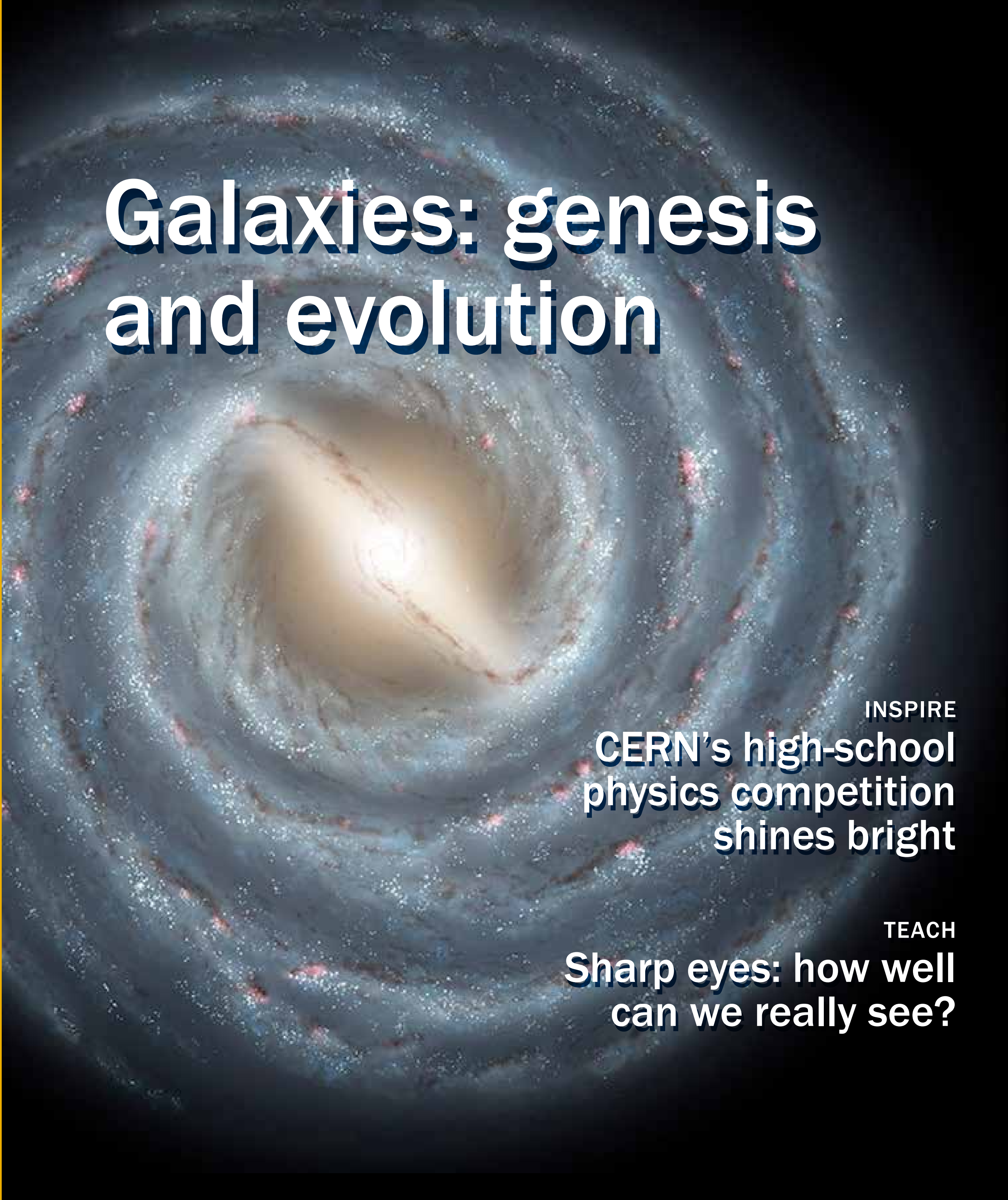
Science in School

The European journal for science teachers



Galaxies: genesis and evolution

INSPIRE

CERN's high-school physics competition shines bright

TEACH

Sharp eyes: how well can we really see?

Autumn 2016 | Issue 37

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EIROforum

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UNDERSTAND

INSPIRE

TEACH

MEASURING THE EXPLOSIVENESS OF A VOLCANIC ERUPTION 46

Using effervescent heartburn tablets, model the action of volcanoes to measure the intensity of the explosions and create your own measurement scale.

EDITORIAL

Laura Howes
Editor
Science in School

The new academic year is a time for new beginnings: new challenges, opportunities, students, colleagues and, most importantly, new ideas. Possibilities stretch out before us, each one beckoning us to a different outcome.

Now, after a summer of travelling and collecting fresh ideas at conferences, I settle back and turn my mind to the future.

Since I joined *Science in School* in 2013, there have been many changes, some obvious and some behind the scenes. The redesign of both the website and print journal was a big change, and we hope it has made the publication more enjoyable for you. But we have also been working to define our plans for the future. One thing remains constant: our purpose is to help you, the science teachers of Europe, engage and inspire your students with science.

Science in School is headed in an exciting direction, and as the journal evolves your input will be, as always, paramount. Your support and feedback have helped make this publication the success it is today.

I am also excited about my own future, as I will be taking on a new job at the European Molecular Biology Laboratory, just a short walk down the corridor from the *Science in School* office. You'll still see my name on articles for a while, but this is my last issue of *Science in School* as an editor.

It is with great pleasure that I pass the torch on to Hannah Voak, who will work with Eleanor Hayes to make *Science in School* even better. Over the past few months I have been lucky to work alongside Hannah, to hand over what I know and to see her enthusiasm for the journal. *Science in School* is in good hands.

Thank you for your support. It has been a privilege to work with and for you all. I'm proud of what we have achieved, and look forward to seeing what new adventures lie ahead.

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

Sign up your students to see the large and the small

CERN:
Fourth Beamline for Schools competition announced

CERN is pleased to announce the fourth annual Beamline for Schools (BL4S) Competition. Once again, in 2017, a fully equipped beamline will be made available at CERN for students. As in previous years, two teams will be invited to the laboratory to execute the experiments they proposed in their applications. The 2017 competition is being made possible thanks to support from the Alcoa Foundation for the second consecutive year.

The competition is open to teams of high-school students aged 16 or older who, if they win, are invited (with two supervisors) to CERN to carry out their experiment. Teams must have at least five students but there is no upper limit to a team's size (although only nine students per winning team will be invited to CERN). Teams may be composed of pupils from a single school or from a number of schools working together.

BL4S does more than just give high-school students a chance to play with real, functioning scientific equipment: it also exposes a host of students and teachers to particle physics and gives them the chance to be real scientists.

Image courtesy of CERN

You can find out more about how to apply, about the beamline and facilities, and about previous winning teams on the BL4S website (http://cern.ch/bl4s). The deadline for submissions is 31 March 2017.

Read about some of the previous winners in p 19 of this issue.

Based in Geneva, Switzerland, CERN is the world's largest particle physics laboratory.

To learn more about CERN, see: http://home.cern

EMBL:
Whose poo is right for you?

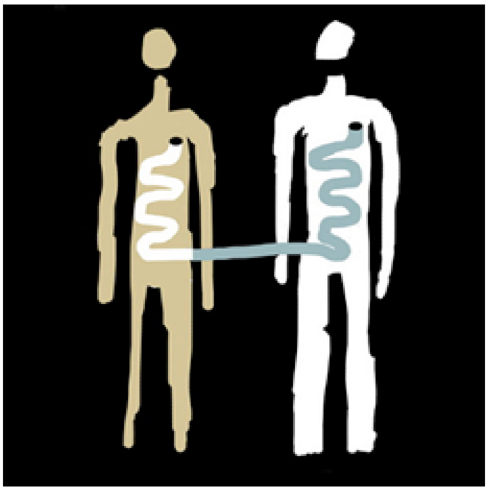


Image courtesy of Andrea Levy/The Plain Dealer

Compatibility between donor and patient in stool transplants is more important than previously thought.

For the first time, scientists studying stool transplants have been able to track which strains of bacteria from a donor take hold in a patient's gut after a transplant. The team, led by EMBL with collaborators at Wageningen University and the Academic Medical Centre, both in the Netherlands, and the University of Helsinki, Finland, found that compatibility between donor and patient likely plays a bigger role in these transplants than previously thought. The study, published in *Science*, could help make stool transplants a valid option for more conditions than they are currently used to treat.

Learn more about the work on the EMBL website: http://news.embl.de/science/1604-poo-transplants/

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

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

ESA:
Citizens' debate

On 10 September 2016, about 2000 citizens from 22 European countries will participate in the first Citizens' Debate on Space for Europe. In the course of the day, participants will have the opportunity to learn, debate, have their say and suggest priorities on all aspects of current and future space programmes.

This consultation, on an unprecedented scale, will take place simultaneously in all 22 Member States of the European Space Agency (ESA). The Citizens' Debate on Space for Europe is a major first – never before has the future of space activities been addressed in such an event held across so many countries.

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

Image courtesy of Suruena Image source Wikimedia Commons

ESO:
The visible and the hidden

During the Christmas holidays in 2016, from Friday 26 December to Thursday 1 January, 56 secondary school students aged 16–18 will spend a week in the Italian Alps doing astronomy activities and becoming part of a vibrant international community of alumni and astronomers.

Applications are now open for the ESO astronomy camp 2016. To apply, students should complete the form available from the website and upload a 3-minute video. The video should be in English on the theme "I would like to invent/ discover... because". Applications close on October 4, so hurry.

More information on the camp and how to apply is available at: www.sterrenlab.com/camps/eso-astronomy-camp-2016/

To read an account of a previous astronomy camp in *Science in School*, visit:

Cenadelli D, Olivotto C, Sandu O, Christensen LL (2014) Camping under the stars — the ESO Astronomy Camp 2013. *Science in School* **30**: 8. www.scienceinschool.org/2014/issue30/ESOcamp

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. To learn more about ESO, see: www.eso.org

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

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

To browse the other EIRO news articles, see: www.scienceinschool.org/eironews

Image courtesy of Julian Durnwalder

ESRF: **New designs for a new generation**

Following on from 20 years of success and scientific excellence, ESRF has embarked upon an ambitious modernisation project – the Upgrade Programme. After the successful delivery of the first phase, the ESRF – Extremely Brilliant Source (ESRF-EBS) project was launched to build a new and highly innovative 845 m long storage ring by 2020.

A blog has been created to tell the story of the construction and commissioning of the first of a new generation of synchrotrons. The blog shares the latest news and follows the evolution of the ESRF-EBS accelerator programme.

Read the blog and keep up to date with the progress of the project at: http://ebs.esrf.fr/

Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. To learn more about ESRF, see: www.esrf.eu

Image courtesy of the National Synchrotron Radiation Research Center

EUROfusion: **Journey to the centre of the torus**

It sounds like a kind of gothic torture – being put in a large bucket and lowered into a 9 m deep hole at the centre of a huge machine. But it's all in a day's work for JET's inspection team, as part of maintenance of JET's central magnet, the P1 solenoid.

Image courtesy of EUROfusion

An internal view of the reaction vessel of JET

The solenoid itself is made up of 1440 turns of copper, separated into 14 sections stacked on top of each other. During the course of experiments, these coils carry up to 60 000 amps and are subjected to huge magnetic forces, which causes them to shift around slightly. A set of spring-loaded keys pulls the coils back into alignment, but over the course of thousands of plasma pulses you would expect these keys to wear and lose their precision.

"Actually no refurbishment was needed, even though this procedure was last done eight years ago," says project leader Michael Porton. "In the intervening time, a number of key staff had retired, so we were partly re-learning how to do the work," says Michael. "It's not often you get to peer down the insides of JET!"

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.

To learn more about EUROfusion, see: www.euro-fusion.org/ To learn more about EUROfusion, see https://www.euro-fusion.org/

European XFEL: **First undulator installed, first superflat mirror delivered**

Early in 2016, the installation of the 35 segments of the first of three X-ray light-producing components of the European XFEL was completed. Set into one of the facility's tunnels, the segments are the core part of three systems called undulators, which are each up to 210 m long and will produce X-ray laser light more than a billion times greater than the intensity of conventional X-ray sources. The undulator installation is a major step towards the completion of the European XFEL.

Also of great importance was the delivery of the first specialised X-ray mirror. The mirror is superflat and does not deviate from its surface quality by more than one nanometre, or a billionth of a metre. It is the first of several needed for the European XFEL. The precision of the European XFEL mirror is equivalent to a 40 km long road not having any bumps larger than the width of a hair. As reported in the last issue of *Science in School*, the mirror's production is the culmination of a long research and development process involving several institutes and companies in Japan, France, Italy and Germany.

Finally, European XFEL has moved to its new headquarters, situated on top of the facility's underground experiment hall in the town of Schenefeld in Germany. User operation at the facility will begin in 2017.

The European X-ray Free Electron Laser (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.

To learn more about European XFEL, see: www.xfel.eu

An engineer runs tests at the first fully installed undulator system in the European XFEL

ILL: **New Director appointed**

Professor Helmut Schober has been appointed, with effect from 1 October 2016, as the new Director of the Institut Laue-Langevin (ILL) in Grenoble, France, the world's flagship centre for neutron science.

Professor Schober joined the ILL in 1994 and led the Institute's Time-of Flight – High Resolution group from 2001 to 2011, before becoming Science Director and German Associate Director of the ILL.

Professor Schober was born and grew up in Bavaria, Germany. His research focused on fullerenes, the dynamics of liquids and glasses, and neutron instrumentation.

Professor Schober is also Associate Professor at the University Grenoble Alpes and was a visiting professor at the Technical University of Munich. He is a former chair of the German Committee for Research with Neutrons (KFN) and was the co-ordinator of the European Neutron and Muon Integrated Infrastructure Initiative (NMI-II).

ILL is an international research centre at the leading edge of neutron science and technology. To learn more about ILL, see: www.ill.eu

Professor Helmut Schober at ILL

The element of surprise

Studies of radiocarbon are helping scientists to understand how neurons remain stable yet adaptable.

Image courtesy of Aad Goudapfel

By Claire Ainsworth

On 30 October 1961, a mushroom cloud more than seven times the height of Mount Everest rolled skywards over Novaya Zemlya, an archipelago in the Barents Sea. It was the signature of the Soviet Union's 50 megaton Tsar Bomba, the biggest atomic bomb ever detonated. Its physical shockwave cracked windows 900 km away, but its political impact was even greater and helped to trigger an international ban on above-ground nuclear bomb tests. Now, more than half a century later, scientists at the European Molecular Biology Laboratory (EMBL) in Heidelberg, Germany, are finding a positive aspect to this dark era of the Cold War: radiocarbon, a harmless component of the fallout from these tests, is providing a window on the workings of the human brain.

EMBL-based researcher Kyung-Min Noh and her colleagues in the USA are tracing the behaviour of radiocarbon to help them understand how our neurons, the longest-lived cells in our bodies, remain stable and yet flexible enough to let us learn, remember and think throughout our lives. The researchers also hope that their work will provide new insights into brain development defects such as autism, and possibly also other conditions such as Alzheimer's disease.

Radiocarbon records

Carbon is the backbone element of all the biological molecules in our bodies. Almost all the carbon in the world comes in a 'regular' form, called carbon-12. Radiocarbon is a slightly heavier, mildly radioactive form that occurs naturally in comparatively tiny amounts. Between 1945 and 1963, above-ground atomic tests pumped a pulse of man-made radiocarbon far in excess of these natural levels into the atmosphere. It made its way into the food chain all over the world, meaning that people who lived through this era incorporated more radiocarbon than normal into their bodies. Once atmospheric levels had dropped back to normal, their bodies gradually replaced most of the ingested radiocarbon with regular carbon, as their cells naturally renewed themselves over time.

But different parts of the body renew at different rates, so scientists can work out which cells are replaced and how often by measuring the amount of radiocarbon in the tissues of people who lived through the atomic-test age. Ten years ago, a team of scientists in Sweden and the USA used this technique to show that neurons in some parts of the brain renew themselves throughout life whereas others stop at birth and are as old as the individual to whom they belong. Now Kyung-Min and her colleagues have adapted this approach to tackle one of the big mysteries of neurobiology: how do these enduring neurons remain stable yet adaptable?

Unpacking cell secrets

Part of the answer lies in the DNA of the neurons. This DNA contains genes that instruct the neuron to make tiny molecular machines, called proteins, which enable the neuron to function. Even though almost every cell in our bodies contains the same set of genes, each cell type uses a different subset of these genes to develop its specialist function. This means that the cell needs to keep certain genes active and others inactive.

One way cells do this is by changing the way that the DNA is packaged inside cells. Rather than floating around in a tangled mess, DNA is wound around proteins called histones, rather like thread coiled around countless tiny bobbins. Inactive DNA tends to be tightly coiled, whereas DNA containing active genes is more loosely wound and thus more accessible to the cell's gene-reading machinery. A vast army of other proteins tweaks the histones to help regulate gene activity. Kyung-Min first became interested in the field of histone biology while pursuing her PhD at the Albert Einstein College of Medicine in New York, USA. While studying the effects of stroke in the brains of rats, she found a protein that altered the histones in stroke-damaged neurons. She then began to investigate what was happening to the histones in cells that had permanently stopped dividing, making neurons a logical choice to study. Scientists already knew that actively dividing cells used regular, or 'canonical', histones, whereas cells that were paused before the next round of division used a different kind, known as 'variant' histones. But they knew very little about what was happening to the histones of cells that had stopped dividing permanently.

Variant histones seem to be associated with active regions of DNA, and so might have a specific role in regulating gene behaviour. This type of control would be especially important in long-lived neurons, which in addition to surviving a lifetime of wear and tear also have to alter their gene activity in a highly dynamic way to respond to an ever-changing environment. During her

REVIEW

- ✓ Biology
- ✓ Chemistry
- ✓ Physics
- ✓ Molecular biology
- ✓ Radioactivity
- ✓ Ages 14–19

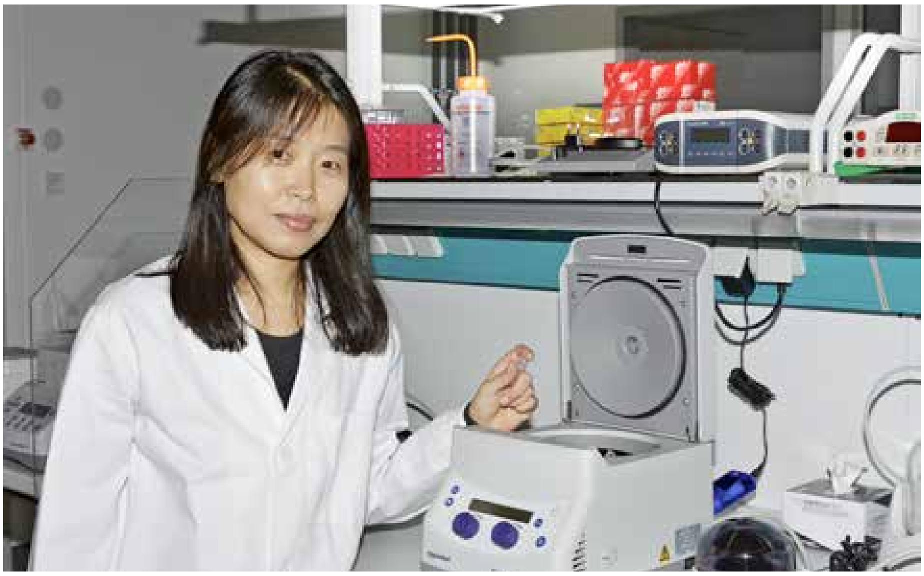
This fascinating article relates historical events to modern research into cellular events, as well as exploring the career path of a young scientist. Examining the use of radioisotopes such as radiocarbon in biophysics and molecular biology, it could be used as the basis of a discussion in an advanced physics or biology lesson, or an intermediate-level chemistry lesson.

Suitable comprehension and extension questions include:

1. What are radioisotopes and what can they be used to investigate?
2. Describe the structure and function of histone proteins in the cell.
3. What is the connection between DNA and histone proteins?

Terry Myers, Banbridge Academy, Ireland

Image courtesy of EMBL Photolab/Marietta Schupp



EMBL Heidelberg group leader Kyung-Min Noh and her colleagues in the USA are tracing the behaviour of radiocarbon to help understand how our neurons, the longest-lived cells in our bodies, stay stable and yet flexible.

postdoc at the Rockefeller University, USA, Kyung-Min and her colleagues discovered that neurons that had ceased dividing did indeed incorporate variant histones into their DNA. But to really understand why, they had to find out when: did the variant histones creep in gradually, or were they added all at once?

Carbon dating

To address this issue in humans, the team turned to radiocarbon. A technique known as accelerator mass spectrometry allowed them to tell the difference between variant histones containing regular carbon and those containing radiocarbon. By studying post-mortem samples from people who lived through the atomic-test age, they found that the incorporation of variant histones seems to take place before puberty. "It's not a gradual process," says Kyung-Min. "A very robust replacement occurs during the early phase of human development, and the brain maintains the status quo over the course of the lifetime."

This suggests that histone replacement is a vital step in child brain development, coinciding with when the brain's most dynamic learning processes are taking place, she explains. What's more, recent genetic research has uncovered a raft of gene faults associated with abnormal brain development conditions such as autism and learning difficulties. Many of these genes are involved in histone biology. "These observations open up some very big questions. For example, what does this histone replacement during development really mean?"

Since joining EMBL in November 2014, Kyung-Min has been tackling these questions by growing neurons in the lab and performing a range of genetic experiments on them to work out what the histones are doing. This is easier said than done: one of the key challenges in the field of neuron biology is getting enough of the right type of cell to work on. So Kyung-Min's team is taking immature cells from mouse embryos and coaxing them to form adult neurons in a petri dish. In addition, they are preparing to work on a kind of cell known as a human iPS cell, which they also intend to turn into neurons. These cells do not come from human embryos but from adult human cells that have been converted back into a more youthful state.

Editing effects

To alter the behaviour of the histones in lab-grown neurons, Kyung-Min's team is gearing up to use a new technique called CRISPR[w1]. It allows scientists to 'edit' the content of genes in the cell by introducing changes into the histones of iPS-derived neurons. These changes, or mutations, will be based on ones known to play a role in human brain development conditions. The iPS studies will allow the team to explore the effects of these mutations on neuron behaviour.

"Although the work is still in its earliest stages, understanding more about neuronal histones could inform research into other conditions, including neurodegenerative diseases such as Alzheimer's disease," says Kyung-Min.

Drugs directed at the cellular machinery that alters histones are now being used to treat certain cancers, such as T-cell lymphoma, and studies of these drugs are providing new insights into how targeting histones could affect a cell. One emerging idea is that disease can result from DNA not being coiled tidily around its histones. "If you start to untangle all of this disorganised thread, the cell tries to find a way to rearrange it in ordered fashion," says Kyung-Min. "Resetting a cell back to an ordered healthy state could represent a new therapeutic approach."

Claire Ainsworth is a freelance science journalist based in Hampshire, UK. She usually writes about genetics and biomedicine, but did once meet a dragon. A real one. Find her on Twitter: @ClaireAinsworth

Acknowledgement

The original version of this article appeared in the Spring 2015 issue of *EMBLetc*, the magazine of the European Molecular Biology Laboratory

Web references

w1 Find out more about the gene-editing technique CRISPR. See: http://news.embl.de/science/nothing-blue-skies

Self-healing aircraft wings: a dream or a possibility?

Taking inspiration from nature's amazing ability to heal wounds, this biology-inspired technology could create aircraft wings that fix themselves.

