Summer 2014 Issue 29

SCIENCE in SCHOOL

The European journal for science teachers

In this issue:

The solar bottle bulb

Also:

Super cold meets super hot

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Editorial

Welcome to the 29th issue of *Science in School*


With the FIFA World Cup, football fever seems to be everywhere and it is amazing to think how much the game has changed since the first one in 1930.

Back then, European teams made the long trip to Uruguay by ship and trained and exercised on board for over two weeks. Supporters back home would have read of their country's progress in the newspapers but today we (and our less enthusiastic friends) can watch the game live almost anywhere in the world. This is made possible by the communication satellites that orbit our planet.

As powerful it can be, modern technology can still go wrong and it is often when things go wrong that we notice how easy modern technology has made our lives. Natural events, such as solar flares, could make you miss that all important penalty kick by disrupting satellite communication and we explore the phenomenon in this issue (p.23) as well as discussing how astronomy can help us understand solar weather and the life cycle of stars (p.49).

Elsewhere, we look at both low and high tech advances. For example, while electricity will light the world cup stadiums in Brazil, we demonstrate how Brazilian mechanic Alfredo Moser used the principle of refraction to create a low cost lighting solution without it (p.18). We also explore the important role of water analysts (p.35) and show how to investigate water transport in plants – how can trees in the Brazilian rain forest grow so tall, the answer is in their internal structure (p.41).

Going even higher up we fly into the clouds and atmosphere onboard airplane laboratories with scientists that analyse the air they fly through (p.9). Beyond that, we look at how virtual clouds and data stored online can help us explore our evolutionary heritage (p.30). We also look at how EFDA-JET took a problem and turned it into a benefit, triggering small incidents in their plasma that could be controlled rather than waiting for larger more destructive events (p.13).

2014, of course, marks 100 years since the beginning of the first world war. When thinking of destructive events, there are few that are so seared into the European consciousness. To open our issue this month, we explore the complicated ethical history of chemist Fritz Haber. A Nobel Prize winner, Haber helped feed the world, yet the Haber-Bosch process facilitated the current rapid population explosion and today it uses 1% of all the energy produced. However, it is Haber's war work that is most controversial and which we look at more closely (p.5).

Whether you flee the football this summer or follow it intently, we hope you also find something useful in this new issue.

Laura Howes and Isabelle Kling
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About *Science in School*

The European journal for science teachers

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

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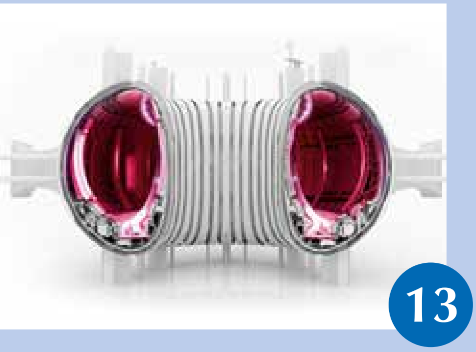

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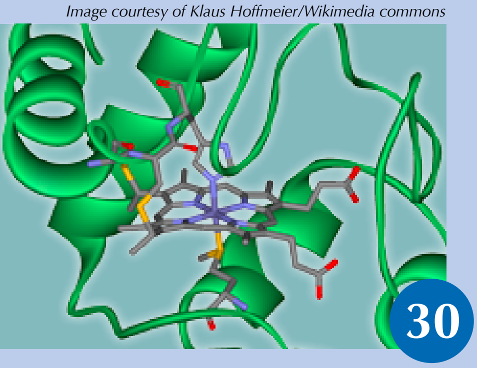

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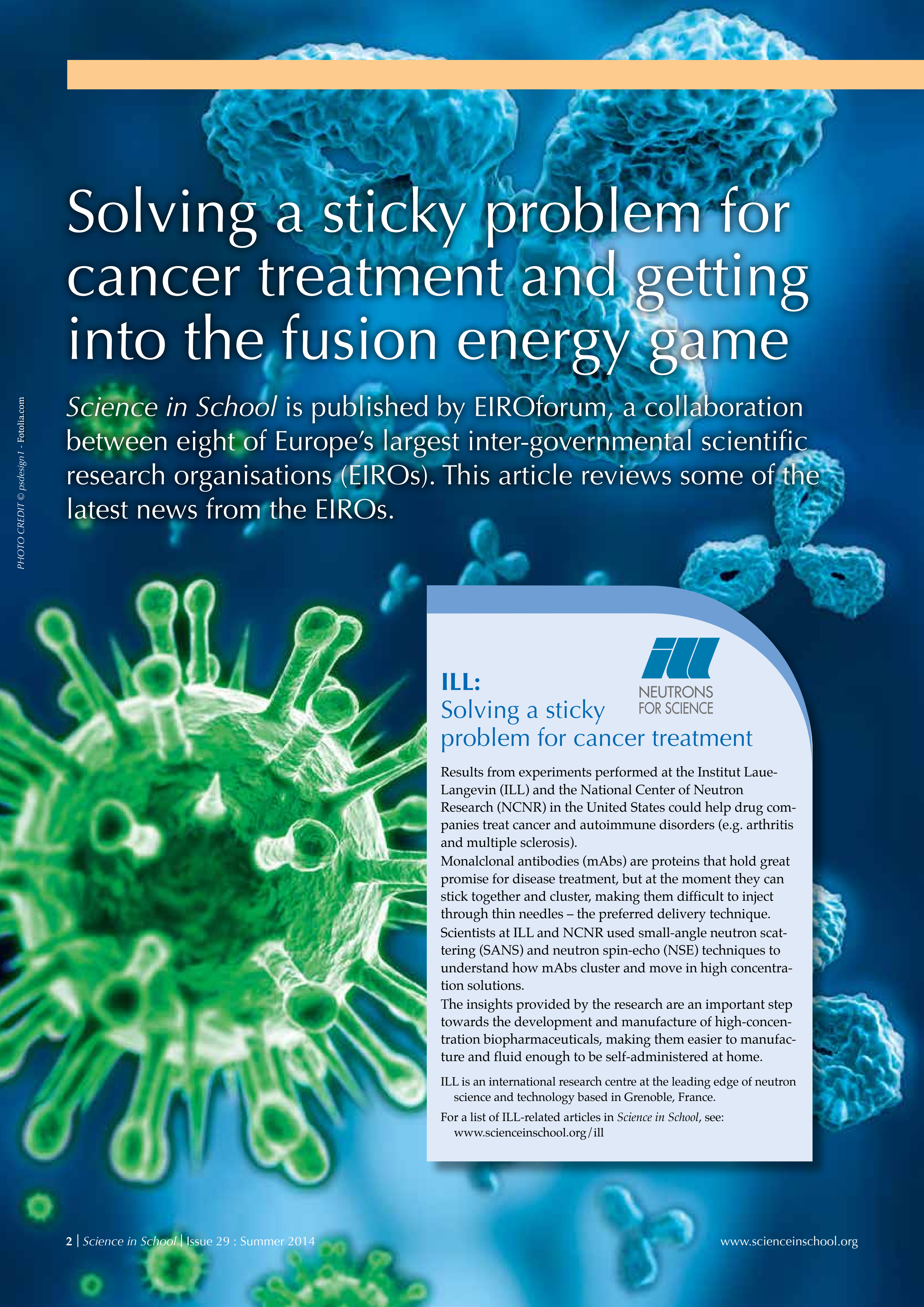

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Solving a sticky problem for cancer treatment and getting into the fusion energy game

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

ILL: Solving a sticky problem for cancer treatment

NEUTRONS FOR SCIENCE

Results from experiments performed at the Institut Laue-Langevin (ILL) and the National Center of Neutron Research (NCNR) in the United States could help drug companies treat cancer and autoimmune disorders (e.g. arthritis and multiple sclerosis).

Monalclonal antibodies (mAbs) are proteins that hold great promise for disease treatment, but at the moment they can stick together and cluster, making them difficult to inject through thin needles – the preferred delivery technique.

Scientists at ILL and NCNR used small-angle neutron scattering (SANS) and neutron spin-echo (NSE) techniques to understand how mAbs cluster and move in high concentration solutions.

The insights provided by the research are an important step towards the development and manufacture of high-concentration biopharmaceuticals, making them easier to manufacture and fluid enough to be self-administered at home.

ILL is an international research centre at the leading edge of neutron science and technology based in Grenoble, France.

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

EMBL: Taken out of context

Cancers are often caused by mutations in DNA that can make one specific gene become hyperactive, causing the cell to behave abnormally. However, few such mutations had been found in medulloblastomas – a rare but deadly form of brain tumour that affects children – so scientists didn't really know what caused the disease and how to cure it.

The team of Jan Korbel from EMBL, in collaboration with Stephan Pfister from the German Cancer Research Centre (DKFZ), looked at the genome sequences of the type of medulloblastoma with the worst prognosis: group 3 medulloblastoma. They found that different patients had different large-scale changes to their DNA (inversions, deletions, duplications or even complex re-arrangements involving many DNA-shuffling events), that all resulted in either a gene called *GFI1B* or one called *GFI1* becoming abnormally active. But the gene itself had no mutations. All that had changed was its context and location within the chromosome: the large-scale DNA changes placed *GFI1B* (or *GFI1*) close to sequences called enhancers, which can dramatically activate genes. This turned the gene on in cells where it would normally be switched off, and that, the researchers think, is what drove the tumour to form.

This is the first time such a mechanism has been described in solid cancers. "This could be relevant for research on other cancers, as we found that those genes had been activated in a way that cancer researchers don't usually look for," says Korbel.

To read more about Jan Korbel and his research, visit his personal webpage: http://bit.ly/U90aH7

To learn more about Stephan Pfister, check this article published previously in *Science in School*:

Schulter D. (2014) Doctor in the morning, researcher in the afternoon. *Science in School* **28**: 50-53

www.scienceinschool.org/2014/issue28/Pfister

For more information on this finding, check the EMBL website: www.embl.org/press/2014/140622_Heidelberg

To read the scientific article:

Northcott, P.A., Lee, C., Zichner, T. *et al. Nature* (in press)

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

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

Jan Korbel and Thomas Zichner

Image courtesy of EMBL photolab/Hugo Neves

EFDA-JET: The physics behind fusion energy in a game

EFDA has developed an App that conveys some core mechanisms behind operating a fusion reactor. In 'Operation Tokamak', gamers create fusion conditions by bringing a plasma up to temperature, confining it with magnetic fields and keeping it stable. If successful, players learn how much energy they produced and how much CO_2 they saved compared to fossil power. Players' tools are magnets, heating systems, and microwave guns, which they use to shoot magnetic islands – instabilities, that weaken the plasma confinement. The game also intends to raise students' interest in taking up STEM careers by giving players a taste of the excitement scientists and engineers feel when conducting experiments.

'Operation Tokamak' offers teachers a modern tool to explain the basic physics behind fusion power – heat and confinement – as well as touching the subject of plasma stability. The fact that fusion plasmas develop instabilities is one main reason why fusion power has not yet been realized. JET dedicates a large part of its research to mitigate these phenomena.

Image courtesy of EFDA-JET

The App is available for Apple and Android devices and you can learn more at: www.efda.org/fusion-expo/operation-tokamak/

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

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

Image courtesy of European XFEL

Work has begun on the above-ground portion of the headquarters complex in Schenefeld, Schleswig-Holstein.

European XFEL: Anticipation builds

Activity has been increasing at European XFEL, the 3.4 km long X-ray free-electron laser facility under construction in the Hamburg area of Germany. Following completion of the underground construction last year, above-ground construction is moving into a new stage, and scientists have been progressing on the development and refinement of instrumentation and methods.

One such method that many future users of the European XFEL are anticipating is the possibility of creating "molecular movies", or datasets showing atomic motion within molecules with unprecedented clarity. The European XFEL's fast repetition rate – 27 000 flashes per second – and intense brightness will allow scientists to collect information at a femtosecond (quadrillionth of a second) timeframe. The scientists could take that data and, like the frames in an animation, show how atoms move within a molecule and how exactly complex chemical reactions occur. A recent experiment, which involved scientists from European XFEL, showed that procedures similar to the theorised "molecular movie" ones can reveal transitional states – the "in-between" forms of molecules found during the progression of chemical reactions.

In another experiment, scientists successfully tested a way of identifying and measuring spiraling, or circularly polarized, X-ray light. Such light could open unexplored areas of chemistry and help reveal new information about the asymmetries, or handedness, of certain molecules crucial to life.

Yet another publication revealed details about the chemistry of hydrogen inside gas giant planets such as Jupiter. Beyond pushing forward the development of several instruments, these studies are examples of the depth and breadth of research possible with light sources such as European XFEL, crossing boundaries of chemistry, biology, physics, and many other fields.

Meanwhile, scientists and engineers have been busy working on special sample delivery systems and detector arrays for the instruments, data handling and control software for the entire facility, devices for monitoring the characteristics of the X-ray flashes, and superflat mirrors specially designed to direct the X-ray flashes so they can keep those characteristics after reflection.

On the construction side of things, work has begun on the headquarters building in Schenefeld. The building sits on top of the 4500 m^2 underground experiment hall, and is part of the same structure. In three years' time, the headquarters and experiment hall will be rich with cutting-edge research projects by users from around the world.

European XFEL is a research facility currently under construction in the Hamburg area in Germany. It will generate extremely intense X-ray flashes for use by researchers from all over the world. To learn more, see: www.xfel.eu.

For a list of XFEL related articles in *Science in School*, see: www.scienceinschool.org/xfel

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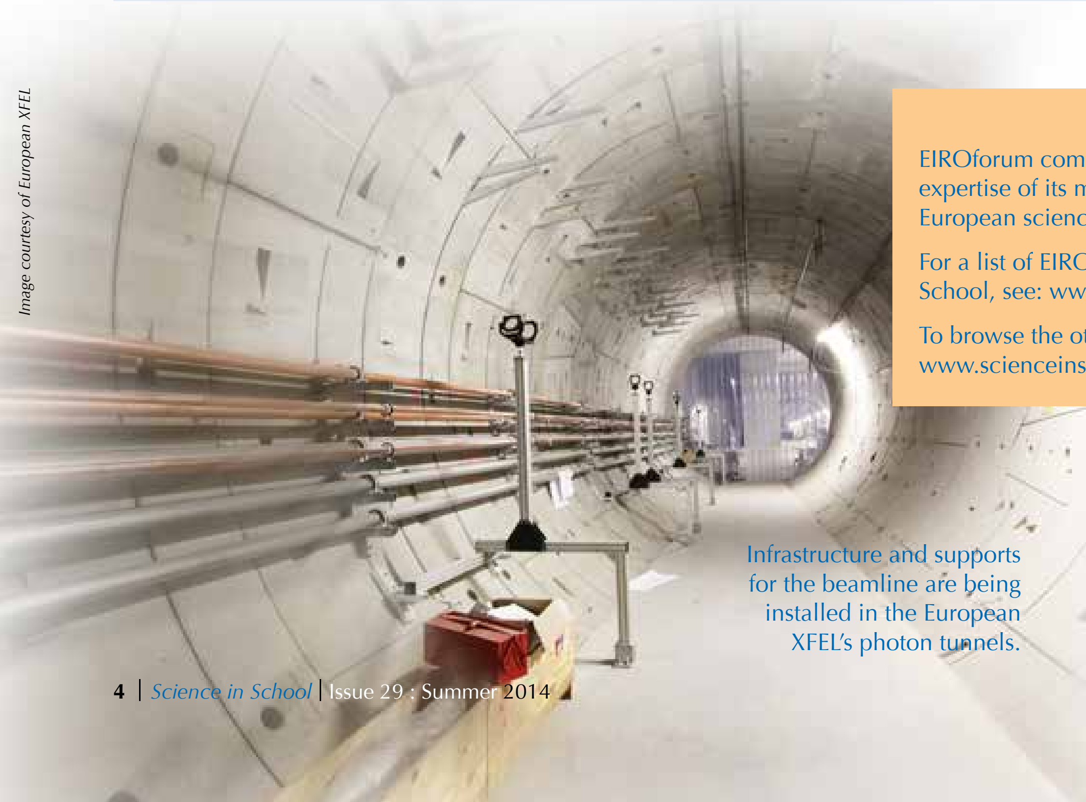

Image courtesy of European XFEL

Infrastructure and supports for the beamline are being installed in the European XFEL's photon tunnels.

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Chemistry

Experiments in integrity – Fritz Haber and the ethics of chemistry

One hundred years after the start of the First World War, chemical weapons are still in the news. We consider some of the ethical questions behind the war's chemical legacy.

Image courtesy of the German Federal Archives/Wikimedia Commons

Fritz Haber (1868–1934)

By Jane Essex and Laura Howes

Our lives today have been greatly improved by chemistry, but no discovery has been universally positive. The negative consequences of chemistry, from pollution to thalidomide, have led to a public distrust of the science and a fear that the work of single-minded chemists in the laboratory will harm society. No more so than in the arena of war. One hundred years ago, at the beginning of the First World War, chemists worked to help their respective countries. The story of chemistry and chemists during that time can help us explore some of the complicated ethical history that underlies the field to this day.

Great power and great responsibility in the industrial age

There is a simple chemical reaction that, for many, symbolises the best and worst of late 19th and early 20th century chemistry: $N_2 + H_3 \rightleftharpoons 2NH_3$. The apparently uncomplicated mixture of nitrogen and hydrogen was in fact a triumph of chemistry that earned Fritz Haber the Nobel Prize in Chemistry in 1918. Today more than

REVIEW

- Chemistry
- Biology
- Geography
- History
- Ages 16–18

This article shows an interdisciplinary approach to the study of the benefits and risks related to scientific research. The article might provide valuable background information for oral presentations or projects.

Angela Köhler, Romain-Rolland-Gymnasium, Germany

Image courtesy of Library of Congress/ Wikimedia commons

"Gassed", a painting by John Singer Sargent about the horrors of chemical warfare in the First World War

Image in the public domain

Image courtesy of US National Archives and Records Administration / Wikimedia commons

Picture posed in France, near front-line trenches, by Major Evarts Tracey, Engineer Corps, USA, to illustrate effects of phosgene gas, 1918

130 million tonnes of ammonia are produced each year using the so-called Haber-Bosch process, providing 99% of all nitrogen fertilisers.

Yet, for many, Haber is a controversial figure who also worked to create chemical weapons. Although his work on nitrogen fixing allows us to grow more food than ever before, Haber's process for making ammonia is also thought to have prolonged the First World War by at least 18 months. The man who 'made bread from air' is a complicated figure.

During the 19th century, chemistry flourished and with it the capacity of chemists to do good or harm on a scale never before imagined. While the science rapidly improved people's lives and health, it raised a spectre that threatened those same individuals. As life expectancy rose, and populations grew, more food was needed. However, the fertiliser of the time, nitrogen-rich guano from South America, had nearly run out. A new source of ammonia was needed. In collaboration with the German chemical firm BASF, and working with Robert Le Rossignol, a young British scientist, Haber achieved the first synthesis of ammonia using just hydrogen and nitrogen – gases from the air around us – in the early 1900s.

The German state and its success allowed Haber, the son of a Jewish city councillor in what is now Wrocław, Poland, to pursue his intellectual thirst. Haber was fiercely patriotic; today, we might feel uncomfortable with such fervent nationalism, but at the time it was quite normal. Haber himself claimed that the sense of Germanhood was something to adjust to "like everything great and eternal" and at the age of 24 he converted to Christianity.

At the outbreak of war, British ships blockaded the import of guano from South America and so industrial production of ammonia was vital to feed the German population. The blockade was also a problem for the production of ammunitions, which need nitrates. As early as September 1914, a team of experts, including Haber, was appointed to find a solution to the problem; soon afterwards, chemical manufacturers were using Harber's method to produce nitrates for explosives. But if Haber's ethical standing could already be considered complicated, his next steps were even more controversial.

Father of chemical weaponry

It soon became clear that hopes of the war being 'over by Christmas' would not be realised and what had been planned as a lightning-fast war was digging in. Increasing the amount of firepower alone would not end the war quickly.

For the patriotic Haber, it seems there was little doubt that all other considerations were secondary to the interests of his country. New technology could, he concluded, give Germany the decisive advantage to end the war quickly. If his efforts had succeeded, the war might have been over sooner with many more lives saved, but instead Haber's discoveries have become one of the most controversial parts of modern warfare – chemical weapons.

Weaponised chemical irritants were already banned by the Hague Conventions of 1899 and 1907, but Haber was not working to produce just an irritant gas. Instead, he focused his ef-

BACKGROUND

Clara Immerwahr

Before marrying Fritz Haber, Clara Immerwahr was an accomplished chemist in her own right. In fact, she was probably the first woman to earn a PhD in chemistry in Germany. Societal expectations at the time were that the highest a woman could hope to rise was lab assistant. After her marriage to Fritz, Clara felt increasingly stifled and found that her research career became incompatible with the role of wife and mother that she was expected to fulfill. However she worked with her husband behind the scenes and continued to give lectures to women.

The marriage was already in trouble by the time Fritz Haber began his war work. A pacifist, Immerwahr pleaded with him to stop his work on chemical weapons, and publicly denounced it as a "perversion of the ideals of science". He responded by denouncing her as a traitor.

This year, Clara Immerwahr has been the subject of a successful biopic on German television

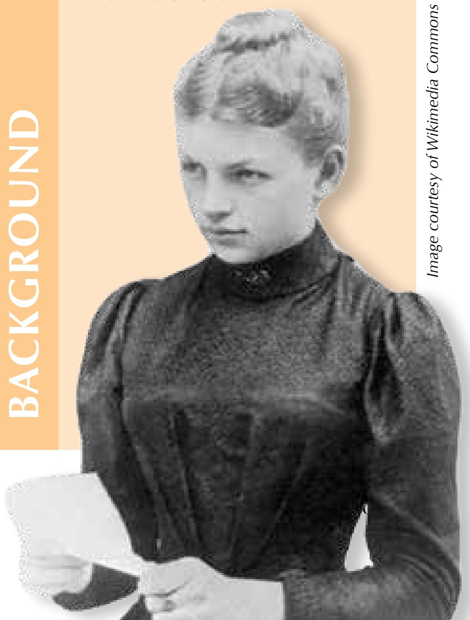

Image courtesy of Wikimedia Commons

Clara Immerwahr (1870–1915)

forts on a gas that would be a weapon in its own right. After extensive tests and analyses, Haber travelled to Ypres in April 1915. It was there that he supervised the first use of chlorine gas, now so inextricably linked to the trench warfare of the First World War.

Chlorine gas worked 'well', killing thousands, but it did not prove to be the military advantage Haber hoped it would be. Instead, chemical weapons just became another weapon during the war, and by defying the Hague Conventions, Germany's actions provided the excuse that the Allies needed to roll out their own gases in response.

Shortly after Haber returned from Ypres, his wife committed suicide in protest at his work. Haber's loyalty to the German cause seems to have remained unshaken and the next morning he left to oversee chlorine gas being used on the Eastern Front.

BACKGROUND

The ethical history of the Nobel Prizes

Another chemist forced to re-evaluate the ethicality of his work was Alfred Nobel, whose name is now most commonly associated with the Nobel Prizes that are funded from his legacy. Nobel made his fortune manufacturing dynamite, originally for mining. However, the use of dynamite in warfare was criticised by the Swedish society, as Nobel was distressed to discover when his obituary was mistakenly published while he was still alive. Perhaps because of these criticisms, when Nobel did die, his will founded the Nobel prizes.

