



Science in School

The European journal for science teachers



Photoacoustics

Seeing with sound

INSPIRE

Understanding the
teenage brain

TEACH

Rocket science
made easy



Universiteitsarchief Katholieke Universiteit Leuven

IN THEIR ELEMENT: WOMEN OF THE PERIODIC TABLE 08

Find out how women scientists contributed to knowledge of the chemical elements – and what this tells us about scientific work, then and now.



Leo Pappas/Flickr CC BY-NC-ND 2.0

UNDERSTANDING THE TEENAGE BRAIN 30

Teenagers are in transition from childhood to adulthood, so why does their behaviour differ from both these phases?



Alexis Fotos/istock.com

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You'll need to put your money on the table for this batch of tricks, then use your scientific knowledge to make 'cents' of what happens!

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Prepare for lift-off with these simple activities that demonstrate some of the key principles of space science.

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artdee2554/Shutterstock.com



EDITORIAL



Susan Watt
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Science in School
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Welcome to the summer issue of *Science in School*. While we are nearing the end of the school year, we are still in the middle of 2019, which has been officially named the International Year of the Periodic Table of Chemical Elements.

Mendeleev's great innovation – one of the central developments in the history of modern science – turns 150 this year. But, as so often in science, there is more to the story of the periodic table than the genius of one man. In this issue, we are delighted to add to the anniversary celebrations, starting by highlighting some of the unsung heroines (and a few heroes) whose painstaking collaborative work on particular chemical elements helped to complete the table as we know it today (page 8). We also take a look at some of the intriguing designs that have been devised for the periodic system (page 26), and – perhaps to wind down the school term – we invite students to test their knowledge of the chemical elements with a quiz (page 38).

Elsewhere in this issue, find out about a new technology that blends sound and light to provide safer, clearer images of living tissues (page 14), and enjoy some light-hearted physics with coins (page 46) and simple rocket science (page 34). On the very topical theme of the environment, we consider some of the lesser-known factors that can contribute to climate change (page 19) and investigate the variety of pigments that enable plants to photosynthesise efficiently (page 41).

Finally, if you have spent some of this school year wondering just why teenagers behave as they do, you might be interested to read about a neuroscientist who is finding new answers to this perennial question (page 30) – and advocating for a better understanding of adolescents in society.

On that optimistic note, may we wish you a successful end of the school year and a great summer break.

Susan Watt

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

The history of our Universe, fusion research with comics, and clues about Alzheimer's disease

CERN

An augmented reality tour through our Universe's history



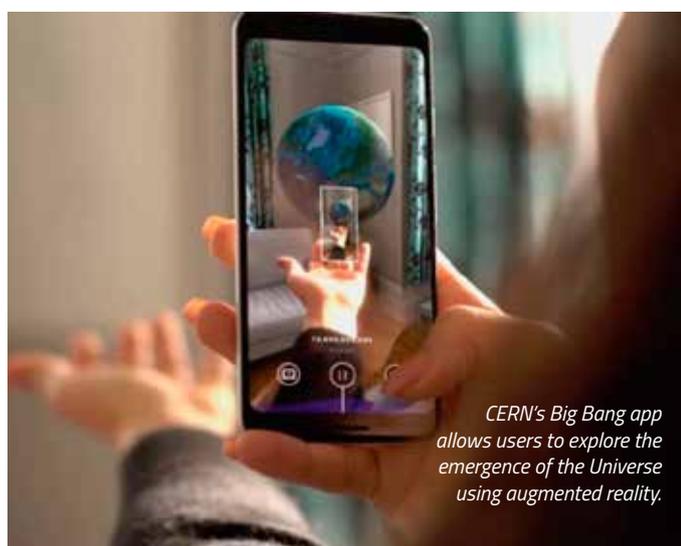
Ever since the Big Bang 13.8 million years ago, our Universe has continued to expand and change. Beginning as a swirling soup of quark-gluon plasma, the Universe has undergone the formation of protons and neutrons, the evolution of atoms and molecules, and the birth of stars and planets – all to become the Universe we know today. Now you can experience this journey in just seven minutes with CERN's new Big Bang augmented reality app.

Launched in collaboration with the Google Arts & Culture project, the free app creates an immersive adventure to explore our Universe's history, narrated by Oscar-winning actress Tilda Swinton.

“One of CERN's missions is to educate and engage people from all over the world with science and technology”, says Charlotte Warakaulle, CERN's director for international relations. “With this app, we hope to reach new audiences and share with everyone the story of the origin of our Universe in an inspiring way.”

Download the Big Bang augmented reality app and explore additional guided tours from CERN on the Google Arts & Culture website. See: <https://artsandculture.google.com/partner/cern>

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



CERN's Big Bang app allows users to explore the emergence of the Universe using augmented reality.

Google Arts & Culture/CERN

Strands of RNA can bind to the p62 protein to prevent the cell from carrying out autophagy.



EMBL

Tobias Musterfeld/EMBL

EMBL

New mechanism in the biological control of RNA and proteins

All cellular processes rely on proteins. For cells to function properly, new proteins must be made in the right amounts and at the right times. Ribonucleic acid (RNA) molecules play many important roles to ensure that this occurs – but the action of RNA is itself regulated by proteins that bind selectively to RNA.

Recently, scientists at the European Molecular Biology Laboratory (EMBL) have discovered an example of a process where this is reversed: here, the action of a particular protein is regulated by RNA. The protein, known as p62, is involved in autophagy – the ‘self-eating’ process whereby cells recycle their redundant or damaged components. These components are broken down into their biological building blocks such as amino acids, which are used to build new structures within the cell.

The researchers found that when amino acid levels are sufficient, RNA binds to p62 and prevents autophagy. This research demonstrates that RNA molecules can control the action of protein molecules, and establishes this mechanism as a new form of biological regulation – which could help deepen our understanding of biology and disease.

Learn more about the study by visiting the EMBL website. See: <https://news.embl.de/science/role-reversal-rna-controls-protein-function>

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 intergovernmental scientific research organisations (EIROs). This article reviews some of the latest news from the EIROs.

ESA

Next mission on board the International Space Station



Orbiting approximately 400 km above Earth, the International Space Station (ISS) brings together astronauts and scientists from across the globe. In July 2019, Luca Parmitano from the European Space Agency (ESA) will embark on his second mission to the ISS, alongside Russian cosmonaut Alexander Skvortsov and NASA astronaut Andrew Morgan. During the second half of his flight, Luca will act as the ISS commander, leading the crew on board the space station.

During his expedition, Luca will carry out research that will contribute to keeping humans safe on longer exploration missions. He will also take part in demonstrations to develop the technological and operational knowledge to allow humans, together with robots, to explore the Moon and Mars from orbit and on their surfaces.



ESA
ESA astronaut Luca Parmitano (right) training with NASA astronaut Andrew Morgan in preparation for their upcoming mission to the ISS

Luca also plans to record several videos to support educational activities being developed by ESA for the next school year, to help promote STEM subjects among European students.

Find out more about Luca Parmitano on the ESA website. See: <http://lucaparmitano.esa.int>

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

ESO

Exchange ideas at an upcoming astronomy education conference



On 16–18 September 2019, the European Southern Observatory (ESO) will host the first Astronomy Education Conference of the International Astronomical Union. The conference will be held at the ESO Supernova Planetarium and Visitor Centre – the ideal setting to bring together astronomers, astronomy education researchers and education practitioners to meet, collaborate and exchange ideas.

Featuring talks, posters and workshops, the conference will focus on three main topics: astronomy education research and standards; curriculum and instruction; and primary and secondary school teacher education. These topics will be explored both in theory and with a view to implementation.

In addition to the conference, the ESO Supernova will host five teacher training workshops this autumn, connecting teachers with scientists and engineers, and allowing teachers to try out hands-on teaching activities.

Find out more about the conference and how to register on the ESO Supernova website. See: <https://supernova.eso.org/news/releases/es1903>

Stay informed about upcoming teaching training offered by ESO Supernova by visiting the website. See: <https://supernova.eso.org/education/teacher-training>

ESO is the foremost intergovernmental 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

The first International Astronomical Union conference on astronomy education will be held at the ESO Supernova Planetarium and Visitor Centre in September 2019.

P.Horálek/ESO



The first components of the Extremely Brilliant Source, lowered into the storage ring tunnel in March 2019

ESRF
Fourth-generation synchrotron enters its installation phase



Work continues at the European Synchrotron Radiation Facility (ESRF) to construct the world's first high-energy fourth-generation synchrotron light source, the Extremely Brilliant Source (EBS). Earlier this year, the EBS officially entered its installation phase, after the first components were put in place in the storage ring tunnel in March 2019.

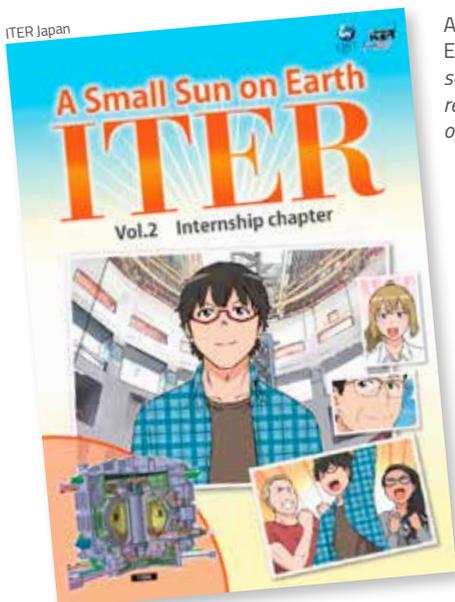
It is a key milestone in the facility's 150 million euro upgrade programme, which will increase X-ray brilliance by a factor of 100 compared to present-day synchrotrons. "It's a great moment for all the teams", says Pantaleo Raimondi, ESRF's accelerator and source director. "EBS represents a great leap forward in progress and innovation for the new generation of synchrotrons."

Once installation is complete in November 2019, commissioning of the machine and beamlines will begin. The powerful new research instrument is set to open to scientists in September 2020.

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

Steph Candé/ESRF

EUROfusion
Discover the world of fusion with manga comics



A Small Sun on Earth, a manga series that introduces readers to the world of fusion

Explaining fusion research can be challenging, but a new manga comic series approaches the topic in a unique and fun way. Titled *A Small Sun on Earth*, the series is produced by the Japanese member of ITER, the world's largest fusion experiment. Currently being built in France, ITER is at the heart of EUROfusion's work.

In the first part of the series, the main character Taiyô Tenno, a young Japanese art student, introduces readers to the concept of fusion and gives them a peek inside ITER. Once constructed, ITER will prove that fusion energy – the process that powers our Sun – can be achieved on Earth. The second part of the series shares Taiyô's story as an intern at ITER's communications department.

Download both parts of the series (in English, French or Japanese) from the ITER website. See: www.iter.org/news/publicationcentre

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

European XFEL Plans for a new visitor centre at the X-ray laser facility



The European X-ray Free-Electron Laser (European XFEL) has announced plans to open a visitor and conference centre on its campus in Schenefeld, Germany, with construction commencing in 2020. The centre will give the general public the opportunity to learn more about the research of the international facility through tours and talks. A 500 m² interactive exhibition space will house displays explaining how the X-ray laser works and what scientists are using it for in their research. The centre will be equipped with two school labs, which will be run in collaboration with the Deutsches Elektronen-Synchrotron (DESY), a European XFEL partner institute.

Although construction of the visitor and conference centre has yet to begin, European XFEL has been hosting schools at the facility since early 2019. The facility welcomes visits from groups of students aged 15 and upwards. If you are interested in arranging a visit, please contact Marieke Sander at marieke.sander@xfel.eu

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



European XFEL

Students from a local Schenefeld school enjoy a tour of the European XFEL tunnel.



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

ILL Neutron experiments uncover clues about Alzheimer's disease

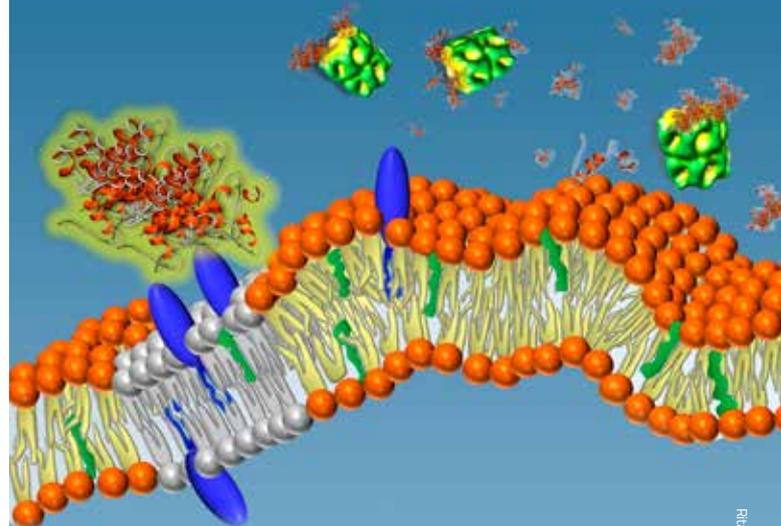


Alzheimer's disease is a chronic neurodegenerative disorder that affects memory, thinking skills and other mental abilities. One of the hallmarks of the disease is the aggregation (clumping together) of a naturally occurring type of molecule (amyloid β -peptides) to form plaques. These plaques accumulate between nerve cells and damage cell membranes in the brain.

Researchers have used neutron experiments at the Institut Laue-Langevin (ILL) to explore the toxic effect of amyloid β -peptides that arise during plaque formation. They found that these plaques caused the nerve cell membranes to become more rigid, but that a certain protein (known as Hsp60) inhibited the aggregation process, stopping the membranes stiffening and ultimately preventing plaques from forming. The next step will be to investigate how exactly the Hsp60 protein achieves this, to learn more about the extremely complex aggregation pathway.

Learn more about the study by visiting the ILL website. See: www.ill.eu/news-press-events/news/scientific-news/neutron-experiments-reveal-proteins-which-can-inhibit-amyloid-plaque-formation or use the direct link <https://tinyurl.com/y2hpnpdw>

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



The Hsp60 protein can prevent the aggregation of amyloid β -peptides into plaques, which is a key characteristic of Alzheimer's disease.



In their element: women of the periodic table

Find out how women scientists contributed to knowledge of the chemical elements – and what this tells us about the nature of scientific work, then and now.



By Annette Lykknes and Brigitte Van Tiggelen

In March 1869, the Russian chemist Dmitri Mendeleev presented his periodic system to the Russian Academy of Sciences (Gordin, 2004). Behind this system was Mendeleev's idea of a periodic law: a law of nature demonstrating regularities among the elements. Mendeleev's system has proved to be robust to new developments in science, from the discovery of noble gases and radioactive elements to the world of quantum physics, and it has now reached its 150th anniversary.

The story of the periodic table and its elements started long before 1869, however – as did the participation of women in this communal venture. The history of any scientific field is often told from the point of view of the main concepts and theories, ignoring the experimental work and unexpected

observations that led to this theoretical understanding – and it is this relatively neglected aspect to which many women made major contributions. As a counterpoint to this tendency, in this International Year of the Periodic Table^{w1} we look at the stories of several women scientists whose work significantly contributed to our knowledge of the elements of the periodic table.

18th century: Marie-Anne Lavoisier and the new notion of the chemical element

The reformation of chemistry that took place in France in the 1780s is often celebrated as the beginning of modern chemistry. Central to this was the French aristocrat Antoine



- ✓ Periodic table
- ✓ Isotopes
- ✓ Radioactive elements
- ✓ Women in science
- ✓ Ages 14 – 19

REVIEW

If asked to identify women who contributed to the development of the periodic table, many people would struggle to name one. This article is a brief but fascinating glimpse into the development of this incredible resource, and it highlights many forgotten women (and men) who did much of the work but received little credit.

The article would make a useful discussion prompt or background reading for a number of topics in chemistry. Cross-curricular links can be made to other scientific areas in which the roles of women have been overlooked,

such as IT, mathematics and space exploration. It would be ideal for a structured reading activity or as a comprehension exercise. Possible questions could include:

- Describe the role of Marie-Anne Lavoisier in establishing the current concept of a chemical element.
- Explain why Jane Marcet's textbook was successful in bringing the chemical elements to the notice of the public.
- Why was determining the proper placement of some elements such a difficult task?

Caryn Howard, head of chemistry, St Mary's School, Calne, UK

Lavoisier. In *Méthode de nomenclature chimique* (1787), Lavoisier and his collaborators gave new, systematic names to all known elements and created a set of rules for naming compounds, which are still valid today. Lavoisier also established the concept of a chemical element as a simple substance – one that could not be decomposed during chemical analysis – and presented a table of 33 elements. Although not all of these are considered elements today, the era of the four elements – earth, air, fire and water – was definitely over.

In a famous painting, Lavoisier is depicted with his wife, Marie-Anne: he's at work, and she poses as his muse. There is much more to their story, though. Marie-Anne participated in Antoine's scientific work by assisting him in the laboratory and in his correspondence, hosting learned gentlemen and ladies from abroad in her salon, and by translating scholarly work in other languages into French and illustrating scientific books. She also played a role in propagating the new chemistry – the element oxygen, in particular – through translating and critically annotating a noted contribution on the rival theory of 'phlogiston' by the Irish chemist Richard Kirwan.



Portrait of Marie-Anne and Antoine Lavoisier by Jacques-Louis David (1788)

Jacques-Louis David, public domain



Wellcome Collection, CC BY 4.0

Marie and Pierre Curie in their workshop, c. 1900



Universitätsarchief Katholieke Universiteit te Leuven

Ida Noddack-Tacke adjusting an X-ray spectrometer in the laboratory, 1944

weights, but the need for a precise atomic weight required the substances to be prepared in their purest state. This task involved repeating precise analytical procedures, and such work was often left to ‘foot soldiers’ like Lermontova. The contributions of this shadow army of chemists – many of them women – who were required to provide pure elements or precise atomic weights are often forgotten, but they show the real challenges met by Mendeleev and his contemporaries to organise all known elements into a meaningful system. Lermontova’s unpublished work remained unknown to historians for a long time, but it was rediscovered in Mendeleev’s archives almost 100 years later.