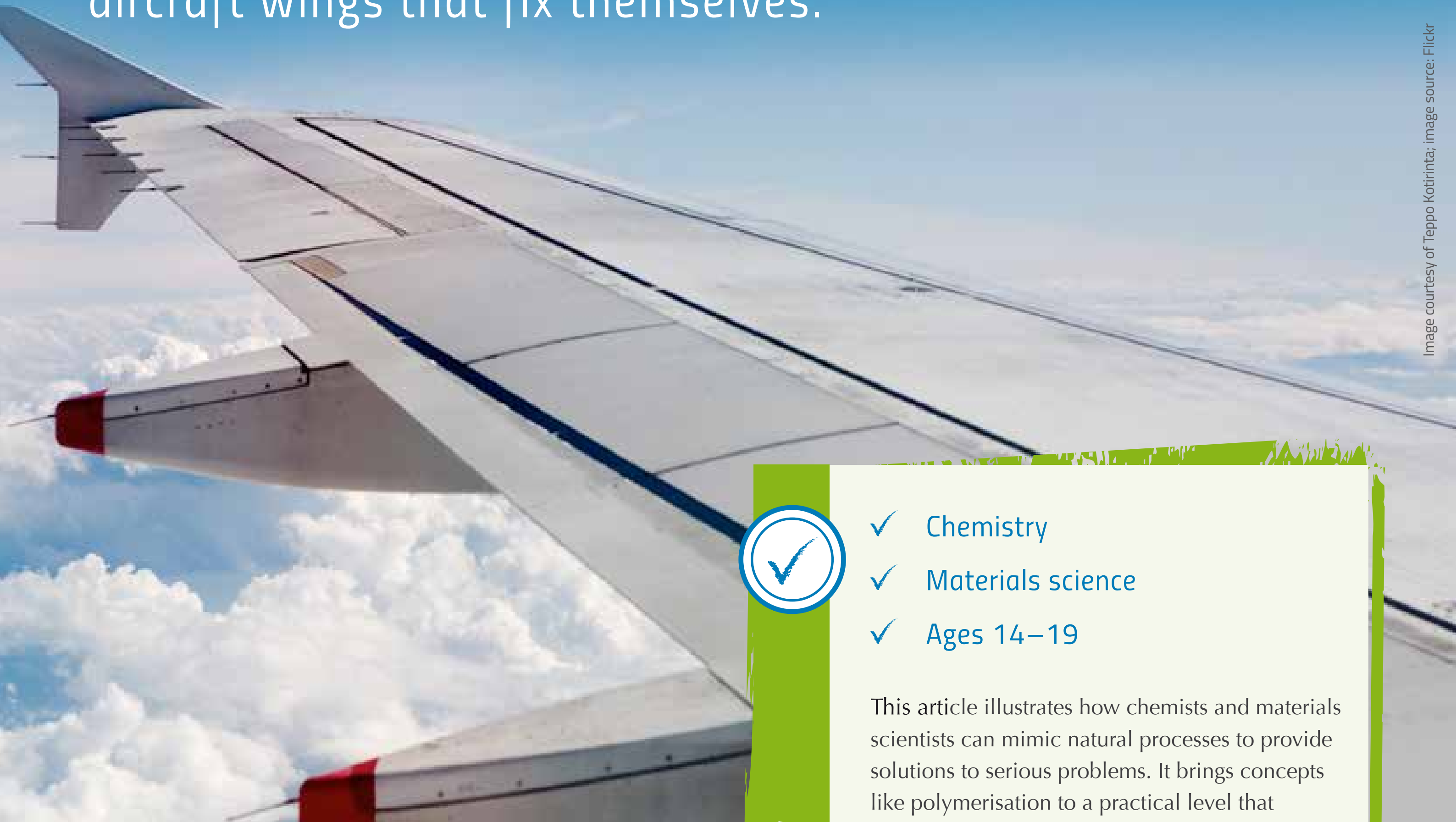


Image courtesy of Teppo Kotirinta; image source: Flickr

REVIEW

- ✓ Chemistry
- ✓ Materials science
- ✓ Ages 14–19

This article illustrates how chemists and materials scientists can mimic natural processes to provide solutions to serious problems. It brings concepts like polymerisation to a practical level that students will identify with. It could be used as the basis of several discussions on topics such as:

1. How technologists can learn from processes in nature.
2. The importance of chemistry in everyday life.
3. How engineering and science need to work together to provide creative solutions.

Suitable comprehension questions include:

1. How do monomers become polymers?
2. How can catalysts help polymerisation processes?
3. How does the repair process described in this article mimic natural biological processes?

Marie Walsh, Ireland

By Duncan Wass and Tim Harrison

A wing is ripped from the aircraft; the cabin roof is swept off, leaving passengers exposed to unpressurised air; or a plane disintegrates mid-flight: sadly these are all real examples of the catastrophic consequences of mechanical failure in an aircraft.

The immediate causes of these events, however, were not substantial: there was no collision with another aircraft, no bird strike, not even severe turbulence. The culprits were minute fatigue cracks within the aircraft structure, invisible to the naked eye. Modern inspection and maintenance requirements mean that microscopic damage like this is likely to be detected before it has serious consequences.

Image courtesy of Caribb; image source: Flickr

Image courtesy of Joshua Davis; image source: Flickr

Currently the repair of such damage can be as crude as gluing or bolting a patch over the damaged area. Scientists at the University of Bristol, UK, however, have developed a novel way to repair small-scale damage to aircraft wings. Involving both catalysis and polymerisation, this new technology is an example of how important chemistry can be in our everyday life.

The downside of modern composite materials

To withstand aerodynamic forces, an aeroplane must be strong, stiff, durable and lightweight. Early aeroplanes used fabric and wood before metal alloys of aluminium and steel became commonplace. Now, carbon-fibre reinforced composites are the modern materials of choice for aerospace structures such as aircraft and for wind turbines. These composites are similar to natural materials such as wood, in which long cellulose fibres are held together by lignin. In these new materials, however, a homogenous matrix component is reinforced by a stronger and stiffer carbon fibre constituent. This is ideal for aircraft wings and wind turbines, which must be light but also strong enough to withstand extreme pressure and other stresses, such as bird strikes. Although these characteristics make reinforced composites better suited for building aeroplanes than the traditional metal alloys, there is one drawback: damage to composite structures is more difficult to detect and repair.

To find a solution, the Bristol scientists have taken their inspiration from nature. Professor Duncan Wass and his team considered what happens when we cut a finger: we bleed, a scab is formed to protect the damaged region, and eventually the wound is repaired. Could such an approach be used to repair man-made structures? Working in the

Image courtesy of Duncan Wass

Figure 1: Close-up of a composite sample that has undergone impact damage. Note that the damage (which is a dent about 2 cm in diameter) looks quite minor.

Image courtesy of Duncan Wass

Figure 2: The reverse side of the same sample. Although not visible from the side that was impacted, the damage is catastrophic.

laboratory in collaboration with a team of aerospace engineers led by Professor Ian Bond, the Bristol team may have found a way to do just this.

How the new technology works

The key to the problem lies in the initial production of the composite, to which the researchers added microcapsules filled with a liquid. These sealed containers are so small that they look like a powder. In an aircraft wing made from such a composite material, damage causes these microcapsules to rupture, releasing the liquid into the resulting cracks. A rapid reaction takes place and the chemicals harden, filling in and 'gluing' together any cracks. How this works involves two key areas of chemistry: polymerisation and catalysis.

The wound is sealed as a result of polymerisation reactions in which small molecules, termed monomers, are joined together in a long chain, called a polymer. The monomers released from the microcapsules contain reactive chemical groups called epoxides (figure 3). These are three-membered ring structures that can be opened by an appropriate catalyst; once one ring is opened, it will react with another opening this second ring and joining the two together. The second ring will then react with a third, and so on, until a polymer is created. By controlling the exact structure of these monomers, researchers ensure that the polymer chains undergo a process called curing, forming a highly cross-linked network that has properties very similar to those of the original, undamaged composite. This 'healing' can recover up to 100% of the material's mechanical strength.

As with most chemical reactions, the speed of curing is temperature dependent. Think of the reaction in terms of bond breaking and bond making. Heating provides more energy so the molecules move faster and are more likely to collide. This means that more chemical bonds are broken in the reactants so that new bonds can be

Image courtesy of Duncan Wass

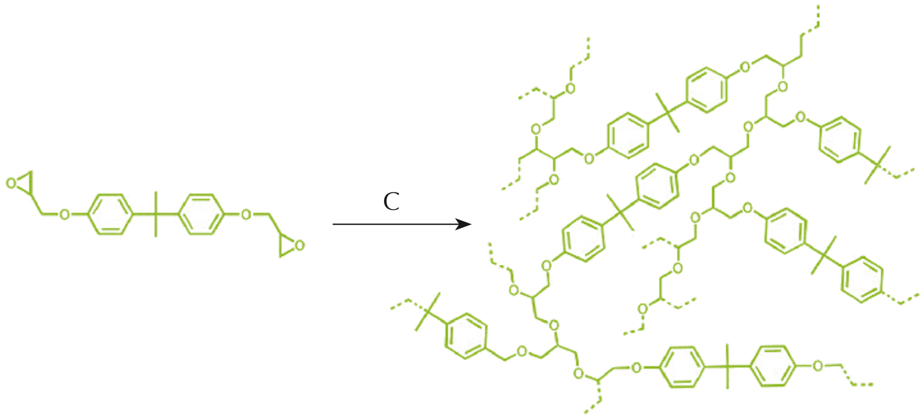


Figure 3: The chemical process of healing. On the left is the healing agent, on the right the cross-linked polymer formed after the healing agent comes into contact with the catalyst (C).

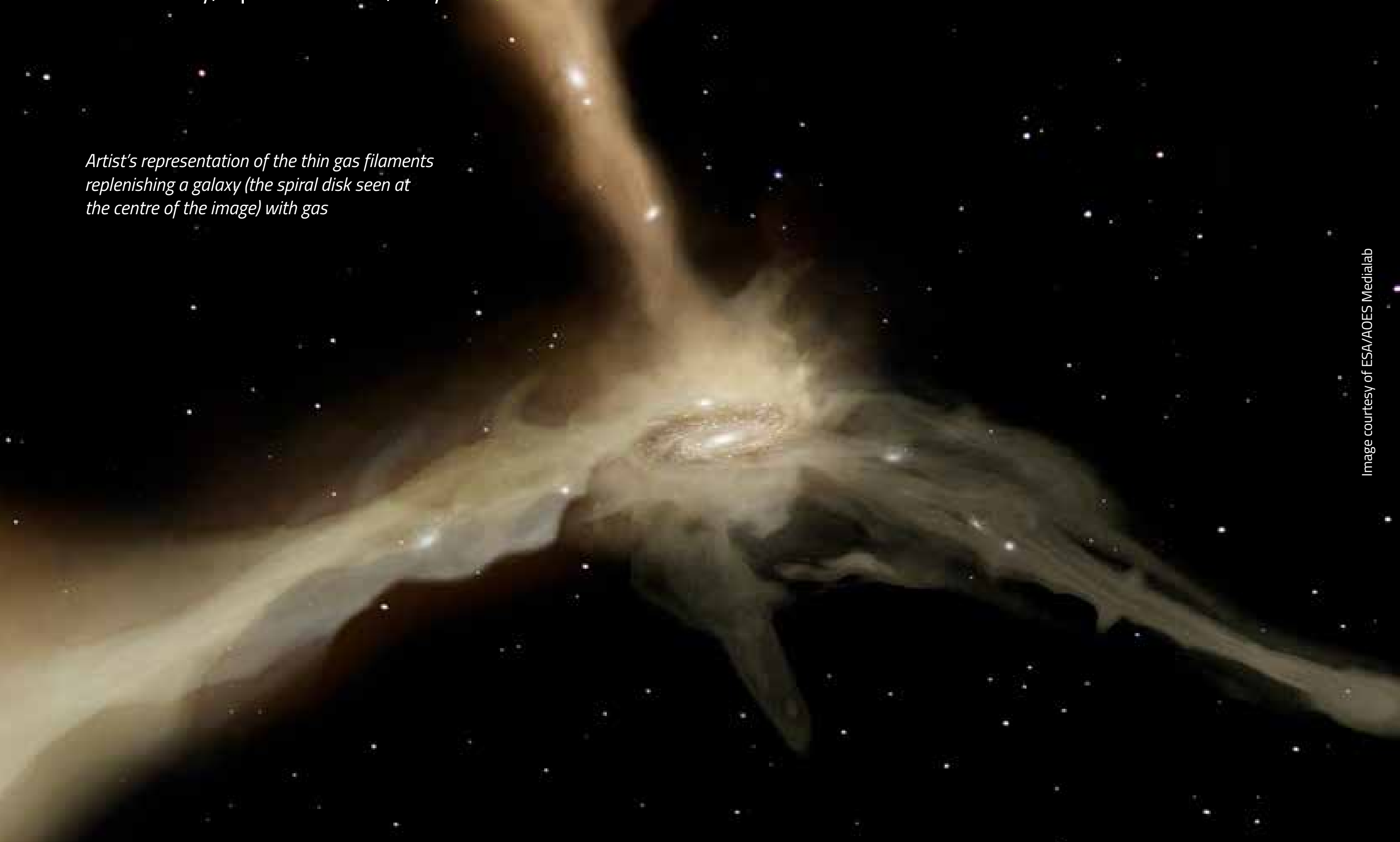
formed in the products. The time it takes to repair a crack will therefore depend on the temperature of the material. If the aircraft is on a runway in Barcelona, Spain, in summer, it would probably heal in a couple of hours, but on a runway in Reykjavik, Iceland, in winter, it could take between 24–48 hours.

Even in the heat of summer, however, the reaction would occur too slowly if it weren't for the presence of a catalyst. The scientists therefore incorporated a catalyst into the matrix of the original composite used to construct the aircraft. When the monomers flow out of the microcapsule, they come into contact with the catalyst, speeding up polymerisation by providing an alternative chemical route to the reaction. This reduces the speed at which the monomers must collide to join together. What's more, the catalyst is not used up in the reaction, so it can be used again and again.

As well as repairing the damage, it is possible to cause a colour change at the same time. The microcapsules could be designed to leak a colour when ruptured, signalling the area of repair. In reality, however, a big red mark showing where the aircraft wings have been repaired might result in some panic from passengers on-board the aircraft!

There is still a lot of testing to do before this technology can be applied in aeroplanes, not least because of the very stringent safety consideration for this application and because the healing agents must be stable enough to last the lifetime of an aircraft. However, there are many other consumer items that are now made from similar composite materials, from bicycle frames to sports equipment, and the application of 'self-healing technology' could soon become commonplace.

Duncan Wass and Tim Harrison are from the School of Chemistry, Bristol University, UK. Duncan is a Professor with an interest in catalysis and new materials, and Tim is the Bristol ChemLabS School Teacher Fellow and Outreach Director.



Artist's representation of the thin gas filaments replenishing a galaxy (the spiral disk seen at the centre of the image) with gas

Image courtesy of ESA/AOES Medialab

Galaxies: genesis and evolution

Astronomers are still trying to discover exactly why galaxies formed in spiral shapes, and what's likely to happen to our galaxy in the future.

By Francesca Iannuzzi and Susan Watt

The stillness of the night sky is as comforting as it is deceptive. Although it takes billions of years, the stars and galaxies that we see are in a constant state of evolution.

Thanks to increasingly sophisticated observational technology, astronomers can now see millions of galaxies at different distances from Earth: the light from what is thought to be the most distant galaxy observed so far has taken over thirteen billion (10^9) years to reach us (Zitrin et al., 2015). Working out the story of how galaxies change and evolve means looking back to the very earliest times in the Universe's existence.

The genesis of galaxies

Early in the history of the Universe, matter was distributed almost homogeneously through space with very small fluctuations in density of around just one part in 100 000 – like very, very tiny lumps of flour in an otherwise perfectly smooth sauce. But the Universe is now very far from homogeneous, with matter densely clustered into galaxies – so how did this change in the distribution of matter come about?

In fact, this question is linked to another mystery of the Universe: dark matter, what it is and what it is made of. Astronomers believe that most of the matter in the Universe is such 'dark' matter, rather than the 'normal' matter we see around us. Although all matter is drawn together by the attractive force of gravity, normal matter is also affected by forces that can push it apart, such as electromagnetic forces. This is not the case with dark matter, which – according to theory – is only affected by gravity. This means that any irregularity in dark matter will always attract more dark matter towards itself and grow, thus forming larger structures called dark matter 'halos'. The gravitational pull of the massive dark matter halos eventually becomes strong enough to affect normal matter too, and so the cosmic production of galaxies can begin.

Initially, the normal matter dragged in by the dark matter will be a cloud of hydrogen gas. As the gas condenses to form stars, a proto-galaxy will begin to form, ultimately developing into a rotating disk – the typical form of a galaxy, like our own, the Milky Way. As the galaxy grows and the hydrogen is fused into helium and heavier elements, the hydrogen needs to be constantly replenished to sustain the stellar birth rate. Astronomers think that this hydrogen is obtained in the form of gas filaments drawn in from outside the galaxy. Observations of a distant galaxy 'feeding' on a nearby hydrogen cloud have confirmed this idea (Bouché et al., 2013).

Galactic transformations

Galaxies can undergo spectacular changes during and after formation, due to the complex internal dynamics of stars, gas and the dark matter within them. For example, the striking spiral design of many galaxies is caused by internal gravitational processes: spiral arms are believed to arise from a density wave squeezing stars together as it propagates through the galaxy's disk.

The central bar seen in many spiral galaxies, including the Milky Way, also results from such processes. The stars that form the central bar, seen in the spiral galaxy image here, are those that have deviated from their circular motion and started moving in increasingly elongated orbits. One possible explanation of this change is that in a rotating disk of stars, the inner stars complete a full circle faster that the outer ones, so they occasionally pass close to each other and 'overtake'. This causes a perturbation of their circular orbits, which becomes amplified until a bar-like shape is created[w1].

REVIEW

- ✓ Physics
- ✓ Astronomy
- ✓ Ages 11–19

This article, which explains the genesis and evolution of galaxies, could be used to deepen students' knowledge about the Universe.

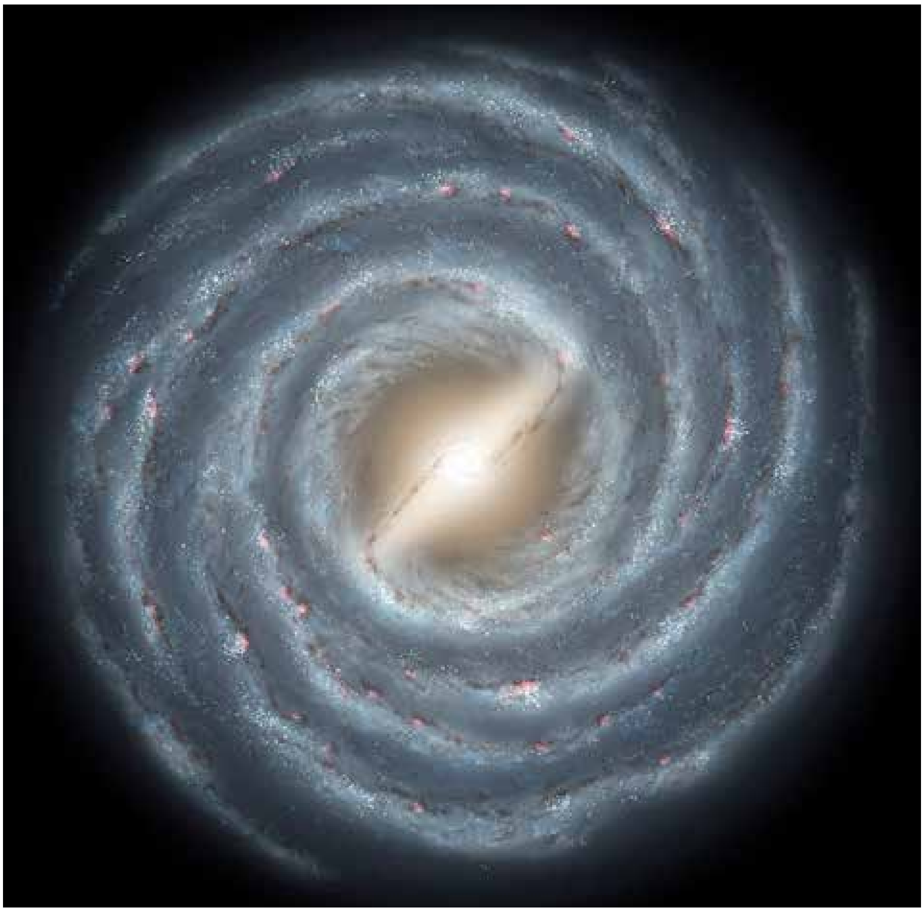
Before reading the text, students could be asked the following questions to start them thinking about the concepts explained in the article:

- What is our galaxy's name?
- Do all galaxies have the same shape and size?
- How do you think galaxies are formed?
- What can make a galaxy evolve?

Finally, the article could be used as a starting point for discussing the importance of the development of observational tools to improve our view of the cosmos. Students have to be aware that, in science, accepted theories are the best explanations available at a certain moment. However, if new evidence is encountered that does not match existing theories, it may be necessary to reformulate them.

Mireia Güell Serra, Spain

Image courtesy of NASA/JPL-Caltech/R. Hurt (SSC)



Artist's representation of a barred, spiral galaxy. Our Milky Way belongs to this class of galaxies.

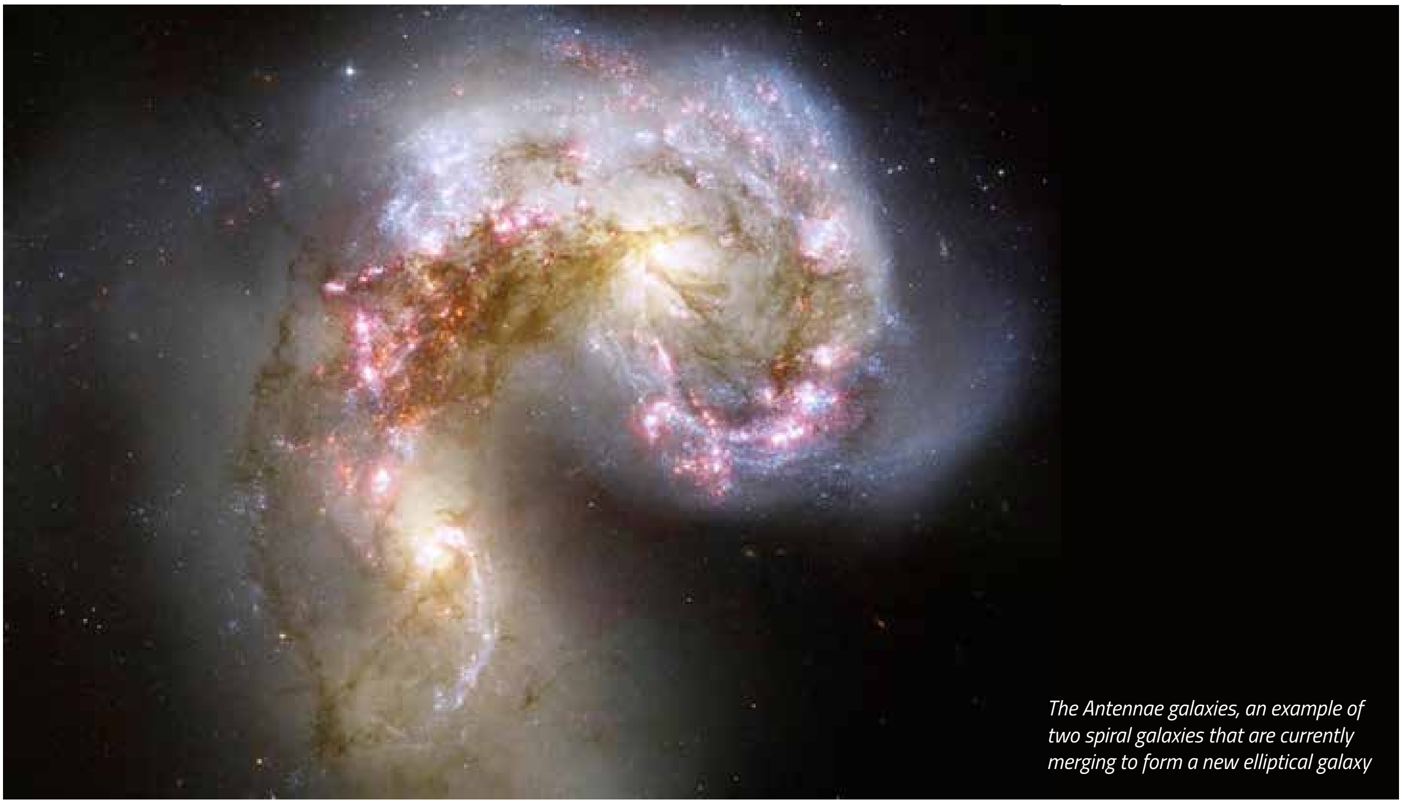
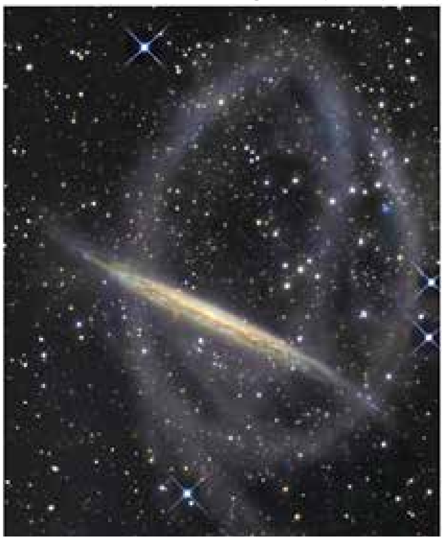


Image courtesy of NASA, ESA, and the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration

The Antennae galaxies, an example of two spiral galaxies that are currently merging to form a new elliptical galaxy

Image courtesy of R. Jay Gabany



Stellar streams surrounding the galaxy NGC 5907. This trail of stars was stripped from a smaller, orbiting galaxy during an episode of cannibalism.

