



# Science in School

The European journal for science teachers



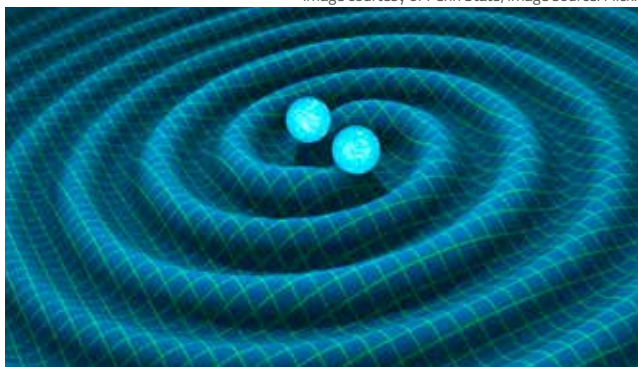
## Science goes underground

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**Where are all the LGBT scientists? Sexuality and gender identity in science**

**TEACH**

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## WHEN THINGS DON'T FALL: THE COUNTER-INTUITIVE PHYSICS OF BALANCED FORCES

Intrigue your students with some surprising experiments – it's a great way to challenge their intuitions and explore the laws of mechanics.

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## EDITORIAL

Eleanor Hayes  
Editor-in Chief  
*Science in School*  
editor@scienceinschool.org

Spring is in the air: the first flush of green, that unmistakable springtime smell and, of course, the rising temperatures. Why not take this opportunity to discuss climate change – and its effect on our oceans (page 12)? These vast bodies of water respond to temperature changes in complex and sometimes counter-intuitive ways.

Counter-intuition is also key to one of the activities in this issue, an investigation of the physics of balanced forces (page 36). You could follow this up by challenging your students to use Newton's laws of motion to perform some impressive tricks (page 45). Your students could then video some of these tricks to use as 'hooks' for science lessons (page 55).

In Germany, the *Foehn* – a dry, warm wind commonly associated with springtime – is often blamed for any number of complaints, including tiredness. Perhaps now is the time for you and your students to investigate the science of energy drinks (page 48)? Whereas the 80 mg of caffeine found in an average can of energy drink might wake you up, pure caffeine is toxic and should be prepared only in very small quantities for the experiments. Similar considerations of toxicity drove one Hungarian teacher to develop a novel idea for microscale chemical reactions – in hydrogel balls (page 31).

From the very small scale to the very large: from the safety of your classroom, you could investigate celestial distances using parallax (page 40) or learn how gravitational waves allow astronomers to 'listen' to the Universe (page 8). To detect other signals from space, some scientists even choose to work deep underground (page 16).

We hope that you enjoy these and the other articles in this issue of *Science in School*. Perhaps they'll inspire you to submit your own article?

*Eleanor Hayes*

Interested in submitting  
your own article? See:  
[www.scienceinschool.org/submit-article](http://www.scienceinschool.org/submit-article)

# Sea cucumbers, celebrations and student internships

## CERN: High-school students internship programme



This year, CERN is expanding its educational programme as it launches a brand new internship opportunity for high-school students. Initially, the pilot programme will be open to students from five member states: Bulgaria, France, Hungary, Norway and Portugal. For each programme, 24 students aged 16–19 will join CERN for two weeks to gain practical experience in science, technology and innovation.

The programme is a unique opportunity for young people to experience CERN and strengthen their understanding of science in a high-tech environment. The students will visit several CERN experimental sites and will work alongside members of CERN staff. At the end of the programme, the students will have the opportunity to present their work.

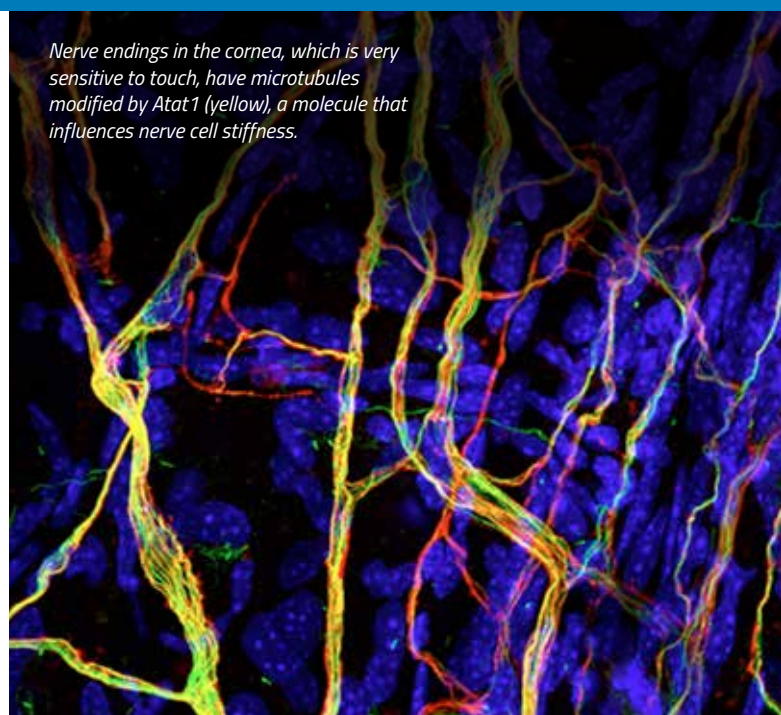
For further information, visit: <http://cern.ch/hssip>

Based in Geneva, Switzerland, CERN is the world's largest particle physics laboratory. See: [www.cern.ch](http://www.cern.ch)

Image courtesy of CERN



High-school students perform physics experiments in the S'cool LAB at CERN.



*Nerve endings in the cornea, which is very sensitive to touch, have microtubules modified by Atat1 (yellow), a molecule that influences nerve cell stiffness.*

Image courtesy of Laura Castaldi / EMBL

## EMBL: Study offers approach to treating pain



For many patients with chronic pain, any light touch – even just their clothes touching their skin – can be agony. Now, scientists at the European Molecular Biology Laboratory (EMBL) and the Werner Reichardt Centre for Integrative Neuroscience of the University of Tübingen, Germany, have found a possible approach for producing painkillers that specifically treat this kind of pain.

The scientists have discovered a molecule that, by influencing how stiff or bendy a nerve cell is, affects how sensitive a mouse is to touch and pain. The nervous system and sense of touch are similar in mice and humans, so the results are likely to hold true for people, too. And although problems in cell stiffness are unlikely to be at the root of most patients' hypersensitivity to touch, controlling how stiff their nerve cells are could nevertheless be an effective way of treating that sensitivity.

For more details, read the full news article. See <https://news.embl.de/science>. Or use the direct link: <http://tinyurl.com/jasab27>

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

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

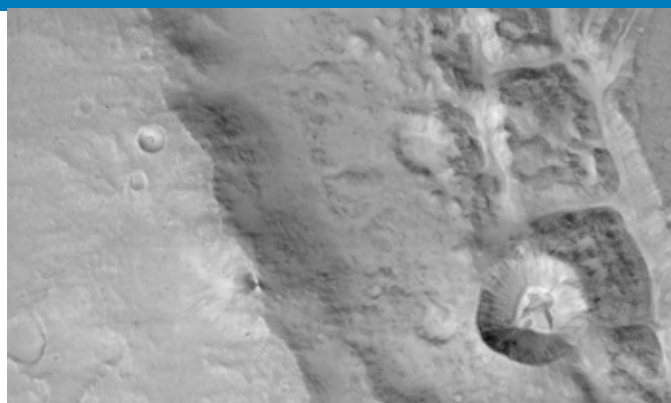
## ESA: The new Mars orbiter



ESA's Trace Gas Orbiter (TGO), a joint endeavour between the European Space Agency (ESA) and the Russian space agency Roscosmos, arrived at Mars on 19 October 2016. TGO's main goal is to make a detailed inventory of rare gases that make up less than 1% of the atmosphere's volume, including methane, water vapour, nitrogen dioxide and acetylene. Of high interest is methane, which on Earth is produced primarily by biological activity and to a smaller extent by geological processes such as some hydrothermal reactions. The orbiter will also serve as a data relay for future lander missions.

Soon after its arrival at Mars, TGO tested its suite of instruments in orbit, hinting at the great potential for future observations when it begins its main science mission in 2018.

During 2017, TGO will use sophisticated aerobraking techniques to steadily lower itself to a circular 400 km orbit



Mars close-up

around Mars. This will be the first time that ESA has used this technology to attain orbit around another body in our Solar System.

Follow the ExoMars mission and some of its first images. Visit [www.esa.int](http://www.esa.int) or use the direct links: <http://tinyurl.com/hh2yylw> (ExoMars mission) and <http://tinyurl.com/h5xl6y5> (images).

ESA is Europe's gateway to space, with its headquarters in Paris, France. See: [www.esa.int](http://www.esa.int)

Image courtesy of ESA / Roscosmos / ExoMars / CASIS / UniBE

## ESO: Spinning black hole swallowing star explains a superluminous event



In 2015, an extraordinarily brilliant point of light seen in a distant galaxy was thought to be the brightest supernova ever seen. Dubbed ASASSN-15lh, it was categorised as a superluminous supernova – the explosion of an extremely massive star at the end of its life.

But new observations from several observatories, including the European Southern Observatory (ESO), have now cast doubt on this classification. Instead, a group of astronomers propose that the source was an even more extreme and very rare event – a rapidly spinning black hole ripping apart a passing star that came too close. Known as a tidal disruption event, this has been observed so far only about 10 times.

In the process, the star was 'spaghettified', and shocks in the colliding debris as well as heat led to a burst of light, giving the appearance of a very bright supernova explosion.

To read the full press release, see: [www.eso.org/public/news/eso1644](http://www.eso.org/public/news/eso1644)

ESO is 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](http://www.eso.org)

Close-up of a star near a supermassive black hole (artist's impression)



## ESRF: Scientists discover how sea cucumbers change shape

Sea cucumbers can rapidly change the stiffness of their bodies, and scientists from Queen Mary University of London, UK, have discovered how they do it using data collected at the European Synchrotron Radiation Facility (ESRF).

All animals have collagen, but one group of marine invertebrates – the echinoderms, which include starfish and sea cucumbers – have evolved collagenous tissues with a unique property: they can rapidly change their stiffness. This type of collagen is known as mutable collagenous tissue and is controlled by the nervous system. It is useful when, for example, the animals need to ‘turn to jelly’ so they can avoid predation. However, the mechanisms by which the sea cucumber can change its stiffness were not known until now.

The scientists analysed the body wall of sea cucumbers at ESRF. The team used the technique of time-resolved synchrotron small-angle X-ray diffraction combined with in situ tensile testing carried out at the high-brilliance beamline ID02. The research can provide a useful basis for developing novel biomaterials for applications in medicine.

For more details, read the full press release on the ESRF website. See [www.esrf.eu](http://www.esrf.eu) or use the direct link: <http://tinyurl.com/zrbzrtl>

Read more in the research paper:

Mo J et al. (2016) Interfibrillar stiffening of echinoderm mutable collagenous tissue demonstrated at the nanoscale. *Proceedings of the National Academy of Sciences of the USA* **113(42)**: E6362–E6371. doi: 10.1073/pnas.1609341113

Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. See: [www.esrf.eu](http://www.esrf.eu)

A sea cucumber



## EUROfusion: A well-earned holiday for JET

EUROfusion’s flagship device, the Joint European Torus (JET), has gone on a well-deserved holiday, starting on 15 November 2016, after finishing one of the most successful sets of experiments in its history.

Located at Culham, UK, JET is a fusion device known as a tokamak, and is currently the only device capable of using fuels that will be used in future fusion plants. These fuels are the hydrogen isotopes deuterium and tritium.

JET’s recent success shows that it is ready to handle experiments with the ‘real’ fusion fuels. But perhaps more importantly, it means that JET has laid solid foundations that ITER can build on. ITER is the world’s largest fusion experiment, which is under construction in Cadarache, France. When it is completed, ITER should be able to prove that obtaining energy from fusion is possible. Once realised, fusion energy has the potential to fulfil our growing energy demands by providing carbon-dioxide-free, sustainable energy.

And, although JET may be on a short vacation, the researchers and engineers are certainly not. They are busy upgrading the device so that it is ready to begin the next set of experiments later this year.

To learn more:

Read the full press release on the EUROfusion website. See [www.euro-fusion.org](http://www.euro-fusion.org) or use the direct link: <http://tinyurl.com/hmcznwr>  
And read more about the recent experimental success of JET.  
See: [www.euro-fusion.org/newsletter/jet-most-successful/](http://www.euro-fusion.org/newsletter/jet-most-successful/)

EUROfusion comprises 28 European member states as well as Switzerland and manages fusion research activities on behalf of Euratom. The aim is to realise fusion electricity by 2050. See: [www.euro-fusion.org](http://www.euro-fusion.org)



An internal view of JET with a complete metallic ‘ITER-like’ wall of beryllium and tungsten



Image courtesy of European XFEL

Installations in the FXE instrument in November 2016

## European XFEL: State-of-the-art instruments coming together



When the first users come to the European X-ray Free Electron Laser (European XFEL) this summer, they will work at one of two state-of-the-art scientific instruments offered by the facility in the initial phase. These instruments, called FXE and SPB/SFX, are currently being assembled in the underground experiment hall.

When complete, the instruments will be able to use European XFEL's 27 000 X-ray flashes per second to perform unprecedented studies of matter. FXE, for example, will be used to observe ultrafast processes and reactions at the molecular scale, such as the movement of atoms and the rearrangement of electronic charge clouds within a molecule undergoing a chemical change. SPB/SFX will determine the structure of biomolecules, atomic clusters, viruses and more. It could also help scientists come closer to what is known as the 'holy grail' of structural biology: being able to determine the structure of molecules without first arranging them in crystal forms.

Scientists expect that results from these instruments will lead to a better understanding of many processes, enabling the development of better medications and potentially leading to more efficient methods of energy capture and storage. Four more instruments will become available to users by 2018 as European XFEL's initial configuration reaches completion.

European XFEL is a research facility currently under construction in the Hamburg area in Germany. Its extremely intense X-ray flashes will be used by researchers from all over the world. See: [www.xfel.eu](http://www.xfel.eu)

## ILL: 50<sup>th</sup> birthday celebration



The Institut Laue-Langevin (ILL) was founded 50 years ago, on 19 January 1967, with the signing of an agreement between France and Germany. What began under the impetus of Franco-German reconciliation is now a shining example of international co-operation: today ILL has 13 member states, and many other countries from around the world participate in its research programme.

ILL owes much of its long-lasting success to its ability to adapt quickly in an ever-changing research environment. By constantly upgrading and developing its facilities, ILL has ensured that it remains state-of-the-art. And indeed, despite the increasing complexity of operating a nuclear facility and the ever-more stringent demands of safety authorities, ILL will continue to set the standards for future neutron sources.

ILL is an international research centre at the leading edge of neutron science and technology. See: [www.ill.eu](http://www.ill.eu)

Image courtesy of ILL



ILL celebrated its 50th anniversary in the presence of the French secretary of state for higher education and research, the German ambassador to France, the British ambassador to France and many other prominent personalities.



EIROforum combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. To learn more, see: [www.eiroforum.org](http://www.eiroforum.org)

For a list of EIROforum-related articles in Science in School, see: [www.scienceinschool.org/eiroforum](http://www.scienceinschool.org/eiroforum)

To browse the other EIRO news articles, see: [www.scienceinschool.org/eironews](http://www.scienceinschool.org/eironews)



# Turning on the cosmic microphone

A new tool lets astronomers 'listen' to the Universe for the first time.

By Diana Kwon

On the morning of 14 September 2015, a signal from two black holes that had collided 1.3 billion years ago reached Earth, alerting scientists around the world. "It took us a good part of the day to convince ourselves that this was not a drill", says Professor Gabriela González. In fact, it was the first-ever detection of a gravitational wave and the latest development in the long history of astronomy.

When Galileo first introduced the telescope in the 1600s, astronomers gained the ability to view parts of the Universe that were invisible to the naked eye. This led to centuries of discovery – as telescopes advanced, they exposed new planets, galaxies and even a glimpse of the very early Universe. In 2015, scientists gained another valuable tool: the ability to 'hear' the cosmos through gravitational waves.



- ✓ Physics
- ✓ General science
- ✓ Ages 11–18

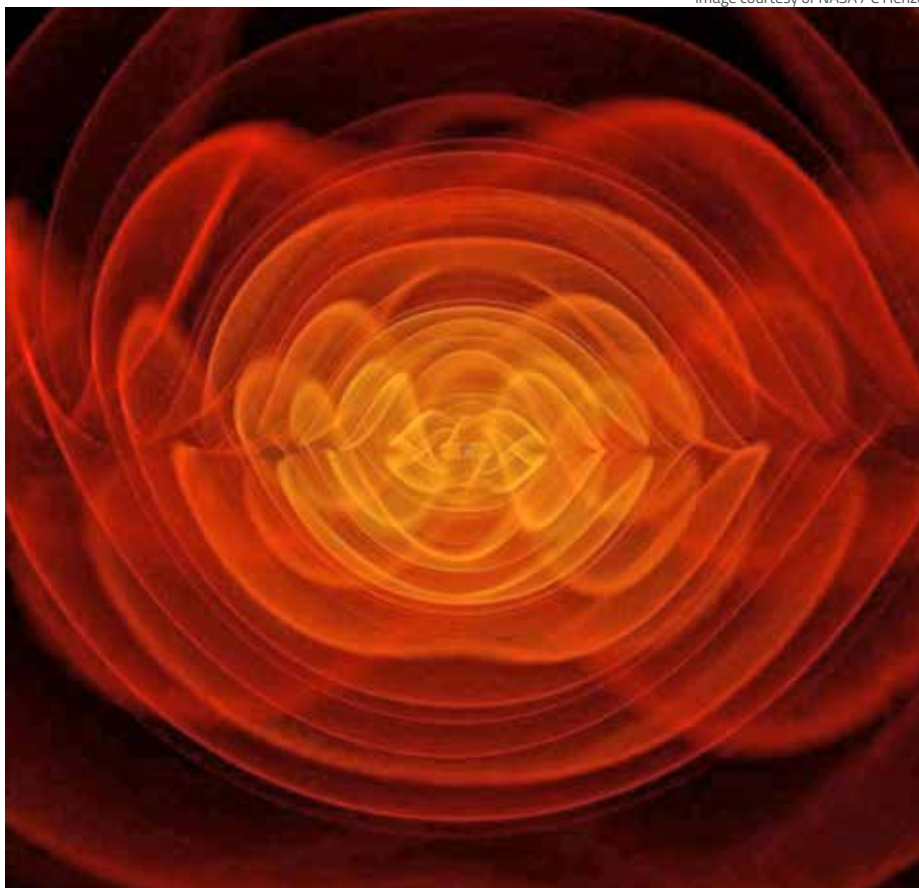
REVIEW

Great news for us all – after years of looking for gravitational waves, scientists have finally detected them. This article makes good reading for physics and general science teachers. It can be used as a platform for discussion in class, focusing mainly on the problems associated with detecting gravitational waves, but more importantly on their applications in everyday life.

Paul Xuereb, Malta



Image courtesy of NASA / C Henze



A simulation of two black holes merging and the resulting emission of gravitational radiation

## Ripples in space-time

Newton described gravity as a force. Thinking about gravity in this way can explain most of the phenomena that happen here on Earth. For example, the force of gravity acting on an apple makes it fall from a tree onto an unsuspecting person sitting below it. However, to understand gravity on a cosmic scale, we need to turn to Einstein, who described gravity as the bending of space-time itself.

Some physicists describe this process using a bowling ball and a blanket. Imagine space-time as a blanket. A bowling ball placed at the centre of the blanket bends the fabric around it. The heavier an object is, the further it sinks. As you move the ball along the fabric, it produces ripples, much like a boat travelling through water.

“The curvature is what makes Earth orbit the Sun – the Sun is a bowling ball in a fabric and it’s that bending in the fabric that makes the Earth go around”, explains González, who is the spokesperson for the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration.

Everything that has mass – planets, stars and people – pulls on the fabric of space-time and produces gravitational waves as it moves through space. These waves are passing through us all the time, but they are much too weak to detect.

To find these elusive signals, physicists built LIGO, twin observatories in Louisiana and Washington, USA. At each L-shaped detector, a laser beam is split and sent down two 4 km arms. The beams reflect off the mirrors at each end and travel back to reunite. A passing gravitational wave slightly alters the relative lengths of the arms, shifting the path of the laser beam, creating a change that physicists can detect.

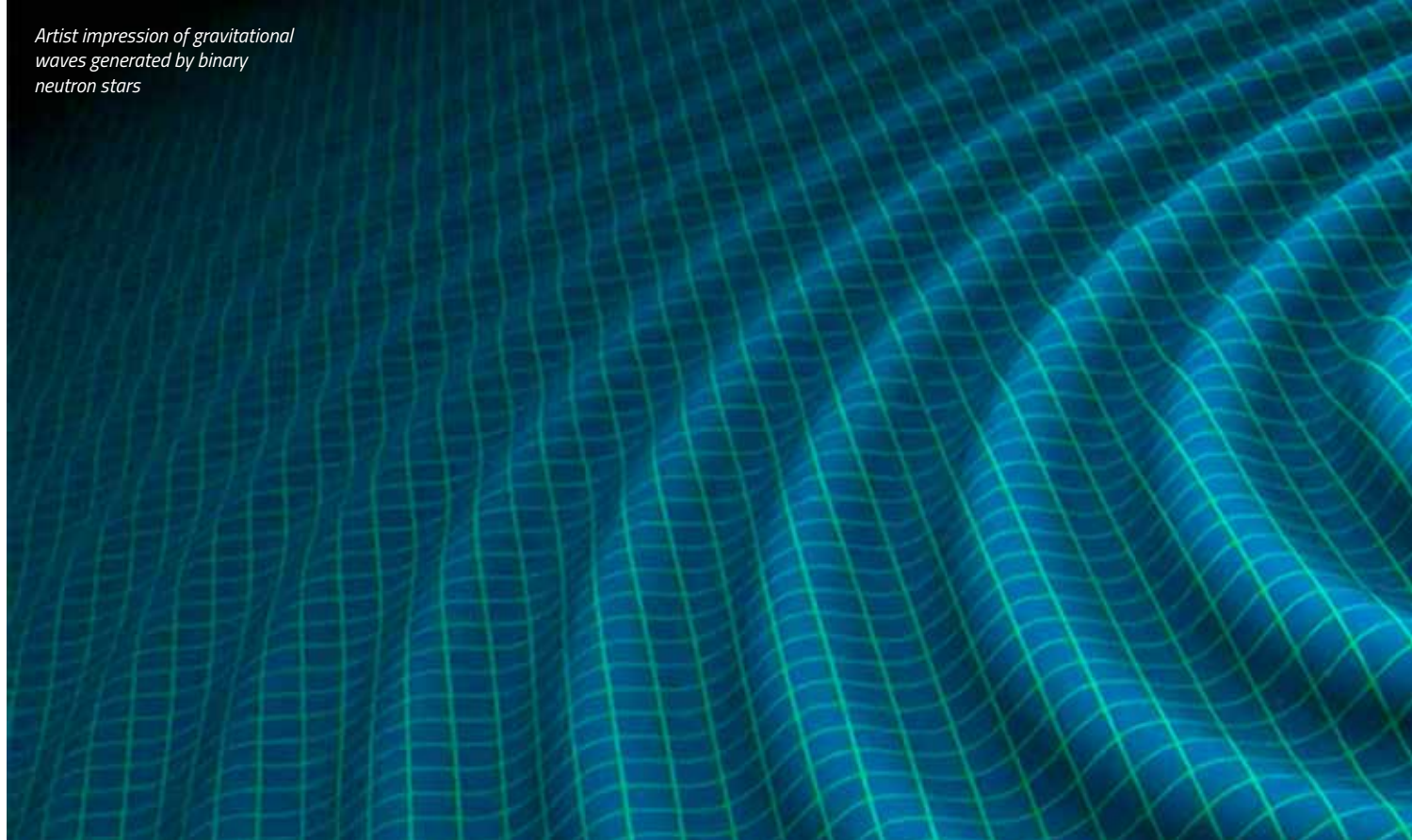
Unlike telescopes, which are pointed toward very specific parts of the sky, detectors like LIGO scan a much larger area of the Universe and hear sources from all directions. “Gravitational waves

Image courtesy of LIGO / Penn State; image source: Flickr



Aerial view of the LIGO gravitational-wave detector in Livingston, Louisiana

*Artist impression of gravitational waves generated by binary neutron stars*



detectors are like microphones”, says Laura Nuttall, a post-doctoral researcher at Syracuse University, USA.