20th century: Marie Curie and the radioactive elements

Although the work of Marie Curie is well known, it is still astounding: ever since discovering polonium and radium with her husband, Pierre Curie, and their co-worker Gustave Bémont in 1898, Marie Curie and collaborators had to work their way, with meticulous

chemical analyses, through tons of pitchblende mineral to obtain 0.1 g of radium chloride in 1902 (Quinn, 1995). Here, the woman of the team, Marie, was married to a scientist, Pierre, but they led independent research projects until Pierre realised the potential of Marie’s work on radioactivity and joined her in the laboratory. In this example, the forgotten figure is not a female assistant, but rather the male chemist Bémont.

Ida Noddack-Tacke and rhenium

The German chemist Ida Noddack-Tacke faced the same exhaustion as Marie Curie when isolating one of the rarest metals on Earth, rhenium (Van Tiggelen, 2001). The announcement of rhenium’s discovery was made in 1925 by Ida Tacke and her husband-to-be, Walter Noddack (with the help of Otto Berg, another forgotten male figure), but it took three more years before the first 120 mg of pure rhenium was obtained, followed by the first measurement of its atomic weight in 1929. In the meantime, the couple had identified the locations that they thought would provide ores rich in rhenium, travelled

to some of these places, and processed thousands of mineral samples to isolate the element. Pages and pages of laboratory notes are witness to the tedious and repetitive tasks that did not always provide the hoped-for results. Like the Curies, the Noddacks were a collaborative couple, even though Ida’s career remained financially and academically in the shadow of her husband’s.

Stefanie Horovitz and the proof of radioisotopes

The work of Polish-Jewish chemist Stefanie Horovitz provided the first authoritative evidence for the concept of isotopes. This idea – that the same element could have different atomic weights – was suggested by the British chemist Frederick Soddy in 1913 using a term coined by a British doctor, Margaret Todd. By that time, around 35 radioactive ‘elements’ had been discovered – many more than the empty spaces in the periodic system allowed for. The concept of isotopes would solve this growing problem, as many of the new radioactive elements later turned out to be isotopes of known elements.



Austrian Central Library for Physics, Vienna

Stefanie Horovitz at the Radium Institute in Vienna, 1915

However, the concept itself was initially met with some scepticism.

To strengthen the case for isotopes, Soddy suggested a basis for experimental investigation: if lead could occur as different isotopes, then lead derived from uranium would be expected to have a different atomic weight to ordinary lead. In 1914, Horovitz was assigned to take up such investigations by her research supervisor, Otto Hönigschmid, at the Radium Institute in Vienna. She spent many a day separating out very pure samples of lead from radioactive uranium ores, followed by precise gravimetric measurements to determine their atomic weights. Her exacting work yielded differences in atomic weight beyond experimental error, thus confirming the existence of isotopes.

Working with Hönigschmid, Horovitz also helped to disprove the existence of one supposed new element, ionium, by showing that it had the same spectroscopic and chemical properties as thorium and differed from ordinary thorium only in its atomic weight. Ionium was thus identified as an isotope of thorium (Th-230).

Ellen Gleditsch and isotopes beyond the radioelements

Although born and educated in Norway, Ellen Gleditsch acquired expertise in radioactive measurement initially through training in Marie Curie's laboratory in Paris (Lykknes,

2005). From there, she moved to Yale University, USA, where her work established a value for the half-life of 'radium' (later identified as the isotope radium-226). Published in 1915, this value provided an important scientific constant, as radium was regarded as the standard substance in this research field.

Later, at Harvard University, USA, Gleditsch (like Horovitz) became involved in investigations on isotopes. It was known that the atomic weight of radioactive elements (or those that resulted from radioactive decay) could vary depending on their geological source. For example, in ores rich with naturally occurring thorium, the abundance of lead-208 would raise the atomic weight of lead, while in uranium-rich ores (where lead-206 is produced), the atomic weight of lead would be lowered. This variability was thought to be true only for elements associated with radioactivity, not for the common lighter elements.

But in 1919, Francis Aston's invention of the mass spectrograph, which allowed very accurate separation according to atomic weight and charge, challenged this assumption. When Aston announced that he had found two

“The whole concept of constant atomic weights, on which the periodic system had been constructed, seemed to be at stake.”

distinct atomic weights of chlorine (35 and 37) with an average atomic weight of 35.46, this was met with scepticism – as if here too the isotopic composition would vary with the source. The whole concept of constant atomic weights, on which the periodic system had been constructed, seemed to be at stake.

When Gleditsch and her collaborators investigated chlorine from different origins, they found that the isotopic composition of chlorine did not, in fact, vary from source to source. Irène Curie (daughter of Pierre and Marie) in Paris had reached a different result, but Gleditsch concluded that Curie's samples must have been contaminated. Chlorine's atomic weight was therefore constant after all, and the threat to the notion of stable atomic weights was overcome.



Chris Koch

Portrait of Ellen Gleditsch, 1927

Complexity and collaboration

Throughout the history of the periodic system, women have contributed to its science: through the salons of the 18th century; as translators of scientific work; as textbook authors and disseminators; as collaborating wives, sisters and daughters; as research assistants, teachers and professors; and in laboratories, schools, homes and industry (Watts, 2007). Stories of individual women who contributed new knowledge about elements show that scientific work is complex and multifaceted, and that it relies on collaboration. Thus, such stories not only bring to light the less well-known contributions of women (and some men) to science: they also convey the true nature of science and scientific work.

Acknowledgements

The authors wish to acknowledge all the authors who have contributed stories about women and elements in the forthcoming volume *Women in their Element: Selected Women's Contributions to the Periodic System* (published by World Scientific, August 2019). Special thanks go to the following authors: Patrice Bret and Keiko Kawashima, Gisela Boeck, Peter Childs, John Hudson, Marelene and Geoffrey Rayner-Canham, and Xavier Roqué.

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Web reference

- w1 The United Nations proclaimed 2019 the International Year of the Periodic Table of Chemical Elements. Read the announcement at the United Nations website. See: <https://iupac.org/united-nations-proclaims-international-year-periodic-table-chemical-elements>

Resources

- Find out more about the International Year of the Periodic Table from the IYPT2019 website. See: www.iypt2019.org
- Read more about Jane Marcet and her textbook in this article in *Chemistry World*. See:

www.rsc.org/images/Woman%20that%20inspired%20Faraday_tcm18-87904.pdf or use the direct link <https://tinyurl.com/y6hok8eo>

Read profiles of several of the scientists featured in this article on the website of the Science History Institute. See:

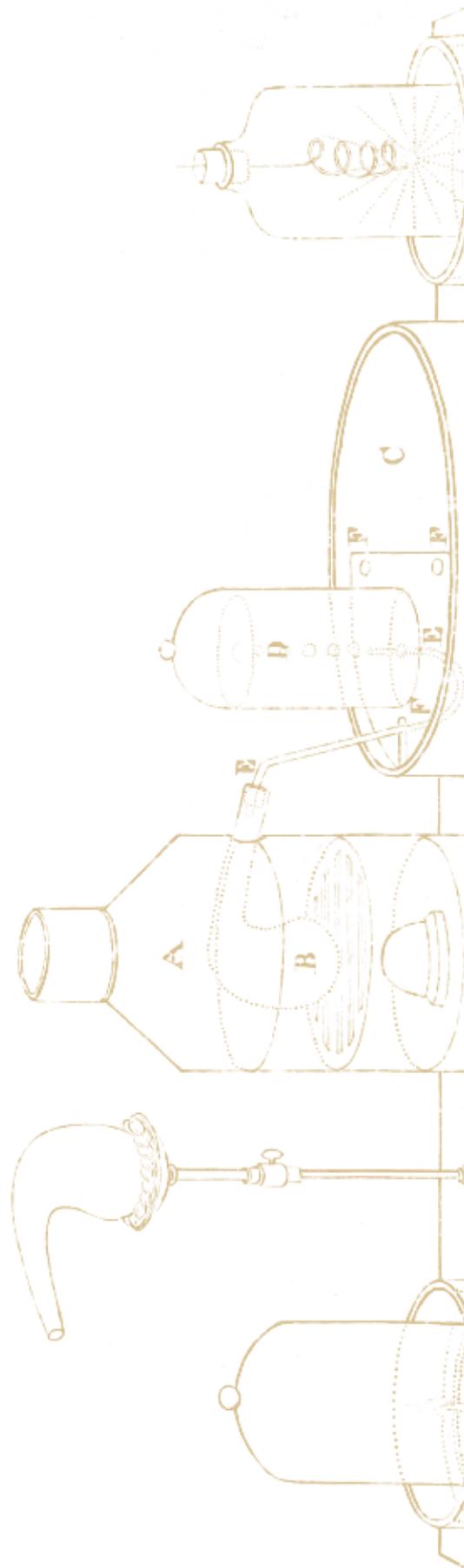
Marie Curie: www.sciencehistory.org/historical-profile/marie-sklodowska-curie
 Antoine Lavoisier: www.sciencehistory.org/historical-profile/antoine-laurent-lavoisier
 Jane Marcet: www.sciencehistory.org/historical-profile/jane-marcet

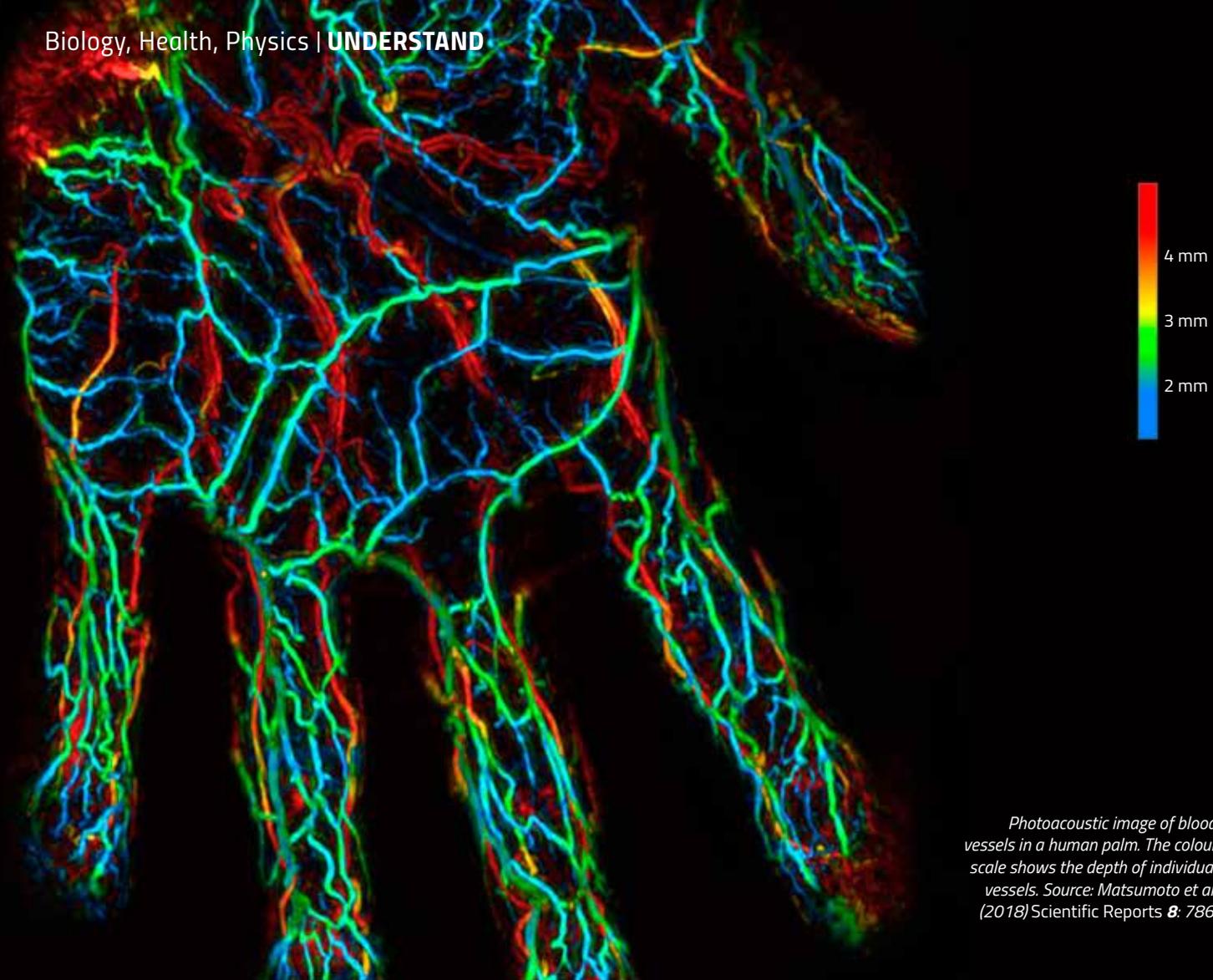
Explore the history of the periodic table by reading about some other proposed ways of arranging the elements. See:

Lorch M (2019) Arranging the elements: the evolving design of the periodic table. *Science in School* **47**: 26–29. www.scienceinschool.org/2019/issue47/PTdesign

Annette Lykknes is a professor of chemistry education at the Norwegian University of Science and Technology, Norway. She holds an MSc in chemistry education and a PhD in the history of chemistry. Since 2005, she has taught teacher trainers in the natural sciences. Her research interests include the history of chemistry, women and couples in science, textbooks in chemistry (past and present), the nature of science, and school science as culture and practice.

Brigitte Van Tiggelen is director for European operations and senior fellow of the Center for Historical Research at the Science History Institute, Philadelphia, PA, USA, and a member of the Centre de Recherche en Histoire des Sciences, Université Catholique de Louvain, Belgium. She graduated in physics and history and wrote her PhD on the history of chemistry. Her research interests include collaborative couples and women in science, domestic science, and Belgian chemistry. To promote the history of science among the public, and especially among secondary school teachers, she founded Mémosciences (www.memosciences.be).





Photoacoustic image of blood vessels in a human palm. The colour scale shows the depth of individual vessels. Source: Matsumoto et al. (2018) Scientific Reports 8: 786.

Photoacoustics: seeing with sound

An advanced technology that combines high-frequency sound waves with laser light is giving researchers and clinicians a new way of seeing living tissue.

By Jakub Czuchnowski and Robert Prevedel

The saying ‘seeing is believing’ is sometimes as true in science as in other areas of life. Scientific images open up hidden vistas that are invisible to our unaided eyes, from the microscopic world of cells, molecules and even atoms to the most distant galaxies. Many of these images are made using systems that rely on light waves. But in biology and medicine, such systems have some drawbacks: light can’t travel far through biological tissue without being scattered, blurring the resulting images and preventing us from seeing deep inside the body (Ntziachristos, 2010). While X-rays can penetrate

further, they are harmful to cells, so their use has to be kept to a minimum.

To overcome these problems, other imaging methods have been developed that rely not on light but on other kinds of wave – such as acoustic (sound) waves, which are used in the familiar technology of ultrasound imaging. Thanks to their longer wavelengths, acoustic waves are scattered much less easily by biological tissues and can penetrate further, allowing clinicians to monitor babies developing in the womb, to study blood flowing through veins, and to identify defects in the



Ultrasound image (left) and X-ray image (right). Photoacoustics potentially offers safer imaging than X-rays with more clarity than ultrasound.

heart. However, standard ultrasound images generally have poor resolution, and they cannot compete with the clarity that light and X-ray images allow.

However, there is now an imaging technology that combines light with sound and promises the advantages of both. Aptly named ‘photoacoustic imaging’, this technique is based on the photoacoustic effect discovered by Scottish-born inventor Alexander Graham Bell in 1880.

How photoacoustic imaging works

As Bell discovered more than a century ago, certain materials emit sound waves when struck by rapidly pulsing light. To understand why, it helps to think of the process as two consecutive steps.

In the first step, the absorption of light generates heat – an effect that will be familiar to anyone who has left a car parked without shade on a sunny day. The light energy causes molecules in the exposed material to enter a high-energy, ‘excited’ state. This state is not stable: within a trillionth or so of a second, the molecules revert to their former stable state by emitting heat energy. The same process happens



- ✓ Instrumentation
- ✓ Disease diagnosis
- ✓ Animal models
- ✓ Ages 14–19

This article shows how physics research can make a difference in the health sector – and gives the reader a sneak peak of imaging scans that will be available in a few years’ time.

The article could be used for project-based learning about different imaging technologies, and to make the topic of waves in physics seem more relevant to students. The link between biology and physics is also very interesting.

The article also supports teachers’ interest in innovative research, and the direct way it is written makes it easy for teachers to share the information with students – and perhaps inspire some to take up physics at tertiary level or beyond.

The article is suitable as a comprehension exercise. Suggested questions include:

- What happens to light when it passes through the body or biological tissue?
- Describe one advantage and one disadvantage of using X-ray imaging.
- Why are ultrasound images limiting for clinicians?
- What are chromophores?
- What is an advantage of photoacoustic imaging in microscopy?

Stephanie Maggi-Pulis, head of physics department, Secretariat for Catholic Education, Malta

REVIEW

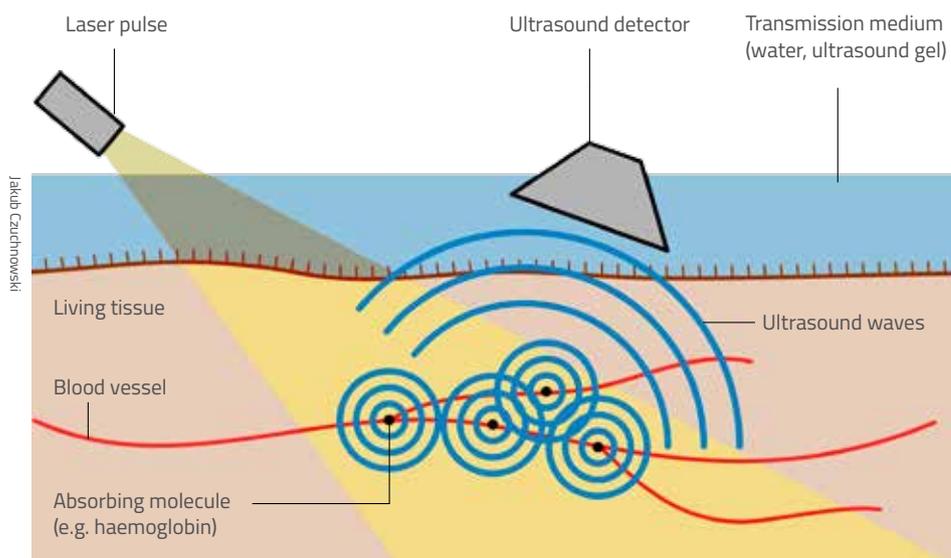


Figure 1: How photoacoustic imaging works. The laser pulses cause ultrasound waves to be emitted, which are picked up by the detector and used to produce images of structures within the tissue.

when we shine laser light onto a cell: certain molecules called chromophores, or pigments, absorb the light energy and then heat up.