Alfred Nobel (1833–1896)

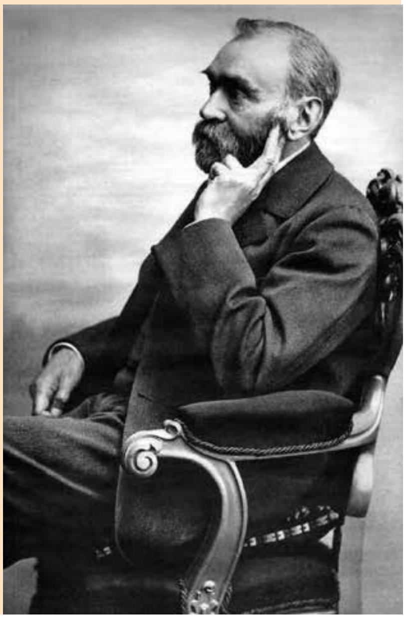

Image courtesy of www.imagebank.sweden.se, Gösta Florman / The Royal Library Wikimedia Commons

Chemistry

The ethical legacy of Fritz Haber

Subsequent generations, who have enjoyed the fruit of ammonia-based fertilisers, may have a more moderate view of Haber's impact than his contemporaries, including his wife Clara. In 1918, just after the end of the First World War, Haber was awarded the Nobel Prize in Chemistry but his war work was widely known and there were protests against the award. However, the Nobel Committee recognised that as well as contributing to the creation of weapons, Haber's work on the synthesis of ammonia meant that he was a man who had "conferred the greatest benefit to mankind".

Haber's work illustrates the idea of individual responsibility. Although some of his work caused suffering and was designed to do so, other parts benefitted humanity. Doing good to others is viewed positively by all ethical criteria, but it could be argued that such good is cancelled out by unethical behaviour and harm.

A poppy field in Flanders

Image courtesy of Tijl Vercaemer/Flickr

Events during the Second World War, many of which were highly dependent on the work of scientists, such as the use of atomic weapons and the events of the Holocaust, were more enormous and more terrible than ever before. Society was forced to re-evaluate whether individual conscience could be sufficient to regulate the work of scientists. In 1947 the Nuremburg Code was drafted to set out the principles by which scientific research on humans should be conducted. All research, whether or not it involves living subjects, is now required to conform to the principles of research ethics, which consider both the reliability of the findings and the ethical impact of the research methods. Research ethics specify the standards of honesty expected of each researcher and make it obligatory to open work up for scrutiny by others. However, we can never truly be sure of the impact of our work, and of what others might use it for.

Resources

The Haber process helps to feed the world but has also taken its toll on the environment. To find out more, watch Daniel Dulek's lesson on 'The Haber process' at TED-Ed: http://bit.ly/1mQunRP

A recent short film about Fritz Haber, called 'Haber', is now available on DVD. The filmmakers have also made free teacher resources including scientific overviews of Haber's discoveries and the surrounding ethical debate. See: www.haberfilm.com/education.html

The First World War website, which describes itself as a multimedia history of World War I, also has an interesting page on the development and use of chemical weapons during the conflict. See: www.firstworldwar.com/weaponry/gas.htm

The Nobel Prize website contains information about all Nobel Prize winners and Alfred Nobel himself. For an article exploring Alfred Nobel's thoughts on war and peace, visit: http://bit.ly/1saZgZv

If you found this article interesting, why not browse the other science and society articles in *Science in School*. See www.scienceinschool.org/society

Jane Essex is a lecturer in Science Education at Keele University in the UK. After graduating from the London School of Pharmacy, she undertook a postgraduate Certificate in Education and qualified as a science teacher with a specialty in chemistry. While teaching, Jane studied for a masters degree in Education and later completed a doctorate in Education. Jane is interested in all aspects of science education, with a major focus on chemistry education and, more widely, interdisciplinary approaches to science. She specialises in the study of the history, philosophy and ethics of science, and how these issues can best be presented in school.

Laura Howes is Editor of *Science in School*. She studied chemistry at the University of Oxford, UK, and then joined a learned society in the UK to begin working in science publishing and journalism. In 2013, she moved to Germany and the European Molecular Biology Laboratory to begin work at *Science in School.*

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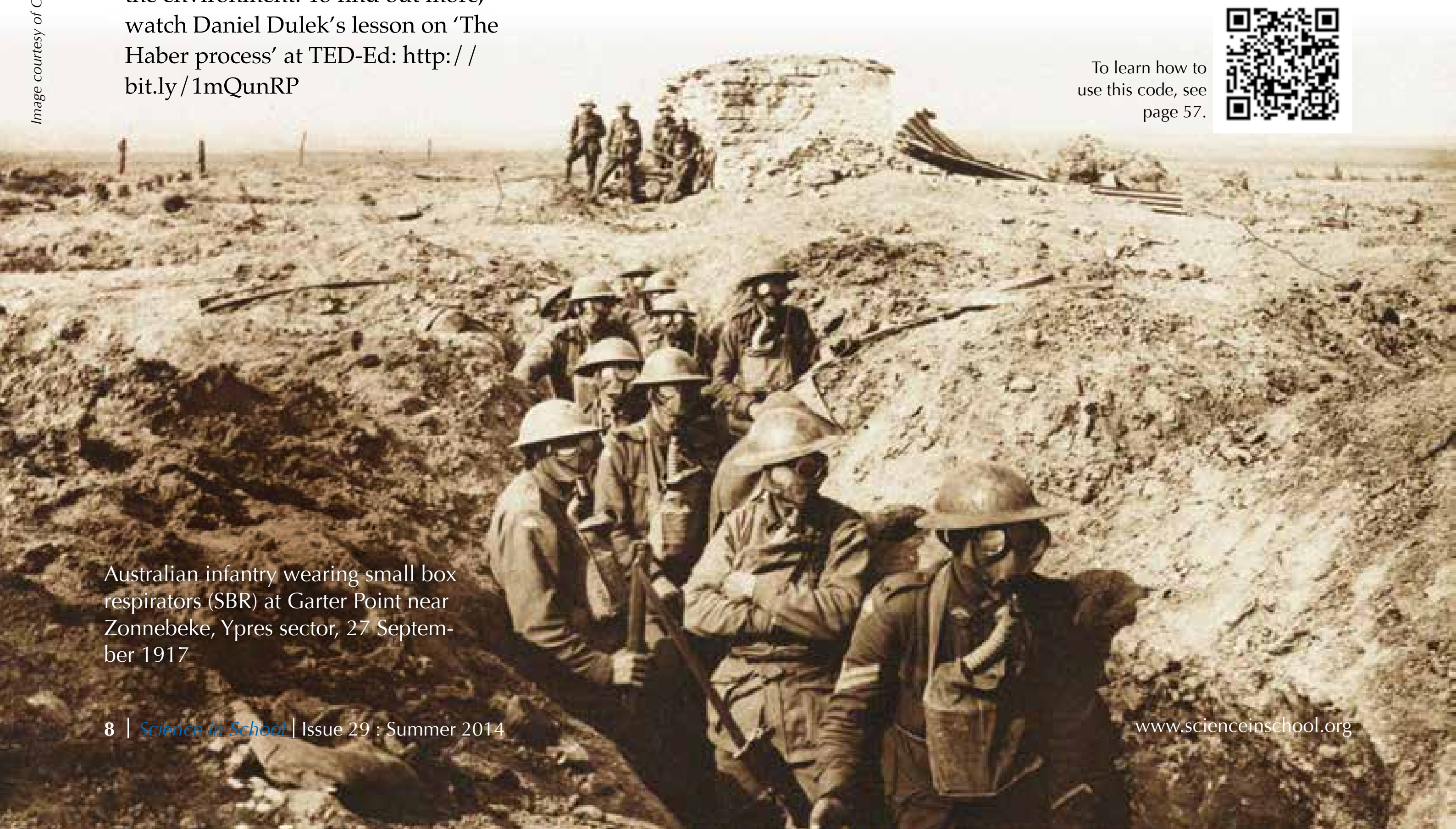


Australian infantry wearing small box respirators (SBR) at Garter Point near Zonnebeke, Ypres sector, 27 September 1917

Image courtesy of Collection of National Media Museum/Wikimedia Commons

Up, up and away: using aircraft for atmospheric monitoring

When measuring the chemistry of the atmosphere, it helps to fly up in specially modified laboratories

By Kimberley Leather, Carl Percival, Tim Harrison and Laura Howes

High above us, airplanes criss-cross our skies – filled with families going on holiday, packages being delivered and colleagues travelling to business meetings. But for some travellers, their destination is the air around them. For the many scientists involved in climate monitoring, much of their research can only be done up in the sky.

The area from the ground up to about 10 km high comprises a layer of air known as the troposphere; beyond that is the next layer, the stratosphere. At the boundary between the troposphere and the stratosphere, air stops cooling as it rises and loses its water. In short, this is the space where clouds are created and the weather we experience begins to form. Looking out of the window of an airplane can provide a beautiful view above the clouds, but it can't tell you much about the chemical reactions taking place or how they might affect air quality and climate. For that, you need something slightly more technical.

The object of the measurements!

Image courtesy of Tim Harrison

View from the atmospheric monitoring aircraft

Image courtesy of the CAST team at Cambridge University, UK

Image courtesy of Tim Harrison

One of the instrument packages

Image courtesy of Tim Harrison

Image courtesy of the CAST team at Cambridge University, UK

Researchers and instrumentation on board

A laboratory in the sky

The facility for airborne atmospheric measurements (FAAM)[w1], for example, is a mobile laboratory hosted in a BAe-146 aircraft, more commonly used as a small passenger jet. In FAAM, there is little luxury and no stewards or stewardesses offering drinks and refreshments. In fact, there is room for only around 10 scientists per flight. The rest of the space is filled with different pieces of equipment. Each instrument rack takes up the same amount of room as two passenger seats and they all have to be electrically and structurally secure.

Currently based at the remote tropical island of Guam, FAAM is taking part in an international measurement campaign involving two other aircraft – the Co-ordinated Airbourne Studies in the Tropics, or CAST. This is the first co-ordinated effort to monitor atmospheric composition in the region to the south of Guam from ground level, through the troposphere and into the stratosphere, with each plane taking measurements at different altitudes. The scientists hope to improve their understanding of the tropical atmosphere and how gases move up from the surface of the Earth to the stratosphere.

As FAAM flies over the Western Pacific Ocean, all the equipment inside receives samples from the air outside. These come from intakes all over the aircraft fuselage and even on the wings. Each piece of equipment measures something different, or uses a slightly different method, but together they quantify the impact of very short lived (VSL) halocarbons and how they change the complex atmospheric chemistry that affects all of us.

These compounds, such as CH_3I, CH_2Br_2 and CH_3Br, are released from the ocean and rise up into the troposphere and stratosphere, where they are broken down by light to create

Image courtesy of the CAST team at Cambridge University, UK

Two of the monitoring aircraft

reactive halogen radicals. Some of these radicals will react with ozone, decomposing it, while others will react with other trace gases. Atmospheric chemistry is very complex.

Measuring molecules

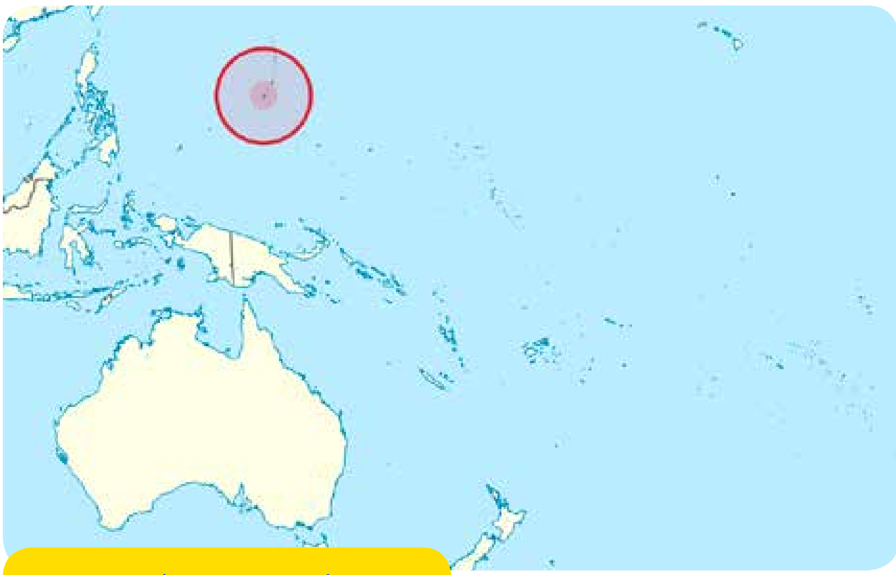
Most of us are used to seeing roadside monitoring instruments in our cities. This equipment measures passing gases but doesn't provide any information on what's happening in the plume further downwind. Satellites, by contrast, can be used to monitor the atmosphere and provide wide spatial coverage, but they take readings of the total air column. To retrieve the profile of a specific altitude, a complex mathematical model is needed. It is therefore important to measure real data and to verify the actual concentration of compounds in a sample so that the mathematical models used can be tested and verified.

Up in the sky, the atmospheric science researchers on FAAM use a chemical ionisation mass spectrometer (CIMS) to detect halogenated compounds as well as organic acids that are thought to promote aerosol formation, which can alter the transport of water vapour and the formation of clouds.

CIMS is used because it is both selective and sensitive. In a traditional mass spectrometer, molecules in a sample are given charge (ionised) with a beam of ions. The charged fragments are then accelerated through an electric field and their path is bent by a magnetic field before being detected, producing a complicated fragmentation pattern that relates to the charge:mass ratios of the fragments. In chemical ionisation (CI) methods, the mass spectrometer can be tuned to detect a specific molecule, or group of molecules, by using a specific 'ionisation gas' to create the charged particles. This produces a simpler spectrum in comparison with traditional mass spectrometry. The CIMS instrument is calibrated for every flight using known and standardised gas mixtures for the compound of interest.

Because the chemical reactivity of compounds can change with temperature and pressure, both of which change with altitude, the aircraft flies as low as 20 m (over the sea) to as high as 10 km. Flying in and out of the same area but at different heights over a five hour flight means that the aircraft measurements can give more spatial information than other techniques, such as sending up weather balloons. The detailed results from the expedition will help scientists refine their models and better understand

Image courtesy of TUBS/Wikimedia Commons



Guam sits in the western Pacific Ocean

REVIEW

- **Chemistry**
- **Earth Science**
- **Physics**
- **Ages 11–18**

When we think of a research laboratory, we imagine a spacious room where people dressed in lab coats move around instruments and benches.

This is not the case for the researchers described in this article, in which the authors provide an insight into a new way of studying our atmosphere and its phenomena.

Although the location is unusual, the object of the research and its relevance are clearly described in plain language and appropriate detail for science teachers and students.

I recommend this article to secondary-school teachers and students interested in environmental sciences and in the methods used to collect data for developing climate models.

Following the release of the 5th Assessment Report by the International Panel on Climate Change, this article is an original and valuable resource to address climate problems in the classroom.

Giulia Realdon, Italy

Roadside display of atmospheric measurements in Seville, Spain

Images courtesy of Tim Harrison

just what is going on in the skies above us.

A safe landing

Back on the ground on the tiny island of Guam, the scientists stretch their legs after their long flight. Their data are downloaded from the instruments on the plane, ready to be analysed and compared to measurements taken by the other planes involved in the CAST project, as well as from equipment on the ground and in satellites far above. At the same time, the plane is refuelled and the equipment recalibrated – ready for another day of testing tomorrow. Although most comparisons of the data will be performed in the UK, the data are also used immediately by other members of the atmospheric research community, including weather forecasting services. The data may also be available to the public: in the UK, for example, much of the data produced by FAAM is publicly available on the British Atmospheric Data Centre (BADC) website[w2].

Slowly, flights like this one are helping to refine what we know about the sky above us. And, as human activities continue to alter the chemistry of the atmosphere, the findings of the scientists in the sky can help inform and advise governments across the world, which in turn will affect all of our lives.

Web references

w1 – The Facility for Airborne Atmospheric Measurements (FAAM) is an aircraft measurement platform for the UK atmospheric science community, particularly scientists employed by the Met Office or working in universities funded by the Natural Environment Research Council. For a list of core instruments and the species measured, see: www.faam.ac.uk/index.php/science-instruments

w2 – To learn more about the British Atmospheric Data Centre (BADC), visit: http://badc.nerc.ac.uk/

Resources

The Manchester team in Guam created a blog to document their trip, which you can find at http://flyinginthetropics.wordpress.com/

Climate change and global warming are 'hot' topics and deserve an important place in the school science curriculum. You can help your students to make their own predictions of climate change using this article on climate change modelling:

Shallcross D., Harrison T. (2008) Climate change modelling in the classroom. *Science in School* **9**:28-33 www.scienceinschool.org/2008/issue9/climate

To understand how our understanding of the atmosphere has developed since the hole in the ozone layer was first discovered, visit:

Shallcross D., Harrison T. (2010) A hole in the sky. *Science in School* **17**:46-53 www.scienceinschool.org/2010/issue17/ozone

An educational webpage on bromine halocarbons and ozone layer is provided by the US Department of Energy's ARM Climate Research Facility: http://1.usa.gov/1lsEvDr

If you found this article interesting, please browse the other chemistry and physics articles on the *Science in School* website: www.scienceinschool.org/physics and www.scienceinschool.org/chemistry

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Carl Percival is a professor of atmospheric chemistry at the Centre for Atmospheric Science, School of Earth, Atmospheric and Environmental Sciences, University of Manchester, UK.

Tim Harrison is the director of outreach and a school teacher fellow at Bristol ChemLabS, University of Bristol, UK.

Laura Howes is the co-editor of *Science in School*. She studied chemistry at the University of Oxford, UK, and then joined a learned society in the UK to begin working in science publishing and journalism. In 2013, she moved to Germany and the European Molecular Biology Laboratory to work at *Science in School*.

One of the authors catching up on some analysis

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

Super cold meets super hot

To keep refuelling its reactor, the EFDA-JET facility fires frozen hydrogen pellets into 150 million°C plasma. But these pellets have an added benefit as well.

By Phil Dooley and Morten Lennholm

At EFDA-JET, near Oxford in England, we are working to develop nuclear fusion – the reaction that powers the sun – into a new energy source. Fusion energy is produced when nuclei collide and combine. As a fuel, JET uses two heavy isotopes of hydrogen: deuterium, which has a neutron as well as a proton, and tritium, which has two neutrons and one proton. When a deuterium nucleus collides with a tritium nucleus and fuses to create a helium nucleus, the energy released is so vast that 1 g of deuterium-tritium fuel can produce as much energy as burning 10 tonnes of coal. In the JET machine we heat the fusion fuel to more than 150 million°C. At this temperature, the fuel becomes the fourth state of matter, plasma, as the electrons are stripped from the atoms to create a gas of ions and electrons. This plasma is held in place inside the reactor's donut-shaped reaction chamber by strong magnetic fields.

One of the problems facing fusion research is how to get the hydrogen fuel efficiently into the plasma at such high temperatures – the solution solves two problems.

Feeding the plasma

If we just put deuterium–tritium gas into the chamber, most of it is wasted and never reaches the centre of the plasma. Instead, at such high temperatures, the gas molecules encounter charged plasma particles as soon as they get near the edge of the plasma. These charged particles collide with the gas, ionising it, and the ionised gas will itself become part of the plasma. Because most of this ionisation happens in the very edge of the plasma, these ionised particles will move along magnetic flux lines. Those particles that are too far out will be on field lines that do not close on themselves;

Physics

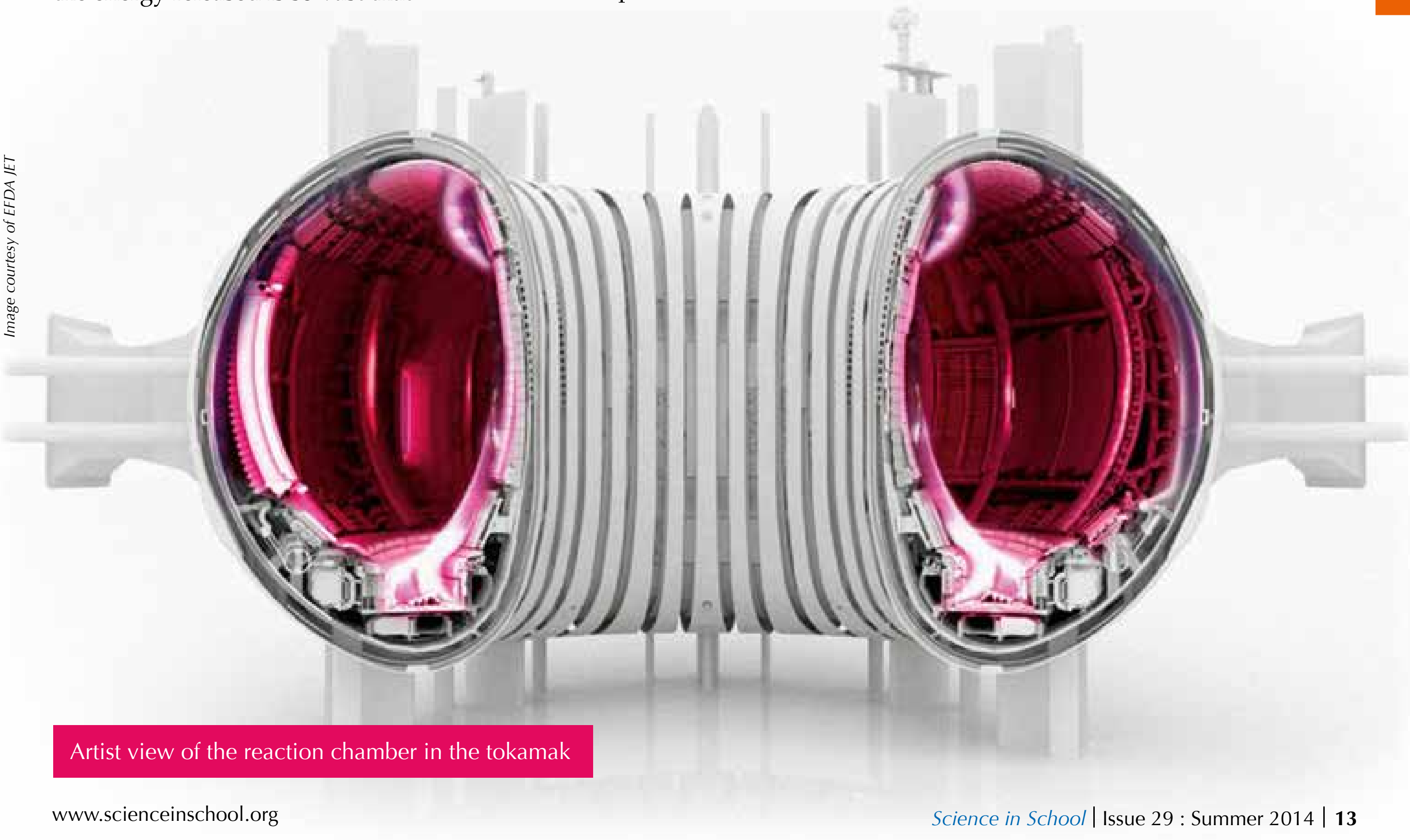
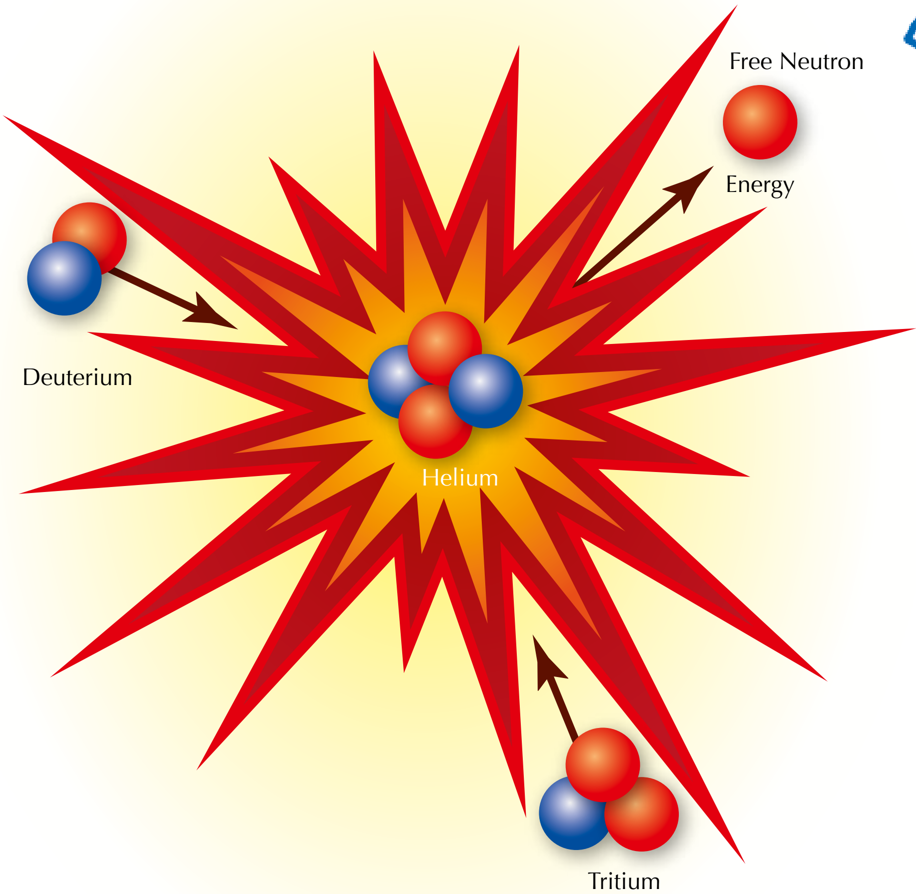


Image courtesy of EFDA JET

Artist view of the reaction chamber in the tokamak

Image courtesy of Nicola Graf

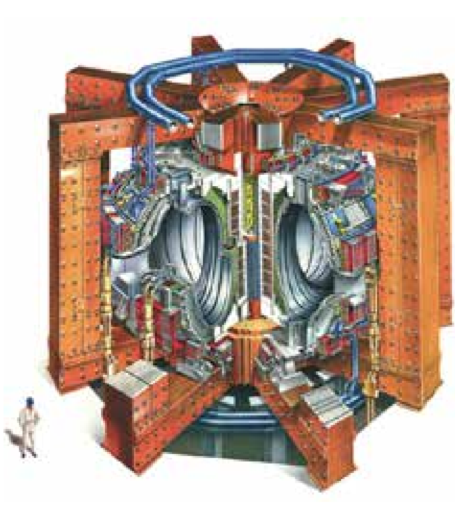


In a nuclear fusion reaction, energy is produced when super heavy hydrogen (tritium) and heavy hydrogen (deuterium) collide and transform into helium and a free neutron.

instead of becoming part of the donut shape of plasma, they will hit a wall and be lost. Even particles slightly inside the plasma edge are likely to be knocked back outside when they collide with other plasma particles.