## First detections

On that September morning in 2015, when the first gravitational wave passed through the two detectors, LIGO was still preparing for an observational run. Researchers were still running tests and diagnostics during the day – which is why they needed to conduct a large number of checks and analyses to make sure the signal was real.

Months later, once researchers had meticulously checked the data for errors or noise (such as lightning or earthquakes), the LIGO collaboration announced to the world that they had finally reached a long-anticipated goal: almost 100 years after Einstein first predicted the existence of gravitation waves, scientists had detected them.

A few months after the first signal arrived, LIGO detected yet another

black-hole collision. “Finding a second one proves that there’s a population of sources that will produce detectable gravitational waves”, Nuttall says. “We are actually an observatory now.”

## Cosmic microphones

Many have dubbed the detection as the dawn of the age of gravitational-wave astronomy. Scientists expect to see hundreds, maybe even thousands, of these binary black holes in the years to come. Gravitational-wave detectors will also allow astronomers to look much more closely at other astronomical phenomena, such as neutron stars, supernovae and even the Big Bang.

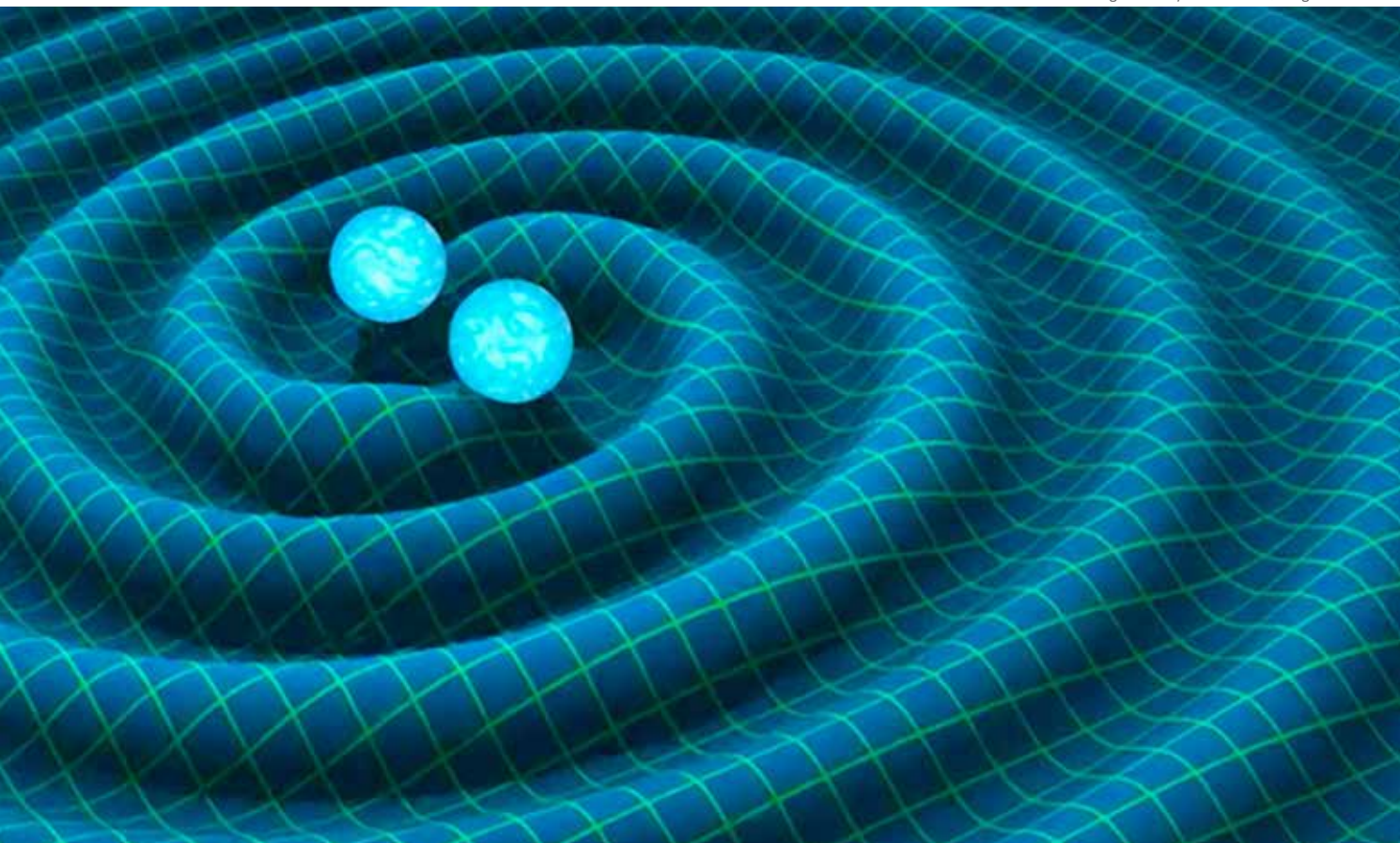
One important next step is to detect the optical counterparts – such as light from the surrounding matter or gamma-ray bursts – of the sources of gravitational waves. To do this, astronomers need to point their telescopes to the area of the sky where the gravitational waves came from to find any detectable light.

Currently, this feat is like finding a needle in a haystack. Because the field of view of gravitational-wave detectors is much, much larger than telescopes, it is extremely difficult to connect the two. “Connecting gravitational waves with light for the first time will be such an important discovery that it’s definitely worth the effort”, says Edo Berger, an astronomy professor at Harvard University.

LIGO is only one of several gravitational-wave observatories. Other ground-based observatories, such as Virgo in Italy, KAGRA in Japan and the future LIGO India have similar sensitivities to LIGO. There are also other approaches that scientists are using – and plan to use in the future – to detect gravitational waves at completely different frequencies.

The evolved Laser Interferometer Space Antenna (eLISA), for example, is a gravitational-wave detector that physicists plan to build in space. Once complete, eLISA will be composed of

Image courtesy of Penn State; image source: Flickr



three spacecraft that are over a million kilometres apart, making it sensitive to much lower gravitational-wave frequencies, where scientists expect to detect supermassive black holes.

Pulsar array timing is a completely different method of detection. Pulsars are natural timekeepers, regularly emitting beams of electromagnetic radiation. Astronomers carefully measure the arrival time of the pulses to find discrepancies, because when a gravitational wave passes by, space-time warps, changing the distance between us and the pulsar, causing the pulses to arrive slightly earlier or later. This method is sensitive to even lower frequencies than eLISA can detect.

These and many other observatories will reveal a new view of the Universe, helping scientists to study phenomena such as merging black holes, to test theories of gravity and possibly even to discover something completely unexpected, says Daniel Holz, a professor of physics and astronomy

at the University of Chicago. “Usually in science you’re just pushing the boundaries a little bit, but in this case, we’re opening up a whole new frontier.”

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Diana is a freelance science journalist based in Berlin, Germany. Her work has appeared both in print and online in numerous outlets including *Scientific American*, *Quartz* and *New Scientist*.

### Acknowledgement

This article is reproduced with kind permission of *Symmetry* magazine<sup>w1</sup>, in which it was originally published.

### Web reference

<sup>w1</sup> *Symmetry* magazine is a free online publication covering particle physics. It is jointly published by Fermi National Accelerator Laboratory and SLAC National Accelerator Laboratory, USA. See: [www.symmetrymagazine.org](http://www.symmetrymagazine.org)



# Climate change: why the oceans matter

The role of our oceans in climate change is more complicated than you might think.

By Tim Harrison, Anwar Khan and Dudley Shallcross

The world's oceans are truly vast, covering 71% of Earth's surface and containing 97% of Earth's water. If we are concerned about factors that affect the global climate, we need to look at the oceans as well.

As with most areas of climate change (that is, a change in the average surface temperature of Earth), the role that oceans play is complex. The main factors involved are ocean-generated compounds (including water vapour) escaping into the atmosphere; carbon dioxide dissolving in sea water; and the role of the oceans as a heat sink.

## Water vapour: warming or cooling?

When we think about gases involved in climate change, we generally think of carbon dioxide and perhaps some other gases in the atmosphere such as methane. These gases contribute to the greenhouse effect by absorbing and trapping infrared energy (heat) from Earth's surface. In fact,



- ✓ Biology
- ✓ Chemistry
- ✓ Earth science
- ✓ Ages 16–19

REVIEW

This article provides a clear overview of the role oceans play in climate change. In particular, the article discusses the effect of compounds such as water vapour, the potential runaway greenhouse effect of dissolved CO<sub>2</sub>, and the differential heat capacity of oceans and the atmosphere. The article can be used to link chemistry, biology and earth science, and covers topics such as the greenhouse effect and the water cycle.

Enrico Capaccio,  
Liceo S Bellarmino, Italy



Image courtesy of Dirk Dallas; image source: Flickr

the most potent greenhouse gas in the atmosphere is not any of these, but simply H<sub>2</sub>O in the form of water vapour (figure 1).

Water vapour in the atmosphere absorbs 36–85% of Earth’s outgoing infrared energy, compared with the much lower figures of 9–26% absorbed by carbon dioxide (CO<sub>2</sub>) and 4–9% by methane (CH<sub>4</sub>). The main source of atmospheric water vapour is evaporation from the oceans.

Although water vapour has a large effect on how much heat our planet retains, it has an impact on climate only because of the warming effect of other greenhouse gases such as CO<sub>2</sub> and CH<sub>4</sub>. If there were no such greenhouse gases in the atmosphere, the average surface temperature of Earth would be much colder – around -18 °C – and very little water would evaporate into the atmosphere. The presence of greenhouse gases in the atmosphere increases the surface temperature of Earth, which leads to water evaporating. This in turn increases warming further, due to the greenhouse effect of water vapour, and so on. This ‘vicious cycle’,

where different factors exacerbate each other, is called a positive feedback loop.

But water vapour also has a reverse effect: more water vapour in the air means more clouds. Clouds reflect much of the incoming sunlight back into space, producing a cooling effect that moves the global climate in the opposite direction to the greenhouse effect. At present, the net effect of clouds is to cool Earth’s surface by about 5 °C, but we do not know which of these two competing factors – the warming or cooling effect of water vapour – would dominate in a warmer climate.

### Other ocean compounds

In addition to water vapour, the oceans release other compounds into the atmosphere that contribute to climate change. Some compounds that escape from the oceans create tiny particles in the atmosphere, which act as cloud seeds, allowing water vapour to condense and form clouds.

One of the most important cloud-seeding compounds in the atmosphere is dimethyl sulfide (CH<sub>3</sub>SCH<sub>3</sub>), a sulfur compound produced by phytoplankton (plant-like plankton) in the oceans. It evaporates easily into the atmosphere, where it oxidises to form sulfur dioxide (SO<sub>2</sub>) and methane sulfonic acid (MSA). The sulfur dioxide combines with water in the atmosphere to form sulfuric acid, yielding sulfate ions, SO<sub>4</sub><sup>2-</sup>. These and the MSA are very effective seeding agents, allowing water vapour to condense into droplets, leading to cloud formation.

Another group of compounds that enter the atmosphere from the oceans are the organohalogens – for example methyl chloride (CH<sub>3</sub>Cl). Like their synthetic counterparts (for example, chlorofluorocarbons, or CFCs), organohalogens promote the breakdown of ozone in the stratosphere by taking part in photochemical reactions with

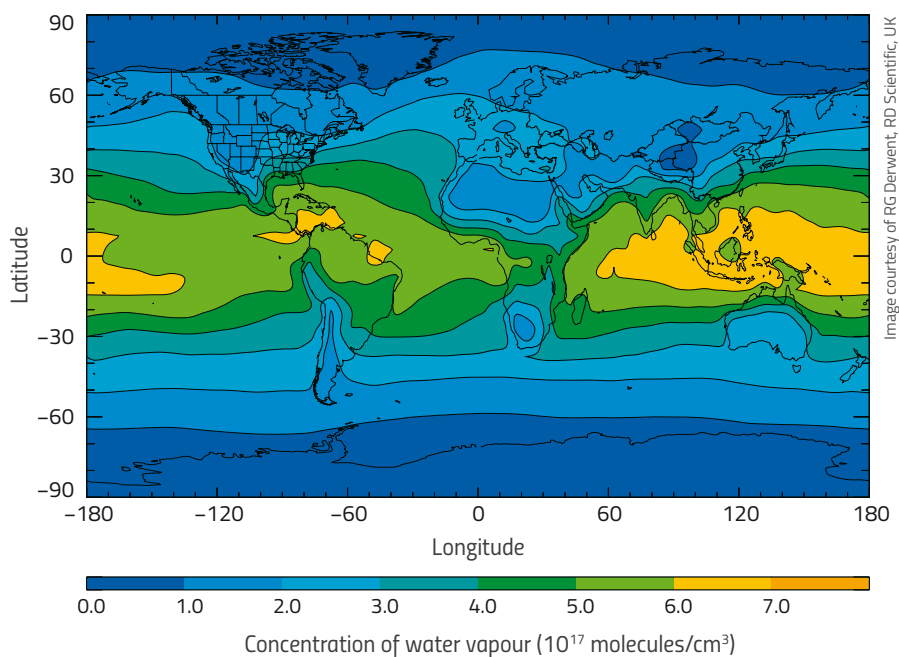


Image courtesy of RG Derwent, RD Scientific, UK

Figure 1: annual average water vapour concentrations across the world at surface level

ozone. Ozone has an important role in absorbing incoming solar radiation and helping to protect us against UV light, but it is also a potent greenhouse gas – and, like carbon dioxide, is produced by human activity. In fact, the increase in ozone levels since the introduction of industrialisation over the past 200 years is responsible for some 15% of the entire anthropogenic (human-caused) greenhouse effect. Ocean-generated organohalogen compounds thus contribute to a reduction in global warming by reducing the concentration of ozone in the atmosphere.

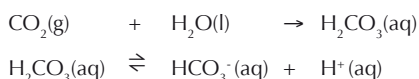
## Dissolved CO<sub>2</sub>: the runaway greenhouse effect

The oceans also have a vital role in absorbing CO<sub>2</sub>. Carbon dioxide released by the burning of fossil fuels and other human activities as well as from the biosphere is absorbed either in the atmosphere or in the oceans. Although Earth's atmosphere contains some 3 trillion (3 × 10<sup>12</sup>) tonnes of carbon dioxide, about 50 times more CO<sub>2</sub> is present in the oceans.

At the ocean surface, carbon dioxide from the atmosphere dissolves in the water. There, it reacts with water



to form carbonic acid (H<sub>2</sub>CO<sub>3</sub>), hydrogencarbonate (bicarbonate, HCO<sub>3</sub><sup>-</sup>) and carbonate (CO<sub>3</sub><sup>2-</sup>) ions:



These reactions reduce the amount of dissolved CO<sub>2</sub>, so more CO<sub>2</sub> is absorbed from the atmosphere.

Dissolved CO<sub>2</sub> at the surface is then dispersed through the ocean depths by a process called the solubility pump. Because CO<sub>2</sub> is more soluble in cold water than in warm water (figure 2), and the ocean depths are colder than the surface, CO<sub>2</sub> is drawn away from the surface into deeper water.

If there is an increase in ocean temperature due to climate change, then more carbon dioxide will be released due to its lower solubility at higher temperatures. The extra CO<sub>2</sub> would contribute to the greenhouse effect, increasing the ocean temperature still more and releasing yet more carbon dioxide, and so on – creating another positive feedback loop and leading potentially to a runaway greenhouse effect.

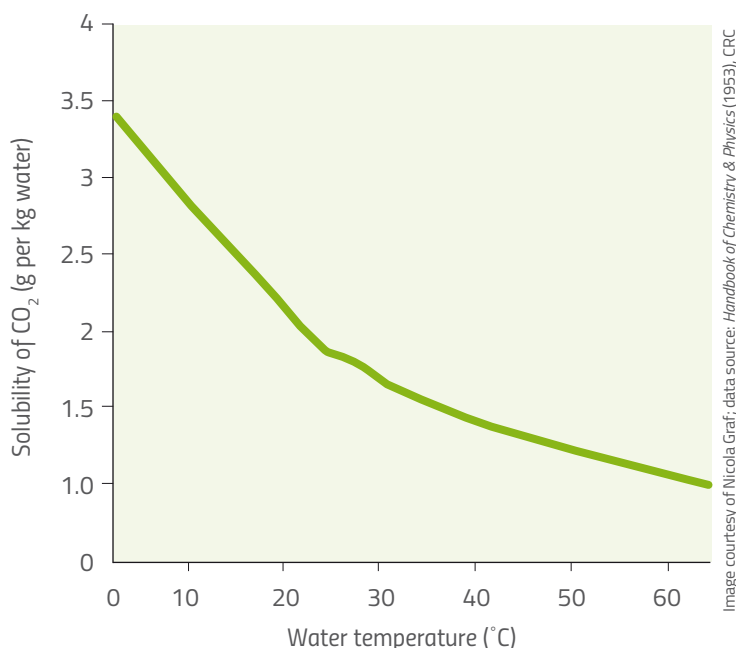


Image courtesy of Nicola Graf; data source: Handbook of Chemistry & Physics (1953), CRC

Figure 2: the solubility of carbon dioxide falls with increasing temperature

## Soaking up heat

The sheer vastness of the oceans is a key factor in their role in climate change. It determines how much of the excess heat produced by global warming can be taken up by the oceans – much more in fact than by the atmosphere.

We can do a calculation to compare the temperature rise of the oceans and the atmosphere when the same amount

of heat is added to both (see box). This calculation reveals that the heat capacity of the oceans is approximately 1000 times that of the atmosphere, so the oceans will show a much lower rise in temperature for the same amount of heat energy absorbed. This means that the timescales for climate change are driven primarily by the ocean's thermal mass, not by that of the atmosphere. Of course, this doesn't mean that temperature will not rise – but it does mean that the timescale will be much longer than has generally been assumed.

## Oceans and the future

So what role *do* the oceans play in climate change? The answer is complex. Compounds released from the oceans can contribute both to climate heating, by acting as greenhouse gases, and to climate cooling, by increasing cloud. The oceans themselves can absorb heat energy and act as a sink for carbon dioxide – but as the water temperatures rise, a positive feedback loop can occur. As yet, the net impact of our oceans on climate change is unclear, but scientists

continue to study all these systems so that as more complex models are developed, we gain a better idea of the future of our planet.

All authors are from the School of Chemistry at the University of Bristol, UK. Tim Harrison is the Science Communicator in Residence, Dudley Shallcross is the Professor of Atmospheric Chemistry and Anwar Khan is the Senior Research Associate of the Atmospheric Chemistry Research Group.

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## Resources

Visit the NASA website to find out more about the effect of water vapour on climate change. See: [www.nasa.gov/topics/earth/features/vapor\\_warming.html](http://www.nasa.gov/topics/earth/features/vapor_warming.html)

For further calculations relating to climate change for advanced physics students, see: Harrison T, Shallcross D (2008) Climate change modelling in the classroom. *Science in School* **9**: 28–33. [www.scienceinschool.org/2008/issue9/climate](http://www.scienceinschool.org/2008/issue9/climate)

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

To learn more about ozone in the atmosphere, see:

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

To learn more about cloud seeding, see:

Ranero Celius K (2010) Clouds: puzzling pieces of climate. *Science in School* **17**: 54–59. [www.scienceinschool.org/2010/issue17/clouds](http://www.scienceinschool.org/2010/issue17/clouds)



## Warming the world: a calculation

We can compare how the temperature of the atmosphere and the oceans would rise if the same amount of heat energy were added to both. To keep things simple, we will use approximate figures throughout. (The heat capacity of a substance is the amount of energy needed to raise the temperature of each kilogram by one kelvin (K) – which is the same as one degree Celsius.)

Mass of Earth's oceans	= 1.3 × 10 <sup>21</sup> kg
Heat capacity of seawater	~ 4.0 × 10 <sup>3</sup> J kg <sup>-1</sup> K <sup>-1</sup>
Heat capacity of the oceans	~ 1.3 × 4.0 × 10 <sup>24</sup> = 5.2 × 10 <sup>24</sup> J K <sup>-1</sup>

So, 5.2 × 10<sup>24</sup> J of energy would be needed to raise the temperature of the oceans by 1 K.

Compare this with the heat capacity of the atmosphere:

Mass of Earth's atmosphere	= 5.1 × 10 <sup>18</sup> kg
Heat capacity of air	~ 1.0 × 10 <sup>3</sup> J kg <sup>-1</sup> K <sup>-1</sup>
Heat capacity of the atmosphere	~ 5.1 × 1.0 × 10 <sup>21</sup> = 5.1 × 10 <sup>21</sup> J K <sup>-1</sup>

So, about 5 × 10<sup>21</sup> J of energy would be needed to raise the temperature of the atmosphere by 1 K.

So we can see that the ratio:

$$\frac{\text{Heat capacity of oceans}}{\text{Heat capacity of atmosphere}} = \frac{5.2 \times 10^{24}}{5.1 \times 10^{21}} = \sim 1000 \text{ J K}^{-1}$$

This means that, at a heating rate of 1 W (1 J s<sup>-1</sup>) per square metre across Earth's surface (about 5.1 × 10<sup>8</sup> km<sup>2</sup>), it would take about 116 days to cause a rise in temperature of 1 K (or 1 °C) in the atmosphere – but 324 years to cause the same rise in ocean temperature.