Another important way in which a galaxy can be transformed is by merging with another galaxy. Sometimes a large galaxy will attract and engulf a smaller one in a kind of cosmic cannibalism. This may happen in our own galaxy in the future, if (as many scientists expect) it eventually swallows up the two nearby satellite galaxies known as the Magellanic Clouds, which are visible from the Southern Hemisphere.

Mergers also take place between galaxies of similar size, producing dramatic events that cause catastrophic changes in the galaxies' properties. Such events leave behind a remnant galaxy that bears little resemblance to either of the original galaxies. As the Universe expands faster and faster, however, and galaxies move farther away from each other, the chance of galaxies merging is reduced.

The future of our galaxy

Today we are at a quiet stage in the Milky Way's history, after the violent phases in which mergers of dark-matter halos and proto-galaxies caused the galaxy's mass to increase substantially. For well over half of the history of the Universe, the main driver of our galaxy's evolution has been internal dynamical processes. This will be the case for a couple more billion years. However, Andromeda, our closest similar galaxy (which appears to the eye as an insignificant star-like blob), moves 110 km closer to the Milky Way every second – and is set for a head-on collision with our galaxy in four billion years (Van der Marel et al., 2012). This major merger will take two billion years to complete, during which the identity of the two barred, spiral galaxies will be lost and a majestic elliptical remnant will be formed.

Open questions

As a result of the enormous technical and scientific progress made in the field of galactic astronomy since the 1970s, we now understand a good deal about the ways that galaxies interact and change. Nonetheless, there are still many open questions. For example, as we look at galaxies farther and farther away, we see that many of them have different shapes than those nearby. We are observing these galaxies at an early stage of their existence, due to the billions of years that it takes for light to travel the vast distances. We know that these early, rather peculiar-shaped galaxies evolve over time into the more

Image courtesy of NASA

Artist's representation of the night sky in 3.75 billion years. Andromeda (left) and the Milky Way (right) are heading for the collision that will end their lives as separate galaxies.

Image courtesy of ALMA (ESO/NAOJ/NRAO)/L. Calçada (ESO)

Artist's representation of the Atacama Large Millimeter/submillimeter Array (ALMA)

familiar elliptical or disk shapes, but we are not yet sure how this happens.

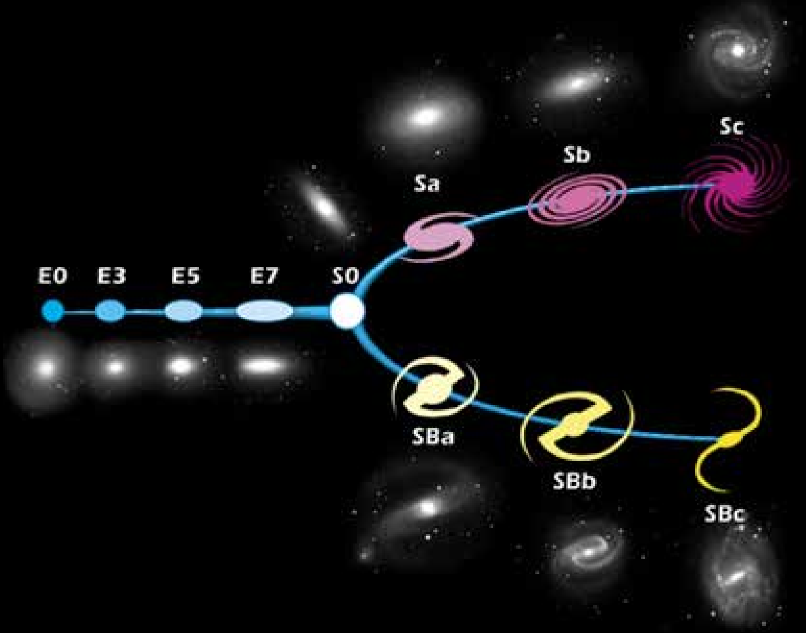
A central problem in galactic astronomy is the fact that we cannot actually observe astronomical processes in action, due to their extraordinarily long timescales. Instead, our understanding comes from building computational models and simulations based on theoretical models combined with observational data. To date, our best simulations do not completely match observed facts. For example, current simulations predict more small, or dwarf, galaxies than we actually see. This discrepancy is a problem, as it suggests that there is something not quite right about the astronomical theories that were used to develop the simulation – but we are still unclear about where exactly the defects lie. Even the properties of our own galactic neighbourhood are at odds with some very fundamental numerical results: our satellite galaxies are too 'fluffy', or diffuse – and possibly too few – compared to the predictions of the most widely accepted cosmological scenario[w2].

In recent decades, however, astronomical simulations have become much more accurate, and we are now able to model the movement of up to a trillion (10^{12}) particles, in contrast to the few hundred particles in early simulations. This reduces the need for approximations, providing scope for much more accurate modelling of astronomical processes, which in turn enables us to understand those processes better theoretically. New observations and discoveries using the most advanced observation tools will also add greater accuracy, as well as new constraints, helping to reveal the flaws in our models.

In fact, the observation tools now coming into use may revolutionise our view of the cosmos. The Atacama Large Millimeter/Submillimeter Array, the largest astronomical project ever realised, and the James Webb Space Telescope, due to launch in 2018, will peer into dense clouds of gas and dust to elucidate the mystery of star formation. They will also be able to spot proto-galaxies that were forming when the Universe was less than five per cent of its current age, thereby adding significantly to our knowledge about the formation of galaxies.

Francesca Iannuzzi has worked for six years in computational astrophysics. During her PhD at the Max Planck Institute for Astrophysics in Munich, Germany, she focused on cosmological simulations of structure formation. She later worked on dynamical simulations of isolated disk galaxies as a postdoctoral researcher at the *Centre National de la Recherche Scientifique* in Marseilles, France. She is currently doing research and development in the field of natural language processing.

Susan Watt is a freelance science writer and editor. She studied natural sciences at the University of Cambridge, UK, and has worked for several UK publishers and scientific organisations. Her special interests are philosophy of science and science education.



The famous 'tuning fork' diagram developed by Edwin Hubble in 1936, which describes the classification of galaxies. Galaxies were classified into ellipticals (E0 to E7), lenticulars (S0) and spirals (S, or SB if a central bar is present).

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Van der Marel RP, Besla G, Cox TJ, Sohn ST, Anderson J (2012) The M31 Velocity Vector. III. Future Milky Way M31-M33 Orbital Evolution, Merging, and Fate of the Sun. *Astrophysical Journal* **753**: 9. doi: 10.1088/0004-637X/753/1/9

Zitrin A, Labbe I, Belli S et al. (2015) Lyman-alpha Emission from a Luminous z = 8.68 Galaxy: Implications for Galaxies as Tracers of Cosmic Reionization. *Astrophysical Journal of Letters* **810**: L12. doi: 10.1088/2041-8205/810/1/L12

Web references

w1 NASA has more information about barred spiral galaxies and galaxy evolution on its Hubble website. See: http://tinyurl.com/hacfoqb

w2 The Preposterous Universe blog takes a more in-depth look at diffuse galaxies. See: http://tinyurl.com/jpcjlsn

Resources

To learn more about dark matter, see:

Boffin H (2008) Intelligence is of secondary importance in research. *Science in School* **10**: 14. www.scienceinschool.org/2008/issue10/tamaradavis

Warmbein B (2007) Making dark matter a little brighter. *Science in School* **5**: 78-80. www.scienceinschool.org/2007/issue5/jennylist

To learn more about the birth and evolution of stars, see:

Boffin H, Pierce-Price D (2007) Fusion in the Universe: we are all stardust. *Science in School* **4**: 61. www.scienceinschool.org/2007/issue4/fusion

Lopes A, Boffin H (2009) The first light in the Universe. *Science in School* **13**: 48. www.scienceinschool.org/2009/issue13/light

Rebusco P, Boffin H, Pierce-Price D (2007) Fusion in the Universe: where your jewellery comes from. *Science in School* **5**: 52. www.scienceinschool.org/2007/issue5/fusion

Watch one of the many wonderful simulations of galaxy formation that you can find online, for example: www.youtube.com/watch?v=-ZcEDqyMbFw

Learn more about the collision between the Milky Way and Andromeda using spectacular visualisations and a simulation movie of the event: http://science.nasa.gov/science-news/science-at-nasa/2012/31may_andromeda/

To find out more about the Atacama Large Millimeter/Submillimeter Array Observatory, see:

www.almaobservatory.org

and:

Mignone C, Pierce-Price D (2010) The ALMA Observatory: the sky is only one step away. *Science in School* **15**: 44-49. www.scienceinschool.org/2010/issue15/alma

To find out more about the James Webb Space Telescope, see: www.jwst.nasa.gov

Discover the Illustris Project, a very ambitious simulation project providing results of unprecedented quality on the cosmological evolution of dark matter and galaxies. www.illustris-project.org

Don't miss your chance to become a citizen scientist! Help astronomers to classify galaxies by signing up to the Galaxy Zoo project: www.galaxyzoo.org

Students from Italy and South Africa, who won the Beamline for Schools competition in 2015, look at data from their experiments.

Image courtesy of Markus Joos/CERN

CERN's high-school physics competition shines bright

By Harriet Jarlett

Not many high-school competitions are endorsed by science-loving celebrities such as musician will.i.am and pop band The Script. But there's something about CERN's Beamline for Schools competition that gets people excited.

"I now have an idea what it must feel like to receive a phone call from Stockholm," says Colleen Henning, a teacher at St John's College from Johannesburg, South Africa, who led one of the winning teams at last year's competition, likening the feeling to winning a Nobel prize. "Learning the news that we were joint winners of the CERN Beamline for Schools competition will be an experience I will always remember."

Launched in late 2013 as part of CERN's 60th birthday celebrations, the competition makes a fully equipped beamline available for high-school students to run an experiment by firing accelerated protons at a target – in the same way that researchers do at the Large Hadron Collider and other CERN facilities.

But the competition does more than just give students a chance to play on actual, functioning science equipment: it exposes a host of new students and teachers to particle physics and gives them the opportunity to be real scientists.

"Particle physics is in hardly any school curriculum around the world for this age, so the competition asks that teachers and teams spend a substantial amount of time with physics to make a meaningful proposal. For many students, this is their first contact with particle physics," explains CERN's Markus Joos, who currently manages the initiative.

Student teams from Greece and the Netherlands won CERN's first Beamline for Schools competition in 2014.

"The competition is about all the teams participating; even those who aren't shortlisted still learn about physics. Some of the proposals are not feasible, suggesting things that even professional physicists can't manage. But while such a proposal might not win, it's still a success as it brought that team to the point that they know what, say, a neutrino is, and they know that understanding its mass is important. Unsuccessful teams can always get in touch the following year and put together a more feasible proposal, building on their past knowledge."

In the past three years, Beamline for Schools has received more than 570 proposals, representing more than 5000 high-school students who have been motivated to learn more about physics just so they can submit a proposal that stands a good chance of winning.

The competition's effect on participants is clear from their proposals. The team 30(ns)toBang, which recently applied for the 2016 competition, wrote: "We have to know who we are, our strengths, our weaknesses, our limits and it is projects like Beamline for Schools that help us do precisely this. This project made us get out of our comfort zone, open our minds, it also made us realise how little we actually know and therefore, it made us curious to learn more about particle physics, a branch we know very little of even now."

Shining bright

Last year, two teams shared the top prize. Colleen Henning's team, Accelerating Africa, and Leo4G – a team of 19 students from Liceo Scientifico Leonardo da Vinci school in Florence, Italy.

"When I first heard the good news I was ecstatic, my hands were shaking and my heart was beating faster than usual," says Malaika, a student from Barnato Park High School who was part of Accelerating Africa. "I've always wanted to pursue a career in physics or engineering and winning this amazing competition has brought me closer to my dreams. I've always wanted to travel abroad as I have never been overseas, nor have I been in an airplane. I'm truly thankful for this opportunity given to me and I know that I will take it with my two bare hands and not let go of it."

Accelerating Africa wanted to use the CERN beamline to produce high-energy gamma rays with a crystalline undulator. The crystal they used was made from diamonds grown in a lab with the aid of De Beers – a benefit of the Beamline for Schools competition is that it allows high-flying academic students to come into contact with international companies.

Leo4G's project was a very simple one that involved using and calibrating a particle detector built from a customised web-cam. To prepare their proposal, the team got in touch with their local physics research centre and visited a linear particle accelerator at the University of Florence.

The competition places a lot of emphasis on treating the students as scientists from the very beginning. Once the winning team is announced, they work with CERN physicists, technicians and staff to fine-tune their proposal for CERN's equipment.

Physicists, engineers and experts in beams, detectors, data acquisition, data analysis, safety and radio protection from across all CERN departments are on-site to guide the students through the experiment, training them in the specifics of shift work and acquiring data. In 2014, detector physicists Cenk Yildiz and Saime Gurbuz spent weeks writing data-acquisition software and preparing the beamline to run the winning teams' experiments.

"Even after the competition and their visit has ended, we encourage winning teams to write two documents: one, a journal of recording their experience for their local media, and two, a research paper, which we help them to publish," says Markus. One of the 2014 winning teams took two years to write their paper, meaning a period in which they team stayed up-to-date on new findings from particle physics the whole time.

The kindness of teachers

"For a teacher to be able to guide their team, he or she will also have to understand the physics they will be using. We provide teachers with the documents to bring them up to a level that allows the students to make a meaningful proposal. We know it can be a big investment," Markus says.

Time is also an important investment: drafting the proposals for the competition takes on average twenty hours of work, which can seem like a lot when students and teachers already have full days.

"From the very beginning I believed in the positive side effects that being involved in such an experience would

To enter the competition, students submit a proposal and a one-minute video, like these Dutch winners.

have on my students and on me," shares Manuela Lima, one of the teachers who led the winning Leo4G team. "It was a race against time because we really had very little time to prepare our project. We worked very hard, also outside of school hours, and everyone contributed by giving his and her best. I am certain that none of us will ever forget this fantastic event and achievement!"

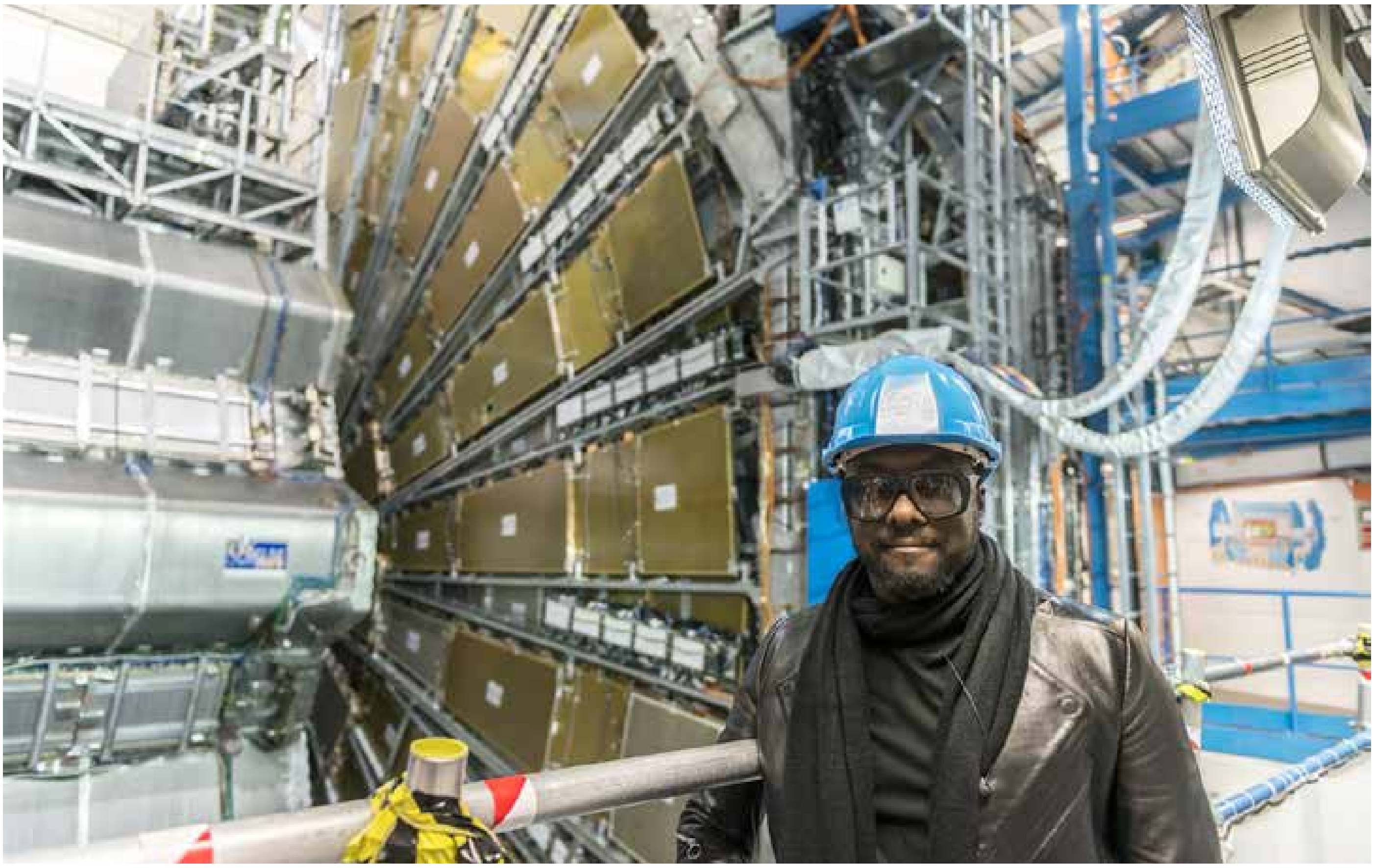
This year, CERN is inviting applications earlier than in previous years (see p. 4), which Markus hopes will allow teachers to factor them into their syllabus plans. "The competition depends entirely on the motivation of the teachers," he explains.

He urges future physicists and their teachers not to be daunted by the time commitment. "Any proposal is OK: it serves the purpose of educating. It shouldn't be a case of not entering because 'our idea won't win', firstly because there's a second category of prizes for shortlisted teams, and also because even submitting a proposal is a success – you've gone through the whole process that a real scientist would go through."

Resources

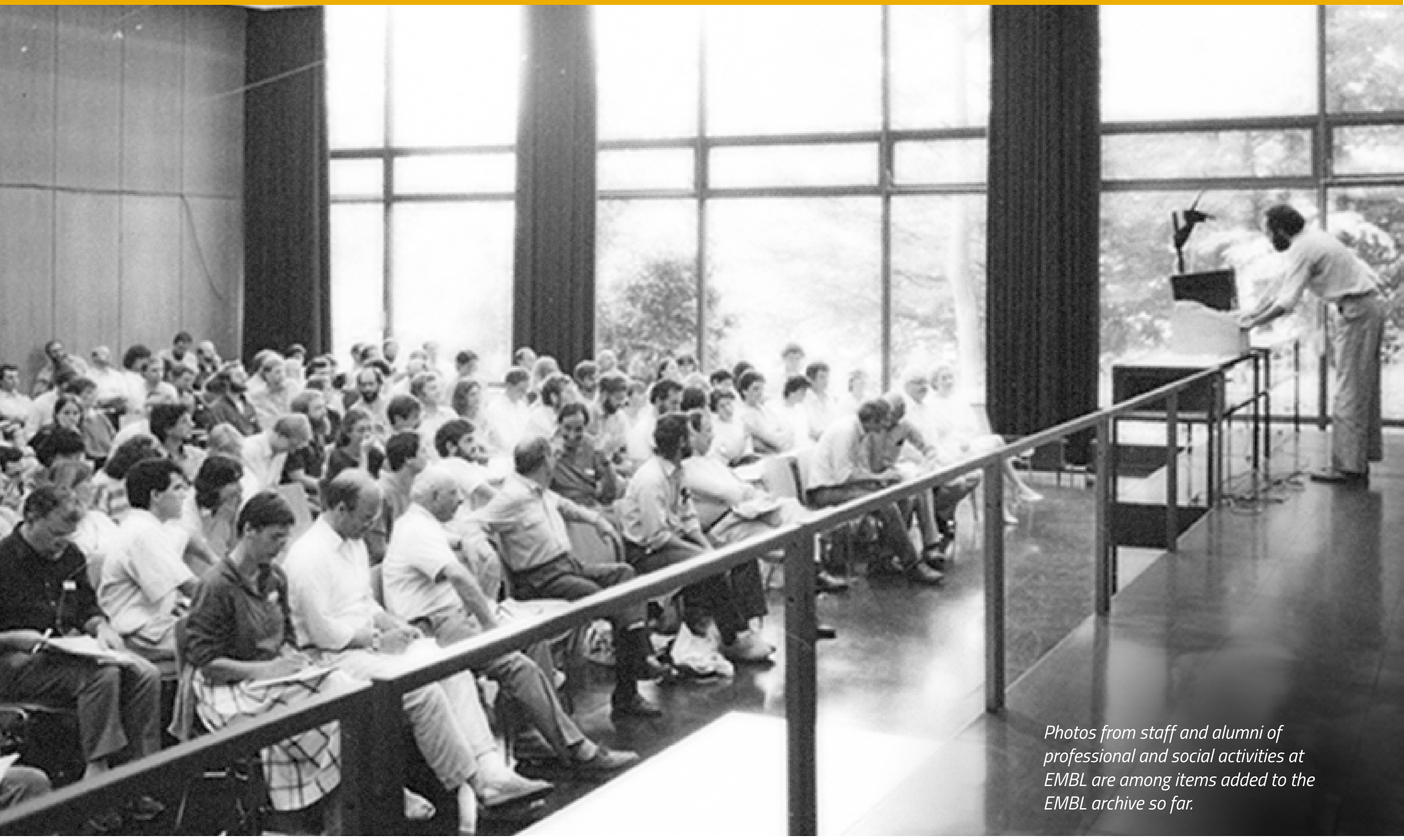
To find out more about the Beamline for Schools competition and how to get involved, see: http://cern.ch/BL4S

Learn more about CERN's Large Hadron Collider, the world's largest and most powerful particle accelerator. See: http://home.cern/topics/large-hadron-collider



History in the making

How Anne-Flore Laloë is chronicling the life and works of a scientific institution



Photos from staff and alumni of professional and social activities at EMBL are among items added to the EMBL archive so far.