A more efficient solution is to shoot frozen hydrogen pellets into the plasma. If these pellets move quickly enough, they get much further into the plasma before evaporating and then becoming part of the plasma, so a smaller amount will be lost and almost all of the pellet particles will stay inside the plasma. So although we ultimately need to heat the fuel to hundreds of millions of degrees, we first need to cool it down to temperatures not much above absolute zero, where hydrogen freezes to become a solid. Systems to inject such pellets into plasmas have been tested for the past 20 years on a number of machines, including JET.

Image courtesy of EFDA JET



In the JET 'Tokamak', the 150 million°C hot plasma is held in place inside a donut-shaped vacuum chamber by strong magnetic fields

REVIEW

- ✓ Chemistry
- ✓ Physics
- ✓ Ages 17–19

This article describes the research activities behind the development of a method to produce electric energy from the fusion of light atomic nuclei – just like the sun does. The largest fusion experiment – the JET – is located in Culham, UK.

The article gives physics or science teachers a short overview of how fusion works and describes in detail how to supply a fusion reactor with fuel using frozen hydrogen pellets. Therefore this article would be useful not only for physics but also for chemistry or for discussions on energy production and sustainability.

The article stimulates comprehensive questions like:

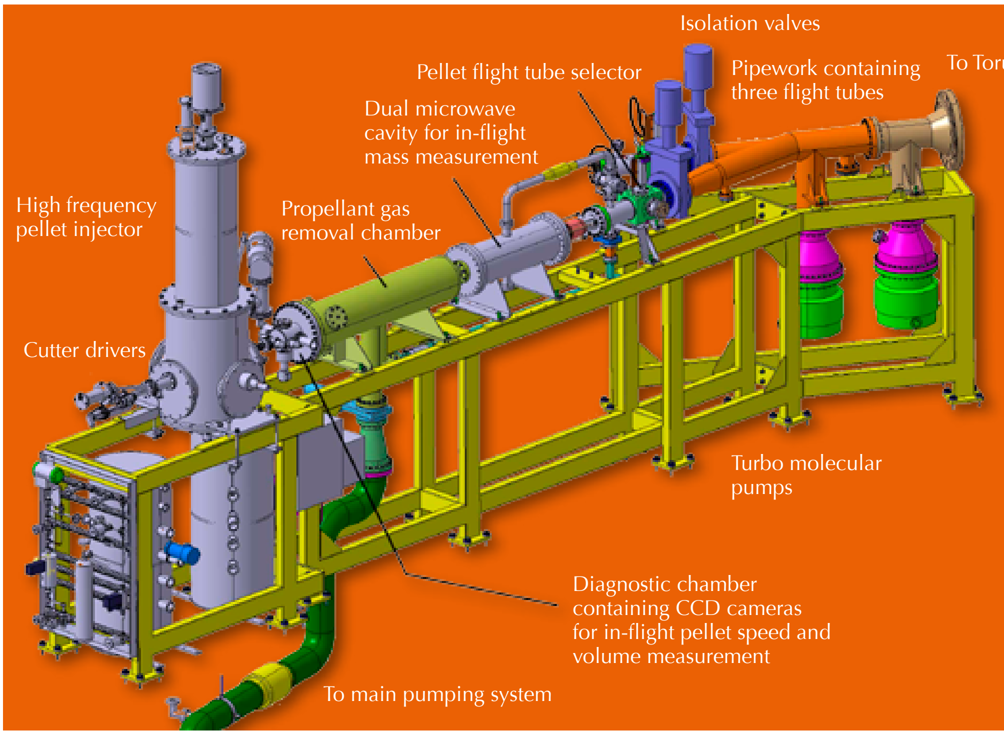
- How does fusion work in general?
- What is plasma? Describe ways to generate plasma.
- Describe the different states of matter.
- Describe a way to feed a fusion tokamak-like reactor. What problems may occur?

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

Added benefits

Recently, it was discovered that when these cold pellets enter the edge of the fusion plasma, they can trigger

Image courtesy of EFDA JET



In the JET pellet injector system, 1–4 mm diameter pellets are produced by the PELIN high-frequency pellet injector (HFPI) and transmitted through 1 cm diameter pipes over distances of 10–15 m at rates up to 50 pellets per second. After the pellets are ejected from the HFPI, the diagnostic chamber uses cameras to check the pellets' size and speed. The pellets then enter one of three flight tubes, each of which enters the reaction chamber at a different place. In this schematic representation, the size of the HFPI is exaggerated by a factor of about three with respect to the JET machine.

Image courtesy of EFDA JET

The pellet injector

what is called an edge localised mode (ELM), a short sharp expulsion of energy from the plasma – a bit like a solar flare.

These expulsions of energy have become a hot topic in fusion research, as some are large enough to damage the walls of the reaction chamber. In JET, we have recently lined these surfaces with the metals tungsten and beryllium, which have the advantage of absorbing less hydrogen fuel than the carbon surfaces previously used. However, no gain ever comes for free and the new walls are more prone to damage by these ELMs.

ELMs aren't just triggered by pellets – they occur spontaneously in almost all 'high performance' plasmas and a lot of work is being done to reduce their impact. The ELMs occur at regular intervals and between ELMs, the pressure in the plasma builds up until it reaches a level that can no longer be sustained. At this point, the particles and energy are released abruptly in the next ELM. We are trying hard to find ways to avoid ELMs, but eliminating them has come at a high price, with the plasma performance dropping dramatically. Instead, we are now moving in the opposite direction by trying to induce more frequent ELMs that are so small that they don't cause any damage.

This is where the discovery that fuel pellets 'trigger' ELMs comes in – as well as refuelling the reactor, they now have ELM control added to their repertoire. This can be seen as the pellet 'tickling' the edge of the plasma, making it sneeze. To tickle

BACKGROUND

The pellet injector, manufactured by the PELIN company from St. Petersburg in Russia, produces a continuous stream of deuterium ice inside a vertical screw, cooled by liquid helium. With the temperature above the freezing point of deuterium at the top of the screw and below freezing at the bottom, the deuterium enters as gas at the top before condensing and freezing as it moves down through the screw. When the screw turns, it pushes the 18 K (-255°C) deuterium out at the bottom. From this solid material, pellets are cut as tiny cylinders before being shot towards the plasma by the equivalent of an air gun. If the ice is too hot, the pellets will melt on their way towards the plasma; if it is too cold, the ice is so hard that it shatters when it is cut. As the pellets leave the pellet 'gun', their troubles are not over. They have to travel through a 10–20 m long, rather tortuous, rollercoaster of pipes before they can do their job in the plasma.

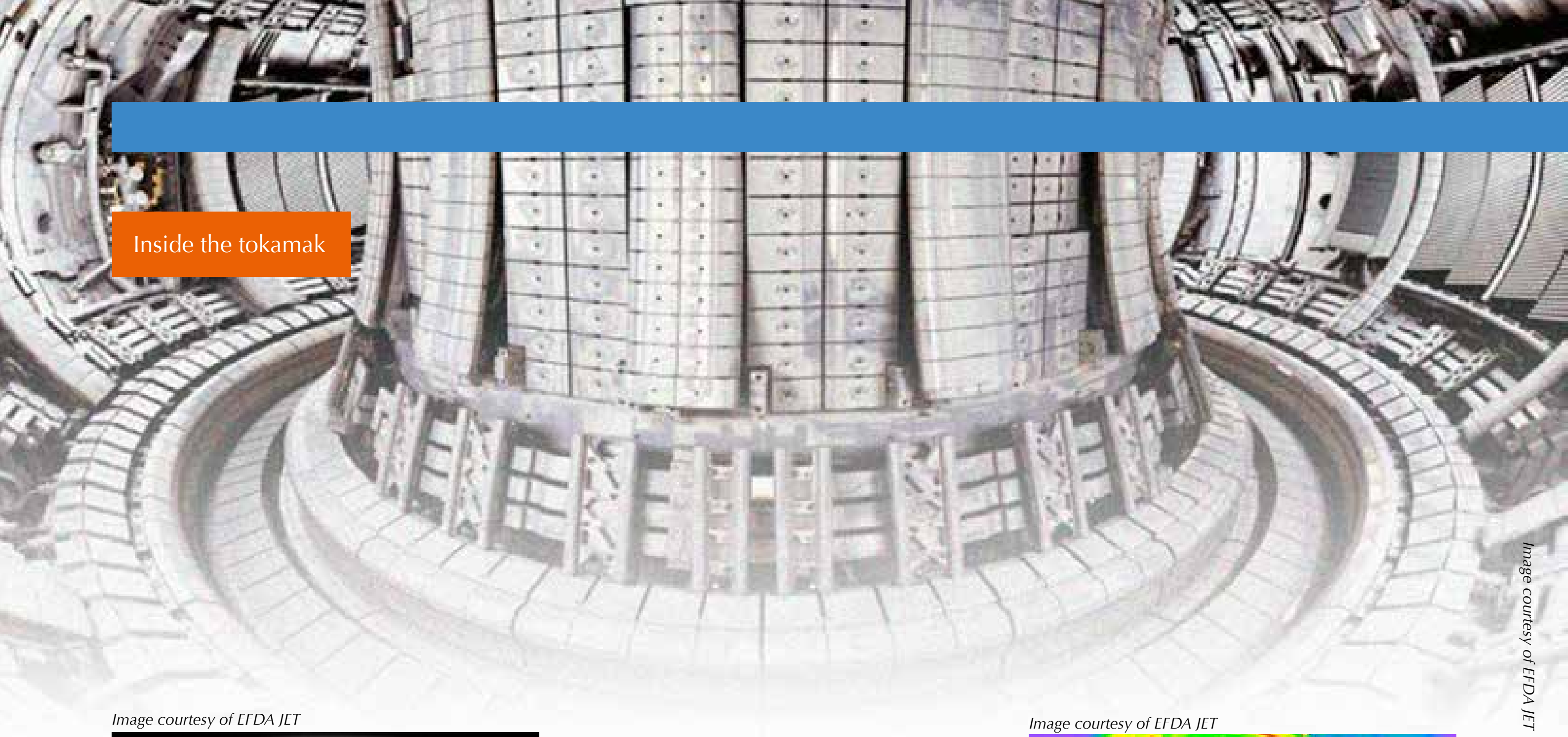
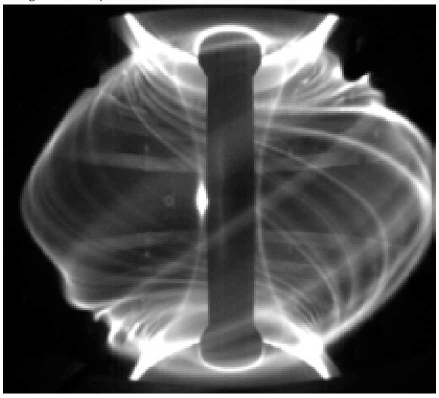


Image courtesy of EFDA JET

Image courtesy of EFDA JET



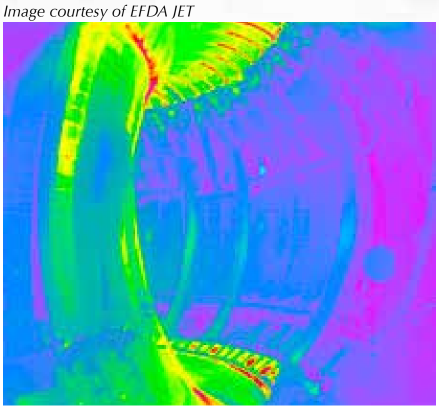
A perturbation, called an edge localised mode, seen in the MAST tokamak (MAST is a smaller British tokamak situated, like JET, at the Culham Science Centre). The ELM, seen as a series of bright ribbons near the surface of the tokamak plasma, expels a significant amount of energy in a short burst lasting less than a millisecond.

the plasma edge, the pellet does not need to get far into the plasma so we can use much smaller pellets than are needed for putting fuel into the middle of the plasma. This is lucky, as we need to trigger ELMs up to 50 times per second and we would be putting too much deuterium-tritium into the plasma if we used the standard size of pellets.

With this new purpose in mind, a new versatile high-frequency pellet injector has been put into operation at JET. It works a bit like a machine gun and can fire long sequences of pellets of a variety of sizes into the plasma. Up to 15 large (10–50 mm^3) pellets per second can be injected to fuel the plasma but we can also use this device to shoot up to 50 small (2–3 mm^3) pellets per second in order to trigger small ELMs.

This fuel machine gun has brought fusion as an inexhaustible energy source not one, but two steps closer. The process of fuelling a hot plasma is now more efficient, and a seemingly problematic side effect has been harnessed as a benefit. We now know how to cope with ELMs, one of the trickier challenges for a functioning fusion reactor.

Image courtesy of EFDA JET



The infrared camera looks inside the reaction chamber of the tokamak

EIROforum

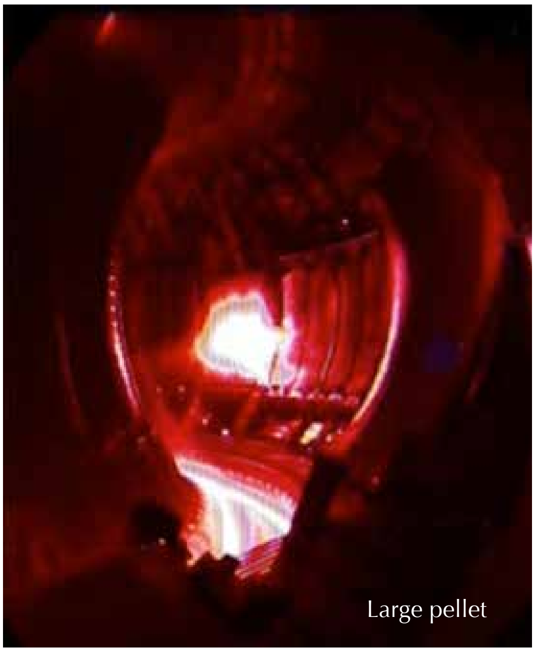
EFDA JET

The Joint European Torus (JET)[w1] investigates the potential of fusion as a safe, clean and virtually limitless energy source for future generations. It can create the conditions (100–200 million°C) in the plasma sufficient for the fusion of deuterium and tritium nuclei to occur, and it has achieved a maximum fusion power output of 16 MW. As a joint venture, JET is collectively used by more than 40 European fusion laboratories. The European Fusion Development Agreement (EFDA) provides the platform to exploit JET, with more than 350 scientists and engineers from all over Europe currently contributing to the JET programme. While deuterium-tritium fuel will be used in fusion power plants, fusion experiments normally use deuterium-deuterium reactions to avoid working with radioactive tritium. JET is currently the only fusion device licensed for working with tritium. It does so very rarely for specific experiments.

EFDA-JET is a member of EIROforum[w2], the publisher of Science in School.

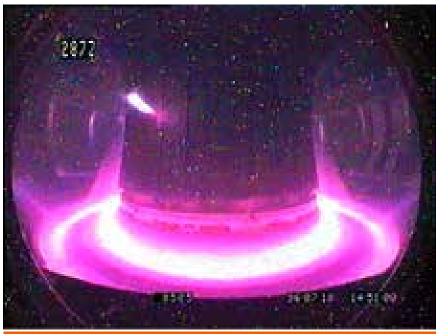
See all EFDA-JET-related articles in *Science in School:* www.scienceinschool.org/efdajet

Image courtesy of EFDA JET



A large and a small frozen deuterium pellet photographed as they enter the 150 million°C JET plasma

Image courtesy of EFDA JET



Another view of a pellet entering the reaction chamber of the tokamak

Web references

w1 – Learn more about EFDA-JET by visiting the organisation's website at www.efda.org/jet

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

Resources

For an introduction to fusion power read:

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

The European fusion education network, FuseNet, hosts material that can be used in schools. See: www.fusenet.eu/node/19

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

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

Morten Lennholm is an engineer at JET. He graduated from the Technical University of Denmark, specialising in Microwave and Control Engineering. Morten completed his master's thesis at CERN in Geneva and, having enjoyed the international environment, applied for positions at various labs around Europe. He joined EFDA in 1987 intending to stay for two years and he's still there. Today one of his jobs is to look after the high-frequency pellet injector.

Physics

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

Light refraction in primary education: the solar bottle bulb

More than 10 years ago, a very clever and inventive inhabitant from a favela discovered he could produce light without electricity. Now solar bulbs are spreading all over the world.

Image courtesy of Africa Studio / shutterstock

By Claas Wegner, Stephanie Ohlberger

Back in 2002, Brazilian mechanic Alfredo Moser came up with a way of illuminating his house during the day without electricity. Instead, Moser's solution just used a plastic bottle full of water. The innovation, which uses the phenomenon of refraction, has now spread throughout the world and it is expected to light over 1 million homes this year.

Many teachers are afraid of introducing physical topics in primary schools but while students might not be able to call it light refraction, many will have seen how a straw seems to bend as it goes from air into water. This article aims at providing a theoretical background to light refraction and shows how the solar bulb can be used in the classroom to demonstrate the phenomenon.

Refraction

Thinking back to the straw in a glass of water, the straw seems to be bent or broken. This happens because water is optically denser than air and so light travels slower in water than air. The change in speed bends the light

Images courtesy of Stephanie Ohlberger

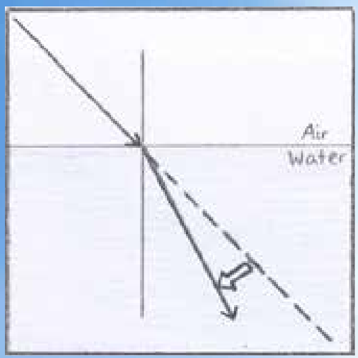


Figure 1: The bending of a light ray when entering a high-index medium

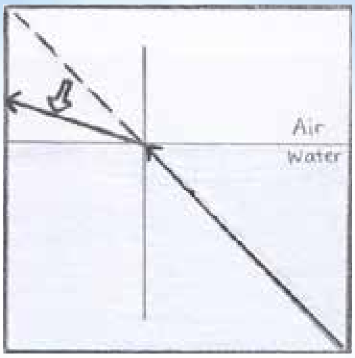


Figure 2: The bending of a light ray when entering a lower-index medium

as it passes from one substance to the other, a phenomenon called refraction.

In refraction, two different things are important: the angle that the light hits the interface between the two materials, called the angle of incidence, and a specific property of each of the two materials involved, the refractive index. Generally speaking, denser materials have higher indices of refraction because denser materials slow light down more.

Think of how a car travels quickly on a road but slows down when driving onto a muddy field.

Refraction does not occur when light rays strike the interface between two transparent media at a right angle, much like driving onto a muddy field straight on will slow you down but you will still be driving in the same direction. However, if you come at the field at an angle, the wheels that hit the mud first will be slowed down and the car will turn. In a similar manner, if light rays strike the surface at an angle the light rays will change direction. The direction of that depends on the refractive indices of the two media involved (figures 1 and 2).

The phenomenon of light refraction can easily be shown in the classroom with some introductory experiments.

The shoebox

Just as we have done, the topic of light refraction can be introduced by discussing how a straw or pencil in a glass appears broken when viewed from the side, which is a good basis for evolving questions regarding this topic. The theoretical laws of refraction can then be demonstrated by building a simple experiment with a shoebox. The experiment should be done in groups of two or three as it is a bit tricky. Depending on the students' age and on how much time the lesson offers, the teacher could also prepare the shoeboxes beforehand in order to shorten the time dedicated to handicraft work in class.

As explained in the detailed document[w1] you can download from the reference section, you will need a torch, a shoebox, a craft knife, and a glass of water. Carefully cut two vertical slits into the short end of the shoebox. The space between the slits should not be wider than the glass. When the torch is shined through the two slits you should see two straight lines of light. Now, place the glass of water in the box so that the two strips of light hit the glass. When the glass of water is placed behind the slits, however, they cross each other. This is the result of the light being slowed down by the water, as it has a higher optical density than air. According to the law of refraction, the light is bent inwards and so the two light rays eventually cross.

REVIEW

- Physics
- Ages 8–11

The article focuses on the important topic of refraction. Children may be aware that a straw appears to bend when it enters a glass of water but it is difficult for them to imagine that it is the light that is actually bending and not the straw. The shoe box experiment should very useful to help them visualize the bending of light rays.

The idea of a solar bulb should intrigue young children. It may be used as the basis for a discussion on its possible every day applications. In which rooms or areas at home may such bulbs be used? Students may be engaged to discuss both the advantages and disadvantages of using such a system at home. One can discuss the use of the solar bulb in the context of developing green buildings, reducing our dependence on electricity as well its economic value.

Teachers can very easily adapt the concept to a school project, in which students investigate the feasibility and value of introducing such a system at home or in the wider community.

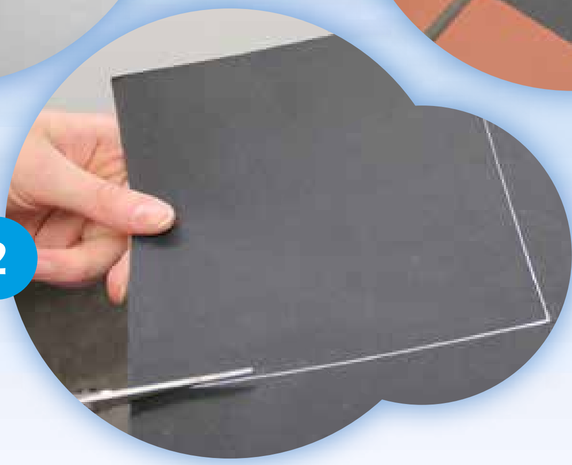
Although the article is mainly aimed for primary teachers, both science and physics teachers in secondary schools should find it useful when introducing the concept of refraction.