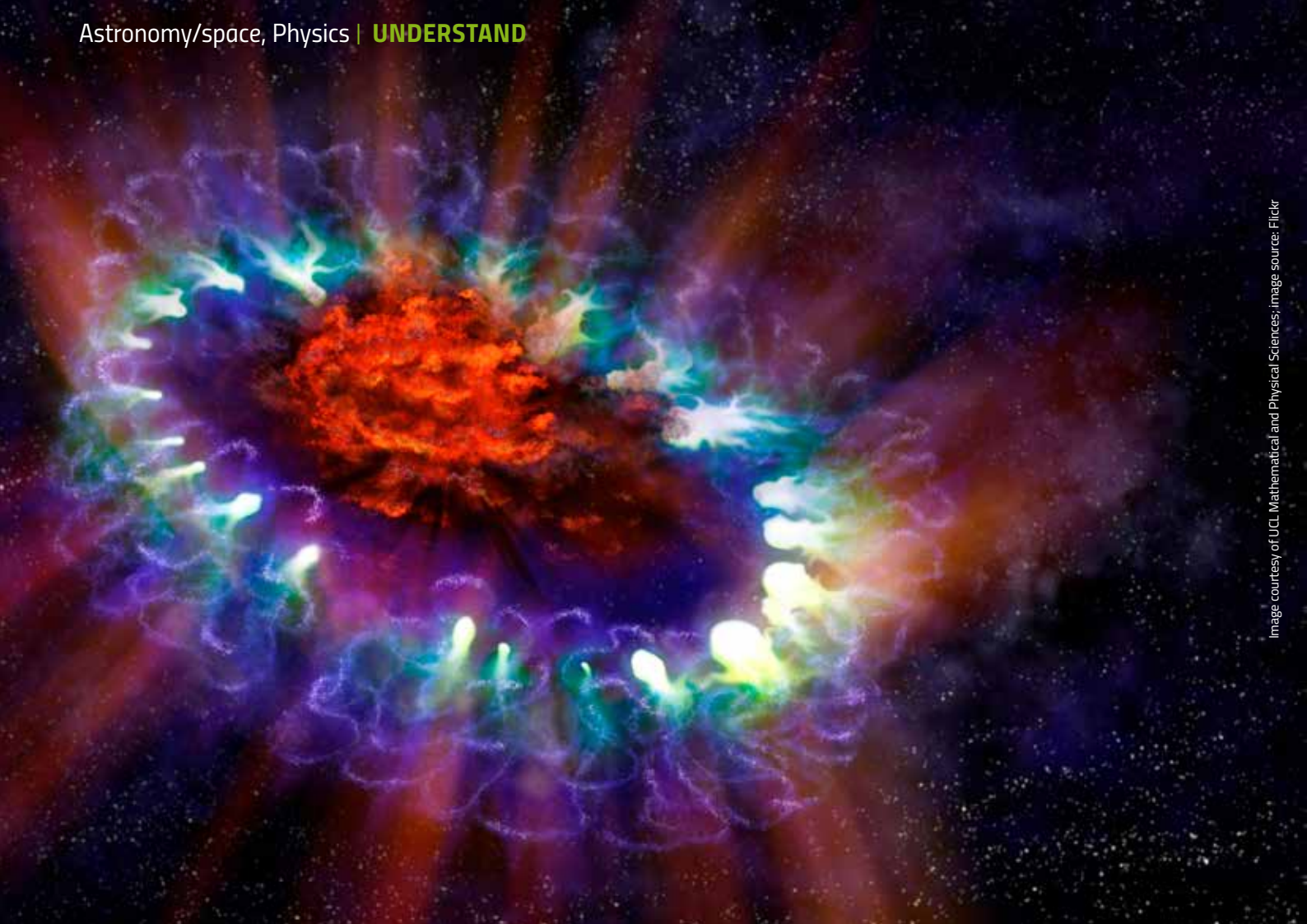


Image courtesy of UCL Mathematical and Physical Sciences; image source: Flickr

Artist's illustration of Supernova 1987A

# Science goes underground

Scientists are searching deep underground for hard-to-detect particles that stream across the Universe.

By Susana Cebrián

Imagine you are in a noisy, crowded street in the heart of a big city. A bird, perched high up, chirps – but would you hear it? Probably not: it would be hard to pick out the bird's song from the sounds all around you – cars, machines, people's voices and so on. Scientists have a similar problem when they are trying to detect particles from space that have travelled to Earth: the weak signals from these 'astroparticles' are completely masked by stronger signals from other sources, such as environmental radioactivity.

You might expect that a good way to overcome this problem would be to position astroparticle detectors at high altitudes, but in fact the opposite can be very effective too: the best place for detecting some astroparticles is actually deep underground. This is because the hundreds of metres of rock

above help to cut out the unwanted 'noise' at Earth's surface.

But why are scientists interested in astroparticles anyway? These elementary particles of astronomical origin are produced in stars (such as the Sun), in supernova explosions and in even more exotic phenomena such as gamma-ray bursts. Often called messengers of the Universe, astroparticles provide information about events hugely distant in time and space – including the Big Bang itself.

## Working underground

There are about 10 deep underground laboratories in the world, all of which are devoted primarily to hunting for astroparticles (Bettini, 2012). Working at this type of facility



Image courtesy of Francesco Arneodo

can be hard. To access laboratories located in mines, a journey in a lift cage is needed, with coming and going timed to fit in with the miners' shifts; work must therefore be very carefully programmed. In the clean areas, humidity and temperature are closely regulated, so workers need to take a shower and change their clothes before entering. And, of course, there are no windows to let in the sunshine.

### The hunt for elusive particles

Many underground laboratories currently focus on hunting for the most elusive type of materials: neutrino particles and dark matter. While these are both abundant in the Universe, they have such weak interactions with 'normal' matter that they are impossible to detect in the outside world, and only very rarely underground.

### Neutrinos: very important particles

Neutrinos are the second most numerous particle in the Universe (after photons – particles of light). Every square centimetre of Earth's surface is hit by  $10^{11}$  neutrinos every second, most of which arrive from the Sun.

Neutrinos are produced in stars and within nuclear reactors, and are also found in cosmic rays. Sometimes called 'ghost particles', they rarely interact with matter and just pass straight through – so despite their vast numbers, detecting neutrinos is extremely challenging. For instance, only a few neutrino detections per month are usually expected, even using enormous detectors. Neutrinos are potentially very important messengers, however, because they can travel without hindrance across the Universe, through places from which no other particles can escape – such as black holes, which trap even light. As they do so, they bring with them valuable information.

In 1987, some underground observatories were amazed to register several neutrinos in just a few seconds; they had witnessed the neutrino signal from supernova 1987A, in the Large Magellanic Cloud (Nakahata, 2007).



Hall C of the Gran Sasso Laboratory, Italy, with the OPERA (Oscillation Project with Emulsion tRacking Apparatus) experiment installed



REVIEW

- ✓ Physics
- ✓ Astrophysics
- ✓ Particle physics
- ✓ Radioactivity
- ✓ Ages 14–19

This article is a must-read as it sheds light on the properties of neutrinos and the valuable information that scientists obtain by studying these particles from sites deep underground. The article highlights the fact that there is still so much left to be discovered within particle physics.

The article can be used as a comprehension exercise about some of the properties of the neutrino itself, and what studying neutrinos can reveal about our universe. It can also be used as an introductory article to trigger the curiosity of educators and students alike, and prompt more research about the subject.

Questions on the topic could include:

- What information is currently available about the properties of neutrinos?
- Why are neutrinos being researched in underground laboratories?
- Where and how are neutrinos produced?
- What are the three types of neutrinos, and what is interesting about them?

Catherine Cutajar, St Martin's College, Malta



## The world's underground laboratories

This map shows the location of some of the most relevant deep underground facilities around the world. There are also similar underground facilities in Finland, Japan, Russia, Ukraine and the USA, and there are plans to build new ones in Australia, India and South America.

- Laboratori Nazionali del Gran Sasso (LNGS), the world's largest underground laboratory, is located in a highway tunnel 120 km from Rome, Italy.
- Three other mid-size underground laboratories have been active in Europe since the 1980s: Boulby Laboratory on the north-east coast of England, UK; Modane Laboratory in the French Alps; and Canfranc Laboratory under the Spanish Pyrenees.
- Sandford Underground Research Facility was built in a former gold mine in South Dakota, USA. This pioneer underground laboratory was where the first studies of

solar neutrinos were carried out in the 1960s (Rosen, 2006).

- SNOlab (Sudbury Neutrino Observatory), near Sudbury in Ontario, Canada, is located in a working nickel mine. The laboratory is one of the deepest in the world, at 2100 m below ground.
- JinPing Laboratory is located within the tunnels of a hydroelectric power company in Sichuan province, China. At 2400 m beneath JinPing mountain, it is the world record holder for depth beneath the Earth's surface.
- Kamioka Laboratory in Kamioka-cho, Gifu, Japan, has the world's largest underground neutrino detector. Groundbreaking neutrino experiments have been carried out at this lab over the past two decades.



Image courtesy of Susana Cebrían

As 99% of the energy liberated in a supernova is thought to be radiated away in the form of neutrinos, their detection provided much information about what actually happens when a star collapses. Neutrinos produced by radioactive beta decays within Earth have also been detected: these

geoneutrinos could become a priceless tool for geophysics (Bellini et al., 2011), as they provide information about the size and location of radioactive sources within Earth's interior, where access is completely impossible.

Neutrinos from the Sun puzzled scientists for several decades. The

number of neutrinos detected overall was much lower than scientists expected the Sun to produce, based on detailed calculations of nuclear fusion processes. The problem was solved in 2001 when it was found that neutrinos, which exist in three types called 'flavours', can flip from one type

Image courtesy of Lawrence Berkeley Nat'l Lab - Roy Kaltschmidt; image source: Flickr

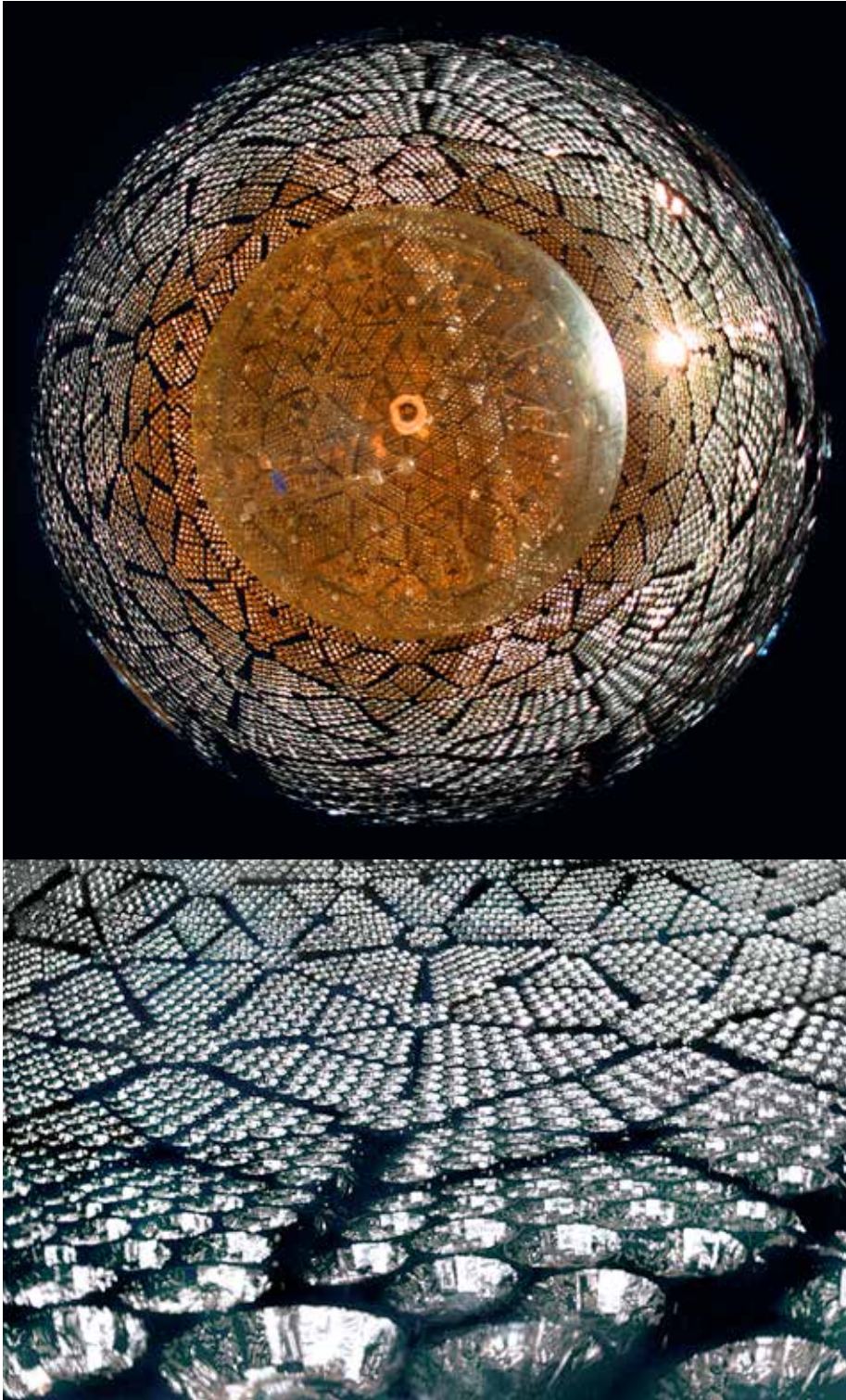


Image courtesy of Lawrence Berkeley Nat'l Lab - Roy Kaltschmidt; image source: Flickr

A total of 9522 ultra-sensitive light sensors are attached to the sphere of the SNOlab neutrino detector.

to another in a process called neutrino oscillation (Jelley & Poon, 2007). This is as if you throw an apple to someone – who catches it as an orange or a pear. The puzzle originated because the first experiments measured only one type of neutrino (the ‘apples’) – the form in which solar neutrinos are produced, but

any neutrinos that flipped to another type were not detected.

This effect has also been observed in neutrinos from other sources, such as cosmic rays, nuclear reactors and research facilities. In 2015, the Nobel Prize in Physics<sup>w1</sup> was awarded to Takaaki Kajita and Arthur McDonald for

their work on neutrino oscillations in Kamioka laboratory (Japan) and SNOlab (Canada).

Neutrino oscillation is important in another way: it confirms that neutrinos have some mass. This is because, as quantum mechanics tells us, such oscillations can only happen if particles have non-zero mass. Observing this in neutrinos was the first evidence of a flaw in the successful ‘standard model’ of particle physics.

### The mystery of dark matter

Despite impressive achievements in cosmology, astrophysics and particle physics in recent years, the composition of most of the Universe is still a mystery. One-quarter of the Universe is thought to be made of ‘dark matter’ – so called because it neither emits nor absorbs electromagnetic radiation (including light, radio waves and X-rays). For this reason, dark matter has not yet been detected, despite the huge amount thought to exist. Dark-matter interactions are expected to be extremely rare: just a few events per year in a very large underground detector. There have been positive hints, like those observed by the DAMA / LIBRA experiment in the Gran Sasso laboratory – but no direct detection as yet, so efforts continue (Reich, 2013; Livio & Silk, 2014).

### Science in the subterranean domain

Particle astrophysics is the main focus for underground laboratories, but their unique features mean they are increasingly used in other areas of science as well. Biologists use them to investigate how micro-organisms can survive in the extreme conditions deep underground, and long-term precision measurements are now carried out for seismology, hydrology and geodynamics. Even space technologies developed for the exploration of Mars are being tested underground, at the Boulby Laboratory (UK), exploiting the similarities between the environments

Image courtesy of Kamioka Observatory / The Institute for Cosmic Ray Research / The University of Tokyo

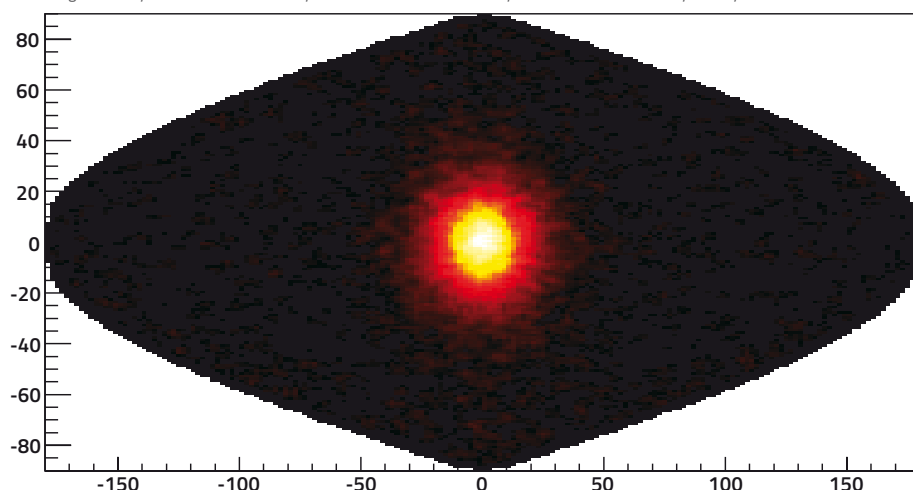


Image from Japan's Kamioka underground laboratory showing the directional intensity of neutrinos. The highest intensity (at the centre) is the direction of the Sun.

below the surface of Mars and in the deep, rock-salt caverns of the Boulby mine. So while the cosmic silence found deep underground is helping to improve our understanding of the distant reaches of the Universe – its origin, composition and final fate – these special laboratories are also allowing us to study, close up, other worlds deep beneath our feet.

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

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*Nature* **494**: 291-292

Download the article free of charge on the *Science in School* website or subscribe to *Nature* today: [www.nature.com/subscribe](http://www.nature.com/subscribe).

Rosen SP (2006) Ray Davis: indefatigable neutrino pioneer. *CERN Courier* **46(7)**: 32-34

## Web reference

- w1 Learn more about the work that won Takaaki Kajita and Arthur McDonald the 2015 Nobel Prize in Physics. See: [www.nobelprize.org](http://www.nobelprize.org) or use the direct link: <http://tinyurl.com/zscha6s>

## Resources

- To discover what work at a subterranean laboratory is like, watch the video 'A day at SNOlab': [www.youtube.com/watch?v=sZPLCv-ASwc](http://www.youtube.com/watch?v=sZPLCv-ASwc)
- To learn more about the main underground laboratories in America, Asia and Europe, visit their websites:
- Boulby Underground Laboratory, UK: [www.boulby.stfc.ac.uk](http://www.boulby.stfc.ac.uk)
  - China JinPing underground Laboratory (CJPL), China: <http://jinping.hep.tsinghua.edu.cn>
  - Kamioka Observatory, Japan: [www-sk.icrr.u-tokyo.ac.jp](http://www-sk.icrr.u-tokyo.ac.jp)
  - Laboratoire Souterrain de Modane (LSM), France: [www-lsm.in2p3.fr](http://www-lsm.in2p3.fr)
  - Laboratori Nazionali del Gran Sasso (LNGS), Italy: <https://lngs.infn.it>
  - Laboratorio Subterráneo de Canfranc (LSC), Spain: [www.lsc-canfranc.es](http://www.lsc-canfranc.es)
  - Sanford Underground Research Facility, USA: [www.sanfordlab.org](http://www.sanfordlab.org)
  - SNOlab, Canada: [www.snolab.ca](http://www.snolab.ca)

Yangyang Underground Laboratory, Korea: <http://dmrc.snu.ac.kr/english/yylab/yylab.html>

The ASPERA European network for astroparticle physics provides an outreach website. See: [www.astroparticle.org](http://www.astroparticle.org)

Visit the Physics World website for a video in which Arthur McDonald, 2015 Nobel laureate in physics, explains why physicists do experiments deep underground. See [www.physicsworld.com](http://www.physicsworld.com) or use the direct link: <http://tinyurl.com/z3snzwt>

To learn more about neutrinos and the standard model of particle physics, see:

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To find out more about the different areas of subterranean science, see:

Paling S, Sadler S (2015) Subterranean science. *Physics World* May 2015. [www.physicsworld.com](http://www.physicsworld.com)

To learn more about dark matter, see:

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# Life models

Model organisms – yeast, worms, flies and mice – help researchers to probe the secrets of life.

*The C. elegans worm survives well in close-packed conditions.*

By Francesca Torti

When we think of a model, we usually think of something smaller and simpler than the original – like a scale-model railway or a pocket-sized version of a classic car. But models are not always toys: maps are models that encode the details of a landscape, and architects and engineers build models to test their ideas before putting them into full-scale practice.

For decades, molecular biologists have used models in a similar way – studying simpler organisms in place of more complex species, including humans. Such ‘model organisms’ often seem to be quite unlike the species they are used to model. For example, *Caenorhabditis elegans* (usually known as *C. elegans*) is a worm that is only a millimetre long, and its lifestyle and appearance are of course nothing like those of humans – yet on a molecular scale it shares with us many fundamental processes of life. Studying *C. elegans* has led to many important findings that apply not only to that species, but to many others. For example, researchers used *C. elegans* to study the effects of beta-amyloid peptides, the molecules that build up in the brains of Alzheimer’s patients. This has helped to reveal some of the molecular mechanisms that underlie this disease.



- ✓ Biology
- ✓ Evolution
- ✓ Ages 16–19

## REVIEW

This article is a good starting point for any biology teacher wanting to discuss issues around the use of living organisms in science. It describes a range of species and techniques that help scientists to study biological processes, which can give insights into human diseases such as cancer. The article also highlights the fact that all life on Earth is related, and that the fundamental processes occurring in a simple organism, such as a worm, are similar to those in humans – something which may amaze your students.

In addition to the obvious way of using the article, as a source of information, there is a more subtle approach: an invitation to inquiry. Starting with the information provided, you could guide your students through a process of conjecture and research into the major trends of evolution, particularly the origin of life. For example:

- The trends from simple to complex and small to large
- The need to encode and store information (RNA and DNA)
- The emergence of self-organisation and (short) cycles of replication and reproduction.

Luis M Aires, Antonio Gedeao Secondary School, Portugal

## Different, but similar

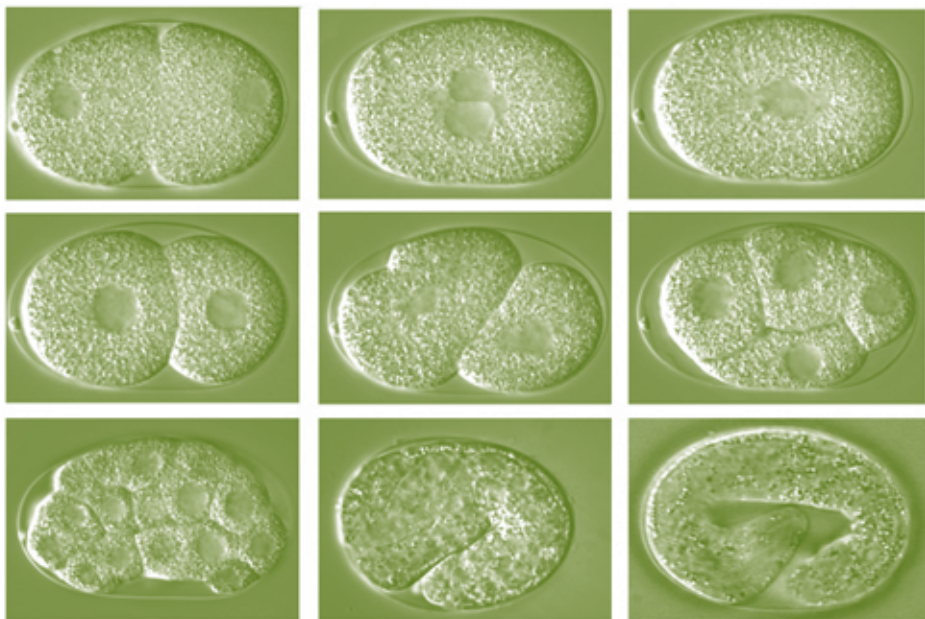
What is the underlying reason for such similarity across species? Comparing the genomes of many different species has revealed that the genes for many key biological functions have been conserved throughout evolution and are now found across species ranging from bacteria to mammals. So, although worms and humans diverged from a common ancestor millions of years ago, some 40% of the coding genes in the *C. elegans* genome have human counterparts.

The yeast *Saccharomyces cerevisiae*, a unicellular organism, is perhaps even more remote from humans – yet this model organism has been vitally important for cancer research. This is because the cell cycle – the set of processes through which cells grow and divide – is so fundamental to life that it has been preserved across all eukaryotic species, including yeast. The cell cycle is also crucial to how cancer cells replicate, so studying this cycle in yeast has led not only to increasing our understanding of a basic life process, but also to clinical benefits.

## What makes a good model organism?

Although every model organism has its own advantages, there are some features and advantages that most model organisms share. One of these is small size, as laboratory space is a limited resource. *C. elegans* scores highly here, as some 10 000 individuals can be kept in a single dish of 10 cm diameter. But perhaps the most important feature shared by all model organisms used in molecular biology, from the bacterium *Escherichia coli* to the laboratory mouse *Mus musculus*, is a very short generation time compared to humans. *C. elegans*, for example, grows from embryo to adult in just three days and has a lifespan of just two to three weeks. This means that experiments involving several generations can be carried out in weeks instead of years.

