life, while not forgetting about the possible dangers resulting from improper use of scientific results. Activities from all areas of science will be offered, aimed at the general public. The festival also offers a special programme for school classes, including lectures and debates, to which prior registration is required.

The application deadline for school classes is 12 September 2009.

More information: www.festiwalnauki.edu.pl

Contact: festiwal@uw.edu.pl

21-25 September 2009

venues throughout Denmark

Science festival: Danish Science Week 2009

The theme of this year's Danish Science Week is 'Building blocks', which can cover everything from atoms, DNA and evolution, to engineering and building blocks of the Universe. Schools and universities, libraries, museums, science centres and companies, as well as volunteer speakers, are encouraged to take part.

There is a festival package with fun experiments, a festival song, a large mass experiment involving as many people as possible, plus the opportunity to book a scientist speaker for your classroom, visit museums, universities and companies that have prepared a programme for school students, organise a science day at your school, become a teacher contact, and much more.

More information: www.formidling.dk/sw174.asp

Contact: Pernille Vils Axelsen (pa@formidling.dk)

25 September 2009

Saarbrücken, Germany

Educational fair: EduNetwork 2009

The EduNetwork fair 2009 at Saarbrücken University is organised by THINK ING., MINT-EC and Science on Stage Germany to develop synergies. Lectures and workshops will be held in five subject categories (mathematics, astronomy, nanotechnology, talent, SET in primary school). In an extended break, a fair/exhibition will take place. Everyone interested is welcome.

Detailed information on the fair and how to register can be found on the website.

More information: www.edunetwork.de, www.science-on-stage.de

Contact: info@science-on-stage.de

26 September 2009

Linz, Austria

Researchers' Night: Research is Diversity

The Upper Austrian Researchers' Night aims to present the people behind science – researchers and their world and life. In direct dialogues with successful researchers, visitors can learn more about the diversity behind the word 'research'.

Several research institutes and universities will be open from 7pm to midnight and have prepared a programme. Participation is free.

More information: www.ooe-forschungsnacht.at

28-30 September 2009

European Molecular Biology Laboratory, Heidelberg, Germany

Training course: ELLS LearningLAB

The European Learning Laboratory for the Life Sciences (ELLS) is an education facility which brings secondary-school teachers into the research lab for a unique hands-on encounter with state-of-the-art molecular biology techniques. ELLS also gives scientists a chance to work with teachers, helping to bridge the widening gap between research and schools.

The three-day course is designed to enable the participating teachers to explore a range of activities, which they can practise in the lab and then take back to the classroom.

The course is open to 24 European high-school science teachers and is run in English. The course, including course materials and catering, is free of charge; accommodation costs will be partially subsidised. However, participants are expected to meet their own travel costs.

More information: www.embl.de/ells

Contact: ells@embl.de

Until 30 September 2009

Austria

Competition: Hands-on X-Netz

The interactive travelling Science Center Network exhibition 'Erlebnis NETZ[werk]E' (The Net(work) Experience) has been touring Austria since June 2007. To enhance the exhibition, a competition is run for Austrians up to the age of 26, who can submit ideas for interactive exhibition stands on the topic of nets/networks. Selected ideas will be realised and added to the exhibition.

Both the science area and the type of activity (game, experiment, model, hands-on activity, computer animation, quiz, etc.) can be chosen freely. If the jury is convinced your idea is feasible and suitable, you will be awarded €300 as an individual or €500 as a group to run the required research on your project, plus material costs, and you have three months to complete your proposed project, for which you can get help from a list of co-operation partners.

The closing date is 30 September 2009.

More information: www.science-center-net.at/x-netz

Contact: office@science-center-net.at

October 2009

Brussels, Belgium

Science event: International Space Station Day

As part of its education activities based on the OasISS mission of European astronaut Frank De Winne from Belgium, the European Space Agency (ESA) has organised a school event to look at a day in the life of an astronaut. Belgian students aged 10-12 years will be invited to attend, as part of their prize for winning a competition. Frank De Winne will demonstrate the properties and behaviour of water in the microgravity environment and answer some questions from the children. Other activities during the day will immerse the children in the life of an astronaut onboard the ISS.

Footage from the event will be used to produce a classroom lesson for teachers, which will be available on the ESA website from mid-October. Teachers are invited to check the website for more details, including videos of the astronaut on board the ISS during his six-month mission. These short videos will come with teaching materials on personal hygiene, exercise and fitness and what the astronauts eat and drink.

The event is organised by ESA in collaboration with ESERO (European Space Education Resource Office) Belgium and UNICEF Belgium.

More information: www.esa.int/esaHS/education.html
Contact: isseducationteam@esa.int

1-31 October 2009

venues across the Netherlands

Science event: October Month of Knowledge (Oktober Kennismaand)

This month-long event brought together more than 250 000 people in 2008, who took part in over 700 activities to bring science and technology closer to the public. Universities, research institutes, observatories, companies, museums and libraries will again open their doors for young and old in 2009, under the theme 'Reis naar het onbekende' (Travel to the unknown), featuring Darwin Year and the International Year of Astronomy.

This is a free and unique event for teachers and students. Educational materials are available online, as well as a newsletter for which teachers can register, and a list of events suitable for children.

More information: www.oktoberkennismaand.nl

Contact: info@oktoberkennismaand.nl

15-17 October 2009

Europa Park, Rust, Germany

Event for schools: Science Days

Europa Park in Rust, one of Germany's biggest theme parks, will host the Science Days, which in 2008 fascinated more than 22 000 visitors. The main topics for this year will be climate and space expedition.

To promote the understanding of science and technology, the Förderverein Science and Technology eV has invited more than 100 institutions to offer workshops, hands-on experiments, science shows, and other activities.

For teachers and school classes, there is a special programme including a preparatory meeting and a tailored information package. Registration is required. The working language is German.

More information: www.science-days.de

Contact: Susanne Frey (frey@science-house.de)

15-22 October 2009

Kaurialan lukio, Hämeenlinna, Finland

International Science Week

The International Science Week in Hämeenlinna, Finland, offers an exciting and versatile scientific programme (physics, chemistry, mathematics, biology and geography) with social and cultural activities for ten students, aged 16-18, and two teachers from each of three selected countries. The students will be accommodated by Finnish host families and the teachers will stay in a hotel nearby in the centre of the town of Hämeenlinna. The programme has been planned by the teachers of the Kauriala Upper Secondary School (Kaurialan lukio).

The registration deadline is 22 February 2009.

Contact: Paula Perkkalainen (paula.perkkalainen@hameenlinna.fi) or Sakari Salonen (sakari.salonen@hameenlinna.fi)

21-23 October 2009

European Molecular Biology Laboratory, Monterotondo, Italy

Training course: ELLS LearningLAB

The European Learning Laboratory for the Life Sciences (ELLS) is an education facility which brings secondary-school teachers into the research lab for a unique hands-on encounter with state-of-the-art molecular biology techniques. ELLS also gives scientists a chance to work with teachers, helping to bridge the widening gap between research and schools.

The three-day course is designed to enable the participating teachers to explore a range of activities, which they can practise in the lab and then take back to the classroom.

The course is open to 24 European high-school science teachers and is run in English. The course, including course materials and catering, is free of charge; accommodation costs will be partially subsidised. However, participants are expected to meet their own travel costs.

More information: www.embl-monterotondo.it/training/ells/learninglab

Contact: ells@embl.de

23 October - 1 November 2009

Genoa, Italy

Science festival: Festivale della Scienza

This annual festival is a chance for researchers, science lovers, schools and families to meet. Meetings, workshops, shows and conferences are among the events organised. There are dedicated events for school groups, and in September, a short series of presentations in Genoa, Piedmont and Lombardy will provide teachers with a preview of these events. Schools in Genoa can also register as partner schools of the festival, to interview a scientist and host a class from another city during the festival.

More information: www.festivalscienza.it

Contact: info@festivalscienza.it

November 2009

Madrid, Spain

Science week: Semana de la Ciencia

For one week every November, over 250 participating institutions offer guided tours, conferences, round tables, debates, workshops, demonstrations, science paths, archaeological, architectural and geological routes, exhibitions, competitions and science movies, with about 2000 scientists taking part. Science centres, universities, companies, public bodies, hospitals, societies, professional colleges and other entities are asked to propose their own programmes.

Activities suitable for primary- and secondary-school groups will be listed separately.

More information: www.madrimasd.org/semanaciencia

Contact: semanaciencia@madrimasd.org

2-8 November 2009

venues throughout the Czech Republic

Science festival: 9th Czech Science and Technology Week

Each year at the beginning of November, the Science and Technology Week is held as one of the largest science communication events in the Czech Republic, presenting the latest scientific achievements and current research approaches. It is organised by the Academy of Sciences of the Czech Republic in the framework of the European Science Week.

It is aimed at the general public and offers lectures, public debates, exhibitions, open days at science institutes, hands-on activities and much more.

More information: http://press.avcr.cz/tyden-vedy-a-techniky

6-7 November 2009

Heidelberg, Germany

Conference: Food, sustainability & plant science: a global challenge

The 10th EMBO/EMBL Science & Society Conference examines the future of sustainable agriculture from the perspectives of plant science, technology and society. How can science contribute to global challenges such as how to feed a growing population, climate change and biological threats to yields? How can individuals determine if new technologies are safe and effective in the battle against hunger?

School classes are welcome to participate, and school students get free entry. To register, visit: http://events.embl.org/iEBMS/reg/reg_p1_form.aspx?oc=10&ct=NORMAL&eventid=5019

More information: www.embo.org/policy-and-society/science-society/conferences/2009.html

8-15 November 2009

venues throughout Ireland

Science festival: Science Week

Science Week is Ireland's biggest annual promotion of science to the general public. It is co-ordinated by the Discover Science & Engineering programme and offers a large variety of lecture series, essay and photo competitions, shows and many other events across the whole country. Special activity packs are available for both primary- and secondary-school teachers.

More information: www.scienceweek.ie

Contact: scienceweek@forfas.ie

9-13 November 2009

Daugavpils, Latvia

Science festival: 4th Daugavpils Science Festival

For the fourth year, Daugavpils University will host a science festival aiming to popularise science and demonstrate that it can be understood by everyone. There will be lectures, competitions, discussions, hands-on activities, workshops, exhibitions, tours of science institutes and more. There will also be special activities aimed at teachers and students.

More information: www.zinatnesfestivals.lv

Contact: Diana Soldane diana.soldane@du.lv

12-15 November 2009

Luxembourg

Science festival

The seventh science festival will take place in 2009 at the Cultural Centre, Neumünster Abbey and the National Museum of Natural History, Luxembourg-Grund. Interactivity is the key word – the exhibited objects demand the visitor's attention. Nowhere will there be signs saying "Do not touch"; on the contrary, there will be inviting notices saying "Do touch and experiment with everything". Without participation there is no result! The whole family is invited to discover science by using all their senses.

More information: www.science-festival.lu

Contact: Monique Kirsch (mkirsch@mnhn.lu), Patrick Delhalt (pdelhalt@mnhn.lu)

13 November 2009

Schoollab network GenaU, Berlin, Germany

Teacher training workshop: Interdisciplinary

Organised by Science on Stage Germany and financed by the Technologiestiftung Berlin, this half-day workshop (3-6pm) presents two projects.

The German project, 'If colours become a health problem – coloured T-shirts with colours of plants', began with a newspaper article about the recall of children's clothing containing harmful dyes. The students then researched which dyes have been and continue to be important and which harmless dyes could be used instead. The subjects covered in the project include biology (e.g. microscopy, cell structure, location of pigments in the cell, chromatography), chemistry (experimental design, isolating pigments and dyes, optimising pigment extraction, methods of dying and fixing), physics (what is colour, colour perception, additive and subtractive colour mixing), history (the development of dyes, cultural significance of colours), and art (the meaning of colour, designing the T-shirt).

The Austrian 'Smoking prevention project', originally presented in a basic form at Science on Stage 2 in Grenoble, France, uses the 'Smoking prevention lab' to discourage 14- to 18-year-old students from smoking. The affordable device – developed together with school students – helps to visualise and explain the effects of smoking on pulse rate, blood flow and blood pressure as well as on the temperature of fingers, without the students having to smoke.

The working languages are German and (in part) English. Participation is free; interested teachers should register by email by 30 October 2009.

More information: www.scienceonstage.de

Contact: info@science-on-stage.de

16-22 November 2009

venues throughout France

Science festival: La Fête de la Science

Organised by the French Ministry of higher education and research, this science festival is a free event relying on enthusiastic people to communicate and share their love of science. This year's topic is 'The origins of life and the Universe: what evolutions, what revolutions?' to celebrate both Darwin Year and the International Year of Astronomy.

It is aimed at the general public and offers exhibitions, workshops, visits to labs, natural and industrial sites, meetings between scientists and young people, science cafés, debates, conferences, shows, and much more.

More information: www.fetedelascience.fr

Contact: Anne Launois (anne.launois@recherche.gouv.fr)

Until 30 November 2009

Austria/Switzerland/Italy

Student competition: Explora! 2009/2010 – Young scientists wanted!

The German- and Italian-speaking border regions of Austria, Switzerland and Italy (Graubünden, Südtirol, Tirol, Trentino) are organising a science competition for students aged 16 to 20 who live or go to school in one of these regions. Up to five people per participating group can submit scientific projects, preferably interdisciplinary ones, in biology, chemistry, physics, geography, geology, ecology, Egyptology, informatics, mathematics, nutrition technology, computer science, history, philosophy, literature, social sciences, linguistics, economy, tourism, art or music. Parents and teachers are allowed to help, and there's a list of partner institutes that offer guidance.

The working languages are German, Italian or English, including a summary in English. The registration deadline is 30 November 2009, and the deadline for submissions is 29 January 2010 at 1pm. Up to eight projects will win prizes between €1500 and €4000.

More information: www.explora-science.net

Contact: explora@eurac.edu

3-5 December 2009

Naples, Italy

Conference: VIII Convegno Nazionale sulla Comunicazione della Scienza

The ICS (Innovations in the Communication of Science) group of the SISSA (Scuola Internazionale Superiore di Studi Avanzati, International Higher Education School) in Trieste is organising the VIII National Conference on Science Communication in collaboration with the IDIS – Città della Scienza (Naples science centre). Projects and experiences with science communication as well as research on the subject will be presented.

The deadline for abstract submission is 1 June 2009 and the working language is Italian.

More information: http://ics.sissa.it/index.php?lingua=IT&pg=7&area=1

Contact: Donato Ramani (cncs@sissa.it)

Until 31 December 2009

Austria

Competition: Hands-on X-Netz

The interactive travelling Science Center Network exhibition 'Erlebnis NETZ[werk]E' (The Net(work) Experience) has been touring Austria since June 2007. To enhance the exhibition, a competition is run for Austrians up to the age of 26, who can submit ideas for interactive exhibition stands on the topic of nets/networks. Selected ideas will be realised and added to the exhibition.

Both the science area and the type of activity (game, experiment, model, hands-on activity, computer animation, quiz, etc.) can be chosen freely. If the jury is convinced your idea is feasible and suitable, you will be awarded €300 as an individual or €500 as a group to run the required research on your project, plus material costs, and you have three months to complete your proposed project, for which you can get help from a list of co-operation partners.

The closing date is 31 December 2009.

More information: www.science-center-net.at/x-netz

Contact: office@science-center-net.at

If you organise events or competitions that would be of interest to European science teachers and you would like to see them mentioned in *Science in School*, please email details – including date, location, title, abstract, price, language, registration deadline, website and contact email address – to editor@scienceinschool.org.

Image courtesy of Science on Stage Belgium

Experiments on lightning gas in a tube

Science on Stage: recent activities

Sonia Furtado and **Marlene Rau** report on the news from the national Science on Stage representatives.

Images courtesy of Chris Schembri

Tim showing a glove after it was dipped in liquid nitrogen, at St Margaret College Boys Secondary School, Malta

The Bristol chemists visiting Malta

Image courtesy of Science on Stage Belgium

The Science on Stage workshop run at Le Printemps des Sciences in Mons

Malta

Following the success of their visit in October 2007 (see Hayes, 2008), Dudley Shallcross, Tim Harrison and their outreach team from Bristol ChemLabS[w1] returned to the Mediterranean islands of Malta and Gozo in April 2009 for an encore. They were invited to the Mediterranean country by a joint committee of science leaders from church and state schools, which included Chris Schembri and Doreen Mizzi, with whom the Bristol team had first established the collaboration at Science on Stage 2 in 2007, and Tano Bugeja.

Over three days, the ChemLabS team delivered six performances of the demonstration lecture 'A pollutant's tale' to students from state and church secondary schools. A total of 1550 students from 15 schools attended and participated in the talk, by identifying volatile organic compounds by smell – a demonstration that the Bristol chemists use as part of their talk. The shows featured several of the experiments previously published in *Science in School*, such as the methanol whoosh bottle, the burning of acetylene and the exploding of hydrogen-filled balloons (see Shallcross & Harrison, 2008).

The team also held a seventh, extended session on the topic of climate change for trainee teachers and science undergraduates at the University of Malta.

As always, the performances were a resounding success, as is evident from the reaction of a participating chemistry teacher from Our Lady Immaculate School in Hamrun: "A big thank you for a very interesting and enjoyable event. My students loved it very much and are looking forward to any future ones." The Bristol chemists will probably be back to Malta to join a science festival planned for November 2009.

Austria

Friday the 13th is thought to be an unlucky day in some countries – not so in Austria, it seems: on Friday 13 March, Science on Stage Austria officially became a non-profit organisation with six members on the board and an advisory committee of twelve, under the name of Science on Stage Austria eV[w2]. They started preparations to present themselves at a range of events. For instance, you can meet them at the YoTech Event in Vienna[w3] and the EXE 09 in Wels[w4]. The Austrians are also rolling up their sleeves for their own national event, scheduled for 25 and 26 February 2010 at the Johannes Kepler University in Linz.

Belgium

In Belgium, the clocks aren't standing still either. Science on Stage Belgium[w5] participated in a variety of events throughout the country last spring to promote science and science teaching. They were present with a stand not only at the Expo-Sciences science fair[w6] in Brussels, but also at the Centre de Culture Scientifique[w7] science museum in Parentville de Couillet (near Charleroi), where they perform a variety of experiments from all areas of science each year. In addition, they did a great job of complementing an exhibition on light and Antoni van Leeuwenhoek's microscope at the science museum in Ghent[w8], presenting experiments on

Image courtesy of Science on Stage Belgium

A xylophone made of empty bottles and water

Image courtesy of Science on Stage Belgium

Image courtesy of Science on Stage Belgium

Young's law and using the EDUkit for teaching photonics and micro-optics that has been developed by NEMO[w9].

For the national science spring fair, Le Printemps des Sciences[w10], which this year was held from 23-29 March under the motto 'Evolutions – Revolutions', Science on Stage Belgium ran two workshops in Namur and Mons. Participants of all ages went on a fun and instructive one-hour journey through physics: they learned about the history of water, were shown a xylophone made of empty bottles and water, learned that infra-red light can be used to listen to music, produced a cloud in a bottle (to try it yourself, see Bultitude, 2009), found out how heavy a litre of air is, and did other entertaining experiments. Some of the experiments can be downloaded from the web[w5] in Dutch, French or English.

The next national Playful Science event will take place on 27 February 2010 in the European School in Brussels. More information will be available shortly on the Science on Stage Belgium website.

Germany

On 27 March 2009, the national steering committees from all countries involved in Science on Stage met in Berlin, Germany, and agreed that the project must continue, also at an international level. To this end, they have set up a committee to come up with a strategy. In the meantime, there is a competition to decide who will host the next pan-European event, under the assistance and guidance of Science on Stage Germany[w11], who will share the experience they acquired in the organisation of the international Science on Stage festival in October 2008 (see Furtado, 2009). An important constituent of this successful event was the workshops on a variety of topics from the area of science education. To follow up on this, the work on four of the topics is now being continued by participants from about 15 countries in a series of teacher workshops (see events list on page 4) in Berlin throughout 2009 and 2010.

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Image courtesy of Science on Stage Belgium

Presenting energy experiments

Web references

w1 – For more information on Bristol ChemLabS and their activities, see: www.chemlabs.bris.ac.uk

w2 – Find out more about Science on Stage Austria eV online: www.scienceonstage.at

w3 – To learn more about the 2009 Yo-Tech events in Vienna and Graz, see: www.yo-tech.at

w4 – Find out more about EXE 09 in Wels on: www.nawi4you.at

w5 – To learn more about Science on Stage Belgium, see: www.scienceonstage.be

w6 – The organisers of Belgium's Expo-Sciences fair in Brussels and Liège have their website here: www.jsb.be

w7 – Find out more about the Centre de Culture Scientifique science museum in Parentville de Couillet here: www.ulb.ac.be/ccs

w8 – The website of the Ghent science museum can be found here: www.sciencemuseum.ugent.be

w9 – To find out more about NEMO, the Network of Excellence on Micro-Optics, and their EDUkit, see: www.micro-optics.org/www/edukit

w10 – To learn more about the Belgian science spring fair, see: www.printempsdessciences.be

w11 – Visit the website of Science on Stage Germany here: www.scienceonstage.de

New approaches to old systems: interview with Leroy Hood

Image courtesy of EMBL Photolab

Leroy Hood explaining systems biology

Leroy Hood talks to **Marlene Rau**, **Anna-Lynn Wegener** and **Sonia Furtado** about his long-standing commitment to innovative science teaching, and how he came to be known as the father of systems biology.

"Students hate being taught didactically, they hate listening to lectures, they hate the presentation of facts. What students, especially the younger ones, like is getting involved, doing things with their hands."

With this in mind, Leroy Hood, a man who decides to change the world and then goes out and does it, set out to change the way science is taught in all Seattle schools: "Hands-on, inquiry-based science is what we wanted to implement when we moved here in 1992[w1]. Our first effort was to convert all 72 elementary schools in Seattle – all 23000 students and 1100 teachers – to this approach. The focus was, over a five-year period, a series of workshops that gave teachers 100 to 150 hours' instruction – both methods and content. You really need both: if it's all gee-whiz and no content, it isn't any good. We probably reached between 90 and 95% of the teachers and really transformed the way the educational system thinks about teaching. We then followed that up with a grant for middle schools to do the same thing, and we would have had a grant for high schools, except we were awarded that grant just when Bush became president, and he cancelled all the education funds, so we had to do high schools on a more piecemeal basis…."

These workshops provided teachers with kits they could use in the classroom, and with the knowledge to back them up: "One kit involved figuring out what Archimedes' principle is all about, having the students build boats with different shapes and trying to figure out the relationship between boat shape and water displacement. But even more important was for the teachers to really understand the science: specific gravity of water, displacement, buoyant forces… Most teachers in the USA have very little grounding in science; in elementary school only 3-4% of the teachers have had any science training at all. And since at that level only one teacher handles each class, many students essentially never had any science teaching before we started this counselling."

Another strength of the project was that it focused on teachers as part of the scientific community, instead of treating them as outsiders: "They absolutely loved that we treated them as colleagues, as an important part of the scientific community, with two roles. One is to catalyse the interest in science in those students who have the inclination and capacity to do it, but the other, even more important, role is educating tomorrow's citizens about science, so that they can go into society with a much more factual and information-based view of all these things, good and bad, and can make judgments. This really rejuvenated the teachers from the point of view of their interest in science as part of a larger community and this was reflected in how they taught science to the kids."

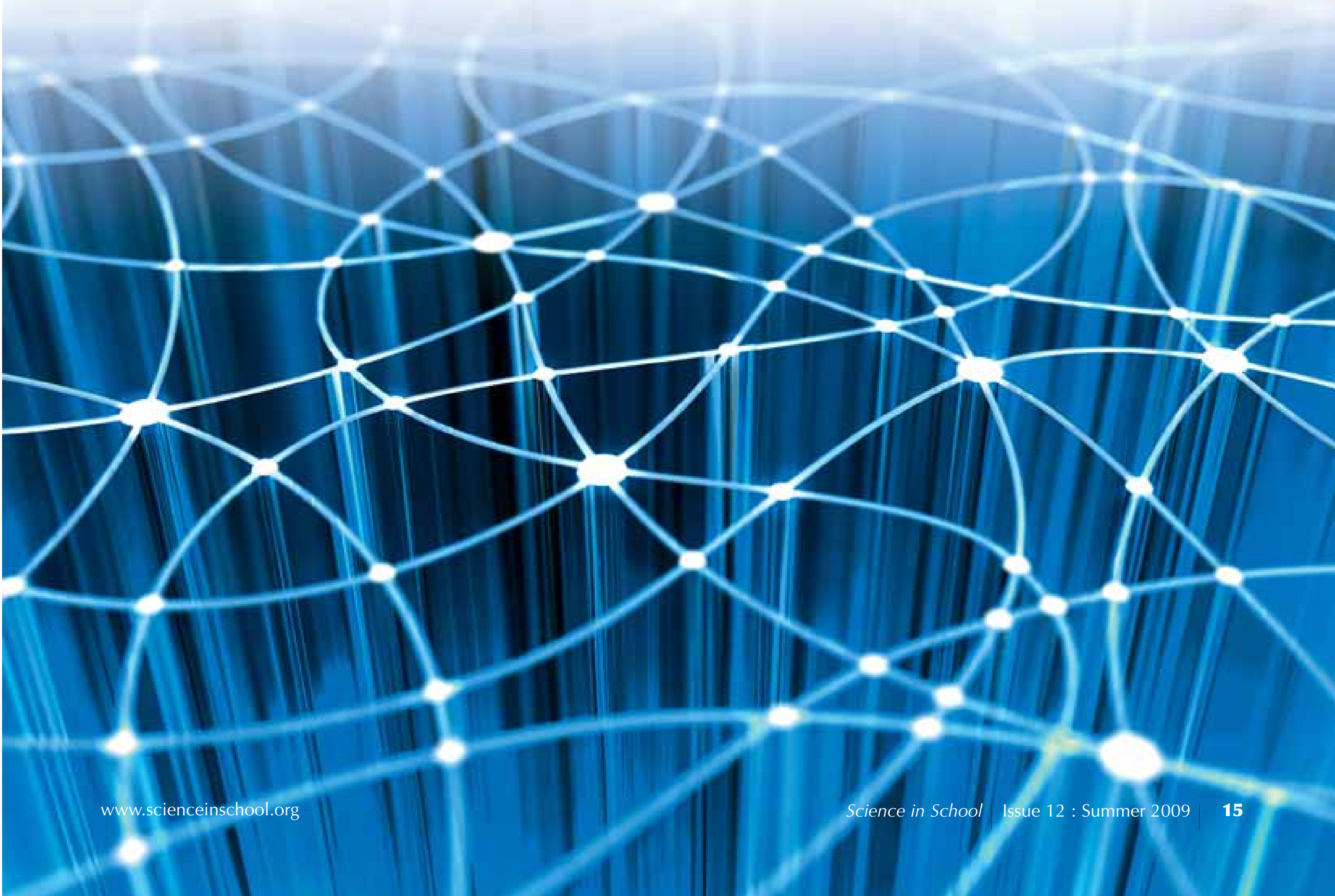
A big part of the project's success came from the strategic partnerships that were set up: "To make this happen, we really had to raise a lot of money. So we created partnerships with Boeing, Microsoft and a lot of other businesses, and used those as leverage to raise substantial resources for the schools. That was really an important part of creating a model that had demonstrable power. And of course the ultimate objective in all of these programmes is sustainability: we'd like to persuade the school systems, once they see the power of what's been done, to start transferring funds to this approach. At some of the schools in Seattle, this has already started happening."

Hood and his team are now reaching out across the state, attracting top-notch teachers and educational administrators to workshops on their approach, so that those teachers can then go out and nucleate such changes in their own communities. "We have recruited six really terrific science teachers who do this full-time now. These are people who can do the science, and who really know how to teach. This is important, because people like me are really great with the science part of things, but we've never had to deal with the reality of a first grader or a high-school freshman.

"For instance, for one of the high schools, we built a couple of modules to teach systems biology. Systems biology is all about understanding networks, so one of the first things we do is have the teacher draw a network of all the kids who have cell phones in the class, and of the numbers they can automatically dial. And then the students sit down and they understand, 'oh, it's the connections', and they understand what would happen if you broke those connections. It's a very simple way of realising that biology operates on information in exactly the same way, and they understand it right away."

So what exactly is systems biology?

"To me, systems biology is an attempt to look at biology from a holistic rather than an atomistic point of view. The only way you can understand all the marvellous



emerging properties of a system is by defining all its components and their interactions, and then looking at how they change dynamically with regard to stimuli that activate the whole system. You create a model that might explain the system and then formulate hypotheses and test them with perturbations to the system, and see if the data you get back really fits your model. It never does in the early stages, so then you just do this in a cyclic way. You never achieve ultimate understanding, but you get models that are more and more predictive about the behaviour of a system."

At the start, this approach was not met with enthusiasm from many sectors.

"Even when we started the Institute for Systems Biology (see box) in the year 2000, there was enormous scepticism. It was exactly what happened when molecular biology intruded on biochemistry. Many schools decided molecular biology was a Johnny-come-lately and trivial, and they focused and committed to just doing biochemistry while others moved into this new field. The ones who made that shift are now the leaders in the biological community. But that doesn't mean the old science is wrong. Biochemistry is important, molecular biology is important. Now we're seeing it's important to consider both in an integrated way. You have to move with the times."

Public domain image; image source: Wikimedia Commons

Max Delbrück

Hood may be credited with coining the term 'systems biology' itself, but it took a colleague's comments to bring him round to this approach.

"In the early 1980s, my laboratory was right next to Max Delbrück's [a German-American biophysicist and Nobel laureate (1906-1981)[w2]], and what I was really interested in then was molecular immunology. Max told me several times, 'You'll never understand how immunology works just one gene and one protein at a time' – he didn't say it quite like that, but that was the gist of it. And I'd say 'Look, we're unravelling these mysteries of antibody diversity, and that's marvellous and transformational'. His reply was 'No, not really! The big problems in immunology are the immune response, tolerance, autoimmunity. We don't understand anything about any of those things'. I realised he was right and started thinking about it – that's when I really started thinking about systems biology. I started using the term in the late 1980s. And in 1990, in *The Code of Codes*, I can't remember whether we used the term there, but in it I wrote a perfect description of what we would say systems biology is today."

