Summer 2016 | Issue 36



# Science in School

The European journal for science teachers

# On track: technology for runners

INSPIRE

## The sweet taste of science

TEACH

## Student competition: the search for the strangest species on Earth

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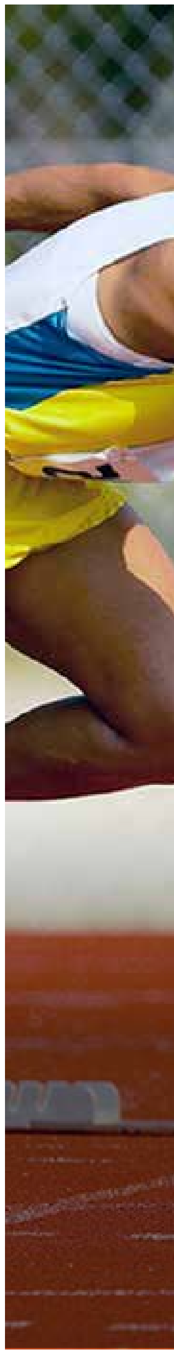


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Image courtesy of iStockphoto


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Image courtesy of tableatny; image source: Wikimedia Commons


# EDITORIAL

Laura Howes
Editor
*Science in School*

Welcome to the new issue of *Science in School*. It may not be so obvious at first glance, but there's something different about this issue.

We have always published our articles and activities under Creative Commons licences to encourage you to share, reuse and republish the material. From this issue onwards, we will make reuse even easier by publishing all *Science in School* content under a Creative Commons attribution (CC BY) licence. One of the most liberal licences available, CC BY lets you distribute, tweak and build upon our articles, even commercially, as long as you acknowledge the original author.

This means we are now publishing fully open educational resources as part of a growing global trend towards open access. We want anyone who wants the text of our articles to have and use it. Full details are available on our website.

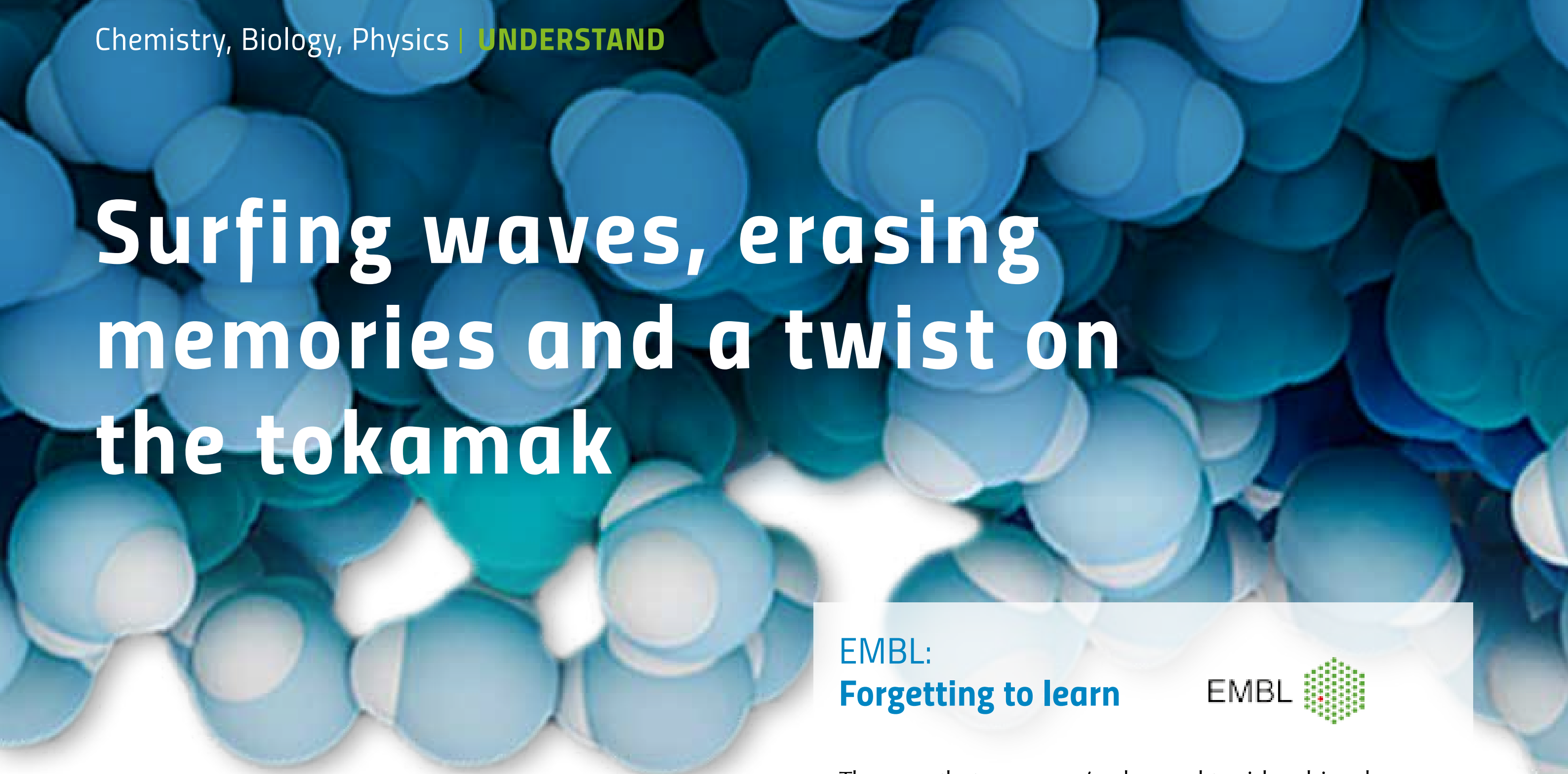
We hope that this change will make it even simpler and more straightforward for you to find and use our articles and activities. We always love to hear how you use them. How have you adapted our activities for your teaching? Which science articles have you used with your students, and how? You could even tell us about it in an article, for us to share with your colleagues around the world.