Image courtesy of Fabio Piano / NYU



Development of the worm *C. elegans* from embryo to larva within the eggshell. Fertilisation to hatching takes only about 12 hours.



## Model organisms around us

It's not necessary to work in a laboratory to encounter model organisms: some of the most important ones are part of our everyday life.

- *Escherichia coli* (*E. coli*) is a bacterium found in food and the guts of humans and animals. Most strains are harmless but some can cause food poisoning.
- *Saccharomyces cerevisiae* is the yeast commonly used for baking bread or for brewing beer.
- *Arabidopsis thaliana* (thale cress), the main model organism for plant biology, is a small flowering plant that grows by roadsides and in pavement cracks.
- *Drosophila melanogaster* is the common fruit fly that we sometimes find in our kitchens.
- *Danio rerio* (zebrafish), a tropical freshwater fish, is a popular and colourful choice for aquariums.
- *Mus musculus* is the house mouse, which is also sometimes kept as a pet.

### BACKGROUND



Danio rerio (zebrafish)

Image courtesy of Thierry Marysaël; image source: Flickr

Using a simpler organism as a model is often an advantage in itself, as it generally makes experiments simpler. For example, the fruit fly *Drosophila melanogaster* has only four pairs of chromosomes while humans have 23, so *Drosophila* became a favourite model organism early on for studying how genes are transmitted across generations. It is also a favourite for research linking genetics to behaviour, as it shares with humans and other mammals some important behavioural genes. For example, researchers use *Drosophila* to investigate the circadian rhythm – the complex biological mechanism that tells us (and flies) when to wake up or sleep. There are fewer factors that influence sleep / wake behaviour in *Drosophila* than

in humans, so it provides a useful simplified model.

Genetic similarity can be another important advantage. The genome of the mouse *Mus musculus* is similar in size to the human genome, and almost every human gene has a mouse counterpart – which is one reason why this species is so widely used as a model, particularly for human diseases. But sometimes, dissimilarity can also be an advantage: researchers used *C. elegans* to investigate a human kidney disease with a known genetic cause – even though this species has no kidneys. This meant the organism could stay healthy with the faulty disease-causing gene inserted into its genome, allowing the biochemical pathway that inflicts the damage in humans to be worked out.

Ultimately, the choice of one model organism over another is based on the particular question that researchers wish to investigate. The completely transparent body of *C. elegans*, for example, is another advantage in developmental biology research: we can observe how every single cell develops in a few days from the fertilised egg, using a simple microscope.

## Gene technology and the future

Today, continuing improvements in gene editing techniques, combined with information from fully sequenced genomes, are making it increasingly easy to modify the genetic information within living organisms very precisely.

Image courtesy of NIAID; image source: Wikimedia Commons



*Escherichia coli* (*E. coli*)

Image courtesy of Marie-Lan Nguyen; image source: Wikimedia Commons



*Arabidopsis thaliana* (*thale cress*)

Image courtesy of Gustavo Leite; image source: Wikimedia Commons



*Saccharomyces cerevisiae* (*yeast*)

Image courtesy of André Karwath; image source: Wikimedia Commons



*Drosophila melanogaster*  
(*common fruit fly*)

CLUSTAL O(1.2.4) multiple sequence alignment



Image courtesy of EMBL-EBI

One of the techniques used in bioinformatics is sequence alignment, which allows us to identify common biological sequences shared by different species. This example compares the amino-acid sequence of a protein (cytochrome c) in Arabidopsis, Drosophila, human (Homo) and mouse (Mus).

Human genes can now be inserted into other organisms that are genetically or anatomically quite different, thus reducing the need to work with species whose genomes are very similar in nature to our own. In addition, bioinformatics – the application of data processing techniques to biology – can now tell us exactly which genes are shared between humans and model organisms.

Together, these technologies provide limitless scope for exploring the causal links between genes and human disease in simple model organisms. Alongside these potential medical benefits, researchers are also exploring new frontiers of knowledge in the science of life, and the common biological systems that connect all living beings.

### Resources

- The website of the international modENCODE project explains how and why model organisms are important in human biology, health and disease. See: <http://modencode.sciencemag.org>
- To watch the development of *C. elegans* for yourself, visit the website of the University of North Carolina at Chapel Hill. See: <http://labs.bio.unc.edu/Goldstein/movies.html>
- The WormClassroom website offers learning materials about *C. elegans* for teachers and questions for students. See: [www.wormclassroom.org](http://www.wormclassroom.org)
- The BioInteractive website provides free multimedia science education resources and classroom activities about evolution. See: [www.hhmi.org/biointeractive/evolution-collection](http://www.hhmi.org/biointeractive/evolution-collection)
- To learn more about the evolutionary relationships between model organisms, see: Hedges SB (2002) The origin and evolution of model organisms. *Nature Reviews Genetics* 3: 838-849. doi:10.1038/nrg929



Francesca Torti trained as a pharmaceutical chemist in Italy, before working in clinical and basic research in Italy, the USA and Germany. She currently lives in Berlin, Germany, and is passionate about communicating science to a general audience.



# Where are all the LGBT scientists? Sexuality and gender identity in science

Do LGBT scientists feel they can be 'out and proud' at work? A biophysicist reflects on his own and other LGBT scientists' experiences.

By Joseph D Unsay

Careers in science are not traditional tracks that LGBT (lesbian, gay, bisexual and transgender) people pursue. Certainly this is the image presented by the media, where LGBT people are often portrayed as working in the entertainment and fashion industries. Lists of powerful LGBT individuals confirm this image: for example, a UK newspaper's World Pride Power List in 2014<sup>w1</sup> contained only



- ✓ General science
- ✓ Careers
- ✓ English
- ✓ Social science
- ✓ Ages 14-19

REVIEW

In our modern world, we should embrace diversity in all aspects of life, including studies and careers. This article may give students and teachers pause for thought about issues they had not previously considered. The experiences described show that, although we live in an 'open' society, people may still need encouragement to be true to themselves.

Marie Walsh, Republic of Ireland



one person – out of 100 – in a science-related occupation: a celebrity doctor. This seems striking, even taking into account the low visibility of science in popular media generally.

My own story reflects this. In the Philippines, where I grew up, being gay is often connected to working as a hairdresser or serving as comic relief in shows and movies. This stereotype of LGBT people didn't appeal to me. In primary school, I was the nerdy, fat kid, and I got my share of bullying for being different. However, being nerdy also meant that I got good grades – good enough to get me into a prestigious high school.

At the Philippine Science High School, students were extensively trained in mathematics and science and were encouraged to take STEM (science, technology, engineering and maths) courses at university. We thrived in an environment that celebrated critical thinking and self-expression, and I gained self-esteem and confidence in being different – and in being gay, which helped me come out, initially to a few friends.

I officially came out in 2003 while in university, where I was able to express myself openly in an accepting environment. After obtaining my bachelor's and master's degrees,

I moved from the Philippines to Heidelberg, Germany, for my PhD. This move initially made me wonder how gay-friendly Germany would be, but fortunately it was not a problem, and I have even found LGBT mentors and friends in the scientific community.

So while I am personally able to live and work in an accepting environment, I often ask myself: is this the same for most gay people? Where are the other LGBT scientists? I decided to find out, and to ask these scientists to tell me their own stories.

## Sarah's story

Professor Sarah Veatch, an assistant professor of biophysics and physics at the University of Michigan, USA, came out early in her career. She was involved in her high school's gay-straight alliance in the mid-1990s, but still struggled with her LGBT identity until college at the Massachusetts Institute of Technology (MIT).

At MIT, Sarah started playing rugby, which helped her come to terms with her identity, as she found it easy to fit in as "one of the guys". In a male-dominated class, her more masculine demeanour helped put her on an equal footing with male classmates and also discouraged romantic interactions. Today, she feels this same approach helps her interactions with colleagues now that she is in a more senior scientific position. Physics, after all, is still male-dominated.

Many of her straight women peers worried about balancing family life with their scientific careers. But Sarah was never much concerned about this issue, as it didn't occur to her that she would one day be in a family playing a traditional gender role. Today, this issue is more complex as there are many options for same-sex couples to have children, although laws protecting the rights of same-sex couples are not yet adequate in many places.

Overall, Sarah is optimistic. "Society's perception of the LGBT community has changed a lot since I was deciding to pursue a career in academic science", she concludes. "It is much more mainstream [now], and I have benefitted from this." ■

## David's story

Professor David Smith's experience was mixed: he didn't feel able to come out as LGBT when he was growing up, but he faced few problems in the workplace once he did so.

When David was growing up in the UK in the 1980s, the atmosphere towards LGBT people was threatening and unwelcoming. "I witnessed homophobic slurs regularly, and would not have even considered coming out or exploring my sexuality", he says. While at secondary school, he didn't quite understand his LGBT identity because it was such a taboo to discuss it even with friends. This resulted in him not coming out until much later in his career, once he had obtained an academic position.

David, who currently works on supramolecular chemistry at the University of York in the UK, says he has not really experienced explicit homophobia in science. He says, "I would say scientists don't care that I am gay; it's a career I can thrive in." He is an advocate of more accessible science, and he has a YouTube channel<sup>w2</sup> where he uploads chemistry tutorials on everything from chocolate and curry to drugs.

David also gives seminars and writes about the importance of the visibility of LGBT scientists, as he believes visible LGBT role models capture the diverse experiences of different people and show young people what's possible for them. "It's easier to relate to someone who may have gone through the same experience", he says. ■

## Pauline's story

Many scientists are still afraid to come out in the workplace – and these fears are not unfounded, as Pauline Gagnon experienced. She studied in Montreal, Canada, and moved to the University of California in Santa Cruz, USA, for her PhD. Afterwards, Pauline obtained a position in Ottawa, Canada, and later at Indiana University, USA, which led her to work at CERN, in Switzerland. There, she worked on the ATLAS experiment, one of the experiments that famously confirmed the existence of the Higgs boson.

"I was completely out in California and Canada," she recalls, "but moving to CERN [in 1999], I experienced a different culture. It was more conservative there." She relates feeling excluded and discriminated against because of her sexual orientation. Several years later, however, some dynamic young people started an LGBT social group in CERN. "Having such a group made a difference; joining the LGBT group was a breath of fresh air", she says.

Aside from her scientific publications, Pauline has written a popular science book<sup>w3</sup> on particle physics and gender and sexuality issues in science, and she speaks publicly about women and diversity in science. "The best protection against homophobia is being out", she says. "Being out means I have nothing to hide; there's nothing wrong with me." Pauline believes that the more LGBT people are out, the faster attitudes will improve. "I paid a high price for it, but I could not have lived closeted", she says.

The president of the LGBT group at CERN, Alex Brown, also believes that the group's existence marks a change for the better, but cautions that changing attitudes does take time. To help achieve this, he would like to see more visible support for LGBT rights from non-LGBT people – not just at CERN, but more generally. "It means a lot to know we have allies who are prepared not only to accept us, but also to openly welcome us", he says. Alex believes that teachers can be key to nurturing this acceptance. "Teachers play such an important role in shaping society's future. I only wish there were more authentic, high-quality resources to better equip them to teach about what can be a sensitive subject." ■



Posters advertising the LGBT group at CERN

Image courtesy of Rolf Landua

## Reflections

Sarah, David, Pauline, Alex and I experienced life in the sciences during different decades and this shows in our varied experiences. The suffering of earlier generations has helped to make being LGBT more acceptable today – but this does not mean that there is no more work to be done.

In the STEM fields, a lot of scientists don't see being LGBT as a hindrance, but some also prefer not to discuss it. "I feel like my being [gay] is a non-issue; it's not something I talk about explicitly", says Sarah. David thinks that this might reflect a 'don't ask, don't tell' attitude in science. "[Senior scientists] often say – what does it matter? All that I judge is the science", he says. "Many scientists say that they do not want to hear about people's personal lives."

But is there something to gain if we talk about these issues openly? I believe there is. A supportive environment helps in work-life balance – nourishing scientists and allowing them to concentrate on the science, instead of thinking about how to keep themselves protected from discrimination.

So how do we bring about this supportive environment? Growing up at a time where being LGBT had a negative stigma, David says that it would have helped him to have a teacher who was a point of contact for students with LGBT issues. While he had many teachers who made a huge difference in his scientific development and his decision to study science, this was not related to finding his LGBT identity. To explore this idea, David carried out an informal survey at York, which revealed that LGBT students do value the presence of an LGBT role model in their department. "This enables them to find a safe and supportive environment", David says.

Of course, the visible presence of LGBT scientists doesn't directly equate to recruiting the younger LGBT generation to science. But as well as providing a more comfortable environment, it helps young LGBT people to find someone they can aspire to be – just as girls may be inspired by Marie Curie, as indeed Pauline was.



University science students: will any find LGBT role models in their chosen career?

And while any inquisitive young person – LGBT or non-LGBT – might find themselves in a science career, today's LGBT scientists still need to be visible. "It is not enough to be simply out", Pauline concludes. "We have to be visible. Science has a lot to gain with diversity, because we come with our own creativity, and creativity is essential to science."

Joseph Unsay studied chemistry at the Ateneo de Manila University in the Philippines before moving to Heidelberg, Germany, to start his PhD at the German Cancer Research Centre. He later moved to Tübingen with his research group and finished his PhD in biophysics in 2016. His research uses advanced microscopy techniques to study membranes and membrane proteins that regulate cell death. He currently works in Germany as an assistant editor for *Chemistry – A European Journal*, and his interests include communicating science in different media (<http://membranebpc.wordpress.com>), theatre, music and volleyball.

## Web references

- w1 The *Guardian's* World Pride Power List 2014 celebrated the achievements of influential LGBT people. See [www.theguardian.com](http://www.theguardian.com) or use the direct link: <http://tinyurl.com/z6a7e7p>
- w2 For David Smith's YouTube channel, see: [www.youtube.com/user/ProfessorDaveatYork](http://www.youtube.com/user/ProfessorDaveatYork)
- w3 Learn more about Pauline Gagnon's book, *Who Cares about Particle Physics: Making Sense of the Higgs Boson, Large Hadron Collider and CERN*. See: <http://paulinegagnon3.wix.com/boson-in-winter>

## Resources

The UK newspaper *The Independent* published its Rainbow List 2015 of the '101 most influential lesbian, gay, bisexual, transgender and intersex people in Britain'. See [www.independent.co.uk](http://www.independent.co.uk) or use the direct link: <http://tinyurl.com/npwmtmuq>

For an article by David Smith reflecting on being a gay scientist, see 'No sexuality please, we're scientists' on the *Chemistry World* website ([www.chemistryworld.com](http://www.chemistryworld.com)) or use the direct link: <http://tinyurl.com/n9zxwbu>

For a schoolteacher's reflections on the experience of being a gay pupil, see 'Schools have come a long way since I was a gay pupil' on *The Guardian* website ([www.guardian.co.uk](http://www.guardian.co.uk)) or use the direct link: <http://tinyurl.com/pcvkvme>

For two schoolteachers' experiences (one positive, one negative) of being openly gay in the workplace, see:

'Secret Teacher: I'm my school's go-to gay guy' on the *The Guardian* website ([www.guardian.co.uk](http://www.guardian.co.uk)) or use the direct link: <http://tinyurl.com/ng7kurw>

'Secret Teacher: my school tried to stop me being openly gay' on *The Guardian* website ([www.guardian.co.uk](http://www.guardian.co.uk)) or use the direct link: <http://tinyurl.com/nggqlnu>

The Queer in STEM website offers a study of sexualities and gender diversity in science. See: [www.queerstem.org](http://www.queerstem.org)

Visit the website of the USA's National Organization of Gay and Lesbian Scientists and Technical Professionals. See: [www.noglstp.org](http://www.noglstp.org)

oSTEM (Out in Science, Technology, Engineering and Mathematics) is a US society to support LGBT scientists. See: [www.ostem.org](http://www.ostem.org)

The lgbt+physicists website helps young LGBT physicists to find mentors. See: <http://lgbtphysicists.org>



# Bringing structures to life

Teachers from across Europe discover the beauty of protein crystallography.

Image courtesy of EMBL / Rosemary Wilson

*Searching for protein crystals under the microscope*

By Eva Haas

“Protein crystallisation is black magic” – these words are heard frequently in structural biology laboratories. In October 2016, 23 secondary-school teachers and teacher trainers explored how to bring the science behind this magic into European classrooms. Travelling from nine different countries, the participants arrived at the German Electron Synchrotron (DESY) campus in Hamburg eager to begin a two-day training workshop, or LearningLAB, organised by the European Learning Laboratory for the Life Sciences (ELLS) in collaboration with the European Molecular Biology Laboratory (EMBL).

The LearningLAB, called ‘Bringing structures to life – new ways of teaching biology’, provided an interactive introduction to the field of structural biology. Bridging the gap between research and schools, the workshop gave teachers the opportunity to work side-by-side with top scientists in an intense programme of hands-on activities, lab experiments, scientific seminars, and visits to the research and education facilities on the DESY campus.

The workshop began with an introduction to the theory behind protein crystallography. The discipline enables scientists to visualise the arrangement of atoms within proteins to understand their function. This in turn helps to understand processes in biological systems and makes it easier to design novel drug targets. To analyse a protein, scientists take advantage of the fact that proteins can be prompted to form crystals. In a crystal, millions of copies of the same protein are packed in a repeating three-dimensional

array. When a synchrotron fires high-intensity X-rays at the crystal, the proteins diffract the beams into a pattern that can then be used to deduce the three-dimensional structure of the protein.

Under the guidance of EMBL scientists, the participants experienced first-hand the trickiest aspect of X-ray crystallography: growing a good protein crystal. To produce a crystal containing a well-ordered array of proteins, the teachers set up a screen to test varying crystallisation conditions – a process crystallographers use to find the perfect experimental conditions for a protein they have never crystallised before. “There are so many factors that play a role



*Protein crystals under the microscope*

Image courtesy of Liliana Rodrigues

in getting a good crystal”, explained Philipp Hornburg, an EMBL PhD student who helped the workshop participants. This is also why protein crystallography is often referred to as ‘black magic’ – whether or not a protein crystallises is often unpredictable.

Unlike crystallographers, who might have to wait in suspense for days, weeks or even months to see whether their crystals grow, the LearningLAB participants only had to hold their breath until the next morning. Using stereo microscopes, 46 excited eyes searched for protein crystals and confirmed that the experiment was indeed a success: beautiful crystals could be observed and optimal crystallisation conditions for the protein determined. The teachers were eager to recreate the activity in their own classrooms, excited to enthuse their students with the art of crystallography and the power of scientific enquiry, just as they had been themselves.

After being introduced to the art of protein crystallography – both theoretically and practically – the teachers explored the EMBL labs and the experimental hall of the X-ray beamlines. Talks from EMBL group leaders Thomas Schneider and Rob Meijers gave participants an interesting insight into current research and hot topics in protein crystallography. The researchers shared their personal stories on what inspired them to become scientists and illustrated what important roles their teachers and mentors played along their career path.

A career-themed session gave the participants the opportunity to quiz EMBL scientists about their motivations for becoming researchers, what they enjoy most about their job and how they deal with the challenges of a research environment. Is working with a method like protein crystallisation a frustrating experience? For Vivian Pogenberg, an EMBL research scientist, it is exactly this characteristic that makes his work particularly exciting: “I really enjoy the artistic aspect of my job. Because it is not an exact science, it allows me to play around with experimental protocols.”

Besides focusing on research and experimental aspects of X-ray crystallography, the course also fostered exchange and discussion about teaching structural biology in the classroom. A core part of the programme was dedicated to the presentation and discussion of ready-to-use teaching resources on structural biology and the study of proteins, presented by ELLS, *Science in School*, and three course participants. To add a further interdisciplinary component, the programme was complemented with a visit to the education facility physik. begreifen, an out-of-school physics lab on the DESY campus.

Portuguese teacher Tânia, from the Escola Secundária Filipa de Vilhena, summed up her experience: “The ELLS LearningLAB for teachers was a unique opportunity to discover and update my scientific knowledge in different biology fields, as well as to develop a new perception about modern science and cutting-edge technologies. I also had access to various innovative educational resources. Now I am able to give students a perspective of how scientific knowledge is really developed, highlighting the scientists’ work at EMBL, and hopefully to raise students’ interest in STEM careers. Every science teacher should try to attend these excellent courses!”

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Eva Haas is a biologist who currently works as the Education Officer at EMBL’s European Learning Laboratory for the Life Sciences (ELLS) in Heidelberg, Germany.

*LearningLAB participants and trainers*

## Resource

To keep up to date with future ELLS LearningLABs, visit their website, where you can also find freely available teaching resources. See: <http://emblog.embl.de/ells>



# Small is beautiful: microscale chemistry in the classroom

Learn how to carry out microscale experiments for greener chemistry teaching – and less washing up.

Image courtesy of joannawnuk / shutterstock

By Éva Dobóné Tarai

Last year, I worked with my students on an international Scientix<sup>w1</sup> project, using chemistry to investigate metal objects found in UNESCO cultural heritage sites, such as the copper and bronze statues in Heroes' Square, Budapest, Hungary. We carried out experiments using compounds of iron, copper, nickel, silver, lead, mercury and other heavy metals – materials that are dangerous, toxic and polluting. Although only one or two millilitres of solution were used in each test tube, a huge amount of toxic waste was produced by the time the whole class had performed each experiment. We are very committed to protecting the environment, so we started thinking about how we could reduce the amount of chemicals used during the experiments.

## Developing small-volume experiments

Our first idea was to replace the test tubes with 'dimple trays' from empty plastic boxes of pills or chewing gum, using the indentations in the trays as the containers for the reactions (figure 1). This method, which we found described in a previous *Science in School* article (Kalogirou & Nicas, 2010), greatly reduced the amount of toxic chemicals used – but we wanted to go further.

Our next idea was to use filter paper as the reaction 'container' for precipitation reactions, using drops of the chemicals reacting together at the same spot. In these



- ✓ Chemistry
- ✓ Ages 14–19

REVIEW

This article demonstrates a novel way to carry out precipitation reactions using the least amount of reagents possible, safely and in such a way that ensures there is practically no waste. This remarkable idea is simple, visual and inexpensive, and can be carried out in the classroom even if no laboratory is available. The article relates to the chemistry of precipitates and electrolysis, and could also be used for discussions on solubility, stoichiometry, redox reactions, neutrality and migration of ions.

Maurice Cosandey, École Polytechnique  
Fédérale de Lausanne, Switzerland

Image courtesy of Gerwin Filius; image source: Flickr



Copper and bronze statues in Heroes' Square, Budapest, Hungary



Figure 1: precipitation reactions in dimple trays

Images courtesy of Éva Dobóné Tarai

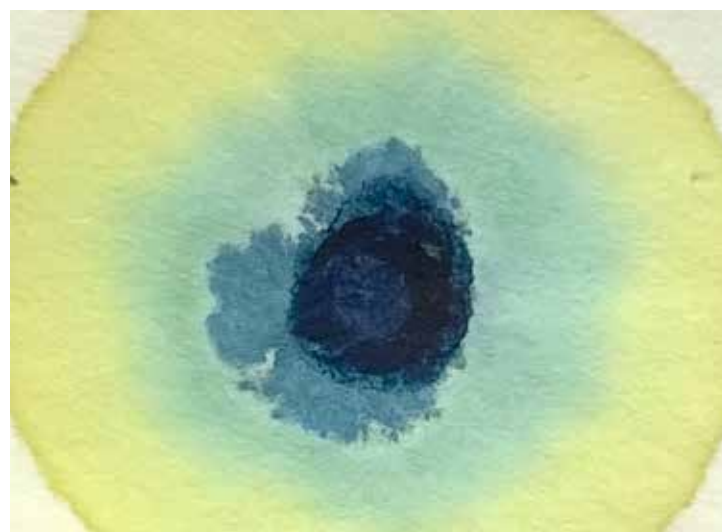


Figure 2: reaction on filter paper of iron(III) chloride with sodium hydroxide (left), and with potassium hexacyanoferrate (right)

experiments, we used just one or two drops of each reagent – about a hundredth of the amount used in the test tube experiments. Because colourful compounds were used, the reactions were immediately visible and the products could be identified just from their colour.