Paul Xuereb, Malta

Images courtesy of Stephanie Ohlberger

1 Cut a hole in the ceiling of the box

3 Draw two concentric circles *on the cardboard*



2 Cut a square in the cardboard

4 Cut out the inner circle

ACTIVITY

The solar bulb

Having demonstrated refraction, you can show how the solar bulb exploits it to light rooms and houses with about as much light as a 50-60 Watt incandescent bulb. With just a plastic bottle full of water people can light up their rooms and huts. Moser's original concept has been further developed by charities to bring sustainable and affordable lighting to communities in Africa, the Philippines, India, and other south-east Asian countries without the use of electricity[w2]. In the classroom, it should only take about 10 minutes to create your own version.

Materials

- Cardboard
- Scissors
- Circle stencils
- Large plastic bottle (1 or 2l)
- Water
- Big cardboard box
- Torch

Procedure

1. Cut out a hole in the ceiling of the box: it should be big enough so that the bottle can pass through it. Then cut a window-like opening on the side so that you can look into the box.
2. Cut a 15x15 cm square out of the cardboard.
3. Draw two concentric circles in the middle of the square with a stencil.
4. Cut out the inner circle.
5. Cut in intervals from the inner to the outer circle and bend these pieces upwards.
6. Put the cardboard hole over the bottleneck and fill the bottle with water.
7. Put your Solar Bottle Bulb in the ceiling's hole of the sample hut and shine a torch at the bottleneck.
8. Observe the solar bulb through the side opening.

5 Cut in intervals from the inner to the outer circle

7 Put your Solar Bottle Bulb in the ceiling's hole of the sample hut

6 Put the cardboard hole over the bottleneck and fill the bottle with water

8 Observe!

Explanation

The solar bottle bulb relies on the refraction principle. Because the light from the torch passes from a lower-index medium (air) to a higher-index medium (water) the light rays bend inside the water, then when the light comes out it is spread out around the room. For this to happen the bottleneck has to be stuck out of the roof, while the spreading of bent light rays is performed by the main part of the bottle which is hanging from the ceiling (figure 3), like a proper light bulb.

The great advantage of this light supply is its sustainability and safety. There are no risks of fire hazards with this type of "lamp" and they are inexpensive to make and fit. In practice, chlorine is added to the water to keep the water clear and free of algae and microbes, and the bulbs are sealed into the roofs to make a weather proof seal[w3]. There are plenty of videos on the internet to show how it is done using proper house building materials[w4].

Follow-up questions

Depending on the students' age, the solar bulb experiment could be part of a larger interdisciplinary project on problems for developing countries compared to the student's own experiences. After seeing the bulb in action, the students should realise how big an advancement the solar bottle bulb is for people without a secure source of electricity. In order to compare our electric equipment with this means of light production, the students can measure the different light levels. The social situation of affected people could also become the focus of attention and could be used as a starting point for a school project to raise money to help spread solar bottle bulbs to underprivileged regions.

Figure 3: Refraction of the light rays in the bottle inside the sample hut.

BACKGROUND

Snell's law of refraction

In physics, Snell's law is used to describe refraction and its properties. Snell's law states that the velocity of the incident light divided by the sine of the angle of incidence is equal to the velocity of the refracted light divided by the sine of the angle of the refracted light, $\left(\frac{v_1}{\sin\theta_1}\right)=\left(\frac{v_2}{\sin\theta_2}\right)$. This means that when light passes from a substance of lower optical density to a substance of higher optical density, slowing it down, the light ray is bent towards the normal of the boundary between the two media. This is what happens when a light beam in the air enters water. In the opposite case, when a light ray enters a medium of a lower index, for example going from water to air, it will bend away from the normal.

Snell's law can also be written in terms of the refractive index, or how optically dense the medium is. A medium's refractive index, n, is defined as the ratio of the speed of light in a vacuum, c, to the speed of light v in the medium, $n=\frac{c}{v}$. That also means that Snell's law can be written as $\sin\theta_1 n_1 = \sin\theta_2 n_2$.

As the speed of light in a vacuum is always 3×10^8 m/s, it is easy to calculate the index of refraction for a medium as long as you know the speed of light in that particular medium. Practically speaking, denser materials have higher indices of refraction as denser materials slow light down more

Conclusion

The solar bulb is an innovative solution to the problem of lighting houses and provides a simple demonstration of physics which will help motivate students to engage with the topic. It also provides an excellent opportunity for interdisciplinary work. Throughout the experiments, the children practice teamwork and the allocation of responsibilities, thus enhancing their social skills. Apart from the content focus, the lesson's emphasis could also be placed on the scientific method by introducing test protocols, which will be beneficial for future work in other natural science-subjects. The approach of including the solar bottle bulb into teaching has already been implemented in many schools as part of projects on light or alternative energy, so your pupils should be given the chance to experience light refraction from a practical point of view as well.

Web references

w1 – Download the detailed procedure to perform the shoebox experiment from the *Science in School* website, see: www.scienceinschool.org/2014/issue29/solar_bulb#w1

w2 – The website from the Myshelter Foundation gives a good overview of the use of solar bulbs around the world: www.aliteroflight.org

w3 – For a step-by-step guide on how to make a solar bulb, see: http://bit.ly/1xT4xoM

w4 – To watch a short video on how to make a solar bulb, see: http://bit.ly/1oWt6wQ

Resources

For more information on solar bulbs, see: Wood, A. (2012). The Solar Bottle Bulb Revolution. Retrieved from http://bit.ly/1jolaz3

For some background information on optics and the physics of light, see:

Hecht, E. (2002). Optics (4th ed.). San Francisco: Addison-Wesley.

Waldman, G. (2002). Introduction to Light: The Physics of Light, Vision and Color. New York: Dover Publications.

For good general background information on science, see:

Taylor, C. (2000). The Kingfisher Science Encyclopedia. London: Kingfisher.

If you found this article interesting, please browse the other teaching activities published on the *Science in School* website: www.scienceinschool.org/teaching

Dr. Claas Wegner is a senior teacher for the subjects Biology and Physical Education at a secondary school and lecturer at Bielefeld University in the Department for Didactics of Biology.

Stephanie Ohlberger is a Master of Education student for the subjects Biology and English at secondary schools. She is an academic assistant in the Department for Didactics of Biology at Bielefeld University.

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

Simulating the effect of the solar wind

The smooth operation of communications satellites can be influenced by solar weather. Mimic this effect on a smaller scale in the classroom with a simple demonstration

Image courtesy of U.S. Air Force / Wikimedia Commons

A communications satellite

By Theodoros Pierratos, Paraskevi Tsakmaki and Christos Papageorgiou

It's the final of the 2014 football World Cup, the score is tied and there is no time left on the clock. Fans all over the world hold their breath, but suddenly all the TV sets in Europe go black! What can cause this to happen?

Keeping connected

Let's start from the beginning. How is it possible to watch, almost in real time, an event taking place thousands of kilometres away? The answer orbits above our heads: satellites.

Physics

Image courtesy of Nick Wiebe / Wikimedia Commons

Image courtesy of Moazzam Brohi /Wikimedia Commons

REVIEW

- Physics
- Ages 14+

Modern communications make much use of geostationary satellites, but these are always at risk from severe storms in the solar wind (a stream of high-energy charged particles from the Sun's outer atmosphere). This article describes pleasant, straightforward experiments to model the effect of solar wind on data communication by light beams. The activities are well worth using with science or physics groups of students about 14 years and older in their spare time (e.g. science club, holiday activities / summer school, or lessons after exam time).

Eric Deeson, UK

Since the launch of Telstar[w1] in 1962, satellite communication has continued to grow. Today, even when news or sport events are taking place just a few kilometres from a TV studio, the camera signals are probably being transmitted using a satellite in geostationary orbit[w2] (this means that the satellite orbits Earth at the same speed as Earth rotates, so it stays above the same position on Earth). For you to watch the final of the World Cup in Rio de Janeiro while sitting at home in Europe, a number of satellites have to work together. However, the environment far above Earth's surface is harsh: there is no atmosphere, lots of cosmic radiation, and extreme temperature variations between sunlight and shadow. Telecommunication satellites contain state-of-the-art technology to cope with these extreme conditions, but a sneaky enemy can still threaten the operation of a satellite: the solar wind.

Solar wind and satellites

The solar wind is a stream of charged particles, mainly electrons and protons, that are released from the very hot corona, the upper atmosphere of the Sun. The particles escape the Sun's gravity because of their high kinetic energy[w3]. This stream of particles reaching Earth varies in density, temperature and speed, depending on time and longitude.

When these particles approach Earth, they can have various effects: from spectacular aurorae to great geomagnetic storms. As geostationary satellites are near the edge of Earth's protective magnetism, they can be exposed to these storms.

In the classroom

The effect of the solar wind on telecommunications is a modern issue that can trigger students' interest in space technology and space weather. But how can we mimic it in the classroom? How can we simulate the solar wind? The Fun Fly Stick toy (figure 1) is a portable wand-like version of the Van de Graaff generator. When switched on, a belt moves inside the Fun Fly Stick and a static charge builds on the wand. Instead of the metal dome of the Van de Graaff generator, the charge accumulates on a cardboard tube. Cardboard has a high electrical resistivity but becomes a conductor when subjected to high-voltage electricity. Furthermore, it discharges more slowly than metal, so the shocking discharge sensation is eliminated.

We can safely use this toy to simulate solar wind by placing a large needle or thin metal axle on the end of the control tube (figure 2). Positive electrostatic charges formed on the cardboard tube are concentrated at the tip of the needle and so ionise the air nearby. Negative ions in the air will rush towards the needle tip and positive ions will move away due to electrostatic repulsion. The movement of these ions creates a form of an 'electric wind' or, for the purpose of our simulation, a 'solar wind'.

To demonstrate the effect of the

Fig 1. The Fun Fly Stick toy

Fig 2. How to place a metal axle on the Fun Fly Stick

All the photographs are courtesy of Theodoros Pierratos

All the photographs are courtesy of Theodoros Pieratos

Fig 3. Demonstrating the effect of the solar wind on an electronic circuit

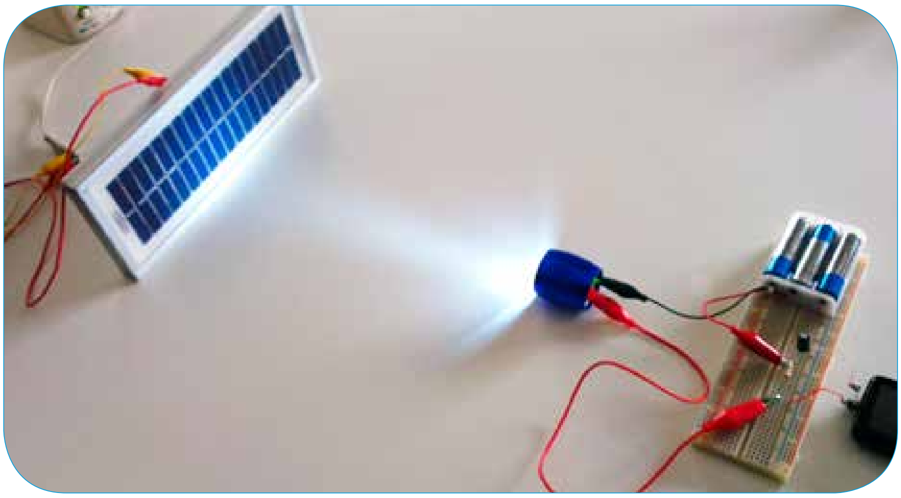


Fig 4. Carrying sound on a light beam

laboratory-made solar wind, we can just use a test screwdriver. Ask your students to imagine that the simple electrical circuit built into this screwdriver (usually including a battery supply and a red LED) is part of the electronic equipment of an orbiting satellite transmitting their favourite TV show. What will happen if we turn on the generator and come close (about 1 metre or less) to the test screwdriver? The red LED starts glowing (figure 3), and as the stick approaches the screwdriver it glows more and more brightly[w4]! The electric circuit starts to overload. What could be the effects of a solar storm on the electronic circuits of a satellite?

Carrying sound on a light beam

As well as overloading and possibly damaging the electronic circuits in a satellite, the solar wind could disrupt the live streaming of the World Cup final. To show this experimentally, we first have to observe that electromagnetic waves can carry usable information. To do this, we propose a modified version of the experiment described by Bernardelli, 2010 (figure 4).

Instead of using a laser pointer and a photo-diode, we use a LED flashlight (torch) and a small solar panel[w5]. In this way, we reduce the distance that the sound is transmitted but make a stronger impression on the students: most of them consider a laser beam to be something special, but by using a normal flashlight, we can focus on the science behind the phenomenon (box 1).

With the screwdriver demonstration above, we showed that the solar wind could overload and probably damage a subtle electronic circuit on board a telecommunications satellite. To repeat our classroom simulation without ruining equipment, we designed and built a simple electronic circuit (box 2).

The concepts of space weather and satellite technology are not part of the curriculum, at least not in Greece. However, space-related topics can increase students' interest in science (Spencer & Hulbert, 2006). An obvious problem for teachers is how to demonstrate effects of this scale and intensity in a classroom. In this article, we hope to convince you that all it takes is a toy and some basic skills in constructing a simple electronic circuit.

Physics

References

Bernardelli A (2010) Stage lights: physics and drama. *Science in School* **17**: 41-45. www.scienceinschool.org/2010/issue17/laser

Spencer P. Hulbert G. (2006) *The Education and Skills Case for Space*. Swindon, UK: Particle Physics and Astronomy Research Council

Web references

w1 – To learn more about the Telstar communication satellites, see: http://telstar50.org/history.html

w2 – To read more about the orbits used for situating telecommunication satellites, see: http://bit.ly/SSPjzH

w3 – Many websites describe the solar wind. For a brief introduction, see: http://sci.esa.int/cluster/2569-solar-wind/

w4 –Watch a brief video of the effect of the Fun Fly Stick on a test screwdriver: http://youtu.be/8sDJm5llJc0

All the photographs are courtesy of Theodoros Pierratos

Carrying sound on a light beam

Materials

Transmitter

- LED flashlight (torch)
- 2 alligator clips
- 3.5 mm stereo plug
- Breadboard
- 100 Ω resistor
- 100 μF capacitor
- Mp3 player with a 3.5 mm jack output
- Battery holder
- 3 1.5 V batteries (depending on the flashlight you use)
- Soldering iron
- Solder
- 2 small pieces of lighting flex wire (about 3 cm each)

Receiver

- Solar panel
- Amplifying speakers with external power supply
- 2 alligator clips

Procedure

The transmitter

1. Unscrew the head of the flashlight (figure 5).
2. Use the breadboard to construct the circuit shown in figure 6. Your circuit should look like the one in figure 4 (instead of using a breadboard, you can construct the circuit using alligator clips to make the proper connections). Be careful to connect the head of the flashlight and the battery holder exactly as it looks in figure 7. The negative pole of the battery holder (black wire) must be connected with the side body of the flashlight's head while the positive pole (red wire) must be connected with the spring-like metal in the centre of the head. Otherwise, the flashlight will not turn on.
3. To connect the stereo plug to the breadboard, solder the two pieces of wire to the stereo plug. Solder one wire (red) to both the first and second segments of the plug (or in just one of them) while the other wire (white) goes to the third segment (figure 8).

Fig. 5. A normal LED flashlight

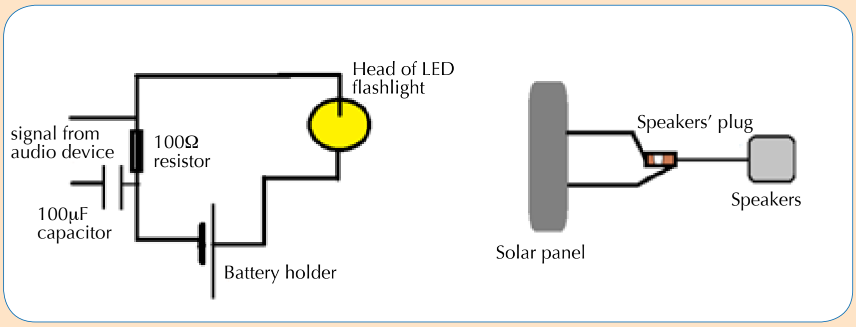


Fig. 6. A diagram of the 'carrying sound' circuit

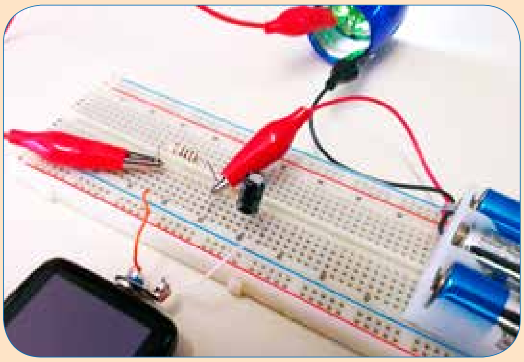


Fig. 7. The transmitter's circuit

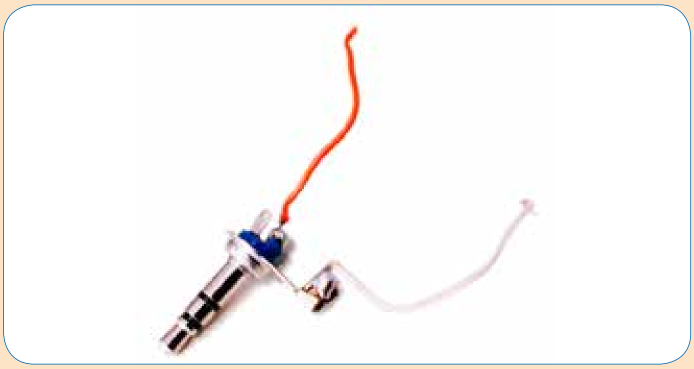


Fig 8. The stereo plug

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The receiver

1. Connect the two wires from the solar panel's output to the 3.5 mm stereo plug or socket of the speakers using two alligator clips (figure 9a,b). Your circuit should look like the one in figure 10.

About what happens

The flashlight batteries provide a strong but constant direct current (DC) to the LEDs. As a result, the LEDs glow with a fixed brightness. When the mp3 player is turned on, it adds a weak but fluctuating electrical signal to the constant current from the battery. The LEDs flicker in sync with the output from the player. The stronger battery current of the flashlight is added to the weaker signal from the player (the capacitor protects the player from being overheated by the input DC). These fluctuations are picked up by the solar panel and are converted into electrical pulses that are turned back into sound by the speaker. This whole process is amplitude modulation (AM). It is the same principle used for transmitting AM radio signals.

a

b

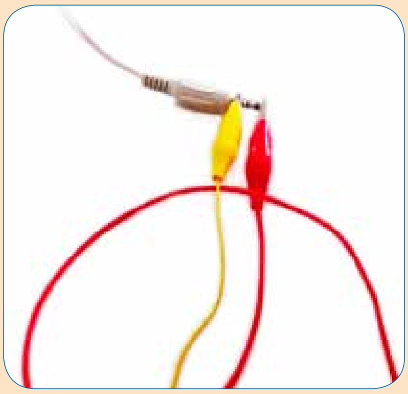

Fig. 9. How to connect (a) the solar panel with (b) the 3.5 mm speaker plug

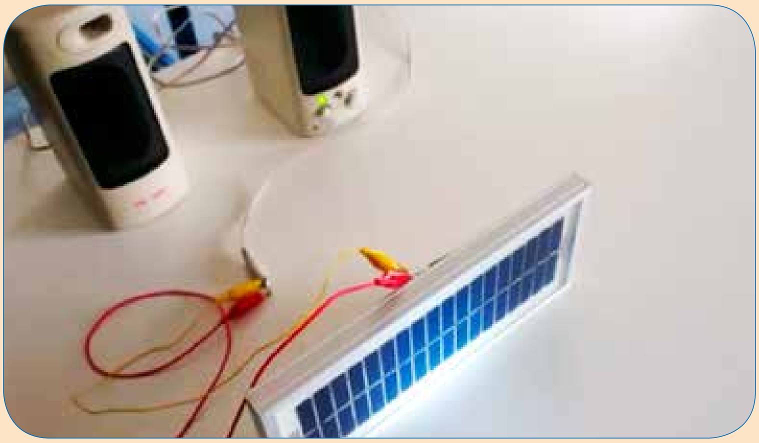

Fig. 10. The receiver's circuit

w5 – To watch a video showing the transmission of sound using this experimental set-up, see: http://youtu.be/Dnqn2S1o_-4

w6 – To watch a descriptive video of the disruption of the transmitter circuit, see: http://youtu.be/e9GxsZFxTR0

w7 – To watch a descriptive video of the disruption of the receiver circuit, see: http://youtu.be/wJ8WxJL9xOg

w8 – For more information about ESA, see: www.esa.int

Resources

To find out more about how the sun produces solar wind, you might like to read:

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

To model a more attractive result of the solar wind – the aurorae (northern and southern lights) – read:

Jeanjacquot P. Jean Lilensten J. (2013) Casting light on solar wind: simulating aurorae at school. *Science in School* **26:** 32-37. www.scienceinschool.org/2013/issue26/aurorae

The simulation described above is part of an integrated educational scenario entitled 'Sherlock Holmes on board the ISS', which was presented at the European Space Agency (ESA) summer workshop held in ESTEC, Noordwjik, The Netherlands, on 21 to 25 August 2013. To learn more about ESA's workshops, visit: http://bit.ly/SFH4qt

To stay informed about the sensitivity of future European space missions to the space environment, see: www.esa-spaceweather.net/

To keep up-to-date with the current space weather, visit: www.swpc.noaa.gov/SWN/

Physics

All the photographs are courtesy of Theodoros Pierratos

A switch activated by the solar wind

Materials

- 470 Ω resistor
- 2 1N4001 diodes
- 1 2N3904 transistor
- 1 CD4069 inverter gate chip containing a U1A gate
- 4.5 V battery or 3-12 V DC power supply unit
- 1 relay coil (3-12 V depending on power supply) with one NC contact
- 1 green LED (as an indicator)
- 2 alligator clips
- One small breadboard

Procedure

1. Construct the circuit in figure 11; the result will look something like figure 12. In this circuit, an optional small piece of aluminium foil has been attached to the wire. This piece of foil plays the role of an antenna (the charge receiver conductor) to increase the sensitivity of the switch.
2. Use two alligator clips to connect the 4.5 V battery (or the power supply) to the corresponding red and black wires (figure 12). The green indicator LED turns on.
3. Interconnect this circuit to the 'sound carrying' circuit from box 1. This can be done in one of two ways:
   a. In series with the transmitter circuit[w6] (to show the effect of the solar wind on the circuit in a satellite that is responsible for transmitting the signal);

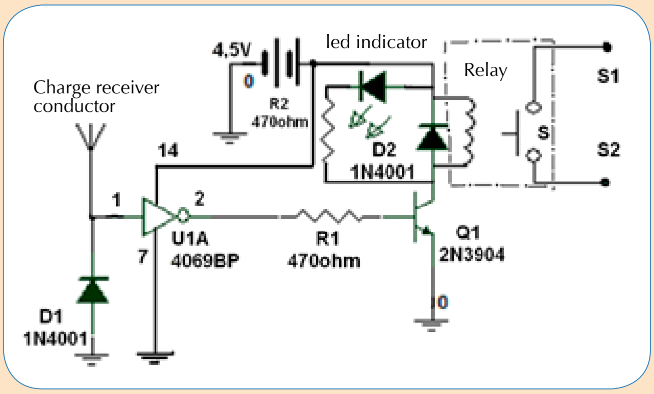

Fig. 11. The diagram of a switch that is triggered by electric charges

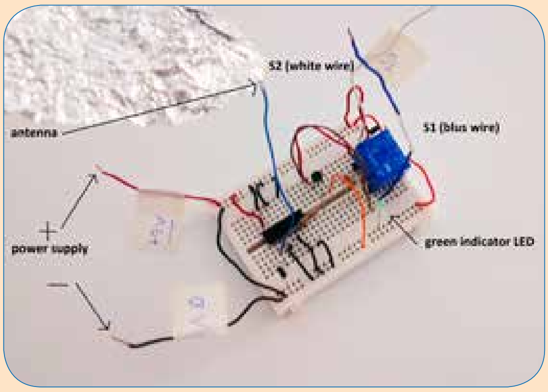

Fig. 12. The switch circuit that is activated by the solar wind

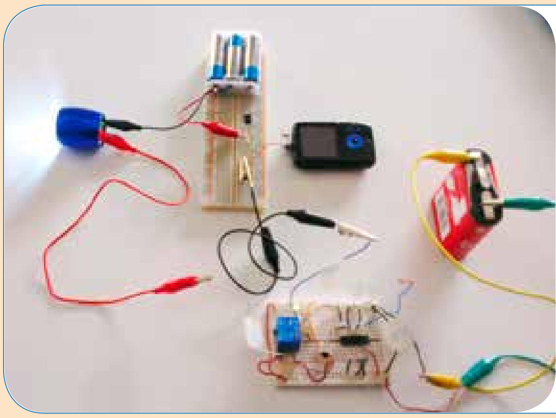

Fig. 13a. The switch circuit is connected to the transmitter

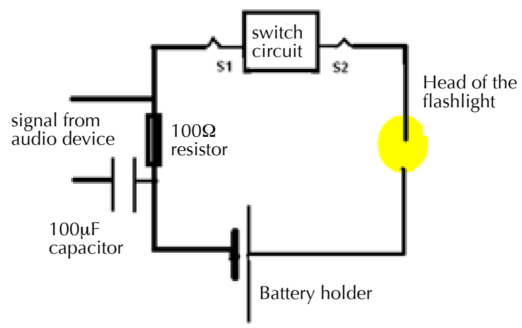

Fig. 13b. The diagram of the circuit presented in figure 13a

ACTIVITY

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b. In series with the receiver circuit[w7] (to reflect the effect of the solar wind on the circuit in a satellite that is responsible for receiving the signal from another satellite or from the ground station).