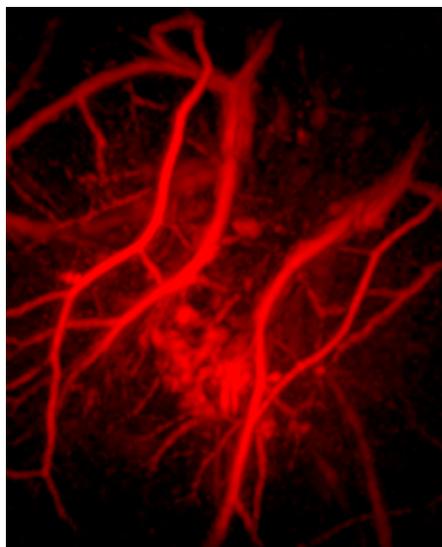
In the second step, the heat generates pressure changes – because, when an object is heated, it expands. If this happens to light-absorbing pigments inside a cell, the pigment molecules start to vibrate strongly and push on the surrounding structures, causing local changes in pressure. A single expansion is not sufficient to generate sound waves, however. For that to happen, the pressure must oscillate rapidly – which is exactly what occurs if the laser is made to fire a succession of very rapid pulses, each lasting a billionth of a second. The resulting fleeting expansions, alternating with cooling and contraction, generate a high-pitched sound wave with a frequency of 1–100 MHz – about 50–5000 times higher than the highest frequency our ears can detect. This sound wave can then be detected and used to produce clear, high-resolution images of biological structures, including those normally hidden beneath other tissues (figure 1).

Using photoacoustic imaging

The photoacoustic approach has distinct advantages over the standard imaging technique, known as fluorescence

microscopy. Here, a fluorescent marker is added to a sample and then made to fluoresce (re-emit light) by a light beam of a controlled wavelength.

In photoacoustic microscopy, no additional ‘marker’ molecules need to be added, and the technique allows all absorbing molecules – including those naturally present in living organisms – to be imaged. In addition, particular types of molecule can be revealed selectively by changing the wavelength of the excitation light, and using multiple wavelengths allows us to see different tissue components at the same time.



Photoacoustic image of mouse vasculature (blood vessels) obtained by the authors

Photoacoustic imaging is also being developed to create a new form of tomography – a computer technology whereby 3D images are built up by integrating digital information. Photoacoustic tomography relies on the fact that each absorbing molecule emits a spherical pressure wave that propagates in three dimensions. Detectors placed in different locations pick up the incoming pulses at slightly different times, and the software uses the time differences to calculate the point from which the spherical waves originated (Ntzachristos et al., 2005).

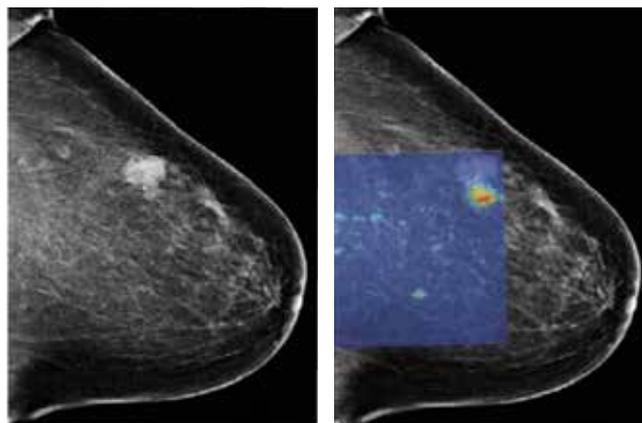
In practice, pressure waves originating from single molecules are too weak to be observed. In photoacoustic tomography, we typically detect signals coming from clusters of billions or trillions of molecules, which correspond to clumps of 10–1000 cells. For comparison, in clinical MRI (a widely used form of tomography), the resolution is on the order of 1 mm³, which corresponds to around one million cells.

Medical applications

Photoacoustic imaging has great potential in medicine, where scientific imaging is an important and powerful diagnostic tool. It is especially well suited to imaging structures that contain blood, since haemoglobin – the red, oxygen-carrying pigment in blood cells – shows up strongly in

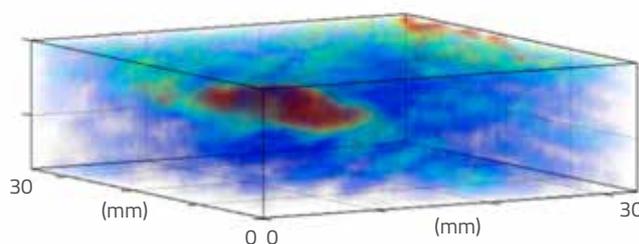
“Unlike X-rays, photoacoustic imaging does not expose patients to potentially harmful radiation.”

photoacoustic images. One application lies in tumour detection (figure 2). When tumours are growing, they trigger the reorganisation of surrounding blood vessels, often causing many new blood vessels to form in a process called neovascularisation. These blood



X-ray image

Combined X-ray and photoacoustic image



3D photoacoustic image

Figure 2: Comparison between X-ray and photoacoustic tomography for breast tumour imaging. As well as avoiding harmful radiation, photoacoustic tomography can reveal an increase in blood vessels associated with tumour growth. Source: Heijblom et al. (2016)

vessels can be seen clearly by tuning the laser to the absorption frequency of the haemoglobin. Preliminary studies suggest that using photoacoustic imaging to reveal neovascularisation might be more effective at detecting breast cancer than ultrasound mammography (Heijblom et al., 2016). And, unlike X-rays, CT scanning and PET scanning, photoacoustic imaging does not expose patients to potentially harmful radiation.

Another application is in detecting arteriosclerosis – the thickening and hardening of arteries that is often a precursor to heart disease or stroke. For this, imaging has to be done through an endoscope equipped with an optical fibre. The fatty ‘plaque’ that builds up inside arterial walls in arteriosclerosis is easy to distinguish from normal tissue, as it has a different absorption spectrum. Again, preliminary research has shown the promise of more accurate diagnosis.

Research applications

Some scientific challenges are best tackled by using ‘model organisms’ such as mice and rats, rather than by studying the human body directly. Rodents are important model organisms in cancer biology and also neuroscience, and their small size makes imaging their internal anatomy relatively easy because the light does not need to

penetrate very far. A number of cancer studies involving photoacoustics have already been carried out with mice: for example, tracking the growth and progression of tumours (Jathoul et al., 2015; see figure 3).

Using rodents as a model also allows us to investigate how the mammalian brain works. There are around 80 billion neurons in the human brain, but the mouse brain has only around 70 million, making it much easier to

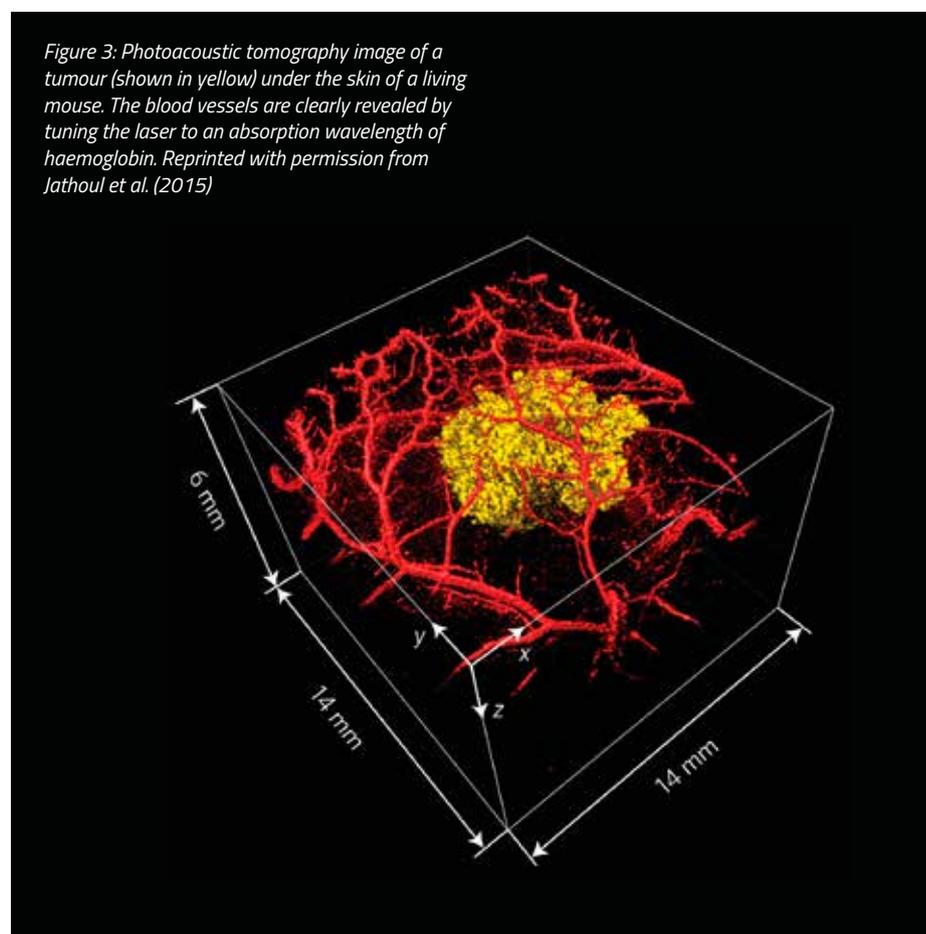
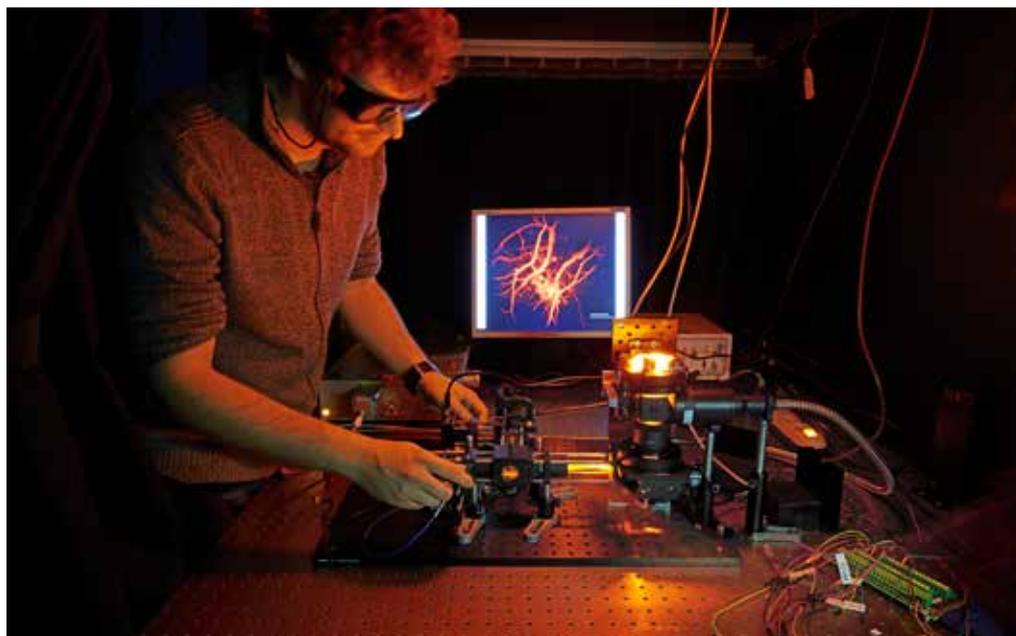


Figure 3: Photoacoustic tomography image of a tumour (shown in yellow) under the skin of a living mouse. The blood vessels are clearly revealed by tuning the laser to an absorption wavelength of haemoglobin. Reprinted with permission from Jathoul et al. (2015)



Marineta Schupp/EMBL

Jakub Czuchnowski working with the photoacoustic microscope built in the lab at the European Molecular Biology Laboratory (EMBL), Heidelberg. The laser is clearly visible.

image in detail. Until now, studies of the rodent brain have relied on imaging technologies that reveal different parts of a brain 'lighting up' as they function. Typical experiments involve stimulating a mouse with smells, sounds or visual stimuli and then imaging the whole brain to see where the sensory information is processed. The standard imaging technology used for this is functional MRI (fMRI). However, as well as having rather poor spatial resolution, fMRI does not reveal directly which neurons are active – only which brain areas are consuming the most energy, as shown by their oxygen consumption in real time. This limitation has motivated scientists to develop better techniques to visualise neuronal activity more directly. In photoacoustic tomography, this is done by revealing changing calcium concentrations within the neurons themselves.

Photoacoustic tomography using rodents promises to be a powerful tool, thanks to its 3D capabilities, its wide field of view and its high resolution (Ovsepian et al., 2017). In principle, it's possible to image the whole brains of animals moving about freely as they find their way through a maze or solve other puzzles. Photoacoustic imaging currently lacks the resolution to record whole-brain function at the single-neuron level, but efforts are ongoing worldwide towards this goal.

Web reference

w1 EMBL is Europe's leading laboratory for basic research in molecular biology, with its headquarters in Heidelberg, Germany. See: www.embl.org

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- Heijblom M et al. (2016) The state of the art in breast imaging using the Twente Photoacoustic Mammoscope: results from 31 measurements on malignancies. *European Radiology* **26**: 3874-3887. doi: 10.1007/s00330-016-4240-7
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Resource

Watch a video that explains the principles and applications of photoacoustic imaging. See: www.youtube.com/watch?v=sJ9ZWnvZkRI

Jakub Czuchnowski is a PhD student in the laboratory of Robert Prevedel at EMBL^{w1} in Heidelberg, Germany. Jakub studied biotechnology and physics at the Jagiellonian University, Poland, and has always been interested in the interplay between technological advancements and biological research. He is working on developing a photoacoustic system to study cancer progression in rodent models, and is also exploring new methods for photoacoustic signal detection to overcome current technical limitations.

Dr Robert Prevedel is a group leader at EMBL^{w1} in Heidelberg, Germany. Robert holds a PhD in experimental physics from the University of Vienna, Austria, for which he developed new approaches in optical quantum computing. During his postdoctoral studies, Robert worked on innovative optical methods and tools for imaging, with a focus on functional neuroimaging in small model organisms. His current research interests lie in developing optical technologies for biomedical imaging and applying these to previously inaccessible questions at the forefront of biology.



Cracks spreading across Antarctica's Brunt Ice Shelf are on course to truncate the shelf and release an iceberg the size of Greater London.

Ten things that affect our climate

Human activities continue to influence our climate on a global scale, but a number of other interlinked mechanisms also play a role.

By Mike Follows

There is no doubt that the Earth's climate has changed over geological time – even before the emergence of *Homo sapiens*. Throughout its 4.6 billion year history, the Earth has endured various extremes, from periods when the planet was almost completely coated in ice, to a time when the Arctic Ocean reached a balmy 23°C.

These climatic changes are a result of many interacting mechanisms, which vary in the magnitude of their effects. Over the past century, however, one factor in particular has played a significant role in influencing our climate: the

overwhelming consensus among climate scientists is that the Earth's temperature is rising as a result of greenhouse gas emissions from human activity.

To reveal the true extent of our impact, scientists are examining the assortment of interacting processes that drive natural and human-induced climate change, both in the past and today. Here, we explore ten of these mechanisms. Each one varies in the extent to which it impacts the Earth's climate, so the order in which they are discussed does not reflect their significance.

1. Without greenhouse gases, the Earth would be a frozen planet

In the greenhouse effect, gases in the Earth's atmosphere (such as carbon dioxide, methane and nitrous oxide) trap infra-red radiation from the Earth that would otherwise be radiated to space. Thanks to this natural process, the Earth's surface has an average temperature of 15°C^{w1}. Without these gases, our planet would be an icy -18°C, and life as we know it would not be possible.

Changes to the level of greenhouse gases can have significant impacts on global climate. For example, in the Earth's geological past, volcanic eruptions or asteroid impacts (see later) have increased the level of carbon dioxide in the atmosphere, resulting in dramatic spikes in temperature. In the Earth's more recent history, humans have amplified this natural effect.

2. Humans are intensifying the natural greenhouse effect

Since the Industrial Revolution, human activities have increased the concentration of greenhouse gases in the atmosphere. Carbon dioxide levels have risen as a consequence of deforestation and the burning of fossil



Coal-fired power station, releasing carbon dioxide emissions into the atmosphere

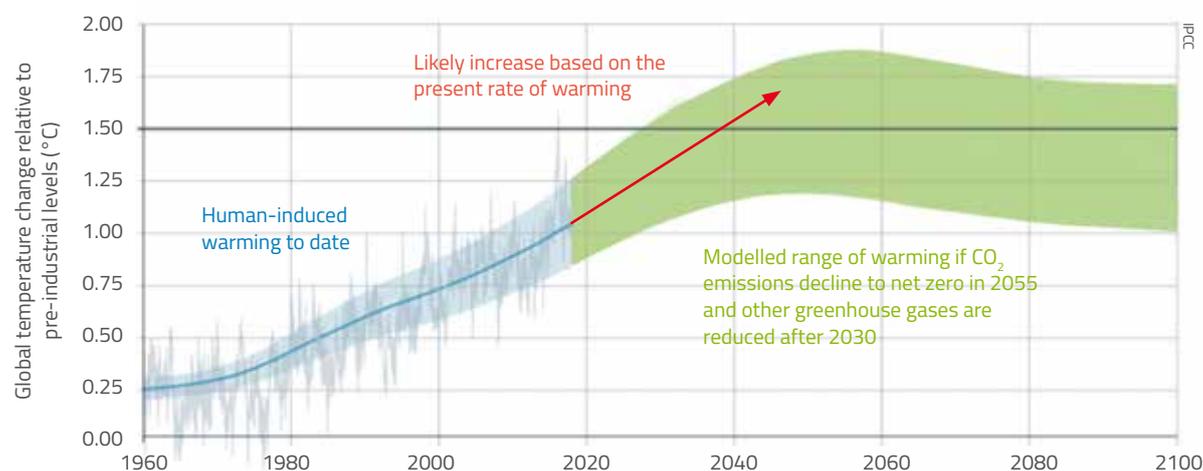
fuels. Methane levels have surged as a result of raising livestock and growing rice.