We found it worked well if we soaked the filter paper in one of the non-toxic reagents, dried it, and then dripped the other reagents onto the paper. Several reactions can be carried out on the same filter paper if gaps are left between the reaction spots.

Figure 2 shows the reactions of iron(III) chloride: first with sodium hydroxide on the filter paper, producing a precipitate of iron(III) hydroxide; and then with potassium hexacyanoferrate on the filter paper, producing the characteristic Prussian blue precipitate. (For the equations for these reactions, please see Activity 1.)

The next method was inspired purely by chance when we found a used air-freshener box containing tiny, dried-up hydrogel balls. Hydrogels are super-absorbent polymers that shrink as they

dry out, but swell up again when they are placed in water. These balls are easily available to buy, and are often used in floral displays as well as in air fresheners. As they swell, they retain their spherical shape, thus forming an aqueous bead in which reactions can take place.

## Reactions in hydrogel balls

Using the hydrogel balls, we first carried out precipitation reactions (as with the filter paper experiments). The results obtained with this method were



interesting and convincing. Not only did we use a minimal amount of reagents, but due to the hydrogel balls' spherical shape, they acted like magnifying lenses and made the reactions more visible.

We therefore tried out some other standard chemical reactions using the hydrogel balls – with mixed results. The acid-base reactions did not work well, because the colours of the indicators (universal, litmus, phenolphthalein and others) were not strong enough, and the procedure was rather complicated.

The electrochemical reactions, however, were a success: for example, electrolysis of silver nitrate solution, zinc iodide solution, water and other solutions all worked well (see Activity 2). Normally in such experiments, a thin layer of metal is deposited on the surface of an electrode, and this layer is often poorly visible. In the hydrogel balls, however, the reduced metal appears within the gel as a spot, where it is more visible and can be studied more easily.

## Activity 1: precipitation reactions in hydrogel balls

To get the reagents into the hydrogel balls, we used syringes and hypodermic needles. For this reason, these experiments are suitable only for students aged 16 or older, and great care and disciplined behaviour are needed. For younger (or perhaps less well-behaved) students, the experiment can be carried out as a teacher demonstration using a computer webcam.

The time needed for this activity is approximately 10 minutes for each precipitation experiment, although the hydrogel balls need to be soaked in advance. Because so little reagent is used in each hydrogel ball, the filled hypodermic syringes can be reused in the next chemistry lesson.

**Safety note:** This experiment is suitable **strictly for students aged 16 or older**, and with a high level of supervision by the teacher at all times. Hypodermic

### i

### BACKGROUND

## The chemistry of hydrogel balls

Hydrogels are super-absorbent polymers, usually made from polymethacrylate polymers. These polymers are xerogellants, which means that when they are placed in water, they swell and significantly increase in size. They are used in agrochemistry to grow plants in hydroculture, and can be found in disposable nappies, pot pourris, air fresheners, and so on.

Chemically, xerogellants are ionic compounds. When placed into water or diluted salt solution, the ions become hydrated as they attract the polar water molecules, which is what makes the hydrogel balls grow in size. In distilled water, a hydrogel may absorb 300 times its weight, but in sodium chloride solution (at a concentration isotonic to human blood), the increase is only around 50-fold. The hydrogel keeps its original shape, thanks to the polymers' cross links.

needles must be counted when given out and when given back, so that all are accounted for. Used hypodermic needles should be bent before disposal in a sharps bin. Safety glasses and disposable gloves need to be worn throughout.

Suitable additional precautions should be taken if any toxic reagents are used (e.g. mercury or lead compounds), with the hydrogel balls containing these compounds placed in a hazardous waste collector.

See also the general safety note on the *Science in School* website ([www.scienceinschool.org/safety](http://www.scienceinschool.org/safety)) and at the end of this print issue.

### Materials

For each experiment, you will need the following materials for each student or group:

- One hydrogel ball
- A white glazed ceramic tile, glass plate or Petri dish
- Two syringes fitted with hypodermic needles (assembled in advance by a teacher / technician)
- Distilled water
- A pair of disposable gloves
- A pair of safety glasses

Reagents:

- Sodium hydroxide (NaOH) solution (1.0 M)
- Iron(III) chloride (FeCl<sub>3</sub>) solution (1.0 M)
- Nickel(II) chloride (NiCl<sub>2</sub>) solution (1.0 M), or nickel(II) sulfate (NiSO<sub>4</sub>) solution (1.0 M)
- Sodium sulfide (Na<sub>2</sub>S) solution (1.0 M)
- Potassium hexacyanoferrate (K<sub>4</sub>[Fe(CN)<sub>6</sub>]) solution (1.0 M)

The method can also be used for other precipitation reactions, so the list of the materials here can be extended or adapted.

### Procedure

First, wash the hydrogel balls several times in distilled water, then leave them to swell in more distilled water for at least 2 hours. Approximately 500 ml of distilled water is needed to soak 30 hydrogel balls.

For each reaction:

1. Place a swelled-up hydrogel ball on one white tile.
2. Fill a syringe with one of the solutions containing a heavy-metal compound (e.g. iron(III) chloride solution) and inject a small amount of reactant into the centre of the ball.



Figure 3: reactions in hydrogel balls: (i) iron(III) chloride with sodium hydroxide



(ii) nickel(II) chloride with ammonium sulfide



(iii) iron(III) chloride with potassium ferrocyanide

- Fill the next syringe with sodium hydroxide solution and inject a similar amount into the hydrogel ball through the same hole.
- As the reaction proceeds, observe the colour change and record what you see. You should observe a coloured, solid precipitate form inside the ball (figure 3).
- Using another hydrogel ball, repeat the experiment with the next heavy-metal compound (e.g. nickel(II) chloride solution), again reacting this with the sodium hydroxide solution.
- Continue repeating the experiment with the other reagents:
  - Nickel(II) chloride with sodium sulfide
  - Iron(III) chloride with potassium hexacyanoferrate
- Finally, compare the results of the different precipitation reactions.

## Discussion

The equations and colour changes for these reactions are:

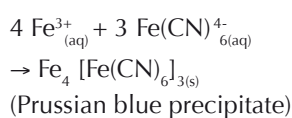
- Sodium hydroxide with iron(III) ions:  

$$\text{Fe}^{3+}_{(\text{aq})} + 3 \text{OH}^{-}_{(\text{aq})} \rightarrow \text{Fe}(\text{OH})_{3(\text{s})}$$
 (red-brown precipitate)
- Sodium hydroxide with nickel(II) ions:  

$$\text{Ni}^{2+}_{(\text{aq})} + 2 \text{OH}^{-}_{(\text{aq})} \rightarrow \text{Ni}(\text{OH})_{2(\text{s})}$$
 (green precipitate)
- Sodium sulfide with nickel(II) ions:  

$$\text{Ni}^{2+}_{(\text{aq})} + \text{S}^{2-}_{(\text{aq})} \rightarrow \text{NiS}_{(\text{s})}$$
 (black precipitate)

- Potassium hexacyanoferrate solution reaction with iron(III) ions (or ferric ions):



For a class discussion, questions could include:

- What are the advantages of the hydrogel ball reaction method? (Small quantities are used, so it is safer and more environmentally friendly.)
- What might be a disadvantage of this method? (It is less suitable for quantitative chemistry than standard methods.)
- Which other reagents might work to produce highly visible reactions? (Examples: copper sulfate and sodium hydroxide; or iron(III) chloride and potassium sulfocyanide.)
- Which reagents might not work so well, and why? (Examples: reactions producing solutions of sodium salts and potassium salts, because these are colourless and soluble.)

## Activity 2: electrochemical reactions in hydrogel balls

In these experiments, instead of injecting the swelled-up hydrogel balls with the electrolyte solutions, we placed the

balls on filter paper soaked with the electrolyte and then inserted electrodes into the balls (figure 4). The electrolyte ions migrate from the filter paper into the balls, where the deposit forms. For the miniature electrodes, we used graphite leads from a mechanical pencil. In the electrolysis of water experiment, the bubbles of evolved gas (hydrogen at the cathode and oxygen at the anode) were very visible (figure 5).

Unlike the precipitation reactions, this experiment does not use hypodermic needles, and so it is suitable for students from age 14. The time needed for the activity is approximately 10 minutes for each of the reactions, if you are using already swelled-up hydrogel balls; otherwise add 2 hours soaking time.

## Materials

You will need the following for each student or group carrying out the reactions:

- Two soaked, swelled-up hydrogel balls, prepared as for Activity 1.
- A white glazed ceramic tile, glass plate or Petri dish
- A Pasteur pipette
- One piece of filter paper (2 cm x 4 cm)
- One battery (4.5–9 V)
- Two cables (to connect each battery terminal to an electrode)
- Two crocodile clips



Figure 4: electrolysis of silver nitrate solution in a hydrogel ball

- Two graphite leads from a mechanical pencil (for the electrodes)
- Distilled water

Electrolyte solutions:

- Sodium chloride (NaCl) solution (2.0 M)
- Silver nitrate (AgNO<sub>3</sub>) solution (1.0 M)
- Zinc iodide (ZnI<sub>2</sub>) solution (1.0 M)
- Distilled water with a few drops of dilute sulfuric acid added

## Procedure

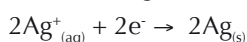
1. Prepare the hydrogel balls as in Activity 1 (this needs to be done in advance).
2. Place a piece of filter paper onto the tile or Petri dish. Drip some sodium chloride solution onto the filter paper, as an electrolyte.
3. Place two hydrogel balls on the filter paper. Insert an electrode into each hydrogel ball.
4. Using a Pasteur pipette, insert some silver nitrate solution into the hole in each hydrogel ball where the electrodes enter it.
5. Clip the cables to the electrodes and the battery. Close the electrical circuit.
6. Observe the changes and record them.
7. Repeat for the other electrolytes.

## Discussion

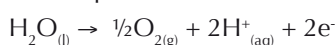
The equations of the electrolysis reactions are:

- Electrolysis of silver nitrate solution:

Cathode (negative electrode):

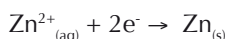


Anode (positive electrode):

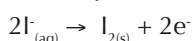


- Electrolysis of zinc iodide solution:

Cathode (negative electrode):

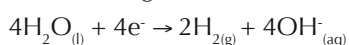


Anode (positive electrode):

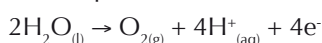


- Electrolysis of water:

Cathode (negative electrode):



Anode (positive electrode):



All these experiments are inexpensive to carry out and encourage students to consider the environment. We also found one final advantage of not using test tubes and other laboratory glassware: we avoided the need to wash up after finishing the experiments – which saves time, water and effort.

Dr Éva Dobóné Tarai has been teaching chemistry for 30 years in Hungary. For the first 20 years, she worked in primary schools; now she teaches at a high



Figure 5: hydrogen gas bubbles appearing during the electrolysis of water

school. Éva has also taught teaching practices to university students who are aiming to become teachers. The main focus of her PhD research was how students' understanding of matter and its changes develops, how and why misconceptions emerge and how to correct them.

## Acknowledgements

The author would like to thank the Doctoral School of Humanities of University of Debrecen, Hungary, for supporting her work.

## Reference

Kalogirou E, Nicas E (2010) Microscale chemistry: experiments for schools. *Science in School* **16**: 27–32. [www.scienceinschool.org/2010/issue16/microscale](http://www.scienceinschool.org/2010/issue16/microscale)

## Web reference

w1 Scientix is a European science education community. For ideas, projects, methods, news and other resources, see the Scientix website: [www.scientix.eu](http://www.scientix.eu)

## Resources

The website of the UK's Royal Society for Chemistry describes some experiments with hydrogels in hair gels and disposable nappies. See: <http://rsc.li/1T37oEK>

The Royal Society for Chemistry offers other ideas for microscale precipitation reactions and methods. See: <http://rsc.li/106QFMq>



# When things don't fall: the counter-intuitive physics of balanced forces

Intrigue your students with some surprising experiments – it's a great way to challenge their intuitions and explore the laws of mechanics.

By Paraskevi Tsakmaki and Panagiotis Koumaras

Why do we teach science? Is it to give students new ideas – or to remove ideas they already hold? In some areas, such as the physics of free fall, it seems the latter is the real task: while the ideas described by Newtonian mechanics are simple enough, our intuitions can make them difficult to accept.

When students arrive at physics classes, they already possess firm ideas about many physical situations. Research in science education has shown that students often hold a set of intuitive rules about the mechanisms underlying physical changes (Viennot, 2014). Some of the most widely held of these rules include:

- The greater the cause, the bigger the effect.
- Several agents have a greater effect than just one.
- If there is a cause, an effect must follow.

In addition, according to our findings (Tsakmaki & Koumaras, 2014; Tsakmaki, 2016), students seem to follow what is known as 'the rule of type': the cause and the effect are both of the same type.

We use the term 'type' here to mean any of the following:

- The spatial orientation of cause and effect
- The kind of change (such as an increase or decrease)
- The intensity of the cause and the effect.

In this article, we analyse three simple experiments that involve the rule of type. They can be used to reveal how students reason and to enable teachers to present physics concepts in a more accessible way.

The first experiment is an extension of the popular textbook problem that asks students to draw the forces acting on a coin tossed straight up into the air. Students have difficulty realising that (if we ignore air resistance) once the coin has left the hand, the only force acting on it is its weight. In fact, the coin is in free fall while going up! Replacing the coin with water demonstrates this fact beyond doubt.

The other two experiments explore ideas of balance: the second using a pulley, and the third using buoyancy. All the experiments are suitable for science students aged 14–16.

*The drag force produced by an open parachute matches the force of gravity, so the upward and downward forces are balanced – even though the parachutist is still falling.*

Images courtesy of Spilios Vasilopoulos



Figure 1: uncovering the hole in the cap: the water flows out through the hole in the bottom of the bottle.



Figure 2: letting the bottle fall: water stops flowing out.



Figure 3: throwing the bottle upwards and letting it fall down: no water flows out during the upwards or downwards motion of the pierced bottle.

## Experiment 1: weightless water

This is a brilliant experiment to demonstrate weightlessness. We suggest doing this as a teacher demonstration (rather than student experiment). Allow 30 minutes for the experiment and discussion, plus 10 minutes for preparation.

### Materials

- One small plastic bottle (e.g. 500 ml or 750 ml soft-drink bottle)

- Tap water
- Location where water spillage is not a problem (e.g. outdoors)
- Smartphone with slow-motion filming capability (optional)

### Procedure

1. Pierce both the base and the cap of the plastic bottle.
2. Fill the bottle with water. Place a finger on the hole in the cap to show that the water stops escaping from the base.

3. Now remove your finger from the cap to show that the water flows out of the hole in the base (figure 1).
4. Ask students to predict how water flow will be affected if we let the bottle fall freely. (Students usually predict correctly that the water will stop flowing out while falling.)
5. Refill the bottle. Test the prediction by letting the bottle fall from shoulder height (figure 2). (If possible, film this using the slow-motion option on a smartphone, so that students can review exactly what happens.)



- ✓ Physics
- ✓ Acceleration
- ✓ Astrophysics
- ✓ Forces
- ✓ Gravity
- ✓ Mechanics
- ✓ Motion
- ✓ Ages 14–16

This article introduces the not-so-simple topic of ‘counter-intuitive experiments’ in physics and describes how students use the ‘rule of type’ to explain the results of the experiments.

Getting feedback from students on the way they think and how they rely on preconceived ideas is a useful outcome for teachers.

The teaching activity seems to be useful mainly for teaching physics to students aged 14–16.

The article encourages teachers to ask questions such as:

- What happens to the water if the bottle is moved up or downwards – and why?
- Do the effects depend on the speed of the movement?
- How would you describe the concepts of gravity, mass and weight?

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- Ask students to predict what will happen if we throw the bottle upwards. Will water flow out or not?
- Refill the bottle and throw it upwards (figure 3), while the students watch (or film it as before) – and then discuss what happened.

## Discussion

When the bottle is at rest, water flows out through the hole in the base. This is consistent with the rule of type: the cause (the water's weight) is directed downwards, and the effect (the downward flow of water out of the bottle) is similar. Most students correctly predict that when the bottle is falling, the outflow of water will be 'cancelled' during the fall because both the bottle and the water are moving downwards in the same way.

But what happens when the bottle is thrown upwards: will water still flow out? Most students (more than 80% of ours) think it will. Their reasoning is often based on what we experience when standing in a lift (Corona et al., 2006). As it moves upwards, we feel heavier, so the water should 'feel heavier' and thus flow out faster.

This prediction is wrong. As the demonstration shows, no water flows out during the upwards or downwards motion of the bottle. After the bottle leaves the hand, the only force acting on it is its own weight, so it is in free fall – even when the bottle is moving upwards (because it is decelerating). Like orbiting astronauts, the water in the bottle 'feels' weightless – and no weight means no water flowing out.

The students' erroneous reasoning is in line with the rule of type: here, the imagined cause is the supposed increase in the water's weight due to being launched upwards, so the effect should be an increase in water flowing out. The experiment shows that what happens is the opposite of what's expected, challenging the students' intuitive reasoning.

## Experiment 2: asymmetrical balance

In this experiment, two weights are balanced – but, unlike with a set of balance scales, they are not on the same horizontal level. Allow 20 minutes for the experiment and discussion, plus 10 minutes for preparation.

### Materials

- Block of wood, about 10 cm x 10 cm x 10 cm (or similar volume)
- Small bucket with handle
- Dry sand (amount similar in mass to the wood block)
- Pulley (single wheel and cord)
- Balance or scales to weigh the wood block, bucket and sand

### Procedure

Steps 1–4 are preparation; the demonstration is steps 5–6.

- Weigh the wood block.
- Add dry sand to the bucket until the bucket plus the sand weigh the same as the wood block.
- Set up the pulley so that the cords are approximately the same length on each side of the wheel. Attach the wood block to one side and the bucket of sand to the other.
- Ensure the wood block and bucket of sand are exactly balanced so that neither falls down. Adjust the amount of sand if needed.
- Starting with the block and bucket in level positions, show the set-up to the students (figure 4). Then, move the wood block upwards so that the bucket is now lower than the block. While holding the wood block, ask the students to predict what will happen if you let go of it.
- Let go of the wood block. What happens? Nothing! Ask the students to explain this.

### Discussion

When we ran this experiment, almost 50% of our secondary school students predicted that the raised block would



Figure 4: the experimental set-up with block, bucket and pulley

return to its initial position – despite the fact that if the two objects are in static equilibrium, the net force acting on each object is zero and the block will not move.

When students see the block and bucket at different horizontal levels, they seem not to notice that the two objects are balanced. Instead, they focus on the most striking observable feature of the situation: the different heights of the two objects. This appears to represent an effect – so, in line with the rule of type, there must be a cause of the same type: unequal forces. As a result, many of the students conclude that one object (the one nearer the ground) must be heavier than the other one.

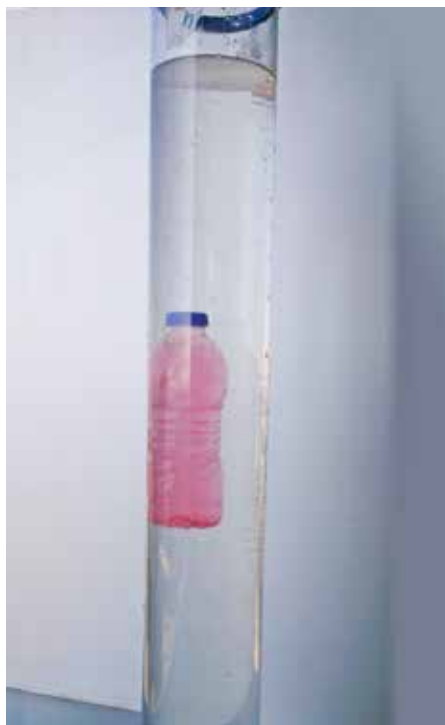
## Experiment 3: floating under water

### Materials

- Plastic bottle (e.g. 500 ml soft-drink bottle) with cap
- Tank (ideally a tall column shape) filled with water
- Sand
- Force meter
- Some cord



Figure 5: the bottle stays at rest in the tank of water when it is placed higher up...



...or lower down.

## Procedure

Steps 1 and 2 are preparation; the demonstration is steps 3–6.

1. Fill the bottle with water.
2. Add a small amount of sand to the bottle and replace the cap. Adjust the amount of sand until the bottle does not move up or down when placed at any level in the tank (figure 5).
3. Initially, place the bottle close to the bottom of the tank.
4. Then, move the bottle close to the water's surface. Ask the students to predict in which of the two places the buoyancy acting on the bottle is greater.
5. Using the cord, connect a force meter to the bottle. This measures the net force on the bottle: weight minus buoyancy. (When moving the submerged bottle to the higher level, move the force meter gently upwards with it so that it does not pull on the bottle.)
6. Read the meter with the bottle in both places: it will show a force of zero.
7. Ask the students to explain this.

## Discussion

When we ran this experiment, more than 40% of our students predicted that the higher the bottle is in the tank, the greater the buoyancy acting on it. In fact, the bottle is in static equilibrium in both positions, so the net force acting on it is zero.

When students see the bottle floating at different levels, some of them seem to ignore the fact that the forces on it are balanced. As in the previous experiment, they focus instead on what they see – unequal levels – and infer that there must be a cause of the same type: unequal forces. The weight of the bottle is the same throughout, so they conclude that when it is higher up, it must have greater buoyancy.

## End note

We believe that these counter-intuitive demonstrations are more than just curiosities: we can use these mismatches between intuition and experiment in the classroom to help understand students' misconceptions. And by integrating these experiments into teaching in a structured way, we can provide some real benefits for learning.

Paraskevi Tsakmaki is a school teacher in the Gymnasium of Goumenissa in Kilkis, Greece. Her main scientific background is in physics, particularly solid-state physics. She is currently working towards a PhD in physics education.

Panagiotis Koumaras is a professor in the Faculty of Education of Aristotle University in Thessaloniki, Greece. His main research interests are studying and developing science curricula to provide knowledge and life skills.