   To do so, insert the switch circuit (using the wires S_1 and S_2 shown in figure 12) to the transmitter or receiver as in Figures 13 and 14.

4. Turn the circuit on and move the charged stick towards and away from the circuit and note what happens.

About what happens

The circuit is in fact a switch triggered by the charges on the cardboard tube of the Fun Fly Stick. When the stick approaches the circuit, the induced electric charge turns on the relay and interrupts transmission[w6]: according to our scenario, the solar wind has just hit a satellite and the transmission of the World Cup final has stopped. As soon as you turn off the charge, the relay turns off too, and the transmission resumes: the damage experienced by the satellite is negligible and reversible.

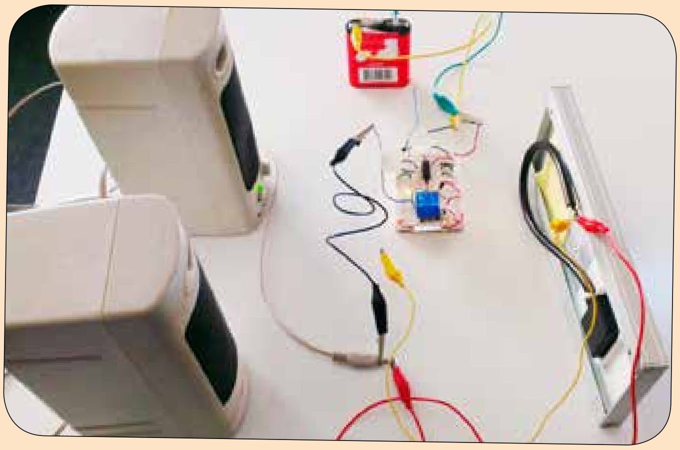

Fig. 14a. The switch circuit is connected to the receiver

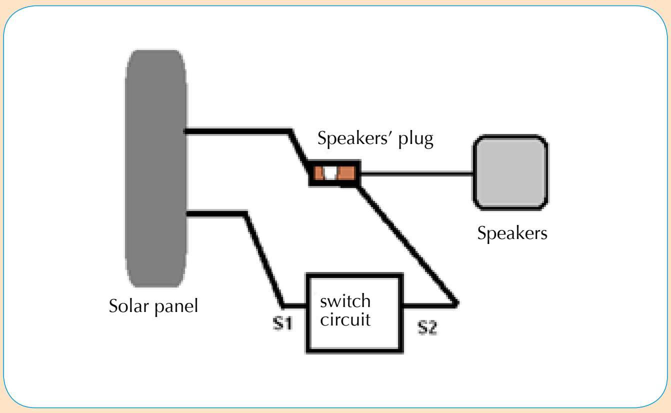

Fig. 14b. The diagram of the circuit presented in figure 14a

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

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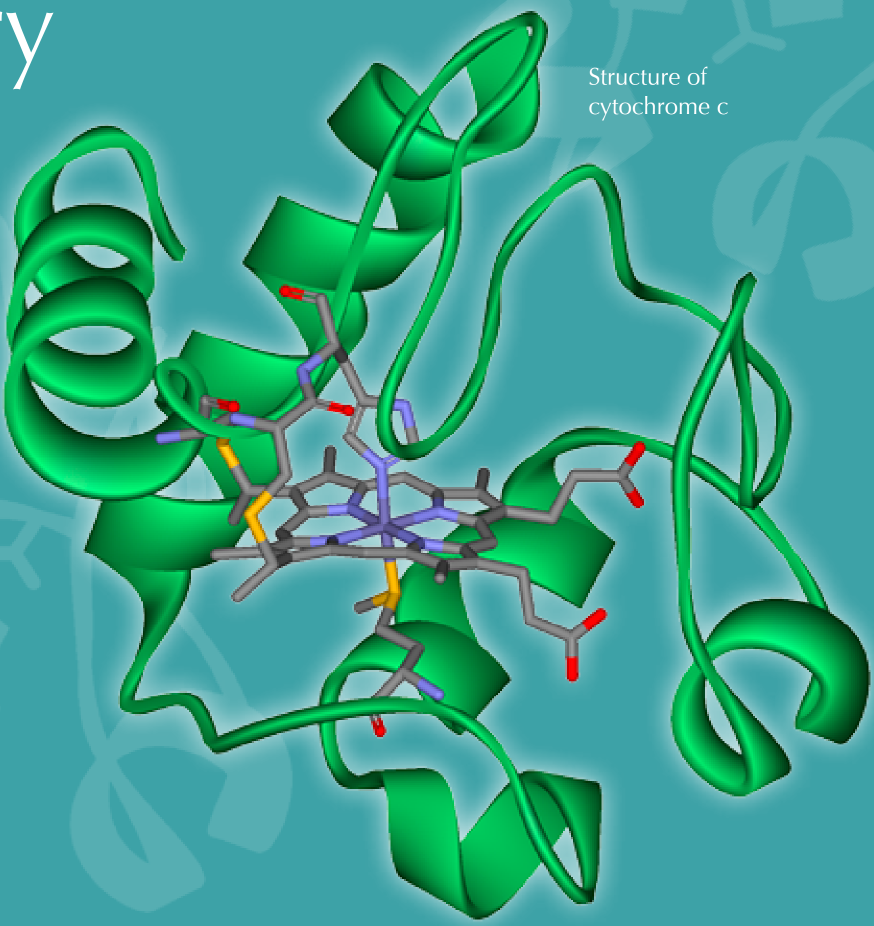
Christos Papageorgiou is a school teacher in the 1st Lyceum of Evosmos in Thessaloniki, Greece. His main scientific background is physics, in particular electronics. He strongly encourages his students to get involved in European scientific projects.

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

Using biological databases to teach evolution and biochemistry



Structure of cytochrome c

Image courtesy of Klaus Hoffmeier Wikimedia commons

Online tools can be used to compare the sequences of proteins and understand how different organisms have evolved.

By Germán Tenorio

In the past, scientists carried out evolutionary analyses by comparing the physical characteristics of species – known as their phenotypes – found in fossil records. Since the discovery of the molecular clock, however, all this has changed. The concept of the molecular clock emerged from the observation that the longer the time since two species diverged from a common ancestor, the more different their DNA or proteins sequences will be (for a review, see Bromham & Penny, 2003). By comparing homologous gene or protein sequences – in other words, those from two organisms with a common ancestor – you can measure how long it has been since the organisms diverged. This can be visualised in a phylogenetic tree.

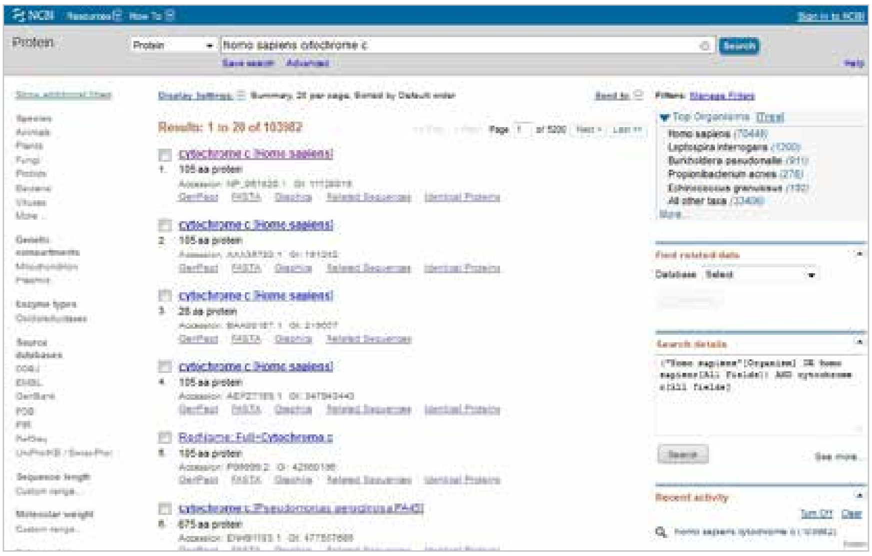
To examine how similar two genes are, you need to have their sequences and align them correctly (Koslowski, 2006). Getting those sequences used to be really difficult, but not anymore.

Your students have probably told you that everything is on the Internet – this time, they're right. There are many examples of freely accessible biological databases containing real research data on the Internet, but for this activity we are going to use two resources in particular.

The National Center for Biotechnology Information (NCBI)[w1] in Bethesda, MD, USA, provides access to biomedical and genomic information, whereas the European Bioinformatics Institute (EBI)[w2], located in Hinxton, UK, provides freely available data from life science experiments and performs basic research in computational biology. The NCBI database will provide you with the sequence of any gene or protein that has already been sequenced, and then you can use tools from the EBI to align the sequences and analyse them.

Activity

When investigating evolutionary relationships between different organisms, it is important to choose carefully which gene or protein you will use. There are some well-known homologous genes that can be used, such as those for the proteins hemoglobin or cytochrome c, and in this activity we will use the latter. Cytochrome c



is a small heme protein that is a central component of the electron transport chain in mitochondria. All aerobic organisms have evolved from a common ancestor that first used cytochrome c, so it is a good choice for our purposes[w3].

This activity is carried out in three different sections:

- finding the amino acid sequence of cytochrome c in different organisms,
- aligning them, and
- making a phylogenetic tree.

Finally, some questions are included to guide the investigation of evolutionary relationships.