By Adam Gristwood

From Albert Einstein's love letters and Marie Curie's scruffy lab notebooks to photos of graffiti scrawled on a wall by Francis Crick, archival material can provide an unparalleled treasure trove for historians to excavate the personal stories hiding behind the science. Anne-Flore Laloë has recently taken up the challenge of chronicling the twists and turns and ups and downs of life at the European Molecular Biology Laboratory (EMBL) – as the lab's first archivist.

Carefully placing a cardboard box in the middle of an empty room, Anne-Flore smiles to herself about the small piece of history she has just acquired. The container, home to a large collection of photographs donated by an EMBL alumnus, is one of the first contributions to the Laboratory's new archive – a project to preserve and catalogue material that is often at risk of being forgotten and to make it widely accessible. "There was a danger that a century from now we might look back and much of EMBL's history would have been inadvertently lost," says Anne-Flore, who joined EMBL in January 2016. "With this project, we are making sure that EMBL's unique past and present is available to scientists, historians, philosophers and more in the future."

Spurred by warnings from the academic community that the history of the molecular life sciences is at risk of vanishing unless active steps are taken to protect it, EMBL's Alumni Association launched the archive initiative with the aim of safeguarding the Laboratory's heritage. "This idea was really galvanised by EMBL's 40th anniversary," says Anne-Flore. "EMBL has grown rapidly and represents a huge chapter in the history of molecular biology in Europe. Each person who leaves the Laboratory takes away a chunk of our story with them – but you can collect this, be proactive and make sure that your past and present is available for the future.

"Our goal is to collect unpublished, original material in whatever format it exists – letters, photographs, reports, notebooks, memoirs, lab books, memos, emails, article drafts, databases, official documents, you name it – and safeguard it for future generations. Archives take the user on a journey of discovery. You might unearth hidden stories, missing information, or inspirational ideas, as well as learn more about what people were actually thinking, feeling and doing at the time. One of my tasks is to find ways to contextualise the material we gather in connection with other science archives – such as at CERN, the Wellcome Trust, the Medical Research Council Laboratory of Molecular Biology, and many more – that collectively tell the wider narrative of the history of science in Europe. It's an exciting feeling to think much of this awaits documentation and discovery."

Deeper footprints

Cutting through the stereotype of a basement-dwelling academic whose only company is row upon row of dusty boxes, Anne-Flore is outgoing, energetic and excited about her mission. She has already met with alumni and people across all five of EMBL's sites, raising awareness and gathering ideas for what she describes as a big community project that belongs to everyone who has been part of the EMBL story. Her take-home message for this large number of protagonists: "Throw nothing away! At least not before considering what you might have to offer the archive."

"Imagine getting your hands on the original manuscript of a famous song, or an initial sketch of an influential painting – look hard enough and the same thing can be found in science,"

Image courtesy of EMBL Photolab

Anne-Flore Laloë

she says. "Archived material can have huge social significance, ignite public interest and provide insights into how things really happened, enriching our understanding above and beyond the 'official' record. Scholars using the Royal Society archive in the UK, for example, have recently shed new light on the crucial role of women in practising, popularising and communicating science during Victorian times by comparing letters, documents and other rare materials with official literature. It revealed remarkable contributions that add new dimensions to our understanding of science during these times."

Anne-Flore is quick to point out that such insights might come from something as unremarkable as a notebook, an article draft or a quick email. "We are looking for the ordinary as much as the extraordinary," she explains. "The creativity of people who have access to archives is mind-blowing – seemingly innocuous notes might inspire plays, songs, books and poems – while at the same time this information can deliver important clues in understanding how certain ideas are generated. What changed between the first draft and the published version? How did the thinking evolve along the way? Why did you circle that paragraph with red ink seven times? All of this information is cocooned in everyday material, both analogue and digital."

How can you contribute?

When people feel they have something to offer EMBL's archive, Anne-Flore urges them to get in touch with her as she can offer advice on ways to effectively capture the information, as well as discussing aspects such as access rights and confidentiality. "Sometimes I meet with people and the first thing they will do is look around their office and say 'As you can see, I do not have much here!'" she explains. "But everyone has their own personal archive – it might be a filing cabinet,

REVIEW

This article, about establishing a scientific archive, is a wake-up call for schools. Although easy access to online information often seems sufficient for students, the originality and objectivity of science topics can be more easily grasped using authentic material. Archives can provide the context to scientific discoveries – a moment of inspiration against a background of routine data collection and analysis.

The article could be used as the basis of a discussion on the importance of building on previous knowledge, to avoid the loss or unnecessary duplication of research results. Students could also discuss appropriate ways to catalogue and store archive materials. They could even create their own archive, after agreeing on what its purpose is, what they want to archive, and how they are going to preserve and catalogue the items.

Friedlinde Krotscheck, Germany

Images courtesy of EMBL Photolab

Among the collection is the original leaflet featuring the flags of EMBL's 10 founding member states.

Image courtesy of EMBL Photolab

Photos of the development and evolution of the EMBL sites will populate the archive.

a box of photographs at the bottom of a cupboard, or document folders on a laptop. These items might seem irrelevant to you, but they could be of significant importance to the collective memory of EMBL. Anything that you donate in confidence will remain so."

The first item to be deposited in the archive came with a certain amount of humour – EMBL Director General Iain Mattaj donated a laser pointer that stopped working during the launch of the concept in 2010. Other items include a copy of the original proposal for the establishment of EMBL from 1967, a box of official and social photographs, and a commemorative flag from EMBL's 40th anniversary celebrations. But Anne-Flore is on the hunt for much more. "The material that we look after might be frozen in time, but our activities are not," she says. "The archive will be active and modern, continuously growing and evolving. There is a massive resource to be tapped in terms of both material and knowledge – ultimately we want to create a resource that is comprehensive, easy to navigate and accessible to scholars the world over."

One challenge lies in getting people to recognise the value of their material, particularly in the digital era when data can be deleted at the touch of a button. "While the medium has changed, the essence of the conversation hasn't – people think that letters were only full of important information, while in fact they could be just as informal as today's emails," she explains. "I once read a letter from a taxonomist to his colleague. He ended the note with a complaint bemoaning the fact that his servant was ill and he was being forced to eat out everyday – poor him! We can learn a lot from these interactions. It's the personal meeting the scientific, and letters of the past are not much different to the email exchanges that we have nowadays."

Creating excitement

Anne-Flore, who holds a PhD in geography, joined EMBL from the Marine Biological Association of the UK, where she was responsible for the Association's varied historical collections. This included a herbarium, with specimens dating back to the 1800s. "Specimens were often beautifully preserved in albums, the colours as brilliant today as when they were collected. But by teasing out the accompanying letters, we were able to learn more about what life was like for collectors, or where a rare species was first spotted. It is interesting to try and imagine, a century from now, how people will look at the work we are doing today at EMBL, and then be able to understand who did what and why. Whether it is a specimen of seaweed, or a re-jigged machine that enables you to focus on something specific, you give a voice to the person who was there in the first place. It is like a time capsule."

A first practical step is to create the database and begin cataloguing in earnest before the end of the year, creating an interface that will make the archive accessible to the world. "Someone might want to know what the first annual report of EMBL looked like, learn more about the first director general, or how the staff association was founded," she adds. "Or it might be that a neat sketch from a researcher can be used in a presentation to school children. The success of the project and the eventual shape that the archive will take [are] entirely dependent on what people are willing and able to give us. And that's the other side to it: our archive is a resource to get people excited about EMBL and the personal stories that are the essence of scientific life."

Adam Gristwood is a journalist and editor of *EMBLetc.* magazine. Reporting mainly on life sciences, he's also covered stories from the Atacama Desert, the Large Hadron Collider and a helicopter.

Acknowledgement

The original version of this article appeared in the Spring 2015 issue of *EMBLetc*, the magazine of the European Molecular Biology Laboratory.

Resources

To learn about the science of preserving historical objects, see:

Leigh V (2009) The science of preserving art. *Science in School* **12**: 70–75. www.scienceinschool.org/2009/issue12/katylithgow

Can something accelerate upwards while falling down?

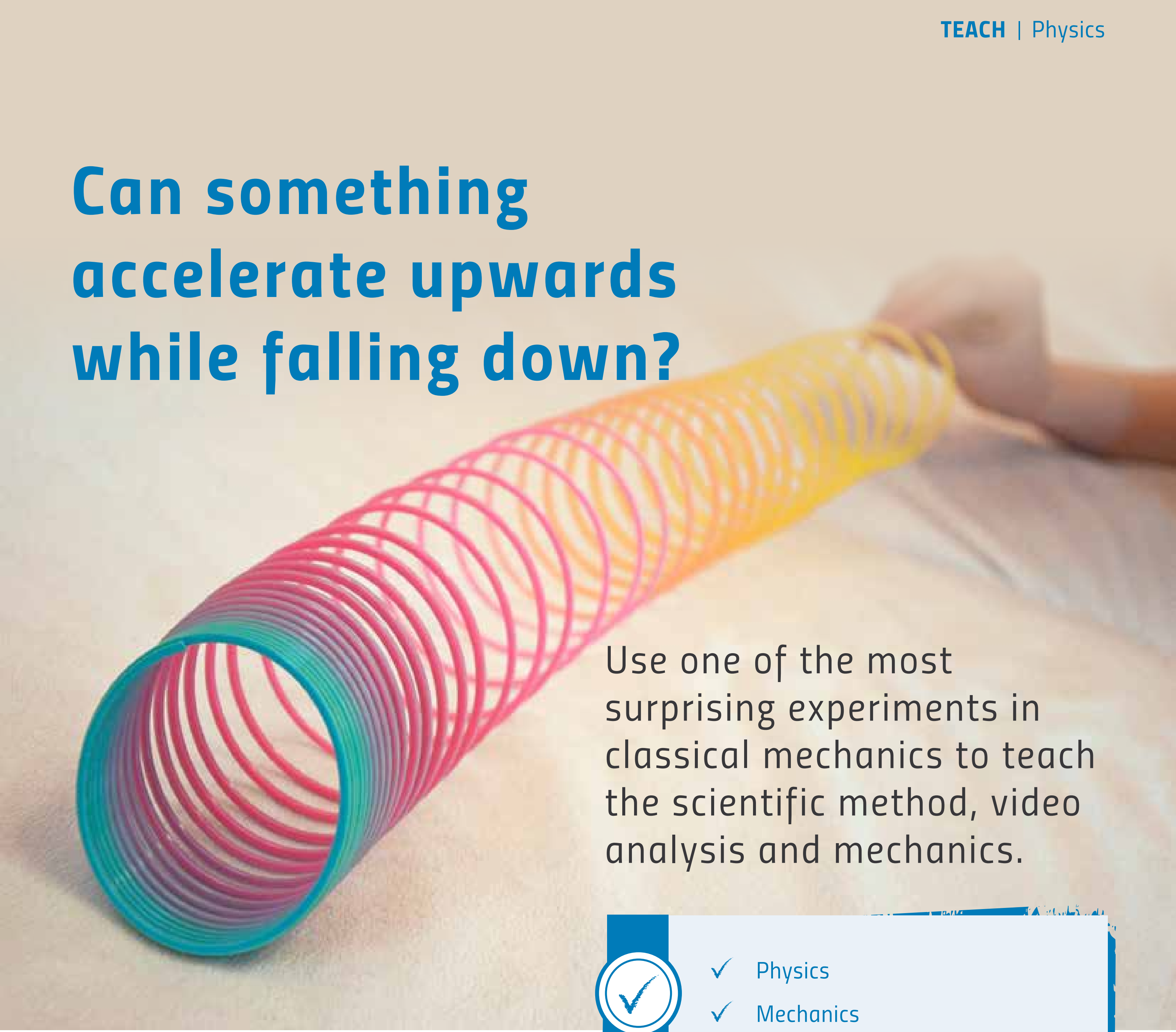


Image courtesy of Markus Norrby

Use one of the most surprising experiments in classical mechanics to teach the scientific method, video analysis and mechanics.

REVIEW

✓ Physics

✓ Mechanics

✓ Ages 16–19

As high-speed cameras and video analysis tools are becoming increasingly available, physics classrooms and laboratories can contribute new perspectives in the investigation of many types of motion. The study of fast moving or changing objects may reveal very interesting and fascinating aspects.

The Slinky (a pre-compressed helical steel or plastic spring) was invented as a toy. In this article, a student's study of the motion and behaviour of a falling Slinky, brings unexpected and surprising results to light. Further inquiry and study of the fascinating behaviour of the Slinky can be continued in more classrooms and labs. And many more phenomena could be investigated by students using video analysis!

Vangelis Koltsakis, Greece

By Markus Norrby and Robin Peltoniemi

Classical mechanics in secondary education can sometimes be challenging to teach and to learn. Most experiments involve things like pulling a wooden block along a flat surface with a Newton meter or spring scale, or dropping a tennis ball from different heights – activities that may neither surprise nor engage the students to any desired extent. But thanks to the fast evolution of mobile phone cameras, video analysis can now be used to easily carry out investigations that a few years ago could be done only in top research labs. And detailed analysis of seemingly everyday phenomena can sometimes lead to the most surprising results!

This suggestion for a lesson activity is the result of such an investigation performed by a student for an ordinary physics course assignment, in which the results completely surprised both the student and the teacher.

Image courtesy of Markus Norrby

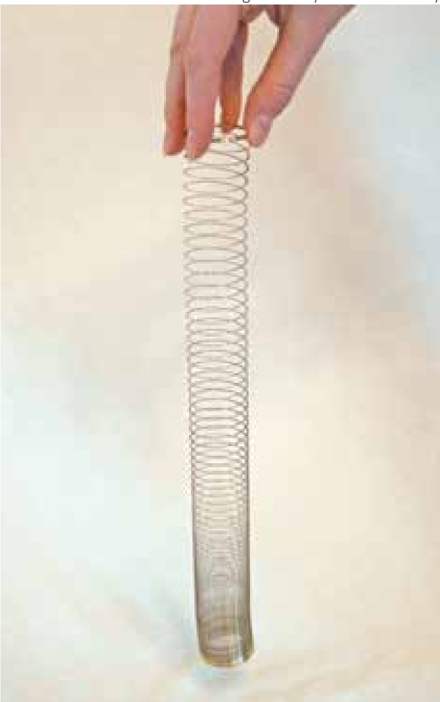


Image courtesy of Markus Norrby

Figure 1: A Slinky hanging under its own weight and then released

The experiment

A Slinky® is essential in any physics classroom. It can be used for many things, from illustrating longitudinal waves to walking down stairs. A Slinky has a surprising yet relatively well known property: if it is held by its top and stretched under its own weight, when released, the bottom of the Slinky will not move until the Slinky has collapsed completely (see figure 1). Many popular videos online show this interesting fact[w1].

The process is usually too fast to see with the naked eye, but it is clearly felt if one places a hand just underneath the bottom of the stretched Slinky before releasing it. You can easily demonstrate this peculiar property in the classroom, preferably by letting all students test it themselves by holding a Slinky with one hand and dropping it onto their other hand.

After introducing the phenomenon, you can pose a research question: *Since the acceleration of the bottom part of the Slinky is zero, what is the acceleration of the top part of the Slinky during the fall?*

The next step, according to the scientific method, would be to make a hypothesis. This could be discussed in the classroom. If the desired end product is a group or individual laboratory report, the hypothesis should be motivated by logical reasoning and possible references to literature and should be written down. In many cases, the hypothesis will be that the acceleration of the top part of the Slinky should be around $2g$ or higher, to give an average acceleration of g for the whole Slinky (at least that was our hypothesis when first conducting this investigation).

To answer the research question, video analysis should be used. For a detailed analysis, the Slinky drop needs to be filmed at a higher than normal frame rate, at least 60 frames per second but preferably 120 frames per second, which can be achieved by many newer smartphones. To reduce uncertainties, the students need to spend some time evaluating the errors that might affect the results of video analysis, such as filming angle, position of an object of known size for reference, and the resolution and shutter speed of the camera. A model procedure is outlined below.

Materials

Each student or group of students will need:

- Slinky
- Metre rule
- Tripod
- Video recording device (video camera or smartphone)
- Video analysis software (a great free tool is Tracker[w2], a video analysis and modelling tool built on the Open Source Physics Java framework. We used Pasco Capstone[w3], a commercial data acquisition and analysis tool. There are also apps available to perform the analysis directly on mobile devices[w4])

Procedure

1. Attach the metre rule vertically to a wall, with the start of the rule (e.g. 0 cm end) at the top.
2. Set up the tripod and camera so that the Slinky's entire fall can be recorded.
3. Hold the Slinky fully extended and align its top with the start of the metre rule.
4. Start filming.
5. Release the Slinky.
6. Stop filming.
7. If needed, import the video into the relevant analysis software.
8. The exact procedure for tracking the object of interest in the video varies slightly between different types of video analysis software. The students should process the video to produce data that can be plotted in graphs showing time against speed, time against velocity or time against acceleration.
9. Analyse results.

Since acceleration is the quantity of interest in this case, students will usually start by looking at the graph showing time against acceleration.

Image courtesy of Markus Norrby

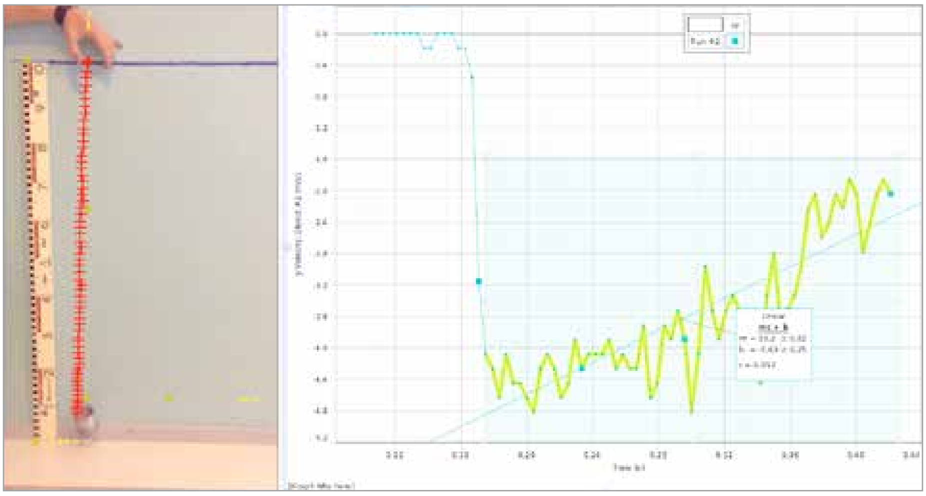


Figure 2: A time-velocity graph showing an analysis of the negative (compared to the acceleration of gravity) acceleration phase of the falling Slinky. Note the huge initial acceleration in the opposite direction.

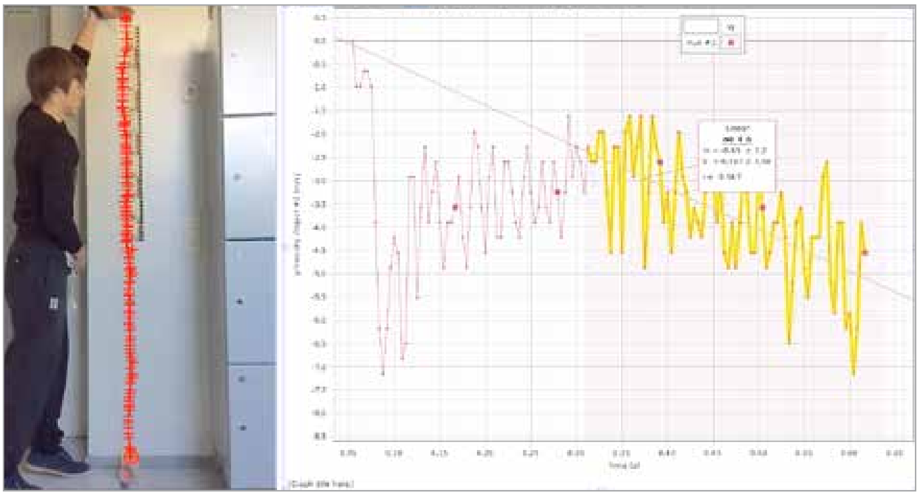


Figure 3: Analysis of the acceleration of the collapsed Slinky. Note the symmetrical shape of the graph and the intersection of the line of best fit with the beginning of the motion, which shows that the total average acceleration is indeed the acceleration of gravity.

However, they will find that their values are all over the place. This is a good learning opportunity to help the students understand why physics teachers keep nagging them about the line of best fit in different diagrams.

If the students then analyse a graph showing time against speed or time against velocity, they will see a much smoother curve and can obtain better results (see figures 2 and 3).

About what happens

The original research question posed when first performing the experiment is how the acceleration of the top and the bottom of the Slinky relate to each other. Our first surprise after watching the slow-motion video was that the only part of the Slinky moving is the top. Each section of the Slinky below the top behaves just like the bottom part, hanging in the air (almost) until hit by the top.

The second, and even bigger surprise, came from the analysis of the acceleration of the top part. It turns out that the top of the Slinky has a huge acceleration in the first few milliseconds of being dropped – usually around 200–300 m s^{-2} on average. After that, the velocity abruptly *decreases*, with a seemingly constant value for the acceleration of about 10 m s^{-2}. In fact, having repeated the experiment many times, and including Slinkies of different materials and diameters (see figure 4), the error bars of the results always include the value 9.8 m s^{-2}, and the average comes very close to that of a negative acceleration of gravity.

A simple way to convince oneself of the validity of the result is to continue the analysis a bit further after the Slinky has collapsed completely but before it hits the ground. The acceleration of the collapsed Slinky is, as expected, equal to the acceleration of gravity. By observing the symmetrical shape of the plot of time against velocity, it is clear that the sign of the acceleration changes during the Slinky's fall, but that the modulus of the value remains much the same (figure 3). Figure 3 also shows that the total average acceleration for the whole motion is 9.8 m s^{-2}, as we would expect.

These results should be discussed in the classroom. The students need to understand that there is no simple explanation for this behaviour; even the simplest models of the phenomenon include differential equations and propagating waves. The uncertainties of the results must be stressed, and professional equipment together with in-depth analysis would show additional structure in the behaviour, as with most real-life phenomena.

The problem of the falling Slinky has recently been investigated in more detail, and over the past few years more and more academic references turn up when you search the Internet for information on the subject. The explanation for the bottom part hanging in the air until the Slinky has collapsed is straightforward: information about the top of the Slinky being released travels as a wave through the Slinky and takes a certain amount of time to reach the bottom. But other aspects are more challenging to explain.

The phenomenon was investigated by Cross and Wheatland (2012), who made a semi-empirical model for the falling Slinky, assuming a finite collapse time of the turns behind a downward propagating wave and comparing to footage from a high-speed camera.

