Winter 2018 | Issue 45

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Science in School

The European journal for science teachers

Elements in the spotlight
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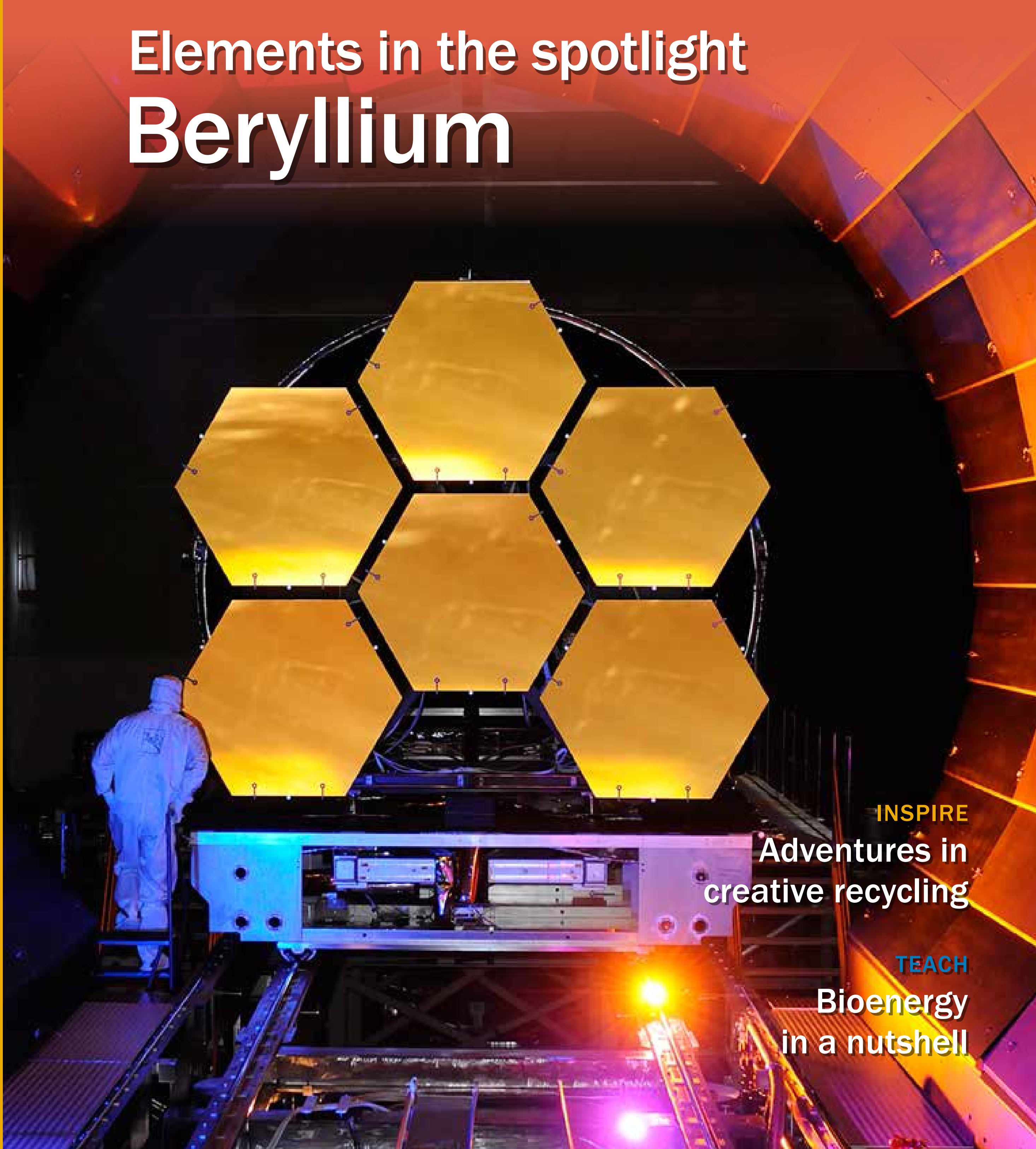

INSPIRE
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TEACH
Bioenergy in a nutshell

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Scalding volcanic springs are home to some remarkable microorganisms, and biotechnology is now finding uses for these microscopic survivors.


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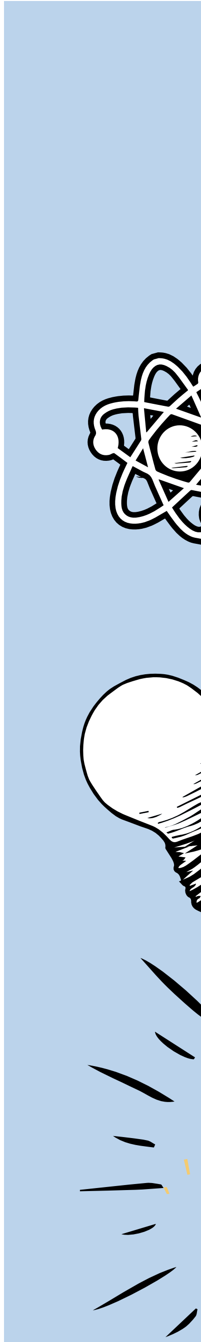


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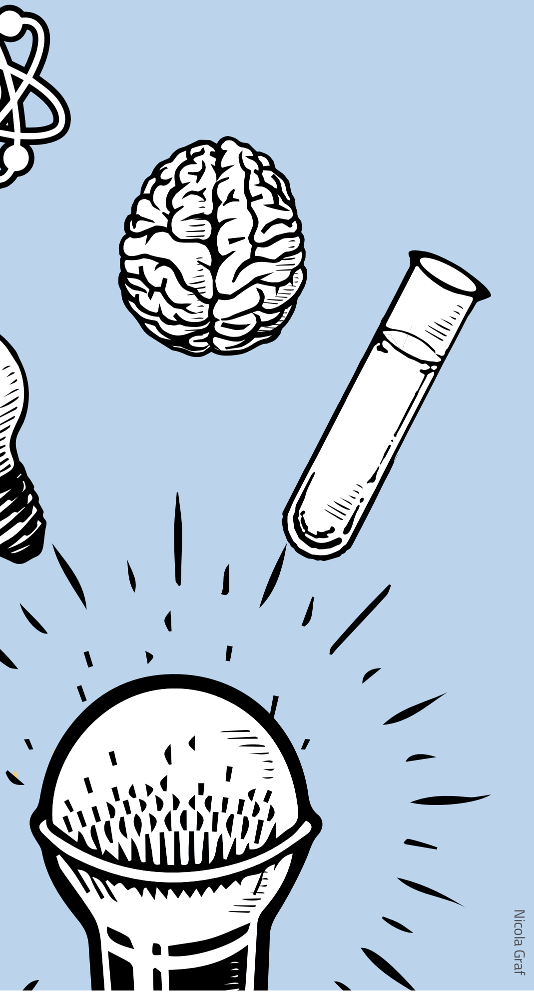


Nicola Graf

EDITORIAL

Susan Watt
Editor
Science in School
editor@scienceinschool.org

As autumn turns to winter and the year nears its end, we often start to think about the coming new year. In this issue, we look ahead and consider some advances in science and technology that could mean a better future for all of us.

Starting with our news section, we highlight a powerful new technology for diagnosing diseases: full-colour X-rays (page 4). We also report on how tomorrow's biology textbooks may need updating in light of a remarkable new discovery about the early embryo (page 4).

In other articles, we look at how a potential new biomass resource – nutshells – might provide a more sustainable source of energy (page 31), and how thermophiles – microorganisms that thrive at hot temperatures – are finding new applications across technology and industry (page 12). And while the SI system of units may seem fixed and timeless, we review the upcoming changes and improvements to the formal definitions of several basic units, due in May 2019, and outline some of the arcane science that underlies these redefinitions (page 8).

Continuing the futures theme, we meet a sociologist who is trying to find better ways to ensure the survival of rhinos and other threatened species (page 23), and a teacher who is intent on finding new uses for old technology – including building a Christmas tree solely from cast-off electronic components (page 27).

Finally, we end the issue with a bang – or a slam, as we give details of how to hold a 'science slam' in your school (page 43), which brings not poetry but lively presentations of science topics to the stage, with voting to decide the winners.

We hope you have a lively and successful end to the year, and a great start to 2019. We at *Science in School* send you best wishes for the holiday season, and we look forward to reading and sharing more brilliant ideas for science teaching from across Europe – do keep them coming.

Susan Watt

Interested in submitting your own article? See:
www.scienceinschool.org/submit-article

Full-colour X-rays, early embryo division and space challenges for students

CERN

3D colour X-ray images for diagnosing diseases

For over 100 years, doctors have used black-and-white X-ray images for diagnosing diseases – from broken bones to heart disease or cancer. Now, a new X-ray scanner has produced the world's first full-colour 3D images, which could provide clinicians with clearer pictures to make more accurate diagnoses.

A 3D image of a wrist with a watch, showing part of the finger bones in white and soft tissue in red

MARS Bioimaging Ltd

The new scanner is based on CERN's Medipix technology, which was developed to track particles at the Large Hadron Collider. Employing the most advanced Medipix chip to detect and count each individual particle, the colour scanner uses this information to generate 3D images. The colours represent different energy levels of the particles, as recorded by the detector. These colours identify different components in the body, such as fat, water, calcium and disease markers.

So far, researchers have used a small version of the scanner to study cancer, bone and joint health, and vascular diseases that cause heart attacks and strokes. In the coming months, patients will be scanned using the new, larger scanner in a clinical trial, paving the way for the potentially routine use of this next-generation equipment.

Learn more about the development of the 3D scanner by visiting the CERN website. See: https://home.cern/about/updates/2018/07/first-3d-colour-x-ray-human-using-cern-technology

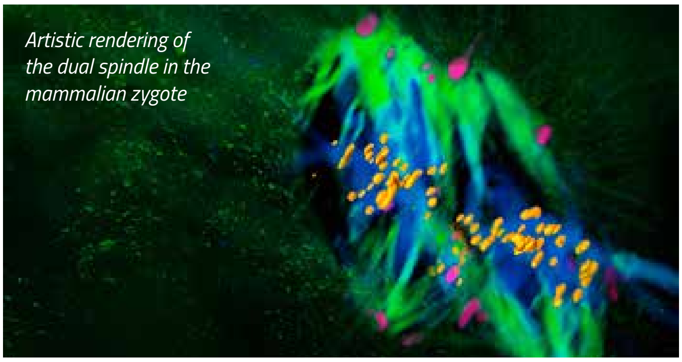
The CERN laboratory sits astride the Franco-Swiss border near Geneva, Switzerland. It is the world's largest particle physics laboratory. See: www.cern.ch

EMBL

A surprising start to cell division

It was long thought that during an embryo's first cell division, a set of fibres called the spindle separated the embryo's chromosomes into two daughter cells. But this textbook account could well change after scientists from the European Molecular Biology Laboratory (EMBL) discovered that in mice, there is not one but two spindles – one for each set of parental chromosomes. What's more, this means the genetic information from each parent is kept apart throughout the first cell division.

"We already knew about dual spindle formation in simpler organisms like insects, but we never thought this would be the case in mammals like mice", says Jan Ellenberg, who led the project. Scientists have always seen parental chromosomes occupying two half-moon-shaped regions of the nucleus of two-cell embryos after the first division, but it wasn't clear how this could be explained. Only when focusing on the microtubules – the dynamic structures that spindles are made of – could the researchers see the dual spindles for the first time. Importantly, this dual spindle formation might help explain why the cell division process has a particularly high error rate in early embryos.



Artistic rendering of the dual spindle in the mammalian zygote

Cartasiova/Hossain/Reichmann/Ellenberg/EMBL

For more information on this research, visit the EMBL website. See: www.embl.de/aboutus/communication_outreach/media_relations/2018/0712_Science_Ellenberg/

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

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.

ESA

New space challenges for school students

ESA/Foster + Partners

Artist's impression of a lunar base currently being constructed by ESA

The European Space Agency (ESA) has launched two new school projects for the 2018/2019 academic year: the Moon Camp Challenge and Climate Detectives.

The Moon Camp Challenge is an interdisciplinary project that invites students aged 18 and under to design a lunar base camp. Students explore the extreme environment of space and must design a camp that is able to sustain at least two astronauts while also keeping them safe from hazards. The project, which is a collaboration between ESA and Airbus Foundation, allows students to use exciting and innovative learning technologies, such as 3D modelling.

The Climate Detectives project challenges students aged 8–15 to 'make a difference' by identifying a climate problem in their local environment and using satellite images or ground measurements to investigate it as 'climate detectives'. Based on their results, teams can propose ways to monitor or raise awareness of the problem. By participating, students learn about climate on Earth as a complex and changing system, as well as the importance of respecting our environment.

Find out how your students can take part in these challenges on the dedicated ESA Education webpages. See: www.esa.int/Education/Moon_Camp and www.esa.int/Education/Climate_detectives

ESA is Europe's gateway to space, with its headquarters in Paris, France. See: www.esa.int

ESO

General relativity at the heart of the Milky Way

Obscured by thick clouds of absorbing dust, the supermassive black hole closest to Earth lies 26 000 light years away at the centre of the Milky Way. This black hole, which has a mass four million times that of the Sun, is surrounded by a small group of stars orbiting around it at high speed. This extreme environment makes it the perfect place to explore gravitational physics, and new observations from the European Southern Observatory (ESO) recently confirmed an effect predicted by Einstein's general theory of relativity.

This effect, called gravitational redshift, occurs when light from the star is stretched to longer wavelengths by a very strong gravitational field, such as a black hole. The new measurements clearly reveal this effect, with the measured change in wavelength agreeing precisely with that predicted by Einstein's theory.

The results were made using the GRAVITY instrument on ESO's Very Large Telescope and follow a 26-year-long observation campaign. It is the first time that effects from general relativity have been observed in the motion of a star around the supermassive black hole at the centre of the Milky Way.

Read the full press release on the ESO website. See: www.eso.org/public/news/eso1825/

ESO is the foremost inter-governmental astronomy organisation in Europe and the world's most productive ground-based astronomical observatory, with its headquarters in Garching, near Munich in Germany, and its telescopes in Chile. See: www.eso.org

ESO/L. Calçada/spaceengine.org

Simulation showing the orbits of stars around the black hole at the heart of the Milky Way

ESRF

Research gives clues to trapping carbon dioxide underground

Carbon dioxide is an environmentally important gas that plays a crucial role in climate change. It is also present inside Earth, and scientists have long studied what happens to carbon dioxide at high temperatures and pressures – the same conditions as occur deep underground. But until recently, research has focused solely on carbon dioxide in the upper mantle, where the compound has been shown to decompose, forming diamond and oxygen.

S Candé

Scientist Mohamed Mezouar, who is responsible for beamline ID27

A team of scientists have now investigated what happens to carbon dioxide in the conditions between the lower mantle and the metallic core, at a depth of 2000 to 2400 km. Using the high-pressure beamline ID27 at the European Synchrotron Radiation Facility (ESRF) to achieve the same conditions, they subjected the sample to 2400°C and 120 GPa of pressure. The researchers found that carbon dioxide was stable in a crystalline form at these more extreme conditions, and did not dissociate as it did at the 40 GPa pressures of earlier upper mantle experiments.

"Our results indicate that the crystalline extended form of carbon dioxide is stable in the thermodynamic conditions of the deep lower mantle, and therefore could be helpful to understand the distribution and transport of carbon in the depths of our planet", explains Kamil Dziubek, the leading scientist of the study. "It could even open doors to the possibility of trapping carbon dioxide underground", he said. This could be a potential solution for mitigating climate change associated with the greenhouse effect.