Finding protein sequences

1. Go to the NCBI webpage[w1].
2. In the search area at the top of the page, select 'protein' in the drop-down menu.
3. Type the name of a species, e.g. *Homo sapiens*, and cytochrome c.
4. Click the search button.
5. A new page will list your search results. Most of them are the same sequence from different sources, but others can be partial sequences or belong to a different species or protein. Carefully choose the correct protein of interest and click

```
>Homo sapiens
MGDVEKGKKIFIMKCSQCHTVEKGGKHKTGPNLHGLFGRKTGQAPGYSYTAANKNKGIIWGEDTLMEYLE
NPKKYIPGTKMIFVGIKKKEERADLIAYLKKATNE
>Pan paniscus
MGDVEKGKKIFIMKCSQCHTVEKGGKHKTGPNLHGLFGRKTGQAPGYSYTAANKNKGIIWGEDTLMEYLE
NPKKYIPGTKMIFVGIKKKEERADLIAYLKKATNE
>Arabidopsis Thaliana
QTLDIQRGATLFNRACIGCHDTGGNIIQPGATLFTKDLERNGVDTEEEIYRVTYFGKGRMPGFGEKCTPR
GQCTFGPRLQDEEIKLLAEFVKFQADQGWPTVSTD
>Zea mays
MASFSEAPPGNPKAGEKIFKTKCAQCHTVDKGAGHKQGPNLNGLFGRQSGTTAGYSYSAGNKNKAVVWEE
DTLYEYLLNPKKYIPGTKMVFPGLKKPQERADLIAYLKEATA
>Aspergillus nidulans
MAKGGDSYSPGDSTKGAKLFETRCKQCHTVENGGGHKVGPNLHGLFGRKTGQAGGYAYTDANKQADVTWD
ENSLFKYLENPKKYIPGTKMAFGGLKKTKERNDLITYLKESTA
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REVIEW

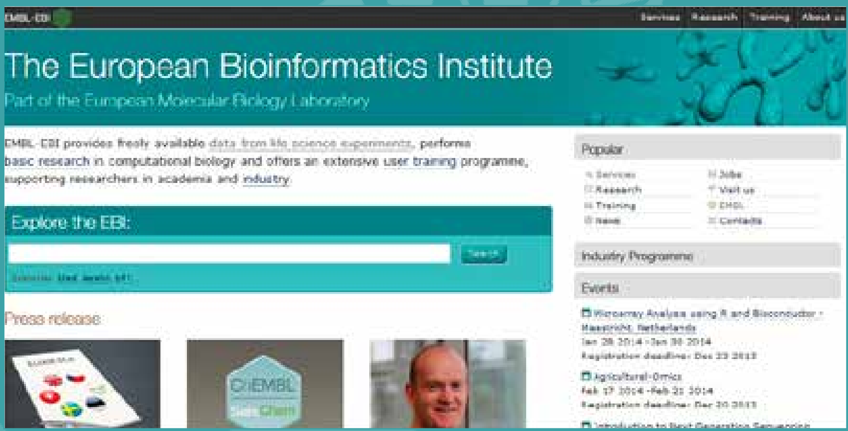
✔ Biology
✔ History
✔ Physics
✔ Ages 16–18

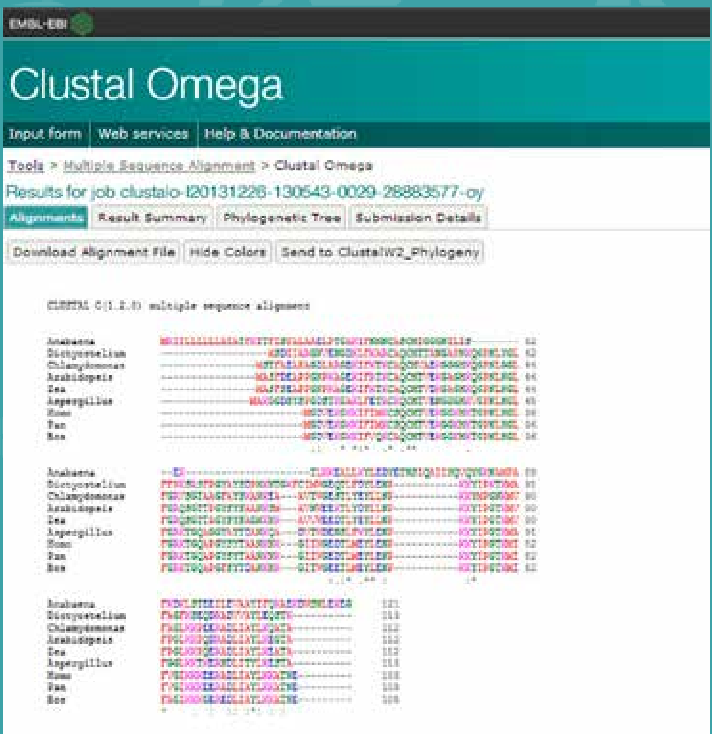
Biology teachers could use this article to link topics of evolution biology, history of science, biochemistry and genetics. To make the most of this article, it is important that students understand the fundamentals of DNA and protein biochemistry.

The activity described in the article is important for motivating students to work with autonomy in real research using scientific databases. Inside the classroom laboratory, students could be guided to work in small groups, comparing sequences of proteins, such as cytochrome c, or DNA, to understand the differences between phylogenetic and cladogram trees. Bioinformatics is very useful in the secondary school for carrying out 'content and language integrated learning' at different levels, with English, history and physics teachers in a interdisciplinary project. This article, which links these different subjects, could also open up discussions about the progress and limitations of such research.

Marina Minoli, Didactic Expert Agora'University Centre, Italy

Biology



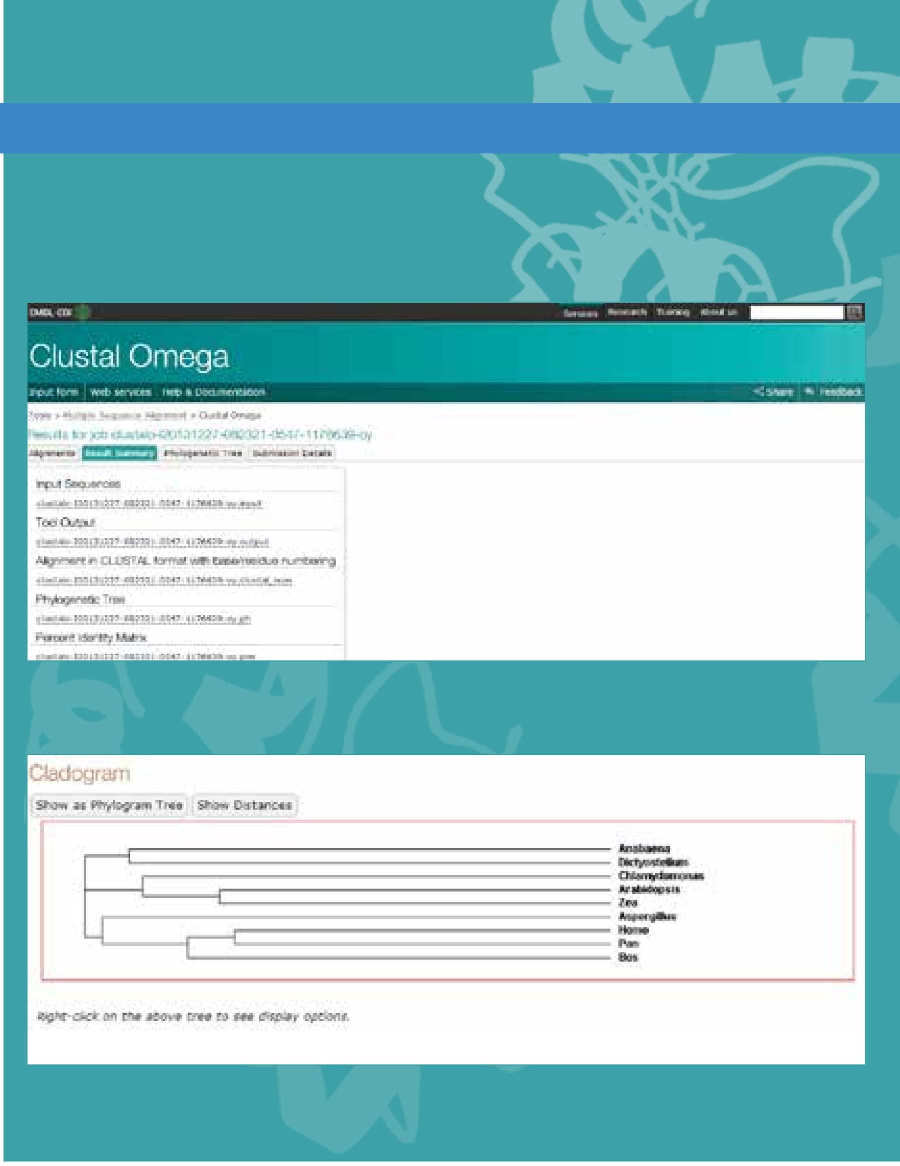


on the link underneath labelled 'FASTA'.

6. From the new page that loads, copy the string of capital letters denoting the sequence of amino acids. Paste the letters into a Word document, remember to label the sequence with the name of the organism it comes from.
7. Do the same for as many organisms as you desire, depending on what you want to investigate with your students. You may include different primates to see how humans evolved or organisms from the five traditional kingdoms to see how life in general evolved. In this activity, 3 animals, 2 plants, 2 algae, a fungus and a protozoan will be used.

Aligning sequences

8. Go to the European Bioinformatics Institute (EBI) website[w2] and click on 'Services'. Then choose 'proteins'.
9. Click on Clustal Omega. Copy the text from your Word document and paste it into the text box labelled 'STEP 1'.
10. In STEP 2, choose a format for the alignment output, such as 'Clustal w/ numbers' which will show the length of each sequence. Finally, click on 'Submit' to complete STEP 3.
11. The alignments for the multiple sequences will appear in a new window. The first thing you can do is click to show colours. This option will give the same colour to each amino acid, so it is easier to identify them.
12. To analyse the alignment, keep the following symbols in mind: an asterisk (*) means that the sequences are identical at that position; a colon (:) indicates conserved substitutions (same colour group); and a period (.) refers to semi-conserved substitution (similar shapes). Colours group the amino



acids by characteristics. Red are small, hydrophobic, aromatic; blue are acidic; magenta are basic; green are hydroxyl, amine, amide, basic; and gray are the rest.

13. If you click on the option 'Result Summary', you can see the percentage of identity conserved between the different organisms after the alignment. In this matrix, you can find out the percentage identity of two organisms for the sequence of protein cytochrome c. In addition, if you have Java™ installed in your computer, you can use Jalview, a free program for multiple sequence alignment editing, visualisation and analysis. With Jalview, you will be able to see the consensus sequence for cytochrome c and the level of conservation for the different amino acids.

Clustal Omega software has many different options that involve more sophisticated mathematical knowledge than is necessary for our purposes. If you want to know more about the use of Clustal Omega, see the article by Sievers et al. (2011).

Making a Phylogenetic tree

14. In the Clustal Omega results, click on 'Phylogenetic tree' at the bottom (you will need to have Java™ installed).
15. You can obtain a phylogenetic or cladogram tree. In a cladogram, the lengths of the branches in the tree are arbitrary, whereas in a phylogenetic tree, the lengths of the branches indicate how much the protein has evolved over time.

For further discussion

1. Homologous molecules are an example of divergent evolution. How can you explain divergent evolution using cytochrome c?
2. Alignments can be made using nucleotide (genes) or amino acids (protein) sequences. Why do you think it is more useful to use protein rather than DNA in order to analyse evolutionary relationships?
3. In phylogenetic trees, a 'clade' is formed by all organisms that have a common ancestor. Give an example from your cladogram.
4. What organisms have suffered a speciation event more recently, according to phylogenetic analyses of cytochrome c? What is the total number of speciation events?
5. Why do you think some amino acids have changed due to mutation but not others? Do you think that conserved amino acids have not changed because their codons have not undergone any mutations at all?
6. Show some of these conserved amino acids in your alignment. Investigate their function on the Internet.

Acknowledgements

The author would like to thank his colleague María Isern for help with revising the English grammar in the article.

References

Bromhan L. Penny D. (2003) The modern molecular clock. *Nature Reviews Genetics* **5:** 216-224

This article can be found at: https://tinyurl.com/l5xc66g

Kozlowski C. (2006) Bioinformatics with pen and paper: building a phylogenetic tree. *Science in School* **17**: 28-33. www.scienceinschool.org/2006/issue2/tree

Sievers F. et al. (2011) Fast, scalable generation of high-quality protein multiple sequence alignments using Clustal Omega. *Molecular Systems Biology* **7:** 539

This article is freely available online and can be found at www.nature.com/msb/

BACKGROUND

Glossary

Cladogram: A branched diagram that shows the evolutionary relationship between species, with arbitrary branch lengths.

Consensus sequence: A known set of conserved sequences, or the calculated order of the most frequent amino acids found at each position in a sequence alignment.

Conserved amino acid: A sequence of amino acids in a polypeptide that is similar across multiple organisms.

FASTA: a text-based format for representing nucleotide or peptide sequences using single-letter codes. A sequence in FASTA format begins with a single-line description, followed by lines of sequence data. The description line is distinguished from the sequence data by a greater-than (>) symbol.

Homologous protein: Those proteins shared by some organisms that are derived from a common ancestor.

Phylogenetic tree: A branched diagram that shows the evolutionary relationship between species, where branch lengths indicate the difference between the two proteins or genes.

Speciation event: The moment at which an ancestral species diverges into new species.

Web references

w1 – The US National Center for Biotechnology Information provides access to biomedical and genomic information. See: www.ncbi.nlm.nih.gov

w2 – The European Bioinformatics Institute provides freely available data from life science experiments, performs basic research in computational biology and offers an extensive user training programme, supporting researchers in academia and industry. See: www.ebi.ac.uk

w3 – John Kimball has written an online biology textbook called 'Taxonomy: Classifying Life'. For a chapter on 'Phylogenetic trees', see: https://tinyurl.com/2wqp7nq

Resources

The 'Understanding Evolution' website from the University of California's Museum of Paleontology offers very good information about building and reading phylogenetic trees. See: http://evolution.berkeley.edu

To learn more about the use of cytochrome c in phylogenetic trees, see: http://bit.ly/1lc0qiy

The Protein Data Bank website in Europe belongs to the European Bioinformatics Institute and can be used for searching and viewing the 3D structure of cytochrome c. See: www.ebi.ac.uk/pdbe/

The Tree of Life website allows you to explore interactively and watch the Tree of Life television series that aired on the BBC with Sir David Attenborough. See: www.wellcometreeoflife.org/interactive/

If you found this article interesting, please browse the other biology articles on the the Science in School website: www.scienceinschool.org/biology

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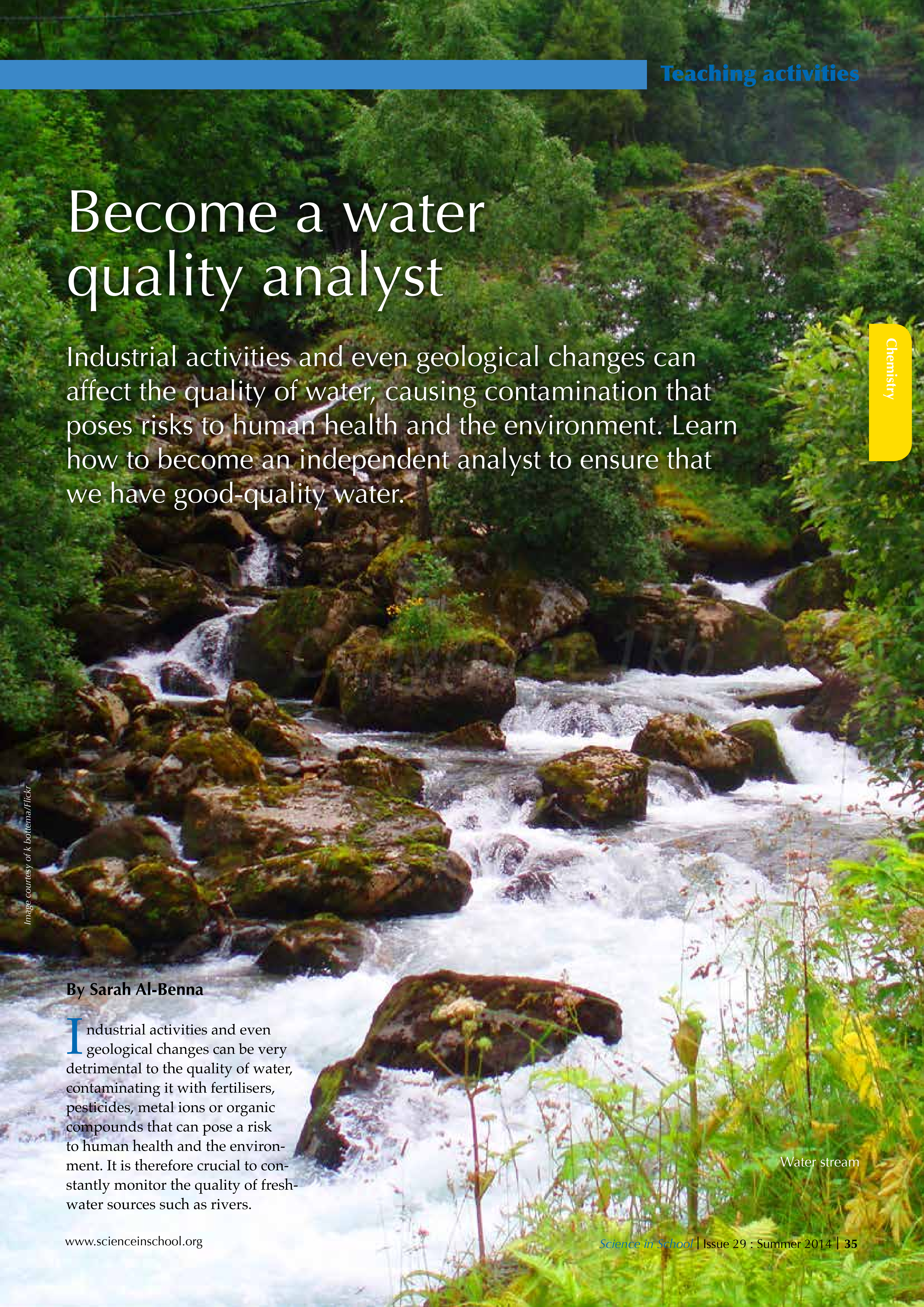
Become a water quality analyst

Industrial activities and even geological changes can affect the quality of water, causing contamination that poses risks to human health and the environment. Learn how to become an independent analyst to ensure that we have good-quality water.



Water stream

Image courtesy of k bottema/Flickr

By Sarah Al-Benna

Industrial activities and even geological changes can be very detrimental to the quality of water, contaminating it with fertilisers, pesticides, metal ions or organic compounds that can pose a risk to human health and the environment. It is therefore crucial to constantly monitor the quality of freshwater sources such as rivers.

Quality analysts are a key part of the process to keep us safe from polluted water. They regularly check water quality by performing quantitative analyses (such as determining the amount of an ion in a solution) on collected samples at various sites before, during and after water treatment.

In the following activity, students put themselves in the shoes of a water-quality analyst working next to a manufacturing plant similar to the Tata Steel site in Scunthorpe, UK. They will have to react to a specific scenario, perform the appropriate analyses, and determine whether the plant is removing thiocyanate from its waste water efficiently.

Image courtesy of the Royal Society of Chemistry

Coal is converted to coke in coke ovens. Thiocyanate ions are a by-product.

Thiocyanates: a ubiquitous poison

Thiocyanate ions (SCN^-) are toxic to aquatic organisms and are known to affect the thyroid gland in humans, reducing the ability of the gland to produce the hormones necessary for the normal function of the body.

Thiocyanates can have many different origins. Coal gasification and the production of industrially useful chemicals from coal, for example, produce large quantities of thiocyanate ions, together with a large number of other toxic compounds such as phenols and ammonium. These by-products are therefore constituents of the plant's waste water.

Thiocyanates can also be found where cyanide is used in the mining of precious metals. The cyanide is converted to thiocyanate by the reaction with sulfur, which is naturally found in ores:

$$8\,CN^- + S_8 \rightarrow 8\,SCN^-$$

Some pesticides also contain thiocyanate ions as their active, poisonous, compound.

Traces of thiocyanate are found naturally in the human body as a by-product of the metabolism of cysteine and detoxification of cyanide – it is then excreted in the urine. It can be taken into the human body through smoking and is a by-product of the metabolism of some drugs used to treat hypertension.

Microbes vs poison

The process of removing thiocyanate ions from waste water takes place in huge open-air concrete tanks that contain activated sludge, a biologically active material comprising a range of micro-organisms that can break down thiocyanate ions and other contaminants into less dangerous compounds. The chemical reaction that takes place to neutralise thiocyanate is:

$$SCN^- + 3H_2O + 2O_2 \rightarrow HCO_3^- + NH^{4+} + SO_4^{2-} + H^+$$

This reaction is an example of bioremediation[w1], a process in which microbes are used to clean up contaminated soil and groundwater. Plants may also be used to clean up

REVIEW

✔ **Chemistry**
✔ **Ages 16–18**

Educational research has shown the value of placing theoretical ideas in 'live' project scenarios – or in real-world contexts. This practical activity is a good example of placing classical analytical chemistry in a real-world context. It also offers the opportunity to develop transferable skills in data processing and communication.

Marie Walsh, Limerick Institute of Technology, Ireland

Image courtesy of jetsandzeppelins/Flickr

Pesticide sign in Manito Park in Spokane, WA, USA contaminated land, in a process called phytoremediation[w2].

Before and after treatment, water can easily be tested for the presence of thiocyanate ions. If the solution turns blood red upon the addition of iron(III) chloride, then thiocyanate ions are present, as per this equation:

$$Fe^{3+}_{(aq)} + SCN^{-}_{(aq)} \rightarrow [FeSCN]^{2+}_{(aq)}$$

or, more fully,

$$[Fe(H_2O)_6]^{3+}_{(aq)} + SCN^{-}_{(aq)} \rightarrow [Fe(H_2O)_5SCN]^{2+}_{(aq)} + H_2O_{(l)}$$

This reaction can be used for the quantitative analysis of low concentrations of thiocyanate ions. By using a colorimeter, you can measure the absorbance at 480 nm of the $[Fe(H_2O)_5SCN]^{2+}$ complex and deduce the precise concentration of thiocyanate ions, provided it is not too high. You can also use simple colour matching, although the results will be less precise and only qualitative.

Scenario

As explained in worksheet 1[w3], the students should place themselves in the role of a quality analyst from a small independent quality control firm that checks results to ensure that they meet the requirements of the UK Environment Agency.

The effluent of an industrial plant such as the Tata Steel site in Scunthorpe is known to contain around 250 mg/dm^3 (250 ppm) of thiocyanate ions. However, the safe level given by the UK Environment Agency is 10 mg/dm^3, so the effluent is treated and the thiocyanate concentration is reduced to 1 mg/dm^3, well below safe limits. The thiocyanate ions are removed from the effluent before it is fed into the River Trent.

There has been a recent period of severe cold weather, which can affect the activity of micro-organisms. The company is concerned that this has affected its water treatment plant and has reduced its effectiveness at removing thiocyanate ions from waste water.

The water is normally analysed for thiocyanate at the plant three times a day using a simple test: an acidic solution of iron(III) chloride is added to the water sample and the concentration of thiocyanate is measured photometrically by measuring the absorbance due to the iron(III) thiocyanate complex. A total of 16 separate tests are carried out every week.Samples of incoming effluent and the water ready for discharge into the river are also taken back for accurate analysis.

The company's analysts have checked, but the company is seeking an independent analyst: you!

Chemistry

Industrial landscape near Vancouver, Canada

Image from Flickr, courtesy of Evan Leeson

Image from Flickr, courtesy of k bottema

ACTIVITY

Become a water-quality analyst – general outline

Safety note

You should wear suitable eye and hand protection to handle acids and thiocyanates. You can check the safety guidelines on the *Science in School* website (www.scienceinschool.org/safety) and at the end of this print issue.

The following activity is aimed at students aged 16–18 and takes about 2 hours.

Preparation work

1. Make the following solutions in advance of the practical activity:
   a Solution of potassium thiocyanate (KSCN) at 250 mg/dm^3 (250 ppm) Dissolve 4.5 g potassium thiocyanate in 500 cm^3 of distilled water. Then dilute 50 cm^3 of this solution to 1 dm^3: it is now at a concentration of 250 mg/dm^3 of thiocyanate ions.
   b Solution of acidic iron(III) chloride ($FeCl_3(H_2O)_6$) at 0.41 mol/dm^3 Dissolve 50 g of $FeCl_3(H_2O)_6$ in about 250 cm^3 of a solution of hydrochloric acid (HCl) at 1 mol/dm^3
   c Twelve labelled samples of different concentrations of thiocyanate ions
      - Samples 1 to 4 represent water from the inlet pipe that goes into the waste water treatment plant. Dilute 10 times the solution of potassium thiocyanate at 250 mg/dm^3 to obtain a concentration of 25 mg/dm^3. It should then be slightly diluted to provide variation in concentration across the four samples.
      - Samples 5 to 8 represent water taken from the pipe releasing effluent from the waste water treatment plant to the river. They should be made at a concentration of 5 mg/dm^3: pipette 10 cm^3 of the solution of potassium thiocyanate at 250 mg/dm^3 into a 500 cm^3 volumetric flask and add distilled water up to the mark.
      - Samples 9 to 12 represent the water from the settling-in tanks. They should be made by mixing the solution of potassium thiocyanate at 25 mg/dm^3 with an equal volume or twice the volume of distilled water. The exact proportions of thiocyanate solution to water are not critical.
2. Provide the students with a plan of the plant (figure 1), worksheet 1[w3] outlining the scenario, and worksheet 2[w4] describing all the details about the analysis process.
3. The students should write a letter to the company that operates the waste water treatment plant requesting samples for analysis. They should specify at what point in the flow of effluent through the plant they would like samples to be taken, how many samples they require and when they should be taken. They should also specify the quantity of each sample needed, how they should be taken and what kind of container they should be collected with.
4. The students should work in pairs to analyse their samples according to the method described in worksheet 2[w4].

Materials

- Burette
- 7 volumetric flasks of 100 cm^3
- colorimeter and suitable filter (blue) – a solution of the complex displays maximum absorption at 480 nm
- 30 cm^3 of a solution of potassium thiocyanate at 250 mg/dm^3 for the thiocyanate ions (250 ppm)
- 70 cm^3 of a solution of iron(III) chloride solution at 0.41 mol/dm^3
- 10 cm^3 of a solution of unknown thiocyanate concentration (which you will need to test in your role as a quality analyst)

Procedure

Care: Wear eye protection: the solution of iron(III) chloride is an irritant.

1. Create a calibration graph

a. Fill three burettes, one with 250 mg/dm^3 potassium thiocyanate solution for the thiocyanate ions, one with distilled water, and one with the iron(III) chloride solution.

b. To six 100 cm^3 volumetric flasks, add 0.0, 2.0, 4.0, 6.0, 8.0 and 10.0 cm^3 of the solution of 250 mg/dm^3 potassium thiocyanate and label them A to F.

c. Add distilled water to each flask to bring the volume up to about 80 cm^3.

d. To each flask, add 10 cm^3 of the iron(III) chloride solution and then add distilled water to bring the volume up to 100 cm^3. Mix the solutions thoroughly.

Image courtesy of the Royal Society of Chemistry

Inside the analytical laboratory at the Tata Steel plant

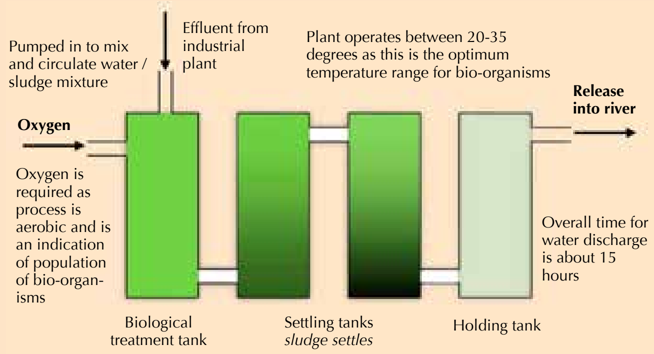


Image from Flickr, courtesy of Global Water Partnership

Figure 1. Annotated plan of the waste water treatment plant showing where samples can be taken

Image courtesy of the Royal Society of Chemistry

Inside the analytical laboratory at the Tata Steel plant

Flask	A	B	C	D	E	F
Volume of potassium thiocyante solution (cm^3)	0.0	2.0	4.0	6.0	8.0	10.0
Thiocyanate	0	5	10	15	20	25 (ppm)

e. Measure the absorbance of each solution using a colorimeter.

f. Plot a graph of absorbance (*y* axis) against the concentration of thiocyanate ions in ppm (*x* axis) for the six solutions.

2. Analyse the sample

a. Add 10 cm^3 of the solution of unknown thiocyanate concentration to a 100 cm^3 volumetric flask and add distilled water to bring the volume in the flask up to about 80 cm^3.

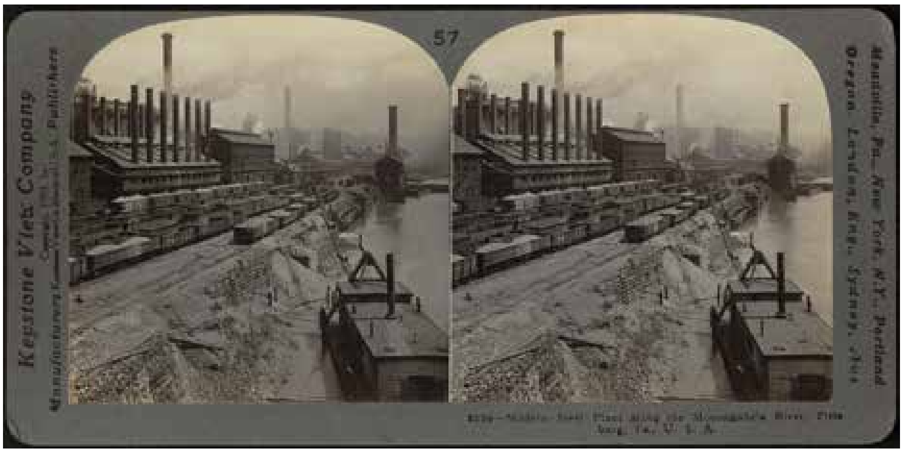