Their more detailed analysis agrees with the results that the students will find above, but the authors also observe a small oscillation in the acceleration during the fall. Their model, which predicts a non-constant deceleration, could not be conclusively proved. In Cross and Wheatland's article, the data clearly imply an average acceleration for the negative acceleration phase of about 10 m s^{-2} but that is not mentioned in the article and not directly supported by the model.

Other researchers have tried different approaches[w5] for modelling the falling Slinky but so far no single model seems to be able to explain fully the details of this complicated motion. So, as the saying goes: "More research is needed." And while we wait for physics theory to catch up, we can use this fascinating experiment as inspiration for physics students around Europe.

There is an opportunity here for teachers to make the connection between this experiment and many historical experiments in which the outcome was completely unexpected. It is often these unforeseen results that can cause science to take a leap forward, such as Rutherford's discovery of the atomic nucleus or Bequerel's discovery of radioactivity.

Markus Norrby is a physics teacher at Vasa övningsskola Vaasa, Finland, and Robin Peltoniemi is a student at the school.

Reference

Cross RC, Wheatland M S (2012) Modeling a falling slinky. *American Journal of Physics*, **80**, 1051. http://dx.doi.org/10.1119/1.4750489. A preprint is freely available on ArXiv at http://arxiv.org/pdf/1208.4629.pdf

Web references

w1 Watch a slow-motion video of a Slinky falling, which also discusses some of the science involved: https://youtu.be/uiyMuHuCFo4

w2 Find out more about the free image processing software Tracker and download it at: http://physlets.org/tracker/

w3 Download Pasco Capstone, the commercial software the authors used, at: www.pasco.com/capstone/

w4 One example of a video analysis app is Video Physics for iOS. Find out more at: www.vernier.com/products/software/video-physics/

w5 Phil Gash, a professor of physics at California State University, has proposed an alternative model for a falling Slinky. Visit his webpage on the phenomenon: www.slinky-frequency-falling.com

Image courtesy of Markus Norrby

Figure 4: Selection of Slinkies tested by the authors

Image courtesy of Les Black; image source: Flickr

Sharp eyes: how well can we really see?

Exploring visual acuity requires not only biological experiments, but also some understanding of the underlying physics.

By Günther KH Zupanc

Visual acuity is a measure of how sharp our vision is, particularly how well we can resolve small details. Opticians assess this by asking us to read from a wall chart until the letters become too small for us to make out clearly.

One of the biological factors that determines visual acuity is the density of the photoreceptor cells in the retina (see box, 'How our eyes work'). This prompts an intriguing question: could increasing the density of receptors in the retina make our vision sharper? To answer this question, we need to consider both the biology of the visual system and the physics of light. These topics are part of most secondary-level biology

REVIEW

- ✓ Biology
- ✓ Physics
- ✓ Vision
- ✓ Optics
- ✓ Ages 16–19

This article describes two experiments related to visual acuity, an example of the numerous links between biology and physics that can be found in nature. Cross-curricular activities can make science more appealing and can offer a great opportunity to collaborate with other teachers.

All the materials required for the experiments are readily available and the instructions are easy to follow, making the activities suitable for students to perform in small groups.

The text could be used as a starting point for discussing the importance of the teamwork and interdisciplinary collaboration to solve many problems in modern science and also in other subjects.

Mireia Güell, Spain

Background

How our eyes work

Light rays reflected by objects enter the eye via the pupil. Four components of the eye – the cornea, lens, aqueous humour and vitreous humour – focus the light rays on the retina, the surface of the back of the eyeball (figure 1). The retina is organised in different layers, one of which is made up of millions of light-sensing photoreceptors that pass signals to the brain via other cells such as the ganglion cells. The photoreceptor cells are specialised nerve cells and come in two types – rods and cones (named for their shape). Cones, found mainly in the centre of the retina, enable sharp colour vision in bright light. Rods, found towards the edges of the retina, help us to detect motion and to see in dim light, and allow peripheral vision. The density of photoreceptors in the retina (which can be over 200 000 cells per square millimetre in the fovea centralis) plays an important role in visual acuity.

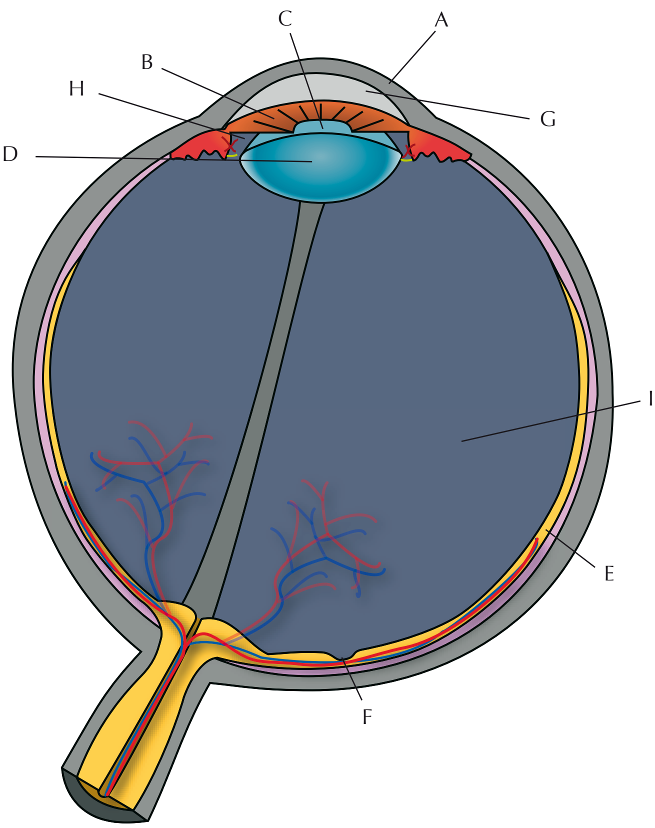


Image courtesy of Rhcastilhos; image source: Wikimedia Commons

Figure 1: A horizontal section of the human eye showing the cornea (A), iris (B), pupil (C), lens (D), retina (E) and fovea centralis (F). Both the anterior chamber (G) and posterior chamber (H) contain the watery aqueous humour; the vitreous chamber (I) behind the lens contains the thick, gel-like vitreous humour.

and physics curricula. However, they are traditionally taught separately, often to different groups of students. In contrast, the cross-curricular approach proposed here will enable students to gain a deeper understanding of both the biology and physics of visual acuity and will convey an important general message: many problems in modern science can best be solved through teamwork and interdisciplinary collaboration.

This article describes a simple way of assessing visual acuity by creating a wall chart and using it to calculate eye resolution. This method can then be used to estimate the smallest distance on the retina at which the images of two points can be identified as two distinctly separate objects. A follow-up experiment, available online[w1], relates this distance to the theoretical limits of visual acuity based on the physical properties of light.

The two activities are most appropriate for students aged 16-19 years and will take about two hours each, including the preparation and data analysis. Another two hours should be allowed for the discussion of the results.

Estimating the resolution of the human eye

The angular resolution of the human eye is a measure of the smallest angle between two points that are perceived as distinctly separate and is related in part to the density of photoreceptors on the retina. It is typically around 1 arcminute (1/60th of a degree). In this activity, angular resolution is calculated by determining the ratio of the distance between the two points and the distance between the observer and the points. This simplified mathematical procedure (which replaces the more complicated calculation of the tangent of the angle α in figure 2) is possible because the angular resolution assumes very small values. In mathematics, this shortcut is known as the small-angle approximation. The calculated ratio can then be used to estimate the distance between these two points projected onto the retina, as shown in figure 2.

Image courtesy of Günther KH Zupanc

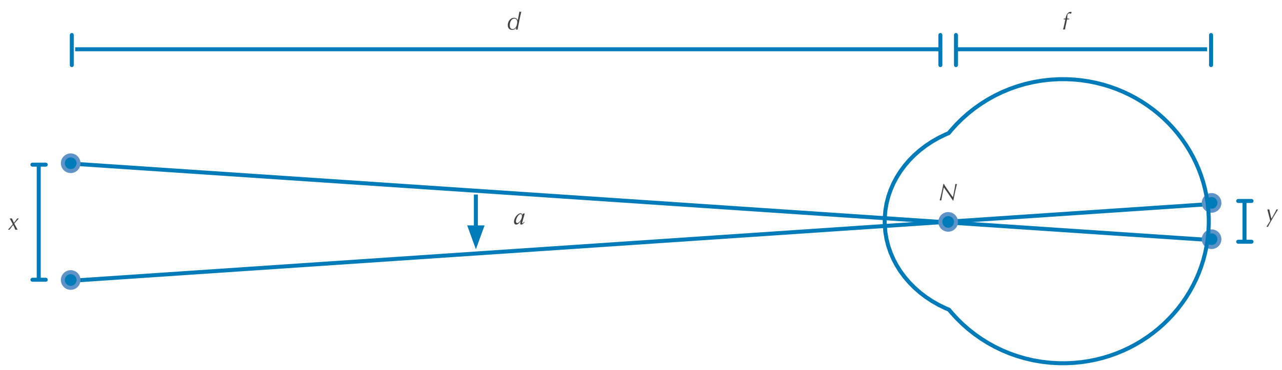


Figure 2: The reduced eye. This simplified model of the ocular system of the human eye approximately matches the ocular dimensions of the real eye, but combines the refractive bodies of the cornea, lens, aqueous humour and vitreous humour into one, assuming a uniform index of refraction.

d = *distance between object (in the experiment, the wall chart) and eye of the test person;* f = *focal length of reduced eye;* x = *smallest perceived gap between two points (in the experiment, the width of the smallest perceived gap separating the two black bars of an interrupted bar pattern);* y = *distance between the images of these two points on the retina;* N = *nodal point.*

The students will create a chart with simple black lines separated by gaps of varying width. They will then be asked to state which lines are perceived as separate and which appear to be merged, and to use these results to calculate an estimate of the angular resolution and thus the spacing between the receptors in the eye.

Materials

- Computer with simple drawing software installed
- Printer and white paper
- Tape measure
- Ruler with millimetre scale

Procedure

1. Instruct your students to use the drawing software to create a chart of black bars interrupted by small gaps. The width of these gaps should vary between 0.5 mm and 5 mm, and the bars should be arranged on one page, rather like in figure 3. Include one or two complete bars with no gap as a control.
2. Ask your students to produce additional charts using the same bar patterns in the individual rows as in step 1 but arranged in a random order.
3. Print the charts onto white paper using a high-quality setting.
4. Fix the charts to the wall in a well-lit room and mark a viewing point on the floor approximately 7–10 m from the chart. Measure this distance (*d*) exactly.
5. Arrange the students into pairs or small groups, so they will be asked to 'read' a different chart to the one they produced. One member of the group is the subject, who waits outside the room, while another, the experimenter, selects the wall chart.

Image courtesy of che; image source: Wikimedia Commons

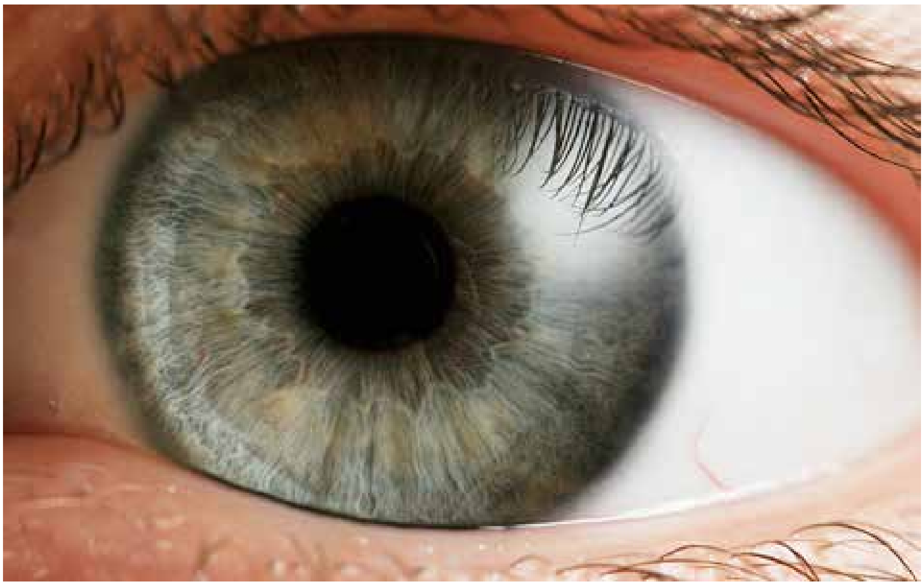


Image courtesy of Günther KH Zupanc

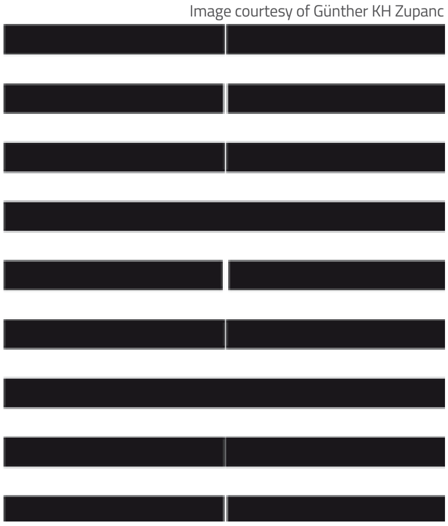


Figure 3: Example test chart for determining the angular resolution of the human eye

Image courtesy of Ken Teegardin; image source: Wikimedia Commons

6. Ask the subject to come into the room and stand at the viewing point, while the experimenter covers the test chart. Uncover the test chart and ask the subject to ‘read’ the bar patterns by identifying which bars appear uninterrupted, and which ones have visible gaps. Record the results.
7. Repeat until all students have served as both subject and experimenter.
8. Using the ruler, determine the width x of the smallest gap on the charts that each student was able to correctly identify.
9. For each student, use the values for distance from chart, d, and smallest perceived gap, x, to calculate the angular resolution α (in arcminutes), which is given by equation 1. Make sure that the units of d and x are identical.

$$\alpha = (180x / d\pi)60 \qquad \text{Equation 1}$$

10. What is the range of values of α for different students? What is the mean angular resolution of this group of students? Give an error estimate for your measurements by taking into account the accuracy when you measure d with the tape measure and x with the ruler.
11. Now calculate the distance y between the images of two points when projected onto the retina. For this calculation, assume a simplified model of the eye’s optic system with a single refractory surface and a uniform index of refraction. The focal length f of this reduced eye is 20.1 mm. The distance y between the two points on the retina is given by rearranging equation 1 to give equation 2:

$$y = (\alpha\pi f) / (180 \cdot 60) \qquad \text{Equation 2}$$

12. Ask your students what, theoretically, would be the minimum number of retinal photoreceptors required to resolve these two points. What would the centre-to-centre distance between these photoreceptors be?

What is happening?

The angular resolution of the human eye typically ranges between 40 arcseconds and 1 arcminute. To perceive two separate points, at least three photoreceptors arranged in a row are required: one to receive light from each of the points, and one for the gap in between the points. For an angular resolution of 1 arcminute (which corresponds to 0.3 m at a distance of 1 km), the images on the retina are separated by approximately 6 µm, meaning the centre-to-centre distance between two neighbouring receptors is 3 µm. At an angular resolution of 40 arcseconds, the distance between the imaged points is approximately 4 µm.

The actual resolution of the eye is affected not only by photoreceptor spacing, but also by the diffraction of light as it passes through the pupil. You can explore this further by downloading experiment 2.

So, could visual acuity be improved by increasing the density of the cones in the retina?

An angular resolution of 40 arcseconds to 1 arcminute is achieved only when we look fixedly at an object. The image of the object is then projected onto a specific part in the centre of the retina, the fovea centralis, which contains only cone photoreceptors. The density of cones in the fovea is much higher than anywhere else in the retina, and the cones here have a diameter of only 3 µm (compared to up to 10 µm in other areas of the retina). Allowing for some extracellular space around each cone (e.g. for transport of nutrients), the centre-to-centre distance between the cones in the fovea is about 4 µm. Thus the density of the cones in the fovea is already very close to the maximum packing density possible.

As can be explored in the follow-up experiment[w1], light diffraction in the eye means the minimum resolvable distance between two points of light is about 5 µm, giving a minimum predicted distance between cones of approximately 2.5 µm. Allowing for some extracellular space between the cones, this theoretically predicted distance is in excellent agreement with the actual distance between the cone receptors in the fovea centralis of approximately 4 µm. Therefore a further increase in the density of cones might not be possible on biological grounds and, based on physical limitations determined by the properties of light, would not lead to any significant gain in visual acuity.

Günther KH Zupanc is a professor of biology at Northeastern University in Boston, Massachusetts, USA. He holds degrees in biology, physics and neuroscience. Over the past 25 years, he has taught a wide range of biology classes to numerous students at German, British and US universities. His book *Behavioral Neurobiology: An Integrative Approach* (Oxford University Press) is the most frequently adopted text for teaching this subject around the world. He would like to thank his son Frederick B Zupanc and his wife Dr Marianne M Zupanc for their helpful comments on this article.

Web reference

w1 A follow-up experiment, exploring the theoretical limits of visual acuity based on the physical properties of light, can be downloaded from the *Science in School* website. See: www.scienceinschool.org/2016/issue37/vision

Resource

Across the USA, huge test charts – similar to the wall charts employed in this experiment – are used to calibrate 'flying cameras'. See www.petapixel.com or use the direct link: http://tinyurl.com/chpvfet

Image courtesy of Nicola Graf

What are stars made of?

Find out how we know what the Sun (and stars) are made of.

By Carla Isabel Ribeiro and Ole Ahlgren

Unlike other components of the Solar System, such as planets and satellites, stars are out of reach for spacecraft or, in the Sun's case, too hot to approach. So how can we understand them, if we can't use probes, rovers or astronauts to study them? The answer is that we must rely on their light. We know that a star's colour gives away its temperature (Ribeiro, 2015), but how do we know what stars are made of? Again, star light, or more specifically, the star's spectrum, is the answer.

At the Science on Stage festival held in London in June 2015, a discussion about combining hands-on experiments with teaching about a star's chemical composition arose between us, and so the idea for this activity was born. The activity is designed to allow students aged 15–18 to explore different light spectra and understand how they can be used to identify chemical elements in lamps and, more importantly, in our closest star, the Sun.

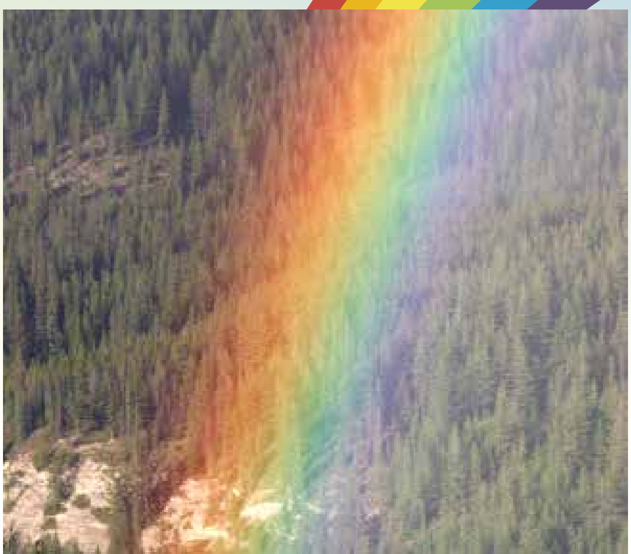


Image courtesy of Wing-Chi Poon, image source: Wikimedia Commons

Light spectra

In his famous experiment in 1666, Isaac Newton used a prism to show that light could be split up into component colours and that these colours could recombine to generate white light. He demonstrated that the colours did not originate in the crystal, as was previously believed, but that instead they were the components (or wavelengths) of sunlight. He introduced the word 'spectrum' to describe the rainbow of colours and his discovery kickstarted the science of spectroscopy.

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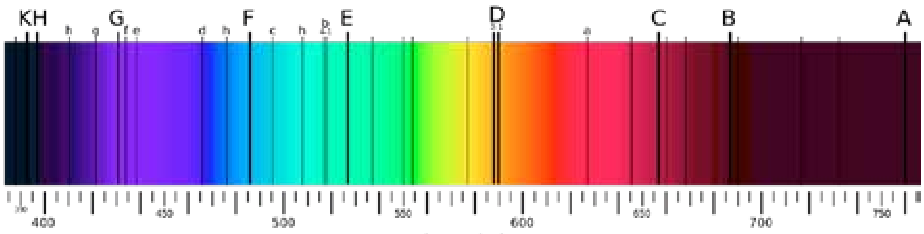


Figure 1: Fraunhofer assigned letters to each of the dark lines in the continuous spectrum, which we now call Fraunhofer lines. The wavelengths of the visible spectrum are shown in nanometres (nm).

To Newton, the Sun's spectrum appeared to be continuous, with no gaps between the colours. But in 1814, Joseph von Fraunhofer discovered that when the light is sufficiently dispersed through a narrow slit, the spectrum contains a number of dark lines, now known as Fraunhofer lines (figure 1). About 45 years later, these lines would prove essential in determining the composition of the Sun, thanks to the work of Gustav Kirchhoff and Robert Bunsen.

In 1860, Kirchhoff and Bunsen studied a different kind of spectrum. Instead of observing dark lines against a bright background, they studied the bright lines on a dark background, emitted when they heated elements in Bunsen's gas flame. One such spectrum was for sodium (figure 2), which can be obtained by burning table salt (NaCl) or shining a low-pressure sodium lamp, like those used in street lights.

Bunsen and Kirchhoff concluded that chemical elements could be identified using these emission lines and, with that in mind, they found two new elements within two years: caesium and rubidium.

Kirchhoff continued his work and realised that the emission lines coincided with several Fraunhofer lines. For example, the bright yellow line of the sodium spectrum was in the same position as a dark line in the yellow region of the solar spectrum, named 'D' by Fraunhofer.

These early experiments revealed that there were three main types of spectra; continuous, absorption, and emission. The first shows all the wavelengths, the second contains only some of the wavelengths of light, and the third shows gaps, or dark lines against a bright background. These spectra are formed according to Kirchhoff's three spectroscopy laws:

1. A continuous spectrum is emitted by an incandescent solid, liquid or gas under high pressure.
2. An absorption spectrum is formed when a continuous spectrum passes through a cool low-density gas.
3. An emission spectrum is emitted by a hot gas under low pressure.

Kirchhoff had not only found that a chemical element was responsible for spectral lines in the same position in both the emission and absorption spectra, but he had also discovered that the Sun contains sodium. So, to know the composition of the Sun, and any other star, we just need to compare the spectra of known elements to the spectra of the star.