For more information on the study, read the original research paper:

Dziubek KF et al. (2018) Crystalline polymeric carbon dioxide stable at megabar pressure. *Nature Communications* **9**: 3148. doi: 10.1038/s41467-018-05593-8

Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. See: www.esrf.eu

EUROfusion

Handing over the EIROforum chair

The role of chair of the eight European organisations that make up EIROforum rotates every year. In July 2018, the European Molecular Biology Laboratory (EMBL) handed over the chair to EUROfusion, which will retain it until June 2019.

In this period, EUROfusion programme manager Tony Donné wants to continue the focus on activities that can have maximum benefit for all EIROforum members. "We want to continue the excellent initiatives that have been started under the present and previous chairmanships", he says. Donné believes that by working together and sharing experiences and views, each EIROforum member can have a greater impact on the future directions of science in Europe.

Also on the agenda is raising the visibility and profile of EIROforum through outreach and education activities, which include the funding of *Science in School*. "To my knowledge, it is the only magazine with first-hand information on science shaped by and targeted at teachers", says Petra Nieckchen, head of EUROfusion's communications office and member of the *Science in School* editorial board.

Read the full release on the EUROfusion website. See: www.euro-fusion.org/news/2018/june/eiroforum-chairmanship/

EUROfusion manages and funds European fusion research activities, with the aim to realise fusion electricity. The consortium comprises 30 members from 26 European Union countries as well as Switzerland and the Ukraine. See: www.euro-fusion.org

Tony Donné, EUROfusion programme manager, takes over as the EIROforum chair.

EUROfusion

European XFEL

First results from the world's largest X-ray laser


European XFEL

European XFEL's first published results were performed at the SPB/SFX instrument, shown here.

The first results from experiments performed at the European X-ray Free-electron Laser (European XFEL) were published in August – just in time to mark the one-year anniversary since the facility was opened. Two independent teams, one from the Max Planck Institute for Medical Research and another from the Deutsches Elektronen-Synchrotron (DESY), used the laser's ultrashort, high-intensity pulses to decipher the 3D structure of several proteins – collecting the data at a faster rate than has been previously achieved.

The experiments were possible due to the laser's very high X-ray pulse repetition rate, equivalent to more than one million X-ray pulses per second. This is the first time that a pulse rate of over 1 MHz has been reached. However, since the pulses are delivered in concentrated bursts followed by long breaks, the actual number of pulses delivered in these experiments was only about 300 per second.

As the time and cost of experiments decrease, many more researchers – among them biologists, physicists and chemists – will be able to perform experiments at European XFEL.

Read the full press release on the European XFEL website. See: www.xfel.eu/news_and_events/news/index_eng.html?openDirectAnchor=1568&two_columns=0

For more information on the results from the first scientific experiment at European XFEL, visit their website. See: www.xfel.eu/news_and_events/news/index_eng.html?openDirectAnchor=1623

European XFEL is a research facility in the Hamburg area in Germany. Its extremely intense X-ray flashes are used by researchers from all over the world. See: www.xfel.eu

ILL

Joining forces to develop new space technologies

Space missions require a broad range of materials, from high-performance metals for vehicle structures to lightweight, inflatable structures for crew habitats. These requirements present several challenges, as the materials must also be durable and functional in such a hostile environment.

Combining resources, facilities and expertise is essential for developing these new technologies. The Institut Laue Langevin (ILL) and the European Synchrotron Radiation Facility (ESRF) have teamed up with two leading European space companies, OHB System AG and MT Aerospace AG, to tackle these challenges.

ILL's neutrons can explore deep inside matter, making them an ideal probe for most materials, while ESRF's high-energy X-rays can penetrate large structures and provide structural data on the atomic to micron scale. By probing matter with neutrons and X-rays, this collaboration aims to advance the technology of aerospace materials and make manufacturing processes more efficient. Developing the materials behind space technologies will in turn pave the way for more successful space missions and potential applications for use on Earth.

Learn more about the collaboration, visit the ILL website. See: www.ill.eu/news-press-events/press-corner/press-releases/big-science-and-industry-join-forces-to-innovate-new-space-technologies/

Based in Grenoble, France, ILL is an international research centre at the leading edge of neutron science and technology. See: www.ill.eu


Serge Claisse/ILL

ILL, ESRF and two leading European space companies agree to combine resources to develop new space technologies.

EIROforum combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. See: www.eiroforum.org
For a list of EIROforum-related articles in Science in School, *see: www.scienceinschool.org/eiroforum*
To browse the other EIRO news articles, see: www.scienceinschool.org/eironews

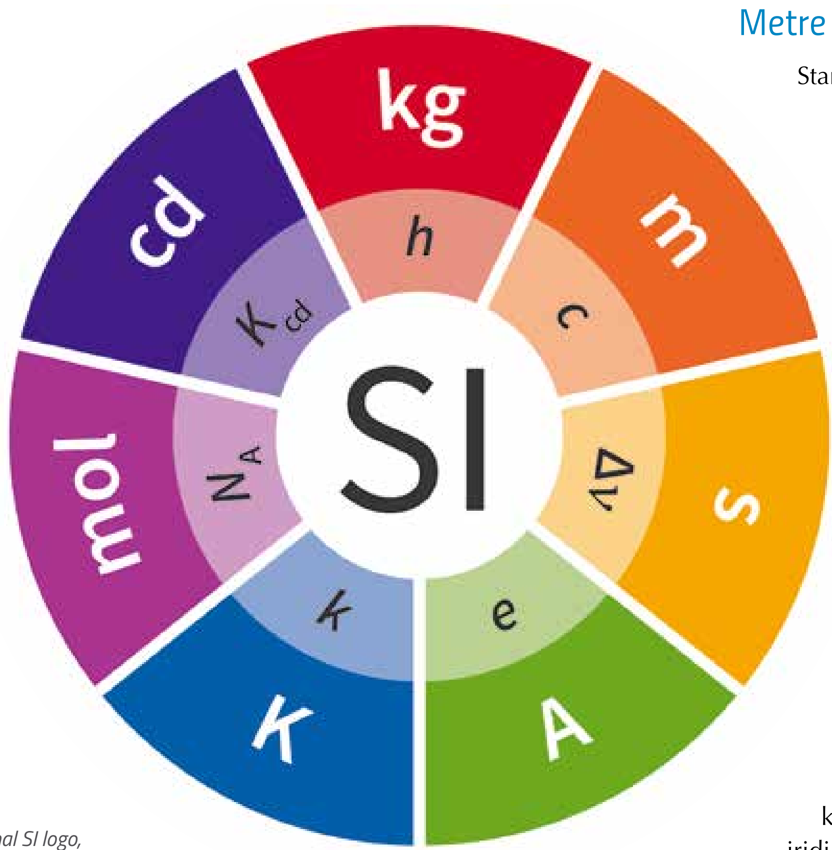
SI units: a new update for standards

In an update using the latest scientific research, all the basic SI units will soon be officially defined in terms of the Universe's fundamental constants.

By Daniel Garisto

While the USA remains obstinate about using units such as miles, pounds and degrees Fahrenheit, most of the world has agreed that using units that are actually divisible by ten is a better idea. The metric system, also known as the International System of Units (or SI units), is the most comprehensive and precise system for measuring the Universe that humans have developed, comprising the seven base units for length, mass, time, temperature, electric current, luminosity and quantity.

Since the metric system was established in the 1790s, scientists have attempted to give increasingly precise definitions for these units. Some revised definitions are now due to be introduced for four of these units – the kilogram (kg), kelvin (K), ampere (A) and mole (M) – bringing them into line with the other units by providing definitions based on natural constants. The updated definitions will be adopted internationally on World Metrology Day, 20 May 2019. After this update, every base unit in the metric system will be defined using the fundamental constants of the Universe.



Courtesy of BIPM

The international SI logo, showing the seven basic units and the fundamental constants their 2019 definitions are based on

Metre (distance)

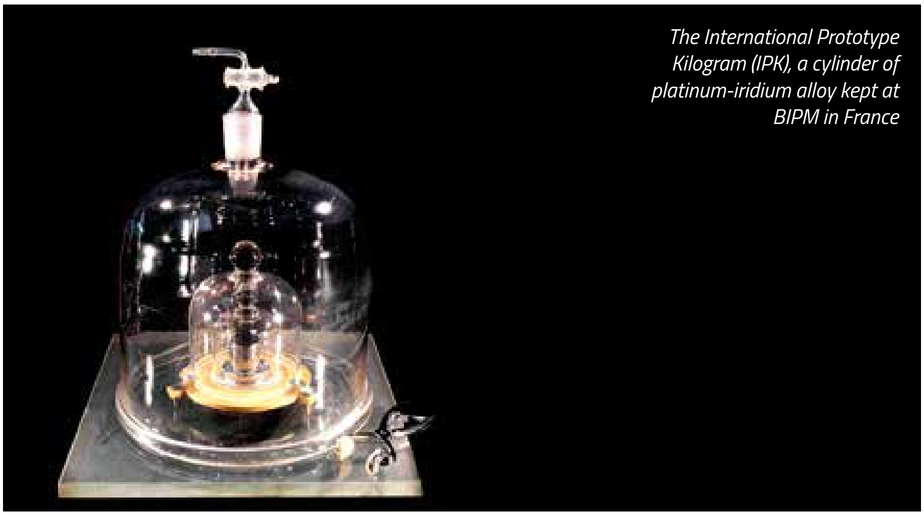
Starting in 1799, the metre was defined by a prototype metre bar, which was just a platinum bar. Physicists eventually realised that distance could be defined by the speed of light, which has been measured with an accuracy to one part in a billion using an interferometer (the same type of detector that was used recently to discover gravitational waves). The metre (m) is currently defined as the distance travelled by light (in a vacuum) for 1/299 792 458th of a second and will remain effectively unchanged after the update.

Kilogram (mass)

For over a century, the standard kilogram has been a small platinum-iridium cylinder housed at the Bureau International des Poids et Mesures (BIPM), near Paris, France. But even its precise mass fluctuates

Courtesy of BIPM

The Bureau International des Poids et Mesures (BIPM) near Paris, where the standard kilogram, or IPK, is held



The International Prototype Kilogram (IPK), a cylinder of platinum-iridium alloy kept at BIPM in France

Courtesy of BIPM

due to factors such as accumulation of microscopic dust. The latest update redefines the kilogram (kg) by setting the value of Planck's constant to exactly 6.626070040 x 10^{-34} kg m^2 s^{-1}. Planck's constant is the smallest possible amount of (quantised) energy. This fundamental value, which is represented by the letter *h*, is integral to calculating energies in particle physics.

Second (time)

The earliest definition of seconds was based on divisions of time between full moons. Later, seconds were defined by solar days, and eventually the time it took Earth to orbit around the Sun. Today, seconds (s) are defined by atomic time, which is precise to one part in 10 billion. Atomic time is based on the periods of radiation produced and absorbed by atoms, called the 'hyperfine transition frequency' (Δ_v). One second is currently defined as 9 192 631 770 periods of the radiation for a caesium-133 atom and will remain effectively unchanged.

NPL Management

Caesium clock providing the standard for the SI unit of time, the second

Kelvin (temperature)

The kelvin temperature scale starts at the coldest possible state of matter. Currently, the kelvin (K) is defined by the triple point of water – the temperature at which water can exist simultaneously as a solid, liquid and gas. The triple point is 273.16 K, so one kelvin is 1/273.16 of the triple point. But water can never be completely pure, and impurities can influence the triple point. In May 2017, a team of German physicists at the Physikalisch-Technische Bundesanstalt made the most precise measurements yet of the Boltzmann constant. Denoted by the symbol *k*, the Boltzmann constant is ubiquitous throughout physics calculations that involve temperature and entropy, and links the movement of particles in a gas (the average kinetic energy) to the temperature of the gas. These results are now being used to redefine units of temperature by setting the value of Boltzmann's constant to exactly 1.38064852 x 10^{23} joules (J) per kelvin.

REVIEW

- ✓ Metrology
- ✓ Heat and temperature
- ✓ Astrophysics
- ✓ Ages 11–19

Science and technology have made great progress during recent centuries, with new technologies leading to higher precision in measurement. As this article describes, metrology is now reacting to this progress.

In their first science classes, students learn about the SI system but do not really understand the physics behind the definitions. This article can be used to introduce the physics underlying the base units to students aged 11–16, or more complex units to more advanced students.

The information about unit definitions can also be used the other way around – that is, to focus on the definitions once the units have already been understood as concepts. So, for example, teaching about gravitational waves can introduce the idea of measurements using interferometers, which can then be connected to the definition of the metre.

Comprehension questions that could be used include:

- What is the International System of Units?
- Explain the differences between the SI system and the system of units used in the USA.
- Name all seven SI base units and their corresponding physical quantities, as defined in the SI system.
- Why are the definitions of some SI units changing?
- Choose a physical quantity from the SI system and explain the corresponding definition of the unit.

Gerd Vogt, physics teacher and coordinator for science and technology, Higher Secondary School for Environment and Economics, Yspertal, Austria

Melting ice: water can exist in all three states – solid, liquid and gas – only at 273.16 K (or 0.01°C), the 'triple point' of water.

Ampere (electric current)

André-Marie Ampère (1775–1836), who is often considered the father of electrodynamics, has the honour of having the basic unit of electric current named after him. Until now, the ampere (A) has been defined by the amount of current required to produce a force of 2×10^{-7} newtons (N) for each metre between two parallel conductors of infinite length. Naturally, it's a bit hard to come by things of infinite length, so the updated definition will instead define amperes by the fundamental charge of a particle. This new definition relies on the charge of the electron, e, which will be set to $1.6021766208 \times 10^{-19}$ ampere seconds.

Candela (luminosity)

The last of the base SI units to be established, the candela, measures luminosity – what we often refer to as brightness. Early standards for the candela used a phenomenon from quantum mechanics called black body radiation, which is the light that all

The light emitted by a single candle is roughly equal to one candela, the SI unit of luminosity.

tristangage/Flickr, CC BY-NC-ND 2.0

objects radiate as a function of their temperature. Currently, the candela (cd) is defined more fundamentally as 1/683 watt (W) per square radian at a frequency of 540 x 10^{12} hertz (Hz) over a certain area, a definition that will remain effectively unchanged. Hard to picture? A candle, conveniently, emits about one candela of luminous intensity.

Mole (quantity)

Different from all the other base units, the mole measures quantity alone and is just a number. Over hundreds of years, scientists starting from Amedeo Avogadro (1776–1856) worked to better understand how the number of atoms was related to mass, leading to the current definition of the mole (M): the number of atoms in 12 grams (g) of carbon-12. This number, which is known as Avogadro's constant (N_A), is is about 6 x 10^{23}. To make the mole more precise, the new definition will set Avogadro's constant to exactly 6.022140857 x 10^{23}, decoupling it from the kilogram.

A balloon, a flask and a beaker, each containing one mole of a substance. The balloon contains one mole of a gas, the beaker one mole of solid nickel (II) chloride, and the flask one mole of copper (II) sulfate in one litre of water (a one-molar solution).

Science Photo Library

Acknowledgement

This is an edited version of an article first published in *Symmetry* online magazine on 7 November 2017[w1].