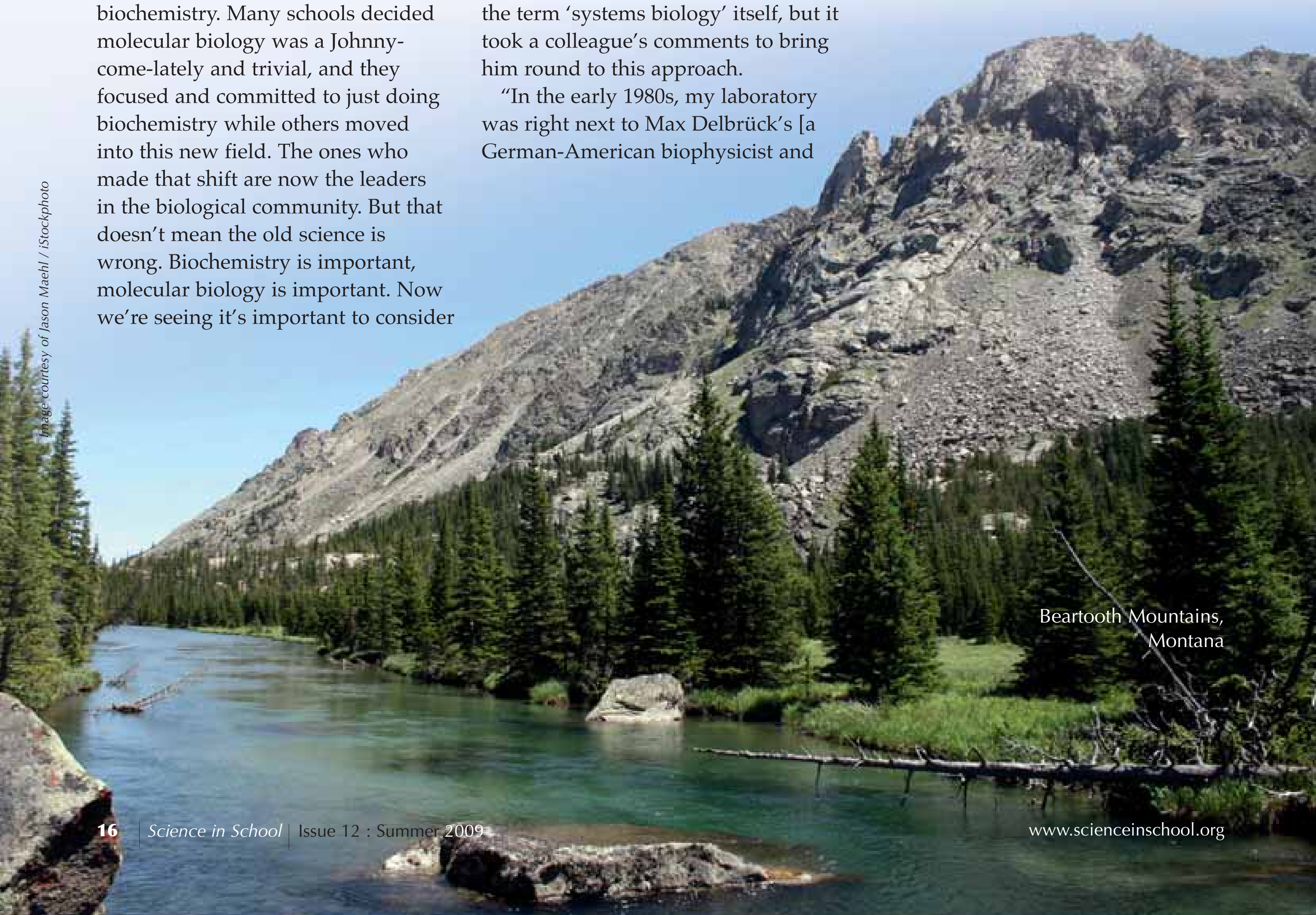


Image courtesy of Jason Maehl / iStockphoto

Beartooth Mountains, Montana

BACKGROUND

Leroy Hood

Dr Leroy Hood is an American scientist interested in immunology, biotechnology and genomics, but the central aspect of his career has been innovation. His career started at Caltech[w3], where he pioneered instruments such as the DNA gene sequencer, which revolutionised genomics by allowing the rapid automated sequencing of DNA and played a crucial role in contributing to the mapping of the human genome. Later, he founded the cross-disciplinary Department of Molecular Biotechnology at the University of Washington, and from there he moved on to co-found the Institute for Systems Biology[w5] in Seattle, Washington, to pioneer systems approaches to biology and medicine.

Hood is currently pioneering systems medicine and the systems approach to disease, and recently forged a partnership with the government of Luxembourg, which he hopes will lead to the creation of a demonstration clinic for an innovative approach to medicine.

Hood has published more than 600 peer-reviewed papers, received 14 patents, and co-authored textbooks in biochemistry, immunology, molecular biology, and genetics and is just finishing a textbook on systems biology. In addition, he co-authored a popular book on the human genome project, *The Code of Codes*, with Dan Kevles.

Image courtesy of Ross Berteig; image source: Wikimedia Commons

Beckman Institute, Caltech

Looking back, Hood's first contacts with science seem to have predestined him for his later interest in networks and complex systems: "My father was an electrical engineer and wanted me to be an engineer, too, but I didn't like engineering. He taught a lot of courses though, and liked me to attend them, so I ended up learning a lot about circuits and networks. Another important influence was my high-school chemistry teacher. In my senior year he asked if I'd help teach the freshman biology course. I said I'd do it if I could use *Scientific American* to teach from, and he agreed. This was 1956, and there was this wonderful article in that magazine on the structure of DNA which made me think, 'Wow! That's really cool! That's the kind of thing I'd like to do'. On the other hand, my grandfather ran a summer geology camp for university students in the Beartooth Mountains in Montana, and I worked there and took courses with them. This exposed me to scientists for the first time, and it was really an incredibly exciting opportunity. I considered doing geology at that point, but that *Scientific American* article turned me to biology in the end. The other thing that was really transformational was when the same chemistry teacher said: 'The place for you to go is Caltech'."

So Hood went to Caltech[w3] to train as a scientist, and in the process he learnt a lot about teaching.

"Caltech was unbelievably inspirational for me. I had Richard Feynman [an American physicist and Nobel Prize winner who helped develop the atomic bomb (1918-1988)[w4]] as a lecturer in my freshman physics class, and seeing teachers like him, who taught almost entirely from a conceptual point of view, showed me that this gives the students the framework for assimilating as much detail as they want, but without losing sight of the deep fundamental conceptual issues. So when I taught undergraduates at Caltech, I used to invent games for the students to play, because there they can apply the principles they've learned in a context that is utterly different. For immunology, I devised one game where students had to analyse

Public domain image; image source: Wikimedia Commons

Richard Feynman

Image courtesy of Eben Calhoun; image source: Wikimedia Commons

The Institute of Systems Biology viewed from Lake Union

a Martian elephant: I gave them a lot of experimental data on how the Martian elephant responded to infectious agents and so forth, and they had to deduce from first principles the basic mechanisms of Martian antibody diversity, which were totally different from those on Earth. Students love this kind of thing. Some wrote to me 20 or 40 years later saying they never forgot those games. Similarly, you can use computer games and populate them with information about biology in really interesting ways."

What would Hood choose as a topic if he were to write a book about the highlight of his career? For someone whose life has been spent creating and advocating innovative approaches to science, teaching and medicine, Hood's answer is perhaps not surprising: he'd write about how to make change happen.

"I know a lot about how you make change happen – I had a bunch of different experiences, and in all cases I had to do it in very different ways. For example, all these instruments we developed when I was at Caltech and a little later: to make that happen I had to start a company called Applied Biosystems, which commercialised all the instruments. Then, when I tried to start a new cross-disciplinary biology department at Caltech, the biologists refused, so I had to go to the University of Washington and start a new department there with Bill Gates' help, instead. And then the Institute for Systems Biology[w5] – I tried to do that at the University and couldn't, so I just left and started it, and it's the best thing I ever did because can you imagine somebody in a university making an agreement with the government of Luxembourg? It wouldn't happen in a billion years! I think that whole set of things has really been one of my most interesting experiences. I mean the science has been great and I still love the science, but I love making the science happen, too."

Finally, what drives that persistence, that perseverance to go against the odds? According to Hood, a blend of small-town stubbornness and confidence.

"I think it was growing up in Montana. It was small and rural, and there was very much the attitude, 'You can do whatever you want to do'. And then it's just having a lot of confidence. If you think about something and you really think you're right, don't worry about the sceptics – just go do it. My career was just this natural evolutionary process. I can't say that in 1980 I had any deep long-term plans, but at each stage I always knew where I wanted to go next, and that always directed me to the next step. And, of course, it always helps to be successful. That never hurts."

REVIEW

This stimulating article, which touches on a number of interesting topics, can be used as a basis for discussing the following questions in class, among others:

- Can you think of biology topics that are taught separately which would be more coherent if integrated?
- What are they, and can you suggest how you would like them to be linked together?
- Would this make it easier for you to link ideas across topics?
- What are the really important developments in systems biology at present?

Devon Masarati, UK

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w1 – Learn more about the partnership for inquiry-based science in Seattle and its development here: www.systemsbiology.org/Center_for_Inquiry_Science/History_and_Accomplishments

w2 – To find out more about Nobel Prize winner Max Delbrück, see: http://nobelprize.org/nobel_prizes/medicine/laureates/1969/delbruck-bio.html

w3 – You can find the website of Caltech, the California Institute of Technology, here: www.caltech.edu

w4 – To learn more about Nobel Prize winner Richard Feynman, see: http://nobelprize.org/nobel_prizes/physics/laureates/1965/feynman-bio.html and www.feynmanonline.com

w5 – The website of the Institute of Systems Biology is: www.systemsbiology.org

Resources

For an introduction to systems biology and its possible place in the classroom, see:

Grivell L (2009) Systems biology in the classroom? *Science in School* **11**: 64-69. www.scienceinschool.org/2009/issue11/systemsbiology

Painting life green: GFP

From jellyfish to arsenic detectors via a Nobel Prize: **Sonia Furtado** reports on the discovery and development of the green fluorescent protein, and interviews scientists at the European Molecular Biology Laboratory (EMBL) in Heidelberg, Germany, about its applications.

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

GFP's amino acid chain folds into the shape of a cylinder, with the fluorophore at its centre

It started with a jellyfish: transparent *Aequoria victoria* has spots around its rim that glow green when it is agitated; a behaviour that was first described by scientists in 1955. Studying this 'oddity' led to what has been hailed as a scientific revolution, and recently, for three scientists, to a Nobel Prize[w1]. All because of a single protein, called green fluorescent protein (GFP), which is responsible for the jellyfish's fluorescence.

In the early 1960s, Japanese scientist Osamu Shimomura discovered aequorin, a jellyfish protein that glows in the presence of calcium. However, aequorin glows blue, while the jellyfish glows green, so something must transform aequorin's blue light into the jellyfish's green light. Shimomura discovered this something is another protein: GFP, which absorbs the aequorin's blue and ultraviolet light and emits green light, giving the jellyfish its glow.

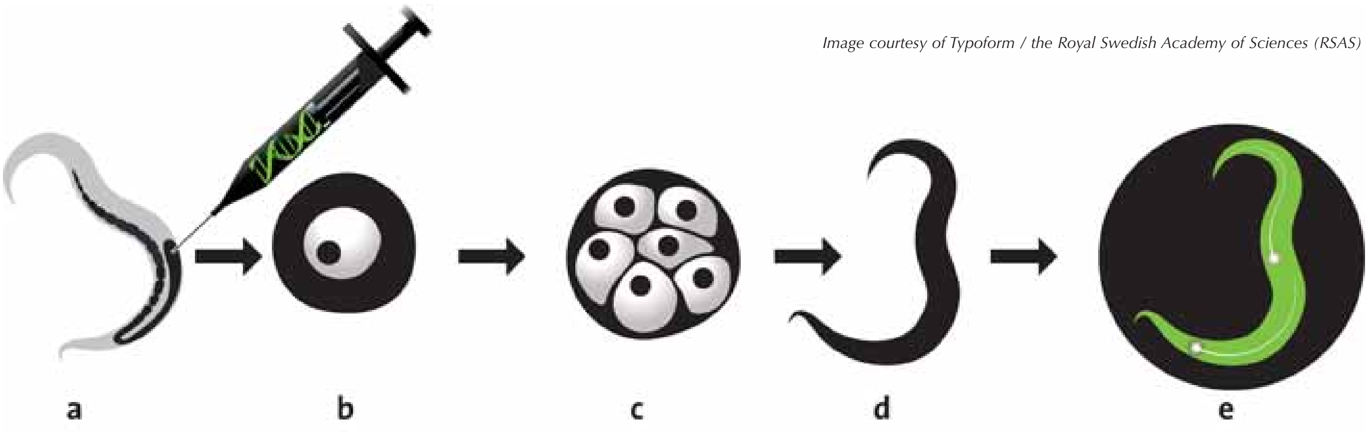
Image courtesy Prolineserver; image source: Wikimedia Commons

Nobel laureates in chemistry Roger Tsien, Martin Chalfie, Osamu Shimomura at a press conference at the Swedish Academy of Science in Stockholm, 2008

Along came US biologist Martin Chalfie with an idea how to make use of this effect: he reasoned that model organisms could be genetically engineered by attaching the gene for GFP to a specific gene that scientists wanted to study. Then, when the gene of interest was expressed, i.e. when the protein it encodes was produced, it would have GFP attached. This would allow scientists to know when and where a particular gene is turned on: they would just have to shine ultraviolet light onto their organism and look for the green glow.

At the time, two things were apparently missing before Chalfie's vision could become a reality. The gene for GFP had to be identified, and the mechanism behind GFP's fluores-

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



Chalfie's experiment: DNA with the gene for GFP attached was injected into the gonads of a *C. elegans* worm (a). The worm is a hermaphrodite, so it can fertilise itself, and the GFP gene was present in many of the eggs it then laid (b). The eggs divided (c), forming new individuals (d) whose touch receptor neurons glowed green in ultraviolet light (e)

cence had to be unveiled. Scientists knew that GFP glows because three of its amino acids form a fluorophore, a chemical group that absorbs and emits light. They assumed that, like most naturally fluorescing molecules known at the time, other proteins called enzymes would be needed to fold GFP into the correct shape, and thought that only *A. victoria* would produce them.

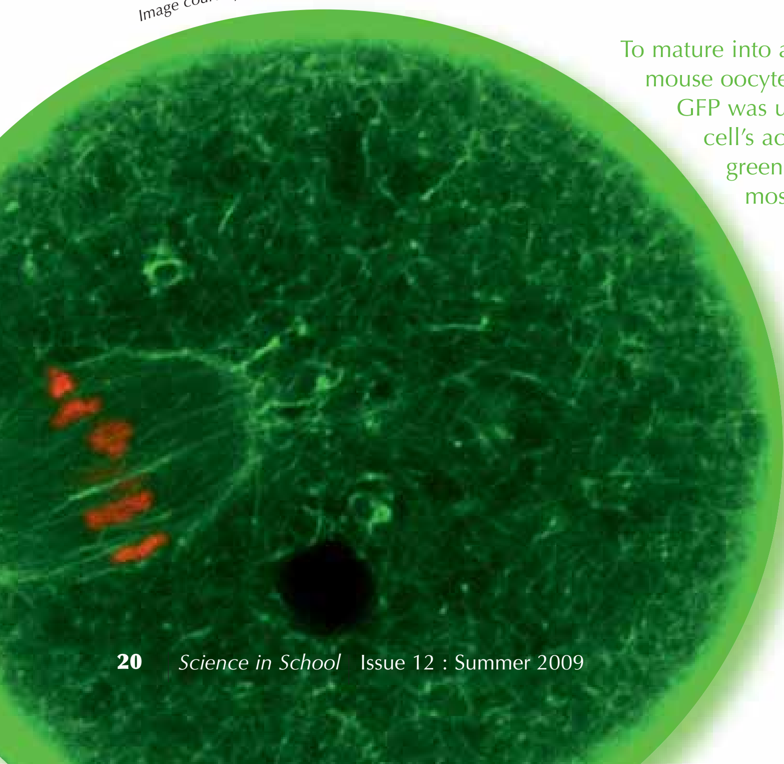
So when biochemist Douglas Prasher identified the GFP gene in 1992, the general consensus was that introducing this gene into other organisms would result in the production of a non-fluorescent version of GFP. However, when Chalfie and his team attached the newly found GFP gene to a bacteria's DNA, the bacteria glowed green!

It turns out that GFP doesn't need enzymes to make it glow. Instead, it spontaneously folds into the fluorescent shape, and, biochemist Roger Tsien discovered, the reaction between the amino acids in the fluorophore requires only oxygen, which is readily available in most living cells. Having established exactly how GFP's fluorophore is formed, Tsien was then able to manipulate this protein. By exchanging different amino acids in different parts of the chain, he developed new versions of GFP which were brighter, absorbed light of different wavelengths, and glowed in different colours: cyan, blue and yellow. And, once a red fluorescent protein was found in coral, Tsien and his colleagues used their knowledge of GFP to make that red fluorescent protein useable as a biological marker too.

Shimomura, Chalfie and Tsien were awarded the Nobel Prize in Chemistry in 2008, "for the discovery and development of the green fluorescent protein", and scientists all over the world have continued to develop variants of GFP which are now available in virtually all colours of the rainbow.

By now, GFP has become an invaluable tool for scientists all over the world. It does much less damage to cells than chemical fluorescent markers do. After being illuminated for a certain period of time, a fluorophore

Image courtesy of Jan Ellenberg / EMBL



To mature into an egg, this mouse oocyte is dividing. GFP was used to label the cell's actin cytoskeleton green and the chromosomes red releases an electron, and after that it will never fluoresce again: it is bleached. The electrons released in this bleaching process very quickly react with oxygen, forming highly toxic oxygen radicals, which damage cellular components, eventually causing the cells to die. But GFP's structure acts as a shield, protecting the cell. When the fluorophore releases an electron, the radicals that are formed react within GFP, so they do damage to GFP but not to the cell.

And even though scientists use GFP as a marker by attaching it to a specific protein, different researchers use it to study different processes occurring on completely different scales, tagging anything from groups of cells to individual molecules.

"That's the beauty of GFP," says Darren Gilmour, a scientist at EMBL[w2]: "with it, you can look at all these different scales – you can paint them all with the same paint, you don't need to change brush." In their work on zebrafish embryos, Darren and his group use GFP to tag groups of cells, which they can then follow as the embryo develops, watching how they behave, where they go, and what tissues and organs they ultimately give rise to. The zebrafish embryos Darren studies are transparent, so you'd think it would be easy to see what was happening in them. The problem, Darren says, is that there is too much happening. "It's an overload. You just can't focus, you can't pick out one thing. But with GFP," he adds, "you can turn out the lights and just focus on a group of cells, or even on a single cell." (To read more about Darren's work, see Spinney, 2007).

This ability to follow dynamic processes is also crucial for Francesca Peri, as it allows her to follow the development of her labelled zebrafish embryos under a microscope for days. The alternative would be to sacrifice the animal, slice it and take still pictures. "It would be like trying to understand a football match based on just half a dozen photographs," says Francesca. "You'd never get the whole picture." She and her group study microglia, cells which are able to eat dying or damaged neurons. "Using GFP, we can colour-code the different cell types, so microglia will be labelled green, for example, and neurons red. So if we see a red cell inside a green one, we know that a neuron has been eaten to prevent it damaging the rest of the brain tissue."

Marcus Heisler and his group use GFP and its variants to study plants. They focus on a plant hormone called auxin, which is transported to the outside of the cell by a carrier that sits on the cell membrane. This carrier can move around the cell, changing the direction in which it sends the hormone. "GFP allows us to follow that very dynamic process in living plants," Marcus says, "and it gives us good 3D resolution."

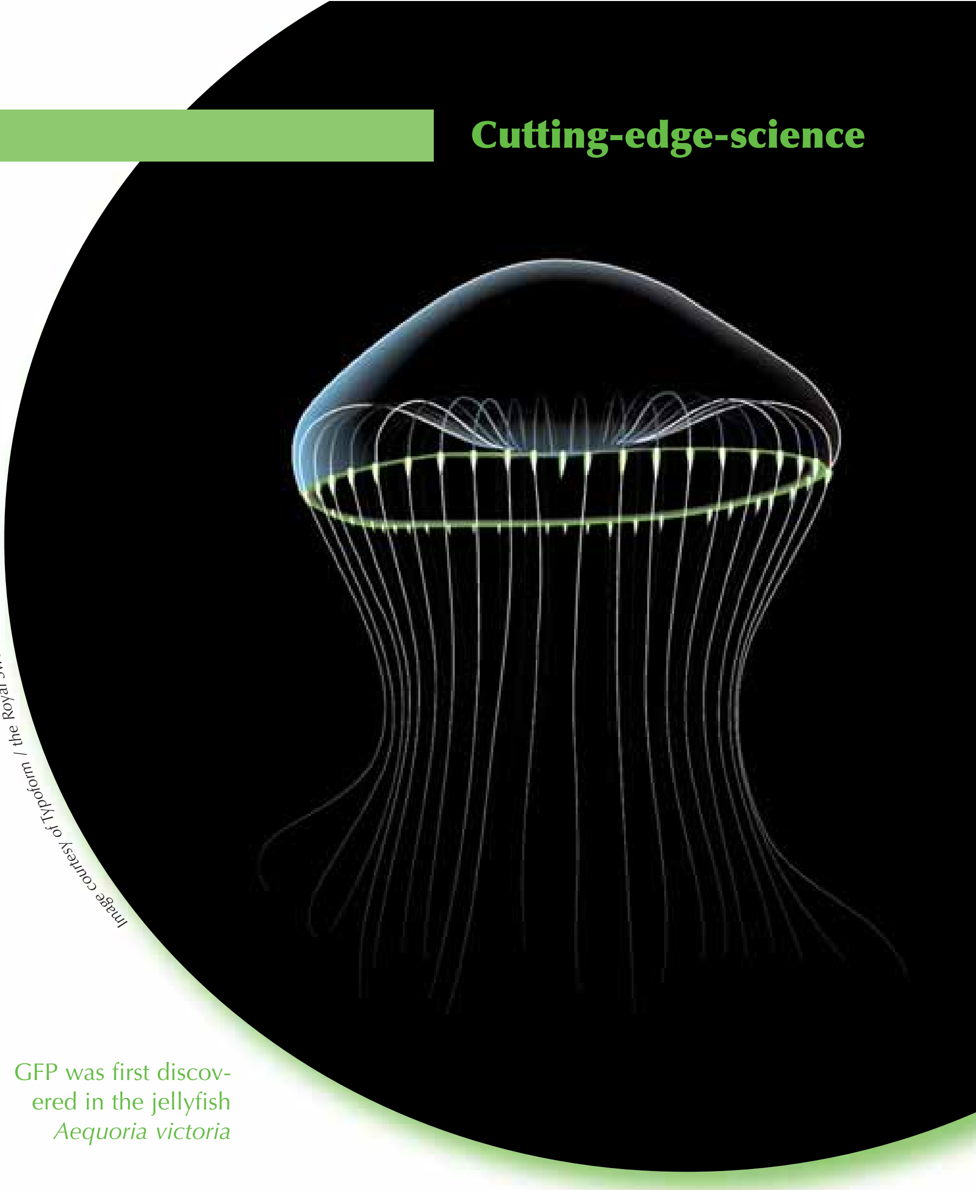
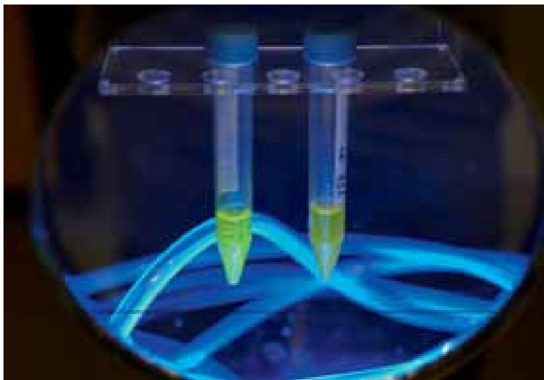


Image courtesy of Typoform / the Royal Swedish Academy of Sciences (RSAS)

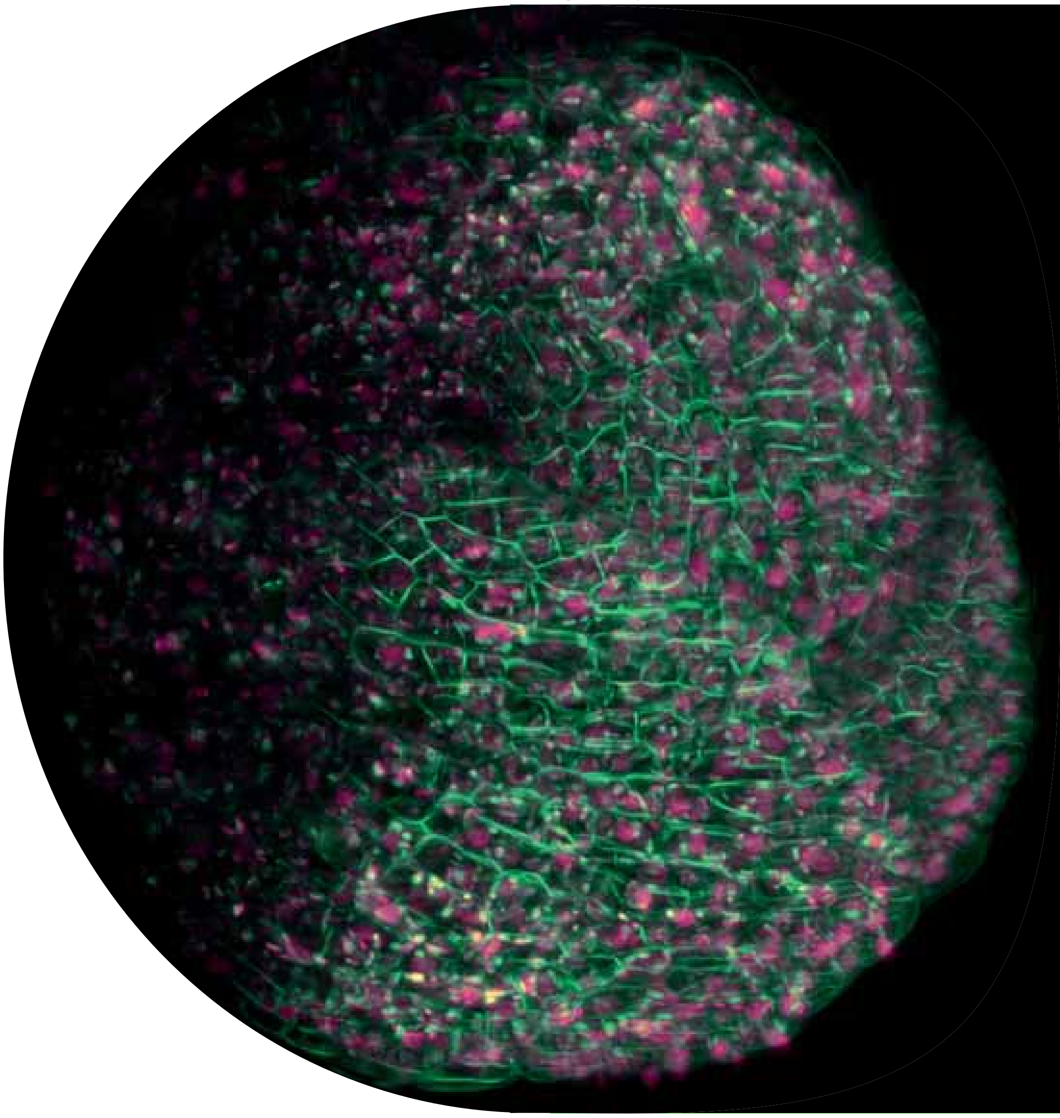
GFP was first discovered in the jellyfish *Aequoria victoria*

Image courtesy of EMBL Photolab



Exposed to ultraviolet light, the GFP in these tubes glows fluorescent green

Image courtesy of Ernst Stelzer / Marcus Heisler / EMBL



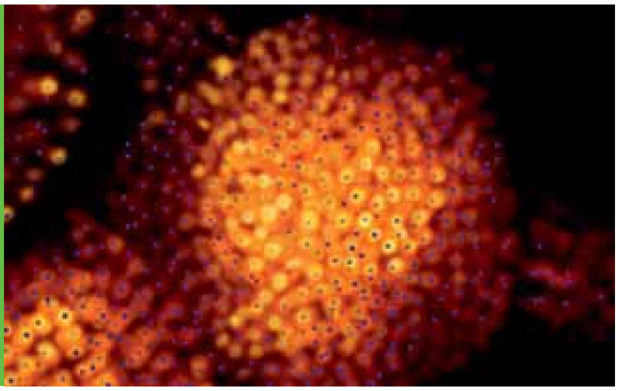
In this 3D image of an *Arabidopsis* plant's shoot apical meristem, which will give rise to the above-ground part of the plant, fluorescent proteins were used to label cell membranes green and nuclei pink

GFP's reliability is crucial for obtaining such 3D images, says Ernst Stelzer, whose group focuses on developing technologies for 3D imaging over time. "Getting the dye into a thick specimen is always a very serious problem." he says. Markers injected into the specimens tend not to penetrate very well, so the labelling tends to be uneven: outer layers will be well labelled, but ones near the middle tend to be badly labelled, if at all. "With GFP," Ernst points out, "we can be really sure that the whole specimen will be labelled, because the dye is produced inside the cells."

Another EMBL scientist, Rainer Pepperkok, says, "With GFP, we can really do molecular biology in cells, while things are moving, instead of in a test tube." He and other scientists take advantage of the fact that GFP now comes in many different colours, and exploit a physical phenomenon called fluorescent resonance energy transfer (FRET). This phenomenon occurs when two fluorescent molecules of different colours – classically red and green – come close to each other. If the green one then receives ultraviolet or blue light, it will absorb that light and transfer some of the light's energy to the red molecule, which will then emit red light, in a manner similar to GFP glowing green in the jellyfish thanks to the blue light emitted by aequorin. "So if you have a protein tagged with green GFP and another with red GFP," Rainer explains, "if they interact with each other, the red will be brighter and the green will be dimmer."