To date, the anthropogenic greenhouse effect has led to a global temperature increase of approximately 1.0°C above pre-industrial levels. If global warming continues at its current rate, this could increase to a warming of 3-4°C by the end of this century. Scientists now stress that warming must be limited to 1.5°C – an additional increase of no more than 0.5°C from today's level^{w2}. To achieve this, we need to reduce our greenhouse gas emissions drastically.

On the positive side, however, the anthropogenic greenhouse effect is a mechanism that we have the ability to change.

3. Ice sheet formation has been linked to the Earth's orbit

We are currently living in the Late Cenozoic Ice Age, which began 34 million years ago. The latest phase of this ice age is the Quaternary period, during which the Earth has switched between glacial and interglacial states



Observed and projected global temperature change. Limiting global warming to 1.5°C requires drastically reducing greenhouse gas emissions. Adapted from the Special Report on Global Warming of 1.5°C (IPCC)

where continental ice sheets have grown or retreated.

These glacial and interglacial states are thought to be driven by variations in the Earth's orbit, known as Milankovitch cycles^{w3}. These cycles are centred on three parameters related to the Earth's movement: its eccentricity, obliquity and precession. Respectively, these terms describe the shape of the Earth's orbit (whether it is more circular or elliptical); the Earth's axial tilt in relation to its orbit; and the wobble in the direction of the Earth's spin axis.

For example, the Earth's axis currently tilts at a 23.5° angle relative to the perpendicular to its orbital plane, but this obliquity varies between 22° and 25° over a period of about 41 000 years. This change affects the amount of solar radiation hitting different regions of the Earth, thus influencing ice sheet formation.

4. Low solar activity coincided with glacial periods

The strength of the Sun varies throughout its 11-year activity cycle. At a solar maximum – when the Sun's activity is greatest – large numbers of sunspots (darker spots) and faculae (brighter spots) appear on the Sun's surface. The net effect is an increase in solar radiation, which can contribute to



- ✓ Physical geography
- ✓ Atmospheric physics
- ✓ Ecology
- ✓ Evolutionary biology
- ✓ Ages 14–19

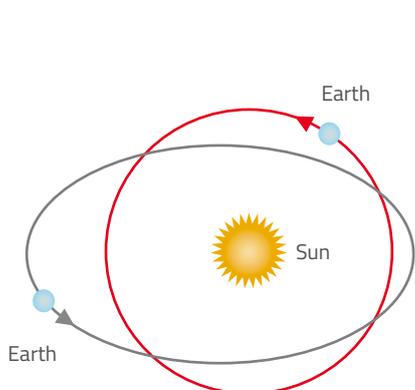
Climate change is an important issue for many school students across the world, as demonstrated by recent student-led campaigns to raise awareness of the problem and demand action to prevent further global warming. This article unravels the mechanisms that influence climate change and can be used as a starting point to discuss the impact of human activity on climate change and its consequences for the Earth. Students could also think about actions they could take to help to preserve our planet. Moreover, studying the mechanisms that influence climate offers the possibility of using biology, earth science and physics at the same time, highlighting the interdisciplinary nature of science.

Potential discussion questions include:

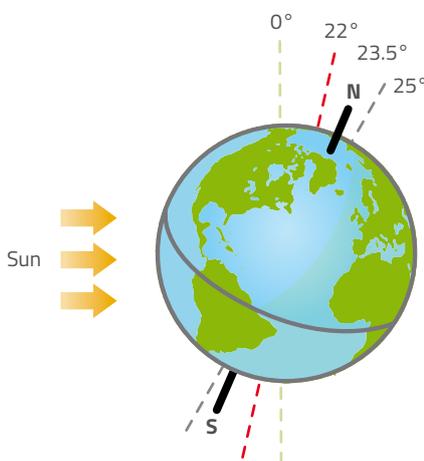
- What are greenhouse gases? Give two examples.
- Without greenhouse gases, what would be the average surface temperature of the Earth?
- What happens on the Sun's surface during a solar maximum?
- What effect did the increase in oxygen levels in the Earth's atmosphere have on the temperature of the Earth?
- What drives the thermohaline circulation?
- How would an asteroid impact affect the Earth's temperature?
- How can volcanic eruptions affect the Earth's climate?

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

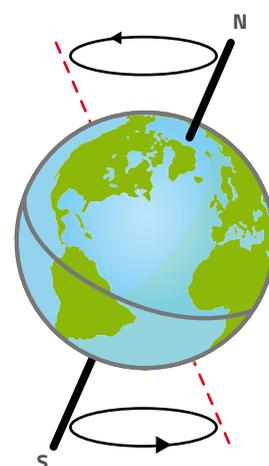
REVIEW



Eccentricity: the shape of the Earth's orbit changes from being slightly elliptical to being very nearly circular over a cycle of about 100 000 years.

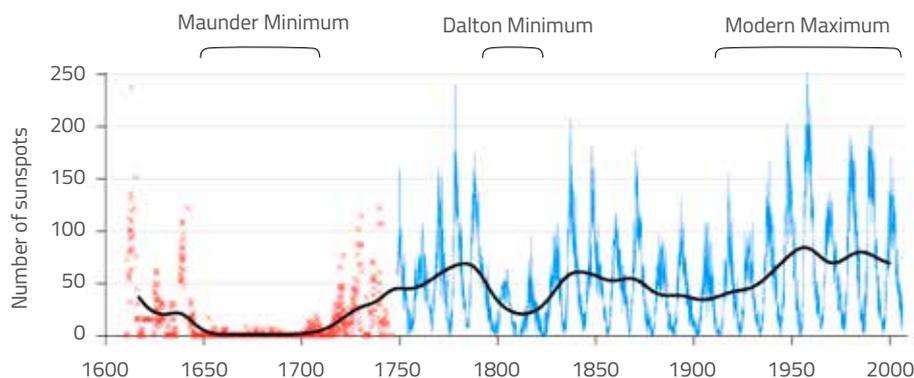


Obliquity: the tilt of the Earth's axis varies between 22° and 25° (relative to the perpendicular to its orbital plane, 0°) over a period of about 41 000 years.



Precession: the Earth's axis wobbles around in a complete circle over a period of about 26 000 years.

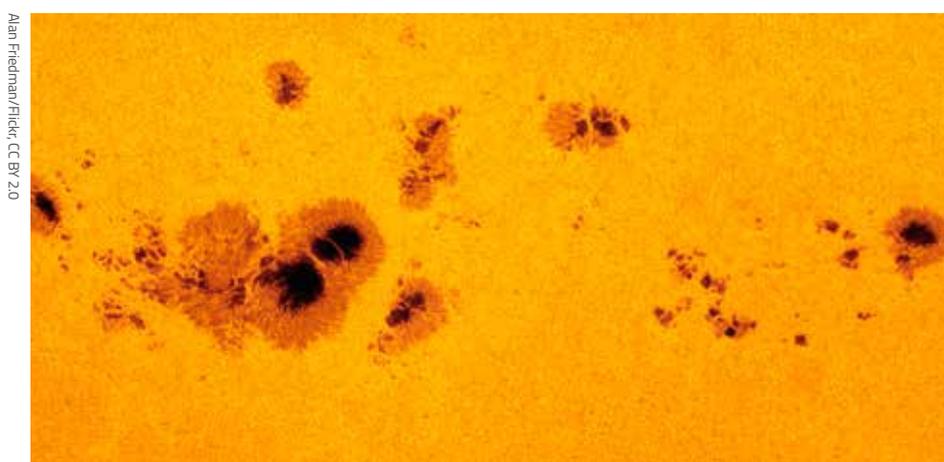
Nicola Graf



Sunspot observations per year since the early 1600s, highlighting solar minima and maxima

x Sporadic observations prior to c. 1750
| Average monthly measurements since c. 1750

Global Warming Art/Wikimedia Commons, CC BY-SA 3.0



Alan Friedman/Flickr, CC BY 2.0

Group of sunspots, captured by an amateur astronomer on 10 July 2012. The group measures 320 km across – wide enough to accommodate 25 Earths side by side.

warmer climates. At a solar minimum – the period of least solar activity – the opposite occurs^{w4}.

A noteworthy example is the Maunder Minimum, which describes the period of sunspot rarity between 1645 and 1715. This solar minimum coincided with the middle of the ‘Little Ice Age’ – not actually an ice age, but the period when Europe and North America suffered from severe cold, and ‘frost fairs’ were held on the frozen River Thames in London, UK.

5. The increase of oxygen caused a cooling event

Some 2.5 billion years ago, there was no oxygen in the Earth’s atmosphere. Although the Sun was less bright back then, our planet was habitable partly because the atmospheric concentration of methane was 1000 times greater than it is now. All this changed, however,

with the Great Oxygenation Event, which was triggered by the presence of blue-green algae^{w5}. These microscopic organisms had evolved to carry out photosynthesis, and they produced oxygen as a waste product.

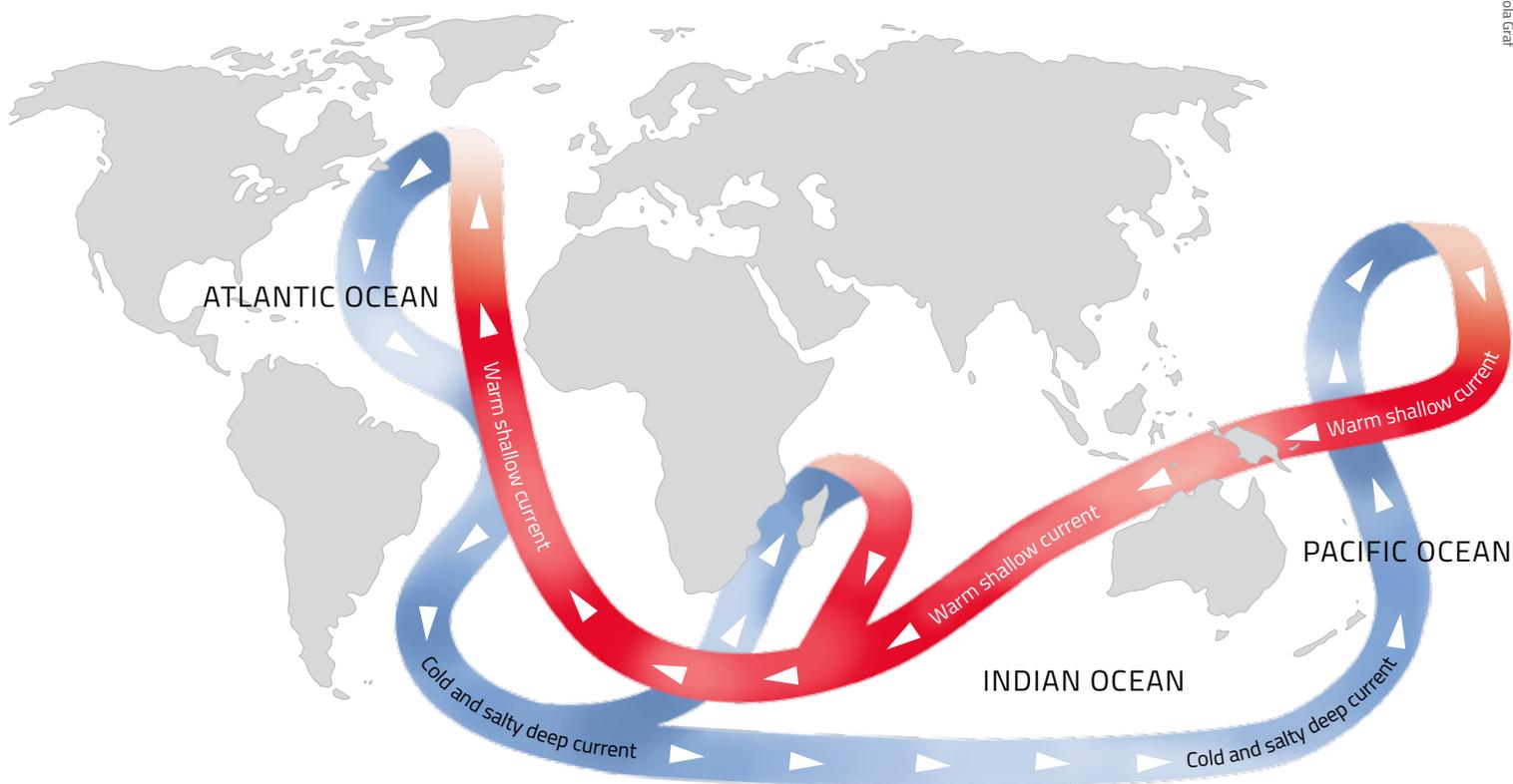
This unwanted oxygen is thought to have reacted with methane in the atmosphere to produce carbon dioxide and water. Carbon dioxide is 62 times less effective at warming the planet than methane, so replacing methane with carbon dioxide led to a dramatic decrease in temperature, plunging the Earth into its earliest ice age – the Huronian glaciation.

6. Warming can disrupt ocean currents

Ocean currents and wind systems are important components of the climate system. As a result of differential

heating, whereby the equator is hotter than the Earth’s poles, convection currents in the oceans and the atmosphere move thermal energy towards the poles. This is the driving force behind atmospheric circulation and the thermohaline circulation in the oceans.

The thermohaline circulation (or ocean conveyor, as it is sometimes known) is driven by differences in the temperature and salinity of the water^{w6}. It brings warm surface waters from the tropics to the North Atlantic, which subsequently warms parts of Europe. There is a concern that global warming will cause the ice sheets on Greenland to melt, diluting the salinity of the North Atlantic Ocean and reducing the density of its waters. If the water is no longer dense enough to sink, the thermohaline circulation would be disrupted.



Thermohaline circulation of the world's oceans, which is driven by differences in the salinity and temperature of the water. Blue paths represent deep-water currents, while red paths represent surface currents.

7. Asteroid impacts caused climate catastrophes

Around 66 million years ago, the 10 km diameter Chicxulub asteroid collided with the Earth, resulting in the demise of the dinosaurs^{w7}. The impact threw dust into the stratosphere, which is thought to have blocked out 50% of the sunlight reaching the Earth. This would have compromised photosynthesis and led to the collapse of food chains. It would also have resulted in a dramatic fall in global temperatures, plunging the Earth into an 'impact winter' that would persist for a decade.

Once the dust settled, however, the Earth is thought to have experienced rapid global warming. This was a result of the masses of carbon dioxide released from both the impact itself (the asteroid is thought to have broken down carbonate rocks) and the subsequent wildfires that spread across the Earth.

Other significant mass extinctions (such as the Permian-Triassic and Triassic-Jurassic extinction events) are also thought to have been caused by impact events, although no craters have been found.

8. Tectonic plates can warm or cool the planet

The Himalayan mountain range – formed as a result of the collision between the Indian and Eurasian tectonic plates – is a prime example of how plate tectonics can have an impact on climate. Over the past 50 million years, the slow uplift of the Himalayas has exposed new rock to chemical weathering. In this process, carbon dioxide from the atmosphere binds to certain minerals in the rock, reducing the amount of atmospheric carbon dioxide and cooling the planet.

The movement of tectonic plates can also have an important influence on ocean currents. For example, the creation of both the Tasmanian Gateway and the Drake Passage – when the continents of Australasia and South America broke away from Antarctica – led to the formation of the Antarctic circumpolar current over 30 million years ago. The current brought cool deep Antarctic water to the surface. This tectonic activity – combined with the burial of atmospheric carbon dioxide from the formation of the Himalayas – is believed to have triggered the Late Cenozoic Ice Age. Scientists can predict where the plates will move over the next 250 million years^{w8}.

9. Volcanic eruptions have mixed effects

Another effect of plate tectonics is volcanic eruptions, which can affect the



Aerial view of Mount Everest and surrounding peaks in the Himalayan mountain range

Earth's climate for periods ranging from days to decades. The large amounts of carbon dioxide that volcanoes emit can warm the planet in the longer term, but the dust and sulfur dioxide they throw into the atmosphere can block incoming solar radiation, leading to global cooling in the shorter term^{w9}.

The eruption of Mount Pinatubo in the Philippines in 1991 ejected 17 million tonnes of sulfur dioxide into the stratosphere. This led to a haze of sulfuric acid droplets that blocked sunlight and reduced global temperatures by about 0.4°C for two years.

10. Cloud cover complicates global warming

Clouds have important consequences for the Earth's climate. Low, thick clouds cool the Earth's surface, while high, thin clouds warm the climate. Key to the formation of clouds are aerosols – tiny particles that are suspended in the

atmosphere. They act as tiny 'seeds' on which water vapour condenses^{w10}. Aerosols are much more than simply what you find in a hairspray can. They can be natural (such as dust or sea salt) or anthropogenic (such as pollutants or smoke). An increase in anthropogenic aerosols could therefore result in more cloud formation, which (depending on the cloud height) could potentially offset the full extent of global warming. The CLOUD experiment at CERN is improving our understanding of aerosols and clouds and is investigating the possible influence of cosmic rays on cloud formation^{w11}. These rays comprise subatomic particles that originate from supernovae outside the Solar System, and they are thought to influence cloud cover through the formation of new aerosols.

Acknowledgement

The author and editors would like to thank Dr Anwar Khan from the atmospheric chemistry research group

at the University of Bristol, UK, for his helpful input on this article.