Public domain image; image source: Wikimedia Commons

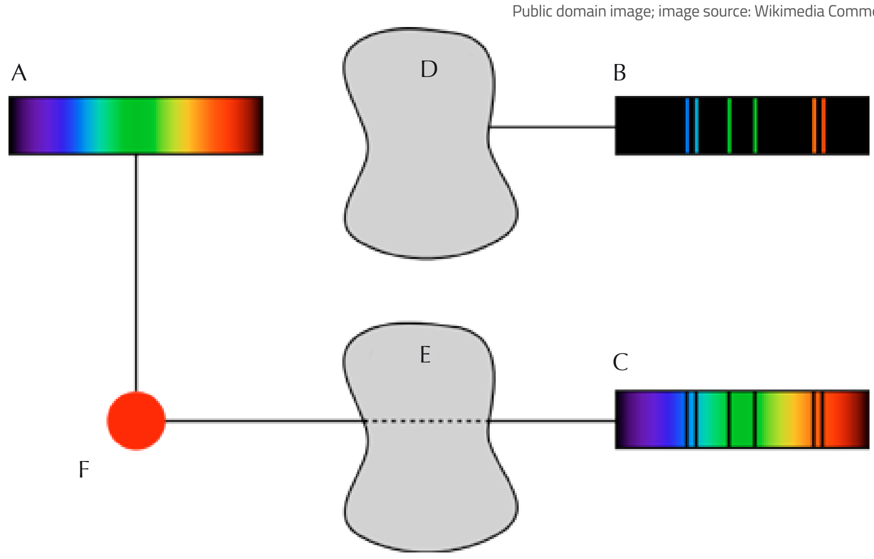


Illustration of Kirchhoff's three laws of spectroscopy. A: continuous spectrum, B: emission spectrum, C: absorption spectrum, D: hot gas, E: cool gas, F: hot source

Public domain image; image source: Wikimedia Commons

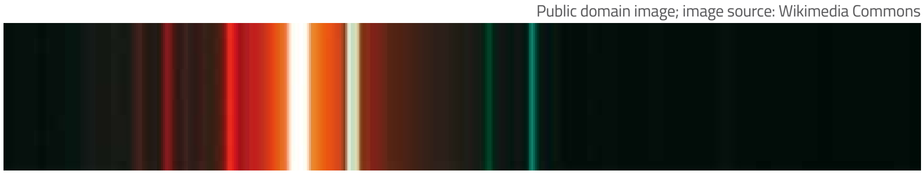


Figure 2: Spectrum of a low-pressure sodium lamp

REVIEW

- ✓ Physics
- ✓ Chemistry
- ✓ Biology
- ✓ Astrophysics
- ✓ Environmental subjects
- ✓ Ages 15–19

Within this article, the authors describe briefly how spectra were discovered and how different kinds of spectra can be used to identify what stars are made of.

They also show how self-made spectrometers can be built and used for spectral measurements. This teaching activity can provide fascinating results using these spectrometers.

Comprehension question on the topic might be:

- How did Newton discover the spectrum of light?
- Which colours are included in the spectrum of light?
- At which colours does the visible light spectrum start and end?
- Describe the discoveries of Bunsen and Kirchhoff.

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

Taking spectra of different light sources

Materials

- Several light sources (such as incandescent lamps, fluorescent lamps, street lamps and neon lights)
- Spectrometers – built using a cereal box[w1] (see right) or by purchasing and assembling a foldable mini-spectrometer kit (available online[w2]).
- Emission spectra for different elements – suitable images can be found in books or downloaded from the internet[w3].

Safety note: Do not look directly into the Sun, even with a spectrometer. Instead, point your spectrometer at the sky to observe a spectrum of diffused sunlight.

Procedure

Comparing spectra

Ask the students to observe the light from the various light sources through a spectrometer. This will show them that not all light sources are the same, because their spectra are not the same.

Questions:

1. What type of spectrum is emitted by each light source?
2. What does this tell you about the type of light source?
3. Which light source is most often used and why?

Explanation:

The students will observe a different spectrum depending on the light source:

- An incandescent bulb emits a continuous spectrum with all visible colours present.
- A gas-discharge lamp typically contains helium (He), neon (Ne), argon (Ar), krypton (Kr) and xenon (Xe) (figure 3).
- Street lamps usually contain sodium so will emit the emission spectrum for sodium.
- The spectrum emitted by an LED bulb depends on the LED's semiconductor material. A blue LED creates a continuous spectrum with a brighter blue part of the spectrum.
- The Sun emits a continuous spectrum. A more sophisticated spectrometer will show the dark absorption lines determined by the elements through which the light passes in the solar atmosphere.

The different spectra indicate that these sources of light, and the mechanism behind their formation, are different, except for the Sun and the incandescent lamp. The light source most often used is incandescent because it has a continuous spectrum like the Sun.

Analysing emission spectra

Using different gas-discharge lamps, ask the students to identify the elements present by comparing the lamp's spectrum with printed images of different elements' emission spectra. This is the basis of spectroscopy as a method of chemical analysis.

Safety note: As gas-discharge lamps require a high voltage, they should be handled by the teacher.

Using a foldable mini-spectrometer to obtain the helium emission spectrum

Image courtesy of Heinrich Pniok; image source: Wikimedia Commons

Questions:

1. Do all the spectral lines have the same intensity?
2. What is the relationship between the spectral lines and a lamp's colour?
3. How can the spectra be used to identify different chemical elements?

Explanation:

Some wavelengths are more intense than others, which results in some emission lines being brighter than others. This is shown in the lamp's colour. For example, the light of a sodium lamp is yellowish in colour because it emits mainly yellow, despite also emitting red and green light. Since each element has its own specific wavelength, you can use spectra to identify which chemical elements are present.

Extending the activity

To get more detailed results, further activities can be carried out with a spectrometer capable of detecting the Sun's absorption lines, and by using appropriate data-logger software. Figures 4 and 5 were taken using the Ocean Optics Red Tide spectrometer and the program LoggerPro.

The spectra obtained are different from those taken with a simple spectrometer, and contain more information, including the wavelength of each spectral line and its relative intensity. The Sun's spectrum can also show that the presence of absorption lines doesn't mean that certain wavelengths of light are completely missing, just that they are less intense than other wavelengths.

Materials

- Spectrometer[w4] (more sophisticated than the one used previously)
- Data-logger software[w5]

Procedure

Students can record the Sun's spectrum using the more sophisticated spectrometer. The data-logger program will give the wavelength of

CLASSROOM ACTIVITY

Building a spectrometer

Materials

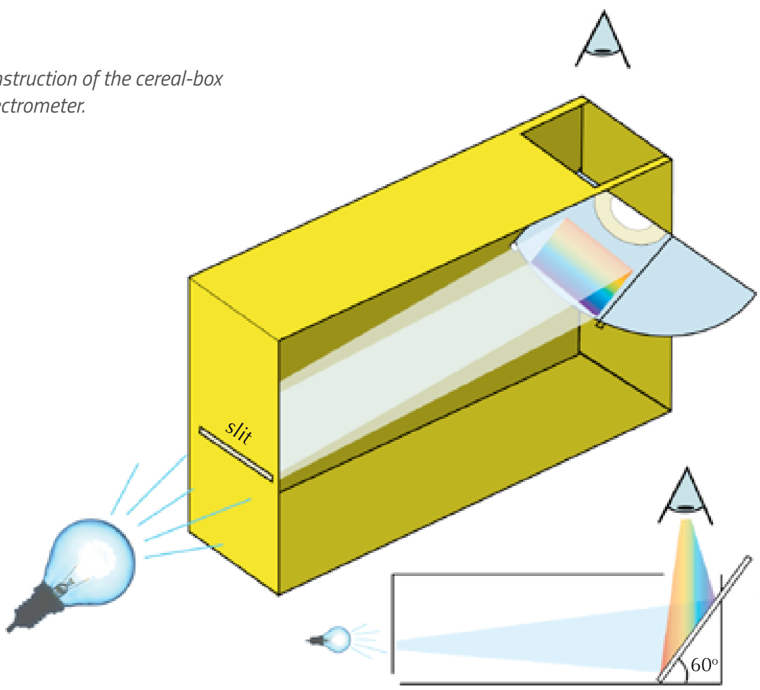
- Cereal box
- Thick paper
- CD
- Scissors
- Dark tape

Procedure

1. On one of the narrow sides of the box, cut into the box to make a horizontal slit. To make a clean line you could use tape to stick two small pieces of thick paper close together, leaving a small slit in between. An ideal width is 0.2 mm.
2. Cut the CD in half using a pair of scissors. On the opposite side to where you just cut the slit, cut another horizontal line. Extend this line beyond the corners of the box on either side so that when you slide the CD through the slit, it is mounted at a 60° angle to the bottom of the box.
3. Cut a hole on the top of the box, through which the CD can be observed.
4. Exclude any stray light from the box by covering the edges of the CD with dark tape.

For more information on building this spectrometer, see www.scienceinschool.org/2007/issue4/spectrometer

An alternative option is to use the foldable mini-spectrometer, available to buy online[w2]. It allows the students to photograph the observed spectra using a smartphone.



Construction of the cereal-box spectrometer.

Image courtesy of Ole Ahlgren

Image courtesy of Heinrich Pniok; image source: Wikimedia Commons

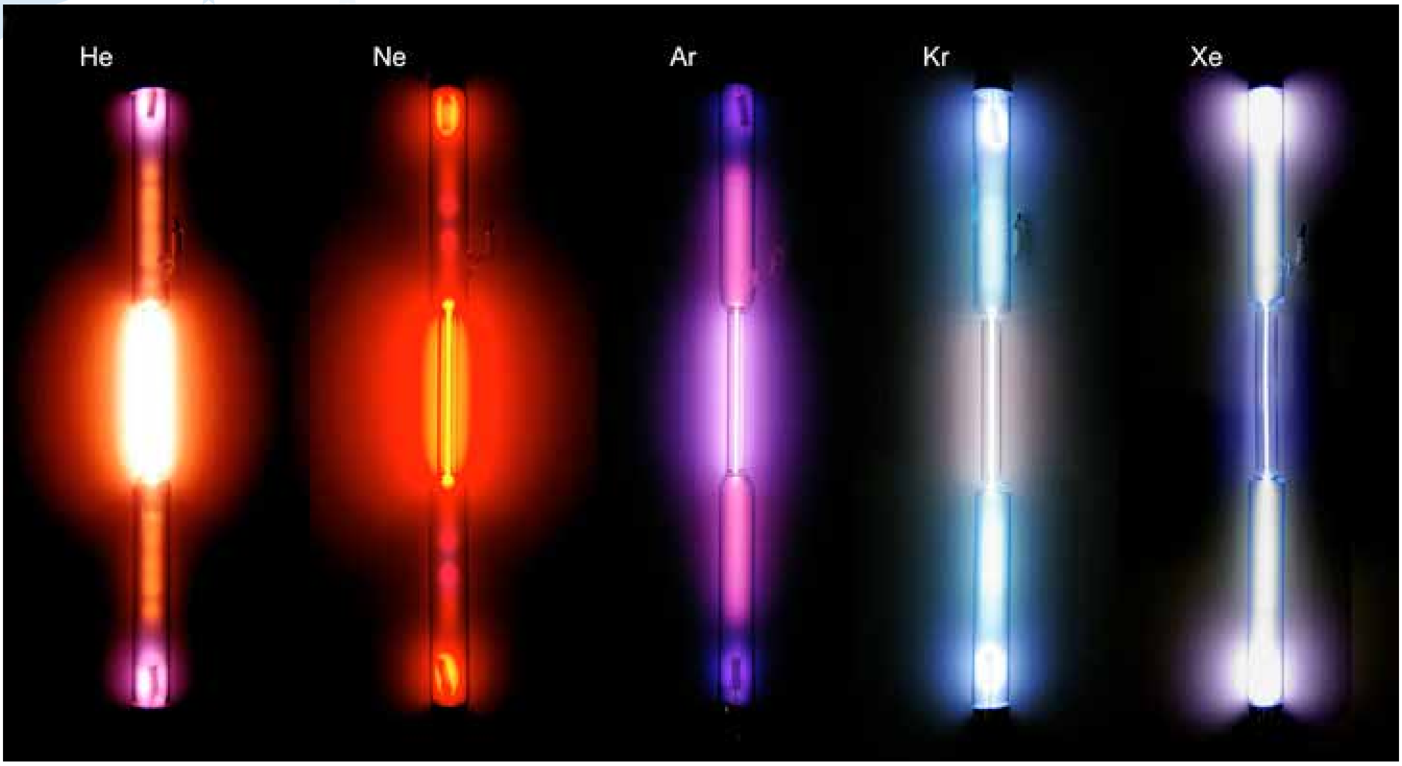
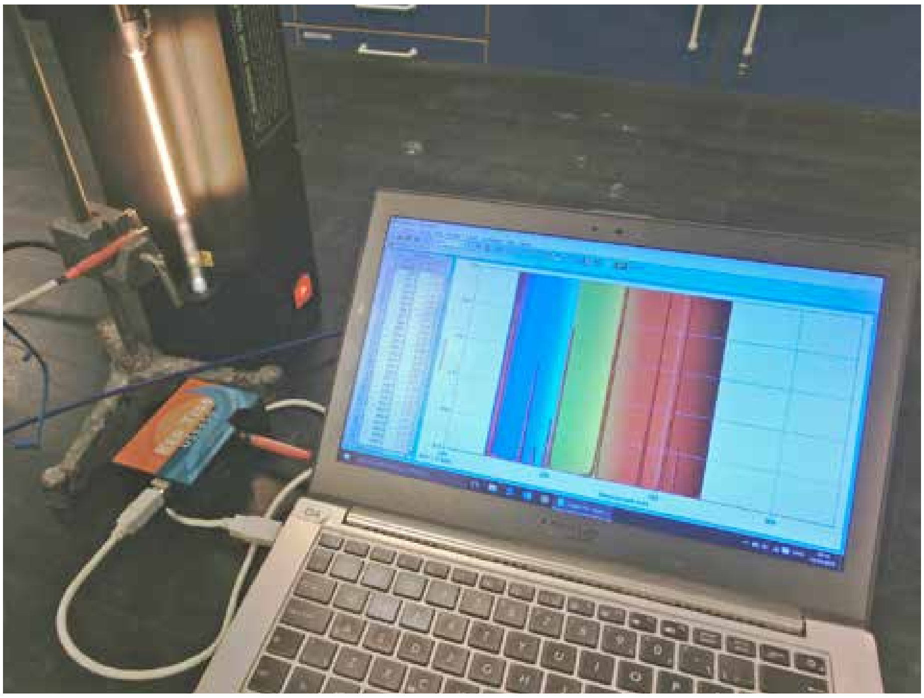


Figure 3: Gas-discharge tubes of helium (He), neon (Ne), argon (Ar), krypton (Kr) and xenon (Xe)

Image courtesy of Mark Tiele Westra



Record of the mercury spectrum with the Ocean Optics Red Tide spectrometer and the programme LoggerPro.

the absorption lines that the students choose. The absorption lines chosen should be the most prominent. To determine the elements present, there are two choices:

1. The students compare each wavelength with the ones from a table, like the one available at the Columbus Optical SETI Observatory page[w6].
2. The students log the emission spectra of several elements and then compare the lines' wavelengths to the ones of the Sun. The number of elements that can be used is limited to those present in the gas-discharge lamps. It is possible to burn metals and obtain the emission spectrum, but there will be lines from other elements. For example, the most prominent lines shown in figure 6 when burning magnesium are due to the presence of nitrogen.

By taking spectra of different light sources and chemical elements and comparing them with the spectrum of the Sun, the students learn how we can determine the composition of the Sun and other stars.

Carla Isabel Ribeiro teaches chemistry and physics at a public Portuguese school, and is particularly interested in astronomy.

Ole Ahlgren teaches physics, chemistry and biology at a secondary school in Denmark, and shares an interest in astronomy and astrophysics.

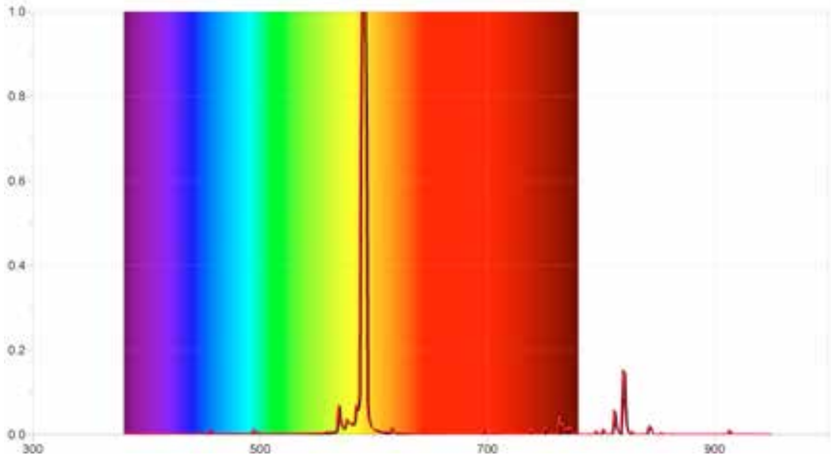


Image courtesy of Ole Ahlgren

Figure 4: Sodium (Na) spectrum showing relative intensity against wavelength (nm)

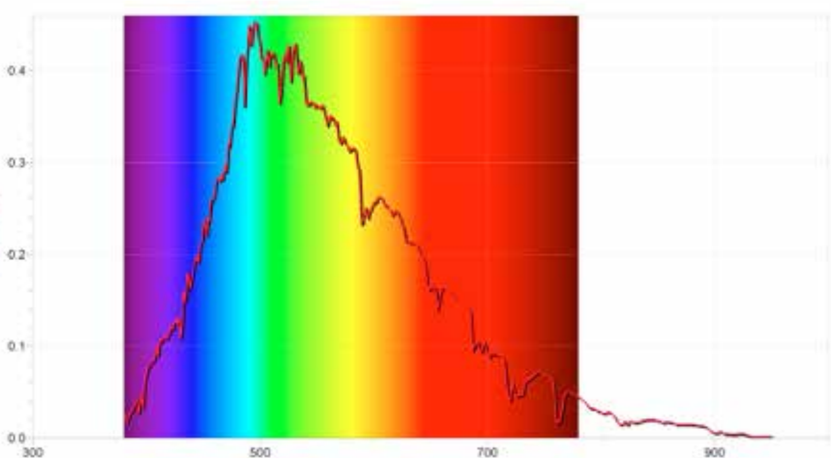


Image courtesy of Ole Ahlgren

Figure 5: Spectrum of the Sun showing relative intensity against wavelength (nm)

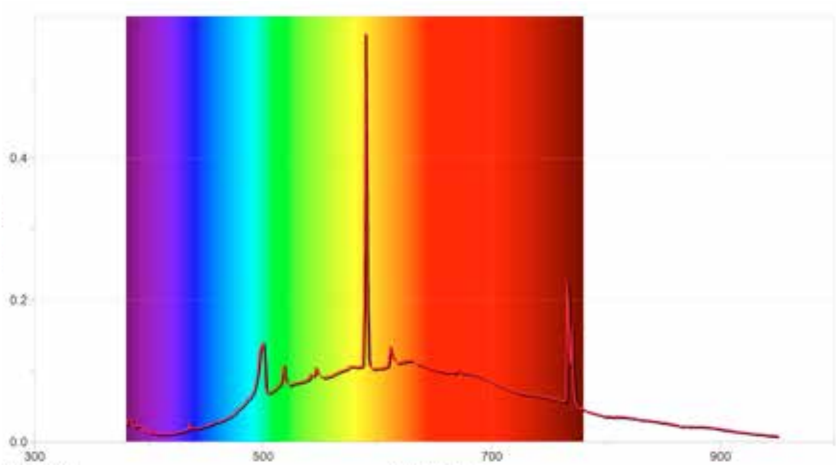


Image courtesy of Ole Ahlgren

Figure 6: Spectrum of burning magnesium relative intensity against wavelength (nm).. The most prominent lines are due to nitrogen .

Reference

Ribeiro C (2015) Starlight inside a light bulb. *Science in School* **31**: 37–42. www.scienceinschool.org/content/starlight-inside-light-bulb

Web references

w1 For instructions for building your own spectrometer using a cereal box, see this *Science in School* article: www.scienceinschool.org/2007/issue4/spectrometer

w2 You can order a foldable mini-spectrometer kit online from the Public Laboratory store: http://publiclab.org/wiki/foldable-spec

w3 Emission spectra for various elements can be downloaded from Open Discovery Space. See: http://portal.opendiscoveryspace.eu/edu-object/spectra-elements-841387 or use the direct link: http://tinyurl.com/hjdg6nl

w4 Examples of suitable spectrometers to use for the extension of this activity can be found online at: www.vernier.com/products/sensors/spectrometers/

w5 LoggerPro is an award-winning, data collection and analysis software for Windows and Mac computers. See: www.vernier.com/products/software/lp/

w6 Fraunhofer lines and their wavelengths can be viewed on the Columbus Optical SETI Observatory website: www.coseti.org/highspec.htm

Resources

For an overview of the practical uses of light, see:

Douglas P, Garley M (2010) Chemistry and light. *Science in School* **14:** 63-68.

www.scienceinschool.org/2010/issue14/chemlight

Science on Stage is 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*. Science on Stage brings together science teachers from across Europe to exchange teaching ideas and best practice with enthusiastic colleagues from 25 countries.

See: www.science-on-stage.eu

Image courtesy of serg_dibrova

Melts in your viscometer, not in your hand

Teaching viscosity can be sweetened by using chocolate.

By Claire Achilleos and Stylianos Friligkos

Chocolate is one of the only foodstuffs that stays solid at room temperature but easily melts at body temperature. This peculiar behaviour is due to cocoa butter, a fatty substance obtained from the seeds of cacao, which is solid under 25 °C but liquid at 37 °C.

As thousands of children around the world could assure you, chocolate quality is an important issue. When chocolate is liquid, its quality is determined mainly by its viscosity. In this article we present a method, designed by our students, of measuring chocolate viscosity using a viscometer constructed from simple and easily obtainable materials.

After building the apparatus, which should take 2–3 hours, you can use it to measure the viscosity of water, syrup, honey and chocolate, and compare the values with published data.

Viscosity

The viscosity of liquids and gases is defined as the material's resistance to deformation under stress, which is determined by the friction between particles in the material. The thicker a material is, the greater its viscosity. According to Poiseuille's Law, the viscosity factor of a fluid that flows out of a syringe

A B

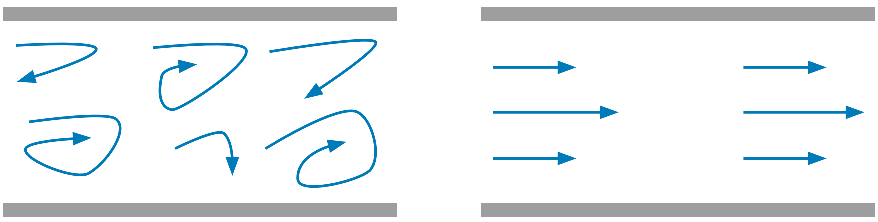


Figure 1: Turbulent (A) and laminar (B) flow

nozzle (meaning that the flow of liquid is laminar instead of turbulent, figure 1) is calculated as:

$$n = \pi r^4 \rho t / 8V$$

where:

- n is the viscosity factor
- r is the radius of the syringe's nozzle
- ρ is the special weight of the fluid, where $\rho = dg$, d is the density of the fluid ($d = m / V$) and g is the acceleration due to gravity (9.8 ms^{-2})
- t is the time required for the fluid to be emptied from the syringe
- V is the volume of the fluid (in our experiments, we used 60 ml for all fluids).

The viscosity is measured with a special instrument called a viscometer. The unit of measurement of viscosity is the Poiseuille (Pl), equivalent to a Pascal second, 1 Pa s = 1 N m^{-2} s = 1 kg m^{-1} s^{-1}. The unit poise (P) = 0.1 Pa s is also used.

Constructing a viscometer

The following experiment outlines how to build a viscometer (figure 3) using a method that we developed with our students. The central idea was proposed by the students, who asked, given Poiseuille's law, how can we build a viscometer using everyday materials? The device in question had to be able to measure viscosity at different temperatures. We chose to develop a flow-cup type of viscometer, because the dark colour of chocolate makes a ball-falling type of viscometer – which measures the time taken for a ball of known volume to fall through a liquid – completely unsuitable.

REVIEW

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

Science teachers are always looking for new and innovative ways to engage students in learning about our world. In this case, it's a world of tasty food. Using popular food – chocolate and honey – for physics education is always of interest. This experiment also encourages problem solving, because the equipment is constructed by the students.

Since food is traditionally an integrated topic between home economics, biology, chemistry and physics curricula, this article could give teachers some ideas for collaboration between these subjects. Design and technology classes could also be involved due to the construction of the equipment.