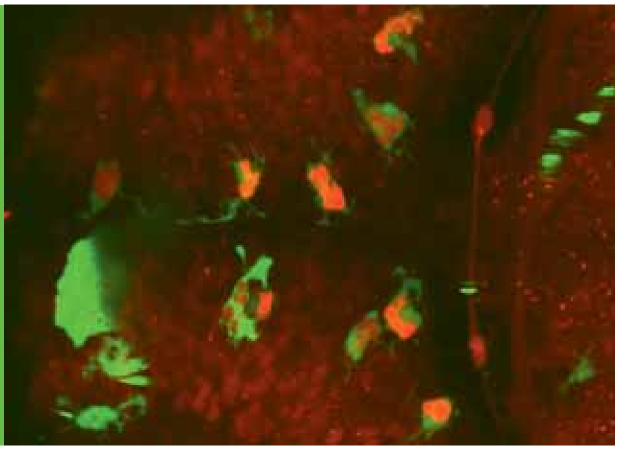
Despite all of GFP's different uses, or perhaps because of them, scientists are still not satisfied. A common request would be GFPs that glow under red or even infra-red light, as this penetrates biological tissues better. "It would also expand the spectrum of available colours," Jan

Image courtesy of Marcus Heisler / EMBL



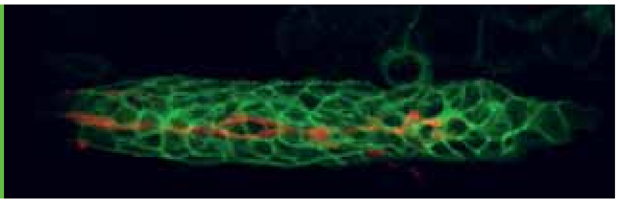
Combining computer simulations with GFP labelling, scientists can compare their predictions (blue) with the real-life location of cell nuclei (orange)

Image courtesy of Francesca Peri / EMBL



With GFP, scientists can look at a living zebrafish embryo's whole brain, observe interactions between microglia (green) and neurons (red) and find neurons inside microglia (bright red)

Image courtesy of Darren Gilmour / EMBL



One group of cells, labelled orange, guides other cells (green) as they migrate along a developing zebrafish embryo

Ellenberg points out, "which would allow us to tag more proteins and follow them at once." It may take a new discovery to make this wish come true, as Jan believes the standard way of making GFPs which glow at longer wavelengths – stacking more amino acids onto the fluorophore – is pretty much exhausted. For his part, Darren says microscopy techniques now need to catch up: "At the moment, we're at a stage where we could make a zebrafish with five colours, but then we wouldn't be able to tell them apart with most of the available microscopes."

Nevertheless, GFP is expanding beyond the realm of science. It is employed in some glow-in-the-dark toys, in glow-in-the-dark fish being sold as pets, and even in bacteria that have been genetically modified to detect arsenic, TNT and heavy metals.

In spite of all these advances, however, the initial mystery remains unsolved: we still don't know why the jellyfish evolved the ability to glow green in the first place.

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w1 – To learn more about the Nobel Prize in Chemistry in 2008, see: http://nobelprize.org/nobel_prizes/chemistry/laureates/2008

w2 – Find out more about EMBL and its scientists here: www.embl.org

Plasma balls: creating the 4th state of matter with microwaves

Eli Jerby (Tel Aviv)

Halina Stanley describes how two Israeli scientists investigated plasma balls and in the process found a potentially useful way to create nanoparticles.

There are things we all know we shouldn't do, but – whether by accident, through curiosity, or simply because we know we shouldn't do them – we do them anyway. Not putting metal objects in a microwave oven is probably rule number one of microwaving – and we all know why, because we've all at some time left a fork on the plate of leftovers to be reheated, creating arcs, sparks and perhaps plasma balls (commonly called fireballs - the two terms are used interchangeably in this article) before we hurriedly hit the 'off' button. Judging by the number of wacky and downright dangerous experiments you can find videoed on YouTube[w1], many young (and not so young) people find creating fireballs irresistible. Scientists from Tel Aviv University in Israel have now deliberately created fireballs in a microwave cavity at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France: they wanted to find out what was in them. Their results show that highly ionised nanoparticles (a dusty plasma) can be made in your school's microwave oven.

The scientists, Eli Jerby and Vladimir Dikhtyar, were interested in using microwaves to produce strong localised heating. In fact, they were deliberately introducing a metal electrode to focus microwaves on a point only a few millimetres across (exactly the opposite of what you want to do when heating food). If you heat materials like glass or ceramics, the amount of microwave energy that they absorb increases as they become hotter (the dielectric constant is very temperature-dependent). Warmer regions absorb more microwaves and heat up more. This positive feedback

Image courtesy of Adam Homfray / iStockphoto

effect, called thermal runaway, is potentially dangerous, especially in materials that are poor thermal conductors where slow heat exchange with surrounding material means that you can get very, very hot spots (over 1200 °C). This was exactly what Jerby and Dikhtyar were aiming to produce: they were developing a drill that uses microwaves to make 2 mm diameter holes in ceramics or glass while leaving metallic substrates untouched. (This drill is silent and does not produce dust, and has the potential for drilling bones in orthopaedic surgery[w2]).

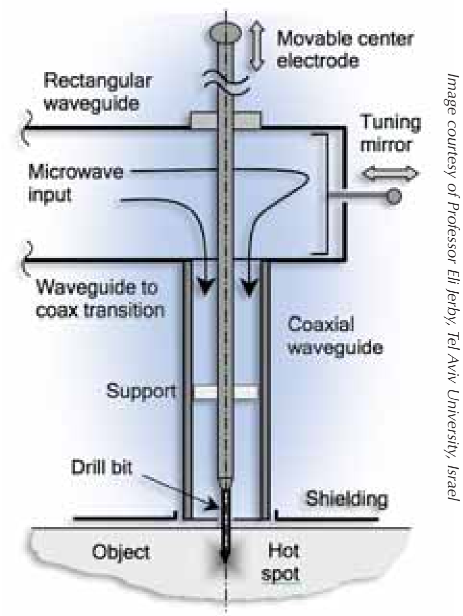


Image courtesy of Professor Eli Jerby, Tel Aviv University, Israel

Microwave drill

One day (perhaps inevitably!) something went wrong: a fireball detached itself from the molten material. "It destroyed a component of the microwave generator worth about $2000," says Professor Jerby. Fireball production must have become quite a problem: "On several occasions a fireball arose out of a hot spot and was blown into the air. The fireball moved like an elastic glowing balloon, floated in the air toward the microwave antenna about 20 cm away and disappeared" (Dikhtyar & Jerby, 2006). Fireballs could appear repeatedly (for example at one-second intervals), but the phenomenon was rare and unpredictable.

Although Jerby and Dikhtyar were not fundamentally interested in fireball production to begin with (just desperate to get rid of it), as time passed, their interest increased. The next few years were devoted to systematic work so that they could intentionally generate fireballs from molten spots of glass. Now, in addition to using their drill to make holes, they can use a modified version of it to make fireballs.

There are some videos of Professor Jerby's fireballs on his website[w3], but plenty of amateur investigators

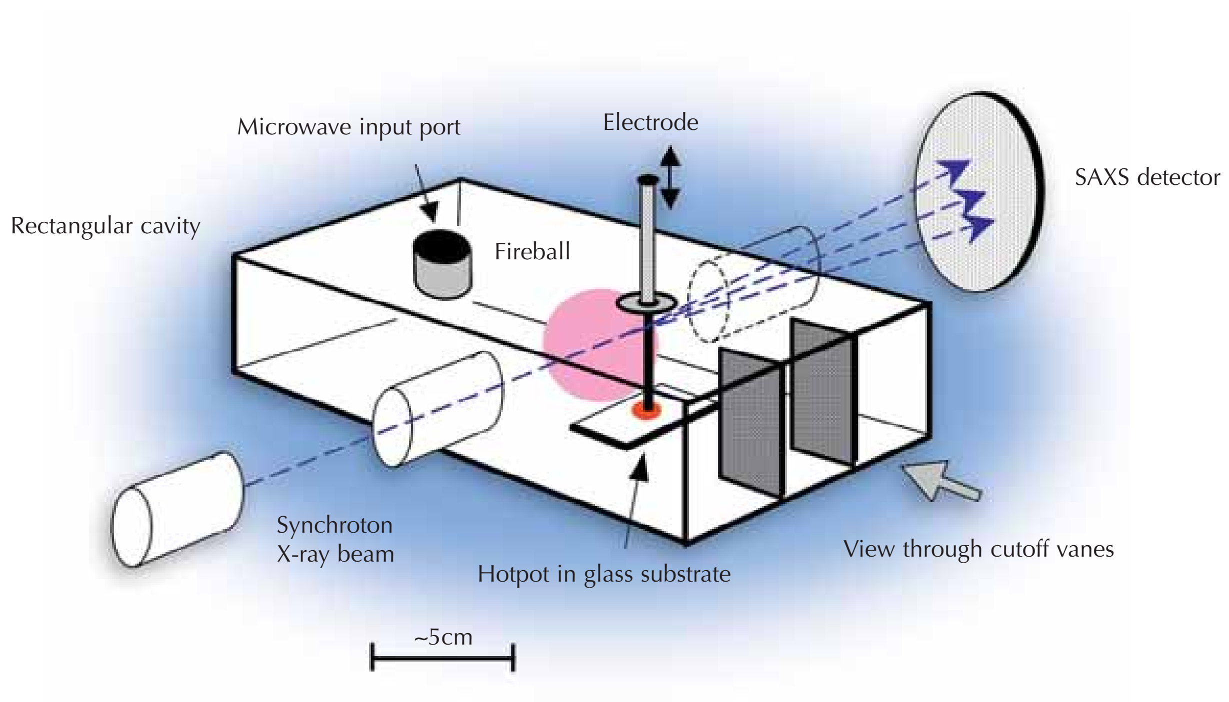


Image courtesy of Professor Eli Jerby, Tel Aviv University, Israel

The experimental set-up

around the world have performed the experiments, too. No one should even think of repeating the experiment done by Bill Beaty, an engineer at the University of Washington in Seattle, USA (the risk of hot flying glass or a broken microwave seems much too great to me) but his video[w4] is too entertaining to miss.

Creating fireballs is one thing. Understanding them is quite another. As you can see on YouTube, people have created fireballs by microwaving burning candles, grapes, bits of aluminium[w5] and smouldering toothpicks as well as molten glass. All these fireballs are buoyant in air and are sustained while being irradiated with microwaves, although they are extinguished shortly after the microwave power is shut off – lasting around 30 ms in the case of molten glass. They have some of the reported characteristics of ball lightning[w6], which, according to a proposed model, is caused by ordinary lightning throwing a cloud of nanoparticles out of the soil that slowly oxidise in the air releasing heat and light (Abrahamson & Dinniss, 2000).

Obviously Jerby, Dikhtyar and their colleagues wanted to understand their fireballs. It appeared as if they were drawing material out of the molten glass (see image above and the videos on Professor Jerby's website[w3]), but if there were glowing particles suspended in the air, they had to be really small. If there were particles even as large as a couple of microns the fireballs wouldn't just disappear (as they do) when the microwaves are turned off – the particles would scatter visible light in the same way as water droplets in a cloud (which have an average size of about 10 µm) and you would see a cloudy haze of glass droplets.

Electron microscopy is usually the first technique that scientists use to characterise sub-micron structures – such as the hypothesised particles in the plasma balls – but you cannot create a sample of a plasma ball to be put in an electron microscope's vacuum tube. However, the technique of small-angle scattering (see box) provides a way to tell whether there are particles in a plasma ball, and – if so – to characterise any particles found.

Therefore, Jerby and his colleagues took a microwave cavity containing their fireball-creating mechanism (the modified drill) to ESRF, where very intense beams of X-rays are used to study materials. The microwave cavity had holes to allow the X-rays in and out, and a viewing port, so that the researchers could see what they were doing. The X-ray entry and exit holes were too small to allow microwaves (wavelength ≈12 cm from a 2.45 GHz magnetron) to pass through, and the viewing window had vanes to prevent microwaves escaping (see image above).

At ESRF, the researchers created fireballs in their cavity using the modified drill. X-rays (wavelength 0.1 nm) were fired from the synchrotron down an evacuated tube, through a cover (transparent to X-rays) and into the microwave cavity filled with air at atmospheric pressure. The X-rays shot through the fireballs (which stayed immobile for about 1 s) and exited the cavity into a second evacuated tube which led to an X-ray detector 5 m away (see diagram). The small-angle X-ray scattering patterns produced

BACKGROUND

Small-angle scattering

Small-angle scattering (SAS) is a technique in which light, X-rays or neutrons are fired through a sample and the radiation that is deflected slightly (scattered close to the straight trajectory) is analysed (see diagram). The angle (2θ) by which the radiation deviates from the straight trajectory depends on the wavelength of the incoming radiation and the size of the scatterer (in this case, the particle in the sample being analysed). For a given wavelength radiation (λ), the larger the angle, the smaller the particle, or conversely, the smaller the angle, the larger the length scale (d) being probed. The relationship between these parameters is given by $\lambda/d = 2\sin(\theta)$. The visible (laser) light used for light scattering experiments has a much longer wavelength (e.g. 600 nm) than neutrons (about 0.1-1 nm) or X-rays (≈0.1 nm) and (although there is some overlap) is therefore probes larger objects.

The SAS technique can tell you the average size of a particle (in the range of about 1 nm to a few hundred nanometres), the size distribution of particles, the shape of the particles, and something about their internal structure, surface roughness or the interparticle separation, but not all this information can be extracted at the same time from any given data. The scattering pattern is relatively lacking in sharp features (usually there is just some overall decline in scattered intensity as scattering angle increases, occasionally there may be one broad peak) and does not uniquely define the scatterers: a very similar small-angle scattering pattern may, for example, be produced by a polydisperse (of varying size and shape) population of spherical scatterers or a fairly monodisperse (of same size and shape) population of cylindrical scatterers. Consequently, data analysis proceeds by a 'guess, check and revise' method, where a plausible model is used to calculate a predicted scattering pattern, which is then compared with the actual data, and the model is revised accordingly with all steps being repeated iteratively.

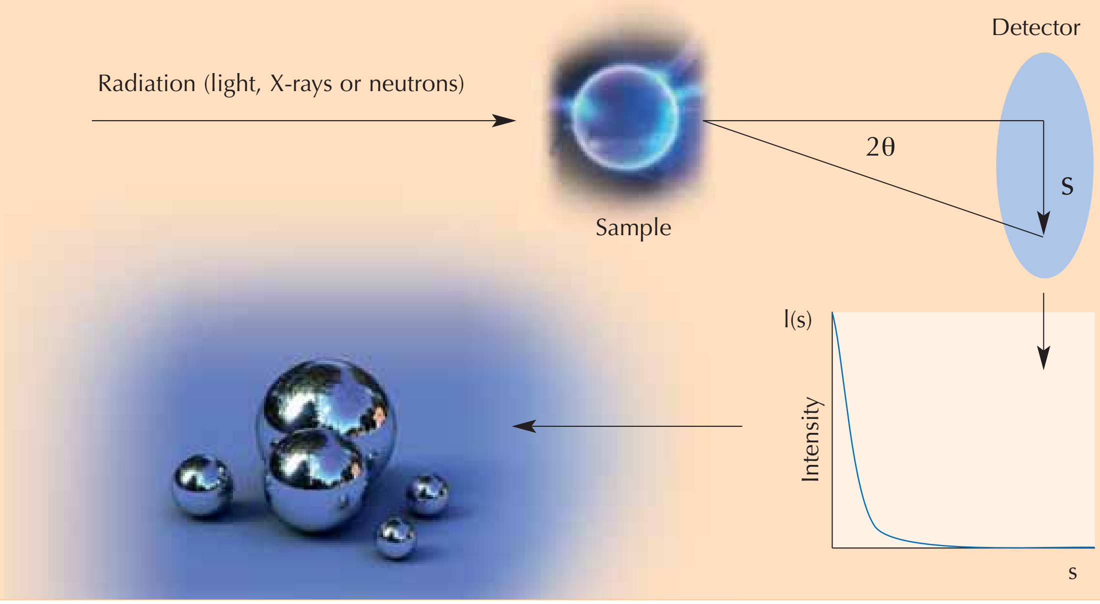


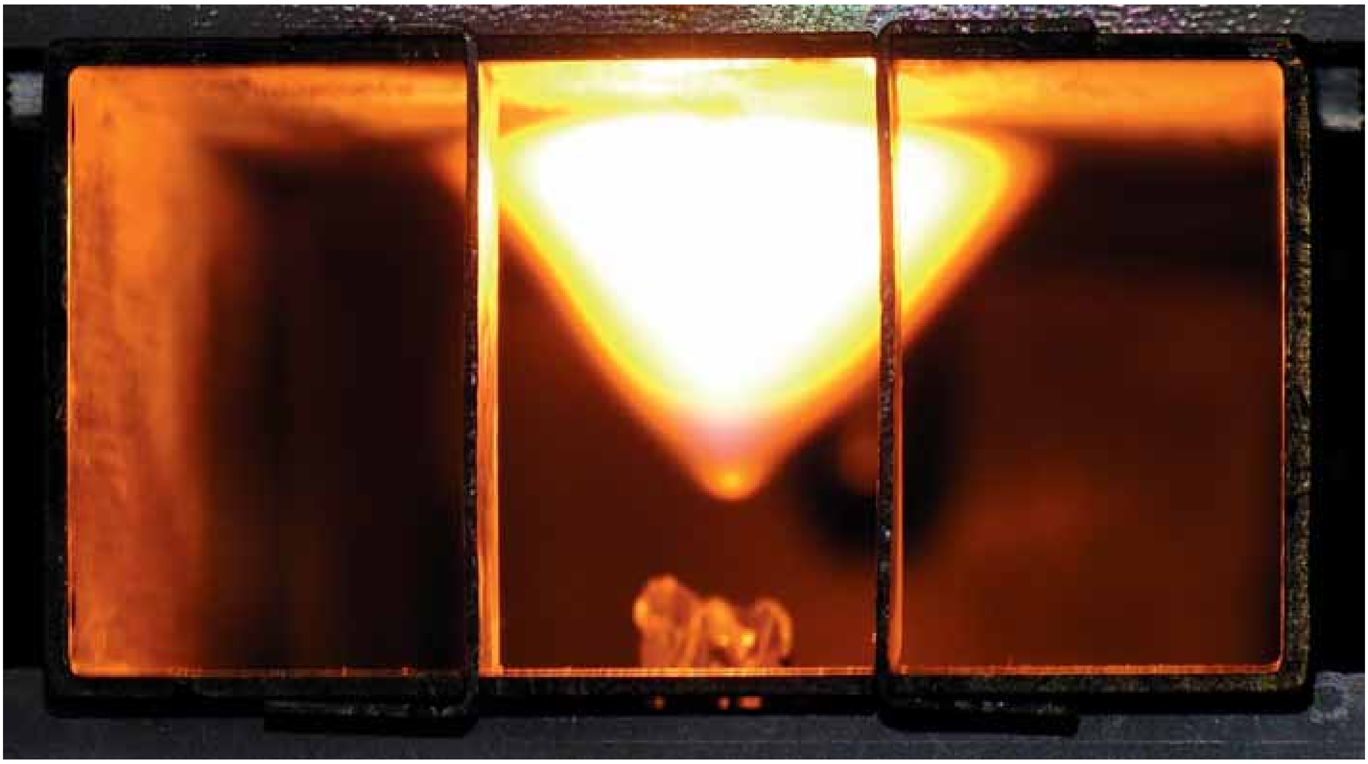
Image courtesy of Nicola Graf

were recorded every 0.1 to 0.3 s.

These patterns proved that the fireballs were indeed full of particles with an average radius of about 25 nm – i.e. they are nanoparticles. The data also showed that the particles varied widely in size (as is typical of aerosols) and that there were about 109 particles per cubic centimetre. This makes the volume fraction of solid material (the ratio of volume of solid to total volume of space) in the fireball around 10^{-7} or 10^{-8}. There was really only a very, very, small amount of matter in the cloud. The analysis also suggested that the particles had quite a rough surface: the scientists found the surface to have a fractal dimension of 2.6 (2.0 corresponds to a smooth 2D surface, 3.0 to 3D).

But why do the particles glow? Why do the researchers say they form a plasma ball? While the particles are being microwaved they absorb microwave energy and heat up to about 730 °C (1000 K). This energy is re-radiated in the form of intense visi-

Image courtesy of Professor Eli Jerby, Tel Aviv University, Israel



A plasma ball

ble light. At 730 °C the particles will also emit electrons due to thermoionic emission, thus making the fireball a dusty plasma (a cloud of solid particles that have lost electrons and are thus highly ionised).

Using X-rays at ESRF, the scientists also investigated what happens to the fireballs when the microwaves are turned off. Visually the fireball vanishes after about 30 ms, but the X-ray data continued to detect particles for about 4 s. The particles were there, but invisible to our eyes because they were so small. These X-ray data showed that the particles (which were charged were stable while being microwaved) initially simply diffuse away as the fireball cools and then, as cooling continues, tend to aggregate and form large clusters (Mitchell et al, 2008).

Professor Jerby has since returned to ESRF with a collection of different materials to microwave. He says, "We examined the structures of plasma balls made from a variety of materials, including copper, salts, water and carbon. It seems that we are able to generate plasma balls from almost any material now...." This means that he now has a method of directly creating nanoparticles of many different substances. This is very interesting, because nanoparticles are increasingly important in a wide variety of applications, and producing them is not always easy. Nanoparticles are being used in medicine (e.g. drug delivery), in catalysis (for cleaning up pollutants), and even in treatments for smelly socks (which rely on nanoparticles of silver to kill bacteria; see Benn & Westerhoff, 2008). For a good overview of nanotechnology, see Pickrell (2006), and of how to use nanotechnology in the classroom, see Mallmann (2009).

This is all a long way from drilling holes in ceramics though, and when asked what he was going to do next, Professor Jerby replied: "I hope to generate energy from common materials in an efficient and practically feasible manner." In the mean time, remember that any attempt to dry your nanotech socks using a microwave oven could lead to fireworks!

For some classroom experiments using microwave ovens, including the production of plasma balls, see Stanley (2009) in this issue.

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Stanley H (2009) Microwave experiments at school. *Science in School* **12:** 30-33. www.scienceinschool.org/2009/issue12/microwaves

Web references

w1 – YouTube: www.youtube.com

w2 – For more information about the microwave drill, see Professor Jerby's web page: www.eng.tau.ac.il/~jerby/microwave_drill/index.html

w3 – Professor Jerby's web page includes several videos of fireballs and their generation: www.eng.tau.ac.il/~jerby/Plasmaballs.html

w4 – Bill Beaty's microwave experiment to melt a beer bottle: www.metacafe.com/watch/1004040/melt_a_frickn_beer_bottle

w5 – Jean-Louis Naudin describes how to create ball lightning in a microwave, using a piece of aluminium: http://jlnlabs.online.fr/plasma/4wres/index.htm

w6 – More information about ball lightning can be downloaded from the *Science in School* website: www.scienceinschool.org/2009/issue12/fireballs

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Halina Stanley is a physicist by training. She spent ten years as a research scientist in industry and academia using neutron and X-ray scattering techniques to characterise materials before joining the American School of Grenoble, France, where she teaches physics, chemistry and mathematics to secondary-school students.

Microwave experiments at school

Halina Stanley introduces a number of spectacular classroom experiments using microwaves.

As reported in this issue of *Science in School* (Stanley, 2009), Israeli scientists have been using microwaves to drill holes into glass and ceramics, and to produce plasma balls. Microwave ovens are a useful resource for teachers as well as scientists. Here is a collection of fun microwave experiments that are suitable for the classroom.

Plasma balls

Using a microwave oven, you can create balls of plasma[w1] at school from nanoparticles of soot. Dr Chris Schrempp, who teaches at a Californian high school, has been doing this in class for some time. He says, "This is a great demonstration that is always a sure hit with students of any level. Although the owner of

Images courtesy of ra-photos & Tyler Boyes / iStockphoto the participating microwave, if present, will be absolutely sure that the appliance will be a total loss after the demonstration, it should remain surprisingly undamaged."

Materials

- A small heatproof glass bowl
- A short wooden splint or toothpick (3-5 cm long)
- A cork
- 50 ml laboratory beakers (or other similarly sized microwavable objects)

Procedure

1. Remove the turntable from the microwave and cover or remove the light.
2. Stick the wooden splint or toothpick into the cork.
3. Support a small heatproof glass bowl upside-down in the centre of the microwave using a circle of beakers. The bowl should be raised high enough that the toothpick stuck in the cork can be placed beneath it.
4. Pre-program the microwave for 30 seconds at full power and turn off the lights in the room.
5. Light the splint and put it into the microwave under the glass bowl.
6. Close the door and turn the microwave on.

The plasma usually forms in about 10 seconds. Schrempp says, "It will make a horrific noise, sounding as though the microwave is frying from the inside out." If a plasma ball does not form in this time, stop the microwave, relight the splint and start again.

Safety note: The microwave should only be allowed to run for about 20-30 seconds, otherwise the glassware might overheat and break. Be sure not to let the toothpick burn right down and set fire to the cork.

The inverted glass bowl serves to contain the plasma so that it can be viewed through the window easily. The demo can be performed without the bowl, but the fireball will then rise to the top of the microwave, so you have to bend down and look up into the window to see it.

The only negative effect of the demonstration is a smoky smell in the microwave. Schrempp says he has never had any real damage to the oven, just some sooty marks, but suggests that an older oven be used just in case.

Schrempp's demonstration of this and lots of other dramatic experiments can be seen on the Exploscience website[w2].

Plasma balls can also be created using grapes, as described in Schrempp's e-book *Bangs, Flashes, and Explosions – An Illustrated Guide of Chemistry Demonstrations*[w3]:

1. Cut a grape almost completely in half along its length, retaining a small piece of the skin on one side to keep the two halves connected.
2. Place the grape on a dish, cut side up, and put it into the microwave.
3. When the oven is turned on, plasma will be emitted from the section of skin connecting the two halves.

A video of the grape plasma can also be found online[w4].

Image courtesy of Pixelmaniak / iStockphoto

Image courtesy of John Madden / iStockphoto

Soap sculpture

When microwaved on full power for about a minute, a bar of soap grows into a strange volcanic lava, or something that looks like horrible fungus. The deformation is caused by tiny pockets of water in the soap vaporising, or by air in the soap expanding as it heats up.

The soap sculpture may leave the microwave oven (and the classroom) smelling quite strongly, so try to find non-perfumed soap and avoid doing this in a microwave that is used to prepare food.

This demonstration has the added benefit that the teacher can leave the microwaved soap lying around the science preparation lab at school to worry colleagues, or the students can take it home to perturb members of their family.

This and other experiments can be found on the physics.org website[w5].

Eggy explosions

If demonstrations are good, explosions are unforgettable. My children will never let me forget the night my son's boiled egg had a rather runny white and I said, "a few seconds in the microwave will just finish it off nicely"! A hen's egg, even with the top cut off, will explode dramatically when heated in a microwave. You can try it in a lesson, but only if you're prepared to clean the inside of the microwave afterwards!

A US TV programme, Brainiac Science Abuse, has taken this experiment to the logical limit by microwav-

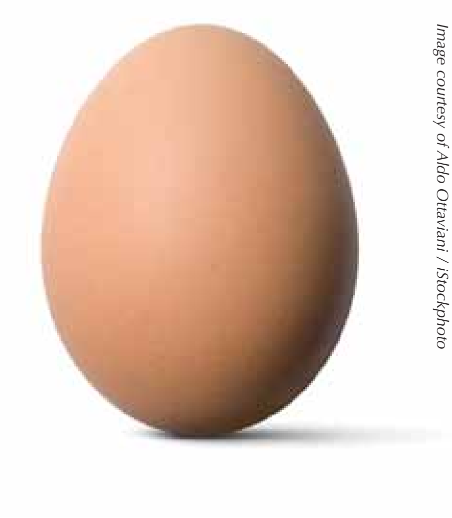

Image courtesy of Aldo Ottaviani / iStockphoto

ing an ostrich egg. This is probably not an experiment that you will want (or be able) to do yourself, but there are many versions of it on YouTube[w6]. I strongly suspect that the experiment was rigged in some way (they call it science *abuse*), but you could use the video to wake up any class.

Light bulbs

Another classic demonstration is to put a light bulb in a microwave oven. An incandescent light bulb (whether or not it is still functional) will light up when irradiated with microwaves, provided the glass is intact. Depending on the type of bulb, you can get different colours.

Image courtesy of Murat Giray kaya / iStockphoto

Remember that the bulb will heat up very quickly; 10 seconds is probably long enough before allowing it to cool down again.

Fluorescent tubes will also light up, and the effect can be used to test for microwave leakage around the doors of microwave ovens. Switch on the microwave and hold a fluorescent tube against the edges of the oven door. If the microwave leaks, it will make the bulb glow. (Switch off the lights in the room so that you can see the glow.) This works much better if the oven is empty, but if you're testing an older (pre-1980s) oven, you might want to include a glass of water. Note that this method only shows the larger leaks.

This and other facts, myths and experiments about or with microwaves are collected on William Beaty's website[w7].

Measure the speed of light with bread and margarine

The 'naked scientists' Chris Smith and Dave Ansell describe a very nice demonstration using standing waves to calculate the speed of light microwaves in their book *Crisp Packet Fireworks* and on their website[w8], where you will also find further microwave and other experiments.

Having been taught all about the really difficult historical experiments to measure the speed of light, students think it is great to use this easy method. The only drawback of this demonstration is a rather strong smell of toast. This experiment can also be used to reinforce the notion that all waves in the electromagnetic spectrum travel at the speed of light.