## References

- Corona A, Slisko J, Planinsic G (2006) Freely rising bottle of water also demonstrates weightlessness. *Physics Education* **41**(3): 208–209
- Tsakmaki P (2016) Looking for causal 'laws' on students' prediction and interpretation of physical phenomena and didactical utilization of them in physics' instruction. *Unpublished PhD thesis, School of Education, Aristotle University of Thessaloniki, Greece (under consideration)*
- Tsakmaki P, Koumaras P (2014) Causal rules: what might be hinting in misconceptions of our students? *8<sup>th</sup> Hellenic Conference on History, Philosophy and Didactics of Science*, Patra 14–16 October 2014 [in Greek]
- Viennot L (2014) *Thinking in Physics: The Pleasure of Reasoning and Understanding*. Dordrecht, the Netherlands: Springer. ISBN: 9789401786652. doi: 10.1007/978-94-017-8666-9

## Resources

These short videos demonstrate the three experiments in the article:

Weightless water: <https://youtu.be/E8es2ppdt6k>

Asymmetrical balance: <https://youtu.be/iBBUNoOcPTI>

Floating under water: <https://youtu.be/JDtJGe32hM>

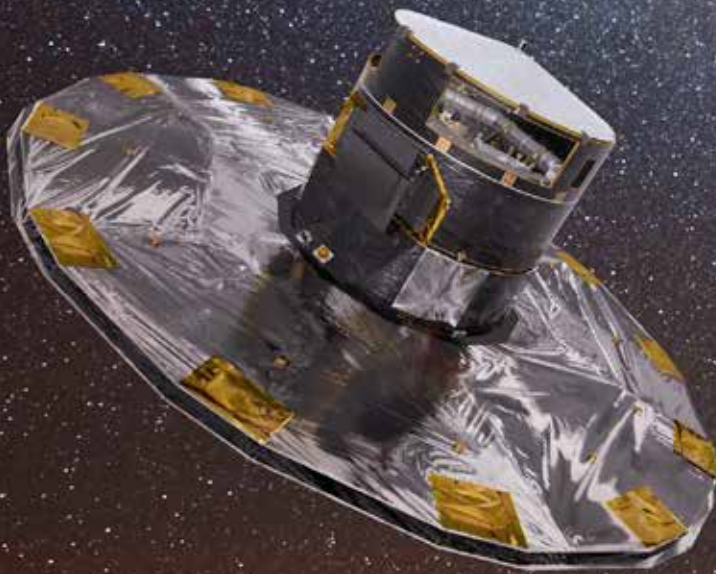
For another article about counter-intuitive effects in mechanics, see:

Norrby M, Peltoniemi R (2016) Can something accelerate upwards while falling down? *Science in School* **37**: 25–28. [www.scienceinschool.org/2016/issue37/counterintuitive](http://www.scienceinschool.org/2016/issue37/counterintuitive)



# Parallax: reaching the stars with geometry

How far away are the stars? Explore in your classroom how astronomers measure distances in space.



Artist's impression of the Gaia spacecraft, with the Milky Way in the background

By Markus Pössel

Look out of a side window of a moving car or train, and you will notice that your view of objects changes with their distance: nearby bushes or trees seem to be rushing by, while a distant tree or building appears to move far more slowly.

This apparent change in position depending on distance is called *parallax*. You can reproduce the effect by making the thumbs-up sign in front of your face and watching your thumb first with only your left eye, then only your right eye. As you change eyes, your thumb appears to jump sideways in relation to the more distant background imagery – because your two eyes are in slightly different positions. Now stretch your arm as far as it will go and, moving your thumb closer to your face, repeat the experiment of looking with each eye separately at different distances: you will notice that the shift in apparent position increases as the distance between your thumb and your eyes decreases.

This effect has been used for centuries to determine distances in space<sup>w1</sup>. In the mid-19th century, astronomers used parallax to work out the first stellar distances. Surveyors also use this kind of measurement to draw accurate maps of the surface of Earth. Currently, the ESA satellite Gaia, which was launched in December 2013, is measuring extremely accurate parallaxes for more than a billion stars in our galaxy, the Milky Way, increasing accuracy by a factor of about 200.

In this article, we describe an activity that explores the way astronomers use parallax to measure interstellar distances by working out the distance of a 'star' set up in a classroom. There is also a short web article about the history of parallax measurements, which you can download from the *Science in School* website<sup>w1</sup>.

The activity we describe here reproduces the basic geometry of parallax measurements, using simple devices to measure





Image courtesy of ESA / ATG medialab ; background image: ESO / S Brunier



- ✓ Physics
- ✓ Ages 14–19

## REVIEW

Stellar parallax is the oldest, simplest and most accurate method for determining the distances to stars. This article explains how to make terrestrial measurements using this method. If you follow the instructions, you will be able to measure the distance within your classroom to an object, the 'star', and your students will understand how astronomers can calculate huge distances in space.

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angles. We have successfully used this activity, which takes between 30 and 45 minutes including setting up, with students aged between 13 and 17. In the next issue of *Science in School*, we will describe a photographic method of using parallax measurements that is even more accurate and astronomically authentic.

### Activity: the geometry of parallax

For this activity, you will need an instrument for measuring the angles between sight lines – a theodolite



Figure 1: a theodolite, with sights (1) and turntable (2)

Image courtesy of Hda / M Pössel

(see figure 1), if there is one in your school's mathematics, physics or geography equipment. If not, we provide instructions here on how to make a similar angle-measuring device from easily available materials.

### Materials

- Two theodolites
- Small sphere or LED as the 'star'
- Tape measure

If you do not have access to theodolites, you can improvise by making the simple devices shown in figure 2. For each one (you will need two), you will need:

- Sheet of paper
- Thin, flat cardboard, about 4 cm x 8 cm
- Small wooden block, about 1 cm x 3 cm x 8 cm
- Table or other horizontal surface

### Procedure

The basic set-up can be seen in figure 3. To simplify things, we make all the angular measurements in the plane defined by points A, B and C, which should be parallel to the ground.

#### Setting up

1. Divide the room into two sections by marking a line on the ground, as shown by the dashed line. The right-hand section of the room with the two theodolites (or, alternatively, the two improvised devices) represents Earth, while the section on the left represents space.
2. Place the 'star' in the space region (position A in figure 3). For the star, you can use an LED, Christmas ornament, ping-pong ball or other small sphere. Mount the star however you can – using a tripod, on a broom handle in an umbrella stand, or from the ceiling.

Follow the set-up steps below if you are using theodolites:

3. Set up your two theodolites, each mounted on its tripod, in the Earth region. You will need to adjust each theodolite's turntable so that it is

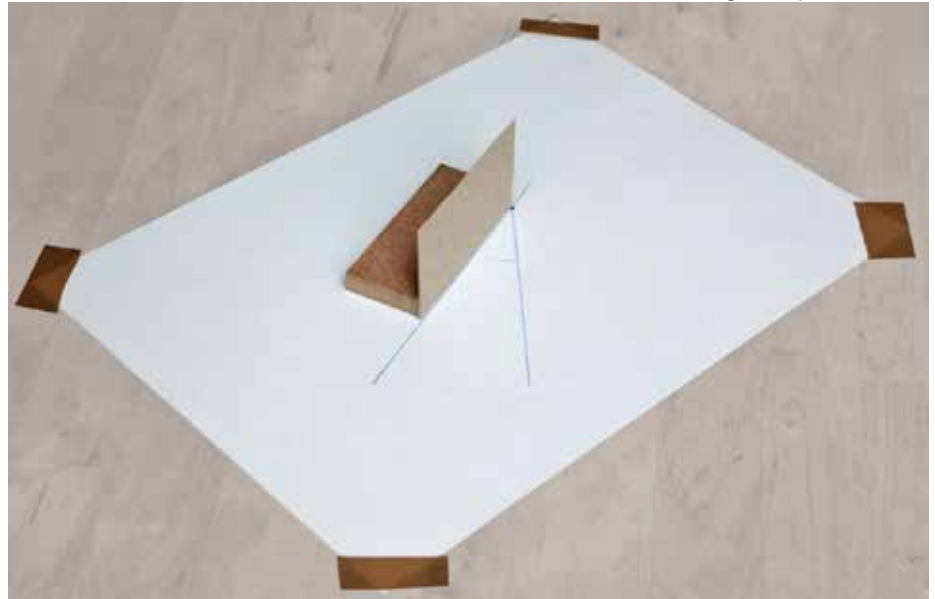


Figure 2: improvised device for measuring angles in a plane, corresponding to the horizontal (azimuth) angle measured by a theodolite



Figure 3: setup for the angle-measuring activity. The dashed line divides Earth (right) from space (left).

4. Set the declination angle (read from the white semicircular scale in figure 1) to zero. This keeps the sight lines (through the sights in figure 1) within the horizontal plane, in which we will be taking all the angle and length measurements.
5. Adjust the height of the theodolite to be the same as that of the star. You can do this using the telescopic

legs of the theodolite's tripod. With the star some distance from the theodolite, look through the sights and adjust the tripod until the star is directly in a straight-line view. You will probably need to readjust the turntable to make sure it's still horizontal.

Alternatively, if you are not using theodolites, follow these steps to make the improvised devices:

3. Fix a sheet of paper onto each of the tables or other level surfaces to create two observing platforms corresponding to the theodolite positions B and C in figure 3.
4. Make the 'sight' (the line you look along) by firmly fixing the piece of card to the edge of the wooden block, as shown in figure 2.
5. Adjust the height of your star (position A in figure 3) so that it is at exactly the same height above ground as your two sights. Then, from each of your two positions, you should be able to adjust the position of the sights so you can look along the card from the side, exactly edge on, straight towards the star.

### Taking the measurements

Your task now is to determine the distance between your observing point and the star, taking all your measurements only on Earth. Obviously, you can't just grab your tape measure and stretch it from B to A, since that would mean leaving Earth. We can't measure the distances to astronomical objects outside our Solar System by flying there.

Instead, we will measure two angles and the length of one side of the triangle ABC, and geometry will help us to find the length of the remaining two sides, AB and AC. With the theodolite at position B, we can measure the angle ABC as follows:

1. Point the sight of the B-theodolite in the direction of the C-theodolite. Read off the azimuth angle on the azimuth disk (the black scale on the turntable in figure 1). This works best if both theodolites are pointed at each other at the same time.
2. Next, point the sight of the B-theodolite in the direction of the star at A. Again, read off the azimuth angle.
3. Subtract one of the azimuth values from the other. This gives you the value of angle ABC.

4. Repeat the procedure with the theodolite at position C to obtain the angle ACB.
5. Finally, measure the distance between points B and C along the baseline using the tape measure.

With the improvised devices, the same angular measurements can be performed as follows, first for the device at B:

1. Mark a dot on the piece of paper. This will be your reference point.
2. Place the sight so that the lower edge of the cardboard touches the reference point, and the upper edge (along which you are looking) points directly at the other device placed at C. (This works best if the two devices are pointed at each other at the same time, with the upper edges of their sighting cards aligned with each other.)
3. Mark the position of the sight by drawing a line on the paper (as shown in figure 2).
4. Repeat the procedure, looking with the B-device to the star at A, again sighting along the upper edge of the card with the lower edge touching the reference point, and drawing a line along the lower edge.

5. Use a protractor to measure the angle between the two lines you have drawn. This is the angle ABC.
6. Repeat the procedure, using the device at C, looking towards B and A in turn, and marking the sight lines. This will give the angle ACB.
7. Finally, measure the distance between points B and C along the baseline using the tape measure.

### Finding the star distance

You now know the angles of view of the star from two different positions on Earth, plus the distance between these positions. So how do we use these results to work out the distance to the star? First, look at the geometry of the situation, shown in figure 4.

In this arrangement, the star position A and the theodolite positions B and C all lie in a horizontal plane and form the triangle ABC (seen directly from above). Angles  $\beta$  and  $\gamma$  are the measured angles ABC and ACB, respectively, and the length  $b$  is the measured distance between B and C along the baseline.

Using your own measurements, draw a scale diagram of a triangle like this as accurately as possible: a scale of

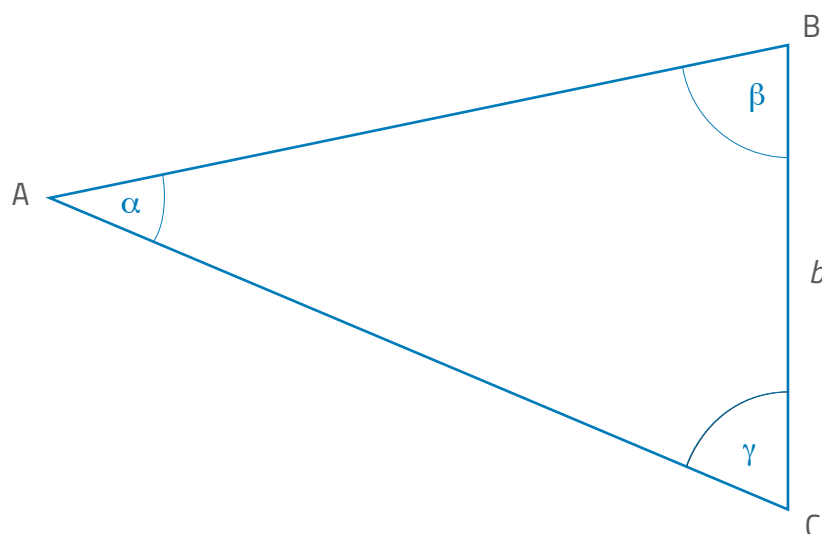
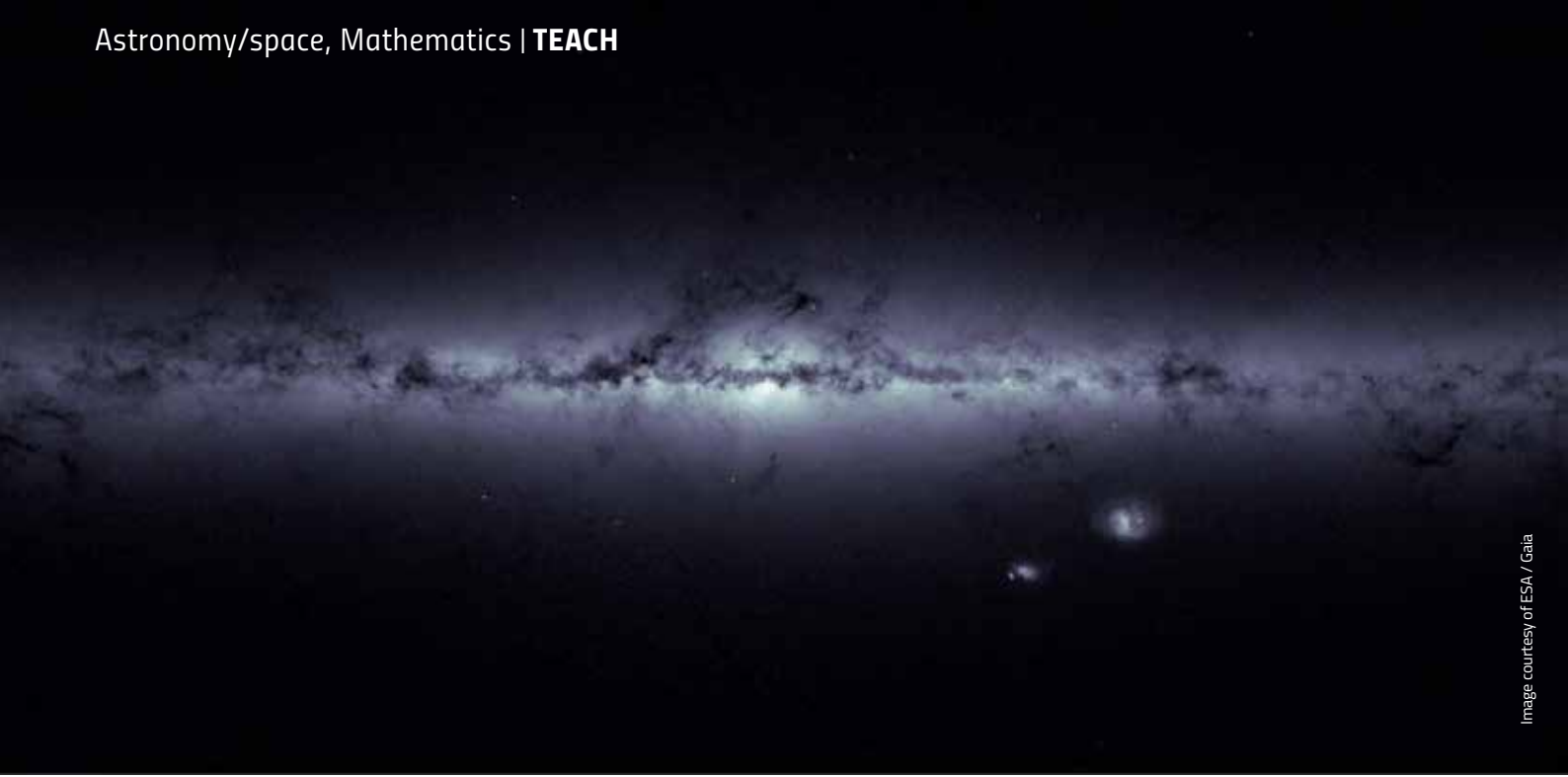


Image courtesy of HdA / M Pössel

Figure 4: basic geometry of the star and theodolite setup



The Milky Way galaxy and its neighbours, the Magellanic Clouds, in an image based on data from ESA's Gaia satellite

1:50 on A3 paper gives good results. Then you can simply measure the distances AB and AC from the diagram, and convert these to real distances to determine the distances of B and C to the star A.

To check your results, break the rules! Travel into 'space' and use the tape measure to measure AB and BC.

Finally, discuss the accuracy of the results obtained by angle measurement. If we had used larger distances, how would this accuracy change – and why?

## Measurements in space

We hope that students will enjoy a sense of discovery from this activity and get some idea of the way distance measurements are carried out in astronomy<sup>w1</sup>. Of course, real procedures use elaborate methods to ensure the best possible accuracy, because the stars are so very far away and their parallax shifts are so tiny. Even our closest stellar neighbour outside the Solar System (Proxima Centauri) is some 100 000 times further away than the longest baseline distance that can be measured from Earth – that is, twice the distance between the Earth and the Sun, if we

take images half a year apart. This is like trying to detect a parallax shift in an object 100 kilometres away when we step one metre to the side.

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Markus Pössel is Managing Scientist of the *Haus der Astronomie* (Centre for Astronomy Education and Outreach) and Senior Outreach Scientist at the Max Planck Institute for Astronomy, both in Heidelberg, Germany.

## Web reference

**w1** Background material on the history of parallax measurements can be downloaded from the *Science in School* website. See: [www.scienceinschool.org/2017/issue39/parallax](http://www.scienceinschool.org/2017/issue39/parallax)

## Resources

For a useful resource on the history of parallax measurements, see:

Hirshfeld AW (2013) *Parallax: The Race to Measure the Cosmos*. Mineola, NY, USA: Dover Publications. ISBN: 9780486490939

A parallax experiment using an improvised angle-measuring device, as in the article, is described here:

Ferguson JL (1977) More parallax without pain. *American Journal of Physics* **45(12)**: 1221-1222. doi: 10.1119/1.10697

For information on how to carry out real astronomical parallax measurements with astronomical telescopes, large and small, see:

Cenadelli D et al. (2009) An international parallax campaign to measure distance to the Moon and Mars. *European Journal of Physics* **30**: 35-46. doi: 10.1088/0143-0807/30/1/004

Cenadelli D et al. (2016) Geometry can take you to the Moon. *Science in School* **35**: 41-46. [www.scienceinschool.org/2016/issue35/parallax](http://www.scienceinschool.org/2016/issue35/parallax)

Penselin M, Liefke C, Metzendorf M (2014) Zweifacher Blick auf erdnahen Asteroiden. *Sterne und Weltraum* **11/2014**: 72-77

Ratcliff SJ et al. (1993) The measurement of astronomical parallaxes with CCD imaging cameras on small telescopes.

*American Journal of Physics* **61(3)**: 208. doi: 10.1119/1.17292



# FANTASTIC FEATS

Entertain your audiences with these tricky feats, which showcase Newton's laws of motion in action.

By David Featonby

This article is the first in a series of light-hearted challenges that are fun to do and also demonstrate some intriguing scientific principles – once you know how to solve them. We hope that readers will be tempted to share their own 'fantastic feats', which we will publish in future issues.

Centuries ago, Isaac Newton set out three scientific principles known as the laws of motion. Here we describe some demonstrations involving these principles and set out the challenges. To solve them, think about where the forces are in each situation, and which of Newton's laws apply.

See if you can work out how to succeed. If not, you'll find the solutions on page 60.

## Feat 1: money grab

The task is to balance a bottle upside down on top of a banknote, and then remove the note without touching the bottle or knocking it over. You can set this up as a challenge to see who can win the banknote, or just perform it to amaze your audience.

This feat needs steady hands and some nerve, especially if you are using a glass bottle. It's best to practice with a plastic bottle first: once you've mastered the feat with this, you can move on to the harder stuff – or stick with the practice version, which is still guaranteed to impress.

## Materials

- A clean, newish banknote
- One plastic soft drink bottle (about 500 ml capacity) – if possible, one with a small, very smooth and perfectly flat cap; or
- One glass bottle (about 500 ml capacity) – a more daring alternative
- A table with a smooth surface

## Procedure

1. Half fill the plastic bottle with water and screw the top on well.

Images courtesy of David Featonby



Figure 1: setting up the feat: the banknote beneath the bottle



Figure 2: the bottle challenge – with two bottles



- ✓ Physics
- ✓ Mathematics
- ✓ History
- ✓ Ages 11–19

REVIEW

This article outlines some fun demonstrations using the familiar principles described by the famous scientist Isaac Newton. As well as being suitable for physics lessons, the experiments provide links to mathematics and history.

Possible questions include:

- What are the equations of Newtonian mechanics?
- How can they be applied to dynamic processes?
- What is the relationship between mass and weight?
- What is the relationship between velocity ( $v$ ), acceleration ( $a$ ) and time ( $t$ )?
- What are some applications of Newton's laws?

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2. Make sure that the bottle cap (or bottle neck, if you are using an empty glass bottle) is perfectly dry. Any dampness will significantly increase the friction with the banknote, making the feat almost impossible to perform. (This is a sure way to win the banknote if you set the task up as a challenge: simply dry the neck when it comes to your turn.)
3. Place the banknote on the table, and place the upturned bottle on top of the note, neck downwards (figure 1).
4. Now try to remove the banknote from under the bottle without knocking it over – or challenge someone else to do this. Hint: think about the forces acting on the bottle, and how to minimise them.
5. Once you can do this with the plastic bottle, perhaps try it with the glass bottle – if you dare. (This is heavy enough, so no need to add any water.)

Trickier tricks

Once you've achieved the banknote and bottle feat, you can try something harder. Can you remove the banknote from between two bottles: an upturned bottle balanced on an upright one (figure 2)? This is a lot more difficult, but it can be done.

Images courtesy of David Featonby



Figure 3: tea for one: the classic tablecloth challenge



Figure 4: holding the rod before dropping, with the catcher's hands above

If you succeed at this, perhaps you'll want to try the ultimate challenge, where keeping tableware upright is needed: the classic tablecloth trick (figure 3).

In this challenge, it's even more spectacular to onlookers if the cup contains coffee and the bottle some liquid – and in fact, this should make the trick slightly easier: can you think why?

## Feat 2: drop catch

In this next feat, we show how understanding Newton's equations can again help you to keep things from crashing to the floor. This time, it's a slightly counter-intuitive way to catch a falling rod.

This feat is also a useful follow-up to the classic reaction-time experiment in which students catch a ruler dropped vertically to determine their reaction time (Thibault et al., 2017).

### Materials

- One rod, about 50 cm long and 1–2 cm in diameter, not too heavy (wooden dowelling is ideal)
- Two people – one to drop the rod, one to catch it

### Procedure

1. One person holds the rod just below shoulder height.
2. The other person (the catcher) must then position his or her hands about 20 cm above the rod (figure 4).
3. The person holding the rod then drops it without warning, while the catcher tries to grab it. Can they get it before it hits the ground?

### Solutions

For solutions and the science behind all these challenges, turn to page 60.

### Invitation to readers

Do you have a science trick that you could share with others across Europe? If so, please let us know!

### Reference

For an account of the ruler-drop reaction time experiment, see the online materials for:

Thibault E, Biedermann K, Watt S (2017) Cans with a kick: the science of energy drinks. *Science in School* **39**: 48–54.  
[www.scienceinschool.org/2017/issue39/energydrinks](http://www.scienceinschool.org/2017/issue39/energydrinks)



# Cans with a kick: the science of energy drinks

If you ever buy an energy drink as a pick-me-up, do you know what it contains? Here we use laboratory chemistry to find out.