Web references

- w1 In a video from 'MinuteEarth', learn how greenhouse gases work to keep our planet warm. See: www.youtube.com/watch?v=sTvqlijqvTg
- w2 The Office for Climate Education (OCE) has produced a summary for teachers of the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of 1.5 °C (SR15)*. See: www.ipcc.ch/sr15/resources
- w3 Watch a video giving a thorough explanation of Milankovitch cycles and how they change our climate. See: www.youtube.com/watch?v=4GUcn07enz4
- w4 A lively account from 'SciShow Space' explains how the Sun affects our climate. See: www.youtube.com/watch?v=JlYgFM9nnd4
- w5 Watch an engaging explanation of the Great Oxygenation Event. See: www.youtube.com/watch?v=qERdL8uHSgI
- w6 Learn more about the thermohaline circulation in a video from YouTube. See: www.youtube.com/watch?v=UuGrBhk2c7U



Dave Harlow/USGS/Wikimedia Commons, public domain

Hot volcanic ash erupting from Mount Pinatubo on 12 June 1991, three days before the main eruption

- w7 In a 3-minute video, BBC Earth explains how the Chicxulub impact wiped out the dinosaurs. See: www.youtube.com/watch?v=JqGphEaJVDE
- w8 Watch an animation of how the continents are predicted to move across the Earth's surface as a result of plate tectonics. See: www.youtube.com/watch?v=cW6rMzS0mvU

- w9 A 2-minute video describes how volcanoes can change our climate. See: www.youtube.com/watch?v=16-lpkiamHU
- w10 Watch a TED-Ed clip explaining the effect that aerosols can have on our climate. See: <https://tedxcern.web.cern.ch/video/2014-ted-ed/ted-ed-cloudy-climate-change-how-clouds-affect-earths-temperature>

w11 The CLOUD experiment at CERN is described in more detail on the CERN website. See: <https://home.cern/science/experiments/cloud>

Resource

Download the following introductory climate science textbook for free on the 'Bookboon' website (<https://bookboon.com/en/introductory-climate-science-ebook>): Sloan T (2016) *Introductory Climate Science: Global Warming Explained* 1st edition. Aberystwyth, UK: Aberystwyth University. ISBN: 9788740314083

Mike Follows is a physics teacher at King Edward's School in Birmingham, UK. Before gaining a PhD in ultralow-temperature physics, he spent a decade working for the British Met Office, so it is perhaps unsurprising that he is drawn to global issues and how physics helps to explain them – and might help to solve them.



			Ti = 50	Zr = 90	? = 180
			V = 51	Nb = 94	Ta = 182
			Cr = 52	Mo = 96	W = 186
			Mn = 55	Rh = 104,4	Pt = 197,4
			Fe = 56	Ru = 104,4	Ir = 198
		Ni =	Co = 59	Pd = 106,6	Os = 199
			Cu = 63,4	Ag = 108	Hg = 200
			Zn = 65,2	Cd = 112	
			? = 68	Ur = 116	Au = 197?
			? = 70	Sn = 118	
			As = 75	Sb = 122	Bi = 210?
			Se = 79,4	Te = 128?	
			Br = 80	J = 127	
			Rb = 85,4	Cs = 133	Tl = 204
			Sr = 87,6	Ba = 137	Pb = 207
			? = 45	Ce = 92	
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		
H = 1					
Be = 9,4	Mg = 24				
B = 11	Al = 27,4				
C = 12	Si = 28				
N = 14	P = 31				
O = 16	S = 32				
F = 19	Cl = 35,5				
Li = 7	K = 39				
Na = 23	Ca = 40				

Wikimedia Commons, public domain

your hand. Mendeleev did the same for scandium, germanium and technetium (which wasn't discovered until 1937, 30 years after his death).

At first glance, Mendeleev's table doesn't look much like the one we are familiar with. For one thing, the modern table has various elements that Mendeleev overlooked (and failed to leave room for), most notably the noble gases (such as helium, neon and argon). And the table is oriented differently to our modern version, with elements that we now place together in columns instead arranged in rows.

But once you give Mendeleev's table a 90° turn, the similarity to the modern version (figure 3) becomes apparent. For example, the halogens – fluorine (F), chlorine (Cl), bromine (Br) and iodine (I) (the J symbol in Mendeleev's table in figure 2) – all appear next to one another. Today, they are arranged in the table's 17th column.

Figure 2: Dmitri Mendeleev's arrangement of the elements, showing gaps for (then) missing elements

laid out what was known, Mendeleev left space for the unknown. Even more amazingly, he accurately predicted the properties of the missing elements.

Notice the question marks in his table, shown in figure 2? For example, next to aluminium (Al), there is space for an unknown metal. Mendeleev foretold

it would have an atomic mass of 68, a density of 6 g/cm³ and a very low melting point. Six years later, Paul Émile Lecoq de Boisbaudran isolated gallium and, sure enough, it slotted right into the gap with an atomic mass of 69,7, a density of 5.9 g/cm³ and a melting point so low that it becomes liquid in

	I		II										III	IV	V	VI	VII	VIII	
1	1																		2
2	3	4											5	6	7	8	9	10	
3	11	12											13	14	15	16	17	18	
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
6	55	56	*	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
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			** Actinides	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	

Amrik/Wikimedia Commons, CC BY-SA 3.0

Figure 3: The modern arrangement of the periodic table

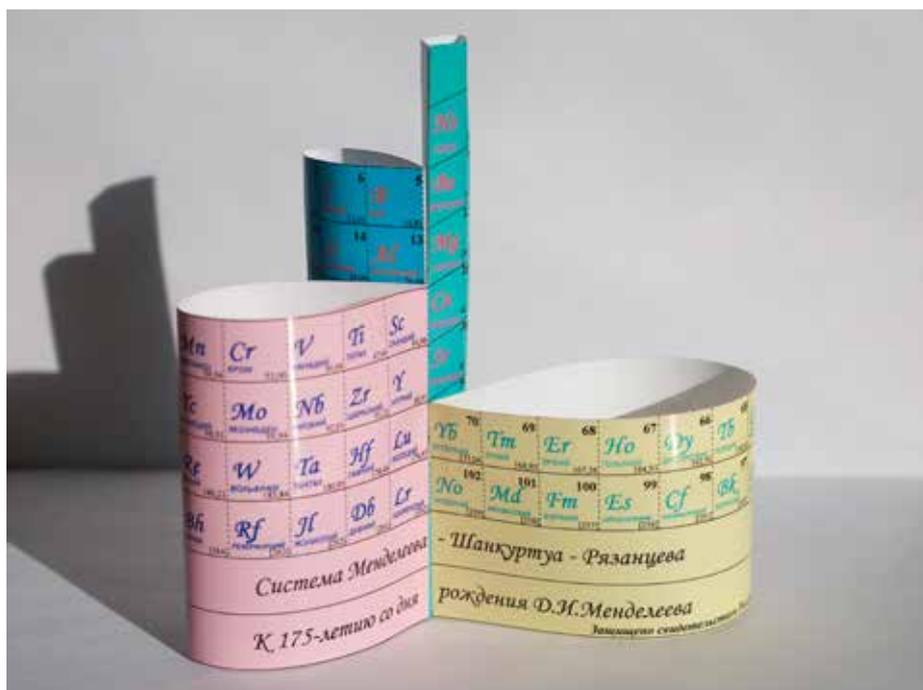
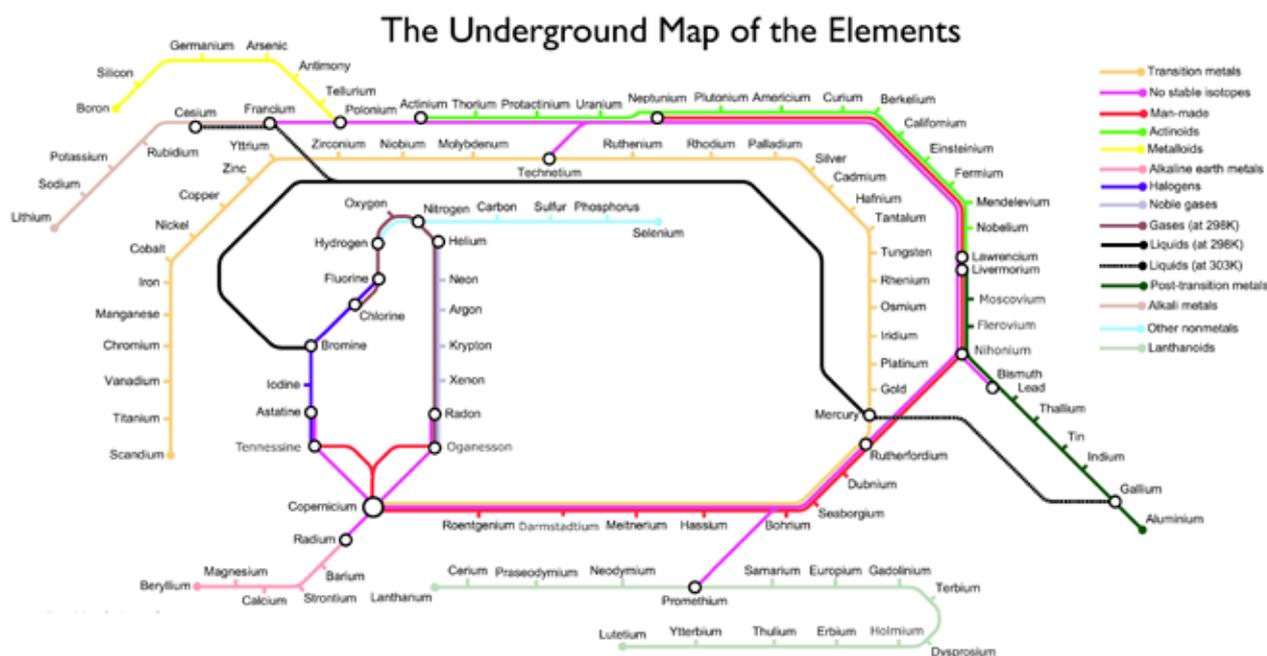


Figure 6: A 3D 'Mendeleev flower' version of the periodic table

Тимохова Ольга/Wikimedia, BY-SA 3.0



Mark Lorch, CC BY-NC-SA 3.0

Figure 7: A map of the elements by Mark Lorch, based on Henry Beck's London Underground map

UK website. See: <https://theconversation.com/the-periodic-table-is-150-but-it-could-have-looked-very-different-106899> or use the direct link <https://tinyurl.com/ycnbnkct>

Resources

Listen to Tom Lehrer's song 'The Elements' about the periodic table. See: www.youtube.com/watch?v=zGM-wSKFBp0

Watch a video of the gallium 'beating heart' experiment from the University

of Nottingham's Periodic Table of Videos series. See: www.youtube.com/watch?v=N6ccRvKKwZQ

Find out about some of the less celebrated scientists, many of them women, who contributed to the development of the periodic table. See:

Lykkes A, Van Tiggelen B (2019) In their element: women of the periodic table. *Science in School* **47**: 8-13. www.scienceinschool.org/2019/issue47/PTElements

Mark Lorch is professor of science communication at the University of Hull, UK. He trained as a protein chemist, studying protein folding and function. His research now focuses on the chemistry of a broad range of biological systems including lipids, proteins and even plant spores.



Understanding the teenage brain

Teenagers are in transition from childhood to adulthood, so why does their behaviour differ from both these phases? Neuropsychologist Sarah-Jayne Blakemore is looking for answers to this perennial question.

By Susan Watt

Everyone who deals with teenagers knows how full of contradictions they can be. On the one hand, they can seem rather grown up: often adult-sized and facing key moments and decisions in their life, with rapidly expanding opportunities and responsibilities. On the other hand, they often seem to behave with startling immaturity, perhaps prompting the comment that they are 'old enough to know

better'. But how well equipped are teenagers in fact to cope with their lives? And what biological changes influence the behaviours and thought patterns that we associate with the teenage years?

One person who knows more than most about this is Sarah-Jayne Blakemore, professor of cognitive neuroscience at University College London, UK. Blakemore began her



The Hamster Factor/Flickr. CC BY-NC-ND 2.0



Adolescent neuropsychologist Professor Sarah-Jayne Blakemore

research career studying schizophrenia, for both her PhD and postdoctoral studies. She soon noticed that, almost without exception, the schizophrenic patients she was interviewing reported their symptoms starting between the ages of 18 and 25, and she began wondering what was special about this time of life in terms of brain development. In particular, if the brain is capable of producing the powerful delusions and auditory hallucinations seen in schizophrenia, what is it about normal adolescent brain development that is able to avoid such problems?

In those days, remarkably little was known about how the brain develops in the teenage years: the textbook dogma was that brain development ends more or less around mid-childhood. So Blakemore discussed her interest in studying this unexplored area of developmental studies with her mentor, the renowned autism researcher Uta Frith, who was unequivocal in her support.

The maturing brain

Today, the adolescent brain is a major area of research, and – thanks to Blakemore and her colleagues – we are beginning to understand much more about typical teenage behaviour and its origins. For example, risk-taking is often seen as a hallmark of teenage behaviour. Schools and wider society often regard this behaviour as due to

hormonal changes associated with puberty – but in reality, the fact that some areas of the brain mature sooner than others is a key factor. Blakemore explains: “Two different systems in the brain develop at different rates. The limbic system – which includes the regions of the brain that give you a kick out of taking a risk – is developing more quickly than the prefrontal cortex, which inhibits risk-taking, so there’s

“Risk-taking and peer influence interact, so teenagers are most likely to take risks when they are with their peers.”

a mismatch in their developmental trajectories.” In other words, because the part of the brain that makes people enjoy risk-taking develops before the part that inhibits risk-taking, the tendency to take risks increases in the years before full maturity – that is, in adolescence and even early adulthood. Planning is another ability based in the prefrontal cortex, so many of the frustrations of teenagers’ parents and teachers – from missed homework to

a failure to realise the consequences of not studying effectively – should perhaps not be so surprising. “We know that the prefrontal cortex is undergoing development, so our expectations of teenagers – to plan their homework, to plan their GCSE [school exam] project – might be too much”, says Blakemore.

Because the brain is developing throughout the teenage years, this means there may be specific periods within this phase when some types of learning may be easier or harder than at other times. Blakemore’s research has found that such variation does indeed exist: there is a dip in performance on certain abstract non-verbal tasks in early adolescence (age 11–14). This is mirrored by – and perhaps helps explain – a known dip in educational performance around this age, with some students in this age group performing worse at school than in the previous year.

Social cognition

Currently, Blakemore is interested in researching social cognition: how teenagers’ thinking is affected by social influences. Here, two aspects of typical teenage behaviour – risk-taking and susceptibility to peer influence – interact, so that teenagers are most likely to take risks when they are with their peers. For example, adolescent



Teenagers are prone to risk-taking – especially when they are with other teenagers.

Naphalie Mheshwa/Flickr, CC BY-NC 2.0



Around early adolescence, some students encounter a 'learning dip' and do less well at school than in the previous year.

car drivers have more accidents than older people overall, but they are most likely to have those accidents when one or more other adolescents are in the car with them. Blakemore believes there may be an evolutionary benefit associated with such apparently disadvantageous behaviour. "There's probably a good reason why adolescents care so much about being included by their social group and take more risks when they're with their

friends", she says. "It makes sense when you think about the need to become independent from one's parents, to go and explore the environment and to affiliate with your social group. It's probably an important and adaptive process we all need to go through."

Becoming themselves

One idea is central to Blakemore's research: that the teenage years are

not just a bumpy transition from childhood to adulthood. Rather, they have an important function of their own: teenagers are becoming who they are as individuals, the people they will be in adult life. Her recent book, *Inventing Ourselves: The Secret Life of the Teenage Brain* (Blakemore, 2018) contains a chapter entitled 'Adolescence isn't an aberration', in which Blakemore emphasises how adolescent behaviours can be observed across different societies and periods of history, and even in other mammalian species. This evidence indicates that this phase of life is a distinct period of biological development, not simply a behavioural aberration.

Through this understanding, Blakemore believes we need to cut teenagers some slack. "Something I've noticed since working with teenagers is that they are the butt of jokes, and demonised in newspapers", she says. "If I tweet anything about the teenage brain, invariably I'll get a reply saying something like, 'Oh, so teenagers actually have brains?'" She thinks this societal attitude to teenagers is quite mistaken: what other section of society would it be acceptable to vilify in this way?

During the teenage years, people are more influenced by their peers than at other stages of life.



Leo Papais/Flickr, CC BY-NC-ND 2.0

As an advocate of a better understanding of teenagers, as well as a neuroscientist, Blakemore was invited in 2013 to become involved in a youth theatre initiative, creating a show where teenagers present their experience of the world. Entitled *Brainstorm*^{w1}, the show was performed at the National Theatre in London. The script is now available to schools, allowing them to develop and perform their own version of this moving and authentic drama. What comes across very powerfully in the drama is the idea that teenage ways of thinking and feeling have their own validity and are purposeful. “We heard about head teachers who saw the play and returned to their schools determined to do things differently”, says Blakemore.

Reference

Blakemore S (2018) *Inventing Ourselves: The Secret Life of the Teenage Brain*. London, UK: Transworld Publishers. ISBN: 0857523708

Web reference

^{w1} Watch an excerpt from *Brainstorm* and find out how to access the script to perform your own version of the show on the Company Three website. See: www.companythree.co.uk/brainstorm#brainstorm-1

Resources

Hear Sarah-Jayne Blakemore talk about her life in science in this BBC Radio 4 broadcast. See: www.bbc.co.uk/programmes/b05mnr29

Watch this short video of Sarah-Jayne Blakemore explaining her research: <https://bold.expert/brain-development-and-sensitive-periods-for-learning-in-adolescence>

Read Sarah-Jayne Blakemore on the teenager's sense of social self. See: www.edge.org/conversation/sarah_jayne_blakemore-sarah-jayne-blakemore-the-teenagers-sense-of-social-self

Susan Watt is a science writer and editor for *Science in School*. She holds a degree in natural sciences from the University of Cambridge, UK, and postgraduate degrees in philosophy and experimental psychology. She enjoys bringing academic psychology research to the wider public. She lives in London and has a teenage son.

The play *Brainstorm* depicts the complex relationship between young people and their parents. Created by youth theatre group Company Three with input from Sarah-Jayne Blakemore, the show draws on the life experiences of the teenage cast.

In this excerpt, the teenagers address their parents.

You say to me

Your brain is broken

It's like an adult brain, but it doesn't work properly.

You say

When you become a teenager, something happens.

Your brain shrinks or something.

It stops working properly.

You get so full of thinking about yourself that you forget about anyone else.

I say

When I'm wild and out of control

It's because I'm finding out who I am

What the world is

All the things I might be

And if I was a real wild animal

Then I'd have left by now.

But I haven't.

And I'm not going to. Yet.

I say

My brain isn't broken

It's like this for a reason

I'm becoming who I am

And I'm scared

And you're scared

Because who I am might not be who you want me to be

Or who you are



Matt Hodges/Nick Hern Books

This extract from Brainstorm by Ned Glasier, Emily Lim and Company Three, with a foreword by Professor Sarah-Jayne Blakemore, is reproduced by permission of Nick Hern Books, www.nickhernbooks.co.uk/brainstorm



artdee2554/Shutterstock.com

Rocket science made easy

Prepare for lift-off with these simple activities that demonstrate some of the key principles of space science.