Web reference

w1 *Symmetry* magazine is a free online publication covering particle physics. It is jointly published by Fermi National Accelerator Laboratory and SLAC National Accelerator Laboratory, USA. To see the original article, visit the *Symmetry* website: www.symmetrymagazine.org/article/a-new-model-for-standards

Resources

Discover more about World Metrology Day. See: www.worldmetrologyday.org

Find out about the project to measure the Boltzmann constant to extremely high accuracy. See: www.ptb.de/cms/en/research-development/research-on-the-new-si/ptb-experiment/the-kelvin-the-boltzmann-project.html

Read an accessible article on the May 2019 changes for each SI unit. See: www.npl.co.uk/si-units/redefining-the-si-units/

Find out about the detection of gravitational waves by the LIGO collaboration. See: www.ligo.org/science/GW-GW2.php

Diana Kwon (2017) Turning on the cosmic microphone. *Science in School* **39**: 8-11. www.scienceinschool.org/content/turning-cosmic-microphone

Dan Garisto is a science writer. You can find him on Twitter at @dangaristo.

Some (microbes) like it hot

Scalding volcanic springs are home to some remarkable microorganisms, and biotechnology is now finding uses for these microscopic survivors.

By Sean Michael Scully

As a child visiting Yellowstone National Park, USA, in the 1990s, I remember being very excited to see the bright, paint-like colours in the hot springs. I was even more intrigued when I learned that the colours were due to microorganisms – living things that actually liked such extreme environments. I found it odd that anything could survive in conditions hot enough to give you a serious burn. Likewise, it amazed me when I later discovered that the dirt-digesting enzymes in washing powder come from organisms living at the opposite extreme of temperature – in water just a few degrees above freezing. Life, it seems, is content to thrive in conditions we once considered lethal. Several decades later, my love of chemistry and my fascination with these organisms has led to a career studying them in Iceland, which is now my adopted homeland.

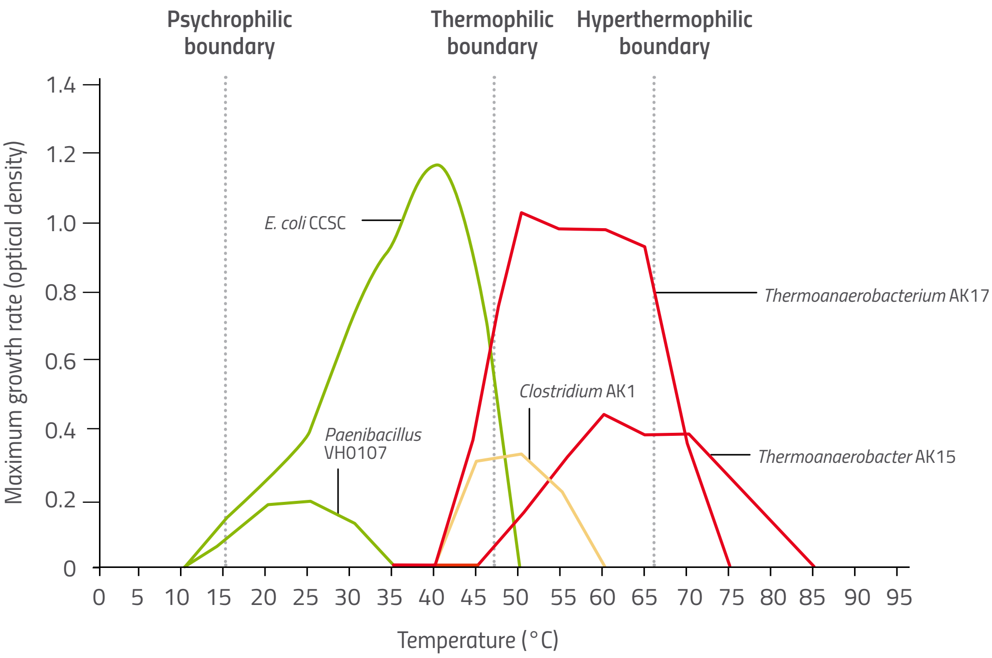
What are thermophiles?

The diverse world of microbial life spans the whole temperature range, from below the freezing point of water to beyond the boiling point. Microbes that have a preference for hot environments are called thermophiles (Greek for 'heat lovers') and are just one of various kinds of 'extremophile' found living in extreme conditions. Thermophiles don't merely tolerate heat – they positively thrive on it, growing best at temperatures above 50°C. Those with an optimum temperature range above 70°C are known as hyperthermophiles, and organisms that prefer cool environments (below 15°C) are called psychrophiles (see figure 1).

A few fungi and algae flourish in hot environments, but the vast majority of thermophiles are bacteria or equally

"Life, it seems, is content to thrive in conditions we once considered lethal."

tiny microorganisms known as archaea. These single-celled organisms were once classed as bacteria because they lack cell nuclei. Studies of their surprisingly complex DNA have revealed that archaea are actually more closely related to multicellular organisms such as humans than they are to



Sean Michael Scully/Nicola Graf

Figure 1: Graph showing the optimum temperature range of several different microorganisms, including thermophiles (shown in red) and ordinary bacteria (green). Clostridium *AK1 (yellow) is moderately thermophilic.*

Grensdalur valley in southwest Iceland. This area is rich in geothermal features, including hot springs.

Sean Michael Scully

REVIEW

✓ Metabolism
✓ Enzymes
✓ Microbiology
✓ Biotechnology
✓ Fermentation
✓ Ages 11–19

This article challenges readers to find out more about the microscopic living organisms called thermophiles and their amazing technological potential. Thermophiles are the exception to the rule in relation to their enzyme activity, so the article can be used as a stimulus for such topics as enzyme function, cell metabolism, and microbiology and its applications.

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

- How does a cell's physical environment affect its enzyme activity?
- How can we use thermophilic bacteria to protect our planet from the greenhouse effect?

It could also form the basis of an art lesson, with photos of colourful thermophiles acting as an unusual stimulus for student portrayals of nature's beauty.

Alina Giantsiou-Kyriakou, biology teacher, Livadia High School, Larnaca, Cyprus

bacteria. They are now considered to make up one of the three domains (superkingdoms) into which all forms of life are classified, alongside bacteria and eukaryotes (organisms with cell nuclei). Myriad types of archaea inhabit the scalding chemical soup found around volcanic vents on the sea floor. Some scientists think life began in such places, which suggests that these thermophiles have very ancient origins.

Here, there and everywhere

Since 1966, when thermophiles were first discovered growing in the hot volcanic springs of Yellowstone, they have been found in a huge range of places, from the deep sea to compost heaps, household water heaters, and the cooling pools in nuclear reactors. They even turn up in canned food: the bacterium *Thermoanaerobacterium saccharolyticus* can survive the sterilising process that destroys other microorganisms, and can then grow slowly at the lower temperatures inside the can, leading to a build-up of gas – sometimes with explosive results. The fact that thermophiles find their way into such diverse places suggests that their spores are widespread, waiting for the right conditions so they can spring back to life.

My particular interest is in the thermophiles that live around geothermal

Sean Michael Scully

Sean Michael Scully

Sean Michael Scully

Volcanically heated water provides ideal conditions for thermophiles in Iceland's many geothermal hot spots. The colours are caused by iron and sulfur compounds. A: a boiling mud pit at Námaskarð; B: a hot intertidal pool near Húsavík; C: a hot spring at Grensdalur

A fumerole (volcanic vent) at Námaskarð, Iceland

Sean Michael Scully

features such as hot springs, boiling mudpots, steam geysers, volcanic vents, and sulfurous steam vents called solfotaras. These sites are scattered far and wide across different parts of the globe, from Italy and Iceland to Yellowstone in the USA and Kamchatka in the Russian Far East. The geographical isolation of these island-like sites allows unique species to evolve in each, although some thermophile species can be found in many locations.

Another interesting feature of geothermal sites such as hot springs is that there is often a sharp temperature gradient: deeper underwater zones are hotter, while those towards the pool's edge are cooler. Different thermophiles find a comfortable niche at different points along the gradient. Thermophiles that can photosynthesise, such as cyanobacteria, live at the cooler end of the gradient, while less brightly coloured types are restricted to the thermal extremes. The result is a multicoloured 'microbial mat' carpeting the rock, with each zone of colour representing the distinct biochemistry of the organisms present, from the yellow-green colours of those that photosynthesise to the diverse shades of those that obtain energy by metabolising hydrogen, iron or sulfur compounds. A famous example of colourful microbial mats is on display at Grand Prismatic Spring in Yellowstone, but the same phenomenon can be seen in geothermal features in Iceland and elsewhere.

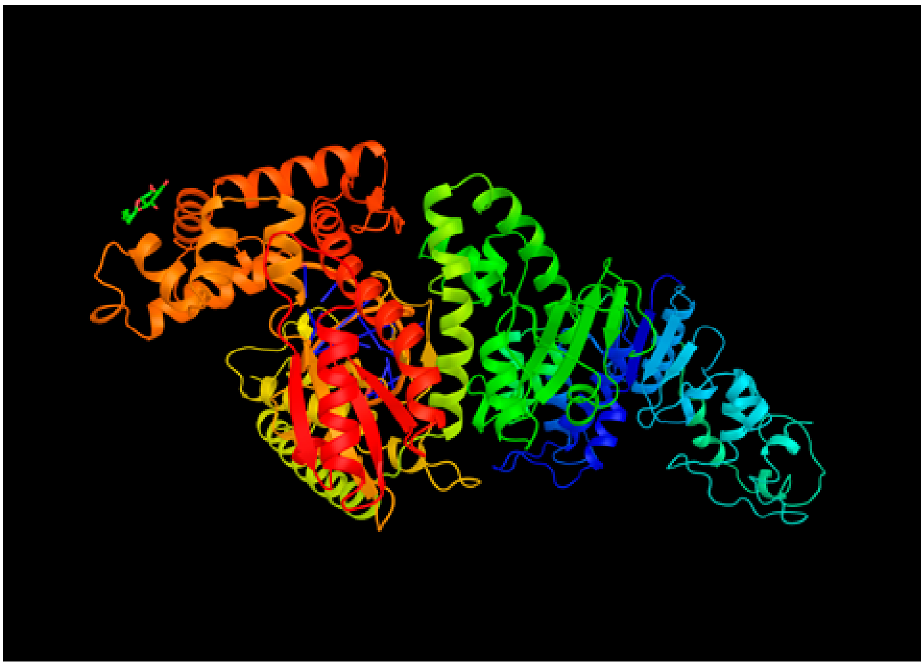
Grand Prismatic Spring in Yellowstone Park, USA. The colours are due to microbial mats formed by thermophiles.

Heatproof enzymes

Thermophiles owe their survival skills to their enzymes – the molecules that perform much of the chemistry of life, working as catalysts inside living cells. Enzymes are proteins, and most proteins are destroyed by heat. Fry an egg, for instance, and the heat denatures the protein molecules, making them unravel and change shape permanently. In contrast, thermophile enzymes are stable at high temperatures, allowing them not only to keep working but also to work faster than normal enzymes, since higher temperatures also mean faster reaction rates.

A famous example of a heat-stable enzyme is Taq polymerase, named after *Thermus aquaticus*, a thermophile found at Yellowstone. The Taq enzyme is now used in labs worldwide in a process called the polymerase chain reaction (PCR), which replicates DNA molecules from small samples. Before

"Thermophile enzymes are stable at high temperatures, allowing them to work faster than normal enzymes."



Taq polymerase enzyme, derived from a thermophilic bacterium and used in DNA replication

Joshua Resnick/Shutterstock.com

Cola and other fizzy drinks often contain high-fructose corn syrup made using thermophile enzymes.

Taq, this was a laborious and expensive procedure that involved repeated cycles of heating and cooling, with fresh enzyme (a polymerase that denatured on heating) added at each cooling stage. Using Taq, the process is automated and runs at a high temperature, with only a small amount of the enzyme required. In a matter of hours, Taq-based PCR can turn a single DNA molecule into 100 billion copies, and a tiny sample of body fluid from a crime scene can thus yield enough genetic material to create a DNA fingerprint.

Although Taq PCR revolutionised molecular biology and forensics, thermophile enzymes are not just useful in genetics labs. They are also finding their way into a growing number of industries, from food and drink manufacture to fabric production. For instance, the high-fructose corn syrup used to sweeten soft drinks is made by heating a gloopy solution of corn starch to boiling point and digesting it with a succession of heat-tolerant thermophile enzymes. Keeping the solution hot has various benefits beyond speeding up the reaction: it makes the liquid less viscous and therefore easier to work with, and it keeps at bay the microorganisms that cause spoilage.

A boost for biofuels

Manufacturing sugary drinks more efficiently might not seem like a big step forward for society, but there are other applications of thermophiles that could prove to be of great benefit to the planet. Perhaps the most significant is the potential use of thermophiles to manufacture biofuels (Scully & Orlygsson, 2014).

Besides fossil fuels, the most abundant organic material on Earth is cellulose – the tough, fibrous carbohydrate made by plants to support their cell walls. Cellulose is all around us: it makes up most of the mass in wood, cotton, paper and all types of plant waste, from sawdust to crop stubble. If a procedure to convert cellulose efficiently into biofuel could be devised, it would provide a carbon-neutral alternative to fossil fuels.

Several thermophiles are capable of degrading cellulose to produce sugars or slightly larger carbohydrate molecules called oligosaccharides, consisting of several sugar molecules linked together. These products could then be fermented to produce alcohol or hydrogen, both of which make good fuels – and thermophiles can help with this second step, too. Although yeast is already widely used to produce alcohol from sugar, thermophiles can ferment a greater variety of sugars. The bacterium *Thermoanaerobacter ethanolicus*, for example, can digest many of the sugars that make up cellulose, such as xylose, galactose and mannose, producing alcohol (ethanol) as a product.

The bacteria *Clostridium thermocellum* and *Caldicellulosiruptor saccharolyticus*

“One challenge is to find a thermophile that can tolerate high levels of ethanol without being poisoned.”

Sean Michael Scully

A researcher samples some high temperature (80 °C) geothermal fluid near Myvatn (northern Iceland), using a sampling pole as students watch.

can even carry out both these steps themselves, breaking down cellulose directly and fermenting the resulting glucose to give a mix of products including hydrogen, acetic acid and ethanol.

Such species are the focus of ongoing research into biofuels, but there are hurdles to overcome. One challenge is to find a thermophile that can tolerate high levels of ethanol without being poisoned, a step that might require genetic modification. Alternatively, ethanol could be constantly removed from a continuous culture, preventing it from reaching toxic levels.

Future prospects

The technological potential of thermophilic organisms is tremendous, and so is their commercial potential. In 1991, the US biotech company that developed PCR from the Taq enzyme sold its patent for $300 million, but none of the proceeds found their way back to Yellowstone National Park, the original source of the enzyme. Today, strict guidelines govern what 'bioprospectors' can take from the site and ensure that any future profits derived from this genetic resource are shared. Such measures may help ensure that these unique and beautiful ecosystems survive to find uses in future biotechnology – and to inspire future generations of budding scientists.