Materials

- A plate (and possibly a bowl)
- Four pieces of toast
- Margarine
- A buttering knife
- A ruler

Procedure

1. Remove the turntable from the microwave.
2. Arrange four pieces of toast in a square shape on a plate.
3. Cover them completely with margarine, making sure to include the joints where the pieces meet.
4. You need to ensure the plate won't turn when you switch on the microwave. If there is a central pillar supporting the turntable, you may cover it with a bowl turned upside down and balance the plate on top of it.
5. Switch on the microwave at full power for 15 – 20 seconds until the margarine just begins to melt. Powerful microwaves may need less time, so check every 5 seconds. Be very careful not to microwave for too long.
6. You should see a series of parallel melted patches or lines separated by unmelted patches. Take out the plate.
7. Measure the distance in centimetres between two of these patches with a ruler. Multiply by two and note down the value: this is the wavelength of the microwaves produced by your oven – it should be around 12–12.5 cm.
8. Now you need to find out the frequency of the microwaves. You should be able to find it on a sticker, usually at the back or door lip of the microwave. If you can't find the specific value of your microwave, use 2450 MHz (2.45 GHz) as a standard value.
9. Multiply the wavelength (about 12 cm) by the frequency. If you are using MHz, you'll need to multiply the result by one million, with GHz by one billion.
10. The result will be the speed of light in centimetres per second. Divide it by 100 to convert it to metres per second. Your answer should be about 300 million metres per second.

Light, including microwaves, is a wave consisting of a series of peaks and troughs. The wavelength is the distance from one peak or trough to the next. The frequency is the number of waves per second. To know how fast a wave is travelling, you need both values.

A microwave oven produces waves on one side of the oven, which are reflected on the opposite side and return to where they started. The reflected waves will encounter the original waves, cancelling each other out in some places, while adding up in others: the waves bouncing about in the oven interfere with each other, creating a standing wave with positions of high amplitude (antinodes) where there will be strong heating, and positions where the amplitude is close to zero (nodes) where there will be little heating. The distance between two hot spots is half a wavelength – the distance from one antinode to the next. In these hot spots, the margarine will melt first.

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Smith C, Ansell D (2008) *Crisp Packet Fireworks*. London, UK: New Holland Publishers

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w1 – To learn more about plasma, see:

The Internet Plasma Physics Education Experience website: http://ippex.pppl.gov/fusion/fusion3.htm

The glossary on the Southwest Research Institute website: http://pluto.space.swri.edu/image/glossary/plasma.html

The Fusion Energy Division of the Oak Ridge National Laboratory: www.ornl.gov/sci/fed/Theory/tt/ttmcp/plasma.htm

The FusEdWeb (fusion energy education) website: http://fusedweb.llnl.gov/cpep/Chart_Pages/5.Plasma4StateMatter.html

w2 – The Exploscience website has many videos of dramatic experiments: www.exploscience.com/ChemTV_Page_5.html

w3 – Chris Schrempp's e-book, *Bangs, Flashes, and Explosions – An Illustrated Guide of Chemistry Demonstrations*, a manual with over 170 chemistry demonstrations and activities, can be ordered here: http://exploscience.com/Book.html

w4 – The grape plasma can also be seen on the Naked Scientists website (www.thenakedscientists.com) or here: http://tinyurl.com/mklx73

w5 – The physics.org website has many fun experiments and games: www.physics.org/interact-wide-template.asp

w6 – For a dramatic demonstration of microwaving an ostrich egg, see: www.youtube.com/watch?v=Wgy1Yhgk_BY

w7 – William Beaty's 'Unwise microwave oven experiments: high voltage in the kitchen' website contains facts, myths and experiments about or with microwaves: http://amasci.com/weird/microwave/voltage3.html

w8 – You can find the margarine experiment, and much more, on the Naked Scientists website (www.thenakedscientists.com) or here: http://tinyurl.com/lhdk7r

Resources

The UK's Institute of Physics describes a number of experiments involving microwaves on its website: www.iop.org/activity/education/Projects

Mobile phones transmit and receive using microwave radiation – either 900 MHz or 1800 MHz – similar to the frequency of the radiation in a microwave oven (2450 MHz). The UK's Science Enhancement Programme has some very useful documents on radiation in the environment, including background information and student activities. See: www.sep.org.uk/teacher/view_resource.asp?resource_id=20

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Image courtesy of Slobo Mitic/ iStockphoto

Looking to the heavens: climate change experiments

In the second of two articles, **Dudley Shallcross**, **Tim Harrison**, **Steve Henshaw** and **Linda Sellou** offer chemistry and physics experiments to harness the Sun's energy and measure carbon dioxide levels.

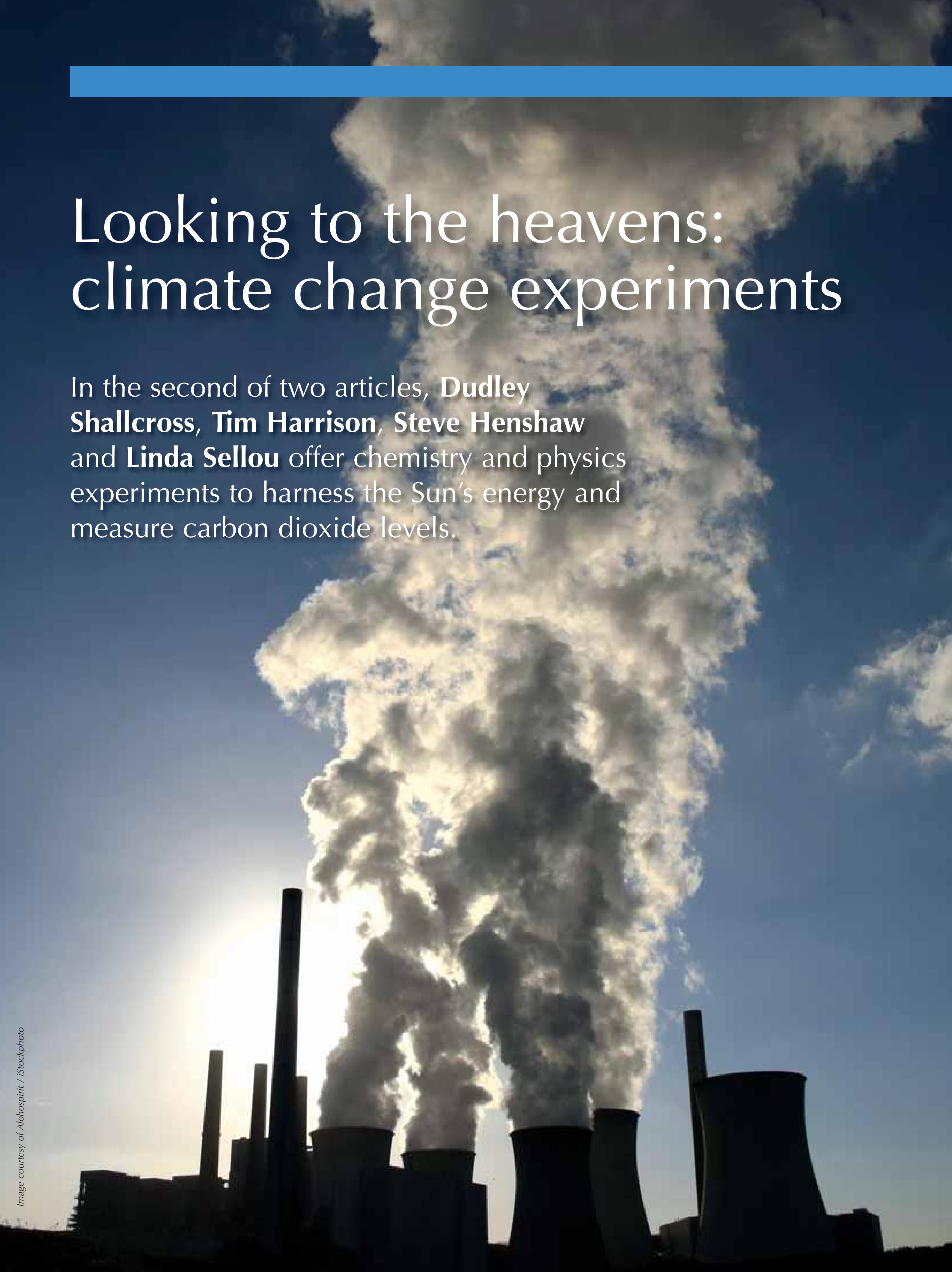


Image courtesy of Alohospirit / iStockphoto

Discussions of climate change in the science classroom can be very wide-ranging, but different sources of energy and their consequences will probably have a role. The topics raised are likely to include different fuels that can be used, how effective they are and how they are produced; alternatives to combustion; solar energy; and the importance of carbon dioxide in global warming. Below, we suggest two laboratory activities to support physics and chemistry lessons on climate change. Three activities relating to fuels were published in Shallcross et al (2009).

1) Grätzel cells: energy from sunlight

The Sun, of course, is the source of all energy on Earth – including that released from fossil fuels or modern 'green' fuels. But sunlight can also be used directly as a source of energy, as can be demonstrated in the classroom using Grätzel cells, also called 'nanocrystalline dye solar cells' or 'organic solar cells'. Named after their inventor, the Swiss engineer Michael Grätzel, Grätzel cells convert sunlight directly into electricity by artificial photosynthesis using natural dyes found, for example, in cherries, blackberries, raspberries and blackcurrants. These purple-red dyes, known as anthocyanins[w1], are very easy for school students to extract from fruits and leaves by simply boiling them in a small volume of water and filtering.

These cells are very promising because they are made of low-cost materials and do not need elaborate apparatus to manufacture. Although their conversion efficiency is less than that of the best thin-film cells, their price/performance ratio (kWh/M2/annum) is high enough to allow them to compete with electricity generation from fossil fuels. Commercial applications, which were held up due to chemical stability problems, are now forecast in the European Union Photovoltaic Roadmap[w2] to be a potentially significant contributor to renewable electricity generation by 2020.

Grätzel cells separate the two functions provided by silicon in a traditional cell design: normally, the silicon acts as the source of photoelectrons, as well as providing the electric field to separate the charges and create a current. In the Grätzel cell, the bulk of the semiconductor is used solely for charge transport, while the photoelectrons are provided from a separate photosensitive dye (the anthocyanin). Charge separation occurs at the surfaces between the dye, semiconductor and electrolyte.

The dye molecules are quite small (at the nanometre scale), so to capture a reasonable amount of the incoming light, the layer of dye molecules needs to be fairly thick – much thicker than the molecules themselves. To address this problem, a nanomaterial is used as a scaffold to hold large numbers of the dye molecules in a 3D matrix, increasing the number of molecules for any given surface area of the cell. In existing designs, this scaffolding is provided by the semiconductor material (titanium oxide), which serves double duty.

Grätzel cells can be made from scratch, but getting hold of the pre-treated glass that makes one side conductible is not easy. Moreover, baking the titanium dioxide paste into the glass surface requires the use of a furnace for about 24 hours. Therefore, it is easier to use commercial kits, such as those available from the Dutch company Mansolar[w3], which allow six Grätzel cells to be assembled per set, costing approximately 80 Euros. If you already have some experience using the required equipment and prefer to build your own Grätzel cells, however, you will find an outline of the required steps below:

1. Take two glass plates, each about the size of a microscope slide, one side of which has been treated with indium tin oxide to render it electroconductible.
2. One plate needs to have titanium dioxide baked onto its uncoated side. The titanium dioxide forms a highly porous structure with a very high surface area, to which the dye can bind. A word of caution: it is very easy to scratch the titanium dioxide powder off the glass plate, and whilst you can purchase titanium dioxide paste, it is inconvenient to bake the plates for a considerable time with a new coating in a furnace. Storage is therefore a consideration. The easiest solution is to purchase the materials ready-made.
3. Cover the other plate with a layer of pencil graphite by simply rubbing a pencil over the uncoated surface of the glass.
4. Fill a Petri dish with anthocyanin dye. Soak the photosensitive anthocyanin dye onto the titanium dioxide by placing the corresponding plate in the Petri dish, then dry with a hair drier. The dye is left covalently bonded to the surface of the titanium dioxide. After use, it is easy to remove the old anthocyanin pigments using ethanol or propanone (acetone).
5. Assemble the cell as follows from bottom to top:
   - At the bottom will be the graphite plate, graphite side up, serving as a cathode.
   - Use a solution of iodine dissolved in potassium iodide as an electrolyte and squirt between the plates.
   - On top will be the dye-coated titanium dioxide plate, indium tin oxide side up. The indium tin oxide will serve as transparent anode.
6. Use a paper clip to keep the plates together.
7. Use two crocodile clips to clip the overlapping pieces of glass (top and bottom, see image on next page) of the Grätzel cell and

connect with two electrical leads to a multimeter to take readings.
8. Shine light onto the cell. If investigating this apparatus in northern Europe during the winter months, a microscope lamp or a desk lamp will be useful to provide the light.
9. Use a light meter to determine the light intensity falling on the Grätzel cells.

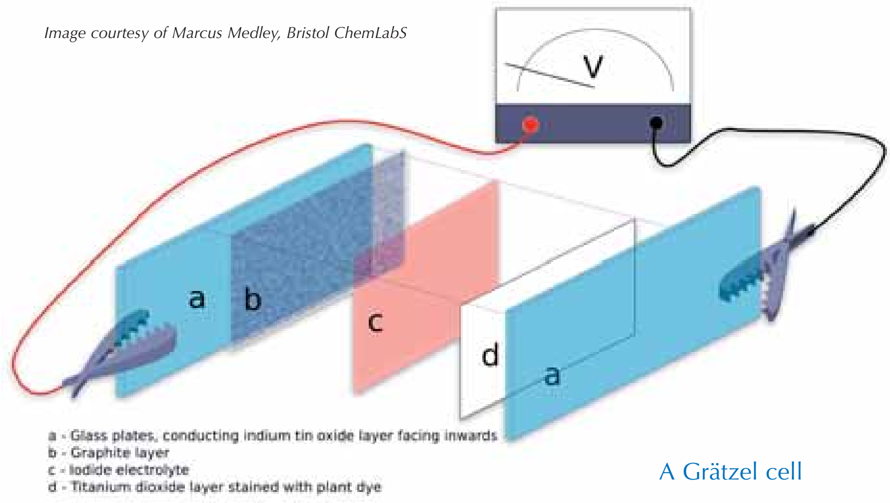
For amusement, the Grätzel cells can be used to power different mechanisms. For example, you can replace the batteries in a calculator with leads that allow several small Grätzel cells in series to power it. Alternatively, you can also power the music circuits from birthday greetings cards or small motors with the cells.

Students may carry out a number of investigations with these cells. These include how the current or voltage produced varies with:

- Anthocyanins from different sources
- Plant pigments other than anthocyanins
- The concentration of the anthocyanin solution used
- The area of the titanium dioxide layer exposed to anthocyanins
- The temperature of the cells
- The frequency of light (using coloured filters)
- Light intensity (using a microscope lamp as a light source)
- Several cells in series or in parallel.

Details on the chemistry behind these cells can be found in an online article[w4].

Image courtesy of Marcus Medley, Bristol ChemLabS

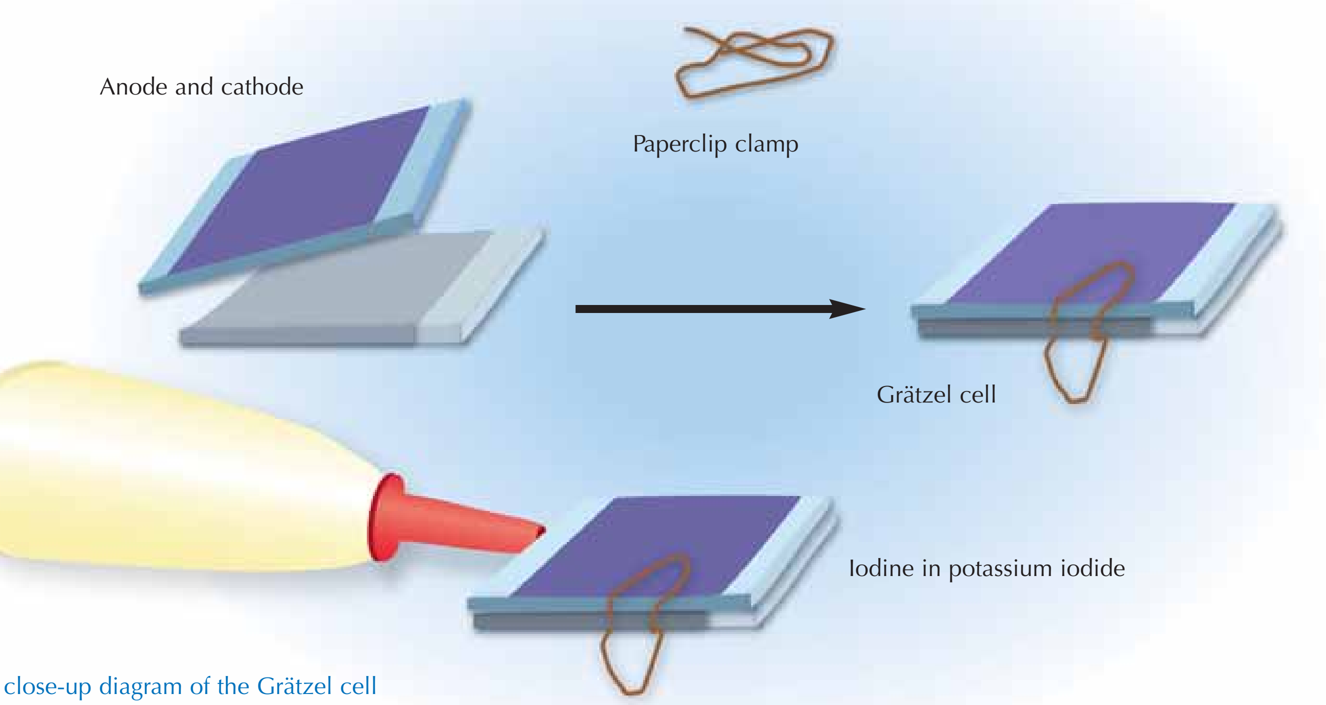


A Grätzel cell

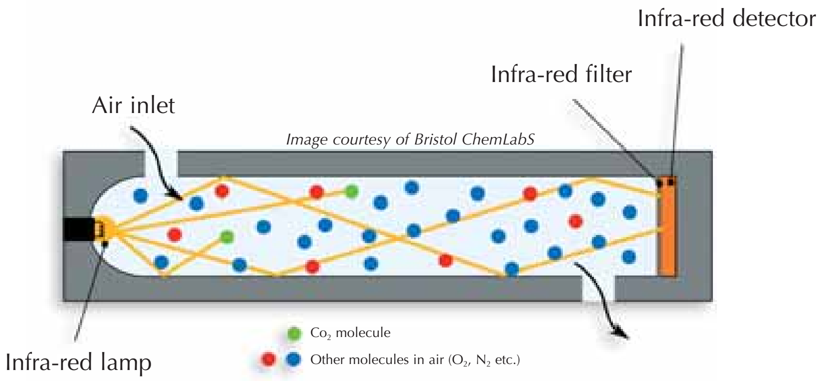
2) Detecting atmospheric carbon dioxide levels

CO_2 is the most commonly known greenhouse gas and one of the major concerns in discussions of climate change. One might well ask how levels of CO_2 are measured in air samples, particularly as their concentrations are

Image courtesy of Nicola Graf



A close-up diagram of the Grätzel cell



A diagram of an absorption cell from a CO_2 sensor

Image courtesy of Bristol ChemLabS

A close-up of a carbon dioxide sensor

so low: the answer is infra-red spectroscopy. Carbon dioxide molecules absorb specific frequencies of infra-red radiation, which affect the covalent bonds between the carbon and oxygen atoms, depending on the energy. Low energies cause a bond-bending motion, and high energies cause bond stretching. The frequencies at which this occurs are within the infra-red part of the electromagnetic spectrum (between 4000 and 650 wavenumbers). A wavenumber is the reciprocal of wavelength and is a unit commonly used in infra-red spectroscopy. This effect can be used to determine the CO_2 concentration as follows.

There are two main types of carbon dioxide sensor (see Harrison et al, 2006). The more expensive research sensors pump air through the sensor, whereas the cheaper devices rely on the diffusion of air. Air passes into an absorption cell, which is effectively a small darkened cylinder within the sensor. At one end of the absorption cell, there is an infra-red light source coupled to a fixed wavelength filter, so as to provide a narrow band source of infra-red light around 2350 cm^{-1} (wavenumbers). At the other end of the tube, there is an infra-red detector or photon counter that measures the infra-red light intensity. The more CO_2 molecules in the air sample, the more infra-red radiation is absorbed in the cell, and the less infra-red radiation reaches the detector. For small absorptions, the Beer-Lambert law tells us that

$$\text{Concentration} = (l-(I/I_0))\ /\sigma 1$$

where:

- l is the path length (length of the cell)
- σ is the absorption cross-section for CO_2 at the wavelength being used and is known to a high accuracy
- (I/I_0) is the ratio of infra-red radiation arriving at the detector when the cell is empty (I_0) to when it has an air sample in it (I)

I_0 is not measured for each reading, but will be measured frequently to check that there are no appreciable fluctuations in the instrument's infra-red light intensity.

Students who have used such sensors, on loan from the University of Bristol, have been surprised that the measured CO_2 level inside an empty classroom is much greater than that outside, well above 0.037% (0.037/100 x 1 x 10^6 = 370 ppm) reported for the CO_2 atmospheric concentration in some textbooks. New school buildings in the UK appear to have windows that are not designed to be opened, so the exhaled CO_2 accumulates!

The CO_2 sensors that we use with students are tuned to the CO_2 ν_3 asymmetric bond stretch at 2349 wavenumbers (Harrison et al, 2006). An asymmetric stretch is where the double bonds between carbon and oxygen (C=O) absorb energy, and one of the two bonds lengthens while the other one contracts (see diagram on page 38). For CO_2 there can only be one asymmetric stretch. This particular bond stretch is important because carbon dioxide is the only molecule present in high quantities in the atmosphere to absorb at 2349 wavenumbers. Therefore, only absorption by CO_2 can cause a change in infra-red light intensity at this wavelength.

Bristol ChemLabS would be interested to hear from schools across Europe that would like to borrow one of these easy-to-use meters for research into the carbon dioxide concentration of air samples. Although the instruments are commercially available, they are quite expensive and thus not commonly available in schools or colleges.

References

Harrison T, Shallcross D, Henshaw S (2006) Detecting CO2 – the hunt for greenhouse-gas emissions. *Chemistry Review* **15**: 27-30

Shallcross D, Harrison T (2008a) Climate change modelling in the classroom. *Science in School* **9**: 28-33.

Bond bending and stretching

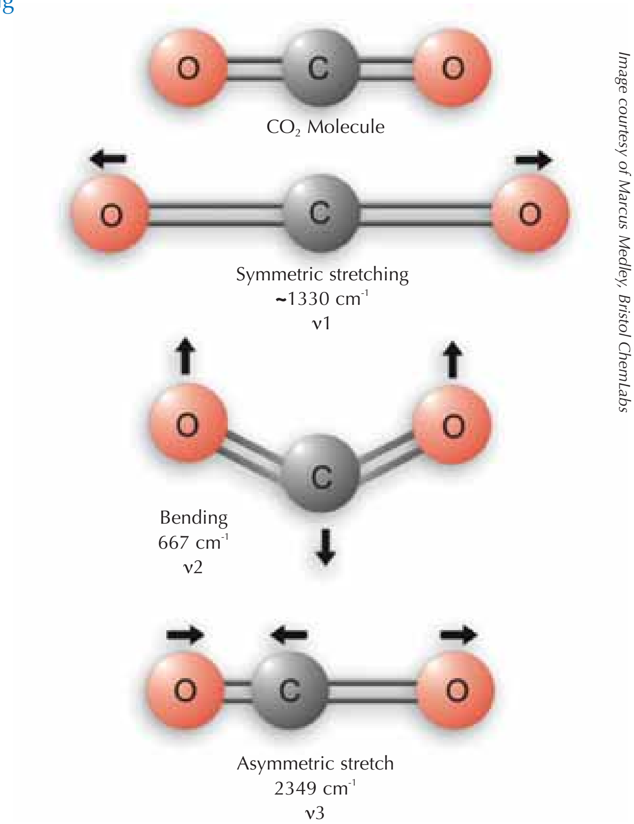


Image courtesy of Marcus Medley, Bristol ChemLabs

www.scienceinschool.org/2008/issue9/climate

Shallcross D, Harrison T (2008b) Practical demonstrations to augment climate change lessons. *Science in School* **10**: 46-50. www.scienceinschool.org/2008/issue10/climate

Shallcross D, Harrison T, Henshaw S, Sellou L (2009) Fuelling interest: climate change experiments. *Science in School* **11**: 38-43. www.scienceinschool.org/2009/issue11/climate

Web references

w1 – For more information on anthocyanins and their natural functions, see Wikipedia: http://en.wikipedia.org/wiki/Anthocyanin

w2 – The 2002 European Union Photovoltaic Roadmap can be downloaded from the PV-NET website (http://paris.fe.uni-lj.si/pvnet) or here: http://tinyurl.com/n8cwfv

REVIEW

The article is a good complement to the previous trilogy of climate change articles by the same authors, on modelling climate (Shallcross et al, 2008a) and classroom experiments (Shallcross et al, 2008b, 2009). This time, the authors highlight the technological side of the climate change issue. They propose a hands-on activity as a possible alternative to conventional solar cells and an investigation of the CO_2 content in different environments using professional equipment that they offer to lend to schools.

I recommend this set of articles to secondary-school science teachers looking for a full set of didactical materials to address the complex topic of climate change, global warming and energy resources. The style is plain enough for non-native English speakers, and the web references allow further learning on the subject. The article is also a valuable starting point for planning a stimulating interdisciplinary science curriculum.

Possible comprehension questions include:

Which of the following statements about anthocyanins is true?
a) they can perform artificial photosynthesis
b) they perform photosynthesis in plants
c) they are used in thin-film cells
d) they are chemically stable

Which of the following statements about titanium dioxide is false?
a) it acts as a semiconductor
b) it provides a 3D scaffold for the dye molecules
c) it has to be baked on the glass surface
d) it is electro-conductible

Carbon dioxide sensors can measure
a) the greenhouse effect
b) infra-red light absorption
c) air pollution
d) UV light absorption

Giulia Realdon, Italy

w3 – A supplier for Grätzel cell kits is the Dutch company Mansolar: www.mansolar.com

w4 – To find out more about the chemistry behind Grätzel cells, see the Royal Sciociety of Chemistry website (www.rsc.org) or here: www.tinyurl.com/mr3bec

Resources

For a full list of *Science in School* articles about climate change, see: www.scienceinschool.org/climatechange

For a full list of *Science in School* articles about energy, see: www.scienceinschool.org/energy

SchoolCO2Web offers information and teaching material for measuring and sharing carbon dioxide data across schools in Europe: http://fwn-school-co2-net.hosting.rug.nl

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Dudley Shallcross is a professor in atmospheric chemistry, Tim Harrison is a school teacher fellow, and Linda Sellou and Steve Henshaw are both postdoctoral teaching assistants at the School of Chemistry, University of Bristol, UK. The school teacher fellowship is a position for a secondary-school teacher that was created to bridge the gap between secondary schools and universities, and to use the resources of the School of Chemistry to promote chemistry regionally, nationally and internationally. For more information about modelling climate change or about the post of school teacher fellow, please contact Dudley Shallcross (d.e.shallcross@bristol.ac.uk) or Tim Harrison (t.g.harrison@bristol.ac.uk).

Physics: a black box?

L'udmila Onderová from PJ Šafárik University, Košice, Slovakia, introduces us to the use of black boxes in the physics classroom.

Images courtesy of L'udmila Onderová

Figure 1. Materials required for the black box

Figure 2. Construction of the black box

Figure 3. The finished black box

The idea behind using a black box in the classroom is for students to try to figure out its contents – prepared in advance by the teacher – without opening it. Once they have experimentally determined what is inside, the students can open the box to verify their hypothesis. An example of how to use black boxes to teach electric circuits, suitable for students aged 15-18, is described below. However, there are many possible uses for black boxes in the classroom, also for younger students and in other areas of physics[w1].

I've had good experiences using this method both in the classroom and in the education of future physics teachers. Many teachers don't seem to be familiar with it, yet it is actually very similar to problems you have to solve in real life. Besides, the experiment fosters the creativity of students, and black boxes are cheap and easy to build.

Building the black box

Materials

- A plastic pill tube (e.g. from effervescent vitamin C)
- A drill
- Two banana jacks (e.g. the plugs on the cables connecting the amplifier to the loudspeakers in a hi-fi sound system)
- Electronic components (e.g. resistors, capacitors, diodes, etc.) to fit inside the tube
- Flexible line wires

Procedure

- Drill a hole into each end of the tube.
- Push the banana jacks through the holes.
- Connect the electronic component(s) to the jacks using the wires (see Figure 2).
- Fit it all inside the tube, and close it.

A removable tube top and flexible wires make it easy to reveal the components and the circuit inside the black box. You should make sure that the connection of elements inside the box is simple and easy to detect for the students. The outside appearance of the box is up to you; I wrap the tubes with a sheet of black paper.

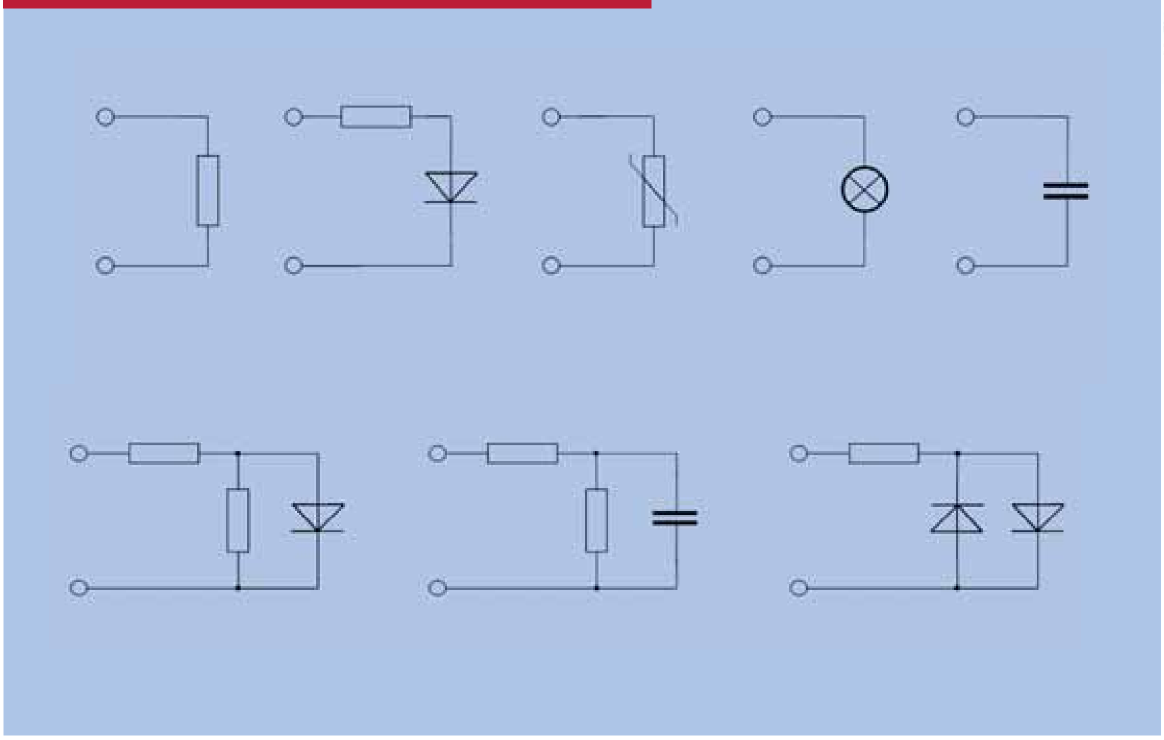
You can create black boxes of different complexity – some of them enclosing only one electronic component (resistor, capacitor, diode, coil, etc.), others containing several components connected to form simple circuits (see Figure 4).