b. Add 10 cm^3 iron(III) chloride solution to the flask and then add distilled water to bring the volume up to 100 cm^3. Mix the solution thoroughly.

c. Measure the absorbance of the solution using a colorimeter.

d. Use the graph to find the concentration of thiocyanate ions in the unknown solution.

3. Write a report to the waste water treatment company summarising your findings, including a recommendation about whether the effluent should be fed into the river or not. Students should describe the evidence on which their recommendation is based and comment on their confidence in the results, taking into account any percent error that may be involved in their analytic procedures.

Image in the Public Domain. Source: Boston Public Library



Steel plant in Pittsburgh, PA, USA, in 1905.

Web references

w1 – To read more about a case study on bioremediation see: http://tinyurl.com/knfrqw3

w2 – To learn more about phytoremediation, visit: http://tinyurl.com/lrcc5ar

w3 – Download worksheet 1, outlining the scenario behind the activity, from the *Science in School* website. See: www.scienceinschool.org/2014/issue29/thiocyanate#w3

w4 – Download worksheet 2, describing the analysis process, from the *Science in School* website. See: www.scienceinschool.org/2014/issue29/thiocyanate#w4

Resources

To learn more about contaminated soils, see: http://tinyurl.com/lmloqgg

This activity was originally designed by the Royal Society of Chemistry. See: http://rsc.li/1kj9YCV

If you found this article interesting, you may like to explore the other articles on chemistry published in *Science in School*. See: www.scienceinschool.org/chemistry

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Image courtesy of Global Water Partnership/Flickr

Water treatment plant in the Netherlands

The Riverside Walk by the River Anton at Goodworth Clatford in Hampshire, UK

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

How water travels up trees

Why do giant redwoods grow so tall and then stop? It all has to do with how high water can travel up their branches.

Photo courtesy of Allie_Caulfield/Wikimedia Commons

Coast redwood, *Sequoia sempervirens*

By Clare van der Willigen

The redwoods of northern California, *Sequoia sempervirens*, are the tallest trees in the world and can grow to heights of more than 110 m. However, what finally limits their height is still debated.

The most popular theory is the 'hydraulic limitation hypothesis' (Ryan & Yoder, 1997), which suggests that as trees grow taller, it becomes more difficult to supply water to their leaves. This hydraulic limitation results in reduced transpiration and less photosynthesis, causing reduced growth.

In tall trees, water supply can be limited by two factors: distance and gravity. Tall trees have a longer pathway of transport tissue – known as xylem – which increases the difficulty of water to travel, something we call hydraulic resistance. In addition, not only is the xylem pathway long, but the trees are tall and the water has to overcome gravity. Increased force is necessary to pull the water up to the highest leaves. This situation differs

Biology
Mathematics
Ages 15–18

The article describes two experiments that can easily be conducted in science classrooms or laboratories to study water movement in plants.

Although the procedures are easy to carry out, the concepts and knowledge that are explored aren't so simple, but are appropriate for upper secondary-school students (aged 15-18). In my experience, there are not very many procedures that consider water movement for this age group, so many science teachers will welcome this article.

There are also relevant opportunities for interdisciplinary teaching involving mathematics in particular. It would be quite interesting to use this experiment as a starting point to introduce students to the development of a database and subsequent statistical analysis (not too complex). For example, students could estimate maximum xylem vessel lengths and measure xylem hydraulic conductivity of different plants and at different times (e.g. winter vs. summer). This database could be extended from year to year with other students. Such a strategy could help students to understand science as a collaborative activity – not only between different disciplines but also between different 'generations' of scientists.

Betina Lopes, Portugal

REVIEW

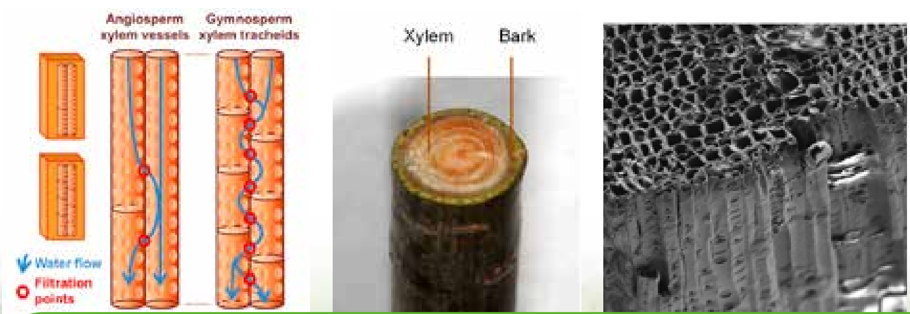
from a long hosepipe lying along the ground: it would have high resistance due to its length, but not the additional difficulty of being upright.

Fast-growing trees often have shorter life spans. To achieve their rapid growth, pioneer trees have wider xylem vessels, increasing their hydraulic efficiency but also increasing the risk of embolisms (air locks). Air locks in xylem vessels prevent water from being able to travel through them.

In contrast, very tall trees are often very long-lived. It is thought that this is partly because they are more likely to adopt a safe hydraulic design, with multiple narrow xylem vessels instead of a few wider ones. This increased safety is counteracted by a decreased efficiency of water transport, which consequently limits growth rates. Tree height, therefore, may also be limited by the safety versus efficiency trade-off in xylem function (Burgess et al, 2006).

The following two activities explore the trade-off that plants make between being efficient with water transport and having a safe design. Both activities can be adapted for students aged 15–18 with a wide range of abilities, but you should assess whether the students can perform all of the experiments or whether it is safer for the teacher to do the cutting. Each activity will take about 50 minutes.

a b c



Images courtesy of Boutilier et al.

a) Structure of xylem vessels in flowering plants and tracheids in conifers b) Photograph of ~1 cm diameter pine (pinus strobus) branch c) Scanning electron microscope (SEM) image of cut section

Species	Mean xylem length (m)
Acer saccharum (Sugar maple)	0.0312
Cinnamomum camphora (Camphor tree)	0.1184
Rhododendron maximum (Great Rhododendrum)	0.0246
Vitis vinifera (Common Grape Vine)	0.1503

Table 1: Some example xylem lengths of branches less than 15 cm in diameter, taken from Jacobsen et al. (2012)

All photos courtesy of Clare van der Willigen

Biology

Estimating maximum xylem vessel lengths

Comparing the lengths of the xylem vessel will allow students to predict their relative resistance to water flow.

Materials

- Selection of recently cut branches from a tree or shrub, including any leaves or side branches, up to 2 m in initial length. If the experiment is to be performed within a few hours of harvesting, keep the plant material in a plastic bag to avoid excessive water loss.
- Rubber/silicon tubing
- Cable ties or jubilee clips
- Sharp pruning shears or scissors
- 60 cm^3 syringes
- Large basin of tap water
- Hand lens
- Ruler

Procedure

1. Cut a length of branch over 1 m, making sure the cut is clean and the end of the branch is not crushed. The branch will be much longer than the xylem vessels inside.
2. Attach a 60 cm^3 syringe, filled with air, to the proximal (wider) end of the branch using silicon tubing and cable ties as required.
3. Pressurise the air in the syringe and branch by compressing the volume of air in the syringe by about half (e.g. from 60 cm^3 of air to 30 cm^3). This pressure must be maintained through steps 4–6.
4. Hold the distal end of the branch under water.
5. Use a hand lens to see if a steady stream of bubbles can be detected from the distal end of the branch.
6. Progressively cut the distal end of the branch back by about 1 to 5 cm at a time, making sure each time that the end of the branch is not crushed and has a clean cut.
7. When a stream of bubbles is observed, the length of the branch gives an approximate maximum length of the xylem vessels.

Safety Note

Students should be warned about the safety precautions necessary when using sharp objects. See also the general safety note.

Follow-up activity

Students could compare maximum xylem vessel lengths in a variety of different plants or different parts (roots, main and side branches) of the same plant. It is common for fast-growing plants to have longer xylem vessels and therefore fewer breaks between xylems. Can the students suggest why this might be?

About what happens

A branch contains several xylem vessels linked together. Between the xylem vessels are perforated wall plates. The fewer of these divisions there are, the lower the resistance, and the faster water can travel.

A detailed study of vessel length in *Chrysanthemum* stems (Nijsse et al, 2001) and in a wide range of shrubs and trees (Jacobsen et al, 2012) can be used for cross-reference.

Pressurise the air in the syringe

Stream of bubbles

ACTIVITY

Measuring xylem hydraulic conductivity

Measurements of xylem hydraulic properties show how well plants can supply water to their leaves. It is possible to measure the hydraulic conductance of stems, branches and roots in the classroom with some simple, inexpensive equipment. To measure hydraulic conductivity, the branch length should be longer than the mean length of the xylem vessels (see previous activity).

Materials

- Selection of recently cut branches from a tree or shrub investigated in the previous experiment. Ensure that the pieces are longer than the longest xylem vessels measured. If the experiment is to be performed within a few hours of harvesting, keep the plant material in a plastic bag to avoid excessive water loss.
- Rubber/silicon tubing
- Cable ties or jubilee clips
- Sharp secateurs, scissors or a large scalpel
- Chopping board
- Large basin of water
- Metre rule
- Reservoir of degassed, distilled water in a container with a tap at the bottom. Degas the water by boiling it or using a vacuum pump for approximately 1 h until all the gas has been expelled from the water. Air bubbles in water that is not degassed may block the xylem vessels.
- Hydrochloric acid
- 1 cm^3 pipette (a pipette with a 90° bend is most effective. A standard glass pipette can be bent in a very hot flame)
- 50 cm^3 plastic beaker
- Retort stand and clamp
- Balance (precision of at least 0.01 g)
- Stop watch or stop clock

Procedure

1. Set up the apparatus as illustrated in the diagram:

a Add hydrochloric acid to the degassed, distilled water to give a final concentration of 0.01 M. For example, add 0.5 cm^3 of 0.1 M HCl to 5 dm^3 degassed, distilled water. Hydrochloric acid prevents the long-term decline in conductance by reducing microbial growth in the xylem. **Safety tip:** Remember to always add acid to water, not water to acid.

b Fill the reservoir with the acidified water. Insert a piece of tubing, sealed at one end with a bung, into the top of the reservoir. The open tubing ensures a constant pressure head because even if the water level drops, the effective height of the reservoir will remain the same.

c To the tap of the reservoir, add some tubing, fill with water from the reservoir, seal the open end and place into the large basin of water.

d Close the tap.

e Submerge the proximal end of the branch in the large basin of water. This is the end of the branch that was nearest to the main stem of the plant.

Branch connected to tubing

Cut end under water

All photos courtesy of Clare van der Willigen

ACTIVITY

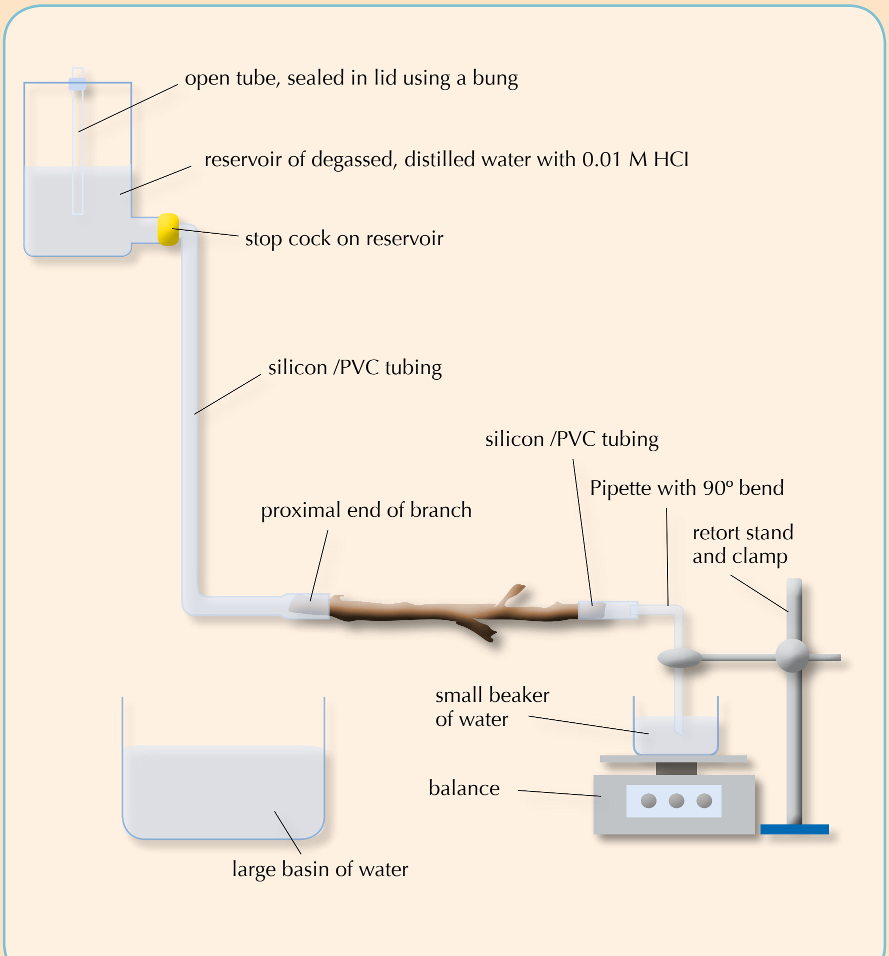


Diagram of the apparatus setup to measure hydraulic conductivity

Image courtesy of Nicola Graf

Whole setup

f Cut approximately 3 cm off the proximal end of the branch under water to ensure that no air pockets remain in the xylem. Shave off the end of the cut using a sharp blade.

g Connect the newly cut end of the branch to the water-filled tubing attached to the reservoir under water. If the bark is very rough, it can be stripped back prior to connection. A watertight seal should be achieved using cable ties or jubilee clips if necessary, however do not over-tighten and compress the xylem vessels.

h Submerge the other end of the branch in the tub of water.

i Cut approximately 3 cm off the end of the branch under water to ensure that no air pockets remain in the xylem. Shave off the end of the cut using a sharp blade.

j Measure and record the length of the branch. Ensure it is longer than the maximum xylem vessel length (see above).

k Connect the bent pipette to more rubber tubing and submerge into the basin of water.

Connect tubing to end under water

Cut proximal end under water

Measure water collection on balance

Measure reservoir height

l Connect the newly cut end of the branch to the water-filled tubing attached to the pipette as above.

m Fill the 50 cm³ beaker with water and place on the pan balance.

n Take the branch end and pipette out of the basin of water with the end of the pipette sealed.

o Place the end of the pipette in the 50 cm³ beaker on the balance.

p Use the retort stand and clamp to hold the pipette in place. The tip of the pipette should not lean on the bottom of the beaker, but should be below the water level. This ensures that as the water drips through the branch, there is a smooth increase in the mass of water in the beaker.

2 Open the tap from the reservoir.

3 Measure the mass of water every 30 s for 3 min.

4 Measure the effective height of the reservoir using the metre rule. This is the height from the bottom of the open tubing in the reservoir to the proximal end of the branch.

Safety Note

Students should be warned about the safety precautions necessary when using sharp objects and acids. See also the general safety note.

Analysis

Hydraulic conductivity is measured as the mass of water flowing through the system per unit time per unit pressure gradient (Tyree & Ewers, 1991). The hydraulic

Table 2. Raw data table to calculate the hydraulic conductivity of a side branch from a Laurel tree (Laurus nobilis)

Time (s)	Mass of water (g)	Mass of water (kg)	Branch length (m)	Effective reservoir height (m)
0	0.00	0.00000	0.32	1.5
30	0.09	0.00009		
60	0.21	0.00021		
90	0.28	0.00028		
120	0.38	0.00038		
150	0.49	0.00049		
180	0.55	0.00055		

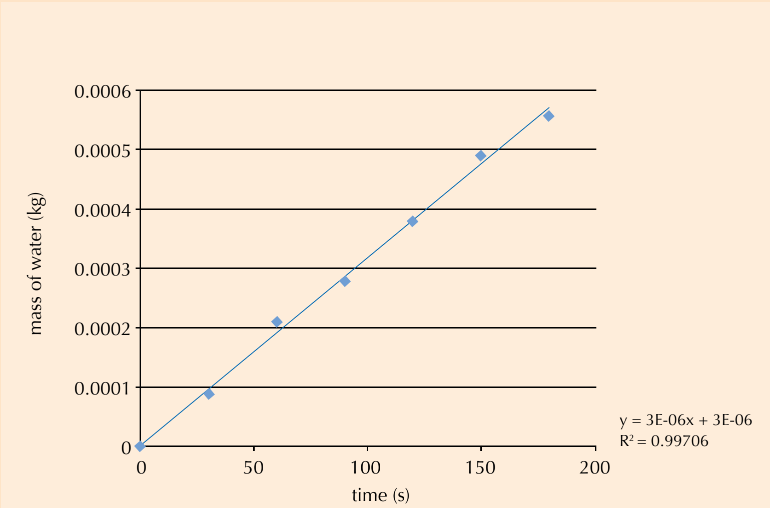


Figure 1: Worked example of plot to calculate flow rate. Data from table 2.

Table 3: Processed data from worked example of a side branch from a Laurel tree (*Laurus nobilis*)

Flow rate (kg/s) see figure 1	Branch length (m)	Hydrostatic pressure head (MPa) w	Hydraulic conductivity k_h (kg m/MPa s)
3×10^{-6}	0.32	0.0147	6.53×10^{-5}

conductivity of the branch, k_h, is calculated using the following formula:

$$k_h = \frac{\text{flow rate x branch length}}{\text{hydrostatic pressure head}}$$

where the flow rate is measured in kilograms per second (kg/s); branch length in metres (m); and the pressure head in megaPascals (MPa).

To calculate the flow rate, plot the mass of water (in kg) measured in step 3 against time (in s). The flow rate will be the gradient of the line of best fit (in kg/s). See table 2 and figure 1 for a worked example.

The hydrostatic pressure head is found by multiplying the effective height of the reservoir, measured in step 4, with the density of liquid and the acceleration due to gravity. The density of the acidified water can be assumed to be 1000 kg/m³ (at room temperature) and a value of 9.81 m/s² can be used for acceleration due to gravity. Thus, with an effective height of the reservoir of 1 m, the hydrostatic pressure head would be 1000 x 9.81 x 1 = 9810 Pa or 0.00981 MPa.

Remember, maximum hydraulic conductivity is only achieved if none of the xylem vessels are embolised (filled with air). To try to prevent this, branches can be flushed with water at a pressure of approximately 200 kPa for 20 min before measuring conductivity. Alternatively, ensure that branches are selected from well-watered trees and that the leaves are covered in a large plastic bag prior to measurement

Follow-up experiments

Investigations on different levels of water stress on the same, or similar, branches would give an indication of plants that are more vulnerable to cavitation, or air bubbles. Hydraulic conductivity can change depending on environmental conditions, and the same species of plant that have adapted to different environments could be tested in the laboratory or in the field. Compare branch cross-sections of different diameter or those supporting different leaf areas.

Students could observe the effect on hydraulic conductivity of changing the branch length and relate this to the height of the plant. They could also investigate the effect on the flow rate of changing the height of the reservoir. The reservoir height (pushing force) could be considered as equal, but opposite, to the pulling force created by the low water potential in xylem vessels.

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BACKGROUND

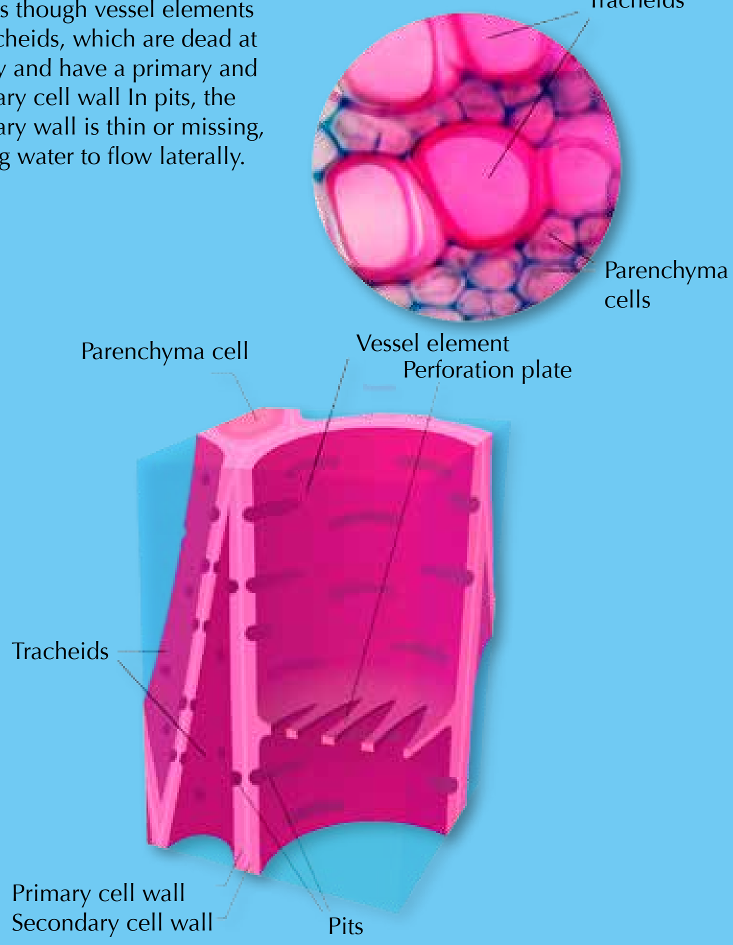
Did you know?

Xylems are essentially porous filters, and scientists think that they could be used to filter water and make it safe to drink. Earlier this year, a group at the Massachusetts Institute of Technology in the USA showed that a 3 cm^3 piece of pine branch could act as a filter and remove 99.9 % of bacteria from water, at a rate of several litres a day. The technique isn't perfect yet: viruses and chemical contamination can't be stopped by twigs, but the work by Boutilier et al (2014) suggests a cheap way to purify water in developing countries.

Image courtesy of Boutilier et al.

Image courtesy of Kelvinsong/Wikimediacommons

Xylem
Xylem transports water and minerals though vessel elements and tracheids, which are dead at maturity and have a primary and secondary cell wall In pits, the secondary wall is thin or missing, allowing water to flow laterally.



Resources

For a scientific analysis of maximum possible tree height, see:

Koch G.W., Sillett S.C., Jennings G.M., Davis S.D. (2004) The limits to tree height. *Nature* **428:** 851–854. doi: 10.1038/nature02417; available free from http://bit.ly/1lsNILK

If you found this article interesting, please browse the other teaching activity articles on the the Science in School website: www.scienceinschool.org/teaching

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

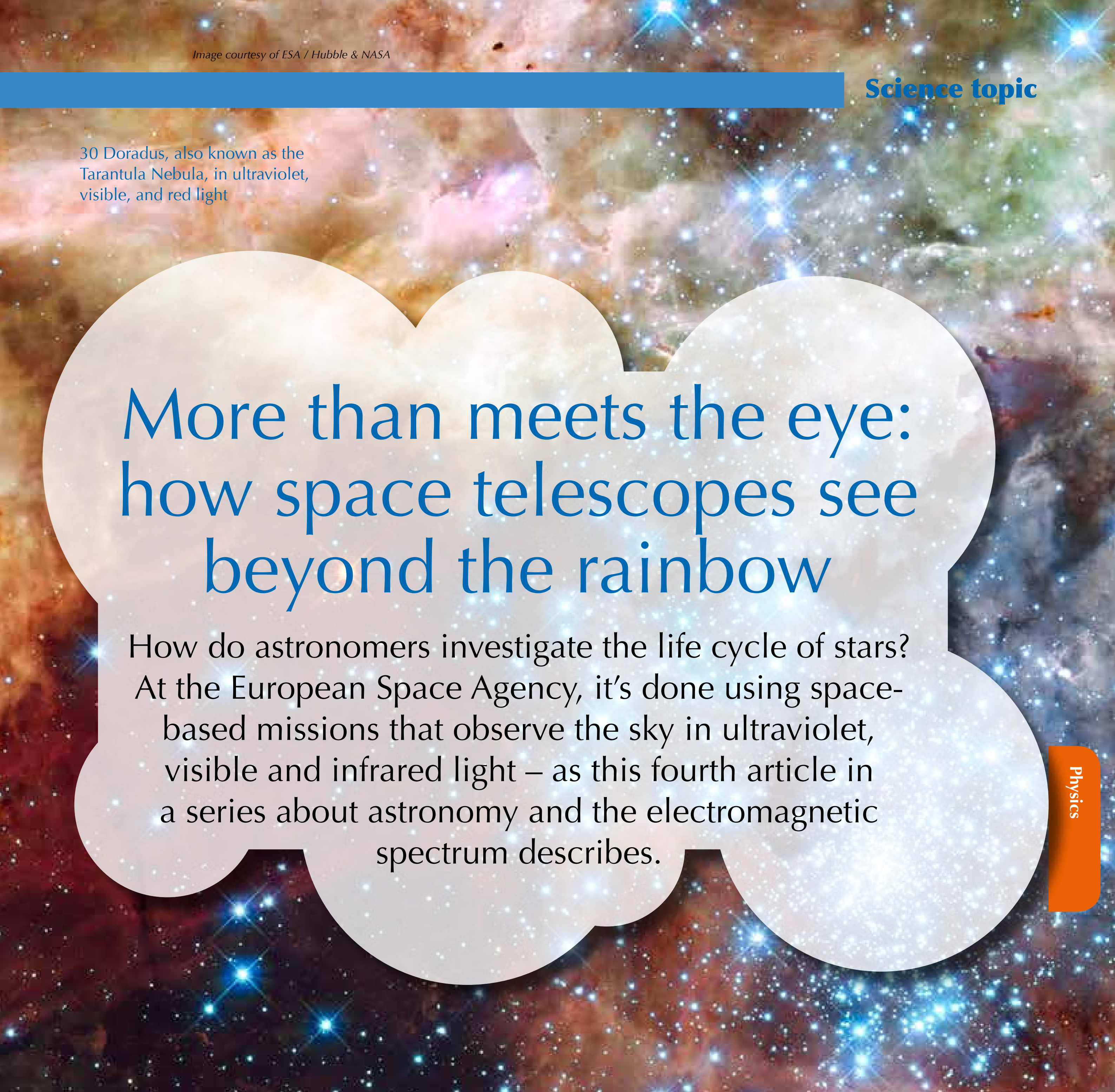

Image courtesy of ESA / Hubble & NASA

30 Doradus, also known as the Tarantula Nebula, in ultraviolet, visible, and red light

Physics

More than meets the eye: how space telescopes see beyond the rainbow

How do astronomers investigate the life cycle of stars? At the European Space Agency, it's done using space-based missions that observe the sky in ultraviolet, visible and infrared light – as this fourth article in a series about astronomy and the electromagnetic spectrum describes.

By Claudia Mignone and Rebecca Barnes

When we look at the night sky, the cosmic landscape that we see is shaped by stars. Although most appear as points of white light, some – even to the naked eye – appear coloured. A striking example can be seen in the constellation Orion, the hunter: his right shoulder is the red supergiant star Betelgeuse and his left knee, the blue supergiant Rigel. The 'colours' are due to differences in the surface temperature of stars[w1]: hotter stars emit most of their light in the visible blue or ultraviolet regions of the electromagnetic spectrum, whereas cooler stars radiate at longer wavelengths, in the visible red or infrared regions (see Mignone & Barnes, 2011a).

But what makes a star hot or cool? There are two main factors: the stage of the star in the stellar life cycle, and its mass. Mass is important because it determines the rate at which a star burns its nuclear fuel: bigger stars burn up faster, producing much higher temperatures.

To probe how stars of all masses develop over their lifespan, their emissions in the range from ultraviolet (UV) to infrared (IR) are particularly important. Unfortunately, a large portion of these wavelengths are blocked by Earth's atmosphere and the rest can be affected by atmospheric turbulence, so space-based telescopes have proved to be a crucial tool for investigating how stars form and evolve.

The European Space Agency (ESA)[w3] has operated various space missions whose goal is to study this wavelength range – most notably the

Infrared Space Observatory and the Herschel Space Observatory, both comprising large infrared telescopes – and participated in joint projects with other space agencies. Currently, ESA's X-ray space observatory (XMM-Newton) is also equipped with a very sensitive UV and visible light telescope, the Optical Monitor (see Mignone & Barnes, 2011b).

From these and many other observations, astronomers have built up a good picture of the stages in the lives of stars, with each stage in the pathway from birth to death depending on the mass of the star.