By Ole Ahlgren

The term 'rocket science' is often used to explain something that is difficult to understand. While designing and testing rockets is a complicated endeavour that requires skill and plenty of brainpower, it is possible – thanks to some simple activities – to explain some of this complex science to your students.

This article outlines a collection of activities suitable for students aged 8–14 years. They are designed to be carried out in a workshop, which can be completed in around 2 hours. If less time is available, however, some of the demonstrations can be omitted or can be spread out over successive lessons. The activities can be adapted for secondary school students, by including more theory and relevant formulas. Note that many of the activities are available to view in a video^{w1}.



- ✓ Newton's laws of motion
- ✓ Forces
- ✓ Gravity
- ✓ Ages 11–14 and under

This article sheds light on a topic that is usually considered particularly challenging, especially by primary school teachers. Each experiment involves a different physics concept (such as reaction forces or air pressure), but they are all connected by the common theme of space. Teachers can carry out all the experiments at once if they want to approach the subject as a whole, or they can pick individual activities to teach alongside the appropriate teaching unit. Overall, the article is very useful for both upper primary and lower secondary levels.

REVIEW

Dr Christiana Nicolaou,
Archangelos Elementary
School, Cyprus

Activity 1: Launching a rocket balloon

Rockets are a perfect example for learning about forces and Newton's laws of motion. During lift-off, there are two forces acting on a rocket: thrust pushes it forwards by expelling gases in the opposite direction, and gravity pulls it downwards. Once a rocket is

“Rockets are a perfect example for learning about forces and Newton's laws of motion.”

moving, drag acts on the rocket in the opposite direction to its motion. The rocket will continue to speed up as long as the force of thrust is greater than the combined forces of gravity and drag.

In this experiment, a rocket launch is illustrated by blowing up a balloon and letting it go. The escaping air exerts a force on the balloon, and the balloon reacts by pushing in the opposite direction with the same force, as described by Newton's third law of motion (for every action, there is an equal and opposite reaction). The opposing force (as with rocket

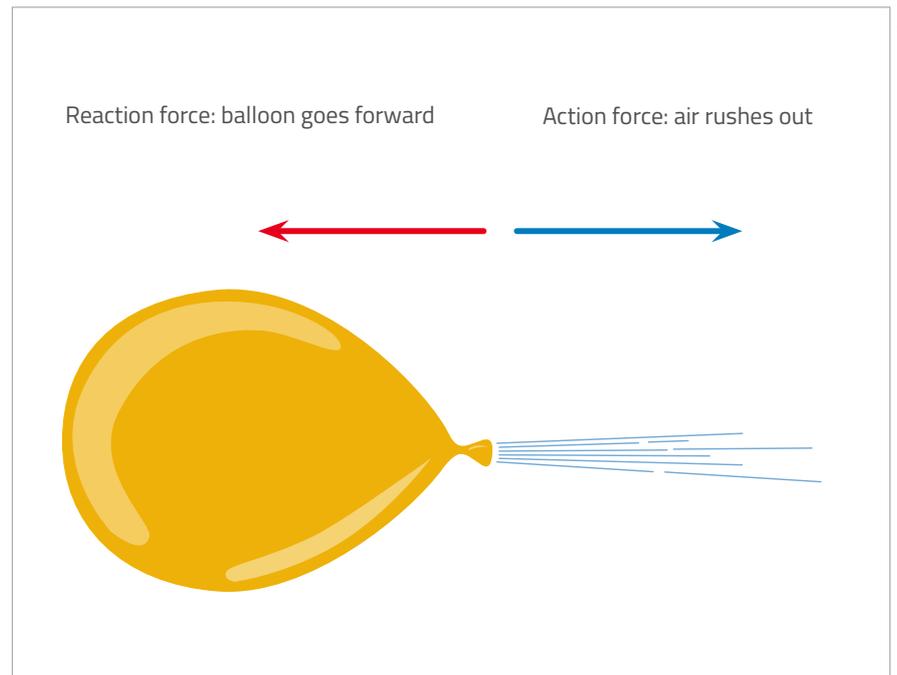


Figure 1: Newton's third law of motion, demonstrated by releasing an inflated balloon

thrust) propels the balloon forward (figure 1). To make the demonstration more controlled, the balloon is attached to a line made from string.

Materials

- Balloon (ideally a long balloon)
- String (approximately 5 m in length)
- Clamp stands
- Straw
- Tape
- Scissors

Procedure

1. Tie one end of the string to a clamp stand that is attached to a table.
2. Cut the straw in half across the middle, and thread the two halves of the straw onto the free end of the string. If you use a regular balloon (rather than a long balloon) this is not necessary.
3. Tie the end of the string onto another clamp stand, ensuring that the string is pulled tight.
4. Inflate the balloon and hold the end closed – do not tie the balloon.



Figure 2: The rocket balloon is attached to the string, ready for launch.

5. Fasten the balloon to the straws using tape (figure 2). You may find it easier to do this in pairs.
6. Pull the balloon to one end of the string. Release the balloon and watch it propel along the string. Who can launch their balloon the furthest?

Activity 2: Boiling water in a vacuum

The pressure inside the International Space Station (ISS) is similar to the pressure on Earth, which is 1 atm. Outside the ISS, however, the pressure is about 10^{-12} atm. If an astronaut were to travel outside the ISS without a space suit, any moisture – such as the saliva on their tongue or the water in their eyes – would begin to boil. This is because the lower pressure reduces the boiling point of water. A liquid boils when its vapour pressure (which

“If an astronaut were to travel outside the ISS without a space suit, any moisture – such as the saliva on their tongue or the water in their eyes – would begin to boil.”

increases with temperature) is equal to the external air pressure. The very low external pressure – close to a vacuum – would also make air flow out from the lungs, and the astronaut would lose consciousness from lack of oxygen^{w2}.

One way to observe this effect for yourself is by placing a glass of room-temperature water inside a vacuum chamber. Pump out the air from the chamber, and observe the water boiling. The first bubbles that appear are likely to be from air dissolved in the water, but soon after it will be the water itself that boils.



Figure 3: By creating a partial vacuum inside the syringe, students see how water boils when pressure is reduced.

If your school does not have access to a vacuum chamber, the experiment can be performed with a syringe, as outlined below.

Materials

- Clear plastic syringe
- Syringe valve (optional)
- Beaker
- Water (heated to different temperatures)

Procedure

1. Place the syringe into a beaker full of water heated to approximately 37°C (body temperature). Pull back the plunger to take in a few millilitres of liquid.
2. Remove the syringe from the beaker. Hold a finger (or place a valve) over the opening of the syringe and pull back the plunger. The water will start boiling (figure 3).
3. Push the syringe in the opposite direction, and the boiling will stop.
4. Repeat the demonstration with water of different temperatures. What do you observe?

When you pull back the plunger of the syringe, you increase the volume inside the syringe, resulting in a decrease in pressure. The pressure is now lower inside than outside the syringe.

If cooler water is used (e.g. at room temperature), its vapour pressure will be lower, so the external pressure needs to be reduced more for the water to be at boiling point.

Activity 3: Overcoming air resistance

Galileo famously concluded that all objects fall at the same speed, regardless of their mass. We now know that, while this is true if there is no air resistance, this isn't usually the case on Earth. In the hammer-feather drop experiment performed on the Moon during the Apollo 15 mission, astronaut David Scott held out a hammer and feather and dropped them at the same time^{w3}. Both objects fell at exactly the same rate; since the Moon has no atmosphere, there was no air resistance. When dropping the same objects on Earth (in normal air), the feather falls much more slowly than the hammer, as the downward force of gravity is greater for the object with the greater mass. This means the opposing force of air resistance affects the feather more than the hammer (figure 4).



Figure 4: In a vacuum, a hammer and a feather hit the ground at the same time. In normal air on Earth, the hammer lands first.

This principle can be easily demonstrated by using a vacuum chamber. A piece of paper and a steel ball can be used for the objects, as shown in our video^{w1}.

Even without a vacuum chamber, you can demonstrate a similar effect by using only a coin and a piece of paper in the manner described below. Here, in addition to the forces of gravity and air resistance acting on the objects, aspects of fluid dynamics come into play.

Materials

- Coin
- Paper
- Scissors

Procedure

1. Cut out a piece of paper, ensuring that it is smaller than the coin (figure 5).
2. Place the paper on top of the coin and hold the coin between two fingers.
3. Drop the coin from a height of about 1 metre. Notice how the paper 'sticks' to the top of the coin and that they land simultaneously.
4. Now drop the paper and the coin separately but at the same time. Notice how the paper falls much more slowly than the coin.



Ole Ahlgren

Figure 5: A piece of paper is placed on top of a coin, and the two objects are dropped together from a height to demonstrate air resistance.

5. Cut out a piece of paper that is bigger than the coin.
6. Place the paper on top of the coin, and drop the coin again. Notice how the paper does not 'stick' to the top of the coin this time.

When the coin falls, it pushes aside the air in front of it. If a smaller piece of paper is placed on top of the coin, the air in front of the paper is also pushed aside. As a result, the paper falls at the same rate as the coin. If the paper is bigger than the coin, the coin cannot push aside all the air in front of the paper, and the paper's fall is slowed by air resistance.

Web references

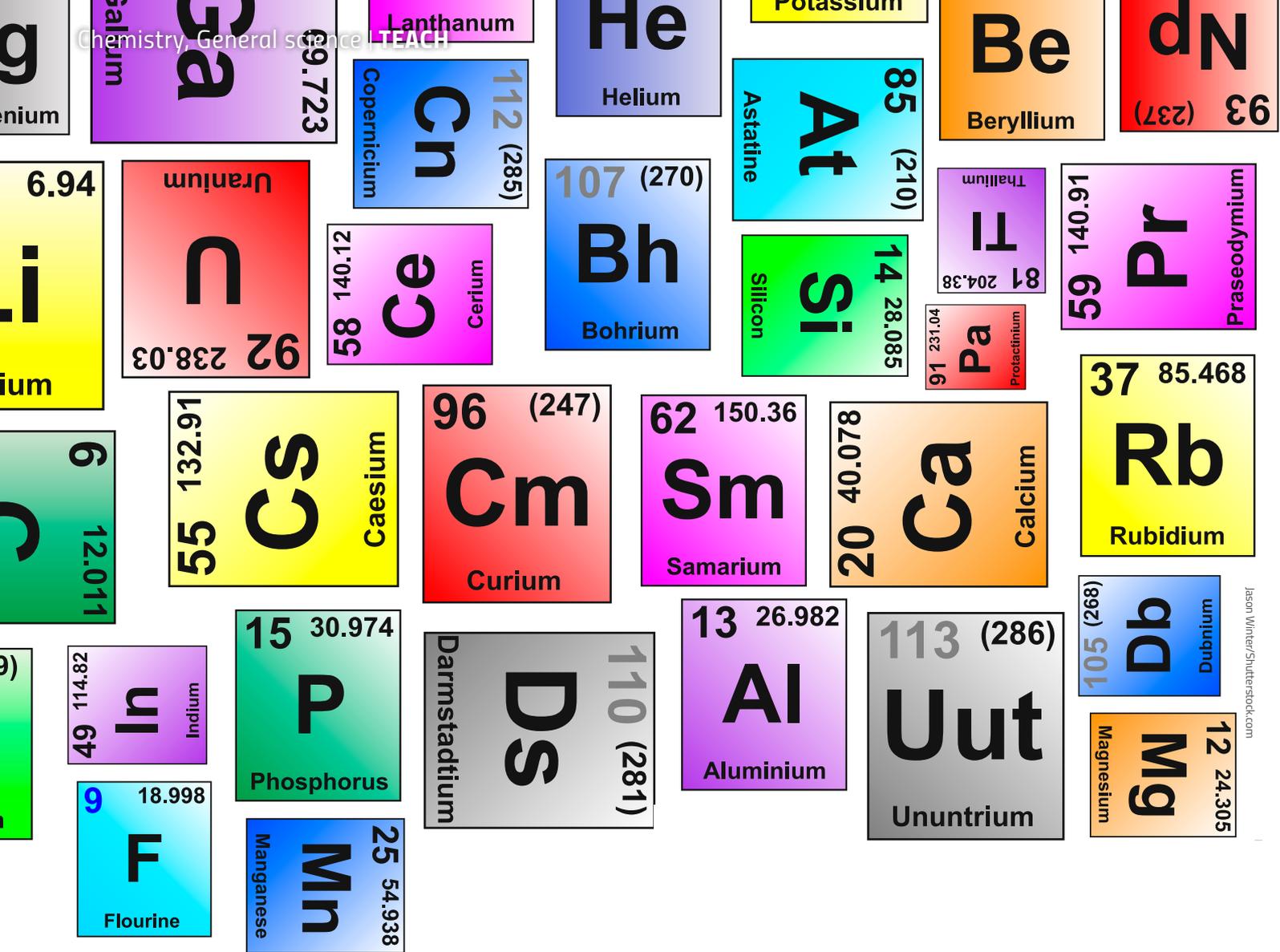
- w1 The author has produced a video showing the activities carried out in his workshop. See: <https://youtu.be/-6Y0vty-eEg>

- w2 To understand what happens to the human body in a vacuum, visit the NASA website and read their library of past questions and answers (see question 5) about being an astronaut. See: https://imagine.gsfc.nasa.gov/ask_astro/space_travel.html
- w3 The famous drop experiment from the Apollo 15 mission is available to view on YouTube. See: www.youtube.com/watch?v=KDP1tiUsZw8

Ole Ahlgren teaches physics, chemistry, biology and astronomy at Roende Gymnasium, a secondary school in Denmark.



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Quiz: elemental pursuit

How much do your students know about the properties of the chemical elements and how they are used? Find out with this elements quiz, based on articles in *Science in School*.

By Matthew HK Cheng

As every science teacher knows, the periodic table is a time-tested directory of elements that arranges all known elements according to their atomic number. Very neatly, the periodic table also reveals links and trends between the elements in terms of their physical and chemical properties.

Over the years, *Science in School* has published a variety of articles that feature many of the elements and how they are used in the sciences, technology and industry. So, to mark the 150th anniversary of the periodic table, we bring you this quiz, which teachers can use to spark discussions about some of the chemical elements, their uses and importance.

Students will be able to complete the quiz using only *Science in School* articles, which are all free to read on the website^{w1}. The quiz is also available as a downloadable worksheet from the *Science in School* website^{w2}.

We hope the quiz will encourage your students to appreciate the huge diversity of the chemical elements and their many fascinating applications. Teachers interested in receiving answers for this quiz – complete with the *Science in School* source article(s) for each answer – are invited to email us at editor@scienceinschool.org.



- ✓ Periodic table
- ✓ Elements and compounds
- ✓ History of chemistry
- ✓ Properties of matter
- ✓ Ages 11–19

REVIEW

Most school students will encounter the elements of the periodic table every year in their studies. This quiz provides a fun way to remind students about the elements they may already know and helps to extend their knowledge of some of the more common or unusual elements. While researching the answers, students may find material that interests them and thus learn more about the elements. With 25 questions, teachers can assign one or two a week so the quiz can be used over a term. Alternatively, the

whole quiz can be used in a competition among teams of students. The quiz could also be useful as a science club activity or extension task. Teachers can expand on the quiz with additional activities, such as trying to link the different elements together, putting the elements in the quiz into periods and groups or in order of toxicity. Finally, the elements mentioned here can be linked to other disciplines, allowing for cross-curricular uses.

Dr Sue Howarth, science education consultant, UK

- 01 Which dangerous element is used at facilities such as the European X-ray Free-Electron Laser Facility (European XFEL^{w3}) to focus X-ray beams?
- 02 Which transition metal has been used to strengthen samurai swords and tank armour, and is also vital for plant and animal life?
- 03 Which toxic element is responsible for the vibrant yellows of many Vincent van Gogh paintings?
- 04 Which element helped Clyde Cowan and Frederick Reines detect neutrinos from radioactive beta decay for the first time in 1956?
- 05 The only stable isotope of which element is used to define seconds, the standard unit for time?
- 06 Mixing which element with salt water results in an exothermic reaction that can be used to warm up self-heating meal packs?
- 07 Which metal with a high melting point is used to line the walls of the Joint European Torus (JET) and ITER nuclear fusion reactors?
- 08 Which element and its radioisotope allow scientists to study gene regulation and adaptation in long-lived neurons?
- 09 Which element is essential for the synthesis of thyroid hormones that regulate growth, development and cell metabolism?
- 10 Atoms of which element were fired into berkelium (element 97) by German scientists to try to create the predicted element 119 (ununennium)?
- 11 Which trace metal is now rarely used in thermometers because of its toxicity?
- 12 Which element can be found in computer hard drives and is used in the most powerful permanent magnets known?
- 13 Which Group 1 metal is commonly found as part of rechargeable batteries in cell phones and laptops?
- 14 Which element allows scientists to reconstruct past climates based on the ratio of the element's isotopes in the 'rings' of mollusc seashells?
- 15 Which element is considered a potential energy carrier of the future, and can be released from food waste by microorganisms?
- 16 'Doping' which element with phosphorus or boron can alter its conductivity?

- 17** Which element is allowed into neurons and muscle cells, in a controlled way, to create an action potential?
- 18** Which mineral is present at around 5 mg per 100 g of fresh mushrooms?
- 19** Which element can exit neuron cells via specialised ion channels to restore a resting membrane potential?
- 20** Ions of which common metallic element are found in Fehling's solution, used to detect the presence of reducing sugars (fructose, glucose or lactose)?
- 21** Which element has more stable oxidation states than any other transition metal?
- 22** NASA uses which inert gaseous element to protect extraterrestrial samples from contamination during investigations?

- 23** Which element forms free radicals which speed up the reaction that destroys ozone in the stratosphere?
- 24** Which rare metal took chemists Ida Tacke and Walter Noddack three years to isolate 120 mg of?
- 25** Which element can be used to thinly coat plastics in order to give them a 'structural colour'?