Reference

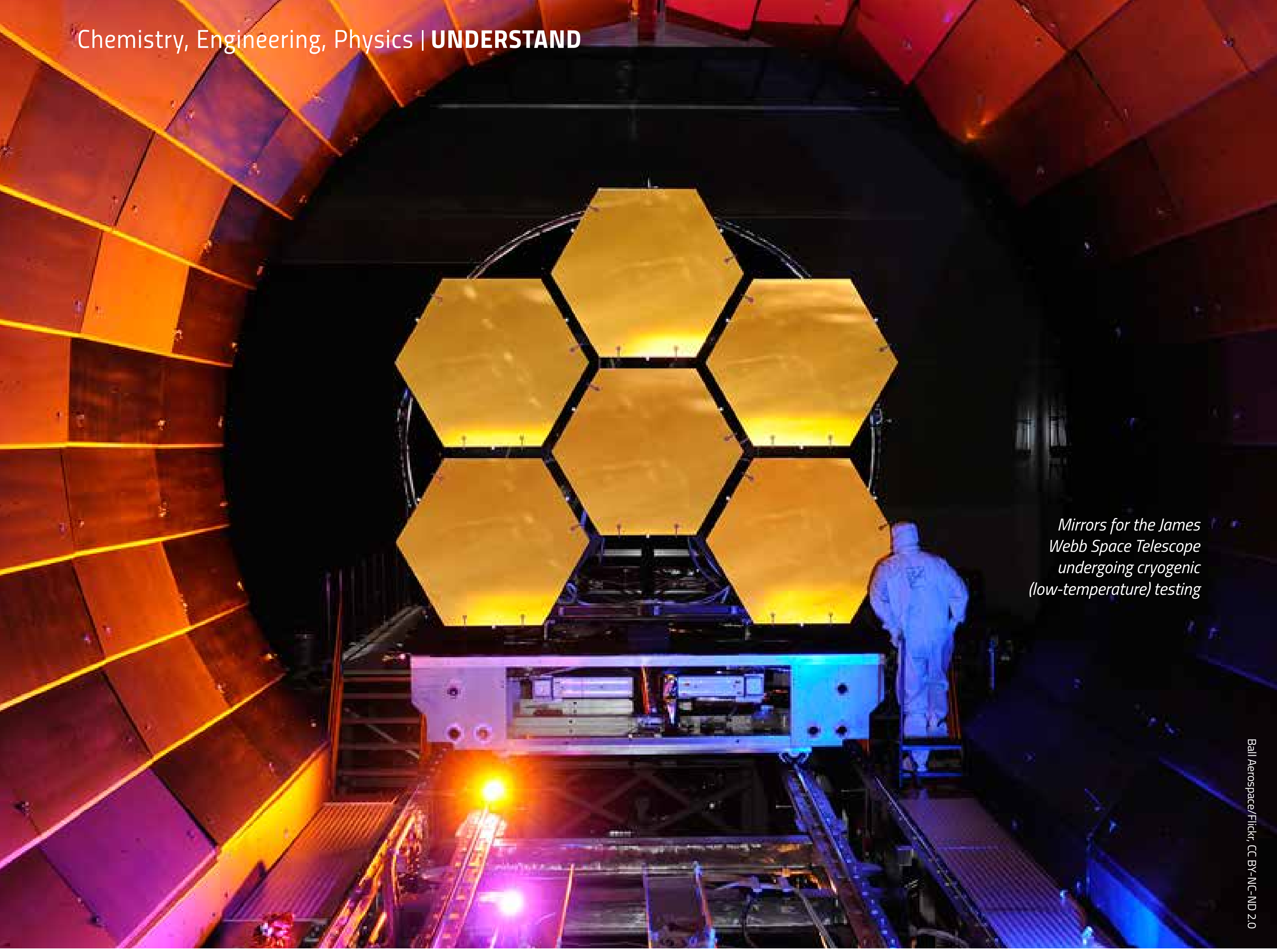
Scully S, Orlygsson J (2014). Recent advances in second generation ethanol production by thermophilic bacteria. *Energies* **8(1)**: 1-30. doi: 10.3390/en8010001

Resources

Take a look at the author's Facebook page about thermophilic anaerobes. See: www.facebook.com/Thermophilic-anaerobes-552801444833510/

Read about 'hot bugs' and how thermophilic bacteria can be used to produce hydrogen for fuel. See:
Willquist K (2012) Hydrogen: the green energy carrier of the future? *Science in School* **22**: 12-16. www.scienceinschool.org/2012/issue22/hydrogen

Sean Michael Scully is a lecturer at the University of Akureyri in northern Iceland. After starting his career in science in the USA and spending some time working in the chemical industry, he emigrated to Iceland. He has a background in organic chemistry as well as microbiology. His research focuses on the biotechnological application of extremophilic bacteria and their enzymes.



Mirrors for the James Webb Space Telescope undergoing cryogenic (low-temperature) testing

Elements in the spotlight: beryllium

As a lightweight, super-strong metal, beryllium is an engineer's dream – but it also has some less convenient qualities.

By Joseph W Piergrossi and Montserrat Capellas Espuny

The element beryllium is perhaps one of the strangest in the periodic table. It is the second lightest metal (by atomic mass), after lithium, and it is also surprisingly unreactive compared to its elemental neighbours. Beryllium is the first element in Group 2, and – unlike the other alkaline earth metals (such as magnesium, calcium and strontium) – it resists interacting with most other substances. In fact, this dark-grey metal would be one of the most useful elements in the periodic table if it were more abundant and not so dangerous to work with.

Alloys and applications

Beryllium's chemical stability is due to its tendency to form a very thin, unreactive oxide layer on its surface. This and its low density are advantages in making very strong, corrosion-proof metal alloys, such as beryllium copper. These alloys have uses in high-stress applications, such as helicopter rotors. They are also used as an alternative to steel in some tools – especially where there are high magnetic fields, such as from radio transmitters or magnetic resonance imaging (MRI) equipment in hospitals.

“The James Webb Space Telescope will have mirrors made from pure beryllium.”

Pure beryllium is also used in some specialist applications, despite its high cost, because of its superb engineering qualities. As well as its lightness and strength, beryllium has a high melting point and relatively low thermal expansion, so it changes very little when heated – or when cooled to exceptionally low temperatures, such as those in space. These qualities have made beryllium the material of choice in many aerospace applications, including for parts of satellites and supersonic aircraft. The James Webb Space Telescope (JWST) – a new space telescope to replace the Hubble – will have mirrors made from pure beryllium. The JWST is expected to be launched in 2021, and once in place, the 18 hexagons of beryllium that make up the telescope's primary mirror will be kept cooled to –220°C. This is to minimise infrared emissions from the mirror itself that could otherwise interfere with signal detection.

Beryllium has another special property: unlike most metals, X-rays can shine straight through it. This transparency to X-rays is due to the low number of electrons in its atoms: as element number 4 in the periodic table, it has just four electrons in each of its atoms (along with four protons and usually five neutrons within the nucleus). Electrons interact with passing X-rays, deflecting or absorbing them and releasing their own secondary X-rays. Since beryllium has only four electrons, X-rays can

Antoine2K/Shutterstock.com

Beryllium (symbol Be), the fourth element in the periodic table

REVIEW

✓ Physical chemistry
✓ History of science
✓ Ages 14–19

In the periodic table, there are some little-known elements that have a lot of applications. This article could deepen students' knowledge about one such metallic element: beryllium.

Before reading the article, students could think about the metals they know and how their applications have changed throughout history. The article could then be used as a starting point for investigating and discussing the uses of different rare elements in our society. It could also help to raise awareness of the huge cost of obtaining them and the importance of recycling.

Potential comprehension questions include:

- What is beryllium's atomic number and what is its position in the periodic table?
- Why is beryllium so different from the other elements of its group?
- Can you list five of beryllium's properties?
- Can you describe in detail three of beryllium's applications?
- Why is beryllium used only when absolutely necessary?
- Can you explain what role beryllium played in the discovery of the neutron?

Mireia Güell Serra, chemistry teacher,
INS Cassà de la Selva school, Spain

European XFEL

At European XFEL, a physicist works on the spectrometer used for monitoring the X-ray pulses fired at samples. The spectrometer has a beryllium 'window' for X-rays to reach the detectors.

Beryllium facts

- Element name: Beryllium
- Symbol: Be
- Atomic number: 4
- Relative atomic mass: 9.01
- Density: 1.85 g/cm^3
- Melting point: 1287°C
- Periodic table group: 2 (alkaline earth metals)
- Abundance in Earth's crust: 2–6 parts per million
- Discovery: Minerals containing beryllium (such as beryl and emerald) have been known since ancient times. The element itself was identified in 1798, but the name beryllium was not used until 30 years later.

European XFEL

A scientist adjusts a fine liquid jet containing samples of viruses, cells or bacteria inside a vacuum chamber, so that they can be probed by X-ray laser flashes at European XFEL.

whizz past its atoms with little chance of coming into contact with the electrons. Although the element lithium – with atomic number 3, and thus even fewer electrons – would in theory make an even better X-ray 'window', it is far too reactive to use in any structural applications, unlike beryllium.

Letting the X-rays shine through

Beryllium's unusual property of transparency to X-rays means that it can be used to enclose samples for analysis using X-rays, as the rays can pass through the enclosure without much disturbance. This is exceptionally useful in research facilities that use X-rays to study matter at the atomic level, such as the European Synchrotron Radiation Facility (ESRF)[w1] and the European X-Ray Free-Electron Laser (European XFEL)[w2]. When intense pulses of X-rays are fired at the samples under investigation, the way the X-rays are scattered or absorbed provides data about the properties and behaviour of the atoms in the sample, which scientists can then interpret. At European XFEL, a finely focused X-ray beam is used to target samples such as individual viruses and biomolecules. At ESRF, the beam enables scientists to study the properties and molecular structure of matter in extremely high detail, leading to the development of new materials, or new uses for existing ones.

In intense X-ray sources like those at ESRF and European XFEL, some parts of the apparatus need to be isolated within airtight vacuum conditions. But putting up barriers to air flow would obstruct the path of the X-rays – unless the barriers are made of beryllium. Beryllium also shields the X-ray detectors from other particles that might interfere with readings – for example, in the spectrometer used to monitor the properties of the X-ray pulses at European XFEL.

Focusing with beryllium lenses

Just as transparent glass is used to focus visible light, beryllium is used to make lenses that focus X-ray beams. When a beam is focused to a fine point, there are more X-ray photons in a smaller space, which increases the effect of the X-rays interacting with the experimental samples.

To focus X-rays, beryllium lenses need to be concave – curving in the opposite direction to the familiar convex lenses used to focus visible light. Because the refracting power of beryllium is very low, the lenses are generally used as stacks of individual lens elements, which are known as compound refractive lenses (CRLs). These stacked lenses produce an impressive focusing power: the final width of the X-ray laser beam can be as little as a fraction of a micron (10^{-6} m) across – some 10 000 times sharper than the initial diameter of the beam.

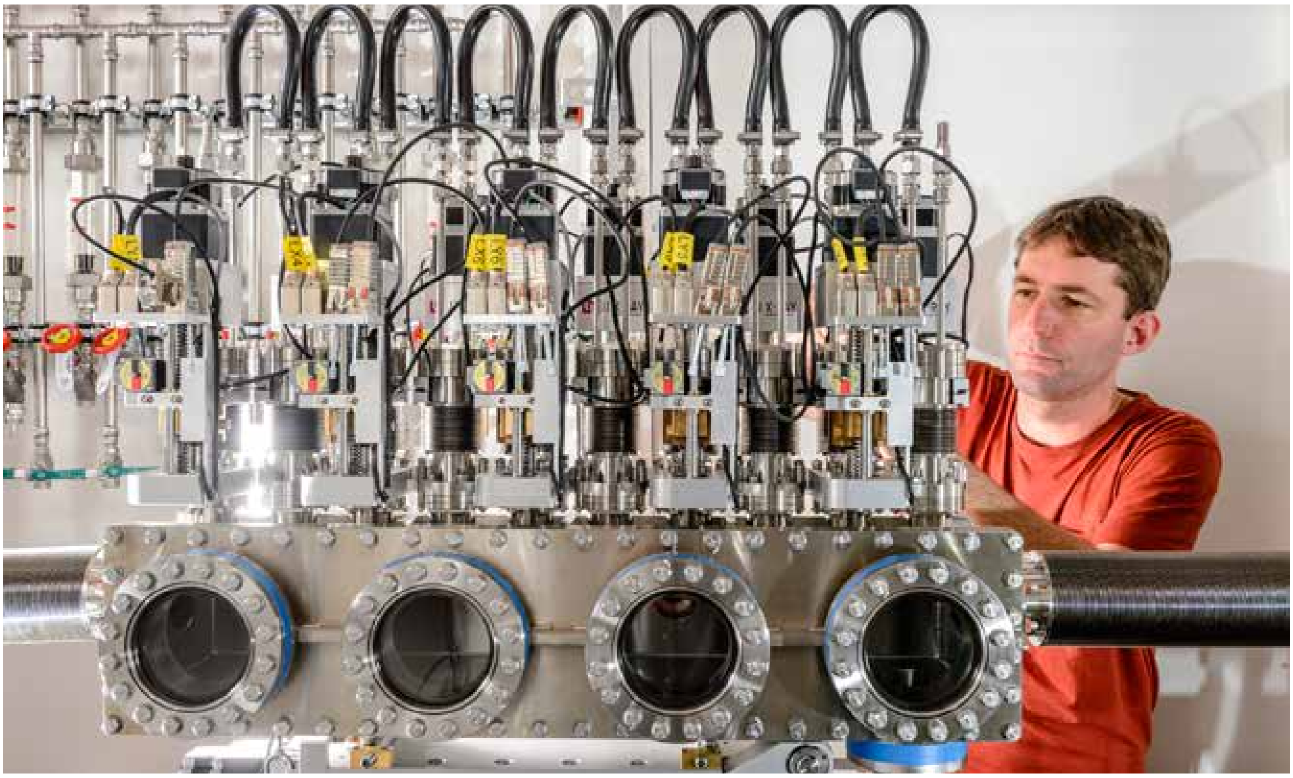
Discovery of the neutron

Beryllium played a crucial role in the discovery of the neutron in 1932. A few years earlier, several scientists had observed that beryllium produced emissions when bombarded with alpha particles. Because the emissions had no charge (unlike the only known subatomic particles, electrons and protons), the scientists concluded that they must be gamma rays – high-energy photons. However, the energy of the emissions was not what would be expected for gamma rays. In 1932, British scientist James Chadwick repeated the experiment and concluded that the emissions must be a new subatomic particle with no charge – the neutron. From this work he was also able to calculate the mass of the new particle, which he found was similar to that of the proton – just as we know today. In 1935, Chadwick was awarded the Nobel Prize in Physics for his discovery.

Rare and dangerous

But as well as these exceptional qualities, beryllium has a troublesome side. First, the element is scarce: it is found only in rare minerals, such as beryl – the type of gemstone that includes emeralds and aquamarines. This scarcity makes beryllium expensive, so it is used only when absolutely necessary. Yet where it is used, it's there to stay: beryllium components within X-ray research facilities could last hundreds of years before they need to be replaced. Another problem is that beryllium is notoriously toxic. Breathing in just a small amount of beryllium dust can cause berylliosis – a disease with persistent, incurable symptoms similar to pneumonia, and which may lead to cancer. As a result, in situations where beryllium metal is used, special precautions need to be taken to keep dust from entering the general environment. Shaping the metal is thus difficult, because the dust produced when machining beryllium is so toxic. For this reason, beryllium lenses are made by pouring molten beryllium into

> **“Beryllium is notoriously toxic: breathing in just a small amount of beryllium dust can cause symptoms similar to pneumonia.”**



European XFEL

An engineer works on the compound refractive lens (CRL) unit of an instrument at European XFEL. The CRL houses a horizontal stack of concave beryllium lenses, which focuses the X-ray beam as it passes through the unit.

standardised moulds, rather than by grinding the metal into shape.