Massive stars

Although they are relatively rare, high-mass stars are the brightest and hottest of all, and are best observed at the shorter, higher-energy wavelengths of UV to visible blue light. Such stars have masses of at least eight times that of the Sun and high surface temperatures of 10 000 K or more, but they exhaust their hydrogen supply more quickly than starts of lower mass: over some tens of millions of years, compared to billions of years for stars like the Sun. During this time, high-mass stars produce powerful 'winds' (streams of energetic particles) that can trigger or halt star formation in their surroundings. Using data from the International Ultraviolet Explorer (IUE) satellite, astronomers have discovered how much of the star's mass is carried away by these winds, which appears to increase as stars age.

Towards the end of their lives, massive stars expand rapidly and become red giants or supergiants, like Betelgeuse in the Orion constellation. With their very large radii and low surface temperatures, these radiate mostly in the longer wavelengths of visible (red) and IR light. Eventually, they explode as supernovae (see Székely & Benedekfi (2007) for more on the death of stars).

On 23 February 1987, light from a supernova explosion in the Large

Image courtesy of NASA, ESA, and the Hubble SM4 ERO Team

These two images demonstrate how observations taken in visible and in infrared light reveal dramatically different views of an object. In the bottom image, taken in near-infrared light, the dense column and the surrounding greenish-colored gas all but disappear. By penetrating the gas and dust, the infrared vision of WFC3 reveals the infant star that is probably blasting the jet.

Image courtesy of ESA / Hubble & NASA

Figure 1: Hubble image of supernova SN 1987A in visible and near-IR light

Image courtesy of ESA / Hubble & NASA

Figure 2: The Hubble Space Telescope revealed that planetary nebulae have a huge variety of shapes. Seen here in visible light is a remarkably asymmetrical planetary nebula (NGC 5882)

REVIEW

- Physics
- Astronomy
- Geography
- Ages 17–19

This article describes the life cycles of stars and how to investigate their behaviour. Research activities focus on ESA missions and their results.

The authors explain in a very interesting way how the mass of a star, its temperature and its wavelength are related to each other, and how this knowledge is applied in the very broad field astrophysics research.

This article is useful mainly for physics lessons, particularly with its focus on astrophysics, but it also contains links to geography and even to languages.

The article would stimulate discussion around a broad range of questions, including:

- Describe the differences in the life cycle of massive stars and low-mass stars.
- Give an overview of the electromagnetic spectrum (e.g. visible, IR and UV light).
- Discuss the relationship between wavelength, energy and frequency
- Why do we use space observatories in addition to our ground-based observatories?
- What is the relationship between surface temperature and the colour (wavelength) of stars?
- How does the life cycle of a star depend on its mass?
- What are stellar clusters?
- What happens to massive stars at the end of their lives?

Gerd Vogt, Higher Secondary School for Environment and Economics, Ysphertal, Austria

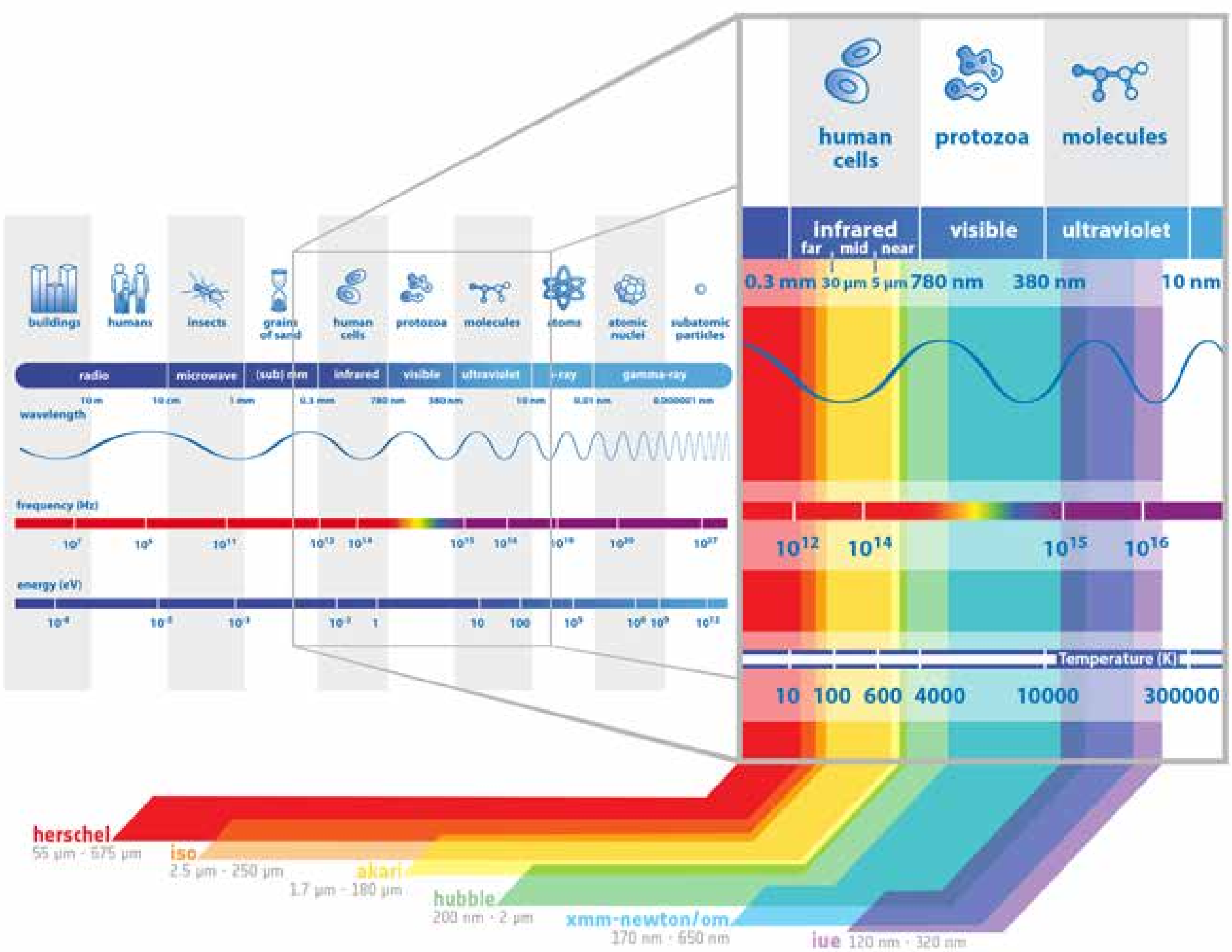

Image courtesy of ESA/ ATC Medialab

The electromagnetic spectrum. The colours highlight the UV, visible and IR regions observed by some of ESA's space observatories (including joint projects with other space agencies)

Physics

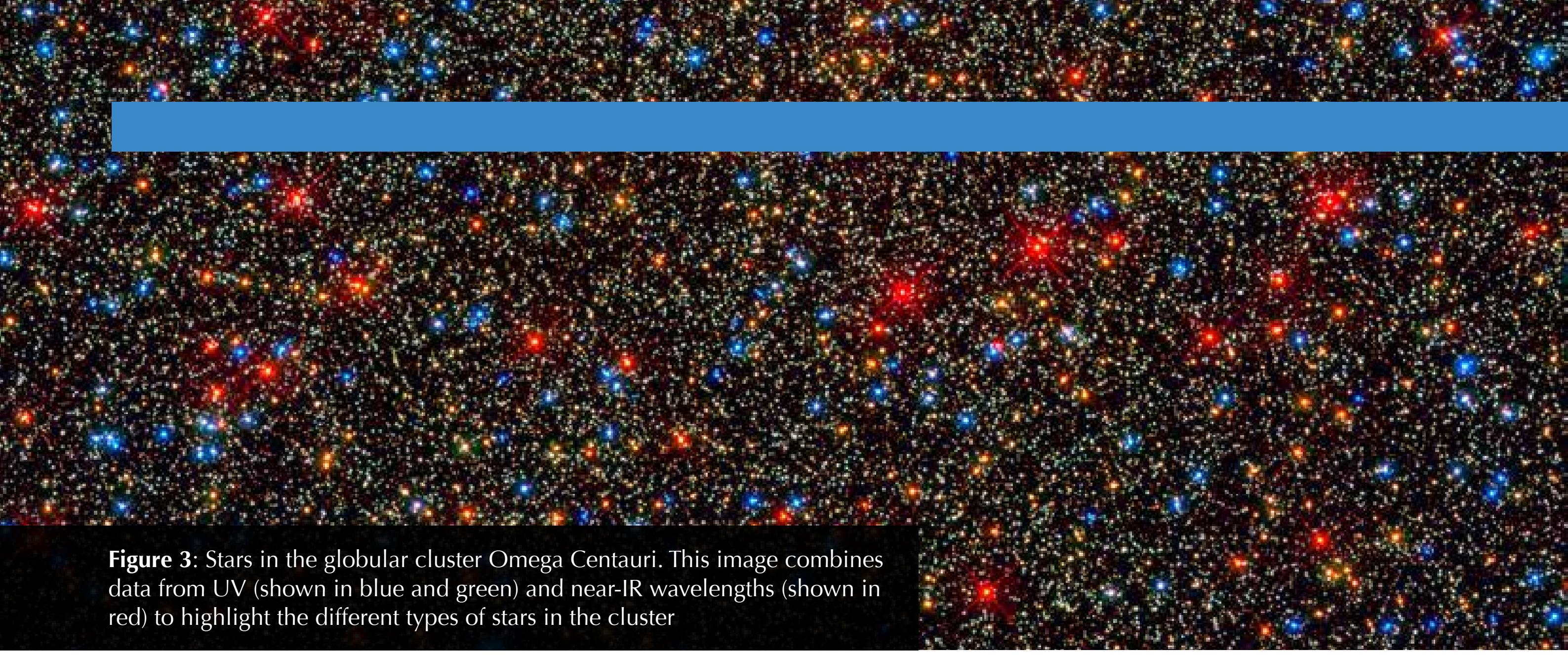

Figure 3: Stars in the globular cluster Omega Centauri. This image combines data from UV (shown in blue and green) and near-IR wavelengths (shown in red) to highlight the different types of stars in the cluster

Image courtesy of NASA / ESA / Hubble SM4 ERO Team

Magellanic Cloud first reached Earth. By comparing data from IUE before and after the explosion was observed, astronomers identified the progenitor star – and found that it was a blue, rather than a red, supergiant. Before 1987, astronomers believed that only red supergiants would explode as supernovae, but this observation proved that other types of evolved stars can produce these explosions too. Blue supergiants are smaller and denser than their red counterparts; an example is Rigel in the Orion constellation. Since then, astronomers have been studying the aftermath of the explosion. Light from the supernova heats up the gas and dust in the surroundings, making it glow at visible wavelengths, while the cooler dust produced in the explosion shines at IR wavelengths (figure 1).

Low-mass stars

The vast majority of stars have relatively low masses, similar to that of the Sun or even less. With surface temperatures ranging between 4000 and 10 000 K, these stars dominate the visible wavelengths, shining brightly in yellow, orange and red light. They burn hydrogen more slowly than massive stars, with lifetimes stretching to tens of billions of years. Low-mass stars also become red giants towards the end of their lives, expanding and cooling at the surface. Finally, they expel their outer layers, producing expanding shells of gas called planetary nebulae (figure 2). These eventually disperse and leave behind hot, compact objects known as white dwarfs.

In our own galaxy, the Milky Way, most stars have even lower masses – around half that of the Sun or less – with cooler surfaces that radiate mainly at the shortest IR wavelengths, called near-IR. The death of such a very low mass star has never been observed, because the age of the Universe itself is less than their lifespan: thousands of billions of years, or even more.

The coolest material in the Universe shines in the far-IR wavelengths targeted by Herschel, and in longer microwave wavelengths as probed by Planck, a satellite that was launched together with Herschel in 2009. In our next article, we will describe how these two missions are further advancing our understanding of star formation across the Universe.

Stellar clusters

As well as looking at single stars, astronomers study the evolution of stars of different sizes by looking at large

i

BACKGROUND

Star formation and cosmic dust

Stars form from the interstellar medium – a diffuse mixture of gas and cosmic dust that is a galaxy's reservoir for star formation. The dust absorbs visible light but is transparent to near-IR wavelengths, so astronomers use the near-IR range to peer through the dust and view complex processes in action, such as the formation of proto-planetary discs around newborn stars. These discs, first seen with Hubble, are seeds of future planetary systems like our own Solar System (figure 4). Protostars, which have not yet reached the temperature of fully fledged stars, also radiate strongly in IR wavelengths. The cosmic dust itself shines brightly at long wavelengths (the mid- and far-IR) due to its low temperature. Using these wavelengths, astronomers can see this dusty interstellar material in our own Galaxy and beyond, providing a preview of stars to come (figure 5). IR observations have also detected molecules that play a key role in the chemical reactions of star formation – such as interstellar water, which was first identified by the Infrared Space Observatory in the late 1990s. Today, astronomers continue to unveil the complex chemical composition of star-forming regions by exploring the rich data set collected with the Herschel Space Observatory.

Image courtesy of NASA / ESA / M. Robberto (Space Telescope Science Institute/ESA) / Hubble Space Telescope Orion Treasury Project Team / L. Ricci (ESO)

Figure 4: Proto-planetary discs seen in the Orion Nebula using visible and near-IR data (Hubble)

groups of stars called stellar clusters[w2]. The Hubble Space Telescope, with its wide spectral coverage from UV to near-IR, provides amazing images of stellar clusters that portray the sheer variety of stars within them (figure 3). These images have led to some remarkable discoveries. For example, before Hubble, astronomers thought that stars in globular clusters (stellar clusters that formed when our Galaxy was still taking shape) were all born at the same time. The Hubble images showed that their stars formed during several distinct episodes, and that globular clusters are much more complex than previously thought. Other Hubble observations confirmed that bluer (hence more massive) stars tend to sink towards the centre of a globular cluster, while redder, smaller stars move to the periphery – an idea that had long been predicted from theory, but never seen.

More about ESA

The European Space Agency (ESA)[w3] is Europe's gateway to space, organising programmes to find out more about Earth, its immediate space environment, our Solar System and the Universe, as well as to co-operate in the human exploration of space, to develop satellite-based technologies and services, and to promote European industries.

The Directorate of Science and Robotic Exploration is devoted to ESA's space science programme and to the robotic exploration of the Solar System. In the quest to understand the Universe, the stars and planets and the origins of life itself, ESA space science satellites peer into the depths of the cosmos and look at the furthest galaxies, study the Sun in unprecedented detail, and explore our planetary neighbours.

ESA is a member of EIROforum[w4], the publisher of *Science in School*.

See all ESA-related articles in *Science in School*.

References

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

Mignone C., Barnes R. (2011b) More than meets the eye: unravelling the cosmos at the highest energies. *Science in School* **21**: 57-64. www.scienceinschool.org/2011/issue21/em

Székely P., Benedekfi Ö. (2007) Fusion in the Universe: when a giant star

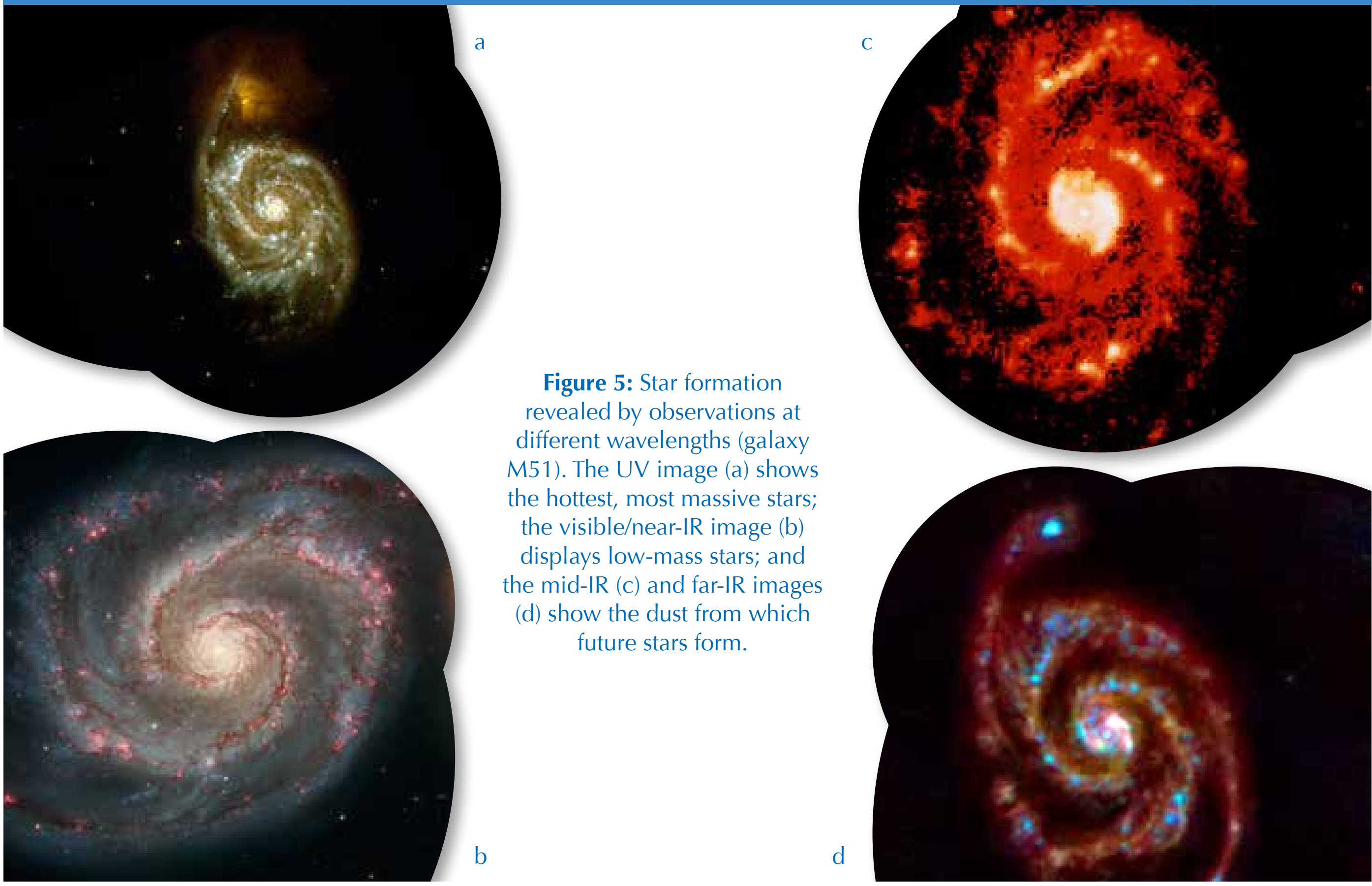

Figure 5: Star formation revealed by observations at different wavelengths (galaxy M51). The UV image (a) shows the hottest, most massive stars; the visible/near-IR image (b) displays low-mass stars; and the mid-IR (c) and far-IR images (d) show the dust from which future stars form.

Image courtesy of: Marco Iacobelli (XMM-Newton SOC) and ESA [a]; NASA, ESA, S. Beckwith (STScI), and The Hubble Heritage Team (STScI/AURA) [b]; ESA/ISO, CEA Saclay and ISOCAM Consortium [c]; ESA and the PACS Consortium [d]

dies.... *Science in School* **6**: 64-68. www.scienceinschool.org/2007/issue6/fusion

Web references

w1 – To find out how the wavelength at which a celestial object emits most of its light is related to the object's temperature, see: http://sci.esa.int/jump.cfm?oid=48986

w2 – To learn more about stellar clusters, see: http://bit.ly/1v9MAQI

w3 – For more information on the European Space Agency, visit the ESA website: www.esa.int

w4 – Find out more about the EIROForum. See: www.eiroforum.org

Resources

To learn more about visible astronomy at ESA, watch Episode 4 of the Science@ESA vodcast. See the ESA Science and Technology website: http://sci.esa.int/vodcast

To learn more about IR astronomy at ESA, watch Episode 3 of the Science@ESA vodcast. See the ESA Science and Technology website: http://sci.esa.int/vodcast

For practical exercises about globular clusters, see: http://tinyurl.com/oo789dt

For many more education materials produced by ESA, see: www.esa.int/educationmaterials

All education materials produced by ESA are freely available to teachers in the 18 ESA member states. Many are translated into several European languages.

To learn more about the activities of the European Space Agency's Directorate for Science and Robotic Exploration, see: http://sci.esa.int

You may also like to browse the rest of the astronomy and space-science articles in *Science in School*. See: www.scienceinschool.org/astronomy and www.scienceinschool.org/space

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

Pieces of light

By Charles Fernyhough

Reviewed by Eric Deeson

Sub-titled "The new science of memory", this is the paperback edition of a title that appeared first in the UK in 2012 and has received several awards.

It is indeed a book that shows a great deal of effective desk research and thought. It also shows a determination to provide a novel account of a subject that enthrals every one of us – but the explanation of which is still a mystery far from final solution. Charles Fernyhough, a writer who is a part-time professor of psychology, deserves congratulation for perhaps having gone a little way to throw pieces of light on that mystery.

Pieces of light is an unusual book, at least partly because its author is unusual. Fernyhough writes very well and fills his pages with personal anecdote, illustrations from literature, and cheerful case studies; all this tends to make what is a somewhat academic text more palatable to interested readers. On the other hand, although although the book is "somewhat academic" and has "science" in its subtitle, the science content is not easy to discover; indeed, this is not a "science book" in any usual sense of the word.

To Fernyhough, the study of memory comes under psychology and (within that) cognition – but he seems to take that as read in his own mind and in those of his readers. I could not find any formal statement, explanation or scientific scene-setting in *Pieces of light*, despite my fairly careful study and Fernyhough's highly detailed and generally accurate index.

Some memory scientists view memory from the angle of physiology – neuroscience of course – and, while Fernyhough doesn't ignore this, his relevant mentions are few and minor. References to the physiology argument are scattered in an almost throw-away fashion throughout the book. It must be said that there *is* just one picture in all those small-print pages – a science-based one, after the text and before the notes, that sketches and labels the relevant parts of the brain; even so, those parts are not indexed and the book's text seems to refer to the picture only once and very casually.

To most memory scientists (I believe, not being one), whether psychologists or neuroscientists, the core message is that memory is the phenomena involved in the brain's systems for

1. receiving, processing and encoding a chunk of information;
2. storing the code and consolidating it, even re-consolidating it; and
3. retrieving it.

Fernyhough's core message is very different, and it is clear from the start:

"I want to persuade you that when you have a memory … you create something new. … Remembering happens in the present tense. It requires the precise coordination of … cognitive processes, shared among many other mental functions and distributed across different regions of the brain."

What *Pieces of light* is saying in practice is that when you remember something, or at least something autobiographical ie personal, your brain constructs the memory along the lines of "this is what must have happened". We can all think of examples – such as how different people in a car recall differently an accident seen in front of them; how those involved in a conversation argue later about what was the final decision; and how chatting about an old family photo leads to clashing recalled stories about that holiday.

Indeed, there is nothing new in the concept that memory is far from objective, whether viewed from a psychological or a neuroscientific viewpoint. But the concept of what I name creative recall? That is a long extra step. And it is a step for which Fernyhough's 280 pages of unappealing small-print text and forty of notes do not add much in the way of hard evidence. Even more disappointing to me is that there are only a couple of mentions of Alzheimer's disease and not a large number more of amnesia and other forms of memory loss; indeed, there is very little too on short-term and long-term memory.

All this is about "autobiographical memory" – the recall of what happened to oneself in the past. It does *not* apply to the recall of facts and principles and learned processes: all those types of memory most important to *Science in school* readers. Fernyhough does not address why autobiographical memory differs so much from those in not being embedded in the brain but "created" during recall; nor does he address why evolution has (presumably) led to such an imperfect recall system that surely cannot improve species survival. But those are science questions – and this *not* a science book.

Pieces of light is without doubt an unusual book, one that remains impossible to recommend as something that must go into the libraries of schools and colleges with post-16 students of science, even of psychology. But I *do* recommend it for such libraries where there are science and / or general studies and / or philosophy teachers keen to encourage cross-cultural, even iconoclastic, reading and thinking.

Details

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

The inGenious code: school-industry collaboration

By inGenious – a project supported by the European Commission FP7 Programme

Reviewed by Jesper Christoffersen

These days, more and more of my colleagues in science, technology, engineering and mathematics (STEM) education are warming to the idea of closer links with industry to show students what these subjects can do in the real world. Several studies have shown that students and pupils often dismiss STEM careers on very flimsy evidence (not a good start in science!), so putting them into contact with working companies can be a great help in adjusting their point of view.

There are two broad ways that industry can bring STEM to life for students: businesses can visit you, or you can visit them. Both can be beneficial – but unfortunately, both can be a nightmare for schools and industry to carry out successfully. Whether it is protecting data, ensuring child safety or providing a worthwhile educational experience, there are so many potential problems that even the most enthusiastic teachers and companies may think twice about organising what could be a mutually beneficial encounter.

This is why the inGenious code for school–industry collaboration is such a useful document. Freely available as a PDF, the code covers pretty much every aspect of organising visits to schools by industry and vice versa. As its introduction states, the code "provides a set of principles, guidelines and checklists that should allow anyone involved in setting up school–industry collaboration to do so as safely, smoothly and securely as possible".

At 24 pages long, it is comprehensive and tackles the general principles of collaboration, as well as dealing with consent, data protection and taking photos and videos – all of which need careful handling in order to stay within mutually acceptable limits.

Perhaps most useful of all are a series of easy-to-follow checklists, focused on organising site visits and managing data protection, which are available for download separately from the inGenious website[w1].

The code is freely available to download as a PDF from the European Schoolnet website[w2].

Web references

w1 – To download the checklists from the inGenious website, visit www.ingenious-science.eu / web / guest / checklists

w2 – The full InGenious code PDF is available to download from the website of European Schoolnet, a network of 30 European ministries of education. See: www.eun.org

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

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EMBL

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

ESA

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ESO

The European Southern Observatory (ESO) is the foremost inter-governmental astronomy organisation in Europe and the world's most productive astronomical observatory. It operates telescopes at three sites in Chile – La Silla, Paranal and Chajnantor – on behalf of its 15 member states. At Paranal, ESO's Very Large Telescope is the world's most advanced visible-light astronomical observatory. ESO is the European partner of the revolutionary astronomical telescope ALMA, and is planning a 40-metre-class European Extremely Large optical / near-infrared Telescope, the E-ELT. See: www.eso.org

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European XFEL

The European XFEL is a research facility currently under construction in the Hamburg area of Germany. It will generate extremely intense X-ray flashes to be used by researchers from all over the world. See: www.xfel.eu

ILL

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