Web references

- w1** Read all past issues of *Science in School* for free on the website. See: www.scienceinschool.org
- w2** Download the quiz in a worksheet format from the *Science in School* website. See: www.scienceinschool.org/2019/issue47/PTquiz
- w3** European XFEL is a research facility in the Hamburg area of Germany. Its extremely intense X-ray flashes are used by researchers from all over the world. See: www.xfel.eu

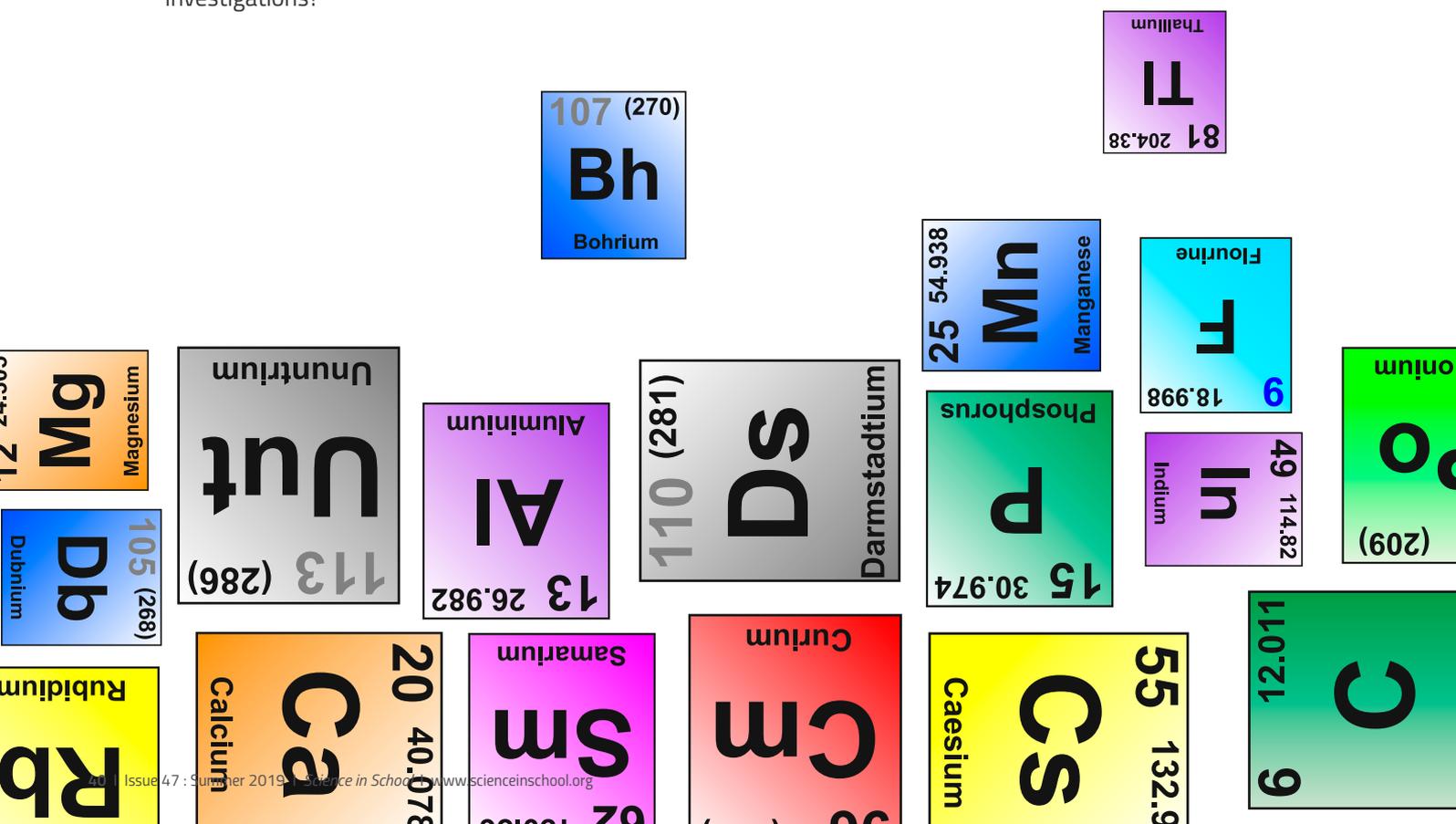
Resources

Once you have found the answers to the quiz, explore the elements further with an interactive periodic table from the Royal Society of Chemistry featuring history, uses, videos and more for each element. See: www.rsc.org/periodic-table

Meet some of the women and collaborative couples who contributed to the periodic table. See: Lykknes A, Van Tiggelen B (2019) In their element: women of the periodic table. *Science in School* **47**: 8-13. www.scienceinschool.org/2019/issue47/PTElements

Discover the past designs of the periodic table. See: Lorch M (2019) Arranging the elements: the evolving design of the periodic table. *Science in School* **47**: 26-29. www.scienceinschool.org/2019/issue47/PTdesign

Matthew HK Cheng is an editorial assistant for *Science in School*. Originally from Toronto, Canada, he completed his PhD in Tübingen, Germany, at the Interfaculty Institute of Biochemistry. He is particularly excited about science research, communication and outreach.



Colour, chlorophyll and chromatography

Use thin-layer chromatography to discover the variety of pigments that play a role in photosynthesis and give leaves their colour.

By Josep Tarragó-Celada and Josep M Fernández Novell

Looking out over a lush green valley or forest, it is fascinating to see the array of different shades. Leaves range from light to dark and even speckled. The colours are determined by the presence of different pigments, many of which are responsible for one of the most interesting and important metabolic reactions in living organisms: photosynthesis.

Photosynthetic pigments are located in the chloroplasts of the leaf. They capture energy from the visible light spectrum, which they use to synthesise carbohydrates from inorganic matter. There are many types of photosynthetic pigments, but the two main groups are chlorophylls and carotenoids (which are further split into two classes: carotenes and



- ✓ Separating mixtures
- ✓ Structural determination
- ✓ Practical techniques

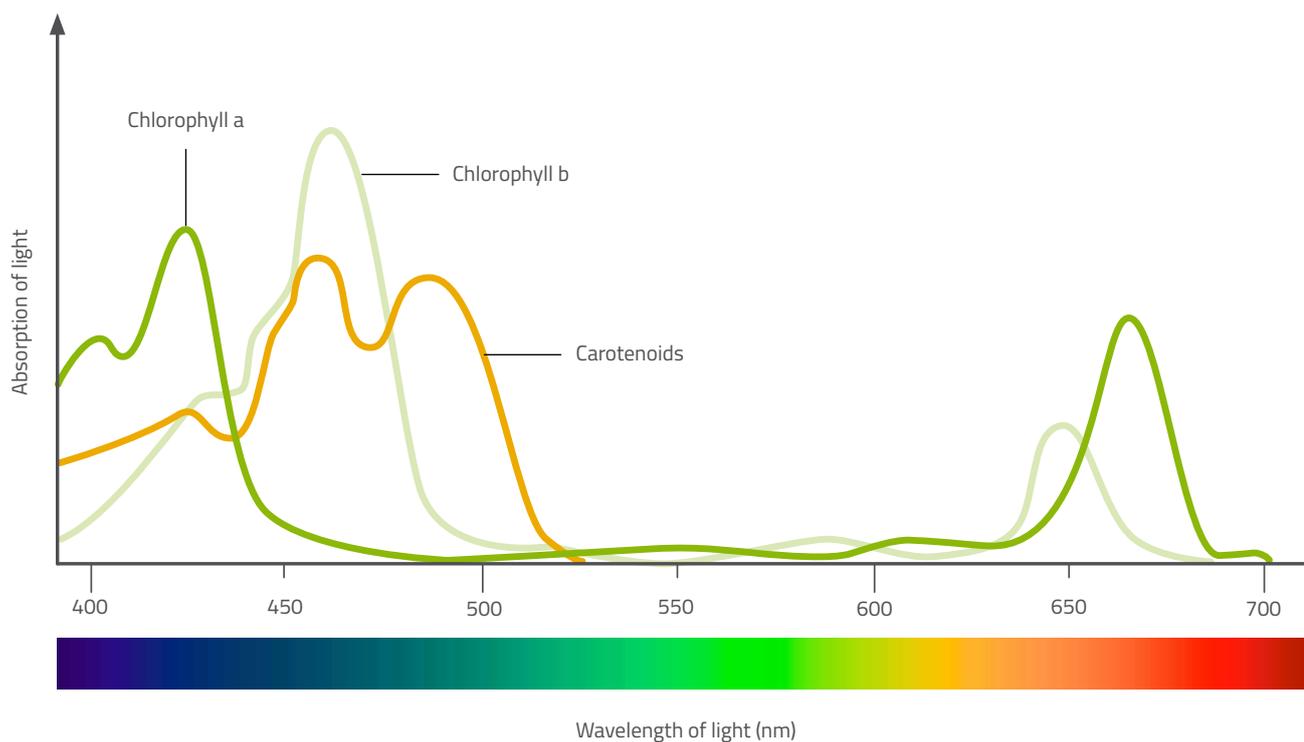
Combining the outdoor element of nature with the identification of different chemical structures produces a perfect applied science lesson. The analysis of the different pigments in leaves has a clear visual outcome that can then be related to the chemical structures of the different photosynthetic pigments.

This practical activity affords students the opportunity to move beyond basic paper chromatography to the more complex technique of thin-layer chromatography. This cross-curricular task will engage students who enjoy biology-based topics such as photosynthesis as well as students who enjoy the problem-solving aspect of analytical techniques in chemistry.

- ✓ Bonding and polarity
- ✓ Photosynthesis
- ✓ Ages 14–19

The activity is most suitable for students aged 14–16 as part of a science club or extension activity. In addition to the main method, the authors provide suggestions for using different solvents to enable students to carry out the experiment entirely independently. With further detail, the activity could also be useful for students aged 16–19. Many new terms are introduced, so the article provides an excellent chance to challenge students to understand concepts such as mobile and stationary phases, polarity of molecules and how biology is fundamentally based on chemical building blocks.

Caroline Evans, head of chemistry, Wellington College, UK



Absorption spectrum for photosynthetic pigments

xanthophylls). Each type absorbs a different wavelength, so that together they capture more light.

Chlorophylls are the pigments primarily responsible for photosynthesis. They absorb red and blue light, and reflect green light, which is what gives leaves their green colour. Carotenoids, on the other hand, reflect yellow,

orange and red – the colour of leaves during autumn. During this time of year, chlorophyll breaks down so the carotenoid pigments become visible.

Carotenoids assist with photosynthesis by absorbing wavelengths of light that chlorophylls cannot absorb. They transfer energy to chlorophyll molecules and also help to protect the leaf from

excess light – they absorb surplus light energy and dissipate it as heat to prevent it from damaging the leaf.

Other non-photosynthetic pigments, such as anthocyanins or other flavonoids, determine the colour of flowers, so their absorption spectra vary. The function of these pigments is to attract insects or birds for pollination.



Joydeep/Wikimedia Commons, CC BY-SA 3.0

Leaves of *Epipremnum aureum*, commonly known as *devil's ivy*



JM Garg/Wikimedia Commons, CC BY 3.0

Leaves of *Ficus benjamina*, commonly known as *weeping fig*

Separating leaf pigments using thin-layer chromatography

This article presents a simple laboratory experiment to understand leaf pigments. Students use thin-layer chromatography to separate the various pigments that are present in two different leaf extracts. They identify each pigment and determine whether the two extracts have any pigments in common. The experiment is suitable for students aged 11–16 and takes 1–2 hours to complete.

“Students use thin-layer chromatography to separate the various pigments that are present in two different leaf extracts.”

Note that we used leaves from *Pipremnum aureum* (commonly known as devil's ivy) and *Ficus benjamina* (commonly known as weeping fig), but any species could be used for the leaf extracts. You might also like to carry out the experiment using a brightly coloured flower, such as those in the *Petunia* genus, and also a yellow or orange leaf.

For the thin-layer chromatography, we use a combined mobile phase of hexane, acetone and trichloromethane (3:1:1) as it provides the best separation result. However, it requires part of the activity to be carried out inside a fume hood by the teacher. This mobile phase separates the pigments most clearly, but you could adapt the activity to use mobile phases of hexane or ethanol alone, which the students can carry out themselves. Both hexane and ethanol successfully separate the pigments, but the distinction between each pigment is not as clear as when the combined solvent is used.

Materials

- Leaf samples (e.g. *E. aureum* and *F. benjamina*), cut into pieces

measuring approximately 2 cm x 2 cm

- Thin-layer chromatography plates (10 cm x 5 cm) pre-coated with silica gel
- Organic solvent comprised of:
 - 3 parts hexane, C₆H₁₄
 - 1 part acetone, (CH₃)₂CO
 - 1 part trichloromethane, CHCl₃
- A beaker and watch glass (or chromatography chamber)
- Spotting tile
- Mortar and pestle
- 1 ml Pasteur pipettes (one for each leaf sample)
- Pencil

Safety note: A lab coat, gloves and eye protection should be worn. The solvents used in this experiment are flammable, so they must not be used near flames. The combined solvent (hexane, acetone and trichloromethane) must only be used inside a fume hood due to the volatility, smell and health risks associated with it.

Procedure

The following steps should be carried out by the students:

1. Place your first leaf sample in the mortar. Pipette 1 ml of acetone into the mortar and use the pestle to grind the sample until the leaf is broken down.
2. Transfer the mixture to a well of the spotting tile using the pipette.
3. Wash the mortar and pestle, and repeat steps 1–2 using the second leaf sample. Use a new pipette to add 1 ml of acetone and use this pipette to transfer the mixture to a new well of the spotting tile.
4. Take the chromatography plate and draw a horizontal line 1.5 cm from the bottom using a pencil. Take care not to touch the plate with your fingers.
5. Using your first pipette (take care not to mix up which pipettes were used for each leaf sample), draw up some of your first leaf sample. Apply a single, small drop to the pencil line on the left hand side of

the chromatography plate. Make sure to leave enough space to fit the second sample on the right hand side.

6. Wait a few seconds until it dries, and apply a second drop on the same spot. Continue until you have added around 10 drops.
7. Using your second pipette, repeat steps 5 and 6 for the second leaf sample by adding it to the right hand side of the plate.
8. Allow the plate to dry completely.

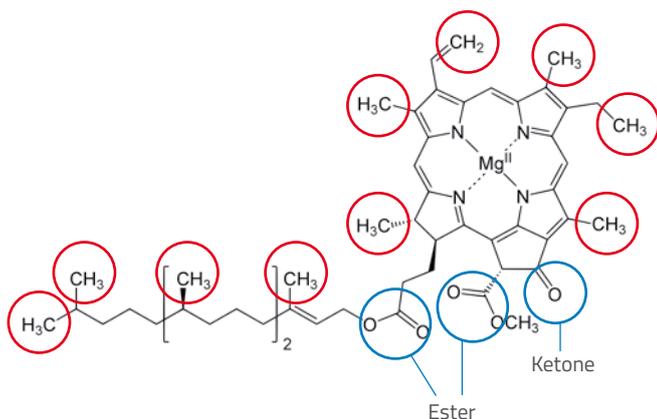
The following steps must be carried out by the teacher:

9. Inside the fume hood, combine the solvents in the following proportions: hexane, acetone and trichloromethane, 3:1:1.
10. Add the combined solvent to the beaker. You should add only a shallow layer of solvent, so that the pencil line on the chromatography plate will not be submerged.
11. Place the chromatography plate vertically into the beaker, with the pencil line at the bottom, and cover the beaker with a watch glass. Students can watch as the solvent moves up the plate and the pigments separate.
12. Wait until the solvent has travelled roughly 6 cm from the starting point (this will take approximately 15–30 minutes) before removing the plate from the beaker, leaving it inside the fume hood.
13. Use a pencil to quickly mark the furthest point reached by the solvent. Allow the plate to dry completely before removing it from the fume hood.

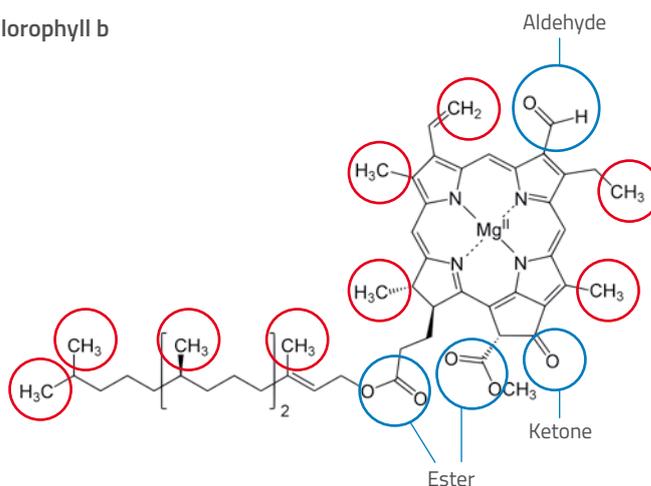
The following steps should be carried out by the students:

14. Photograph the chromatogram as soon as it is dry. The colours will fade within a few hours. Print out a copy of the photograph for your notes.
15. Using the chromatogram photo, try to work out how many pigments are present in each leaf extract.

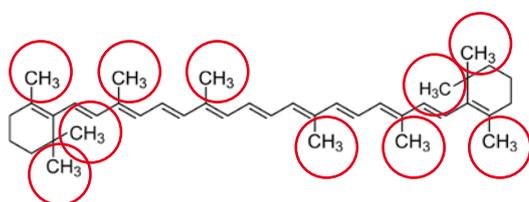
Chlorophyll a



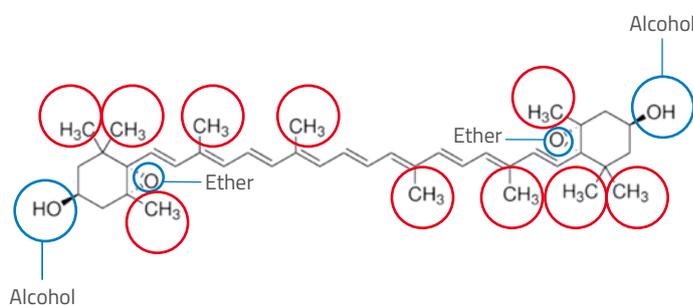
Chlorophyll b



β-carotene



Violaxanthin (xanthophyll)



○ Polar
○ Nonpolar

Figure 1: Chemical structures of photosynthetic pigments: chlorophyll a and b, β-carotene, and violaxanthin (a xanthophyll pigment). Polar groups circled in blue, nonpolar groups circled in red.