So while beryllium is tantalizingly versatile, its rarity and the risks it poses mean that it can be considered only for the most select and costly applications. And there is always a need to respect the inherent dangers of this highly unusual metallic element.

NASA/Chris Gunn

Inspecting the hexagons of beryllium that will make up the primary mirror of the James Webb Space Telescope

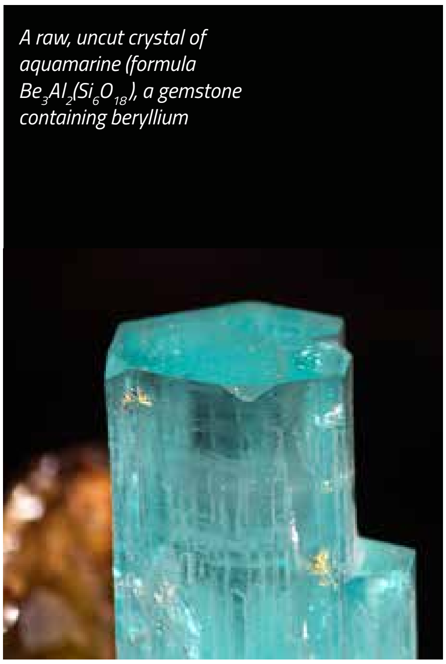
Acknowledgement

The authors would like to thank Dr Peter Zalden, instrument scientist at European XFEL, for his assistance in providing information for this article.

Web references

w1 Situated in Grenoble, France, ESRF is the world's most intense X-ray source and a centre of excellence for fundamental research in condensed and living-matter science. The Extremely Brilliant Source project, planned for completion in 2022, will be a new source 100 times greater in brilliance and coherence for better understanding of materials. See: www.esrf.eu

w2 European XFEL is a research facility in the Hamburg area in Germany. Its extremely intense X-ray flashes are used by researchers from all over the world to study the structure and behaviour of materials at the atomic level and at ultrafast time scales. See: www.xfel.eu



A raw, uncut crystal of aquamarine (formula $Be_3Al_2(Si_6O_{18})$, a gemstone containing beryllium

greyloch/Flickr, CC BY-SA 2.0

Resources

For more information about beryllium and its uses, check the website of the Beryllium Science and Technology Association (BeST). See: http://beryllium.eu

Read a short book all about beryllium and its applications. See:
Adair R (2007) *Beryllium*. Rosen Central, New York. ISBN: 1404210032

Watch a video on beryllium and its uses, which includes an explanation of a beryllium 'window' at the MAX-lab synchrotron in Sweden, as part of the University of Nottingham's 'Periodic Table of Videos' series. See: www.periodicvideos.com/videos/004.htm

The James Webb Space Telescope is a collaboration between NASA, the European Space Agency (ESA) and the Canadian Space Agency. Find out more about it and its primary mirror made from beryllium on the NASA and ESA websites. See:
https://jwst.nasa.gov/mirrors.html
https://jwst.nasa.gov/about.html
http://sci.esa.int/jwst/

Watch a video from the UK's Royal Institution about beryllium and the JWST. See: www.youtube.com/watch?v=PuUwGXRwViQ

Read about the discovery of the neutron on the American Physical Society website. See: www.aps.org/publications/apsnews/200705/physicshistory.cfm

For information on all the chemical elements, read this book:
Gray T (2009) *The Elements: A Visual Exploration of Every Known Atom in the Universe.* Black Dog & Leventhal Publishers, Inc., New York. ISBN: 1603764054

Joseph W Piergrossi is a science writer based in Hamburg, Germany. He holds master's degrees in education from the University of Georgia, USA, and in science journalism from Boston University, USA. He has previously been an environmental science and physics teacher in the USA. Since 2013, Joseph has worked as a science communicator at European XFEL in Schenefeld, Germany.

Montserrat Capellas Espuny is a senior scientific communication specialist at ESRF. She writes articles about science and its applications and is involved in the Humans of ESRF project, https://humans.esrf.fr/, a website that portrays people working at ESRF to mark the 30th anniversary of the facility.

Crime and conservation: tackling the illegal trade in rhino horn

As attempts to save the rhino continue to fail, is it time to involve local communities?

By Hannah Voak

When Annette Hübschle first stepped into the Limpopo National Park in Mozambique to begin fieldwork for her PhD, she was taken aback. "It was surreal", Annette says. "The reality of the situation hit me as soon as I entered the park. Rangers armed with rifles were running around, and one of them stopped to talk. He told me: the poachers live by the motto 'get rich young or die trying.' They live by the gun, die by the gun."

As a criminologist and sociologist, Annette had previously studied organised crime in Africa, ranging from drug markets to human trafficking. Now she was about to embark on a journey to study a commodity with a street value higher than heroin or cocaine: rhino horn.

Investigating the rhino horn trade

Growing up in Namibia, Annette was always conscious of the threats to rhinos. "I was a teenager during the rhino poaching crisis in the late 1980s and early 1990s, so I was aware that rhinos were threatened", she says. "When you grow up on

Annette Hübschle

Criminologist and sociologist Annette Hübschle

Peter Chadwick/Science Photo Library

Skulls of poached rhinos at a game reserve in Swaziland

the African continent, you are often surrounded by conservation areas. You are aware of wildlife issues, as well as the wider historical problems associated with protected areas."

When the opportunity arose to study the illegal market in rhino horn, Annette knew it was the right field for her. She began her PhD in 2011 at the Max Planck Institute for the Study of Societies and the University of Cologne, Germany. At the time, rhino poaching had again become a serious concern. In the 14 months that followed, Annette travelled to seven countries and interviewed over 400 people to delve into the devastating world of the illegal rhino horn trade, tracing its journey from southern Africa to consumer markets in southeast Asia, where its supposed medicinal value and use as a status symbol are driving demand.

"Wildlife conservation continues to benefit economic and political elites: the state, hunters, farmers and tourist operators."

Over the course of her fieldwork, Annette interviewed private rhino breeders, local communities, smugglers and poachers. "In South Africa, there is a huge variety of people involved in the trafficking of wildlife at different levels, including helicopter pilots, wildlife veterinarians, game farmers, conservation officials, police, even government ministers", says Annette. What she found most striking from talking to low-level poachers, however, was that many of them felt discontent with park authorities, anti-poaching personnel and the government. She highlights that wildlife conservation continues to benefit economic and political elites: the state, hunters, farmers and tourist operators. "Many poachers I spoke to felt they had been left without opportunities; the land used to belong to them, but now these areas of national park – along with hunting rights and access to natural resources – are inaccessible to them", she says.

In Annette's interviews, many local people expressed feelings of anger, disempowerment and marginalisation. One elderly woman, who had recently been relocated from a national park, said: "There's no peace here, no hope. They can give you a house and the next day, they can remove it from you, and give it to someone else. The youths are struggling to get jobs in this village. Some end up stealing because of the lack of jobs, others do rhino poaching. Some come back, some die and some get arrested." Given that many local people could make more money from selling a single rhino horn than they would earn in a year in another job, it is perhaps not surprising that criminal networks can easily tempt locals into poaching.

Empowering communities

Understanding why people participate in poaching and focusing on community-oriented strategies to combat it is at the heart of Annette's latest research[w1]. Since finishing her PhD, she has been working as a senior researcher and postdoctoral fellow at the University of Cape Town, South Africa, and she is also a senior fellow of the Global Initiative against Transnational Organized Crime. "I've been working on a project that looks into why people poach. At the moment, incentive structures are against rhinos – for people living close to national parks and reserves, rhinos are worth more dead than they are alive", Annette explains. "We are trying to change this incentive structure to curb the illegal wildlife trade."

Annette considers local communities to be the most important stakeholders in the wildlife economy debate but says that they are often ignored. "They live not only on the edge of parks, but also on the edge of society", she says. Local people in rural areas are often excluded from public services, for example. As a result, kingpins and poachers sometimes take on state-like functions by building roads, shops and water wells, or improving basic education and healthcare – all paid for with money from the horns of poached rhinos. If local communities were granted ownership of land and benefitted from the conservation of rhinos, they might become protectors rather than poachers of wildlife. One country where this community-based approach has succeeded is Namibia, where former poachers and local people now act as wildlife guardians and are responsible for managing the land and protecting endangered species[w2].

> **"For people living close to national parks and reserves, rhinos are worth more dead than they are alive"**

In recent years, however, most conservation operations have chosen to boost security measures. Additional rangers, improved weaponry, helicopter gunships and anti-poaching drones are all contributing to this 'green militarisation'. "The shoot-to-kill approach certainly doesn't help forge better community–park relationships", Annette says. She believes that the current anti-poaching measures do not engage with local people who live in or near protected areas and game reserves. In fact, they can make matters worse: many of the local people that she interviewed expressed their anger towards the state for valuing wild animals' lives more highly than their own.

A ranger patrols the border between Kruger National Park, South Africa, and Limpopo National Park, Mozambique.

Annette Hübschle

Hein waschefort/Wikimedia Commons, CC BY-SA 3.0

A mother and calf killed for their horns in Gauteng, South Africa

lulu and isabelle/Shutterstock.com

A ranger at Kruger National Park, South Africa, holds up the skull of a white rhino.

Bildagentur Zoonar GmbH/Shutterstock.com

The Eastern Cape giant cycad, endemic to South Africa

Africa's rhinos and beyond

Despite the numerous measures put in place to protect rhinos, the illegal market remains buoyant. In 2017, 1028 rhinos were killed in South Africa – an average of nearly three rhinos every day[w3]. "Rhino population numbers have dropped immensely since the days of my initial fieldwork", says Annette.

UK Home Office/Flickr, CC BY 2.0

Horns seized by officers at ports and airports across the UK

And, of course, it's not just rhinos that are in need of protection. "There are so many species that don't get any attention", says Annette. "The pangolin is the most trafficked animal in the world, for example, but few people know it even exists. Then there are the beautiful cycads – palm-like plants that are actually more endangered than the rhinos in South Africa." The illegal trade of wildlife takes place not just in African or Asian countries: Europe also plays an important role. "There are quite a few European ports of entry through which wildlife contraband is trafficked. There are also lots of European consumers of wildlife products – especially when it comes to exotic birds and lizards – and of course, Europeans are involved in trophy hunting", says Annette. "Recently, there have been a lot of robberies in Europe too, where rhino horn and ivory have been stolen from museums or private collections."

Rhino poaching is a highly complex issue, and Annette points out that there is no one recipe for stopping wildlife crime. She is certain, however, that the key to rhino conservation is to work with communities. "Although we are trying to save the rhino, we can only do so if we consider the people that live close to them", she concludes.

Web references

w1 Read Annette Hübschle's latest research on wildlife trafficking, published in August 2018 on the Global Initiative website. See: http://globalinitiative.net/ending-wildlife-trafficking/

w2 Watch John Kasaona share the story of Namibia's wildlife guardians in his TED talk 'How poachers became caretakers'. See: www.ted.com/talks/john_kasaona_from_poachers_to_caretakers#t-640176

w3 The charity Save the Rhino provides recent poaching statistics on its website. See: www.savetherhino.org/rhino-info/poaching-stats/

Resource

Annette Hübschle writes about the importance of empowering communities in her article published on The Conversation. See: https://theconversation.com/the-fight-against-poaching-must-shift-to-empowering-communities-83828

Hannah Voak is an editor of *Science in School*. With a bachelor's degree in biology and an enthusiasm for science communication, she moved to Germany in 2016 to join *Science in School* at the European Molecular Biology Laboratory.

Adventures in creative recycling

Do you have a drawer full of old mobile phones? One teacher is exploring new uses for such items, while nurturing his students' creative imaginations.

By Cristina Florean

Bright, shiny electronic components form the top of an e-waste 'Christmas tree.'

Marco Spinato

Teenagers can hardly imagine life without smartphones. As adults, we also depend on these and other electronic devices, which are now an essential part of our lives. While smartphones, tablets and laptops often have intensely useful lives, they do not have very long ones, usually lasting much less than a decade. Once they are damaged or their performance declines – or they just fall out of fashion – they become part of the ever-increasing pile of 'e-waste'.

Marco Spinato

Marco Spinato

Teacher Roberto Zamparini, reflected in an e-waste Christmas tree decoration

E-waste is considered a hazardous material, as it contains heavy metals such as lead, mercury, cadmium and chromium, so it needs to be disposed of carefully. It can also generate toxic compounds if burned. But e-waste presents a challenge and an opportunity, both for the economy and for the environment: it is, in effect, a goldmine due to the rare metals it contains.

It is not easy to recover these metals from e-waste, however, because many exist in only trace amounts. Metal compositions also differ from one device to the other, and from one year to the next, so it is difficult to optimise the recovery of these materials commercially. As a result, only a small proportion of the hidden value within e-waste is recovered at present, even using the most up-to-date techniques.

> **"E-waste is, in effect, a goldmine due to the rare metals it contains."**

Learning to disassemble

One person who is well aware of this challenge is Roberto Zamparini, a teacher of informatics and computer graphics in a high school in northern Italy. Outside the classroom, Roberto works with local enterprises as a consultant and software developer. He has also set up a recycling project that brings together commercial metal recovery companies and university researchers, with the aim of finding new ways to maximise the recovery of precious metals from e-waste.

At school, Roberto is very engaged in finding uses for yesterday's technology in his teaching. His role gives him access to a lot of old electronic material, and he has used this to set up a 'disassembly lab', where students are challenged to take apart these technologically complex objects. They learn how to open smartphones and computers to repair and recycle them – or even to create artistic objects. In 2016, Roberto and his students created an e-waste Christmas tree in the disassembly lab, made solely from recovered electrical components, complete with festive flashing lights.

The disassembly lab: Roberto (at the back) and his students at work

Marco Spinato

Roberto Zamparini

Roberto's students take a trip on the rail rider on the track in Austria.

Exploring science with e-waste

Another use Roberto has found for e-waste items is to help teach scientific concepts by revealing the science behind how these devices work – from the physics underlying touchscreens and microphones, to the peculiar properties of the chemical elements inside them. This approach helps to make the ideas more appealing to students, especially those who are reluctant to engage with the theoretical side of science and technology.

The components themselves are also useful for hands-on science experiments: for example, Roberto uses the neodymium magnets found in hard drives in an experiment to demonstrate eddy currents[w1], and light polarisation can be investigated using old LCD screens.

Recently, Roberto collaborated with a biology teacher to set up an interdisciplinary project on taxonomy, adapting the principles of biological classification to sorting e-waste components so that they can be better recognised and separated. The aim was not only to achieve greater re-use, but also to discover classification principles that make disassembly easier.

The rail rider

Another of Roberto's successful recycling projects focused on technology from a much earlier era: railways. Having found a disused railway track near his home, Roberto and his students set about building a human-powered vehicle – made almost entirely from recycled parts – to run on the track. The prototype 'rail rider' first ran in April 2017 and attracted a lot of attention – so much so that the track re-opened in 2018, complete with passenger trains.

The rail rider project even made an impact internationally: in September 2017, an Austrian group that was trying to re-open a local railway in Kötschach-Mauthen asked to borrow the rail rider. So Roberto and some students drove across the border with the prototype, to ride it on the disused railway in Austria – which itself now has better prospects of re-opening.

Positive interactions

Roberto's projects are linked not only by a creative approach to recycling, but also by the positive interactions that he works hard to stimulate within the classroom. Some of his students have to deal with difficult personal situations, and their problems can affect the mood and productivity of the entire class. As well as being ready to listen to them and provide practical help, Roberto finds that the best approach to successful learning is to encourage his students to engage with their studies on an emotional level.