Experiments with black boxes

Once students have been introduced to the basics of DC and AC electric circuits, they can start experimenting with black boxes to apply what they have learned to the solution of a practical problem. They are given materials (listed below) to be used for determin-

Figure 4. Electrical circuits contained in the black boxes

Image courtesy of L'udmila Onderová



ing the individual elements contained in a black box. They are informed in advance about all possible internal configurations of the boxes. In the first stage, each group of students receives five black boxes containing only one electronic element per box. In the next stage (not necessarily in the same lesson), they receive eight black boxes with either a simple or more complex configuration inside each one. Their task is to find out the contents using their experience and an algorithm they develop for analysis of the boxes.

Materials per group

- Five numbered black boxes containing individual electronic elements (resistor, coil, capacitor, diode, insulator)
- Eight numbered black boxes containing both simple and more complex circuits (see Figure 4)
- Leads
- An ampere-meter
- A voltmeter
- A source of DC and AC voltage
- A sketch of all possible internal configurations.

Procedure

1. Divide the students into groups of 2-3 students.
2. Hand out all materials.
3. Students have 30 minutes to measure the five simple boxes and determine their contents.
4. Each group reports their results.
5. Compare the results, and verify by opening the black boxes.
6. If the hypothesis was wrong, determine where the mistake comes from. In my experience, students have a success rate of about 80%. They usually have trouble distinguishing a coil from a resistor, as they are usually satisfied with finding that a box conducts electric current and don't analyse its value.
7. Try to set up an optimum algorithm to determine the elements in the box. This is what a possible algorithm could look like:
   a) Set up an electric circuit consisting of a black box, a voltage source, an ampere-meter and a voltmeter.
   b) Use a DC voltage source, connect the circuit, measure the current and the voltage, and write down the results.
   c) Change the polarity of the DC voltage source, measure the current and the voltage again, write down the results and compare them with the previous ones.
   d) Use an AC voltage source, measure the current and the voltage and compare the results with the two previous measurements.
   e) Propose a hypothesis about the structure of the black box.
   f) Verify the hypothesis by additional measurements.
   g) Determine the contents of the black box.
8. Next, students have 40 minutes to determine the contents of the eight simple and complex boxes.
9. Repeat the evaluation as before. In my experience, students find this task more difficult, and not all groups are able to determine the contents of all boxes in the given time. The success rate is also lower, at about 70%. This is still a very good result, though, and would probably not be achieved if individual students were trying to solve the task, rather than groups.

In the second test, students tend to have problems not with determining simple elements, but with determining more complex circuits and distinguishing between a resistor, a thermistor and a bulb. They have to apply their theoretical knowledge and need to realise that it is necessary to change the voltage and, eventually, to draw a diagram to be able to determine the elements in the boxes correctly.

What value do students get from these experiments?

Manipulating black boxes is an attractive task for students to test their knowledge and enjoy their success. Some even try to find further opportunities to use this method in physics teaching themselves. Most importantly, students learn to use a systematic method of investigation. The black box experiment encourages students to ask and answer their own questions, express their predictions, test their hypotheses and communicate the results to their peers. Such an active method also helps to better understand the nature of science. In addition, this is also a good way to solve problems in real life, for example if you need to work out how a device (black box) works when you have lost the user manual.

A critical point in setting the task is the amount of information given on the possible structure of the box's contents. The teacher needs to ensure that the students have sufficient previous knowledge and to give clear instructions on how to proceed. Fewer instructions provoke more creative thinking, but if not enough information is provided, students may feel overburdened by the task and lose interest.

REVIEW

This is an interesting activity to be performed with secondary-school students. It is useful to practise a range of concepts in physics in a didactic way.

Amador Menéndez Velázquez, Spain

Web references

w1 – For further examples of using black boxes in physics teaching, see:

The optical black box on the Science Olympics website:
www.physics.uwo.ca/science_

olympics/events/grades_9_to_10/optical_black_box.html

The black box mystery on the Science Olympics website: www.physics.uwo.ca/science_olympics/events/grades_9_to_10/black_box_mystery.html

Two black box experiments (IphO 2004 experimental question problem and IphO 2002 experimental question 2 problem) on the International Physics Olympiads website www.jyu.fi/ipho

'Archimedes: A Black Box Mechanics Laboratory' on the website of Colgate University, USA: http://departments.colgate.edu/physics/research/PhysicsEd/labs.htm

Resources

For further examples of using investigative methods in the science classroom, see:

Tifi A, Natale N, Lombardi A (2006) Scientists at play: teaching science process skills. *Science in School* **1**: 37-40. www.scienceinschool.org/2006/issue1/play

Tifi A, Natale N, Lombardi A (2006) Scientists at play: contraptions for developing science process skills. *Science in School* **2**: 20-23. www.scienceinschool.org/2006/issue2/play

Further reading on the use of black boxes in the classroom:

Amato JC, Williams RE, Helm H (1995) A "black box" moment of inertia apparatus. *American Journal of Physics* **63**: 891-894

Barney DM (1955) A "black box" laboratory assignment. *American Journal of Physics* **23**: 546

Burling RL (1957) Black boxes in the instructional laboratory. *American Journal of Physics* **25**: 492

Singh VA, Khaperde RB (2005) The mechanical black box: a challenge from the 35th International Physics Olympiad. *Resonance*, **10(4):** 75-82. www.ias.ac.in/resonance/Apr2005/pdf/Apr2005Classroom2.pdf

Terry C (1995) Black-box electrical circuits. *Physics Teacher* **33**: 386-387

Ľudmila Onderová works at the Institute of Physics, Faculty of Science, at the PJ Šafárik University in Košice, Slovakia, and is responsible for the education of aspiring school physics teachers. Her main interests are hands-on experiments and activities dedicated to developing creativity and process skills in students.

Fishing for genes: DNA microarrays in the classroom

Anastasios Koutsos, Alexandra Manaia, and **Julia Willingale-Theune** bring a sophisticated molecular biology technique into the classroom

Fishing for genes one step at a time: a short story

Once upon a time in a small village, there was a man. Every day he went to a pond to catch fish for his dinner. One day it would be a catfish, the next day an eel — sometimes it would be a different fish each day of the week. Then one day he wondered how many different species of fish there were in the pond, and how many of each species. How could he find out? It was obvious that catching one fish at a time wouldn't work — for all he knew the pond might contain thousands of fish. So he browsed the Internet for ideas and found a book listing 20 000 species of freshwater fish, with the bait used to catch them.

Eventually, he thought of a complex but clever solution: he cast 20 000 fishing lines, each with an array of hooks, into the pond. Using the information from his reference book on fish, he attached a particular type of bait to the hooks on each line to attract a particular species of fish, and in this way created different lines to catch all fish species. The rest was easy: he waited for the fish to find their bait and collected his catch.

[Note – this is a fictitious story: about 9000 species of freshwater fish are known today, and there is not a different bait for each one.]

A scanned microarray

Image courtesy of EMBL Photolab

Monitoring gene expression: the analytical power of DNA microarrays

Now that the draft sequence of the human genome has been published (along with the genome sequences of many other organisms), the challenge is to work out what the individual genes do, and to do so, scientists are designing sophisticated tools. One such tool is the DNA microarray.

Our story of the fisherman is fictitious, but the principles used by the man to find out how many fish there were in the pond are very similar to the principles underlying DNA microarray technology – a technology that has revolutionised the way scientists look at living processes.

Until the 1990s, biologists could measure the activity of only a handful of genes in a cell at any given time. A gene is active when it is being transcribed to its messenger molecule, mRNA, which in turn is used to make one or several proteins.

Frustrated that they could not look at the expression of genes in concert in a single cell, scientists began to search for ways to simultaneously measure the activity of all genes in a cell. To do this, they needed to find out how many different mRNAs were present in a cell at any given time, and which genes those mRNAs corresponded to. It was this revolutionary idea that culminated in the development of DNA microarrays. Those scientists created something similar to the 20 000 fishing lines in our story. They took a piece of treated glass similar to a microscope slide and immobilised batches of single strands of DNA on its surface, each batch corresponding to a single gene. These DNA strands could then act as bait to attract the corresponding mRNA molecules belonging to the gene, just like the specific bait attracted a particular type of fish. When viewed with the naked eye, those groups of DNA strands look like small dots. Each glass slide is printed with thousands of dots arranged in an array, making up a DNA microarray.

Microarray experiments can take a lot of time. Scientists need to prepare the slides in advance and then analyse the information from thousands of spots. The analysis requires expertise in mathematics and advanced statistics, and can take months. To illustrate the underlying concepts of this technology in the classroom, you need to go virtual.

The real and virtual microarray experiment step-by-step

The virtual microarray[w1], developed by the European Learning Laboratory for the Life Sciences (ELLS)[w2] at the European Molecular Biology Laboratory[w3], is an educational activity that uses everyday materials to simulate a microarray experiment in the classroom. The game simulates the different steps that researchers take in performing microarray experiments and in analysing the results. The activity is aimed at 16- to 18-year-olds and can be used to complement lessons on genetics, cell development and genetic diseases.

The following step-by-step guide describes how a real microarray experiment is performed, alongside the steps of the virtual microarray. In this activity, the virtual microarray will be used to detect differences in gene expression between a normal cell and a cancerous cell. You can download technical information and suggestions on how to perform the virtual microarray experiment in the classroom from the ELLS TeachingBase ('In the classroom' PDF)[w1].

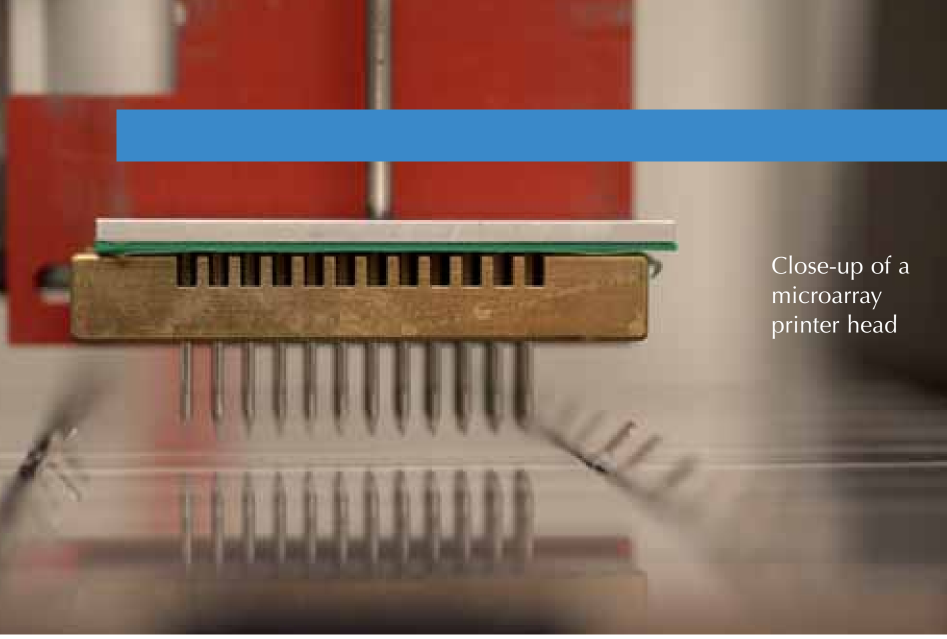
If prepared in advance, the basic exercise takes about one hour. The discussion exercises could be used in class or set for homework.

Materials

- A mat large enough to accommodate 10 circles (35 cm in diameter) that represent the DNA spots
- 5 red, 5 green and 5 yellow circles, 35 cm in diameter, made of coloured plastic or paper.

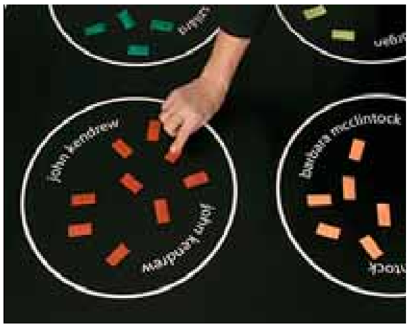
Gene name (circles)	Gene colour	Total mRNA amount for this gene (number of Velcro strips)	Amount of mRNA in normal cell (green torches)	Amount of mRNA in cancerous cell (red torches)
alexander fleming		3	0	3
barbara mcclintock		7	1	6
francis crick		18	9	9
jacques monod		4	4	0
james watson		0	0	0
john kendrew		3	2	1
leo szilard		12	9	3
maurice wilkins		6	3	3
rosalind franklin		2	1	1
thomas morgan		12	4	8

Table 1: The names and colours of the genes and the amount of mRNA that is used for each gene

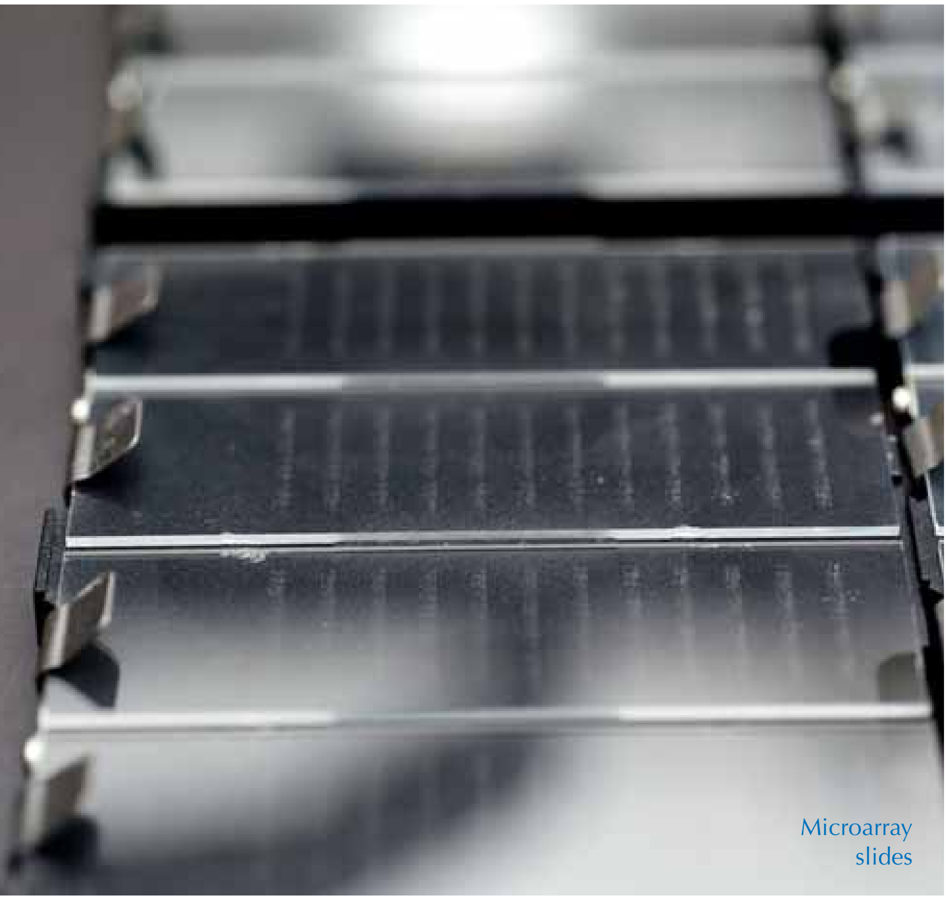


Close-up of a microarray printer head

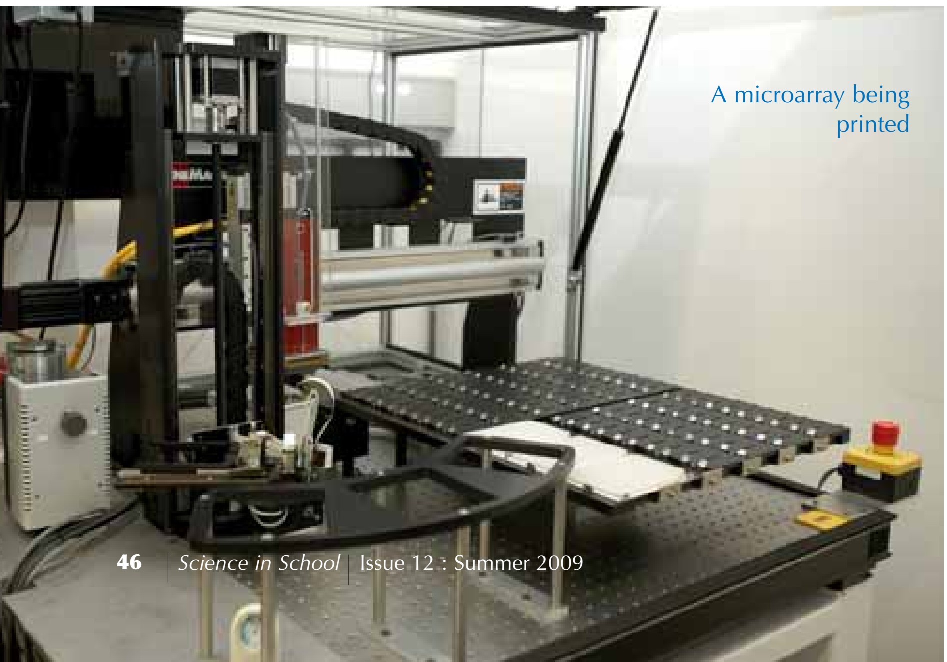
Images courtesy of EMBL Photolab



Manufacturing



Microarray slides



A microarray being printed

- A pen/marker to draw the circles and label them
- Velcro in different colours (a colour for each gene), which you can make yourself by colouring white Velcro with felt-tip pens
- 33 green and 34 red torches, plus a few extra. We use small "promotional flashlights" that can be purchased relatively cheaply. However, students can also bring their own torches and cover them with red or green paper. You might have to stand the torch in a small mug or pencil holder to ensure the light is emitted from the floor to the ceiling. For variants using smaller numbers of torches, see the ELLS TeachingBase ('In the classroom' PDF)[w1].
- 2 boxes to hold about 35 torches each
- Printouts of Table 1 (available for download[w4])

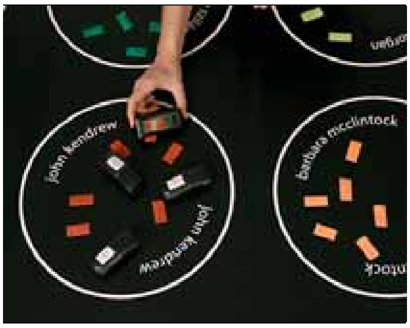
Use a room or classroom that can be darkened (with curtains or blinds).

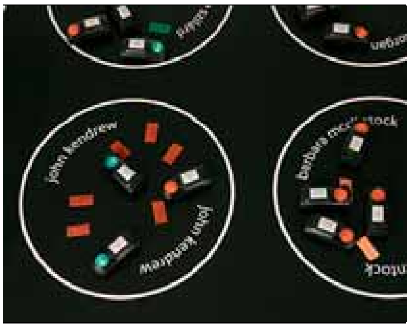
Manufacturing

Real

DNA microarrays are printed onto small glass slides, similar to microscope slides. Placing minute spots on this glass surface by hand is tricky, so scientists have developed special printing robots. Their printer heads have special pins that carry an aqueous solution of DNA from reservoirs and print it onto the glass surface in a grid of small spots. By controlling those robots, you can control all the

Images courtesy of EMBL Photolab





Hybridisation

Scanning

features of the array: the number, size of and distance between the spots. As many as 20 000 spots can be printed onto a slide, and each spot contains billions of copies of DNA for a specific gene[w4].

Virtual

1. Draw 10 circles of about 35 cm in diameter on the mat to represent the DNA spots.
2. Label each circle according to Table 1 to represent a gene named after a famous scientist.
3. According to the second column in Table 1, stick at least the corresponding number of Velcro strips (the soft, loop side only) of the same colour in each circle (if there are more strips than needed, it doesn't matter). The Velcro pieces correspond to the DNA strands and each colour represents DNA from one gene. Note down the colour in the table.

mRNA extraction

Real

In a microarray experiment, the first step is to extract mRNA from cells of the two conditions under study, such as normal and cancerous liver tissue. mRNA is extracted by a standard lab procedure and then labelled with a fluorescent dye: for example, green for the normal cells, and red for the cancerous ones.

Virtual

1. The fluorescently labelled mRNA molecules are represented by small torches. Each torch corresponds to a single chain of mRNA from a particular gene. Green torches represent mRNA extracted from a normal cell; red torches represent mRNA extracted from a cancerous cell.
2. According to Table 1, stick coloured Velcro (hook side) on the underside of the corresponding number of green and red torches, using one colour of Velcro per gene.
3. Label a few extra torches either with multicoloured pieces of Velcro or Velcro in a colour that is not represented in the virtual array. These will represent mRNA molecules that bind only weakly or not at all to the DNA on the mat, i.e. the 10 genes.
4. Place all green torches in one box (normal cell) and all red ones in another (cancerous cell).

Hybridisation

Real

In the hybridisation step, control (green) and test (red) mRNAs are mixed together, and the mRNA molecules are flooded over the surface of the microarray to bind to their complementary, immobilised DNA strands. mRNA molecules with a sequence that is not complementary to any of the genes will not bind. Those with a sequence partially similar to DNA strands from one gene will bind weakly (non-specific hybridisation). These molecules will be removed by a subsequent washing step.

Virtual

1. Extract the torches (mRNA molecules) from the boxes (cells), look at the colour of the Velcro tape and match it to the colour of the Velcro on the array (the mat).
2. Some mRNA molecules have colours that do not match any of the genes, and some have multicoloured tape that matches weakly to some genes.
3. Remove the unbound and weakly bound torches from the array by performing a virtual washing step.

Scanning

Real

Now it is time to look at the results of the experiment to see which mRNA has hybridised with which gene. Because mRNA molecules are not visible to the naked eye, scientists can only estimate the amount of hybridised mRNA indirectly, by measuring the fluorescence of each

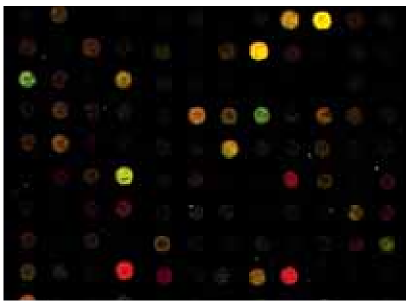


Image courtesy of EMBL Photolab

A scanned microarray (detail)

Image courtesy of EMBL Photolab

spot. Using a special laser scanner, red and green fluorescence is detected independently and two images are produced. Putting these two images together results in a characteristic picture with coloured spots (see image on page 47). A red spot indicates that the gene is active in the cancerous cell, and a green spot indicates that the gene is active in the normal cell. A yellow spot indicates that the gene is equally active in both cells types.

Virtual

1. Switch on the torches and darken the room.
2. Ask the students to describe what they see for each gene. How many green and red torches does each gene have? In other words, is the mRNA expression different in the normal and cancerous cell for different genes (i.e. if there are the same number of red and green torches in each circle, the expression is unchanged)? Encourage the students to draw their own conclusions.
3. Explain to the students that the red, green and yellow signals of the real microarray depend on the amount of mRNA from those two cells. *Note*: for light, red and green mixed together give yellow. For pigments, red and green produce purple.
4. Switch off the torches, hand out the coloured circles, and ask the students to indicate which spots would show up as red, green or yellow in a real microarray, depending on the number of torches.

Analysis

Real

Microarray analysis starts with measuring the fluorescent intensity of each spot. This is done automatically by a scanner. Although analysis of the resulting images depends on the specific experiment, a typical step is to group genes with similar behaviour, in a process called clustering. After clustering, the scientists attempt to define similarities and differences among the genes belonging to the same clusters.

Virtual

1. Using Table 1, ask the students to cluster the genes into groups according to similar behaviour in the microarray. (See 'Teacher's guide to clustering exercises' and 'Clustering exercises for the classroom' in the ELLS TeachingBASE[w1]).
2. Discuss the different solutions of clustering genes. Mention to the students that there is no wrong or right clustering solution, but that the conclusions drawn from each cluster can be different.
3. Ask the students to search for information about the scientists after whom the genes were named, to find out if the genes in a cluster have something in common.
4. Depending on the clustering, you may come up with a group of the scientists who discovered the double helix, a cluster of geneticists, a cluster of scientists who did research on micro-organisms, or even scientists responsible for the establishment of

the European Molecular Biology Laboratory.

Conclusion

After performing the virtual microarray experiment, students can discuss how microarray experiments are used in biomedical research, and the medical and ethical implications of this technology. For more information, there is a 'Reading club' section in the ELLS TeachingBASE[w1], with simplified versions of original research articles describing how microarrays were used to answer important biological questions.

Acknowledgements

The authors would like to thank Rosanna de Lorenzi for playing and refining the activity. They would also like to express their obligation to Mehrnoosh Rayner for commenting on the article, Thomas Sandmann for help in the initial stages of the virtual microarray, and John Watson for helpful discussions.

Web references

w1 – For more information on the virtual microarray activity in English, German and Greek, see the TeachingBASE on the ELLS website – a freely available collection of molecular biology teaching modules designed for teachers and students: www.embl.org/ells

The following PDF materials in the virtual microarray section are particularly relevant to this article:

In the classroom

Reading club

Teacher's guide to clustering exercises

Clustering exercises for the classroom

w2 – For more information about the European Learning Laboratory for the Life Sciences (ELLS), see: www.embl.org/ells

w3 – For more information about the European Molecular Biology Laboratory, see: www.embl.org

w4 – A video of a robot printing microarrays at the European Molecular Biology Laboratory and a Word document of Table 1 can be downloaded from the *Science in School* website: www.scienceinschool.org/2009/issue12/microarray

A classroom in space

Lucy Patterson spoke to Greek science teacher Theodoros Pierratos, who recently won the chance to bring physics to life for his students in a truly extraordinary way with the help of the European Space Agency.

Images courtesy of Theodoros Pierratos and Carsten Przygoda

Image courtesy of Theodoros Pierratos

Theodoros Pierratos and his physics class

Theodoros Pierratos (aged 39) comes from a physics background and has been teaching science since 1998. He now teaches physics, astronomy and technology to 15- to 18-year-olds at the 2nd Lyceum of Echedoros, an upper secondary school in the western suburbs of Thessaloniki, Greece. He is also working towards a PhD thesis on physics didactics in the physics department of the Aristotle University in Thessaloniki.

Like many others, Theodoros feels that there is room for improvement in the way science is taught in schools. What especially concerns him is that, due to curriculum time constraints and a focus on preparation for university entrance exams, many teachers often end up abandoning the more experimental side of science teaching. He feels it is difficult for students to get inspired by science.

"Science is often taught in a way to make students believe that scientific discoveries are revealed to scientists in a magical way and last forever. Scientists themselves are thought to be extremely intelligent but antisocial people who work in secret underground laboratories. How could a student feel positive about this kind of science? We have to convince them that scientists are people like them and that they make mistakes like everybody does. Through hands-on activities that deal with real life, using trial and error methods, students will realise that science is everywhere: in playing football, when making a phone call, when cooking lunch. After all, I believe that we have to educate young people to be scientifically literate in order to make decisions about the future of our planet."

Trying to keep in touch with the developments in science and science education, Theodoros spends a fair amount of his time visiting websites and reading journals. This is how he found out about the European Space Agency (ESA)[w1] competition 'Take your classroom into space'. "First I found the announcement on the ESA website[w2], and a few weeks later I read it in *Science in School*," he says.

ESA invited European educators to propose new ideas for experiments to be carried out on board the International Space Station (ISS) (for more information on the ISS, see Hartevelt-Velani & Walker, 2008, and Hartevelt-Velani, Walker & Elmann-Larsen, 2008). Participants were asked to come up with original ideas that use the ISS to demonstrate the effects of gravity and free-fall to students.

Theodoros recognised that this was a fantastic opportunity to bring science alive for his students: to participate in a great space event and teach them basic physics in a truly remarkable way. The challenge then was to come up with an original idea.

"One day, as I was introducing the topic of oscillation to my 12th grade students, I asked them to imagine that they were on board the ISS, in a microgravity environment. What would happen if they pulled down a mass hooked to a spring and then let go? Many students answered that nothing would happen because there

Images courtesy of ESA


ESA astronaut Frank de Winne

is no gravity! After many discussions with them, using known equations, the students finally managed to predict what would really happen: the mass will oscillate just as it would on Earth's surface!"

Theodoros told his students about ESA's competition and is especially proud that his students took up this chance, as the school has its difficulties: "There are many students who are immigrants. Some of them have language difficulties. In addition, many students come from low-income families; therefore, they lack stimuli and do not have easy access to resources."

They formulated their proposal to ESA, entitled *Objects do not weigh in space, so they have no mass: measuring the mass of an object in a zero gravity environment*, which plays on students' misconceptions about the ideas of weight and mass. It demonstrates two important ideas: firstly, that weight and mass are not the same, and secondly, that mass remains constant as we move from Earth's surface into space. The students will also calculate the mass of an object at zero gravity.