16. Now look at the chemical structures of different pigments (see figure 1). Can you determine which pigment is which (see the explanation section for more guidance)? Write down your answers.
17. Measure the distances travelled by the solvent and the pigments, and calculate the retardation factor (R_f) using the following equation:

$$R_f = \frac{\text{distance travelled by pigment}}{\text{distance travelled by solvent}}$$

Record your results in a table. Compare these to the values in table 1: were your answers correct?

Explanation

The different pigments in a leaf extract are separated based on their affinities for the stationary phase (the silica on the thin-layer chromatography plate – a polar substance) and the mobile phase (the solvent – a nonpolar substance). Compounds with a high affinity for the

solvent (i.e. nonpolar compounds) will move much further than compounds with a high affinity for silica (i.e. polar compounds).

In our example (see figure 2), both leaf extracts contained four pigments. Pigment 4 moved a shorter distance than pigment 1, indicating that pigment 4 is more polar and pigment 1 is less polar. By looking at the chemical structures of different pigments and the polar and nonpolar groups, students can try to identify the pigments in each of the leaf extracts.

They will need to know that, of the functional groups present in the pigments in figure 1, alcohol groups are the most polar, ester and ether groups the least polar, and aldehyde and ketone groups are in between. From this, we can deduce that carotenes are the least polar pigments (no polar groups), and xanthophylls are the most polar (two alcohol groups, one at each end of the molecule). Therefore, pigments 1 and 2 are likely to be

carotenes, and pigment 4 is likely to be a xanthophyll. Pigment 3 is likely to be chlorophyll, since it is more polar than carotenes but less polar than xanthophylls. You can observe the characteristic green colour from chlorophyll on the chromatogram.

Now look at the R_f values, which range between 0 and 1, with 0 being a pigment that does not move at all, and 1 indicating a pigment that moves the same distance as the solvent. The R_f value varies depending on the solvent used, but the general order of the pigments (from the highest to the lowest R_f value) usually remains the same, because the nonpolar compounds move further than the polar compounds. R_f values for various pigments (using hexane, acetone and trichloromethane (3:1:1) for the solvent) are shown in table 1.

Discussion

After the experiment, you can ask your students some of the following

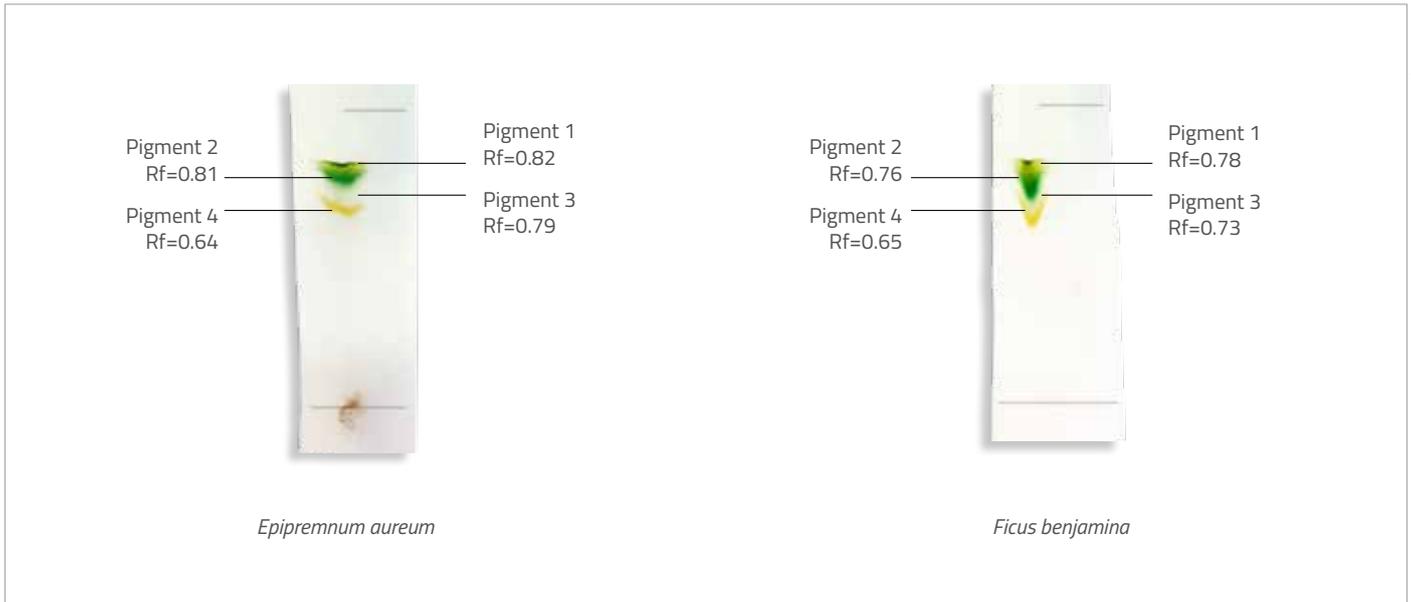


Figure 2: Chromatograms and corresponding R_f values for two leaf samples (*E. aureum* and *F. benjamina*) using a mobile phase of hexane, acetone and trichloromethane

Pigment	R_f value
β -carotene	0.98
Chlorophyll a	0.59
Chlorophyll b	0.42
Anthocyanins	0.32–0.62
Xanthophylls	0.15–0.35

Table 1: R_f values for a variety of plant pigments, calculated from a chromatogram using hexane, acetone and trichloromethane (3:1:1) for the mobile phase (Reiss, 1994).

questions to gauge their understanding of plant pigments and thin-layer chromatography.

- Look at absorption spectra for various plant pigments. Which pigments absorb the most light from the red end of the spectrum? What colour are they?
- If chlorophyll is the most important photosynthetic pigment, which colours of the visible spectrum are most useful to a plant for photosynthesis?

- Seaweeds are often yellow-brown in colour. Do you think light from the red end or the blue end of the spectrum penetrates water best?
- What species of plants have non-green leaves? How could you find out what pigments they contained?
- Where are photosynthetic pigments located within a leaf?
- Why is it useful for plants to contain several different photosynthetic pigments?
- Why is it important to use a nonpolar solvent (such as hexane, acetone and trichloromethane) and not a polar solvent (such as water) to investigate plant pigments using thin-layer chromatography?
- Why should you avoid touching the thin-layer chromatography plate?
- Why should the plate be completely dry before putting it into the beaker?
- Why do some pigments have a larger R_f value than others?

Reference

Reiss C (1994) *Experiments in Plant Physiology*. Englewood Cliffs, NJ, USA: Prentice Hall. ISBN: 0137012853

Resources

For an infographic explaining the chemicals behind the colour of leaves, visit the Compound Interest website. See: www.compoundchem.com/2014/09/11/autumnleaves

Read more about the chemical structure of different plant pigments by visiting the Harvard Forest website from Harvard University. See: <https://harvardforest.fas.harvard.edu/leaves/pigment>

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FANTASTIC FEATS

MAGIC WITH MONEY

You'll need to put your money on the table for this batch of tricks, then use your scientific knowledge to make 'cents' of what happens!

By David Featonby and Victoria Demianets

In this third 'fantastic feats' article, we present some entertaining challenges involving money – and, of course, some physics along the way. One-cent coins from the USA and aluminium coins from various countries are especially useful for these activities – so if you encounter these on your holiday this summer, perhaps bring some back with you.

Feat 1: Jumping coin

Can you get a coin to jump into a cup without using your hands? Remarkably, the answer is yes – just by using the power of your breath. The challenge is to get the coin to 'jump' into the cup by blowing hard enough.



Marc Camille/pixabay.com

After you have succeeded, you can try to calculate the minimum breath speed needed to get the coin into the cup. You can also repeat the trick – and the calculation – with other coins.

Materials

- One small, light coin – if possible made from aluminium (e.g. Chinese yen)
- Other small coins (optional)
- Small match box
- Cup or mug, preferably with sloping sides
- A table or other level surface

Procedure

1. Set up the coin, match box and mug as shown in figure 1.
2. Position yourself as shown in figure 1, so that your breath will go straight over the coin.
3. Blow quickly and forcefully – the coin should 'jump' into the mug (figure 2).

4. For additional fun, the coins can be made to do a 'high jump' or 'long jump', by using pencils stacked up or laid next to each other, instead of the cup.



David Featonby

Figure 1: The setup for the coin jump trick

Discussion

How does fast-moving air manage to lift the coin into the cup, when there is nothing pushing up from below? The explanation lies in Bernoulli's principle – the same idea that explains how aircraft wings gain lift by moving fast through air. This principle states that when the speed of air (or any fluid) increases, its pressure decreases. So here, the fast-moving breath leads to a reduction in air pressure above the coin, which lifts the coin into the mug.



David Featonby

Figure 2: The coin is lifted into the cup by the reduction in air pressure above it.

Mathematically, Bernoulli's principle can be stated thus:

$$P + \frac{1}{2} \rho v^2 = \text{constant}$$

where:



- ✓ Bernoulli equation
- ✓ Surface tension
- ✓ Mathematics
- ✓ Statistics
- ✓ Ages 11–19

This article describes some activities that illustrate some basic principles in physics – particularly the Bernoulli principle and the surface tension of fluids. One wonderful feature in the Bernoulli activity is that it includes the mathematics needed to calculate the physical parameters involved. As well as providing practical activities for a physics class with interesting explanations, the article could be used as a basis for class discussion. Suggested questions include:

- What is the Bernoulli principle, and what terms does the Bernoulli equation include?
- Using the Bernoulli principle, can you explain how aircraft wings gain lift?
- How can you decrease the surface tension of water?
- Some insects such as the pond-skater (or water strider) can run over water. How do they do this?

REVIEW

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

P = pressure (force exerted divided by the area on which it is exerted)

ρ = density of the fluid (air)

v = velocity of the moving object or fluid

So

$$P_1 + \frac{1}{2} \rho v_0^2 = P_2 + \frac{1}{2} \rho v^2$$

The pressure difference between stationary air ($v_0 = 0$) and moving air (v) is thus:

$$P_1 - P_2 = \frac{1}{2} \rho v^2$$

The uplift force due to the reduced pressure is:

$$(P_1 - P_2) \times A \text{ (where } A = \text{area of coin)}$$

$$= A \times \frac{1}{2} \rho v^2 \text{ (from above)}$$

The force required to lift the coin is $m \times g$ (where m = mass of coin, and g = acceleration due to gravity, approximately 9.8 m s^{-2})

This means that the coin's weight is balanced when

$$\frac{1}{2} \rho v^2 \times A = m \times g$$

We can therefore calculate the minimum speed (v_{\min}) of breath needed to lift the coin:

$$v_{\min} = \sqrt{\frac{2 m g}{\rho A}}$$

For circular coins, $A = \pi r^2$

For a Chinese yen (mass = approximately 1 g, diameter = 20 mm)

Density of air = 1.225 kg/m^3

$$v_{\min} = \sqrt{\frac{2 \times 0.001 \times 9.8}{1.225 \times 3.14 \times 0.01 \times 0.01}}$$

$$= 7.2 \text{ m/s}$$

For a euro one-cent coin (mass = 2.3 g, diameter 16.25 mm)

$$v_{\min} = \sqrt{\frac{2 \times 0.0023 \times 9.8}{1.225 \times 3.14 \times 0.008125 \times 0.008125}}$$

$$= 13.32 \text{ m/s}$$

For a euro five-cent coin (mass = 3.9 g, diameter 21.25 mm)

$$v_{\min} = \sqrt{\frac{2 \times 0.0039 \times 9.8}{1.225 \times 3.14 \times 0.01065 \times 0.01065}}$$

$$= 13.23 \text{ m/s}$$

Note that these last two values are very similar. Can you show that coins of the same thickness and material will have the same lifting velocity, no matter what their diameter is?

Feat 2: Water pile-up

This feat involves another property of fluids: surface tension. We use a coin as a base on which to 'pile up' water. The challenge is to get as many drops of clean water from a dropper onto a clean coin without spilling any off the edge of the coin. You can carry out this feat as a contest to see who can get the most drops on a coin – but be sure everyone has coins and droppers of the same size.



David Featonby



David Featonby



David Featonby

Lift off! Photo sequence showing the coin at rest, then taking off and landing in the mug.

Materials

Each person or group will need the following:

- One small copper coin (a euro one-cent coin is ideal)
- Dropper (e.g. a pipette or syringe)
- Clean water
- A table or other level surface

Procedure

1. Most coins that have been handled are quite greasy, so first wash the coin in hot soapy water, then rinse and dry it thoroughly. The detergent also needs to be removed completely.
2. Fill the dropper with clean water.
3. Hold the dropper over the coin (without touching it) and place a drop of water on the coin (figure 3).
4. Keep on placing water drops onto the coin, counting the number of drops as you go. The water will pile up over the surface of the coin, but eventually it will

spill over. Note how many drops you added before this happened (figure 4).

5. What's the highest number of drops you can place on the coin? Try the challenge again to find your personal best – or find out what others managed and try to beat them!
6. As an extra challenge, try to work out what will happen if you add soap or detergent to the water pile on the coin. Think about it and make a note of your prediction – then touch the water gently with a piece of soap or a drop of detergent. What happens – and why?

Discussion

It should be possible to put approximately 40 drops onto a clean coin, although this number will vary considerably with the cleanliness of the water and the size of the coin. But as water is liquid, why does it stay on the coin at all, rather than flowing over the sides?

The answer, of course, is surface tension: forces of attraction between molecules in the water act like a 'skin' to hold the water together on the coin. Although these forces are quite weak, they really do affect how liquids behave – as this activity shows. Surface tension is also what causes drops of liquid to form a spherical shape, minimising their surface area.



David Featonby

Figure 3: The first few drops



David Featonby

Figure 4: Full coin with about 40 drops

However, dirt on the surface of the coin can reduce the surface tension of the water dropped onto it, meaning that fewer drops can be added: the water does not 'pile up', but spreads out over the surface. And when the water is contaminated by soap or detergent, the surface tension forces are greatly reduced. As the drops are no longer held together, only a few drops can be placed on the coin before they flow over the coin's edge.

Feat 3: Heads versus tails

This activity is not really a feat or a physical challenge – but it does challenge our notion of a 'fair' coin.

We all know that coins have two sides – heads and tails – and that the chance of a tossed coin landing one particular side up (heads, say) is 50%. But while this assumption is widely held, and relied upon in situations ranging from football match kick-offs to probability questions in maths, is it really true in practice?

For most coins, the answer is probably 'yes, just about' – but it's not true for all coins. In particular, US one-cent coins are not perfectly balanced between their two sides: the 'tail' side is marginally heavier than the 'heads' side. This means that, given a perfectly fair spin, these coins will land heads-up significantly more often than tails-up.

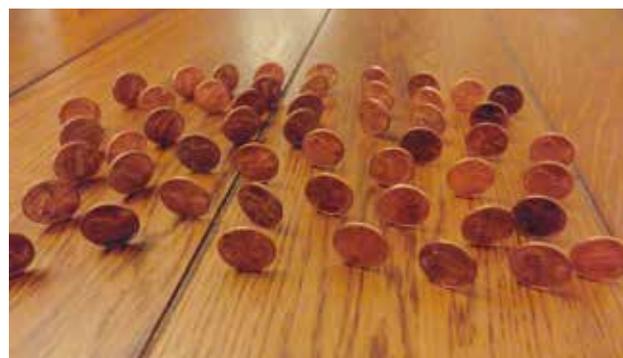
In this activity, we use an ingenious method that effectively tosses 50 coins at once – revealing in a single action whether that type of coin is fair or not.

Materials

- A large number (e.g. 50) of identical low-value coins, preferably US one-cent coins
- A table or other level surface

Procedure

1. Place the coins flat on the table.
2. Balance all the coins on their edges, one by one, facing in different directions (figure 5).



David Featonby

Figure 5: 50 US one-cent coins balanced on their edges

- When the coins are all balanced, hit the table sharply with your fist (figure 6). The coins will fall over onto their faces – either the heads or tails side.
- Separate the coins into those that landed heads-up and those that landed tails-up (figure 7). How many are there of each? Do you think the coin is fair – or biased?
- If possible, repeat the activity with another set of a different coin. If you are going abroad for a summer holiday, perhaps try to bring back a set of coins to try.

Discussion

Tossing a coin, as at the beginning of a football match, does not reveal whether the coin is fair or not, as the way in which the coin is tossed has more effect on how it lands than any slight mass difference between the two sides. The challenge is to give the coin a totally neutral spin, giving it an equal chance to land on either side – if it is truly fair. Here, we do this by balancing 50 or so coins on their edges and seeing how many fall each way.



David Featonby

Figure 6: The coins fall after the table is hit sharply



David Featonby

Figure 7: The fallen coins after sorting – showing many more 'heads' as the 'tails' side is slightly heavier

If you are lucky enough to have a set of US one-cent coins, you should have been able to witness how far from fair this seemingly normal coin is. If you are interested in probability and statistics, you can try posing and answering follow-up questions with your students, such as:

- What is the probability of your result (numbers of heads and tails) occurring purely by chance?
- Is your result statistically significant? (Assume $p < 0.05$ for significance.)
- From your results, can you work out the probability of a single toss of this coin landing (i) heads, or (ii) tails?

As far as we know, based on our experiments, no coin other than the US one-cent coins has a sufficient mass difference for this effect to be reliably observed. So here is a further challenge: by obtaining coins from countries around the world and repeating this balancing experiment, can you find any other coins that are significantly biased? If so, please write and tell us!

Resources

Read an accessible article illustrating Bernoulli's principle, complete with several demonstrations, from *Wired* magazine. See: www.wired.com/story/bernoulli-demonstrations

Explore fluid dynamics and the Bernoulli equation with an online app. See: www.geogebra.org/m/ZUtGMEZt

Watch a video from Physics Girl, which shows some fun experiments demonstrating surface tension. See: www.youtube.com/watch?v=WsksFbFZeeU

Read about a study of biased coins from the *Smithsonian* magazine. See: www.smithsonianmag.com/science-nature/gamblers-take-note-the-odds-in-a-coin-flip-arent-quite-5050-145465423 or use the direct link <https://tinyurl.com/y8osjuo6>

David Featonby is a retired physics teacher from Newcastle, UK, with 35 years of experience in the classroom. He is the author of various hands-on articles in *Science in School* and *Physics Education*, and is on the executive committee of Science on Stage. David has a keen interest in revealing the physics in everyday things. He has presented physics workshops all over Europe to both children and teachers.

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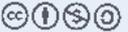
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