For example, he believes one key strategy is to give students as much


cheyennezj/Shutterstock.com

Generations of mobile phones: these essential gadgets are constantly being replaced with newer models.

autonomy as possible. "Teenagers are too controlled, at home, at school, in society. The only way for them to have some freedom is by breaking the rules", he says. "For example: if you are younger than 14 years old, in Italy, you may not be allowed to go home from school without an adult in charge. In this way the autonomy of students is not fostered, at an age where they are striving to achieve it."

For this reason, Roberto's teaching approach encourages freedom in the classroom. He lets the students make their own choices, and he often splits the class up according to what different groups would like to do. Sometimes he leaves a group of students alone in a lab, trusting them with the delicate equipment, while he stays with other students elsewhere in the school. "The thrill of being alone in an important school lab, doing what you really want to do, is an incredible impulse for learning", he says. "I try to make the students part of a process of trust. To do that, of course, I also have to put my own emotions in the game."

He sums up his philosophy with this message: "Students at school should do at least one thing every day that they are really good at. The ability of the teacher is to find for each one of them this little something, and to make the student proud of this", he says. "The rest will come from the consciousness of this achievement." Once again, the key is to appreciate the precious material within, and to take care of it for the future.

The Christmas tree built from e-waste

Marco Spinato

Acknowledgement

The author would like to thank the school, IPSIA Della Valentina of the Istituto di Istruzione Superiore Statale di Sacile e Brugnera, Italy, for their help with preparing this article.

Web reference

w1 Find out about a classroom activity to demonstrate eddy currents using neodymium magnets on the *Science in School* website. See: www.scienceinschool.org/2018/issue45/disassembly

Resources

Find out about all the different chemical elements in a smartphone in a graphic by Compound Interest. See: www.compoundchem.com/2014/02/19/the-chemical-elements-of-a-smartphone

Learn about how much e-waste is recycled across the world. See: https://arstechnica.com/science/2017/12/just-20-percent-of-e-waste-is-being-recycled/

Read an article on the benefits, processes and challenges of e-waste recycling. See: www.thebalancesmb.com/introduction-to-electronics-e-waste-recycling-4049386

Cristina Florean works as a biomedical researcher in Luxembourg. After gaining her PhD, she spent some time teaching in the Italian school system. She is passionate about science writing and education, and is member of the Fondation Jeunes Scientifiques Luxembourg, which organises the national student science contest in Luxembourg.

Bioenergy in a nutshell

Could leftover nutshells be the next renewable energy source? Challenge your students to find out using calorimetry.

By Claire Achilleos, Stavros Papadopoulos, Stylianos Friligkos and Hariton Polatoglou

The world is waking up to the harm caused by burning fossil fuels. As a result, many countries are turning towards more environmentally friendly alternatives, including energy derived from biomass[w1]. Although these sources are generally considered better than non-renewables, one argument at the heart of most bioenergy debates is that farmland is often diverted for the production of the biomass, which comes at a cost to the food supply. One obvious way to avoid this 'food versus fuel' dilemma (and reduce carbon emissions in the process) is to derive bioenergy from waste.

In recent years, one material that we normally think of as a food source – nuts – has started to be used as an energy source. At present, whole nuts are used, but would burning leftover nutshells be a more sustainable way to use this material? And could waste nutshells help to meet future energy demands? In the following activities, we challenge students to find out.

Using a homemade calorimeter, students aged 14–19 determine the amount of heat energy released by various nutshells. By comparing their results to data from scientific

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Burning waste nutshells could provide a more sustainable alternative to other sources of bioenergy.

REVIEW

- ✓ Thermodynamics
- ✓ Calorimetry
- ✓ Energy
- ✓ Ages 14–19

In this exciting investigation, teachers are provided with information to enable students to make their own calorimeter. This could be a fun activity to run in a science or technology club outside lessons, although it might be possible within a lesson if all the materials are ready to use.

Another novel aspect of the investigation is the exploration of nutshells (which are usually seen as waste materials) as potential biofuels. This investigation links well to physics and chemistry, as students calculate heat energy released, calibrate their calorimeter, assess the reliability of data collected, apply correction factors and compare final results to published values. These steps offer much potential for students to discuss sources of error and how to minimise them, an aspect that is applicable to all branches of science. The ideas surrounding bioenergy could also link to biology, environmental science, geography and economics.

If safety issues concerned with nut allergies make this activity problematic, other materials that are also considered as waste could be used instead of nuts. These could include stones of fruits such as olives, plums, peaches or avocados, and possibly grape seeds.

Dr Sue Howarth, science education consultant and former senior lecturer in science education, UK

literature, the students evaluate whether nutshells could replace other renewable energy sources that are currently in use.

Preparation: building a combustion calorimeter

Constructing the calorimeter takes 1–2 hours. We suggest that students work in groups of 2–3 and build one calorimeter per group. If your school already has calorimeters that can be put in contact with a flame, you can omit this part of the activity and start immediately with the experiment.

Materials

For one combustion calorimeter (figure 1):

- Metal base or tripod for supporting the calorimeter
- Three large pieces of insulating polystyrene
- 50 ml beaker with polystyrene lid
- Thermometer
- Wire gauze mat with a ceramic centre
- Adhesive aluminium foil
- Craft knife
- Rasp

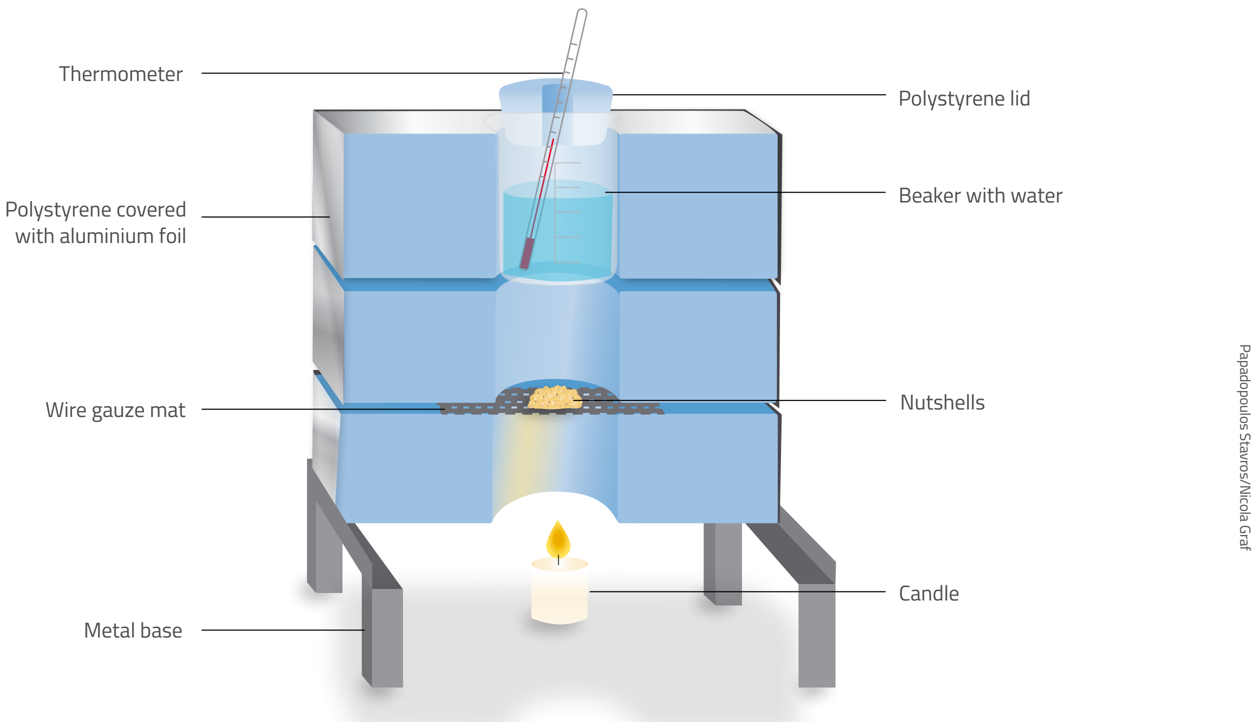

Figure 1: Diagram showing a cross section of the homemade calorimeter

Procedure

1. Find a suitable metal structure to act as the base of your calorimeter. The pieces of polystyrene will sit on top of this base, so the structure creates a space underneath where the candle can be placed. We used a metal structure that we already had available in our school laboratory (figure 2), but you can scale down the size of the calorimeter by using a tripod.
2. The polystyrene part of the device will hold the beaker. Using a craft knife, cut the three pieces of polystyrene to fit the dimensions of your metal base or tripod. Note that one of the pieces of polystyrene (to be placed on top of the other two) should be thick enough (e.g. 6 cm) to fit the beaker inside. The other two pieces can be thinner (e.g. 3 cm).
3. In the centre of each of the polystyrene pieces, cut a hole with the diameter of the beaker. Smooth the walls of the holes using a rasp. The beaker should fit snugly to prevent the passage of air.
4. Using a leftover piece of polystyrene, cut out a lid for the beaker, which will act as a bung. Cut a small hole in the lid for the thermometer to pass through (figure 3).
5. Sandwich the wire gauze mat between the two thinner polystyrene pieces (figure 4) and place the thicker piece of polystyrene on top.
6. Wrap each of the three pieces of polystyrene in aluminum foil, folding the ends of the foil into the holes for the beaker. Make sure the polystyrene is completely covered by the foil, as this will ensure that the polystyrene does not catch fire.
7. Position the beaker (complete with the lid and thermometer) in the top of the calorimeter (figure 5).

Experiment: burning biomass

In the same groups, students burn various nutshells and kernels using their calorimeter and calculate the amount of heat energy that is transferred from the kernel or shell to the water in the beaker. Although the aim of the experiment is to determine the amount of energy released by nutshells (not kernels), students also need to burn the kernels to compare their results to published values, as these values are more widely available than those for nutshells.

For the calculations, students use the following equation:

$Q = m \times c \times s\Delta T$

Where:

Q = heat energy transferred (J)

m = mass of water (kg)

c = specific heat capacity of water (4200 J kg^{-1} K^{-1})

ΔT = change in temperature (K)

Papadopoulos Stavros

Figure 2: A metal base, such as this, acts as the main support for the calorimeter.

Papadopoulos Stavros

Figure 3: The beaker is sealed with a polystyrene lid, through which a thermometer passes.

Papadopoulos Stavros

Figure 4: The wire gauze mat is sandwiched between the two thinner polystyrene pieces.

Papadopoulos Stavros

Figure 5: The finished calorimeter is ready for carrying out the experiments.

We suggest that students burn kernels and nutshells for four different types of nut, in which case the whole experiment will take approximately 2 hours including calculations and repetitions.

Materials

- Calorimeter
- Nuts, e.g. walnut, hazelnut, almond, pistachio
- Mortar and pestle
- Electronic precision balance (readability of 0.1 g or smaller)
- Thermometer
- Nutcracker
- Tweezers
- 50 ml water
- Candle, e.g. tea light (and matches)

Safety note: This activity should not be carried out if any students or staff involved have an allergy to nuts. Remember that remnants may stay in the air following the grinding or burning of nuts, which could affect other individuals with severe allergies that use the same room afterwards.

Safety goggles should be worn and special care should be taken with the open flames.

Procedure

1. Using a nutcracker, break each type of nut and separate the kernels from the shells. Gently grind each sample (kernels and shells separately) with a mortar and pestle.
2. Weigh 0.2 g of each sample using the electronic precision balance. This amount is enough to cause a measurable change in water temperature when burned.
3. Remove the upper piece of polystyrene and place your first ground sample on the wire gauze mat.
4. Add 50 ml of water to the beaker and seal it with the polystyrene lid. Ensure that the thermometer is in contact with the water. Record the initial temperature.
5. Light the candle and place it under the wire gauze mat to ignite the sample.
6. As soon as the sample ignites, remove the candle to avoid heating the water from the flame of the candle. Place the upper piece of polystyrene (with the beaker) back into position.
7. Closely watch the burning sample from underneath the calorimeter. As soon as it stops burning, read and record the water temperature again.
8. Calculate the temperature change of the water and then determine the amount of heat that the sample transferred when it burned, using the equation $Q = m \times c \times \Delta T$. Remember that 1 ml of water weighs 1 g.
9. Repeat the steps for each of the nut samples at least three times, replacing the water in the beaker between each sample.
10. Calculate the mean heat energy per kilogram for each material (table 1). Note that values for kernels from published literature are shown in table 2.

Assessing reliability

Students should compare their own results for nut kernels to values that are widely available in scientific literature. This allows them to assess the reliability of their results for nutshells. Students can search for the literature themselves or use the values provided in table 2. Our students found that their own experimental values for nut kernels differed by roughly 50% from the published values they obtained (Brufau et al., 2006). This large difference provides an opportunity to discuss why the experimental setup and procedure may cause such a discrepancy. Later, students will calculate a correction factor by which to amend their data. There are a number of sources of error that you can discuss, for example:

- At the start of the experiment, students weigh 0.2 g of nut material using an electronic precision balance. This measurement could introduce some error depending on the readability of the balance.
- To check whether the samples have finished burning, students may need to remove the beaker and polystyrene to see the sample, which would release heat from the calorimeter and

	Mean heat energy per kg (x 10^4 kJ/kg)	
Nut type	**Kernel**	**Shell**
Walnut	1.4595	0.5320
Hazelnut	1.4175	0.5285
Almond	1.1690	1.0745
Pistachio	0.6685	0.5180

Papadopoulos Stavros

Table 1: Student results from classroom experiments showing the mean heat energy for various nut kernels and shells

affect the final temperature of the water.

- When the material stops burning, can students be sure that the entire sample burned or might combustion be incomplete? Leftover ashes or unburned pieces of nuts, for example, would add to the error.

Overall, however, the biggest source of error in calorimetry occurs as a result of heat being lost to the surroundings. To deal with this, students need to calibrate their calorimeter. In the next activity, they do this by measuring the combustion energy of a paraffin wax candle with a specific mass.

Kapilbutani/Wikimedia Commons, CC BY-SA 3.0

Wood pellets are currently used as an alternative to non-renewables such as coal.

Calibration: improving accuracy

Students calculate the amount of heat energy that the water in the beaker absorbs from the heat of the candle, and compare this to the amount of heat energy that the candle releases. By comparing the two values, students can calculate the heat loss and the error in their measurements. This procedure takes approximately 1 hour including repetitions.

Materials

- Calorimeter
- 50 ml water
- Candle, e.g. tea light (and matches)
- Electronic precision balance (readability of 0.1 g or smaller)
- Stopwatch

Procedure

1. Weigh the candle using the precision balance and record the value.
2. Remove the upper piece of polystyrene and place the candle on the wire gauze mat.
3. Add 50 ml of water to the beaker, seal it with the polystyrene lid, and record the water temperature as in the first experimental procedure.
4. Light the candle using a match and quickly place the upper piece of polystyrene (with the beaker) back into position.
5. Using the stopwatch for timing, allow the candle to burn for 10 minutes before blowing it out. Record the water temperature and calculate the change in temperature.
6. Weigh the candle again and calculate the change in mass.
7. Calculate the amount of heat energy transferred to the water using the equation $Q = m \times c \times \Delta T$.
8. Repeat the procedure at least three times and calculate the mean heat of combustion of the paraffin wax by dividing the heat energy (Q) by the change in mass of the candle.