By Emmanuel Thibault, Kirsten Biedermann and Susan Watt

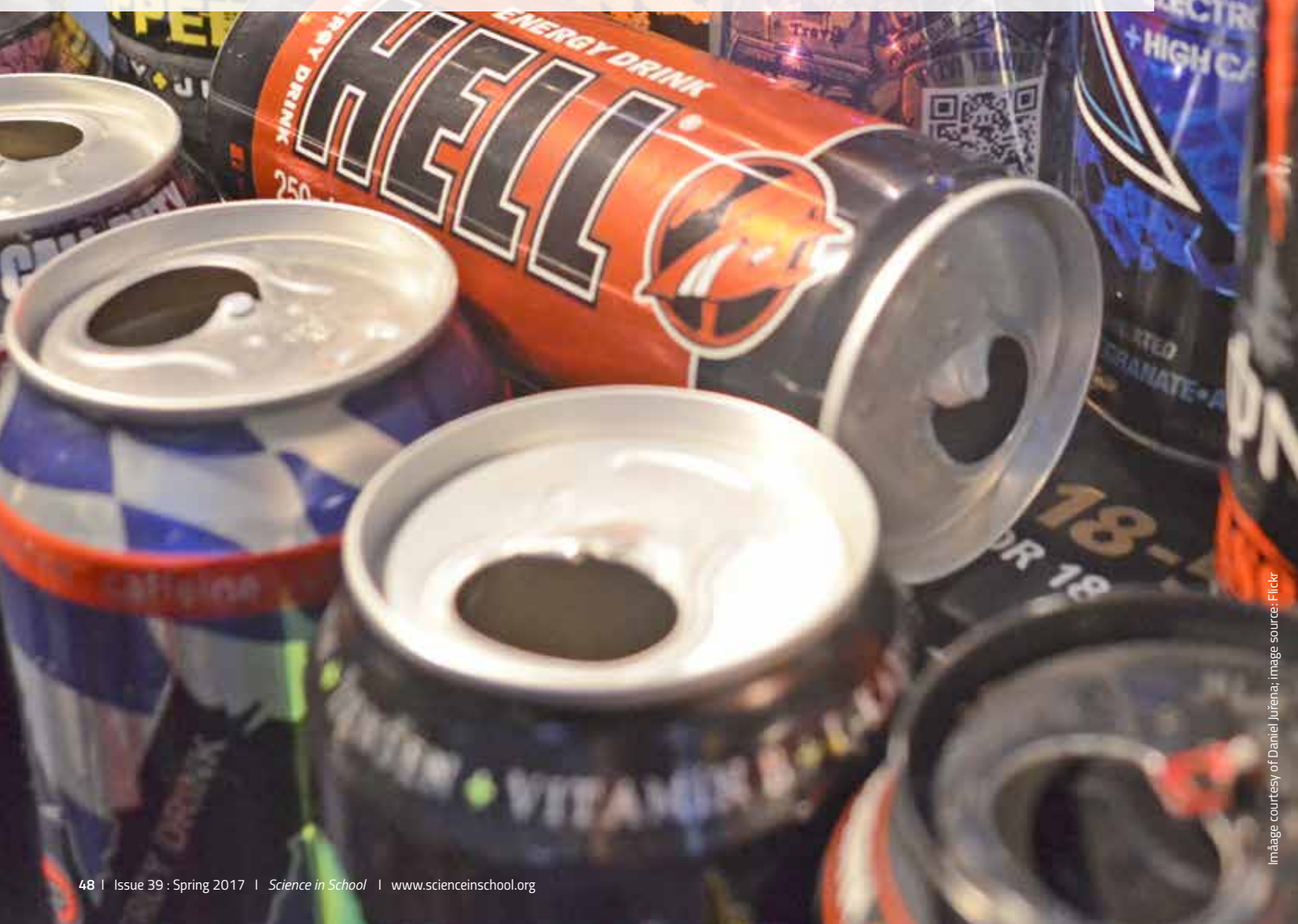


Image courtesy of Daniel Jurena; image source: Flickr



Look along the shelves in any local convenience store, and you'll see an increasing number of 'energy drinks', all offering the promise of improved performance in sports and other activities – and with a strong appeal to many teenagers. But what's in these drinks, and how much of it? Are they just high-priced sugar solutions – or can they actually be dangerous?

In this article, we show how you can check out some of the ingredients of energy drinks and their concentrations using the laboratory techniques of chromatography and colorimetry. Because of the advanced techniques involved, these activities are most suitable for older students (ages 14–19), and together take around 3–4 hours to complete. If your own school does not have all the equipment needed, perhaps link up with other schools: the activities work well as a collaboration.

## Preparation: reading the labels

Manufacturers have to list the ingredients of energy drinks on the packaging (figure 1) or a website, so we start with this without doing any chemistry. Later on, we will compare the manufacturers' information to the laboratory results.

The ingredient in energy drinks that has the greatest effect is caffeine, which is also found in other drinks including

Figure 1: energy drink label showing ingredients



Image courtesy of Susan Watt



- ✓ Biology
- ✓ Chemistry
- ✓ Physics
- ✓ Ages 14–19

Do you need to teach organic chemistry but are worried that your students are not enthusiastic about the subject? Then this article is what you need to really engage your students.

Starting from energy drinks, a very popular beverage among teenagers, the authors provide activities that cover a wealth of science topics ranging from chemistry (including analytical techniques) to physics, biology, and health and nutritional education.

The activities begin with a web quest before continuing to qualitative and quantitative investigations, which together provide a progressive understanding of the topic and ensure your students stay engaged.

The activities may also be valuable for promoting critical thinking and encouraging students to make responsible choices about nutrition and health.

The online extension activity provides teachers with the opportunity to perform inspiring experiments on the effect of energy drinks on the brain, with further opportunities to address scientific methods, experiment planning and data processing.

Possible questions include:

1. Which of the following beverages does not contain caffeine?
  - a) Tea
  - b) Beer
  - c) Coca-Cola
  - d) Espresso
2. How much caffeine is contained in one litre of an average energy drink?
  - a) 120 mg
  - b) 320 mg
  - c) 520 mg
  - d) 720 mg
3. The concentration of caffeine in energy drinks measured with a colorimeter (according to the article protocol) is:
  - a) Lower than that stated by manufacturer due to the presence of vitamin B<sub>3</sub> and B<sub>6</sub>
  - b) Higher than that stated by manufacturer due to the presence of vitamin B<sub>3</sub> and B<sub>6</sub>
  - c) Equal to that stated by manufacturer because vitamin B<sub>3</sub> and B<sub>6</sub> do not interfere
  - d) Higher than that stated by manufacturer due to the presence of vitamin B<sub>3</sub>, C and B<sub>12</sub>

Giulia Realdon, Italy

## REVIEW



tea, coffee and Coca-Cola®. Its effect as a stimulant is well known. In this preparatory activity, students research and compare caffeine concentrations in different drinks and work out how many portions would be needed to cause harmful side effects. We suggest allowing 30–60 minutes for this activity.

### Materials

- Internet access to carry out research
- Notebooks to record findings

### Procedure

Ask the students to do the following, on their own or in groups:

1. Make a list of around five energy drinks, especially those that are promoted as containing caffeine. Include coffee (as a single espresso) for comparison.
2. Use the internet to research each drink's ingredients, including

caffeine. Note the amount of caffeine in a single can or bottle and per 100 ml, if listed. If not, note the volume of the can or bottle so that you can work out the caffeine concentration (we will use this in one of the experiments).

3. Use the internet to find out the caffeine dose at which harmful side effects are expected. Does this depend on any other factors, e.g. body weight, or whether the consumer is an adult or a child?
4. Make a table showing the following characteristics for each drink:
  - List of ingredients
  - Amount of caffeine in one can
  - How many single espressos this is equivalent to
  - How many cans you would need to drink to risk harmful side effects.

### Discussion

Discuss the results as a class. What do students conclude about the ingredients of energy drinks and how safe they are? Could they kill you?

In our research, we found that an average can (250 ml) of an energy drink contains about 80 mg of caffeine, which is similar to the amount in a single espresso (60–100 mg). This is close to the dose that is likely to cause side effects (100–160 mg).

### Extracting the caffeine

Now we move on to the practical chemistry: extracting the caffeine and other organic compounds from the energy drink, and then identifying the caffeine using thin-layer chromatography. This activity takes 1.5–2 hours to complete.

**Safety note:** This procedure involves the use of pure caffeine (figure 2),

Image courtesy of Emmanuel Thibault and Kirsten Biedermann

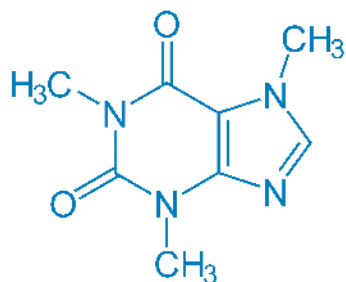


Figure 2: the molecular structure of caffeine

which is toxic and should therefore not be available to students as a reagent. Teachers are advised to prepare the very small quantities needed for the experiment in advance.

See also the general safety note on the *Science in School* website ([www.scienceinschool.org/safety](http://www.scienceinschool.org/safety)) and at the end of this print issue.

## Materials

### For the extraction

- 50 ml of an energy drink
- 2 x 15 ml of an organic solvent that evaporates easily, e.g. ethyl ethanoate (ethyl acetate)
- 10 ml of a 1 M solution of suitable alkali, e.g. sodium carbonate
- 10 g anhydrous magnesium sulfate (for drying)
- Rotary evaporator, if available
- Universal indicator paper
- Separating funnel
- Filter paper
- 100 ml beakers
- Graduated cylinder
- Glass rod for stirring

### For the chromatography

- Stationary phase: thin-layer chromatography plates pre-coated with silica gel, about 10 cm x 5 cm
- Eluent (mobile phase): 10 ml of a mixture of 30% methanoic (formic) acid and 50% butyl ethanoate (butyl acetate)
- Sample of pure caffeine (to provide a reference spot), made by dissolving the tip of one spatula of caffeine in 2–3 ml of ethanol
- UV light source

Image courtesy of Emmanuel Thibault and Kirsten Biedermann

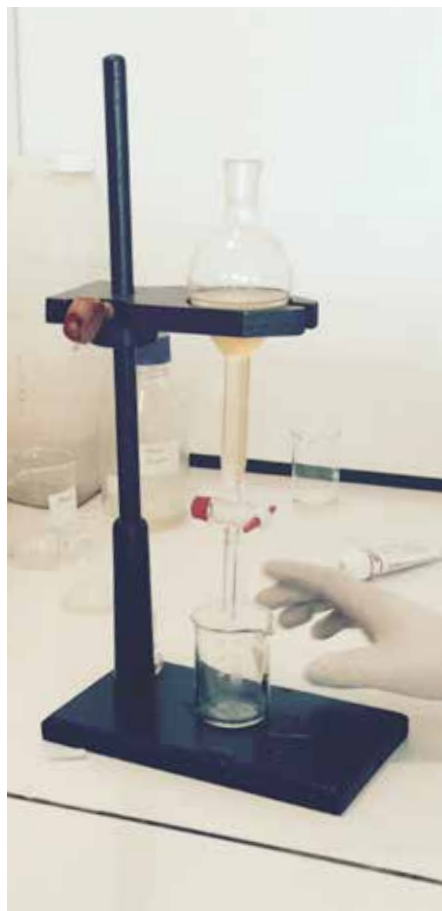


Figure 3: extracting the organic phase (containing caffeine) using a solvent

## Procedure

1. Take 50 ml of the energy drink and add it to 9 ml of a 1 M solution of sodium carbonate in a beaker.
2. Using indicator paper, check that the pH of the solution is between 8 and 10. If not, adjust the pH by adding a little more alkali or energy drink.
3. Pour this solution into a separating funnel and add 15 ml of ethyl ethanoate. Shake the mixture well and leave it to settle so that the aqueous phase and the organic phase separate.
4. Run off the aqueous phase (lower layer), then collect the organic phase (the top layer) in a clean beaker (figure 3).
5. Add another 15 ml of ethyl ethanoate to the beaker containing the organic phase and repeat the operation, shaking and then collecting the organic phase.
6. Remove the water from the organic phase by adding the anhydrous magnesium sulfate (figure 4).

Image courtesy of Emmanuel Thibault and Kirsten Biedermann



Figure 4: drying the organic phase using anhydrous magnesium sulfate

7. Evaporate the solvent from the organic phase using the rotary evaporator, if you have one. The water bath temperature should be 40 °C. Once the solvent has evaporated, you are left with a white powder – this is the caffeine extract. If you don't have a rotary evaporator, continue to the next step with the caffeine extract still dissolved in the solvent.
8. Now you are ready to analyse your sample. If you evaporated the solvent, add 1 ml of ethyl ethanoate to the caffeine extract powder to re-dissolve it.
9. To begin the chromatography, prepare the 10 ml of eluent and pour this mixture into an elution tank (or a beaker with a cover).
10. On a chromatography plate, make one spot using the pure caffeine solution (as a reference) and one spot using the caffeine extract solution.
11. Allow the chromatography to proceed (10–15 mins; figure 5), and then carefully remove the chromatogram.
12. Finally, view the chromatogram under UV light, so that the spots become visible (figure 6). What do you see?

### Discussion

After the practical work, the whole class can discuss what they found. Try the following questions:

- In the extraction, why is the caffeine found in the liquid and not on the filter paper? (The caffeine dissolves in the solvent.)
- Why do we use an organic solvent for the extraction rather than water? (Sugars and minerals dissolve in the water, while caffeine is an organic compound.)
- Why is UV light needed to see the caffeine on the chromatogram? (Caffeine is not coloured, but its chemical bonds absorb light in the near-UV region.)

For some drinks, there will be other spots visible on the chromatogram under UV light as well as caffeine, which students can try to identify from the drink's list of ingredients. Probable compounds are the vitamins B<sub>3</sub> (pyridoxine) and B<sub>6</sub> (niacin), because some of the bonds in these compounds (figure 7) also absorb light in the near-UV region.

### Testing the concentration

In this final activity, we use another chemical technique – colorimetry – to

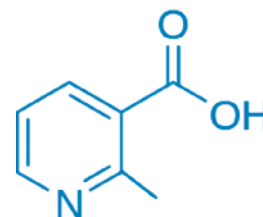
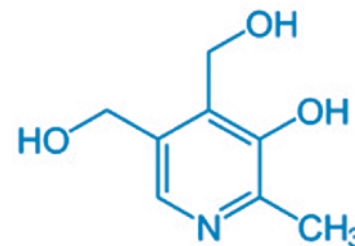


Figure 7: the molecular structures of B<sub>6</sub> (pyridoxine; above) and B<sub>3</sub> (niacin; below)

work out the concentration of caffeine in an energy drink and compare this to the advertised figure. Allow 60–90 minutes for this activity.

The strategy here is to use a set of reference solutions of caffeine at different known concentrations, and to compare the absorption of the energy drink to these values via a calibration graph.

**Safety note:** As with the previous activity, this procedure involves the use of pure caffeine, which is toxic

Image courtesy of Emmanuel Thibault and Kirsten Biedermann

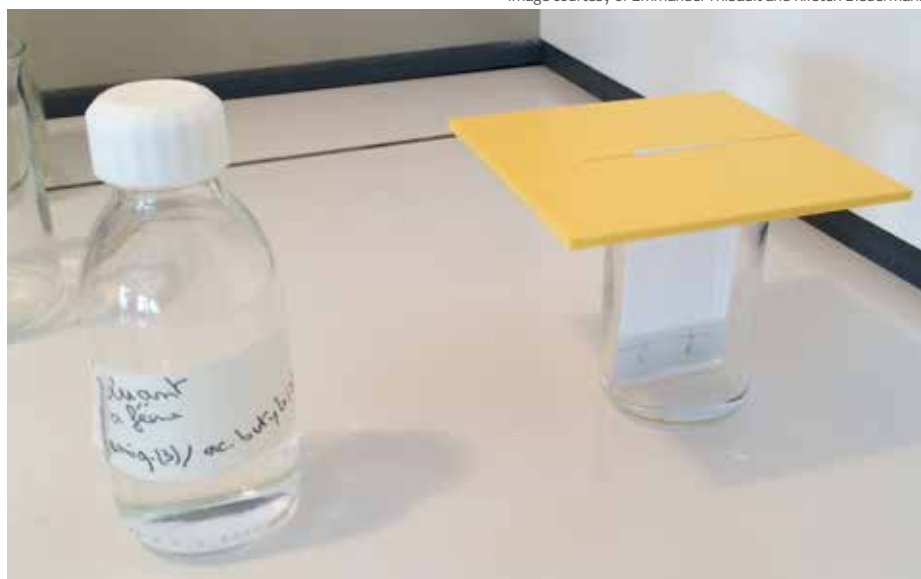


Figure 5: using chromatography to separate and identify the caffeine

Image courtesy of Emmanuel Thibault and Kirsten Biedermann

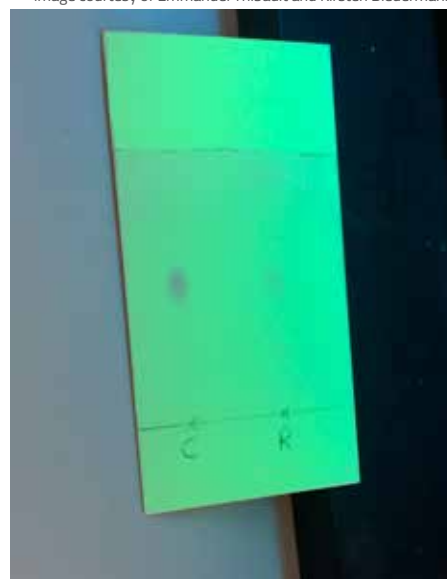


Figure 6: viewing the chromatogram under UV light

and should therefore not be available to students as a reagent. Teachers are advised to prepare the reference solutions of caffeine needed for the experiment in advance.

See also the general safety note on the *Science in School* website ([www.scienceinschool.org/safety](http://www.scienceinschool.org/safety)) and at the end of this print issue.

## Materials

- Energy drink (at least 20 ml)
- Reference solutions of pure caffeine in distilled water at concentrations of 5, 10, 20 and 50 mg/l (at least 20 ml of each)
- Distilled water
- Colorimeter that is sensitive to wavelengths between 250 nm and 380 nm (near-UV light)
- 20 ml volumetric flask
- Pipette
- Weighing balance and weighing dish

## Procedure

1. Calibrate the colorimeter using distilled water.
2. Using the colorimeter, measure the absorption at 271 nm of each reference solution in turn and record these readings. (Caffeine absorbs very strongly at this wavelength; figure 8.)
3. Use the readings to plot a calibration graph linking absorption at 271 nm to caffeine concentration, drawing a straight line of best fit between the points (figure 9).
4. Using a volumetric flask and pipette, dilute the drink by a factor of 20. (In normal concentrations, the absorption of caffeine is too high for the colorimeter to measure accurately.)
5. Measure the absorption of the diluted drink at 271 nm.
6. Using the calibration curve you have drawn, estimate the caffeine concentration of the diluted drink solution. Multiply this by 20 to find an estimate of the caffeine concentration of the original energy drink, in mg/l.

7. Compare this result to the concentration of caffeine stated by the manufacturers (making sure you are using the same units in each case). Are they the same? If not, can you think of any possible reasons why this is? Has the manufacturer cheated?

## Discussion

Ask students to compare their results for the caffeine content of different energy drinks as a class discussion.

Then discuss what they found when they compared their own results to those published by the manufacturers. Were

any of the experimental results higher than those published?

To explain this, students should think back to the first part of the experiment where some compounds other than caffeine were revealed by the chromatogram – typically the vitamins B<sub>3</sub> and B<sub>6</sub>. In fact, these same compounds also absorb at the 271 nm wavelength, so they increase the energy drink's absorption at that wavelength. So when the drink's absorption is used to find the caffeine concentration via the calibration graph, the reading is higher than it should be as a measure of the caffeine alone.

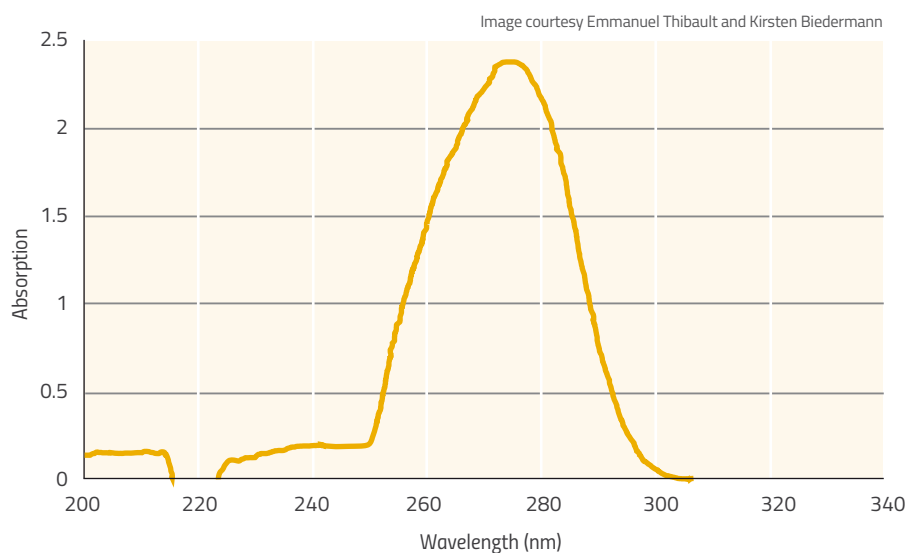


Figure 8: graph showing absorption spectrum of caffeine in the wavelength region 200–340 nm

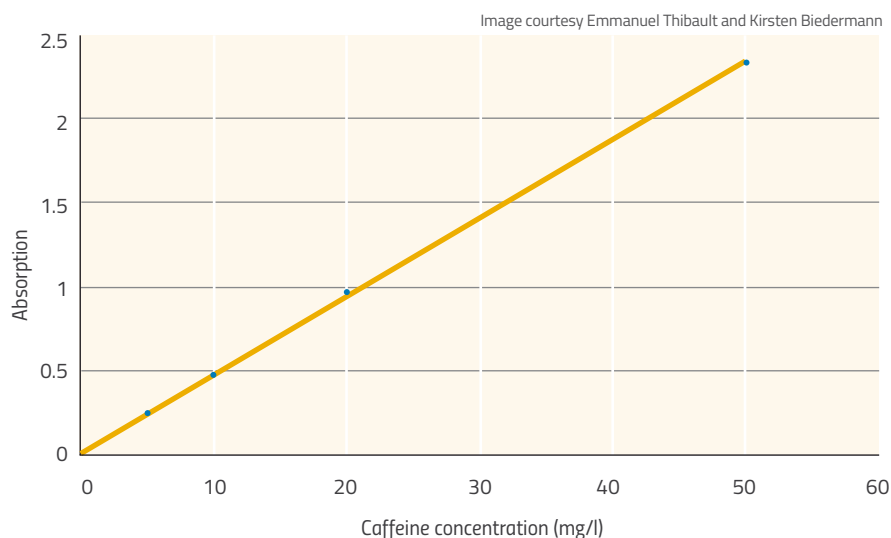


Figure 9: calibration graph showing increase in absorption at 271 nm with caffeine concentration



Image courtesy of Daniel Jurena; image source: Flickr

## Caffeine and the brain

Energy drinks are popular because of their branding and association with sports and physical stamina. But can they also affect the way our brains work by stimulating our mental powers?

If you would like to find out about ways to investigate this, two classroom experiments that assess mental agility by measuring thinking and reaction times can be downloaded from the *Science in School* website<sup>w1</sup>. One is a number-matching task, the other a catching task.