Dr Ingela Bursjöö,
Johanneberg School and
University of Gothenburg,
Sweden

Materials

- One 60 ml syringe with a 2.5 cm long nozzle
- An empty shampoo bottle, 7 cm in diameter and longer than the syringe
- Insulating polystyrene material
- Self-adhesive aluminium sheets
- Two thermometers capable of measuring between 0 and 100 °C
- A method for securely supporting the apparatus above the collection flask / beaker. This can be a frame designed and assembled by the students, an arrangement of stands and clamps, or simply two stacks of books.
- Craft knife or scissors
- Sticky tape
- A flask / beaker with a volume scale on the outside
- Pan balance capable of measuring 0.1 g increments
- Modelling clay, e.g. Plasticine®
- Calipers or a ruler.

Procedure

1. Measure the internal size of the syringe nozzle using calipers or a ruler, or note the manufacturer's description.
2. Remove the lid from the shampoo bottle.
3. Use the knife or scissors to remove the base of the shampoo bottle.
4. Invert the bottle so the neck is pointing down.
5. Insert the syringe, with the nozzle down, into the neck of the shampoo bottle.
6. Seal the syringe nozzle and the space between the syringe nozzle and shampoo bottle with modelling clay.
7. Cut the insulating foam to produce three pieces each measuring 30 cm x 30 cm x 5 cm.
8. Place the long edges of the three foam pieces together to make a triangular tube and tape together.
9. Place the syringe-bottle construction inside the insulating foam tube.

10. Wrap the construction in aluminium.
11. Cut a small piece of insulating foam to fit over the top of the syringe-bottle construction and make two holes for the thermometers, so that one thermometer goes into the syringe and one sits between the wall of the syringe and the shampoo bottle.
12. Insert the thermometers through the two holes in the foam (figure 2).
13. The whole experimental device should then be placed on the base so that the nozzle of the syringe points vertically down.
14. Place the flask / beaker on the pan balance and set the balance to zero.
15. Place the balance under the experimental device so that the syringe points into the flask / beaker.

Using the viscometer

The actual construction of the viscometer by the students is already a valuable piece of experiential learning. In the next step, the students encounter important research questions concerning the role of water in the shampoo bottle as a water bath and the necessity of using a pair of thermometers to make sure that thermal equilibrium between the measured liquid and the water bath is reached.

Materials

- Viscometer apparatus, as described above
- Another 60 ml syringe with a 2.5 cm long nozzle (identical to the one used in the viscometer apparatus)
- Pan balance
- Water (enough to fill the shampoo bottle)
- Kettle or other water heater
- Glass beakers (one for each liquid to be studied)
- Stopwatch or mobile phone with timer function
- Different liquids to be studied; water, honey, syrup, milk chocolate and dark chocolate can all be studied. Experimenting with white choco-late should not be attempted as the emulsifiers used can cause clotting, which stops the liquid chocolate from flowing.

Procedure

1. Heat the water and pour it into the shampoo bottle in the viscometer.
2. Weigh the empty extra syringe using the pan balance.
3. Heat the liquid to be studied.
4. Put 60 ml of the heated liquid into the extra syringe.
5. Weigh the filled syringe.
6. Subtract the weight of the empty syringe from the weight of the filled syringe to determine the fluid's mass. Taking into account the fluid's volume, you can then estimate the fluid's density using the equation on page 41 (mass divided by volume).
7. Use the fluid's density to calculate the special weight of the fluid, ρ.
8. After checking that the syringe is sealed into the apparatus, transfer the heated liquid into this syringe.
9. Place the foam lid over the top of the viscometer and wait until the temperatures of the water bath and the heated liquid are the same.
10. Remove the modelling clay from the syringe nozzle so that the liquid can start flowing. Start the timer.

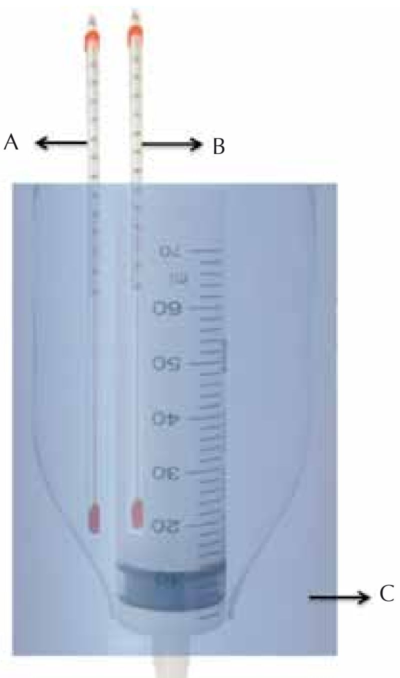


Figure 2: A depiction of the experimental design showing the thermometer in the water bath (A), the thermometer in the syringe (B), and the styrofoam insulation (C).

Figure 3: The real device

11. The liquid will flow into the flask below the syringe and the pan balance will measure the mass of the escaped liquid.
12. Use the pan balance to determine when all the liquid has left the viscometer. When this has happened, stop the timer.
13. Record the time taken for the liquid to flow through the viscometer.
14. The viscosity factor can then be calculated using Poiseuille's law.

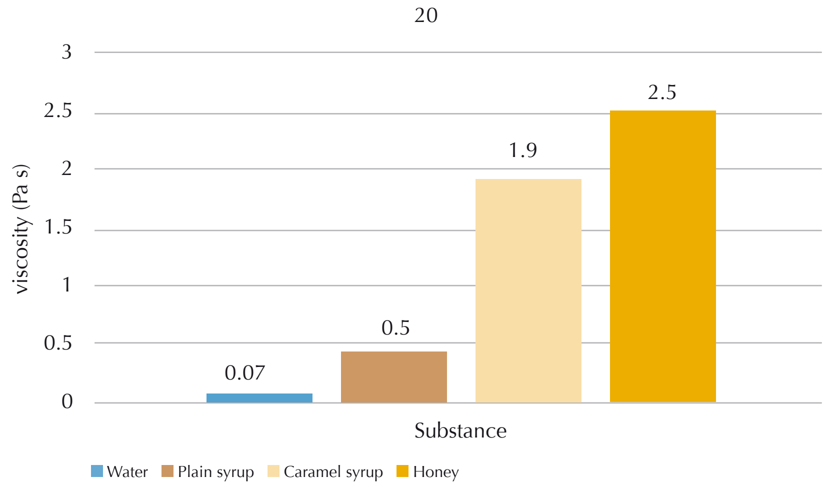


Figure 4: The viscosity of different substances at 20 °C

Experimental measurements and calculations

Experiment 1

Students can measure the viscosity values for different materials at two different temperatures (20 °C and 80 °C) and rank the liquids in order of increasing viscosity. You can discuss what might cause differences in viscosity between the liquids.

Our students' results are shown in figures 4 and 5, and tables 1 and 2.

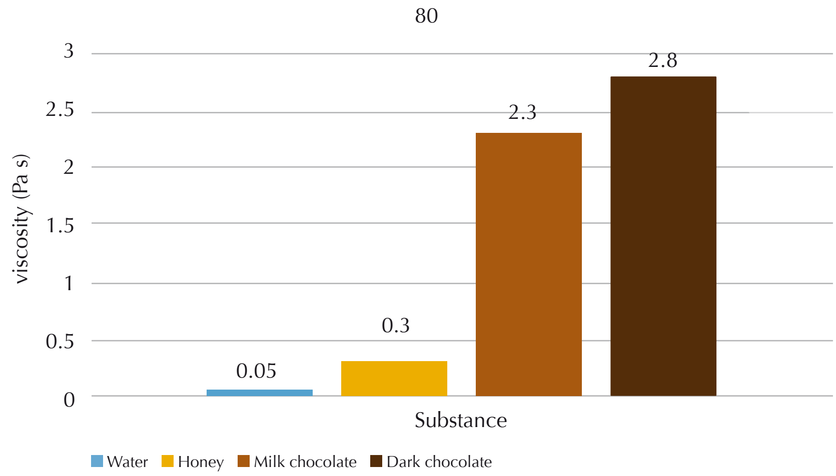


Figure 5: The viscosity of different substances at 80 °C

Experiment 2

Ask your students to measure the viscosity values of chocolate, honey and water at five or more temperatures to study the change in viscosity in relation to temperature.

The time required for water, honey and chocolate to pass through the viscometer at different temperatures, along with their calculated viscosity values, are shown in tables 3, 4 and 5, respectively. In figure 6, changes in viscosity as a function of temperature can be seen for these fluids.

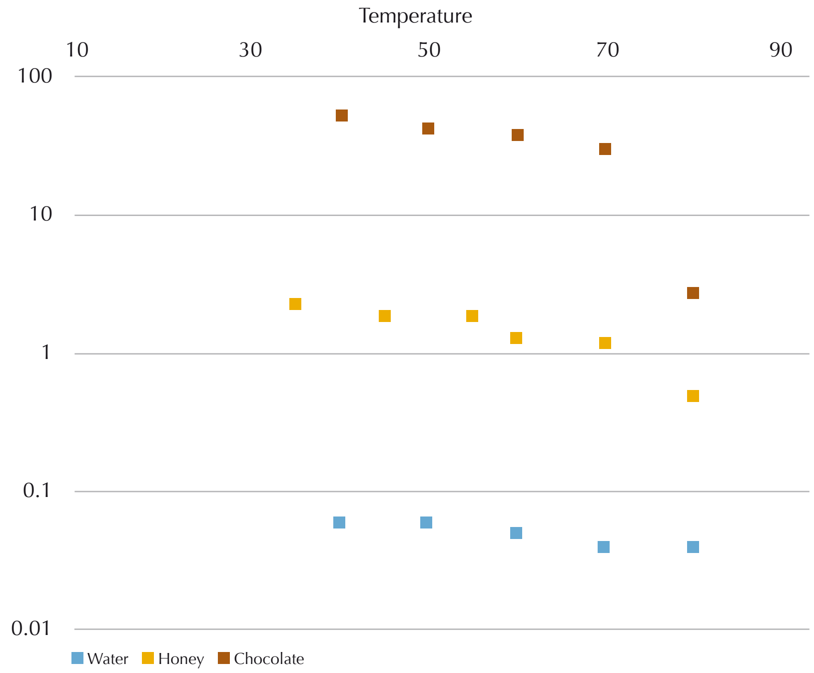


Figure 6: The variation of viscosity versus temperature for dark chocolate, honey and water

Further questions

To extend the activity, you can ask your students additional questions such as:

1. What is the range of the viscosity values for different materials at 20 °C and 80 °C? Why does dark chocolate appear to have a higher viscosity than the other substances?
2. What can you conclude about the dependence of viscosity on temperature?

Substance	Flow time *t* (s)	Viscosity *n* (Pa s)
Water	4.2	0.07
Plain syrup	6.3	0.5
Caramel syrup	23.5	1.9
Honey	32.5	2.5

Table 1: The viscosity of different substances at 20 °C

Substance	Flow time *t* (s)	Viscosity *n* (Pa s)
Water	2.3	0.05
Honey	4.5	0.3
Milk chocolate	38.0	2.3
Dark chocolate	43.0	2.8

Table 2: The viscosity of different substances at 80 °C

Temperature Θ (°C)	Flow time *t* (s)	Viscosity *n* (Pa s)
30	4.207	0.07
40	3.92	0.06
50	3.5	0.06
60	3.05	0.05
70	2.73	0.04
80	2.3	0.04

Table 3: Experimental values of flow time and viscosity as they were calculated for water

Temperature Θ (°C)	Flow time *t* (s)	Viscosity *n* (Pa s)
35	30	2.3
45	24.38	1.9
50	17.5	1.3
55	15.5	1.2
60	7.1	0.5

Table 4: Experimental values of flow time and viscosity as they were calculated for honey

3. Does chocolate or honey have a higher viscosity at 80 °C? Try to document your answer based on further bibliographic research.
4. Do the viscosity values that you found experimentally for water, honey and chocolate agree with values that appear in your bibliographic research materials? If there are any discrepancies, can you provide any explanations?

The viscosity of chocolate

Molten chocolate represents a dense blend of phospholipid-coated sucrose and cocoa particles in liquid fat. Because of this, the viscosity of chocolate has a complex pattern that is described as non-Newtonian. A particular force is required for chocolate to begin flowing; once the fluid begins flowing, as this force increases, the fluid thins.

Essentially there are two parameters that describe how chocolate flows. The first one is the limit in elasticity, the force that chocolate needs to begin flowing. The second parameter is the plastic viscosity, which is related to the energy that the chocolate requires in order to remain in motion at a constant rate (Beckett, 2004).

Understanding how chocolate flows is not just an interesting lesson for students but also of course very important for chocolate manufacturers.

Dr Claire Achilleos is a science teacher in the 1st Model Lyceum of Thessaloniki “Manolis Andronikos”, Greece. Dr Stylianos Friligkos, who serves as headmaster in the same school, also specialises in science teaching.
1st Model Lyceum of Thessaloniki “Manolis Andronikos” belongs to a special type of Greek school called model (or experimental) schools. The specific mission of these schools, which are staffed with highly qualified teaching personnel, is to design and implement innovative educational programmes and conduct educational

Temperature Θ (°C)	Flow time t (s)	Viscosity n (Pa s)
40	800	52.6
50	660	43.4
60	590	38.8
70	480	31.6
80	43	2.8

Table 5: Experimental values of flow time and viscosity as they were calculated for chocolate

research in close co-operation with universities.

In this framework, for example, science teachers at the school have organised for four consecutive years the Creative Science Experiments Contest for students of lower and upper high schools of the Central Macedonia Region. In these contests, students conduct experiments designed to be carried out with basic, everyday materials in a way that fosters creativity and imagination. Furthermore, Dr Friligkos served for two years as the National Coordinator for Greece for the EU NANOPINION programme, bringing all the relevant momentum and expertise to the school.

Acknowledgements

We express our deepest gratitude to our students, Zoe Efthimiadou, Viktoria Kelanastasi and Aggeliki Kosma, for their conscientiousness, bright ideas and hard work.

We also express our thanks to Professors KG Efthimiadis, H Polatoglou and K Melidis from the Physics Department at Aristotle University, Thessaloniki, Greece, for their useful suggestions.

Finally we express our deepest appreciation to Mr N Kyriakides, a school parent who undertook the task of constructing the metal base upon which the whole apparatus was built.

Reference

Beckett ST (2000) *The Science of Chocolate*. London, UK: Royal Society of Chemistry. ISBN: 9780854046003

Image courtesy of MaraZe

Measuring the explosiveness of a volcanic eruption

Using effervescent heartburn tablets, model the action of volcanoes to measure the intensity of the explosions and create your own measurement scale.

Image courtesy of John David Bigl III

By Christopher Roemmele and Steven Smith

Mount St Helens, Pinatubo, Vesuvius, Pelee, Krakatoa. These volcanoes have become famous, or infamous, for significant eruptions that caused havoc to the land, ecosystems and planetary atmosphere. It would therefore seem logical that measuring and comparing the intensity and destructiveness of volcanic eruptions would be a task for geologists. Employing basic models of volcanoes that use effervescent heartburn tablets, students can measure the intensity of their explosions and create their own scale in experiments taking 80–90 minutes.

Well-known rating scales exist for describing and classifying natural phenomena, such as the Richter scale for earthquakes, the enhanced Fujita scale for tornadoes, and the Saffir-Simpson scale for hurricanes. Students will therefore not be surprised to hear that a scale exists for measuring volcanic eruptions; it's just that it is nowhere near as well known as the others mentioned.

Volcanologists have developed a logarithmic scale called the volcanic explosivity index (VEI) to measure the intensity of an eruption. Eruptive episodes are rated from 0 to 8, however, because the scale is logarithmic, an eruption classified as a 2 on the VEI is ten times more explosive

Image courtesy of Christopher Roemmele

A group of students get ready to create an eruption: teamwork and timing is essential.

than an eruption rated as a 1, while a VEI of 3 is 100 times more explosive than a VEI of 1. Logarithmic scales are fairly common throughout science, and representative examples that students should become familiar with are the Richter scale, the pH scale and the Hertzsprung–Russell diagram. The logarithmic aspect of explosivity is based on the volume of tephra that is expelled during an eruption (tephra is the material, such as lava, ash, and rock, that is ejected from the volcano). Volcanologists also look at the plume height, or how high the erupting cloud of ash reaches into the atmosphere during an eruption. How far into the surrounding area the erupting gas and tephra are blown is also considered.

Comparing the 1980 Mount St Helens (a VEI-5) disaster to a VEI-8 eruption is like comparing a firecracker to a briefcase of C-4 explosive. Although Mount St Helens caused a significant level of damage to the surrounding region, the explosion produced by a VEI-8 eruption would be 1000 times greater, causing widespread destruction for hundreds or even thousands of miles. On the other end of the spectrum, volcanic activity at Kilauea in Hawaii is non-explosive, churning out lots of lava and tephra without explosive fanfare. So if Mount St Helens is a firecracker, then Kilauea resembles a melted chocolate bar oozing out of its packaging.

Why do volcanic eruptions behave so differently? Although each behaves in a unique way as the result of many variables, it is possible to make some generalisations about explosivity based on the nature of the magma – the molten rock and other materials underneath the surface of the volcano. Magmas that are silica-rich are often very viscous, with large amounts of trapped gas, and they tend to erupt violently because the gases cannot escape easily. The more viscous the magma, the larger the energy needed to expel gases within it. These trapped gases build up pressure until they achieve enough force to blast out of their confinement and are released in a single, explosive event. Low explosivity occurs when magma has a low viscosity. Gases escape readily from such magmas, and fluid lava burbles out periodically and non-explosively. As an analogy for students, try blowing through a straw into a glass of milk, and notice how easily bubbles form and rise to the top and burst: this is analogous to the low-silica, low-viscosity mafic lava. Then repeat using a milkshake. But wear a towel! It is much more difficult to blow a bubble, but when you do, the milkshake explodes outward, causing a large upheaval.

Modelling eruptions

This activity allows students to create pressurised gas within closed plastic bottles. Before doing this activity

REVIEW

✓ Chemistry
✓ Physics
✓ Earth sciences
✓ Maths
✓ Ages 11–19

Most science teachers are probably familiar with "chemical volcanoes", but this article presents a novel and interesting use of this classical activity. In fact, the authors propose using a chemical volcano to devise and build a customised VEI scale, helping students to fully understand the meaning of this scientific and technical instrument.

The article is written in a plain and enjoyable style, which presents scientific information interspersed with vivid metaphors linked to common experience. The methodological approach is enquiry-based and involves making hypotheses and testing them by modifying experimental conditions, another added value that makes this activity very suitable for promoting scientific reasoning.

Finally, it is a beautiful example of science communication, soundly researched and funny at the same time: if I see a picture of Kilauea, I won't be able to help thinking of "a melted chocolate bar oozing out of its packaging".

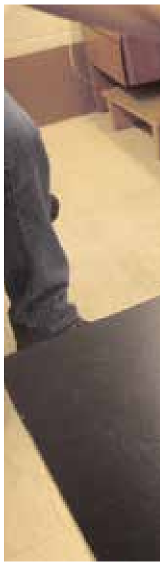
Giulia Realdon, Italy

Image courtesy of Christopher Roemmele

Waiting to poke a hole in the plastic cover, students prepare to measure aspects of the eruption.

Image courtesy of Christopher Roemmele

Higher VEI eruptions may extend beyond the basin!



with students, collect several 500 ml plastic bottles and remove the labels. Indigestion or heartburn tablets such as Alka-Seltzer® are the source of gas as these tablets contain both citric acid and sodium bicarbonate, which react to form carbon dioxide once they are mixed with water. Each group of students should start with six tablets, although be sure to keep a large quantity on hand for errors and failed eruptions. The groups will measure how much material each 'volcano' produces by catching the 'lava' in a flat container and then measuring the volume collected.

Increasing the amount of Alka-Seltzer changes the pressure inside the model volcanoes and thus the magnitude and style of eruption. Changing the temperature of the water will also affect the eruption. Students can then determine the resulting effect on the eruption and create their own VEI rating.

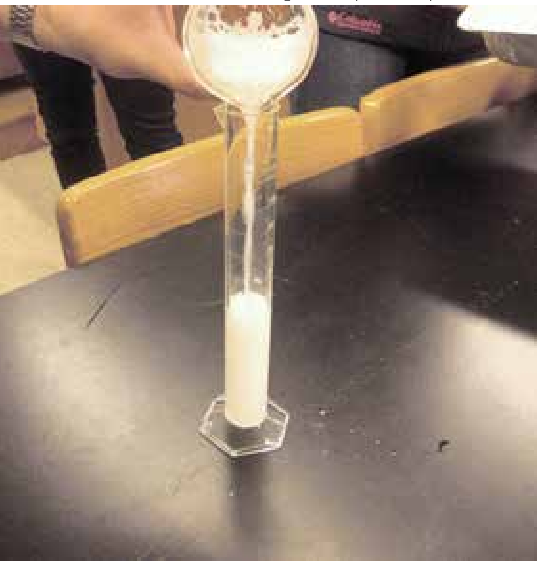
Materials

- 500 ml plastic bottle
- Water
- 6 effervescent heartburn tablets
- Washing-up liquid
- Metre rule
- A large flat tray
- Measuring cylinder
- Safety goggles
- Rubber bands
- Plastic food wrap
- Toothpicks
- A stopwatch or timer
- Lab coats
- Paper towel (optional)

Procedure

1. Develop and write a hypothesis, considering what will happen when the tablet is added to the liquid, and what will happen as the number of tablets increases and the temperature of the water changes.
2. Fill the plastic bottle with water, level with the bottom of the cap screw.
3. Add about ½ teaspoon of washing-up liquid to the water.
4. Place the bottle in the centre of the tray.
5. Break the tablets into pieces (making sure hands are dry) to fit them through the bottle neck. We also recommend that the tablet pieces are placed on a towel and slid into the bottle when the experiment is ready to begin.
6. One student should slide the tablet into the bottle, while another covers the opening with plastic wrap, and a third secures the plastic tightly with a rubber band (using multiple loops) at the top of the bottle to prevent air from entering. Teamwork and co-ordination are key to this sequence, so it should be practiced in a dry run several times until the students can perform it in about 8 seconds.
7. The reaction should be plainly visible immediately. After less than a minute, one person should poke a hole in the plastic to allow the eruption to occur (use judgment as to when to poke the hole, as the intensity of the eruption may force the plastic and rubber band off on its own).
8. The rest of the students must be ready to record the approximate height of the eruptive plume and the lateral distance it travels, using metre rules.
9. Measure the duration of the eruption with a stopwatch.
10. When the eruption is deemed complete, the tephra collected in the tray should be poured into a measuring cylinder. If some tephra has erupted explosively beyond the pan, or has perhaps hit the ceiling, estimate the missing quantity (which is not difficult since it will likely be visible as sudsy water).
11. Record the observations and features of the eruption in a data table.

Image courtesy of Christopher Roemmele



Measuring the 'tephra' is part of obtaining the VEI

Image courtesy of Steven Smith

Side-by-side eruptive styles, more explosive on the left, compared with more oozing on the right.

12. Repeat steps 2–11 but using two and then three tablets.
13. If time allows, repeat the experiment using water at a different temperature or a different liquid entirely (e.g. vegetable oil).

Based on a combination of their data and observations, students can assess the eruptions and create a VEI scale of their own. They should be able to support or reject their hypotheses, and describe patterns underlying how and why things happened the way they did, and explain their VEI scale. A more formal lab report, as per the individual teacher's format, can also be completed, but be sure to have students re-state the purpose of the activity and the relevance and application of VEI and studying volcanoes to science and society in general.