   In our case, the experimentally determined mean heat of combustion of the wax was 2.1589×10^4 kJ/kg. The heat of combustion of paraffin wax is known to be 4.2×10^4 kJ/kg (Seager et al., 2011).

	Mean heat energy per kg ($\times 10^4$ kJ/kg)		
Nut kernel	**Experimental values without calibration**	**Experimental values with calibration**	**Published values**
Walnut	1.460	2.840	2.735
Hazelnut	1.418	2.757	2.679
Almond	1.169	2.274	2.302
Pistachio	0.669	1.300	1.147

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Table 2: Heat energy values for nut kernels from classroom experiments (with and without calibration), compared to the values sourced from literature (Brufau et al., 2006)

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The production of almond nuts is greatest in countries such as the USA, Spain and Iran.

9. Using these two values, determine a correction factor (D) by calculating the ratio. Using the values above:

$$D = \frac{4.2 \times 10^4}{2.1589 \times 10^4}$$

$$= 1.945$$

10. Multiply your experimental values by the correction factor, which takes into account the heat energy that was lost to the surroundings.

Your experimental data should now be more closely in agreement with the values obtained from scientific literature (table 2). Variations may still exist, however, highlighting the importance of discussing all sources of error in the investigation.

Drawing conclusions

For the final part of the activity, students evaluate whether nutshells could replace other renewable energy sources. To do this, students can obtain data from scientific literature regarding the energy released by burning existing sources of biomass, such as hardwood, wood pellets or olive stones, and compare these to their own experimental results for nutshells. Alternatively, students could use the values in table 3, which are sourced from published literature. They can then plot this information on a graph (figure 6).

	Mean heat energy per kg (x 10^4 kJ/kg)		
Biomass (nutshells and other sources)	**Experimental values without calibration**	**Experimental values with calibration**	**Published values**
Walnut	0.5321	1.0349	-
Hazelnut	0.5285	1.0279	-
Almond	1.0745	2.0899	-
Pistachio	0.5180	1.0075	-
Hardwood	-	-	1.5823
Wood pellet	-	-	1.9088
Olive stone	-	-	1.8944

Papadopoulos Stavros

Table 3: Heat energy values for nutshells from classroom experiments (with and without calibration), compared to the values for other solid biofuels sourced from literature (Telmo & Lousada, 2011; Lee, 2015; Miranda et al., 2008)

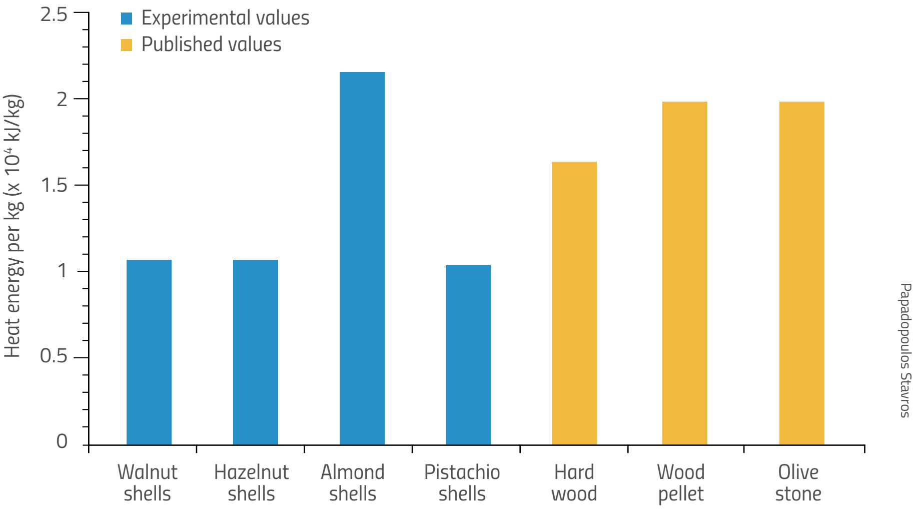

Figure 6: Energy released by various nutshells (from students' own calibrated experimental results) compared to other renewable sources (taken from Telmo & Lousada, 2011; Lee, 2015; Miranda et al., 2008)

Overall, our results showed that the energy released from the combustion of nutshells was approximately 46% lower than the energy released by these three other renewable sources. However, note that our energy value for almond shells was actually comparable to that for wood pellet and even better than those for hardwood or olive stones.

If time allowed, students could actually perform the calorimetry experiments for these other sources of biomass themselves, and compare their own values for hardwood, for example, to their values for nutshells.

To fully assess whether nutshells could be a suitable alternative, students should also consider the advantages and disadvantages of using nutshells for bioenergy. For example, the major advantage is that shells are a waste material, so the production cost is very low. Nutshells also contain very little moisture, so they don't require any further drying – unlike (for example) wood pellets – which reduces processing costs. However, the amount of energy produced by certain nuts is much lower than other potential sources, as the results show. In addition, using nutshells as a bioenergy source is feasible only in countries where the production of nuts – and in particular, almond nuts – is high, such as the USA, Spain, Iran, Italy and Syria[w2].

Overall, our students appreciated the importance of using nutshells as a source of energy, and came to the conclusion that using shells – which would otherwise go to waste – for bioenergy production is a valuable and innovative practice. What conclusions will your own students draw?

Acknowledgements

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w1 The *Sustainable Energy Handbook*, available on the European Union website, provides information regarding the use of biomass for heat and electricity. See: https://europa.eu/capacity4dev/file/29374/download?token=iLlWnWQA

w2 Visit the website of the Food and Agriculture Organization of the United Nations (FAO) to read more about production quantities of almonds in different countries. See: www.fao.org/faostat/en/#data/QC/visualize

Resources

Find case studies describing how nutshells are used to generate power on the Biomass Producer website. See: http://biomassproducer.com.au/producing-biomass/biomass-types/crop-residue/nut-shells/#case

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Hearing waves: how to build a loudspeaker

Explore the science of sound and electromagnetism with this practical build-it-yourself activity.

By Antxon Anta and Elizabeth Goiri

Humans have made music since prehistoric times: from the rhythmic beating of sticks or stones by our early ancestors, to the creation of complex symphonies in recent centuries. Today, we can listen to music anytime and anywhere, thanks in part to loudspeakers in our smartphones or mp3 players. It's something most students do every day, yet how many understand how loudspeakers actually work?

This article describes how to build a loudspeaker using simple materials (Capell Arques, 2011). The activities allow students to directly observe a widespread and surprisingly straightforward application of the physics of sound and electromagnetism in a fun and motivating way.

How does a loudspeaker work?

A loudspeaker converts an electric current into sound (changing electrical energy into acoustic energy) using two main components: a magnet and a wire coil. When an electric current flows through the coil, it produces a magnetic field (as described by Faraday's law of induction), transforming the coil into an electromagnet.

The current produced by an audio signal is not constant, however; it alternates rapidly between positive and negative values. This means that the current in the coil continuously switches directions, as does the polarity of the magnetic field induced by this current. If we now bring a permanent magnet with a constant magnetic field close to the coil, the permanent magnet and the electromagnet (the coil) interact, rapidly switching between attraction and repulsion, resulting in to and fro movements (vibrations) of the magnet and coil. These vibrations are passed on to the surrounding air. When they reach our eardrum, our brain interprets the vibrations as sound if the frequency is in the audible range (between 20 Hz and 20 kHz).

In our setup, we use a neodymium disc magnet, and we fix the coil and magnet to old CDs or DVDs for support. When the coil-CD is placed on top of the magnet-CD, and the coil is connected to the audio signal, the coil and magnet interact. Since the magnet-CD is much heavier than the coil-CD, we can disregard the vibration of the magnet-CD and only consider the vibration of the coil-CD.

REVIEW

- ✓ Electronics
- ✓ Electromagnetism
- ✓ Engineering
- ✓ Ages 11–19

Electromagnetism is often considered to be a hard topic to grasp, but this article illustrates an interesting and novel application that allows teachers to incorporate active learning into their lessons.

The topic is suitable as a demonstration for students aged 11–14 and can be used with students aged 14–16 as an activity to explore how a loudspeaker works. To build on the activity, teachers could organise a class competition to find the loudspeaker with the best sound quality, and discuss the reasoning with their students. For older students (e.g. aged 16–19), the article could be used as a starting point to introduce the notion of eddy currents, with students researching the effect that these currents have on the sound quality of the speaker.

The principles outlined in this activity could also be linked to seismology, with students using the electromagnetic coil to pick up oscillations caused by vibrations (e.g. tremors), which they can view in Audacity.

Colin Oates, physics teacher, Scotland, UK

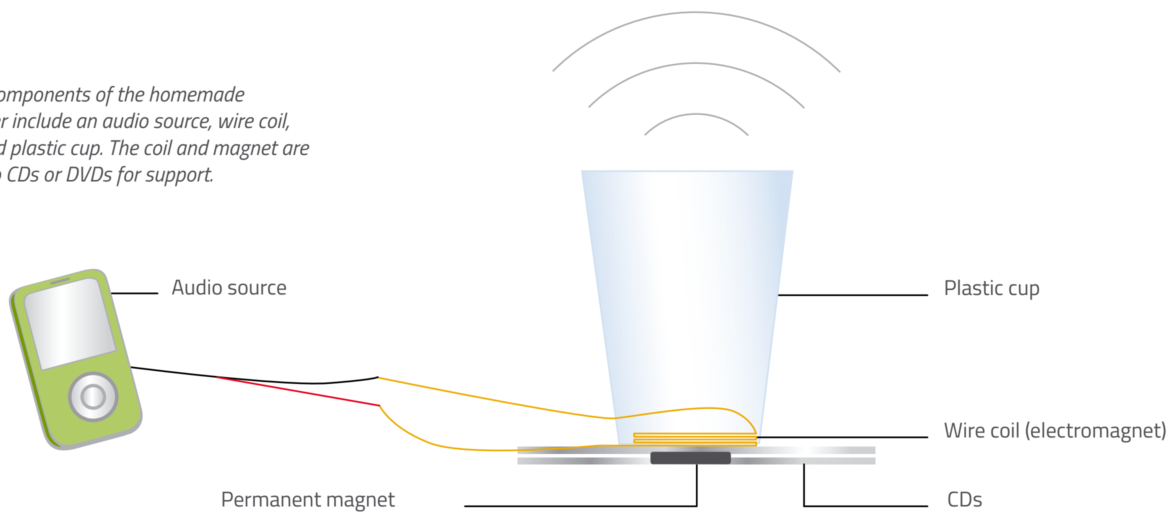
Activity 1: Building the loudspeaker

The activity can be carried out by students aged 14–16 and will take about 50 minutes. We suggest working in groups of 3–4 students.

Materials

To build one loudspeaker:

- A neodymium disc magnet, about 20 mm in diameter and 10 mm in depth
- Enamelled copper wire, 0.2 mm in diameter and about 3.5 m in length
- 3.5 mm audio cable, mono or stereo (see figure 1 to determine the type of cable you have). Old earbuds can also be used. Note that the procedure requires the cable to be cut.
- Toothpick
- Two old CDs or DVDs
- Two crocodile cables
- Wine cork
- PVA glue
- Sandpaper or cutter blade



The main components of the homemade loudspeaker include an audio source, wire coil, magnet and plastic cup. The coil and magnet are attached to CDs or DVDs for support.

Elizabeth Goiri

Elizabeth Goiri

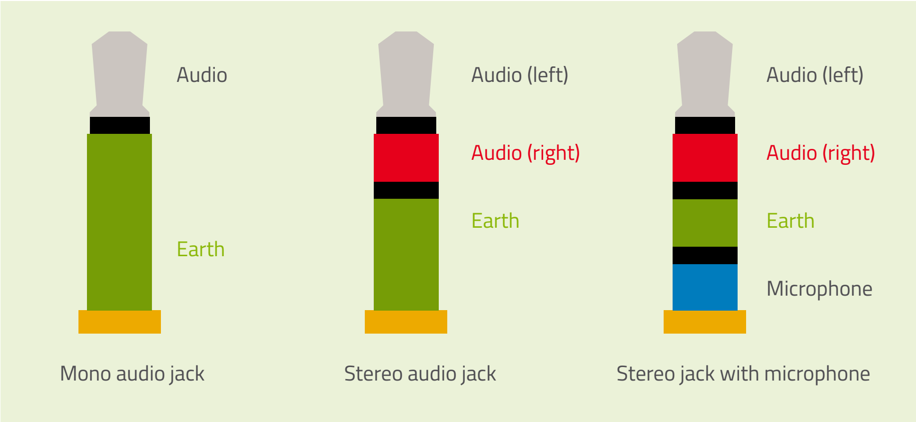


Figure 1: Identify the type of cable (and the different wires it contains) by counting the number of black insulating rings on the audio jack.

- Scissors or wire strippers
- Tape
- Plastic cup
- Audio signal source with an audio jack socket (e.g. computer, mp3 player, smartphone)

Safety note: Take care when handling neodymium magnets to avoid damaging electrical equipment or trapping fingers between two magnets. Caution should also be taken when stripping the audio cables with scissors or wire strippers.

Procedure

1. Coil about 50 turns of copper wire around the wine cork as compactly as possible, keeping 5–10 cm of loose wire at the start. You will need to remove the coil from the cork when you are finished, so don't wind it too tightly. You can place a toothpick between the cork and the wire to maintain a gap.
2. Cut the wire, leaving about 40 cm to spare at the end.
3. Carefully remove the coil from the cork. Wrap the long piece of spare wire around the coil to keep it from coming apart, leaving just 5–10 cm of wire at the end, as shown in figure 2.
4. Use sandpaper or a cutter blade to remove the enamel from the last 1–2 cm of both ends of the wire.
5. Glue the coil to the centre of a CD using PVA glue (the disc will serve as a support for the coil).
6. Using a pair of scissors or wire strippers, cut and strip the audio cable to expose the wires inside. Normally earth wires are bare and audio wires are covered in plastic (figure 3).
7. Connect the audio wire to one end of the coil and the earth wire to the other end of the coil using the two crocodile cables. In the case of a stereo cable, connect only one of the audio channels to the coil (left or right audio wire) and leave the other unused.
8. Glue or tape the neodymium disc magnet to the centre of a second CD (figure 4).
9. Place the magnet-CD on a flat surface (magnet side up) and position the coil-CD on top (coil side up).

Antxon Anta

Figure 4: Using tape or glue, the magnet is fixed to a CD for support.

10. Connect the audio jack to your audio source (figure 5). In our experience, a computer is the most reliable source, as the current from some smartphones can be too weak.
11. Play a song or audio file and turn the volume all the way up. If properly connected, you should hear the sound faintly but clearly. Depending on the strength of your magnet, you might even be able to feel the coil vibrate when you touch it.

Elizabeth Goiri

Figure 2: The coil for the loudspeaker is created by winding copper wire around a wine cork.

Elizabeth Goiri

Figure 3: A stripped stereo audio cable shows two audio wires and one bare earth wire.

12. To increase the volume, press the plastic cup against the coil.
13. Vary the distance between the coil and the magnet by moving the CDs. How does this affect the volume, and why?

Sounds and waveforms

Volume (the amplitude of vibration) and pitch (the frequency of vibration) are determined by the shape and form of the transmitted current as a function of time, i.e. the waveform. All the information about the sound encoded by the audio file is contained in this waveform. The waveform essentially describes the time dependence of all three components – the electric current, the induced magnetic field and the vibration of the coil.

A wonderful tool for studying sound (waveform, amplitude, pitch, timbre) is to use the open source audio software Audacity[w1]. In the next activity, students use this software to view the waveform of the sound that is played through the homemade loudspeaker.