## Acknowledgements



This article is based on an activity published by Science on Stage, the network for European science, technology, engineering and mathematics (STEM) teachers, which was initially launched in 1999 by EIROforum, the publisher of *Science in School*. The non-profit association Science on Stage brings together science teachers from across Europe to exchange teaching ideas and best practice with enthusiastic colleagues from 25 countries.

At Science on Stage workshops, as well as discussions via email, 20 teachers from 15 European countries worked together for 18 months to develop 12 teaching units that show how football can be used in physics, chemistry biology, maths or IT lessons. These units were then published in 2016 by Science on Stage Germany as *iStage 3 - Football in Science Teaching*<sup>w2</sup>. The project was supported by SAP.

The follow-up activity of *iStage 3* is the European STEM League, which readers are invited to join and compete to become the European STEM Champion<sup>w3</sup>.

Emmanuel Thibault is an associate professor of physics and chemistry at Vaucanson High School in Tours, France. As well as teaching, he works on scientific and technical projects with his students, which has allowed them

to win several prizes in national and international contests. Since 2013, Emmanuel has been involved with Science on Stage, and he contributed to the recent *iStage 3* publication.

Kirsten Biedermann teaches at Widukind-Gymnasium (high school) in Enger, Germany. A graduate in physics, mathematics, fine arts and education, he specialises in teaching gifted and special-needs students. He is president of Ravensberger Erfinderwerkstatt, a non-profit club that supports STEM activities for young people, and is also active with Science on Stage, presenting projects at national and international festivals.

Susan Watt worked as a freelance science writer and editor before joining *Science in School* as an editor in 2016. She studied natural sciences at the University of Cambridge, UK, and has worked for many publishers and scientific organisations, including UK science research councils. Her special interests are in psychology and science education.

## Web references

- w1 Download the supporting classroom experiments from the *Science in School* website. See: [www.scienceinschool.org/2017/issue39/energydrinks](http://www.scienceinschool.org/2017/issue39/energydrinks)
- w2 The *iStage 3* publication can be found on the Science on Stage website. See: [www.science-on-stage.eu/istage3](http://www.science-on-stage.eu/istage3)
- w3 Find out more about the European STEM League. See: [www.science-on-stage.eu/STEMleague](http://www.science-on-stage.eu/STEMleague)

## Resources

- The US Department of Agriculture website provides a breakdown of ingredients for a huge variety of foods and drinks available in the USA. See: <https://ndb.nal.usda.gov/ndb/foods>
- The Authority Nutrition website has an informative article about the amount of caffeine in coffee. See: [www.authoritynutrition.com/how-much-caffeine-in-coffee](http://www.authoritynutrition.com/how-much-caffeine-in-coffee)
- The How Stuff Works website has an accessible article on the history and composition of energy drinks. See [www.howstuffworks.com](http://www.howstuffworks.com) or use the direct link: <http://tinyurl.com/6v4w6s7>





Image courtesy of zimmytws / shutterstock

## Hooked on science

Encouraging your students to create science videos can be a way of catching – and keeping – their attention.

By Martin McHugh and Dr Veronica McCauley

Everyone knows how journalists and newspapers try to grab readers' attention by using a 'hook' – an eye-catching headline or idea at the start of an article. Hooks are also a good way to draw students into learning about science – although not usually in the form of celebrity gossip or some shocking speculation, of course.

### What are hooks in teaching?

A hook is any short instructional activity that gets students more interested or engaged during a lesson. Usually, hooks are used to introduce a lesson, but they can be used at any point. Hooking strategies include mysteries, questions, practical work, new technologies and anything that appears novel to students. Anomalies such as the counter-intuitive situation shown in figure 1 can also be used as a hook, because – like mysteries – they catch our interest by posing a puzzle.



- ✓ General science
- ✓ Ages 11–18

#### REVIEW

In this article, Martin McHugh and Veronica McCauley present a modern and interesting way to get students more engaged during lessons. They describe a detailed procedure that can be followed by any teacher or adapted to the teacher's own needs and plans. As science teachers may occasionally find it difficult to make science lessons exciting, the idea of using videos as hooks may be a great help. This idea can easily be applied to almost every science classroom or lab, even using students' own smartphones or cameras. The fact that these short science videos are produced by the students themselves offers extra added value.

Vangelis Koltsakis, Greece

To keep students engaged, teachers need to develop new hook ideas on a regular basis. Videos, for example, are often used as an effective way to introduce or add interest to science topics.

In the activity we describe in this article, we pass the hook-making task to the students and encourage them to construct their own hooks – by making short films on science topics. In the process, students work together creatively to explore a science-related topic of their choice, and capture it on film (McCauley et al., 2015; McHugh & McCauley, 2015). The activity takes 2–3 hours, ideally split over two lessons, and is suitable for students aged 12 to 16. It can be used in relation to a specific science topic or more broadly.

### Film-making as a hook

The idea of film-making as a hook has a double benefit: students engage with their chosen science topic while making their film; and watching films – especially those made by their peers – helps to interest other students in the topic. Also, uploading the films to blogs or video-hosting websites allows students to extend their engagement with science outside the school.

This is all in addition to the skills they will learn in the process of creating the short films: planning, teamwork, critical thinking, reflective writing – and, of course, filming.

### Materials

Each group of students will need:

- Filming device (camera, tablet, webcam or smartphone) – any device that can record and save video so that it can be played back on a projector linked to a computer or an electronic whiteboard
- Tripod or other support for the camera
- Storyboarding sheets (blank template sheets can be made in class and photocopied, or can be found easily online; see figure 2)



Image courtesy of Martin McHugh

Figure 1: oddly balanced: example of a seemingly counter-intuitive situation

- Any equipment or materials needed for their chosen topic, sourced from the classroom or from home

### Procedure

The activity works best if teachers guide students through each stage, as follows.

#### 1. Introducing hooks

First, introduce students to the idea of short science films as hooks by showing some fun videos on science phenomena.

The idea is to draw the audience into the science, rather than to explain the science. You can see some ready-made examples in the Resources section at the end of the article.

Then tell students they are going to make their own films, and divide the class into groups of three or four students. Ask them to develop ideas for a short film on a scientific theme that would look good on video and make the rest of the class say “Wow!”

Image courtesy of Martin McHugh

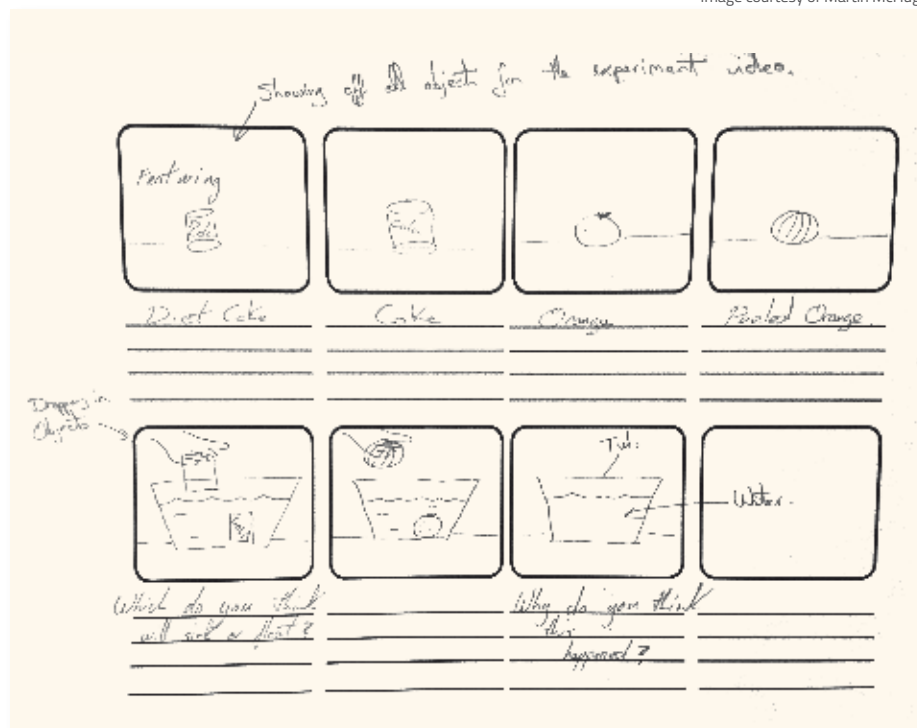


Figure 2: a storyboarding template filled out by a student





Image courtesy of Africa Studio / shutterstock

## 2. Research

Encourage students to research ideas online or using books, and also to discuss their ideas with each other. If students are struggling to find ideas, you can provide suggestions for simple

science tests or experiments (see Table 1 and the Resources section). Don't simply give the list of ideas to the students – rather, just use them if needed to help the creative process along.

- Creating paper airplanes from various materials, and testing which is best
- Performing a 'sink or float' experiment with a variety of objects
- Demonstrating the interplay between iron filings and a magnet using a sheet of paper
- Making and testing parachutes for eggs so they can be dropped from a height and land without breaking
- Adding milk to cola and watching what happens
- Placing a vibrating tuning fork in water
- Finding out how many times you can fold a piece of paper

Table 1: simple science ideas to film

## 3. Development and testing

Students then need to find the materials for the phenomenon or experiment they have chosen to film. This is the development phase, so students can decide to remove or add elements to make their film better. At the end of this stage, students should be confident that they can make their demonstration work smoothly and film it in a single take (to avoid the need for editing different shots together).

## 4. Storyboarding

Before they can start filming, students need to storyboard their video using the storyboarding sheets (figure 2). Storyboarding is a way of organising the filming, so that sketches of shots are shown in sequence along with



Image courtesy of jordeangielovik / shutterstock

Image courtesy of Martin McHugh

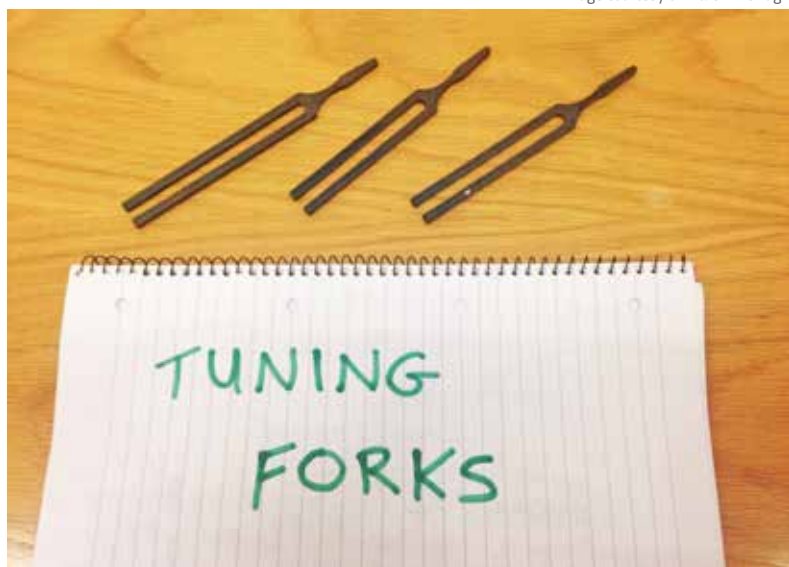


Figure 3: clear labelling of items in the video

any other elements for that shot. These elements are usually:

- Any narration or music
- Any labels or other objects needed for the shot
- Any directions or descriptions
- Time in minutes and seconds (e.g. 0.01 to 0.10 means the first ten seconds of the film) – this is essential.

Storyboards act as a type of pre-visualisation for the film and form the exact plan that students have to follow when filming. They therefore need to be carefully thought through so that the action takes place in the right sequence

with the right narration and other elements at each step. The storyboard sheets are designed to allow all the different elements to be shown alongside each shot in one frame. Both visuals and narration should be given specific timings in the storyboard. Students soon learn that the better the storyboard, the easier the filming.

A narration can help the viewer understand what is happening. The video should be simple enough that a few short lines will suffice. Posing a question at the start of the video is often an effective strategy. For example,

“Do you think object X will sink or float?” This type of narration introduces and sets up the action: the viewer immediately knows the context and the purpose of the video. The demonstration or experiment can then proceed without any more explanation.

Any labels needed should also be created at this stage, using bold, clear writing or print (figure 3).

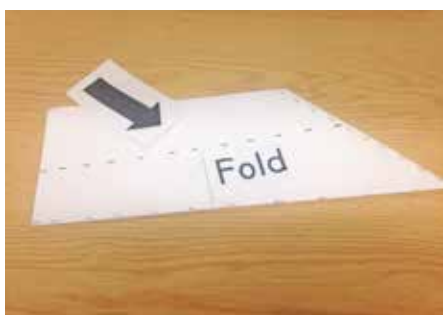
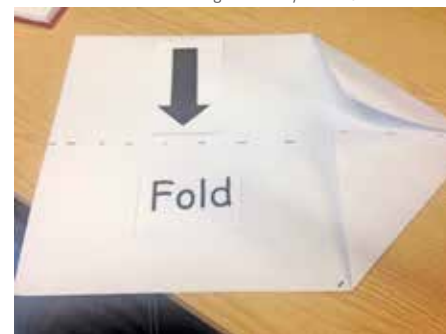
Before filming, students will also have to work out where to place the camera, bearing in mind that all the filming will be done from the same viewpoint (again, for simplicity and to avoid the need for editing).

## 5. Filming

Before filming, set out some rules for students to follow:

- Work with a fixed camera. This means that students need to work their experiment around the camera’s field of view while moving any objects and labels by hand.
- Shoot the film in one continuous take without breaks.
- The narrator can speak from behind the camera.
- Try not to film faces – this is distracting when replaying the video. The focus should be on the science action, not the people making the film.
- Follow the storyboards strictly, and truly understand the content of the storyboard before starting to film.

Images courtesy of Sara Jane McGeachy



How to make a paper plane: still images from a student video

Once filming is completed, the film should be saved or emailed to the teacher for the last step: the replay.

## 6. Replay

The replay is the final step in the film-making process, and the reward for all the students' hard work. They will be very interested not only in their own film, but also in what other students have created.

It's up to you as the teacher to decide how to use their creations. You can devote the next lesson to watching all the films, asking each group of students to present theirs in turn. The class can then judge which is the best video hook.

Alternatively, you can use one film per lesson, perhaps as a theme for a whole term or half-term. This way, the films made by the students will continue to garner the students' interest for longer – engaging them not only with science, but with their own process of learning and creation. Either way, in the end the focus should be on the learning journey that the class has taken, rather than the content of the individual video hooks.

Martin McHugh is a doctoral researcher and Dr Veronica McCauley is a researcher and lecturer in the School of Education at the National University of Ireland, Galway. Their current work uses a design-based research framework focused on the testing and development of physics video hooks in classrooms across Ireland.

## Acknowledgements

This work has been funded by the NUI Galway Hardiman Scholarship.

## References

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- McHugh M, McCauley V (2015) Designing physics video hooks for science students. *Physics Education* **51(1)**: 015015. doi: 10.1088/0031-9120/51/1/015015

## Resources

The website of the Science Education Resource Hook Series offers examples of hooks from biology, chemistry and physics with explanations of phenomena. See: [www.sciencehooks.scoilnet.ie](http://www.sciencehooks.scoilnet.ie)

The Physics Hooks Series channel on Youtube offers a collection of engaging physics videos. See [www.youtube.com](http://www.youtube.com) or use the direct link: <http://tinyurl.com/physicshooks>

The GoAnimate Resources Blog, though aimed at businesses, offers detailed advice on storyboarding that is just as applicable in the classroom. See: <https://resources.goanimate.com> or use the direct link: <http://tinyurl.com/zf4asgs>

As part of an activity guide to making a film, the BBC website provides a storyboard template. See: [www.bbc.co.uk](http://www.bbc.co.uk) or use the direct link: <http://tinyurl.com/nttkbqg>

The website of the ReelLIFE SCIENCE competition includes some useful tips and examples of student-made videos. See: [www.reellifescience.com](http://www.reellifescience.com)

Additional ideas for counter-intuitive demonstrations can be found in:

- Tsakmaki P, Koumaras P (2017) When things don't fall: the counter-intuitive physics of balanced forces. *Science in School* **39**: 36–39. [www.scienceinschool.org/2017/issue39/counterintuitive2](http://www.scienceinschool.org/2017/issue39/counterintuitive2)
- Featonby D (2017) Fantastic feats. *Science in School* **39**: 45–47. [www.scienceinschool.org/2017/issue39/feats](http://www.scienceinschool.org/2017/issue39/feats)
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- Onderová L, Featonby D (2015) Kinder eggs and physics? *Science in School* **32**: 41–46. [www.scienceinschool.org/2015/issue32/eggs](http://www.scienceinschool.org/2015/issue32/eggs)



# FANTASTIC FEATS

SOLUTIONS TO THE CHALLENGES ON PAGE 45



## Feat 1: money grab

1. To perform the feat, first pull the banknote very gently towards the edge of the table, so the bottle moves with it. You need to do this because it is easiest to move the banknote from under the bottle at the table's edge.
2. Then, hold the banknote outwards away from the table edge and slightly below the table surface, as shown in figure 1.
3. Now the tricky bit: you need to pull the banknote away from the bottle very sharply and with a downwards motion, so as not to lift the bottle. The best way to do this is with something like a karate chop: with your free hand, strike the note downwards, keeping a hold of the note with the other hand. This should remove the banknote easily, leaving the bottle standing upright.
4. An alternative method is to roll up the banknote so that centre of the roll is in contact with the bottle (figure 2).
5. Then, continue rolling up the note very gently, so that the rolled-up note pushes the bottle very slowly off the rest of the note.

Images courtesy of David Featonby



Figure 1: removing the note with a karate chop



Images courtesy of David Featonby



Figure 2: using the rolled-up note technique to remove the banknote

This feat is of course just a variation of the old tablecloth trick, where a magician astonishes the audience by removing a tablecloth from a table fully laden with fragile china, teapots, milk jugs and so on. As with the banknote, this is achieved by pulling the cloth sharply down over the edge of the table.

So why do these tricks work? The change of position of a stationary object depends upon the impulse that it receives, as described by the famous Newtonian equation:

$$F = ma$$

where  $F$  is the force,  $m$  is the object's mass and  $a$  is the acceleration caused by the force.

Here, we want there to be as little change as possible in the stationary object's position, which means that the difference between its initial velocity,  $u$  (which is zero), and the final velocity,  $v$ , should be as small as possible.

We know that:

$$a = (v - u)/t$$

where  $t$  = time.

So:

$$F = m(v - u)/t$$

or

$$Ft = m(v - u)$$

For the change in the stationary object ( $v - u$ ) to be as small as possible, either the force ( $F$ ) or the time ( $t$ ) needs to be very small – or preferably both.

In the karate chop method, the time that the force is applied is very short. Ensuring the bottle rim or top is very smooth also helps to keep the force to a minimum.



Figure 3: removing the note between two bottles with a karate chop

In the rolling-up method, the force is so small that it does not supply enough turning effect to topple the bottle.

Both methods can also be applied to a full-sized wine bottle. Which of the two sizes of bottle do you think will prove to be most difficult to keep upright?

If you think the bigger bottle is more difficult, you would be wrong. Look again at the equation

$$Ft = m(v - u)$$

We can see that, for the same force and time, a larger mass will mean a smaller change in the bottle's position – so the larger bottle is less likely to topple.

### Trickier tricks: two bottles and a banknote

It is much more difficult to remove the banknote from between the two bottles, because the tops of the bottles – which are in contact with each other through the note – are likely to be more uneven than the table in the single-bottle version.

However, if the bottles are exactly lined up, a sharp downwards chop will again remove the note, leaving the two bottles standing upright (figure 3).

### Trickier tricks: the tablecloth trick

This is another example of the appliance of Newtonian science to tableware. For this trick to work, you need to make sure that the cloth is completely smooth at the edges and does not have a raised hem; and – as with the banknote trick – use a short, sharp pull (figure 3).

Image courtesy of David Featonby



Figure 4: tablecloth trick: applying Newtonian science to tableware

Find a silky cloth for better slip (less friction, so the force  $F$  is reduced), and check that the base of anything on the table is smooth rather than rough.

Adding some liquid to the teapot and the bottle makes the trick easier to perform, because (as with the larger bottle, above), increasing the mass of an object by filling it with liquid reduces the effect of any forces on it, so it will accelerate less (and therefore move less) in response to a force.

## Feat 2: drop catch

In this feat you need to work out how to make the best use of the small amount of time available for catching the rod. This time, it's the Newtonian idea of how gravity makes falling objects accelerate that provides the clue.

The equation for this is:

$$d = \frac{1}{2}at^2$$

where  $d$  is the distance of fall, and  $a$  is the acceleration due to gravity ( $9.81 \text{ m/s}^2$ ).

If – as most people do – you try to snatch the rod immediately after it's dropped, you'll find that by the time you have reacted to seeing the rod fall, it will have dropped below your hands and out of reach, and it will then be falling too fast to follow.

We can calculate the time you have to catch the rod high up (say within 50 cm of its starting point) thus:

$$\begin{aligned} t^2 &= \frac{2d}{a} \\ &= 2 \times \frac{0.5}{9.81} \end{aligned}$$

$$\begin{aligned} \text{So } t &= \sqrt{\left(\frac{1}{9.81}\right)} \\ &= 0.32 \text{ s} \end{aligned}$$

Instead, the trick is to aim to catch the rod much lower down, just before it reaches the floor. This gives you more time to get your hands in position.

So if you try to catch the rod after it has fallen 1.5 m, the time-to-catch calculation becomes:

$$t^2 = 2 \times \frac{1.5}{9.81}$$

$$\begin{aligned} \text{So } t &= \sqrt{\left(\frac{3}{9.81}\right)} \\ &= 0.55 \text{ s} \end{aligned}$$

This may not seem much more than the high-up time, but remember that you need some time to react, which is the same in each case – and roughly around 300 milliseconds for the average person. This means that, for the high-up catch, you have only 0.02 seconds ( $0.32 - 0.3 \text{ s}$ ) to move your hands 0.5 m – meaning your hands have to travel at a daunting average speed of 25 m/s.

However, if you go for the low catch, your hands have 0.25 seconds ( $0.55 - 0.3 \text{ s}$ ) to travel 1.5 m, allowing a more feasible 6 m/s – far less than the speed needed for the high-up catch.

So immediately after the rod is released, quickly move your hands right down as fast as possible, bending your knees at the same time. In this way, you should have enough time to catch up with the falling rod – and then, with luck, grab it.

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David Featonby is a retired physics teacher from Newcastle, UK, with 35 years 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 unusual things connected with physics, and in revealing the physics in everyday things to everyone, whatever their age.

## Resources

For an entertaining video showing the tablecloth experiment, see:  
[www.youtube.com/watch?v=zWeKRMh3kT8](http://www.youtube.com/watch?v=zWeKRMh3kT8)

Test your own reaction time online. See: [www.humanbenchmark.com/tests/reactiontime](http://www.humanbenchmark.com/tests/reactiontime)



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*Science in School* is published and funded by EIROforum ([www.eiroforum.org](http://www.eiroforum.org)), a partnership between eight of Europe's largest inter-governmental scientific research organisations.

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 Germany  
[editor@scienceinschool.org](mailto:editor@scienceinschool.org)  
[www.scienceinschool.org](http://www.scienceinschool.org)

**Publisher:** EIROforum, [www.eiroforum.org](http://www.eiroforum.org)

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**Composition:** Graphic Design Studio Nicola Graf, Germany

**Printer:** Colordruck Leimen, Germany

**Distributor:** CFG Circle Fulfillment GmbH, Germany

**Web development:** Alperion GmbH & Co KG, Germany

### ISSN

Print version: 1818-0353

Online version: 1818-0361

### Cover image

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