When the announcement came that their proposal had won, they were, of course, thrilled. However, Theodoros's involvement in the project was far from over. ESA consulted him on the technical development of the equipment to be taken aboard the ISS and asked to contribute to a booklet, written by teachers for teachers, introducing the two experiments which were selected to be carried out in space out of the five winning entries. You can download this teaching guide in seven languages and order an education kit online[w2] that uses the same hardware that ESA astronaut Frank de Winne will use in orbit. The kits will be distributed for free to European

BACKGROUND

Materials offered by ESA

The European Space Agency (ESA) is an international organisation responsible for co-ordinating the efforts of its member states in programmes designed to find out more about Earth, its immediate space environment, our solar system and the Universe. Education is a high priority for ESA. They are aware that the ideas of human spaceflight, the ISS and space in general hold a certain fascination for young people, and try to capitalise on this to foster an interest in science and technology, in the hope that it will encourage more students to study and consider careers in these subject areas. To achieve this, they support science teaching by producing a range of educational materials for primary, secondary and university students, as well as providing unique hands-on opportunities for students such as experiments to be carried out on board the ISS or a microgravity airplane.

To support science, technology, engineering and mathematics (STEM) education on a national basis, ESA has installed ESEROs (European Space Education Resource Office) and contact points in the Netherlands, UK, Belgium, Spain, Norway and Ireland. They use and disseminate existing ESA/ESERO education materials, and if appropriate, develop specific resources tailored to the needs of the local education community. The ESEROs also organise national ESERO teacher conferences for secondary and primary education.

To find out more about educational materials and opportunities offered by ESA, visit their education portal online[w5].

Images courtesy of ESA

The 'Take your classroom into space' education kit

teachers on a first-come, first-served basis.

Theodoros will also be integrally involved, along with his students, in the final event, hopefully with a live in-flight call to Frank de Winne on board the ISS. The experiments are scheduled to take place on 21 September 2009. The demonstration – a 20 minute broadcast live from the ISS – will be the highlight of a larger ground event dedicated to 'Schools in space'. This will connect the four hometowns of the five winning schools. For maximum impact, and to reach as many students as possible, the events will be hosted in a science centre in each host country (Belgium, Greece, Italy and Spain). In Greece, ESA has proposed the Thessaloniki Science Centre and Technology Museum. Shortly after the event, the broadcast will be made available on the ESA website.

"The high-quality level of interaction with ESA was a pleasant surprise to me. The communication with Dr Cristina Olivotto is frequent, particularly analytical and extremely friendly. ESA acts like we have been their collaborators for years. I have the feeling that I've got new friends in the Netherlands."

For Theodoros and his students, the interaction with the ESA has been a boon for science teaching at his school.

"The students discovered that science can be exciting. They feel so anxious about their experiments on the ISS that they remind me of the scientists at CERN who couldn't wait for the LHC to start working [to read about the LHC, see Landua & Rau, 2008, and Landua, 2008]. When I suggested this to them, they replied that they feel as though they have in some way become scientists too! In science classes they're not afraid to ask 'What will happen if…?'; they defend their opinions, but can also change them, and they have realised that the only way to decide whether something is correct is to run the experiment."

The experience also opened his students up to the possibility of further collaboration and involvement in other European initiatives, which they previously didn't think feasible. This year alone, they have participated in an eTwinning[w3] astronomy project and, together with eight other European schools, submitted an application to the European Commission's Comenius partnership programme[w4]. As Theodoros says, "All of this happened after the engagement with the ESA's competition. I am sure that the students are going to gain even more through their active participation in the forthcoming space event."

However, not many teachers and students are aware of the opportunities that ESA offers, at least in Greece: "Recently at a pan-Hellenic conference on science education, I presented a teaching module my colleagues and I had developed using ESA's DVD series to introduce Newton's law. No one attending the conference was aware of this excellent educational material, which is a real pity. Most of them were pleased to learn about

ESA's website[w1] where such material can be found.

"I realise that my students and their families now see school in a different way; until recently they thought school was boring or just an examination centre. Now they know that school is much more. I think this was achieved through this experience and I'm very pleased as a teacher."

Theodoros also believes that, for his students, this experience has opened their eyes, and they now realise that they really have the option of considering science as a career.

"Many of my students who have positive feelings towards science are concerned that there are very few possibilities to pursue a science career in Greece. Most of them overlook the possibility of working in another European country. I think that projects such as ESA's competition and the participation of schools in European partnership programmes (such as eTwinning and Comenius) could give them a better idea about what scientists really do: they use state of the art technology, they come across people from all over the world, and they travel a lot – so their job is far from routine. Moreover, learning about young scientists, their work and their life, can be inspiring for students."

On a personal level, for Theodoros, the collaboration with the ESA has also given him the chance to satisfy a life-long dream.

"Of course it would have been even better if I was an astronaut on board the ISS, but, since I am not trained for this, I'm not complaining. So I think that the competition was a great chance for me to take myself into space in an unexpected way!"

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Hartevelt-Velani S, Walker C (2008) The International Space Station: a 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* Issue **10**: 76-81. www.scienceinschool.org/2008/issue10/iss

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

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

Web references

w1 – To visit the ESA human spaceflight education website, see: www.esa.int/esaHS/education.html

w2 – You can find more information on the 'Take your classroom into space' competition, download the teacher booklet and order kits here: www.esa.int/esaHS/SEMNDV0OWUF_education_0.html

w3 – To learn more about the eTwinning project, see: www.etwinning.net

w4 – You can find information on the European Commission's Comenius programme here: http://ec.europa.eu/education/lifelong-learning-programme/doc84_en.htm

w5 – Find out more about ESA education here: www.esa.int/SPECIALS/Education

See also: www.esa.int/SPECIALS/ESERO_Project/SEMMHT4KXMF_0.html and www.esa.int/SPECIALS/ESERO_Project/SEM0LW4KXMF_0.html

Lucy Patterson finished her PhD at the University of Nottingham, UK, in 2005, and has since been working as a postdoctoral researcher, first in Oxford, UK, then in Freiburg and Cologne, Germany. During this time she has worked on answering several different questions in developmental biology, the study of how organisms grow and develop from a fertilised egg into a mature adult, using zebrafish embryos. She has a broad interest and enthusiasm for science, and is currently developing her own embryonic career as a science communicator.

Human Spaceflight
SPACE FOR LIFE

esa

→ International Space Station (ISS) Education Kits

Primary (8-10 years) and Secondary (12-15 years)

Consists of text and explanations about the **International Space Station**, inter-disciplinary exercises, teacher's guide, glossary and colour overhead transparencies or classroom posters.

All related materials are curriculum based and available in the following languages: *Danish, Dutch, English, Finnish, French, German, Greek, Italian, Norwegian, Portuguese, Spanish and Swedish.*

→ Space Exploration Kit 1

Primary (10-12 years)

Reflects themes of exploration beginning with our own planet and Mankind's journey to the Moon; feedback from robotic missions; the possibility of human spaceflight to Mars.

This Kit (with accompanying CD-ROM) will be available later in 2009 in the above languages.

→ ISS lesson series: project: zero gravity

Secondary (12-15 years)

DVD1: Newton in Space
DVD2: Body Space
DVD3: Space Matters
DVD4: Space Robotics

Based on ESA missions to the ISS. Astronauts were involved in filming scenes in zero gravity conditions to show behaviour of materials in weightlessness. Basic laws of physics are demonstrated together with ground experiments filmed at schools throughout Europe.

→ Space Transportation - an ATV Perspective

Secondary (16-18 years)

Covers orbital mechanics, propulsion, space navigation and the future of space transportation. Brings together curriculum related topics with an emphasis on ESA's ATV (Automated Transfer Vehicle).

WINNER
1ST PRIZE

→ Ingredients for Life - on Earth and in Space

Secondary (15-18 years)

Looks at the vital ingredients that terrestrial life relies on and that make our planet an ideal place to inhabit. Also demonstrates how ESA develops technologies to mimic these processes and systems in space.

WINNER

→ ISS 3D Teaching Tool: Spaceflight Challenge 1

Secondary (12-15 years)

A fully navigable 3D model of the interior and exterior of the ISS. 26 science tasks, links to reference material, scientific simulation to experiment with, and more...

→ ESA Human Spaceflight Education online

The HSF Education team also produce a series of downloadable web lessons and short video clips called **Space in Bytes** suitable for schools - see:

http://www.esa.int/esaHS/education.html

Contact: **isseducationteam@esa.int**

Radioactivity in the classroom

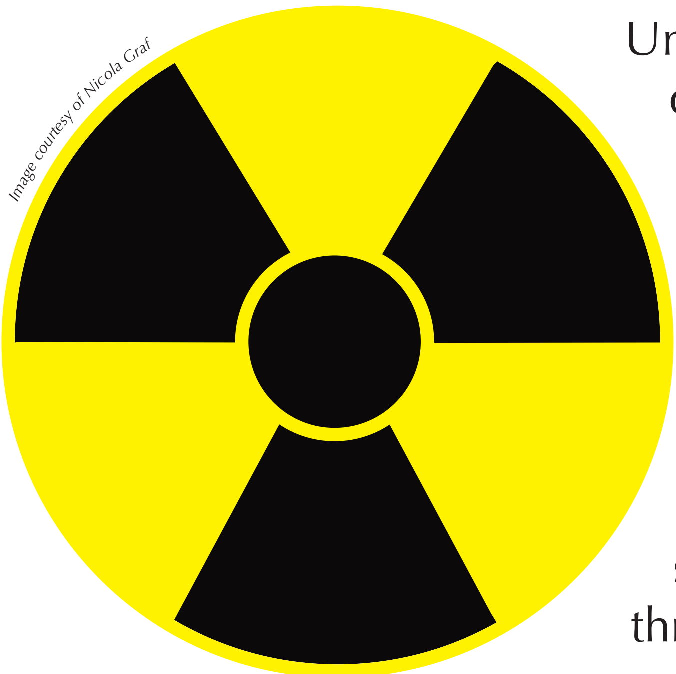


Image courtesy of Nicola Graf

Luis Peralta, professor at the University of Lisbon's physics department, and **Carmen Oliveira**, physics and chemistry teacher at Casquilhos High School in Barreiro near Lisbon, describe the 'Environmental radiation' project, in which students become actively and enthusiastically involved in science through easy and inexpensive experiments that highlight the thrilling world of invisible particles.

The 'Environmental radiation' project, which started in 2007, emphasises the importance of ionising radiation – radiation with enough energy to remove electrons from atoms or molecules – in daily life. It now involves students (aged 12-18) and teachers from 25 high and middle schools throughout Portugal and the Azores, who receive technical and logistical support from the physics departments at the universities of Lisbon and Beira Interior, and from the Laboratory of Instrumentation and Experimental Particle Physics. The idea for the project was born when students from several high schools visited Lisbon University for a few days in Summer 2006, and a first trip to uranium mines was organised for them.

Teachers and students involved in the project are invited to conduct hands-on experiments and share their results on the project's website[w1] (see graph on page 58) and during an annual one-day workshop hosted by one of the participating schools. This includes a science fair where students present their results and share new ideas, and the best works are awarded symbolic prizes. At the end of this day, there is a 'pros and cons' debate between the students and guest scientists concerning radiation issues. This workshop is also an interesting social event, attracting the attention of newspapers and local radio stations.

Adapted from an image courtesy of Rei-artur; image source: Wikimedia Commons

Location of Portuguese schools participating in the project

Image courtesy of the 'Environmental radiation' project

The radioactive map of Portugal: one of the pieces of work presented by school students in 2008

The 'Environmental radiation' project also provides extracurricular activities. In 2008, students and teachers, accompanied by two geologists, visited the uranium mines near Nisa, a small town about 200 km north-east of Lisbon. This is one of several locations in Portugal where rocks with some degree of radioactivity can be collected. The students collected over 50 kg of rocks at the site, which were later used to perform experiments at school. There are several areas in Europe where such rocks can be collected, for example in the Czech Republic.

The project's chosen topic may seem controversial, as we are dealing with radioactivity and young people, but all the samples we use have a low radioactive content and, in fact, this negative aspect can be transformed into a positive one, as this project enables students to develop a culture of protection and good practices that carry through to the way they deal with radioactivity in everyday life – for instance, in medical imaging. To that end, the project's website has a dedicated forum where students are encouraged to debate radiation-related issues.

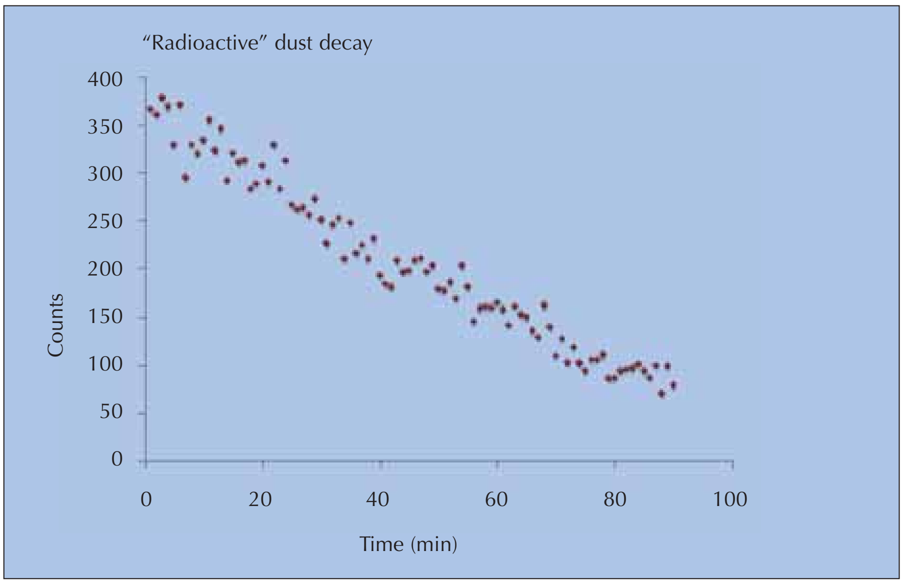


Image courtesy of the 'Environmental radiation' project

'Radioactive' decay of the dust caught by a balloon

The experiments

We come across natural radiation in a variety of situations. For instance, radiation caused by radon and the elements into which it decays represents around 50% of the total radiation that people are normally exposed to in Europe. In turn, radon itself forms naturally when uranium present in rocks, most commonly granite, decays. Radon gas leaks from the soil and through cracks in the walls, and accumulates in closed rooms such as cellars, or inside buildings near the ground floor, where its presence can be detected through simple experiments that students can perform at their own schools.

The experiments developed for this project can be performed using a minimum amount of inexpensive materials. Each of the participating schools was provided with a kit comprising a Geiger counter, irradiated seeds, X-ray dental film, and a plastic box with up to 2 kg of rocks collected at the uranium mines. The schools provided lab space, computers and the enthusiasm of students and teachers.

A wide range of experiments can be performed to introduce and explore radioactivity, with varying degrees of complexity. For instance, students can use Geiger counters to measure radiation levels in and

Image courtesy of the 'Environmental radiation' project

Detection of radioactivity in the rock

Becquerel´s experiment

Plants germinated from irradiated seeds

Field trip to the Nisa mines

around their schools, and create a local radiation map using GPS coordinates which they then feed into Google Earth[w2]. Other simple experiments using only a Geiger counter involve detecting radiation in salts used in food preparation, such as potassium chloride, and in natural rocks; in more complex experiments, students can place metal plates with different thicknesses and compositions (lead, aluminium) between radioactive material and the Geiger counter, to discover how radiation diminishes when it traverses metal. Experiments developed by the 'Environmental radiation' project also include using a balloon to catch radioactive dust from a closed room: rub the balloon with a furry cloth to create static electricity which will attract the dust, hang it for 30 minutes in a room which is usually kept closed, deflate it and use a Geiger counter to measure the radiation it emits. Students can even re-enact Becquerel's historic experiment that led to the discovery of radioactivity, in which radioactive rocks are placed on dental X-ray plates and developed to reveal the 'auto X-ray' they have created. For detailed descriptions of all the experiments and a discussion forum on radioactivity (all in Portuguese), visit the project website[w1].

Using the protocol below, students can explore a commercial application of radioactivity. The experiment has been successfully performed by students aged 13-20, but is also suitable for younger students, if the evaluation (measurements and graphs) is adapted accordingly.

While the fact that ionising radiation damages DNA and other cellular structures poses a risk to humans, it can also be – and frequently is – used to our advantage. Ionising radiation is used to kill all microbes on surgical instruments, sterilising them, and it is also employed in a similar fashion to extend the shelf life of some foods, and even in agriculture, where it is used to eliminate parasites from plant seeds. In Portugal, seed irradiation is done for research purposes only, while in the USA, this is common practice. Of course, the latter could inflict radiation damage to the seeds themselves. However, plant seeds are generally more resistant to radiation than the micro-organisms that plague them, so it is a question of finding the right balance: the radiation to which the seeds are subjected must be strong enough to kill the parasites, but not so strong as to harm the seeds. By tracking the development of plant seeds subjected to different amounts of radiation, students can observe the effects of radiation on plant germination and growth.

For this experiment, the 'Environmental radiation' project had their seeds irradiated at the University of Lisbon's physics department and at a facility that sterilises surgical implements. You can contact similar institutions in your country to irradiate the seeds you need.

Equipment and materials per group of 2-4 students

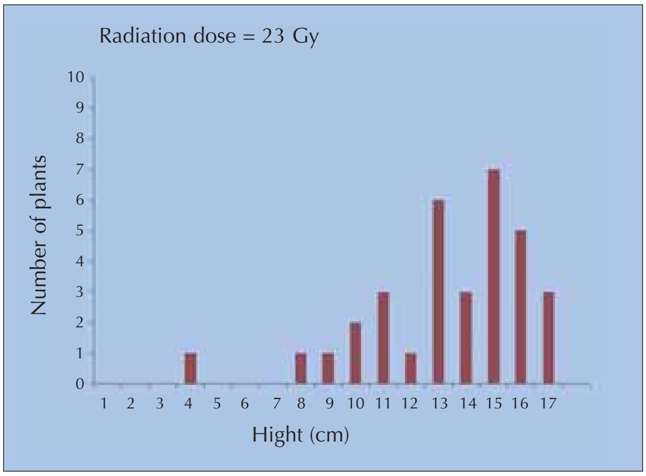
- Several trays (all the same shape and size)
- Plant seeds previously subjected to different (known) doses of radiation (ideally 0-400 Gy)

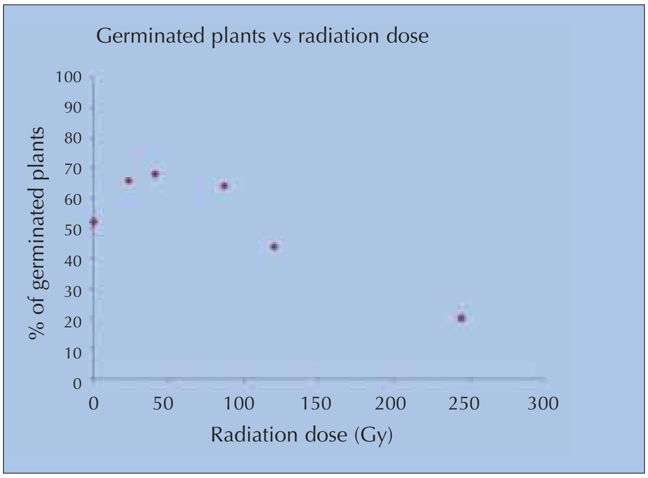
We recommend the use of wheat seeds if possible, but canary grass (*Phalaris canariensis*, a common birdseed) will also work and is perhaps easier to find.

The most important factor is dose uniformity (i.e. when irradiated, all seeds in a batch should receive the same amount of radiation). We used a Philips high-power X-ray tube to perform the irradiation. The seeds (a volume of about 0.5 l at first) were placed inside a plastic cup, which stood about 0.5 m from the X-ray tube window. To control the delivered radiation dose, a PTW Farmer ionisation chamber was placed inside the cup, right in the middle of the seeds. When one of the desired doses was reached, part of the seeds were taken out of the cup and separated in a labelled bag. In this way the dose was cumulative for the remaining seeds in the cup.

One of the problems during irradiation was the fact that the seeds closer

Images courtesy of the 'Environmental radiation' project





to the tube window received a higher dose, even though the cup was rotated by 180° between irradiations. A better solution in the future would be to place the cup on a rotating base (such as an old record player).

- Soil (garden earth will do)
- Water
- A ruler
- Optional: temperature, light, pH and humidity monitors.

Procedure

1. Place equal amounts of the same kind of earth in each tray.
2. Divide the trays into equal areas (one area for each radiation dose), label them accordingly, and sow the seeds that received each radiation dose in their respective area. Make sure you sow the same number of seeds (50-100) in each area and note down the number! If possible, sow in a grid – this really helps when you have to measure and count individual plants later on.
3. Cover the seeds with a 2-3 mm thick layer of earth (if you use more, they will take longer to sprout).
4. Regularly water all your seeds with the same type and quantity of water.
5. Keep all trays in the same place throughout the experiment, to ensure growth conditions are the same.
6. If you have the necessary instruments, measure and register the environmental variables (temperature, light, pH and humidity) regularly. If you perform this as an extracurricular activity, students can perform daily measurements. Otherwise, checking the plants during class hours will do.
7. For each radiation dose, count how many seeds germinate. You may also want to make a note of which dose led seeds to germinate first.

   The growing time is very dependent on local conditions. We have experienced differences of more than a week among our schools. Light and temperature are very important factors, as is the depth at which the seeds are sown. In one of the schools, plants could already be measured after 4 days, while in others it took 12 days. As a rule of thumb you can make the first measurement when the tallest plants have reached 4-5 cm.
8. Measure the height of each plant 8 and 12 days after it started to germinate and record it. As mentioned above, this is only a guideline as growing time is variable. Each individual plant is measured, which takes about 15 minutes for 50 plants. Sowing the seeds in a grid makes this step easier.
9. For each radiation dose, group the measured heights in intervals of 0.5 cm, and draw a histogram showing the number of plants in each height group (see example histogram above).
10. Calculate the average plant height for each radiation dose 8 and 12 days after germination.
11. Note down these results in the tables and draw a graph showing how the average plant height varies with radiation dose.
12. Calculate the percentage of seeds that germinated for each dose (relative to the number of seeds you planted for that dose). Display these results in a graph showing how radiation dose affects the percentage of germinated seeds (see example graph above).

Safety notes:

- Place the radioactive rocks in a plastic box and wear gloves when you handle them.
- Experiments involving radioactive rocks should be performed in a ventilated room.
- For the experiments with irradiated seeds, it is enough for the students

to wear gloves when they sow the seeds. The irradiation of seeds is carried out in the Physics Department of Lisbon University by technical experts who follow appropriate security.

- For the Becquerel experiment, gloves must be worn to handle the X-ray dental film when students are developing the film.

Discussion

- Does the radiation dose influence the number of seeds that germinate? How?
- Does the radiation dose affect how tall plants become? Does it affect how fast they grow?
- What radiation dose leads to the largest possible number of germinated seeds? Which is the right dose to obtain the greatest plant height?

Students should conclude that increasing radiation dose increases the percentage of germinated seeds and the average height the plants reach, up to a certain dose of radiation above which the radiation becomes harmful to the seeds themselves and so the number of germinated seeds and the average plant height decrease. In our experience, depending on plant species, above 300-400 Gy, most seeds will not germinate, and those that do germinate have serious problems, for example they rot after only a few days.

The organisers of the 'Environmental radiation' project are currently in contact with biologists and biology teachers in an effort to further expand this experiment to encompass a multidisciplinary approach, in which students may be able to observe the effects of radiation on the plants' cells and genetic material. Interested teachers may contact the organisers through the forum on the project's website.

Web references

w1 – The website of the 'Environmental radiation' project can be found here: www.lip.pt/radao

w2 – To download and install Google Earth for free, see: http://earth.google.com

Resources

Rego F, Peralta L (2006). Portuguese student's knowledge of radiation physics. *Physics Education* **41**: 259-262

For a table of radioactive isotopes, see: http://nucleardata.nuclear.lu.se/nucleardata/toi/

The UK's Institute of Physics has developed a teaching unit on radioactivity, which can be found on its website (www.iop.org) or here: http://tinyurl.com/lsr5r5

Acknowledgement

This project was financed by Ciência Viva, the Portuguese National Agency for Scientific and Technological Culture, the Science and Innovation Program for 2010, and ERDF (European Regional Development Fund).

Luis Peralta is a professor in the physics department of Lisbon University. He obtained his PhD in 1991 working on a high-energy physics experiment at CERN, in the field of heavy-ion collisions. In recent years, he has been working on radiation physics applied to medicine and is now interested in environmental radon-related problems.

Carmen Oliveira is a physics and chemistry teacher at Casquilhos High School in Barreiro, near Lisbon. She obtained a masters' degree in physics in 1996, working on radioactivity and the environment. Currently, she is working towards a PhD in physics, developing ionising radiation detectors for primary and secondary schools.

REVIEW

With its various forms and applications, radioactivity has come to play an increasingly vital role in our everyday lives. Nowadays, the amount of radiation from human activities is already roughly equal to the amount of radiation originating from natural sources (Earth and space). In addition, the number of nuclear power plants continues to increase.

As future citizens will be forced to make critical decisions on related issues, students of today should start to prepare by studying the potential applications of radioactivity and the possible consequences of its use.

In this article, Luis Peralta and Carmen Oliveira offer information and ideas on involving students in motivating educational activities relating to the importance of ionising radiation. The variety and the number of ways in which these activities can be integrated into the curricula are remarkable.

Vangelis Koltsakis, Greece

Hydrocarbons: a fossil but not (yet) extinct

Image courtesy of the Shell Image Library

Continuing our energy series, **Menno van Dijk** introduces us to the past, present and future of hydrocarbons – still the most common of all fuels.

While researchers today are working on the development of clean, renewable fuels, our society is still almost entirely dependent on fossil fuels. How are they formed, how much is there of them, and how long will they last?

Hundreds of millions of years ago, the world was a wilderness, but not void. A diversity of animals and plants populated the landmass. The seas bubbled with life and, like today, the largest part of the biomass consisted of microscopically small organisms. They all extracted the energy for their organic molecules either directly or indirectly from sunlight.

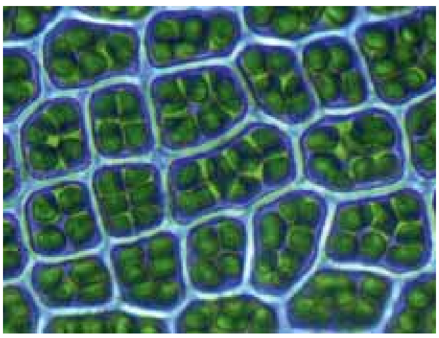


Image courtesy of Kristian Peters and Hans Ferdinand Maßmann; image source: Wikimedia Commons

Detailed image of a carpet moss leaf (*Mnium hornum*); the parts of the plant cells which store light energy as molecular fuel (chloroplasts) are clearly visible.

Storage in reservoirs

Since then, the continents have drifted apart, with some landmasses disappearing into the depths and others being heaved up. Wind, ice and rain caused erosion on land, which created great masses of sediment, especially in river estuaries. Some sediments were porous (such as sand or the skeletons of calcareous animals), others impermeable (such as clay). Organic material was buried, too, and the vertical movements of landmasses could take it several kilometres below the ground. There, it was warmed up by heat from the interior of Earth.

The high temperature and high pressure at that depth caused the organic material to break down and be converted to a fluid with a diverse collection of chemical structures: volatile hydrocarbons such as methane and ethane, short and long paraffinic molecules, aromatics, and highly complex and large polycyclic structures. Since they all consist mainly of carbon (C) and hydrogen (H), they are collectively called 'hydrocarbons'. This fluid, mostly together with water that was also trapped, worked its way up through porous rock until it was – in some cases – stopped by an impermeable layer of sediments. Where the geometry, determined by breaks and deformations, had formed three-dimensional enclosures, or reservoirs, the fluid accumulated and remained there to simmer quietly.

Due to the absence of oxygen, the solar energy stored as chemical energy in the molecules was not burned up (oxygenated), but preserved for millions of years. Sometimes a sepa-

The Brent Alpha platform in the North Sea

Image courtesy of Mayumi Terao / iStockphoto


An offshore drilling rig

rate gas phase was formed above the oil, and on other occasions, when only very small hydrocarbon molecules found their way to a reservoir, a 'gas bubble' formed. Note that such a gas bubble, just as an oil reservoir, is enclosed in porous rock, the pores of which are filled with oil and / or gas and / or water.

On land, organic material such as trees and plants got buried, too. Under favourable conditions, when they were quickly covered by sediment and thus sheltered from oxygen, preventing rot, these were converted to thick layers of coal. In some places, the hydrocarbons came into contact with bacteria with an appetite for certain molecules, which changed their composition. So each reservoir storing accumulated solar energy will have its own character in terms of reservoir shape and hydrocarbon composition.

Energy hunger in the modern world

Over time, we humans have developed a great hunger for energy. Originally, this was fulfilled by firewood. When the growing of wood couldn't keep up with the growing demand for energy, we started digging up million-year-old firewood from coal mines. But the solid form of coal was cumbersome, dangerous to dig up and not very economical. Eventually, oil reservoirs were discovered. While man's use of oil dates to prehistory, the first modern oil well was drilled in the United States on 27 August 1859 by Edwin Drake in Pennsylvania. Later, wells were drilled especially in the Middle East, where vast resources of fairly easily extractable oil appeared to be situated under the sand.

The combustion engine caused an explosive growth in the demand for oil. This grew so quickly that the end of the supply seemed near. The Club of Rome, a global think tank for political issues, warned that mankind was quickly running out of energy reserves. So people started to search in more inaccessible places and discovered much more oil under water: the North Sea, the Gulf of Mexico, the Niger Delta in Nigeria. Driven by high oil prices, technology was developed to recover oil from increasingly deep water. Moreover, natural gas came into view. Originally, striking gas on a drill was considered bad luck. Locally, you may have been able to use it, but exporting it over long distances was far too expensive. Here too, technological developments changed the situation.