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Steven Smith is the K-12 (primary and secondary) outreach coordinator for the Earth, Atmospheric and Planetary Sciences Department at Purdue University. A former elementary school teacher, Steven has 16 years of outreach service at Purdue, attending academic conferences, participating in regular visits to teachers' conferences, participating in school partnerships, making regular visits to teachers and classrooms, providing professional development workshops and scientific equipment to classrooms. Steven can be reached at mrsmith@purdue.edu

Image from the USGS in the public domain

Resources

The United States Geological Survey has produced a useful table of data about VEI. See http://ete.cet.edu/gcc/style/docs/VEI_information.pdf or use the direct link: http://tinyurl.com/zn9awbc

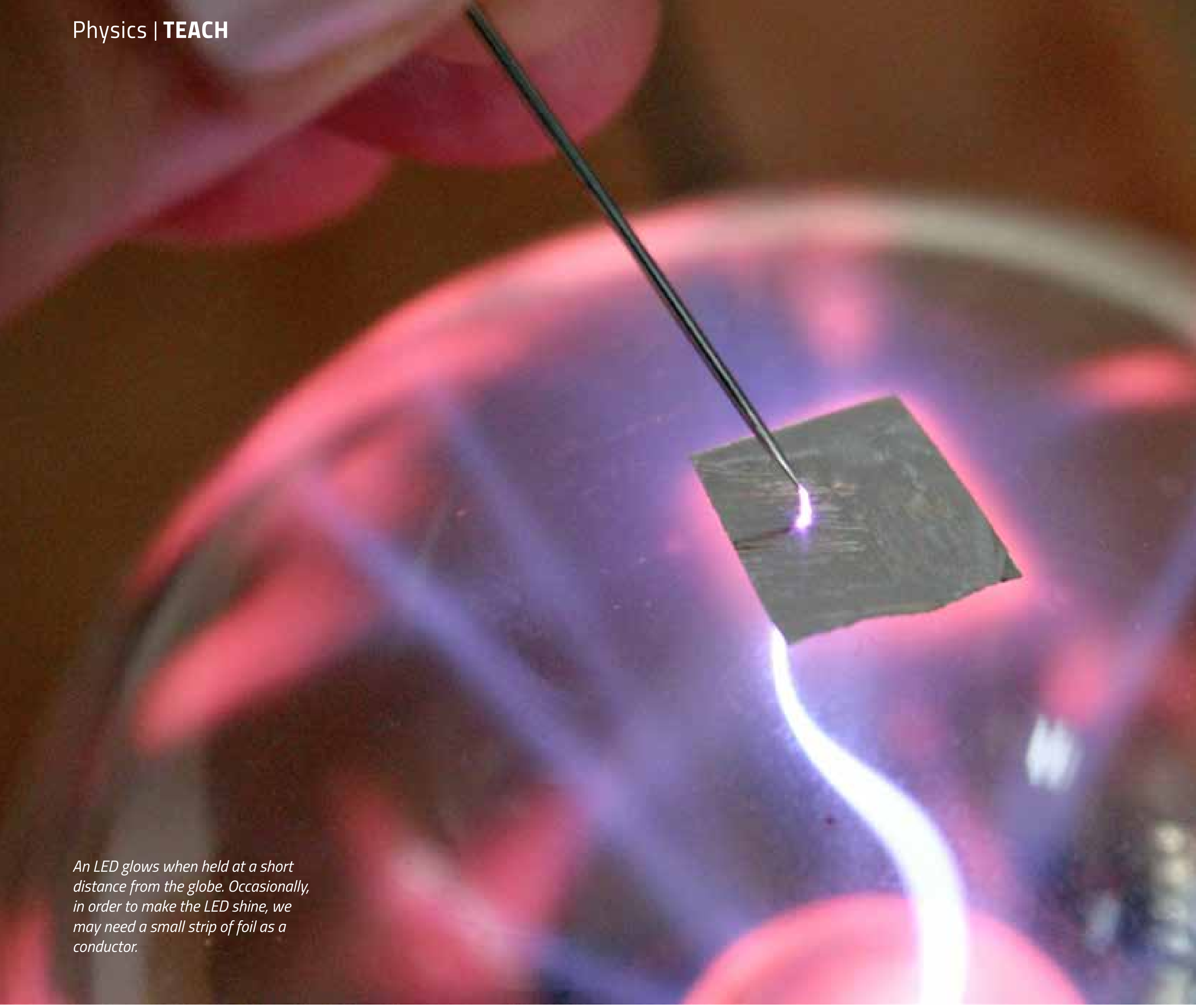
An interactive volcano simulator by Alaska Museum can help your students explore the explosivity of volcanoes even more. See www.alaskamuseum.org/education/volcano

For more *Science in School* articles on volcanoes, see:

Capellas M (2007), Recovering Pompeii. *Science in School* **6**: 14. www.scienceinschool.org/2007/issue6/pompeii

Pathmanathan SM (2015) Experimenting with storytelling. *Science in School* **34**: 41. www.scienceinschool.org/content/experimenting-storytelling

Strolin P (2013) The secret life of volcanoes: using muon radiography. *Science in School* **27**: 6. www.scienceinschool.org/2013/issue27/muons



An LED glows when held at a short distance from the globe. Occasionally, in order to make the LED shine, we may need a small strip of foil as a conductor.

Image courtesy of Jorge Yáñez González

Plasma: the fourth state

Plasma is the fourth state of matter, after solid, liquid and gas – but what is it like and what can it do? Plasma globes allow us to answer these questions – and more.

By Jorge Yáñez González

With their glowing pink flares and threads of purple lightning, plasma globes are fascinating to watch. But are these striking luminous orbs anything more than just a novelty table-top toy? This article aims to show that there is plenty of interesting physics to demonstrate – entertainingly – using these intriguing devices.

What are plasma globes?

A plasma globe (or plasma ball) consists of a thick glass sphere on a base with an electrical connection. Inside the sphere is a central electrode and some inert gas. When the globe is switched on, the electrode produces a high-voltage current that alternates at high frequency, which heats the gas to a high temperature and splits the atoms into ions – forming a state of matter called plasma.

The plasma transmits current easily because of its ionized state, and this produces the glowing streamers we see – just as the gas in a fluorescent tube or neon light glows when is it switched on. But unlike a neon light, in which the electrical discharge passes directly between two electrodes, a plasma globe has only one electrode at its centre. With no single best path for the electrical discharge to take from the centre of the globe, the streamers constantly move and flip around – like lightning finding a path to earth.

The electrode at the centre of a plasma globe is a device called a Tesla coil, which creates an alternating electric field that reaches beyond the globe itself and into the surrounding space. This sets up an associated electromagnetic field in the same region, although the intensity of these fields diminishes with increasing distance from the coil.

REVIEW

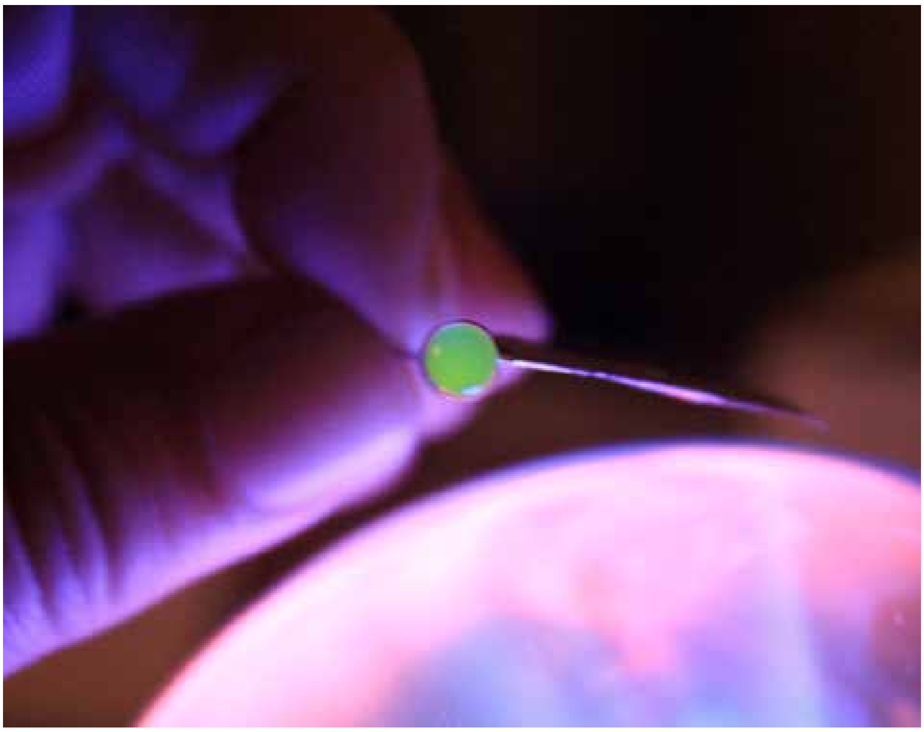
✓ Physics

✓ Ages 14–19

Plasma balls are often used to provide a "wow" factor that will enthuse students. This article suggests ways in which a plasma ball can be used in lessons and provides some detail about the underlying physics.

Stuart Farmer, Robert Gordon's College, UK

Image courtesy of Jorge Yáñez González



An LED glows without touching the plasma globe.

Exploring plasma

In physics, plasma is referred to as the fourth state of matter (after solid, liquid and gas)[w1]. Although it is the most abundant form of ordinary matter in the Universe (accounting for more than 99%), plasma is never usually encountered in normal life. Plasma globes can provide this experience and reveal some of the properties of plasma – for example, its ability to conduct electricity.

In this first experiment, students bring their hands close to the globe and see what effect this has. You can challenge them to explain why almost all streamers combine into one, which is attracted towards a hand and will follow it. (The reason is that a hand placed near to the globe helps it to discharge, because the human body is a better conductor than the air and so provides an easier escape route for the electrical energy from the globe.)

Safety note

- Plasma globes are high-voltage electrical devices, so when using them always ensure all safety measures needed when working with electric currents are in place.
- Avoid touching the globe with metal objects that will rapidly heat up and can cause burns. A possible experiment, if conducted with care, is to place a coin on top of the globe and then place a piece of paper on top of the coin. If the paper is then touched using another metallic object, such as another coin or a paper clip, a hole will be burned in the paper.
- For the same reason, never cover the globe when it is on or still hot.
- Plasma globes should be able to run for an entire lesson without overheating, but if you notice that your plasma globe overheats after constant use, we recommend that you switch it off between one experiment and the next, or every 30 minutes. (This means you will need to switch the plasma globe on and let it run for a few minutes before starting each experiment.)

Exploring the electromagnetic field

How can we confirm that the invisible electromagnetic fields around the globe are actually there? In these three experiments, students use different types of light bulb to detect the fields and discover some of their properties.

Suggested time: 20–30 mins (including discussion).

Materials

- Plasma globe
- Standard miniature LED (light-emitting diode)
- Compact (energy-saving) fluorescent bulb (15 W)
- Incandescent bulb (15 W)
- Straight fluorescent tube (18 W)

Procedure

1. Using the LED

This simple experiment allows students to explore how an electromagnetic field varies with distance, and how it can make a current flow in a lamp without wired connections or a battery.

With the plasma globe switched on, start the experiment by asking a student to pick up an LED and hold it a long way from the globe, and then gradually to bring the bulb closer until it finally makes contact with the surface of the globe. The student will need to grasp the LED by just one of its electrodes, because holding an LED by the glass bulb or by both electrodes will not allow a current to flow.

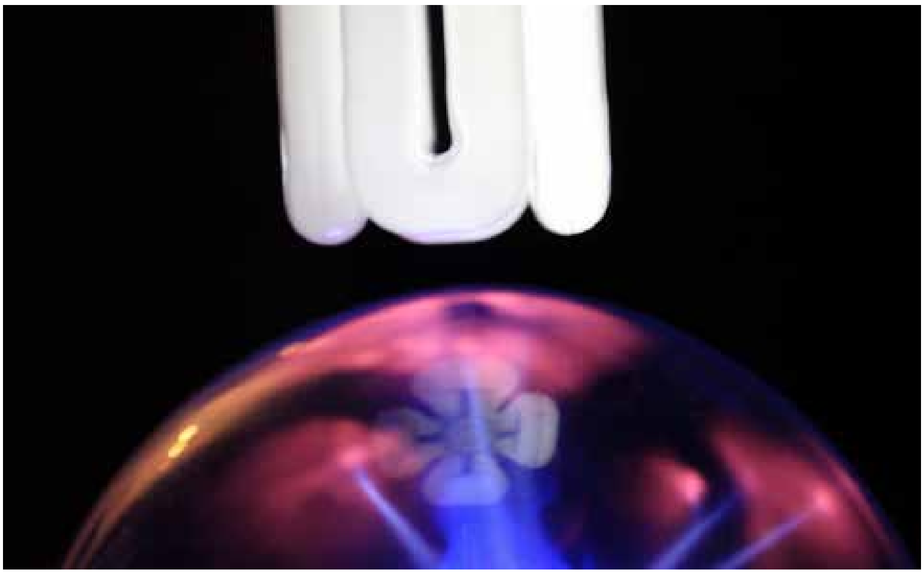
At a certain distance from the plasma globe, the LED should start to glow, shining more intensely as it is brought closer to the globe.

Ask the students to think about these questions:

- Why does the LED light up when it is close to the globe?
- Why doesn't the LED glow when it is far from the globe?
- Why do you need to hold the LED by just one electrode for it to shine?

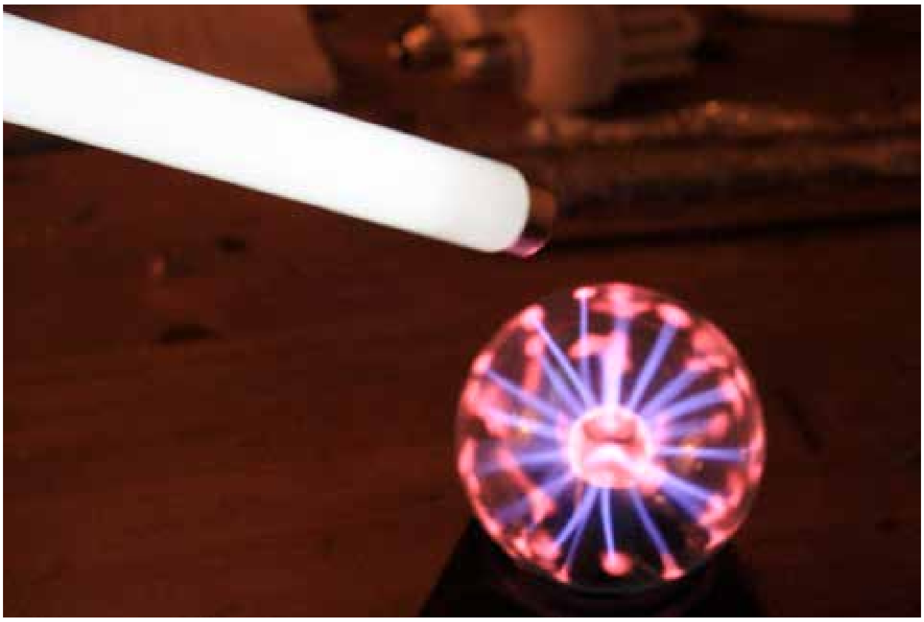
When the LED is a long way from the globe, the electromagnetic field produced by the plasma globe is not strong enough to affect the bulb. When the LED is close to the globe, the field causes a small voltage difference across the LED's electrodes. This will make a current flow in the LED if there is a closed (complete) circuit, which happens if the LED is held by only one electrode. This is because the holder's own body acts as both a conductor and a connection to earth, so it closes the

Image courtesy of Jorge Yáñez González



A fluorescent bulb glows without touching the plasma globe.

Image courtesy of Jorge Yáñez González



A fluorescent tube glows. The size is not important as it will always shine.

Image courtesy of Jorge Yáñez González

The hand makes a border. There is no light behind it.

circuit – and the LED shines. When both electrodes are held, there is no potential difference across the LED and it does not light up.

2. Using a compact fluorescent bulb

We can explore the same ideas further using a compact fluorescent bulb, holding it from its base. As with the LED, its brightness changes depending on how near or far it is from the plasma globe. In this case students can also see for themselves the effect of quantised energy levels in atoms.

Ask the students to experiment by holding the bulb at different distances from the plasma globe (as with the LED), and to think about these questions:

- Is there a maximum distance from the globe at which the bulb lights up?
- What might be happening inside the bulb to make it glow?

If the bulb is close enough to the globe, the electrons of the mercury vapour atoms inside the bulb will be excited by the globe's electromagnetic field, which makes the atoms jump up to a higher energy level, emitting UV radiation when they fall back to their normal level. Because this excitation requires a specific minimum amount of energy to happen, the bulb needs to be within a specific distance of the globe. The UV radiation is invisible to the human eye, but it is absorbed by the bulb's fluorescent coating and re-emitted at a lower energy, which we see as the bulb's glowing white light.

Image courtesy of Jorge Yáñez González

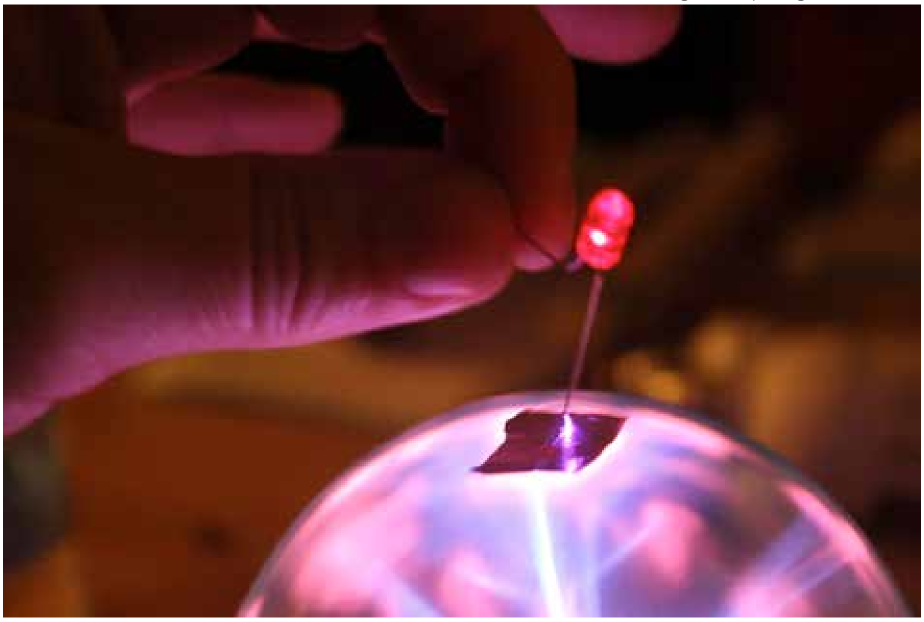
We can see how the electricity goes beyond the limits of the plasma globe

3. Further explorations with light bulbs

It's interesting to try this experiment with an old, non-functional fluorescent bulb (if available), as the bulb's ability to light up will probably be revived in the plasma globe's electromagnetic field. Most fluorescent bulbs fail because the start-up mechanism for the lighting process stops working, although the physical processes inside the bulb are unaltered – so in some conditions the bulb can still produce its glow.

You can also try repeating the experiment with an incandescent (tungsten filament) bulb. Fluorescent bulbs and LEDs are now in common use because of their low energy usage – which is also why they can light up just by being in the electromagnetic field around a plasma globe. Incandescent light bulbs, however, use much more

Image courtesy of Jorge Yáñez González



The spark lights an LED.

energy and so will not light up under these conditions.

Using a straight, low-voltage fluorescent tube to explore the electromagnetic field can also be revealing, because its long shape allows students to hold it in different orientations and at different points along its length.

Ask the students to move the fluorescent tube towards the globe so that it glows brightly. If they now grasp the tube at its midpoint with one hand, they will see that it stops glowing from the contact point to the furthest end.

Here, the contact of the hand with the tube allows the electrical energy to discharge towards earth at the point of contact, preventing the illumination from extending all the way along the tube.

Making sparks fly

In this experiment, we show how to make some safe sparks using the plasma globe.

Suggested time: 15–20 mins (including discussion).

Materials

- Plasma globe
- Aluminium kitchen foil
- Sewing needle
- LED

Procedure

When the plasma globe has been switched on for a couple of minutes, place a small piece of kitchen foil (1 cm x 1 cm) on the top of the globe. Then, very slowly bring the needle towards the foil. When it is about half a centimeter from the foil, you should see an electric arc (spark) jump from the foil to the needle.

The spark is created because the kitchen foil is a good electrical conductor, and the globe's alternating field progressively builds up electrical charge on the foil. When we approach with the needle, which is also an electric conductor but has no charge, a vast number of electrons jump from the kitchen foil to the small needle to neutralise this difference in electrical potential between the two materials.

When we place the kitchen foil on the plasma globe, a capacitor is created. The two conductive sides would be the plasma on one side and the kitchen foil on the other. The glass of the plasma globe acts as a dielectric. When we bring a metallic object (the needle) into close proximity, a quick discharge is produced and a small spark can be seen.

We can also go back to our experiment with the LED and see the effects of placing the conducting foil on the globe. With the foil on the globe, hold the LED by one of its electrodes and slowly bring it towards the foil. You should notice that, even when fairly close, the LED does not light up – unlike in the first experiment. However, at a distance of about 0.5 cm, you should see a spark jump from the foil to the LED electrode, and the bulb will glow while the spark extends towards the electrode.

In this case, the LED is only lit by the spark and not by the globe's electromagnetic field. This is because the intensity of the electromagnetic field is directly related to the size of the plasma globe. In big plasma globes, the electromagnetic field is able to make an LED shine from a certain distance, but with the small plasma globes generally used in education, the electromagnetic field produced is less intense; for the LED to shine from a certain distance, we need to connect it to a capacitor (the kitchen foil that we fold on one of the LED's electrodes).

Extension activities

The activities described above can be used as a basis for further research on a variety of topics. Students can find out more about:

- Tesla coils and their inventor, Nikola Tesla.
- Plasma as the fourth state of matter. It is said that plasma is the most common form of matter in the Universe; why is this?
- The energy performance of different light bulbs and which bulbs are best for the environment. What should we do with them when they no longer work, bearing in mind that fluorescent bulbs and tubes contain mercury?

Jorge Yáñez González has a degree in chemistry from Complutense, University of Madrid, Spain. He is concerned about gender differences in science and is interested in experimental work in the classroom, having worked as a physics and chemistry teacher at secondary schools in Andalucia (Spain) for 15 years. At present, he works in the Science Museum of Granada as a technician in educational activities.

Web reference

w1 For a broad and informative article about plasma, plasma balls and their electromagnetic fields, see www.cpepphysics.org/fusion-materials/ElectricFieldNearPlasmaGlobe.pdf or use the direct link: http://tinyurl.com/zkh63yz

Resources

For more information about the physics of how plasma globes work, see www2.physics.ox.ac.uk/accelerate/resources/demonstrations/plasma-ball or use the direct link: http://tinyurl.com/gsxzupw

For a very accessible account of how plasma globes work, suitable for younger students, see http://wonderopolis.org or use the direct link: http://tinyurl.com/zv92ftb

For an article on how scientists accidentally created plasma in their microwave, and how they used it for their research, see:

Stanley H (2009) Fireballs: creating the 4th state of matter with microwaves. *Science in School* **12**: 24-29. www.scienceinschool.org/2009/issue12/fireballs

Further reading on plasma as the fuel in fusion is available on the EUROfusion website (www.euro-fusion.org):

Starting the plasma: http://tinyurl.com/j5xb4pj

How is plasma formed from cool material (in the fusion process): http://tinyurl.com/jg6ukg8

Colour me a plasma: http://tinyurl.com/hyuxlxe

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