Antxon Anta

Figure 5: The components of the loudspeaker, using an mp3 player for the audio source

Activity 2: Visualising waveforms

From the activity, students should understand that the waveform they see has the form of the time-varying current that is transmitted from the audio source to the coil. This current induces a changing magnetic field through the coil, again with the same waveform. Students should work in the same groups as before; the activity will take approximately 20 minutes.

Materials

- Homemade loudspeaker
- Computer with Audacity software installed
- Audio files of your choice

Procedure

1. Begin by generating a pure (sinusoidal) tone through the loudspeaker using Audacity (Menu: Generate > Tone). Students will see the generated wave on the screen (figure 6A). Play the tone through the speaker.
2. Next, import an audio file such as a song (Menu: File > Import > Audio).
3. Use the zoom function to see the waveform clearly. Figure 6 shows successive zoom images of the waveform of Van Morrison's 'The Healing Game'. If we zoom in far enough, the actual waveform becomes visible.
4. Experiment with the software, exploring differences in amplitude and waveform when scrolling through the audio file.
5. Audacity shows the length of a selected time interval at the bottom of the screen. Use this feature to estimate the timescale of the vibrations by measuring the time intervals from peak to peak.

Discussion

In our experience, students find this project to be a simple and fun way to understand the physics behind a loudspeaker. The following questions can help evaluate how well the students have understood the concepts involved.

- What is a loudspeaker? Name the main components.
- What devices do you use that work using a coil and a magnet to produce sound?
- What is the sequence of events that results in the production of sound from the loudspeaker?
- What is the purpose of pressing the plastic cup against the coil?
- What effect does increasing or decreasing the distance between the two CDs have?
- What would happen if we removed the permanent magnet fixed to the CD?
- What type of interaction causes the coil to vibrate?
- What does the waveform (as seen in Audacity) describe?
- How is the vibration of the surrounding air related to the vibration (displacement) of the coil?

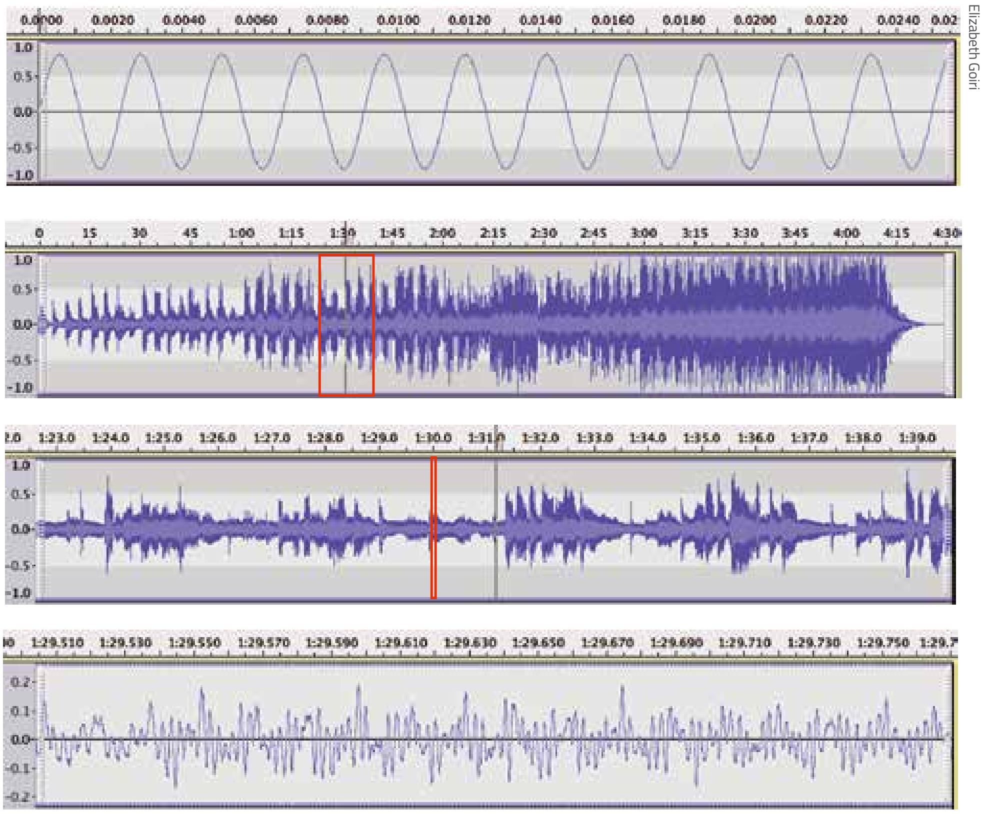


Figure 6: A: pure 440 Hz sine wave generated by Audacity; B: entire audio clip of 'The Healing Game' by Van Morrison imported into Audacity; C: close-up of the red-outlined area in panel B; D: further zoom showing part of the waveform from panel C (marked in red), which corresponds to the current through the coil

- What can you deduce about the timescales involved in the vibrations from viewing these waveforms?

Other ideas

Our project can be adapted or supplemented in a number of ways, for example:

- For a variation, glue the coil to the bottom of a paper or plastic cup and connect it to an audio source using the audio cable. Bring the opening of the cup to your ear and hold a magnet close to the coil to hear the sound[w2].
- Carefully 'dissect' a pair of old earbuds to identify the components inside them (e.g. coil, magnet)[w3].
- Illustrate the operation of the phonograph (the mechanical version of a loudspeaker) for an alternative way to understand the relationship between sound and waveforms[w4].

Reference

Capell Arques C (2011) Construcción de un altavoz con dos CD. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias* **8** (Núm. Extraordinario): 422–426

Web references

w1 Audacity is free audio software that is available to download from the Audacity website. See: www.audacityteam.org/download/

w2 Visit the Exploratorium website for instructions on how to build a cup speaker. See: www.exploratorium.edu/snacks/cup-speaker

w3 For a guide to dismantling earbuds and headphones to find out how they work, visit the Explain that Stuff website. See: www.explainthatstuff.com/headphones.html

w4 For instructions on how to build a gramophone, visit the Exploratorium website. See: www.exploratorium.edu/snacks/groovy-sounds

Resource

The Explain that Stuff website provides useful information on how loudspeakers work. See: www.explainthatstuff.com/loudspeakers.html

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Together, they participated in the 2017 Science on Stage festival in Debrecen, Hungary, with their project 'Physics for Everyone'.

Scientific stand-up: organising a student science slam

Bring students and scientists together for an evening of multilingual scientific entertainment.

Nicola Graf

By Guillaume Chevallier and Naomi Field

In bars, theatres and lecture halls across the world, an event for communicating science is gaining popularity. During the course of an evening, scientists inform and entertain an audience of inquisitive minds. The only rule is that they have just 10 minutes on stage to bring their research to life. The event is known as a 'science slam' (like a poetry slam), as scientists go head-to-head to win the audience vote.

In 2014, we adapted the concept for our school, the Franco-German Secondary School in Freiburg, Germany, and hosted our first event, called 'La soirée DupleX'. The event gives students the chance to learn from scientists from a variety of fields, and also encourages students to research and present scientific talks of their own.

The name 'La Soirée DupleX' stems from the principles of our event, as there are two aims: to communicate scientific research, and to entertain. On-stage experiments and humour are key. Students are also asked to present their talks in two languages (French and German, French and English, or German and English); and there are two types of candidate (students and scientists). It's a perfect way to bridge the gap between scientists and schools.

The final duplex element in the event is that candidates must incorporate two subject areas in their presentations. This can be two scientific disciplines, or one scientific and one non-scientific. For example, candidates have presented talks entitled 'Crystal clear drug design' (combining physics and biology) and 'Genesis as opposed to the Big Bang theory' (combining physics and philosophy).

Our now-annual Franco-German science slams have continued to evolve since 2014. In March 2018, we expanded the idea and brought together different schools to host an inter-school science slam, which was attended by an audience of 400 pupils, parents, scientists and teachers. For 2019, we have modified the concept to allow students and scientists to team up and present a talk together.

In this article, we describe how to organise a school science slam, in the hope that the concept will continue to spread throughout schools in Europe. Organising one at your school requires input from a team of teachers and students, and parents may be happy to get involved too.

Phase 1: The selection process

We recommend starting to plan your science slam one year in advance. In our experience, the ideal number of presentations for the course of the event is eight. Aim to confirm your speakers a few months before the event.

Choosing the speakers: students

The science slam is most suitable for students aged 14–19. At the beginning of the school year, we give students some presentation guidelines in addition to a marking scheme outlining how they will be judged. A jury of teachers on a committee uses this marking scheme to choose the final candidates. For each school involved in our inter-school science slam, 2–4 jury members are involved in the pre-selection.

We allocate a total of 50 marks to six categories as follows:

- Originality of topics (5 points)
- Clarity of presentation (12 points)
- Scientific approach and accuracy (15 points)
- PowerPoint presentation (6 points)
- Communication skills (6 points)
- Balance of languages and fluency (6 points)

Choosing the speakers: scientists

Approach local universities and businesses to find scientists to present at your science slam. Use your network of parents and former students to help. This is one of the hardest aspects of organising the science slam, but the more events you organise, the easier it becomes to find scientific speakers as your network grows from year to year. For our event in 2018, all

Guillaume Chevallier

Colourful chemical reactions add extra excitement to this student's talk.

REVIEW

✓ Science communication

✓ Ages 14–19

This article outlines how to organise a science slam, an event that enables science to be explained and shared in different ways. The article provides lots of help and advice for teachers who might be interested in organising an event like this for the first time.

At a time when fake news is plentiful, it is essential to disseminate science while promoting critical thinking and rationality. A science slam is a great way of spreading science to schools and the general public, and reminds us of the importance of science for society.

Dr Bartolome Piza Mir, science teacher, CC Sant Vicenç de Paül Sóller, Spain

Students present their talks in two languages, here in French and German.

Guillaume Chevallier

three scientists were former students, now studying in the fields of clinical bioinformatics, cancer research and engineering. In past years, we recruited other scientists who were friends of teachers or parents of students.

Art students illustrate the talks as they happen.

Guillaume Chevallier

Phase 2: The preparations

Once you have confirmed your speakers, there are a number of other aspects to consider in preparation for your event. These details can be adapted depending on the desired scale of your science slam.

Presentation practice

The preparation phase is an intense period for students, with many of them investing numerous hours of their time to research, write and practice their presentations. Students test out experiments, create eye-catching visuals and aim to make their talks as entertaining as possible. Teachers will need to be available to offer guidance.

One month before the event, we hold a workshop for all the student candidates, which is run by our drama teacher. This helps them with their presentation skills (e.g. articulation, body language, stage presence, use of space) and also improves their self-confidence. Feedback from our students after the workshop is always positive, with many commenting that the skills they gained from the workshop will help them throughout life.

Why not involve your school's art department too? During the event, students can set up large canvasses at the side of the stage that illustrate the scientific topics as they are being presented. The artists can choose which presentation they want to illustrate before the event, allowing them to practice with the presenter in advance.

Publicity and sponsorship

Invite your school community (students, teachers, parents) to be part of the science slam audience. You may also wish to extend the invitation to other schools, local universities and businesses that are involved in the event – and to consider inviting other

Guillaume Chevallier

On-stage experiments and demonstrations bring the science to life.

Guillaume Chevallier

The audience waits in anticipation for the announcement of the winners.

organisations, to encourage them to take part the following year. If you have the capacity, you could even open the event up to the general public.

Create posters and flyers, and contact local press agencies to publicise the science slam. If entrance is free of charge, don't forget to mention it in your advertising. We are very happy to share our templates for posters and flyers – you can find our details at the end of the article.

Depending on the size of your event, you may wish to find organisations to provide sponsorship. This can help cover the cost of prizes, publicity materials, food and drink for the event or any extra equipment you may need, such as stage props, lighting or sound kit.

Finding a jury

After each presentation, a jury (along with the audience) will assess the talks and score them on a scale of 1 to 50 using the same point system from the initial selection. Invite teachers, parents and scientists to be part of the jury, and ask a scientist who hasn't presented in the slam to act as the jury's president. The president could also hold a talk or workshop at your school during the day of the event.

In 2018, we formed an ongoing partnership with Eucor – The European Campus, which is a consortium of five universities across three countries. We invited Florence Dancoisne, the local coordinator for Eucor from the University of Freiburg, Germany, to give a talk on the afternoon of the event. In other years, we invited professors from the University of Freiburg and University of Strasbourg, France, and we hope to invite a Nobel Prize laureate in chemistry for next year's event.

Phase 3: The event

At the science slam, a compère should start by welcoming the audience, introducing the jury, and giving an outline of the event. They could also introduce each presentation in turn. This year, we asked students who had applied to present at the science slam but who had not been chosen for the final to host the event, so they could still participate in some way. For the presentations, a stopwatch should be easily visible to speakers so they can gauge the timing of their talk. You could use lighting or sound effects to indicate when their 10 minutes are up.

Audience voting

The audience should be grouped into ten teams and each team should be given five cards with the numbers 1–5 clearly marked. At the end of each presentation, the team decides on a score to give (with 5 being the best) and, when requested, they reveal their card. A small team of students can record the scores and hand these in to the jury. The total audience score (like the jury's) gives a mark out of 50. Past experience has taught us to avoid using a clapometer as this method is inaccurate and does not encourage audience interaction.

Scores from the jury

The jury's scores should not be revealed until the end of the event. This leaves an element of suspense and allows the jury to confer and agree on its scores after all the speakers have given their talks. It is worth remembering that the first speaker is at either an advantage or disadvantage because the audience does not yet have any comparison.

Announcing the winner

Add up the scores from the audience and jury (a total of 100 points) to determine the two winners of the science slam – one from the scientist category, and one from the student category. The candidates put a lot of work into their talks, so prizes are a good way to motivate them and show your appreciation. Local businesses are often keen to donate prizes or offer sponsorship to encourage young scientists.

Spreading the word

We hope this article has sparked your interest and encourages more teachers to organise science slams across Europe and beyond. Remember, you can tailor your science slam to suit the needs and circumstances of your school. Whatever the extent of your event though, you can be sure that it will be a fulfilling experience for all involved. Do not hesitate to send us an email (chevallier@dfglfa.net, field@dfglfa.net) for more information.

Our 2019 science slam will be held on Friday 17 May in Freiburg, Germany. We are happy to welcome anyone who is interested in attending and seeing us at work!

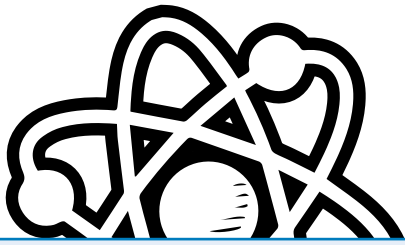
Resources

Watch a short video (in English, French and German) outlining the 'La Soirée DupleX' science slam. See: www.youtube.com/watch?v=_PYQIuQV2Kk

Watch a video (in English, French and German) from the 2017 science slam, featuring interviews with participants and organisers. See: www.youtube.com/watch?v=zBae7C3OtBg

To view and download materials from past science slam events, visit the author's Padlet page. See: https://padlet.com/la_soiree_duplex/science_slam_LFA

Find more information regarding past and future science slam events on the Franco-German Secondary School website. See: www.dfglfa.net/dfg/fr/actualites/e-eduplex-fr/soiree-duplex



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Naomi Field has taught English at the Franco-German Secondary School since 2008. She began working with the science slam team in 2017 to help develop it into a multinational event.

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