Liquefied gas

With liquefied natural gas technology, natural gas is compressed to about $1/600^{th}$ the volume, and became transportable over long distances. Recently, it also became possible to chemically transform gas on a commercial scale to heavier (liquid) hydrocarbons such as gasoline or diesel fuel (GtL, gas to liquid). Thus, huge gas reserves (in the Persian Gulf, for example, there is a reservoir 10 times as large as Slochteren in the Netherlands, the largest European natural gas field, estimated at 1.5×10^{12} m^3; Russia also holds vast gas reserves) could be used to satisfy the hunger for energy.

All this was possible thanks to the development of highly advanced technology. The first oil well for Shell in Malaysia, in Miri, was only 140 m deep, and was drilled in 1910 with a technique that the Chinese had used for centuries to drill for salt. In the 60 years of its existence, 100 000 m^3 of oil were retrieved by a pumpjack.

Image courtesy of Jupiterimages Corporation

A pumpjack

Today, oil is extracted from reserves in up to 2.5 km deep water, 6 km below the seabed. This requires the precise drilling of a 6 km deep, 50 cm diameter hole from a drilling platform bobbing a few kilometres higher up on the sea. Then, at the bottom of the sea, a construction called a subsea well head has to be placed on the well, from which the oil must flow to a production platform which sometimes lies dozens of kilometres away. This is not to be confused with the drilling platform, which drills and constructs the wells and then goes away. Production platforms instead contain the processing equipment.

Between the reservoir and the platform, a multitude of problems can occur which must be known and mastered. Besides knowhow and technology, this requires a lot of money, and this type of oil field can only be profitable if it produces large quantities of oil per day: off the coast of Malaysia, a new field has recently been found, which will produce in four days as much as the first source in Miri produced in 60 years: that's 650 000 barrels of oil, about 100 000 m^3.

Where to go from here?

One thing is clear: all the oil or gas that has been pumped out is gone forever. Slochteren is running out, the famous North Sea fields are running out, and even in the Gulf of Mexico, the most important oil source for the most energy-hungry country in the world – the USA – the fields being found are increasingly small. Will the hydrocarbon economy soon die a slow, or perhaps a quick, death? Ultimately, supplies are certainly finite, but there are still a few aces up the hydrocarbon sleeve.

Enhanced oil recovery

Depending on the precise circumstances of an oil reservoir, approximately one-third of the available oil is generally extracted. The rest stays behind in the pores of the rock. Using technology, something can still be done to extract more oil: from relatively simple water injection to press the oil from the reservoir, to sweeps with surfactants and polymers to loosen some of the oil from the rock. Thanks to high oil prices, these enhanced oil recovery techniques are becoming very interesting.

Heavy oils and oil sands

There are also reservoirs which contain very heavy, i.e. viscous, oil. Previously, these were not economically developed, but here too, technology can bring about change. But it is not easy and will require large investments, also in knowledge building.

Hyperheavy oil is still in abundance. In oil sands and oil shale, reserves of hydrocarbons are stored – the size of many times the amount of 'easy' oil. In Canada, 200 000 m^3 of oil are produced daily from excavated tar sands. This is a costly and difficult process, if only because of the extremely low temperatures that pre-

BACKGROUND

Tankers and pipelines

The technology of oil transportation has evolved alongside the oil industry. Break-bulk boats and barges were originally used to transport oil in wooden barrels. But such barrels were heavy, leaky, and expensive, accounting for up to half the cost of petroleum production. In 1876, Ludvig and Robert Nobel, brothers of Alfred Nobel, founded Branobel in Baku, Azerbaijan, one of the largest oil companies in the world during the late nineteenth century. They pioneered successful oil tanker engineering, but also experienced some of the first tanker disasters. Today's supertankers are up to 400 m long, with a capacity of up to 500 000 DWT (deadweight tonnage, a measure of how much weight of cargo a ship can safely carry). They can transport two million barrels of oil, which corresponds to the oil consumption of France per day in 2007.

A new tanker of 250 000-280 000 DWT cost US$116 million in 2005 – but oil tankers are often sold second-hand. As of 2007, the CIA statistics counted 4295 oil tankers of 1000 DWT or greater worldwide: this amounts to about 37% of the world's fleet in terms of DWT. In 2005, 2.42 billion tonnes of oil were shipped by tanker: 76.7% of this was crude oil, the rest consisted of refined petroleum products. With the exception of the pipeline, the tanker is the most cost-effective way to move oil today.

By the sheer amount of oil carried, modern oil tankers have to be considered a threat to the environment, with oil spills having devastating effects. Crude oil contains polycyclic aromatic hydrocarbons which are very difficult to clean up, and last for years in the sediment and marine environment. Marine species constantly exposed to them can exhibit developmental problems, susceptibility to disease, and abnormal reproductive cycles. The International Tanker Owners Pollution Federation has tracked 9351 accidental spills that have occurred between 1974 and 2008. Most spills result from routine operations such as loading and discharging cargo, and taking on fuel oil. While over 90% of the operational oil spills are small, resulting in less than seven tonnes per spill, spills resulting from accidents like collisions, groundings, hull failures, and explosions are much larger, with 84% of these involving losses of more than 700 tonnes.

Modern pipelines have existed since 1860, , and today span the world in a growing network millions of kilometres long, with Russia and the rest of Europe each contributing about 250 000 km of gas and oil pipelines (70% of these transport gas). They generally constitute the most economical way to transport large quantities of oil or natural gas over land. Oil pipelines are made from steel or plastic tubes with inner diameters ranging from 10-120 cm, and are typically buried 1-2 m deep. The oil flow of about 1-6 m/s is ensured by pump stations along the pipeline. Multi-product pipelines are used to transport two or more different products in sequence in the same pipeline. There is usually no physical separation between the different products, so some mixing occurs, producing polluted interface which is removed from the pipeline at the receiving facilities. For natural gas, pipelines are constructed of carbon steel and vary from 5-150 cm in diameter, depending on the type of pipeline. The gas is pressurised by compressor stations and is odourless unless mixed with a mercaptan odorant, where required by a regulating authority.

Gas and oil pipelines are not merely an element of trade: they connect to issues of geopolitics and international security, and their construction, placement, and control often figure prominently in state interests and actions. Pipelines cross areas prone to earthquakes and wars, nature reserves and the bottom of seas. As they contain flammable or explosive material, they pose special safety concerns, with ruptures and deadly explosions being the most common accidents.

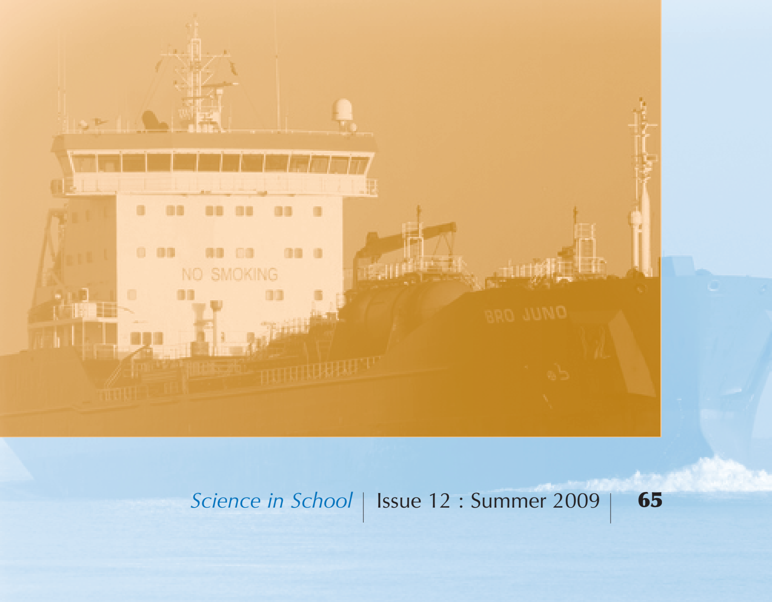


Image courtesy of Rob Belknap / iStockphoto

A handful of the black, oil-rich sand recovered in Fort McMurray, Alberta, Canada

Image courtesy of Ivars Zolnerovichs / iStockphoto

A coal train

vail in that region. Moreover, the process of producing useful fluids from oil sands requires quite a bit of energy and is not so efficient. For the deeper stocks (80% of the total), no recovery method is yet available.

Coal

Coal reserves are still in abundance, too. In recent years, coal has been the fastest growing energy source. This is because of the growing economy – and consequent demand for energy – in China, which itself has only limited oil and gas reserves, but a lot of coal. China consumes about 40% of the global coal production. But this is not without its price: the deaths of dozens of miners per day (!) and huge environmental damage (by acid rain, among other causes) are associated with the burning of coal. With modern processes (such as transformation of coal to gas) it is possible to produce energy from coal in a less environmentally damaging way. And with more money and less haste, the safety situation can also be improved.

Gas hydrates

Methane, of bacterial or fossil origin, which is released at the bottom of the sea, can form what are known as gas hydrates. This is a kind of ice which, due to methane trapped inside (under pressure), has a higher melting point. Great quantities of methane are likely to be stored in such huge hydrate fields at the bottom of the ocean, including the east coast of the United States. The total energy resources in gas hydrates on Earth are estimated to be greater than those of all other known fossil fuels combined – ever. However, people don't have even the slightest idea yet of how to exploit these reserves (safely).

For a science fiction outlook on what might happen if these hydrate fields were to be destabilised, see Schätzing (2004).

Reserves and production

Large parts of Earth have been examined for the presence of oil and gas fields. Most hydrocarbon regions

	Reserves		Annual production		R/P
	m^3	Joules	m^3	Joules	
Crude oil	1.9×10^{11}	6.8×10^{21}	4.7×10^{9}	1.7×10^{20}	41
Natural gas	1.8×10^{14}	6.4×10^{21}	2.7×10^{12}	9.6×10^{19}	67
Coal	8.0×10^{17}	1.7×10^{21}	2.9×10^{15}	6.1×10^{19}	277
TOTAL		3.0×10^{21}		3.3×10^{20}	93

Global proven reserves and annual production of hydrocarbons in terms of volume (m^3 gas under standard condition of 1 bar, 15 °C) and in terms of energy content. R/P is the ratio of reserve to annual production, giving the amount of years the known reserves will still last if exploited at the current production rate. Source: BP statistical review (www.bp.com)

BACKGROUND

Hydrocarbon facts

Estimated R/P: up to 93 years

Cost per kWh: The cost depends enormously on the source. Production costs range from a handful of dollars per barrel for easy oil in Saudi Arabia to tens of dollars per barrel for heavy oil in remote locations.

Risks: Pollution during transport and production; CO_2 production when used

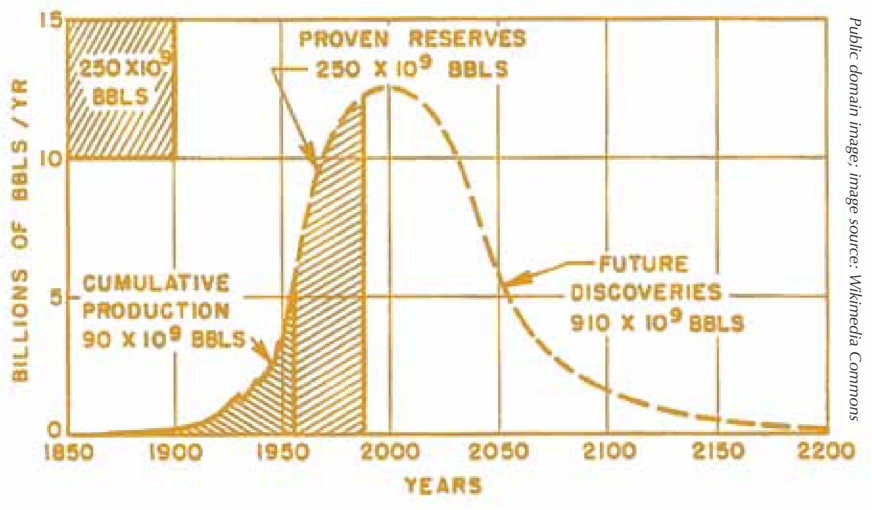
Estimated research time: Research will be done for as long as these fuels exist, to make them cheaper, cleaner and more energy efficient, to extract a greater fraction of oil from a reservoir (e.g. by enhanced oil recovery), and to be able to economically exploit small reservoirs, too.

have been found: those are the known oil and gas regions, including our own North Sea. Within these areas, reservoirs are still being found, but the really big ones are known, and it is becoming increasingly difficult and costly to develop the new ones. The table on page 70 gives an overview of the current proven reserves. There is considerable uncertainty in these numbers, though, both of a technical (estimating the size of a reservoir is very difficult) and of a political nature (countries and companies can have all sorts of reasons to make the reserves look larger or smaller).

According to this table, at the current consumption level we would still have 93 years ahead of us if we were to use all fossil energy. That sounds more reassuring than it is, for several reasons:

- There is a large uncertainty in the number 93. It doesn't mean that after exactly 93 years of wasting energy, time will suddenly be up – we are already starting to feel the effects of the fossil fuels running out.
- Processes to retrieve heavier oils also require more energy, so less energy will effectively be at our disposal from these than from 'easy' oils.
- When the energy consumption, and consequently its production, grows, the number of years we can still use the reserves decreases (R/P).
- New projects that could add reserves require huge investments and take a long time from concept to production. A simple oil well costs around €1 million, but a deep-water well may be more than €100 million. A small production platform costs €1 billion. In the Athabasca oil sands project in Canada, $45 billion has already been invested, and there are still $50 billion to come by 2012. Between the discovery of a reservoir and the first production, eight years can easily pass. So shareholders and politicians have to supply time and money, but they generally have little patience. If there is no short-term reason to invest, we will therefore create a long-term energy shortage.
- For many sites, poorly predictable political complications play a role. Therefore, it may not be possible to access the resources.

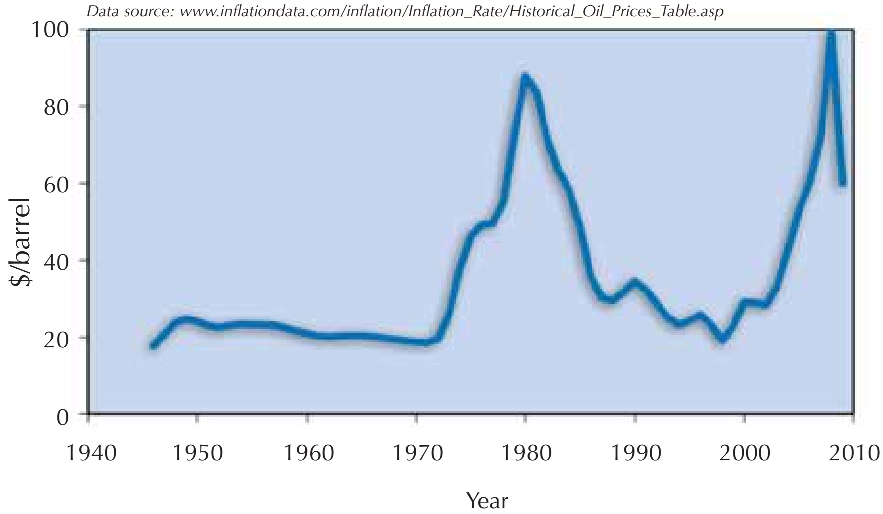
There are many factors which play a role in finding and producing fossil fuels, but the main ones are that the amount of hydrocarbons is finite and that the proven reserves should not be seen as a reserve barrel that we can open at any moment: a lot of time and money has to be invested before they can be used. It is conceivable that there will be production problems before the lack of reserves becomes problematic.



Public domain image; image source: Wikimedia Commons

Figure from the original proposal by Hubbert in 1956

Data source: www.inflationdata.com/inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp



Oil price development since the 1940s

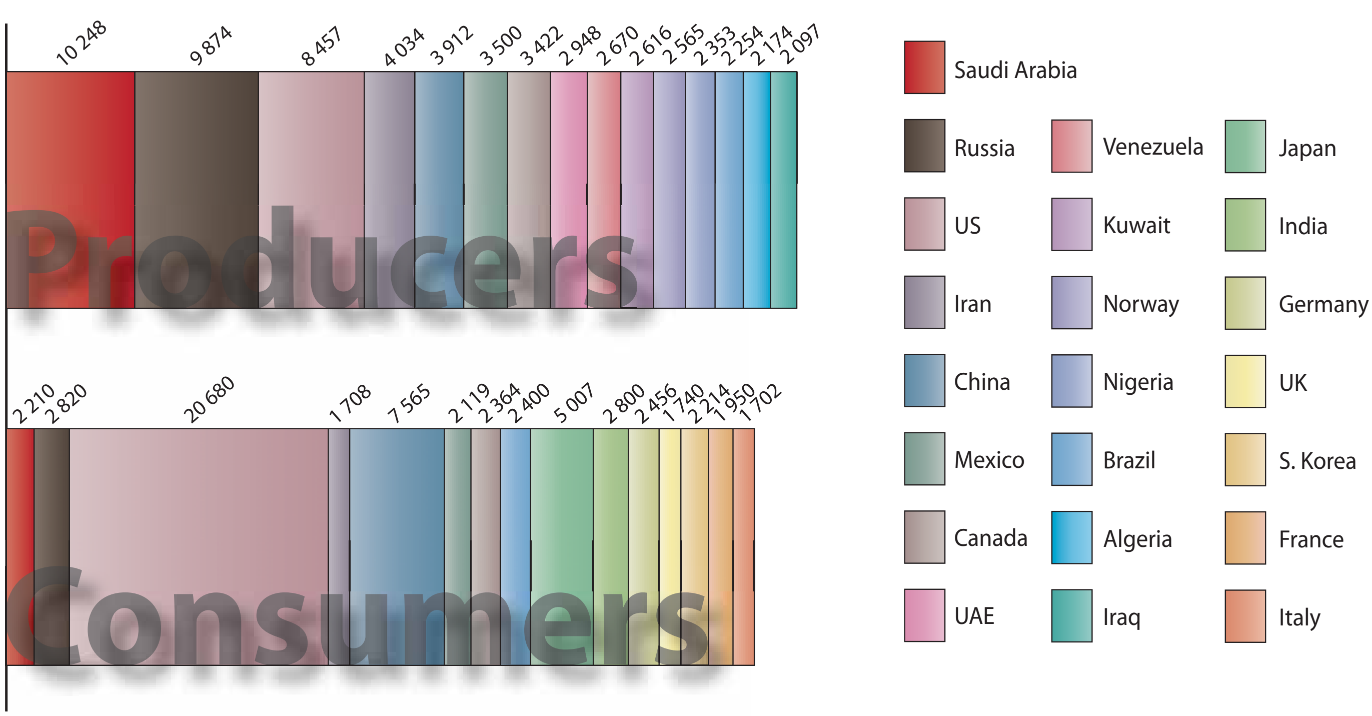
Hubbert peak

Based on an analysis of the cycle of discovery, development, investment in infrastructure, more discoveries, and then slowly running out of reserves, Marion King Hubbert, a geoscientist who worked at the Shell research lab in Houston, Texas, developed a method of analysis which successfully predicted the peak production rate of oil on the American continent for 1970. He made this prediction in 1956. His theory can be applied to an individual oil field or a whole a country, and also worldwide. Applying this method to our planet, we should have reached this peak point by now. If so, we have already passed the peak oil production per capita.

Finally, it should be noted that hydrocarbons are not only used for energy. Approximately one-tenth is used in the (petro)chemical industry to produce a huge range of products: from plastics to solvents, drugs and detergents. Just like energy, these

Image courtesy of Vienna Leigh

Top world oil producers and consumers (thousands of barrels per day)



REVIEW

The technology may be dinosaurial, but fossil-fuel burning continues to be an integral and increasingly costly part of our modern way of living, not least because of the rapid industrialisation of the most populous nations on Earth.

Along with pharmaceuticals, oil is big business with massive science input. Van Dijk's article can give science teachers a route into discussing some of the following issues with their classes. Students could consider the economics of how even relatively inaccessible fossil fuel reserves are worth extracting today. How much will a barrel of oil have to cost before exploiting the 'hyperheavy' reserves described is worth the hassle? Students could look at how the distribution of hydrocarbon reserves across our planet has affected international relations, from both strategic and economic perspectives.

And while the non-renewable nature of this resource is well known to most students, the fact that around one-tenth isn't used as fuel at all is less appreciated. What arguments could the students develop to reduce consumption of fossil fuels to secure reserves of fossil feedstock for uses including 'plastics, solvents, drugs and detergents'? The energy question will require a host of answers, and today's science students may develop some of the solutions, as well as being made to live with a smaller hydrocarbon footprint in the future.

Ian Francis, UK

have become an essential part of our lives. In short, fortunately, there are still fossil fuels, but concerning the R/P, we should not think of it as Reasonably Problem-free but as ResPite!

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Schätzing F (2006) *The Swarm*. Hodder & Stoughton (London, UK): ISBN-13 978-0340895238

Resources

For a full list of *Science in School* articles about energy, see: www.scienceinschool.org/energy

Acknowledgments

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Menno van Dijk works for the flow assurance department at the Shell technical centre in Amsterdam, the Netherlands. The article was written on his own account, not in connection to his work.

Image courtesy of the National Trust Photo Library / Nick Meers

Blickling Hall in Norfolk

Image courtesy of the National Trust Photo Library / Paul Harris

Katy Lithgow

The science of preserving art

As Head Conservator at the National Trust, Katy Lithgow's education turned her into 'more an arts person' than a scientist – but her work has shown how the two can be inextricably linked. **Vienna Leigh** finds out how.

If you've ever holidayed in Britain, you'll know that the countryside is awash with historic properties and their gardens, areas of natural beauty, castles, ruins, forts and nature reserves. Whether it's a house with a literary or historical connection – Hardy's Cottage, Wordsworth House, or Cliveden, once the glittering hub of high society – or a World Heritage Site – the Giant's Causeway, the Avebury stone circle or Hadrian's Wall – there's something for everyone, and much of it owes its continued existence to the National Trust[w1].

Keeping these examples of national heritage in good condition – as well as open to the public – not only requires the help of the Trust's 52 000 volunteers, but also relies on the expertise of a team of conservation specialists behind the scenes, including wardens, gardeners and curators.

Head Conservator Katy Lithgow is one such expert. Originally an art historian, Katy is now responsible for the preventive and remedial conservation of collections and historic interiors in the National Trust's houses. Having graduated from Cambridge, her first foray into the field was at London's Courtauld Institute[w2], training in wall painting conservation. "It seems to me that people stumble across this career path, often through pursuing an interest, in my case by trying to combine a love of painting and drawing with an interest in the history of art and the technology of art production," she says. "At school it's hard to get to know about my sort of job – it's not something on the standard careers list."

There's much more to her job than renovating old paintings. Katy's working day might include reviewing the installation of solar cells or insulation in a castle's roof, examining potential acquisitions to determine their conservation needs, providing training to National Trust staff, giving talks at museums or art galleries, or participating in policy meetings. She often works alongside the wider conservation community to identify research needs in cultural heritage, for example by participating in collaborative research promoted by the Science and Heritage programme[w3] or taking part in the UK's National

Heritage Science Strategy steering group[w4]. "Though I think of myself as more of an arts and humanities person than a scientist, it's science that enables us to continue to welcome visitors by preserving our properties for the future," Katy says. "If we opened houses without taking account of what causes their deterioration, we would risk them being damaged and destroyed. Specifically, we're concerned with how environmental factors, such as humidity and light, affect objects, materials and structures.

Flooding at Calke Abbey and Coughton Court was the result of climate change

"Science helps us in an endless number of ways. After the flooding of the library in the Long Gallery at Blickling Hall (a Jacobean house in Norfolk), we were able to treat the precious contents using our understanding of the way materials behave when they become wet. We use pho-

Image courtesy of the National Trust Photo Library / Andrew Butler

Powis Castle, the Italianate terraces at dawn

Image courtesy of the National Trust Photo Library / Nadia Mackenzie

Chastleton House, the Jacobean Long Gallery

tomicrographs to see how the products of bacteria – called 'sticky exopolymers' – combine with damp and the calcite in dust particles to bind the dust onto historic surfaces. This led to the development of a method of monitoring the production of dust by visitors, which tells us how to manage the rate of cleaning to prevent objects becoming irreversibly soiled. We use sensors to tell us whether the amount of light to which a surface has been exposed is too great, and that helps us control light for the benefit of visitors and our collections; we design conservation heating systems using relative humidity and temperature data. We even used science to determine why John Hungerford Pollen's paintings on the frieze of the Long Gallery at Blickling Hall look so worn (scientific analysis showed he had a poor painting technique!)."

So, as a self-professed 'arts person', how does Katy take to the scientific side of her work? "I was always aware through my studies of Italian Renaissance painting how close the arts and sciences really are. Art is and always has been heavily influenced by scientific theory and discoveries – the science of colour, pigments, perspective, and so on – and scientific data is needed to support arts research, for example to establish the authenticity of a work of art.

Similarly, science can be artistic, too – during a moment of inspiration, for example – and humanities skills such as writing and giving presentations are required to communicate science. In addition, both arts and sciences rely on evidence, which is tested by validating hypotheses. In both cases,

Image courtesy of the National Trust Photo Library / Nadia Mackenzie

Insect pests – moth larvae eating woollen textile on a cushion from Tyntesfield

BACKGROUND

Case study: James II's bed

"As head conservator, I'm responsible for identifying the most urgent conservation work needed to be done on National Trust collections. The priority of the work depends on the rate of change in condition, the quality of the display environment, and how the project would fit into the overall plans for presenting and developing the property.

Currently, the top national priority is the James II bed at Knole – one of the great treasure houses of England and the birthplace of author and poet Vita Sackville-West – near Sevenoaks in Kent. Research has shown that the bed is likely to have been commissioned by King James II of England, Scotland and Ireland in around 1688, shortly before he was chased out of the country in the Glorious Revolution of 1689 that saw the installation of William and Mary as joint Protestant monarchs. The Lord Chamberlain of the time, Thomas Sackville, 6th Earl of Dorset, acquired the monogrammed bed – now an undesirable symbol of a defunct regime – and moved it to Knole in 1701.

When the National Trust's staff at Knole noticed that the bed's curtains were ripping under their own weight, our textile conservation adviser, Ksynia Marko, investigated the options for treatment. Analysis showed that the hangings are made of a silk velvet which is extremely sensitive to damage from exposure to light. Over time, the oxidation of the silk fibres has caused them to shatter and collapse, aided by the forces of gravity.

There have been at least three attempts to treat the hangings. During the most recent endeavour, which was as long ago as 1959, a natural latex adhesive called 'gutta-percha' was used to glue the fragments of silk velvet to new linings – but 50 years on, the glue has chemically altered. It's now brittle and dark, staining the original textile and no longer able to support its weight.

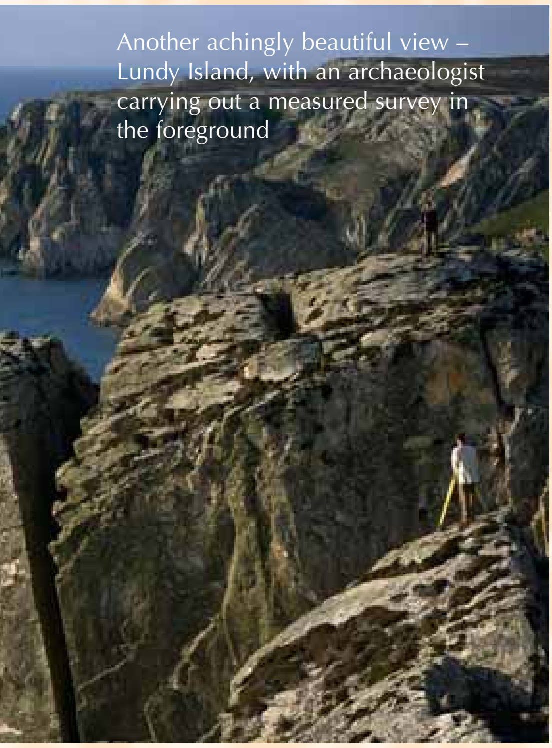
We removed the curtains from display to identify the solvents and method of treatment needed to remove the old adhesive, and cleaned the silk velvet and reattached it to new supporting fabric. In the meantime, we've started to raise the £850 000 needed to fund the conservation of the rest of the bed, its hangings and associated furniture, and redisplay."

Image courtesy of the National Trust Photo Library / Andreas von Einsiedel

James II's bed at Knole

Image courtesy of the National Trust / Textile Conservation Studio

Conservator Clare Golbourn with cleaned fragments of the silk velvet curtains



Another achingly beautiful view – Lundy Island, with an archaeologist carrying out a measured survey in the foreground

Image courtesy of the National Trust Photo Library / Joe Cornish

Hadrian's Wall, Northumberland, Cuddy's Crag

Image courtesy of the National Trust Photo Library / Charlie Waite

Sissinghurst Castle from the White Garden

Image courtesy of Jonathan Buckley

these hypotheses have to hold in relation to different sorts of research.

"At school, though, science and I didn't get on. I still maintain that it was mere coincidence that led me to choose boiling flasks with hairline cracks that exploded and etched the wooden worktops with bubbling black viscous treacle, but my teacher seemed to think that my main aim in life was to subvert all her lessons. It was only during my training as a wall painting conservator that science really came back into my life in an applied sense.

"Nowadays, a scientific background is a tremendous asset to have in conservation. There are specific courses available for people who come from the humanities, such as the Chemistry for Conservators correspondence course offered by International Academic Projects Ltd[w5]."

The National Trust carries out scientific research within projects with other heritage and educational institutions, gaining funding through grants and initiatives such as the EU-funded research project Climate for Culture[w6], which will begin in October this year.

"It may not occur to our visitors, but climate change is having a huge effect on the work of the National Trust," Katy says. "It's the challenge of our times, and it affects everything. Flooding at Calke Abbey (a Baroque mansion in Derbyshire) and Coughton Court (a Tudor family seat in Warwickshire) in the summer of 2007 was the result of severe and unseasonal rainfall attributed to climate change. The Engineering Historic Futures project[w7], funded by EPSRC (Engineering and Physical Sciences Research Council)[w8] as part of its Sustaining Knowledge for Changing Climates programme, is another scientific research project which looked at adapting historic environments to the effects of climate change, and it used the flooding at Blickling Hall as a case study.

"In historic houses we also see climate change in the form of increased insect pest activity by furniture beetle and moths; there's also more mould. All our work is set in the context of trying to save energy and reduce the carbon footprint to help mitigate climate change, as well as adapting to its impacts."

Science aside, though, it's the aesthetics of her job that get Katy out of bed in the morning. "Solitary moments with achingly beautiful views of houses and landscapes… there's nothing like it," she smiles.

Web references

w1 – For more information about the National Trust, see: www.nationaltrust.org.uk

w2 – For more information about the Courtauld Institute of Art, see: www.courtauld.ac.uk

w3 – The Science and Heritage programme supports and funds interdisciplinary research. To learn more, see: www.heritagescience.ac.uk

w4 – National Heritage Science Strategy steering group is responsible for developing a national strate-

REVIEW

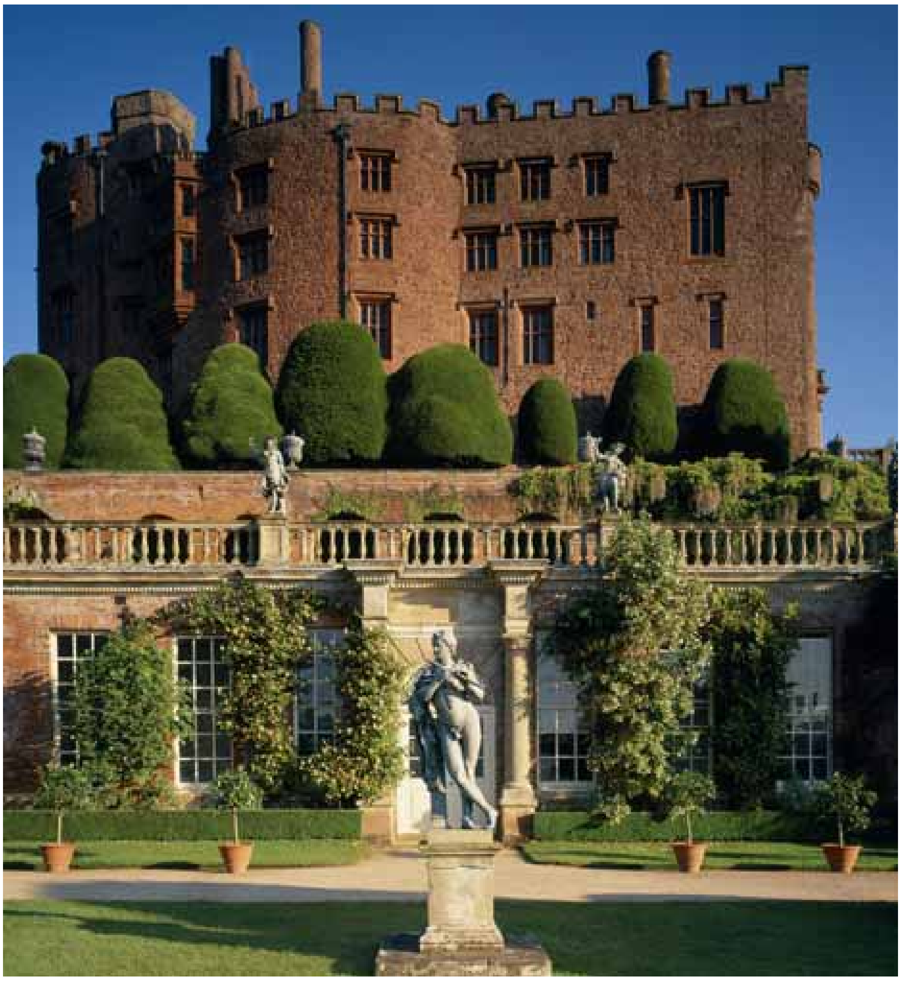
The article provides general information on what a career in conservation of sites and objects of artistic and historical significance is all about, and how science is involved in such efforts.

The many examples included are valuable in directing discussions in the science classroom focusing on how various environmental influences could affect objects, materials and structures in ways that would lead to their deterioration, and how global climate change is negatively affecting our cultural heritage.

The text is most suitable to be used in science, history and arts classes to show how these three areas of research can be combined to achieve the conservation of historic sites and artefacts. In school, interdisciplinary studies could be organised, with history and arts groups specifying specific environmental situations that threaten to destroy sites and artefacts of cultural value and science groups trying to find the solutions.

Michalis Hadjimarcou, Cyprus

Image courtesy of the National Trust Photo Library / Andrew Butler



Powis Castle in Wales, and its orangery

gy for heritage science. For more information, see: www.english-heritage.org.uk/nhss

w5 – For more information about International Academic Projects Ltd, which promotes education, training and research into conservation, archaeology and anthropology, see: www.academicprojects.co.uk

Information about the course Chemistry for Conservators can be found here: www.academicprojects.co.uk/chemistry.htm

w6 – For more information about Climate for Culture, see: www.moez.fraunhofer.de/en/gf/FuE-Kooperationen/Projekte/ClimateforCulture.jsp

w7 – For more information about the Engineering Historic Futures project, see: www.ucl.ac.uk/sustainableheritage/historic_futures.htm

w8 – To find out more about the UK's Engineering and Physical Sciences Research Council, see: www.epsrc.ac.uk

Resources

If you're looking for activities to link arts and science in the classroom, you might like the following *Science in School* articles:

Farusi G (2006) Teaching science and humanities: an interdisciplinary approach. *Science in School* **1**: 30-33. www.scienceinschool.org/2006/issue1/francesca

Farusi G (2007) Monastic ink: linking chemistry and history. *Science in School* **6**: 36-40. www.scienceinschool.org/2007/issue6/galls

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

Image courtesy of EMBL Photolab

Jeanne Keweloh taking part in an ELLS workshop

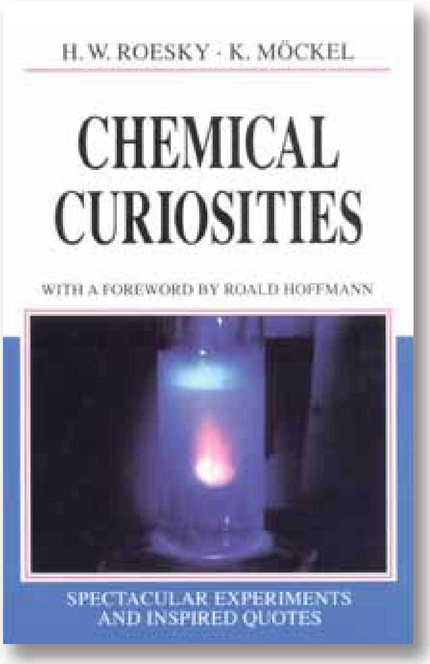
Teaching on the move

Jeanne Keweloh is a substitute teacher, going wherever she is needed to share her passion for science. She tells **Sonia Furtado** about the ups and downs of teaching on the move, and shares some of her strategies.

When a staff science teacher is sick or on leave at a secondary school in Lower Saxony, Germany, Jeanne Keweloh comes to the rescue. She takes on the class, and teaches biology, chemistry and/or physics, according to the school's needs. Two or three months later, she moves to another school and starts all over again. "It's not easy, being a 'travelling' substitute teacher," she says. "I have a new school every few months – sometimes even more than one school at the same time – and every school has its own style. There are new students, new colleagues, and new topics to teach, because although there is a common curriculum for all schools in Lower Saxony, each school develops its own detailed curriculum within those limits. Occasionally, I attend the teacher's classes before I start, to have a clearer idea. Generally, however, I only meet the teacher I substitute for at the end of my stay (if at all), so I have to figure things out for myself. Usually, the head of department and I agree on how to proceed. Of course I have to make sure that my grading is fair, so I check previous grades for orientation and discuss some cases with the head teacher, if necessary. I also learn a lot from my colleagues. The older ones have tremendous experience, and I sometimes seek their advice or attend their classes to see how they do things. It takes a lot of energy and I have to adapt to every school very quickly. It is a lot of work in a relatively short time, and then it's the same procedure again at the next school!"

This fast turnover has its up side, too, Jeanne vows. "The schools are happy to have me because I'm substituting for someone who is missing, so people are usually kind and helpful, and if I feel it's not the school of my dreams, it's still no big deal since I know I'll only be there for a limited time. Another good thing is that I get to know a lot of people and can compare the way different schools are run. So I can see what works and what doesn't. Importantly, that applies to my own work, too. I can see which environments I can function best in and why, so I'm constantly learning from this experience."

Experiencing different approaches to teaching – and different cultures – was very much a part of Jeanne's own training, not as a teacher, but as a scientist: she studied for a Baccalaureate in experimental sciences (série D) in France, a BSc and MSc in chemistry in the USA, and a PhD in chemistry in Germany, synthesising new compounds and testing their structures. What drove her to swap the lab for the classroom? A poignant personal experience, and a desire to be more involved in 'the real world', she says. "I had a rather unusual and particularly important, though extremely sad, experience in my private life. My son Albert was three years old when we discovered he had a brain tumour. He was put on therapy and really became very mature during that last year of his life. This sad event awakened in me a fascination for children and their development, and triggered a wish to participate in this process. I felt that as a chemist I had been too busy with matter and far too remote from people. I felt too detached from the outside world and real life. Luckily, I was able to start teaching life science, earth science and physical science at a private international school in Germany run by an



American director, since my experience teaching undergraduates during my PhD would have been sufficient qualification in the United States."

Later, Jeanne heard about the shortage of science teachers in Lower Saxony. "This shortage meant they also accepted qualified scientists with a minimum of three years' teaching experience, which I had. So I applied for a teaching position, but before I became a staff member in a particular school, I thought it would be helpful and interesting to try different schools."

Jeanne believes that being a scientist was an added advantage. "I can communicate my passion for science. Since I spent several years of my life in a laboratory, that makes it sound more credible to the students."

It was also during her scientific training that Jeanne came into contact with an approach she has found very successful in motivating students: the Christmas performance. "My PhD professor in Göttingen, Germany, Herbert W. Roesky, was well known for his chemistry Christmas performances and wrote a best-seller about them (Roesky & Möckel, 1996). I adapted the idea for the classroom, when I was teaching at Gymnasium Ganderkesee just before the Christmas break. At this time of year, I had some freedom to mix and combine classes, and we prepared the event in the students' spare time. Ninth- and tenth-graders (aged 15-17) performed spectacular experiments for their fellow students, whereas the younger sixth-graders (aged 12-13) ran easier ones and read some beautiful quotes – for example from Goethe or Hermann Hesse – which were related to the experiments. The students chose the experiments themselves – each trying to get the most spectacular ones, of course – so there was excitement for everybody."

"The Elements, who doth not know,
Their energies,
Their properties,
The Spirits' Master
Ne'er will grow!"

Johann Wolfgang Goethe, Faust Part I

Always ready for innovation, Jeanne embraces computers and the potential they bring to the classroom. "The computer lab always lifts everyone's spirits," she says. "In physics for example, computers or electronic white-boards enable us to work with animations, digital quizzes or crosswords, which the students love. At high-school level, when we talk about haemoglobin, sickle cell anaemia and oxygen transport in the blood, I like to work with programmes that provide 3D images of molecular structures, such as RasMol or RasWin[w1]. Working with macromolecules in 3D can be a lot of fun."

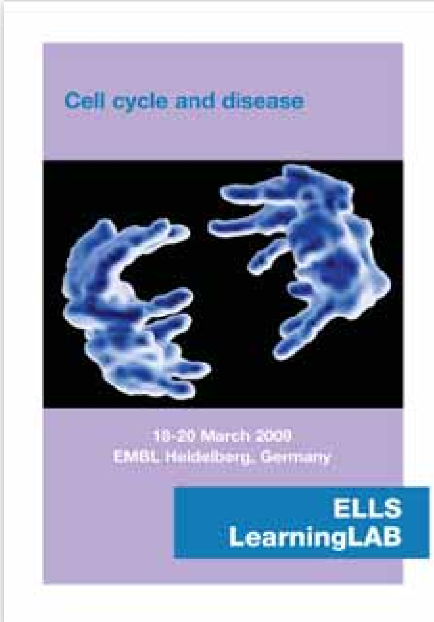
As helpful as these strategies are, Jeanne is also keen to stress the importance of teaching the methods and concepts of science. "In Germany, the new curricula for science emphasise the experimental side of teaching. This means students can experience what 'experimental sciences' really mean, and, since they have to be able to plan and perform their own experiments, teaching becomes interactive, too: it's not one-way anymore. The new curricula also emphasise conceptual aspects, which is great, because concepts are very important in science. If you understand them, you do not need to learn so much by heart," Jeanne tells us, and her students.

"Hands-on activities are a great way of motivating students, and helping them understand the concepts," she explains. "A good example for physics classes is the self-made battery: whether it is called the potato clock, the lemon clock or the mud clock[w2], it is always a great hit! And it is such a nice way to explain a difference in potential, because if you put the same metal on both sides, it does not work.

"In biology classes, a big hit for young and old is the extraction of your own DNA; it's a classic. Whether I run it in grade 7, 9 or 11, the students always leave holding their glass vials with radiant faces, as if they had just met Santa Claus! I usually invite school directors to this experiment, and they are always surprised by how good a mood it spreads among students."

To Jeanne, hands-on activities are not limited to scientific experiments, though. "Another simple but great idea for young biology students is to let them make their own 3D plant cell. If the school has arts or handicraft classes, this can be done as a joint project. The students usually create a wonderful collection of beautiful cells made of all kinds of materials – they have a lot of imagination! Multidisciplinarity can also come into play in larger projects like science fairs, which are always a big success. Projects can include pieces of art representing the solar system, renewable energy sources, volcanoes and so on."

Forever in search of new ideas, Jeanne keeps on the lookout for training opportunities of her own, even though substitute teachers have to find their own funding to attend such events. "Teacher training activities are very useful, as they give you the distance to evaluate your work and the opportunity to improve its quality, with new ideas and techniques. I recently attended a LearningLab on cell cycle and disease[w2], organised by the European Learning Laboratory for the Life Sciences (ELLS)[w3] in Heidelberg, Germany. It was



LearningLab on cell cycle and disease

Image courtesy of EMBL Photolab

REVIEW

Changing times in the world of work: perhaps the opportunity to teach peripatetically could be the answer for those who haven't obtained, or perhaps indeed don't want to commit to, a permanent post. Jeanne's experiences certainly provide food for thought about the possibilities and challenges of substitute teaching.

Marie Walsh, Republic of Ireland

Image courtesy of EMBL Photolab

organised as a combination of seminars and practical activities. We learned innovative and inspirational science teaching in a very nice atmosphere and met scientists as well as colleagues from all over Europe. As a teacher, what I find really helpful are usually little experiments, which are not very complicated to prepare, run or finance, and which I can easily integrate in my classes at any time. Of course, more challenging experiments are also useful to provide insights into a new field or illustrate important concepts, but one does not run them very often. The good thing about the ELLS workshops is that they provide us with both."

And for both students and teachers, Jeanne concludes: "Fun is an important factor in the learning process. No fun is a closed door, whereas fun is an open door."

References

Roesky HW, Möckel K (1996) *Chemical Curiosities: Spectacular Experiments and Inspired Quotes*. Weinheim, Germany: Wiley-VCH. ISBN-13: 978-3527294145

Web references

w1 – You can download RasMol and RasWin for free here: http://rasmol.org

w2 – The potato clock:

www.ehow.com/how_18637_make-potato-clock.html

www.kidzworld.com/article/4726-how-potato-batteries-work

The lemon clock: http://pbskids.org/zoom/activities/sci/lemonbattery.html

One of many suppliers of the mud clock kit: www.toysandlearning.co.uk/make-your-own-mud-clock.htm

w2 – LearningLab on *Cell Cycle and Disease*: www-db.embl.de/jss/EmblGroupsOrg/conf_122

w3 – To learn more about ELLS, see: www.embl.de/ells

Whynotchemeng.com website

By the Institution of Chemical Engineers, UK

Reviewed by Tim Harrison, Bristol, UK

Whynotchemeng.com is an excellent website designed for students who are considering a career in chemical or biochemical engineering. The website has two particular strengths: careers information, and a resource of practical demonstrations designed to inspire potential young physical scientists and chemical engineers.

After logging on according to region – the UK and Ireland, Australia or the rest of the world – students, parents and teachers can find out about the various fields in which chemical engineers are involved, and hear about the lives and work of practicing engineers in the *Time of Our Lives* section. The website also lists university courses and explains the application procedure in several parts of the world, and provides the contact details of companies that offer employment opportunities to graduates in the field. Specifically for teachers, there are lesson plans on how to use the careers resources in class.

The *Future Life* section informs students about four key working areas for chemical engineers: health, energy, food and water, and the environment. Each of these sections presents four or five easy-to-understand descriptions of the work that chemical engineers do to help address the particular problems of each field; under health, for example, users will find information about stem cell research and tissue engineering.

The Institution of Chemical Engineers' *Top Ten Flash Bang Demos* can be found in the teachers' section of the site, and provides instruction sheets and videos to help teachers recreate the fun, safe and inspiring demonstrations – which include *Flying Cake Cases* and *Screaming Jelly Babies* – in their own classrooms. While designed to fit the UK's Key Stage 4 curriculum (students aged 14-16), the demonstrations are so engaging that I'm sure teachers will find ample opportunity to present them to other ages too.

The only criticism I have of some of the well-made videos is that the demonstrator sometimes doesn't follow safety procedures by tying her hair back or wearing safety glasses. For teachers new to such demonstrations, I strongly suggest practicing the performance several times without the presence of students and also to consider the space required for some of the demos.

Gene ABC website

By the Swiss National Science Foundation

Reviewed by Fabienne Jäggi

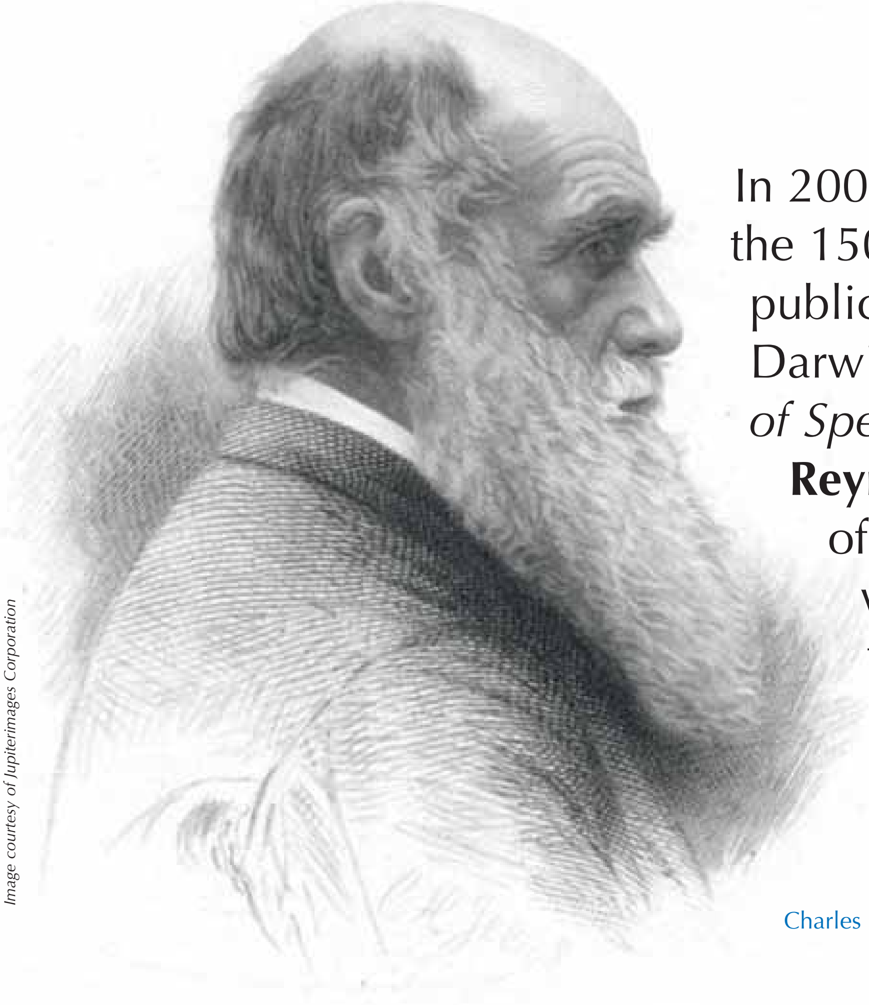
DNA, also known as the molecule of life, has fascinated scientists since its discovery over half a century ago. But what exactly is DNA? What does it look like? What are genes and how do geneticists work with them? Gene ABC, a website by the Swiss National Science Foundation (www.gene-abc.ch), invites everyone on a journey into the world of genes. Available in German, French and Italian, it is regularly used by biology teachers as well as students aged 14-20.

The website has eight sections, ranging from gene technology and the history of genes to a question-and-answer section. Apart from the history, glossary and Q&A, each section features a selection of films which combine video footage and animations to explore a topic in depth. In an introductory section, visitors discover the nature of a cell. They find out what genes are, where they are stored, how they are transmitted from one generation to the next and how the information in a gene is translated into function. A second section describes genes and their meaning in greater detail.

Yet another section presents the techniques of genetic engineering and explains the methods used to introduce additional genes into bacteria or animal or plant cells. This part takes its examples from gene technology applications in medicine, explaining how gene therapy works, how drugs are produced by genetic engineering, and how pathogens are identified. The techniques and goals behind genetically modified plants, as well as details about Golden Rice and its potential in developing countries, explain how knowledge about DNA and genes is applied in agriculture.

Using illustrative animated graphics, easy-to-understand texts and examples taken from everyday life, the Gene ABC website is a tool which enables visitors to easily learn about the complex subject of genes.

The *Beagle*



In 2009, the world celebrates the 150th anniversary of the publication of Charles Darwin's *On the Origin of Species*. **Emmanuel Reynaud** revisits the story of the vessel aboard which the foundations for Darwin's publication were laid.

Image courtesy of Jupiterimages Corporation

Charles Darwin

Say the word 'beagle' and people will automatically think of Charles Darwin. The naturalist never owned a scent hound of this breed, confining his hunting to fossils and bones rather than rabbits ands hares – but the association comes, of course, from the name of one of the most famous ships in history.

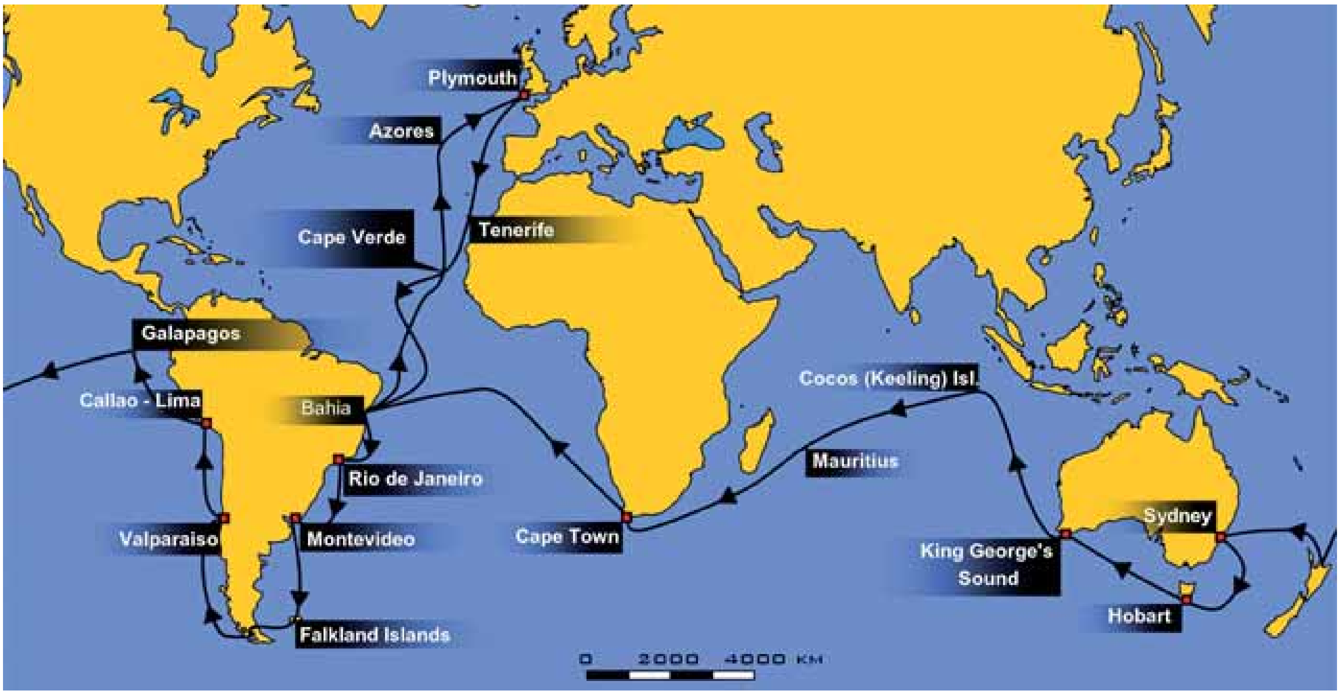
HMS Beagle, the Royal Navy ten-gun brig-sloop (a sailing warship) that carried Darwin around the world in the 1830s, was first launched in 1820 from the Woolwich Dockyard on the River Thames. In July of the same year she proudly took part in the fleet review organised for the coronation of George IV, and was the first ship to sail under the newly built London Bridge.

But that, so far, was it. There was no further use for her at the time, and the ship found herself already put out to pasture; she was moored afloat without masts or rigging for the next five years. It was when the Royal Navy decided to turn her into a survey boat that the real story of the *HMS Beagle* began.

Image courtesy of Jupiterimages Corporation

In May 1826, after losing a few cannons and gaining a mast, the *Beagle* set sail from Plymouth under the

Image courtesy of Badseed; image source: Wikimedia Commons



The voyage of the *Beagle*

Public domain image; image source: Wikimedia Commons

HMS Beagle (centre) from an 1841 watercolour by Owen Stanley, painted during the third voyage while surveying Australia

command of Captain Pringle Stokes. She accompanied the *HMS Adventure* on a hydrographic survey of Patagonia and Tierra del Fuego at the southernmost tip of South America. As she sailed the desolate waters, her captain became melancholic and fell into a depression, locking himself in his cabin for two weeks; eventually he shot himself and died 12 days later. This wasn't the best start for a survey boat, and this curse might have deprived the *Beagle* of any future, were it not for the fact that humans have an extraordinary ability to learn by experience.

Flag Lieutenant Robert FitzRoy, a 23-year-old aristocrat, was awarded the responsibility of sailing the *Beagle* back to England. The young man was re-appointed as captain on 27 June 1831, and the *Beagle* was commissioned on 4 July of that same year under his command for a second voyage to Tierra del Fuego. FitzRoy decided that to avoid ending up the same way as Pringle Stokes, he would have to find himself a companion. He went in search of a self-financing passenger who would provide company during the voyage, ideally a geologist or a naturalist – and who should step forward but Charles Darwin, a recent graduate from Cambridge University, who wanted to visit the tropics before becoming a rural clergyman.

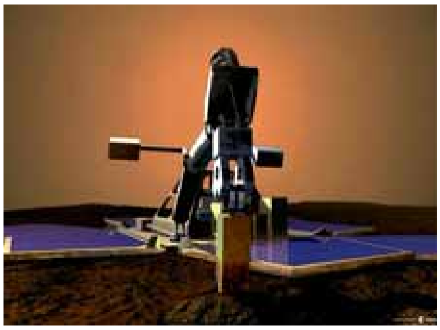
The outcome of that successful second voyage is well known. Darwin went into the jungle and was puzzled by the origin of its diversity. He climbed mountains and found fossils of sea shells: had the sea level been this high before, or was the Earth's crust able to fold up to such heights? He collected birds on different islands of the Galápagos archipelago and observed swimming iguanas. He discussed his findings with Captain FitzRoy until the small hours, debating creation and struggling with this evidence that seemed to contradict his own beliefs. Returning to England in 1836, Darwin went back to his house in the countryside, and after years of struggle he published *On the Origin of Species* in 1859.

While Charles Darwin tried to conquer his demons and tie his findings together in a book, the *HMS Beagle* set off for a further voyage in 1837, this time around the coast of Australia. Eventually, the ship's evolution from warship to peacekeeper was complete, when it became a static coastguard watch vessel in the River Roach to control smuggling on the Essex coast. Her last years ended with a whimper rather than a bang; oyster traders complained that she was

Image courtesy of Jarek Wieczorek, Antofaya Expeditions

Captain Pringle Stokes's grave

Image courtesy of ESA / MediaLab



Artist's impression of the *Beagle* lander on the Martian surface

blocking their route, and she was eventually sold to William Murray and Thomas Rainer, who used her timbers to build a farmhouse.

In the following years, half a dozen ships bore the famous name; eventually, a *Beagle* also sailed forth into space in 2003, when the British named a landing spacecraft in ESA's Mars Express mission '*Beagle 2*'. This time the name brought misfortune rather than glory: the spacecraft was lost before it even touched down on Mars' surface, and either missed the planet altogether or burned out somewhere, just like poor Captain Pringle Stokes.

But the *Beagle* is set to have its day again: the UK-based *HMS Beagle* Project[w1] is making plans to build a replica ship to sail the world in its wake and apply the tools of modern science to the work started by Darwin and Captain FitzRoy 170 years ago. As well as fostering international friendships and scientific alliances, the project will carry out original research in evolutionary biology, biodiversity and – perhaps most importantly – climate change.

Web references

w1 – A replica of the *HMS Beagle* is planned for 2009: www.thebeagleproject.com

Resources

The sad story of the *Beagle 2* is available at: www.beagle2.com/index.htm

The *HMS Challenger* carried out another major survey in 1871-1876 and became popular through the works of Ernst Haeckel and the Blaschka family: http://life.bio.sunysb.edu/marinebio/challenger.html www.richardcorfield.com/pages/books/silent_landscape.htm www.warmus.com/Blaschka%20Sea%20Creatures%20Cornell%20Warmus.htm

The Tara Oceans will survey the seas from 4 September 2009 for three years, in a modern version of the *HMS Challenger* expedition: http://oceans.taraexpeditions.org

Dr Emmanuel G. Reynaud is Stokes Lecturer at the School of Biology and Environmental Sciences at University College Dublin, Ireland. He works on the biology of epithelia and has a particular interest in the evolution of this tissue. He uses a variety of experimental models, from choanocysts, sponges and marine protists to 3D cell culture of mammalian cells. He is the coordinator of the Tara Oceans imaging platform.

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