And if your students are also interested in science writing, on page 32 of this issue we are launching a science writing competition them. Any students up to the age of 19 are welcome to participate, as long as they are based in Europe. Submissions are not due until January 2017, but now is the time for students to start planning and researching. I can't wait to read the results, and we'll be sharing some of the best entries in *Science in School*.

Despite a few new features, this issue includes the same inspiring mix of articles, profiles and activities. We hope that you enjoy it and the coming summer break.

*Laura Howes*

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



# Surfing waves, erasing memories and a twist on the tokamak

## CERN: Surfing the wakefield

The AWAKE (Advanced Wakefield) experiment, which explores the use of plasma to accelerate particles to high energies over short distances, is due to switch on at CERN's Super Proton Synchrotron (SPS) in late 2016. It will accelerate electrons by 'surfing' them on waves of electrical charge ('a wakefield'). The project aims to prove that electrons can be accelerated to multi-GeV energies over a distance of a few metres: up to 1000 times greater than acceleration in a conventional collider of the same distance. Although far from rivalling future high-energy colliders, such as the Large Hadron Collider (LHC), wakefield accelerators could, for example, drive X-ray free-electron lasers, shrinking their size from kilometres to metres and enabling their use in labs or hospitals.

For more information see http://awake.web.cern.ch/awake/

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

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

Image courtesy of Maximilien Brice/CERN

*AWAKE's 10 metre-long plasma cell has been moved into the experiment tunnel.*

## EMBL: Forgetting to learn

They say that once you've learned to ride a bicycle, you never forget how to do it. But new research suggests that even while learning, the brain is actively trying to forget. The study, by scientists at the European Molecular Biology Laboratory (EMBL) and University Pablo Olavide in Sevilla, Spain, was published in *Nature Communications*. "This is the first time that a pathway in the brain has been linked to forgetting, to actively erasing memories," says Cornelius Gross, who led the work at EMBL. "One explanation for this is that there is limited space in the brain, so when you're learning, you have to weaken some connections to make room for others."

See the press release here and the research paper at:

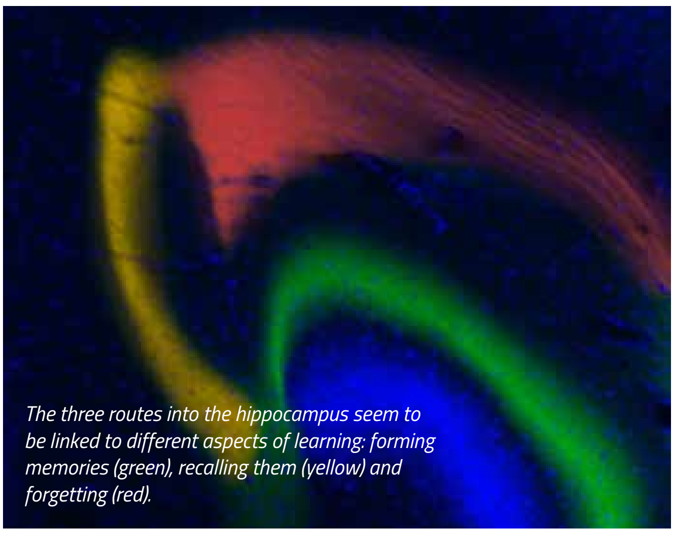
http://news.embl.de/science/1603-forgetting-to-learn/

Madroñal N et al. (2016) Rapid erasure of hippocampal memory following inhibition of dentate gyrus granule cells. *Nature Communications* **7**: 10923. doi: 10.1038/NCOMMS10923

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

Image courtesy of John Wood



*The three routes into the hippocampus seem to be linked to different aspects of learning: forming memories (green), recalling them (yellow) and forgetting (red).*

*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.

Image courtesy of ESA

## ESA:
## The magic of light

A new teaching resource containing eight light-related activities is now available to download from the European Space Agency's (ESA) website. Combining science with art, The Magic of Light uses spectroscopes and colour wheels to allow pupils to explore how different colours of light can be produced and broken down. The resource, aimed at pupils aged between 8 and 12 years old, contains a teacher's guide as well as a separate worksheet for the activities.

To download the teacher's guide and worksheet, visit the ESA website at http://tinyurl.com/zvr8ra4

ESA is Europe's gateway to space, with its headquarters in Paris, France. To learn more about ESA, see: www.esa.org

*Johannes Kepler*

Image courtesy of ESO/Wikimedia

## ESO:
## Teacher training on Kepler's laws and modern astronomy

The European Southern Observatory (ESO) Supernova Planetarium & Visitor Centre, in collaboration with the House of Astronomy in Heidelberg, Germany, is organising a workshop for secondary school teachers, before the building is even complete.

On 1 July, teachers from ESO member states will visit ESO headquarters in Garching, near Munich, to learn the importance of Kepler's laws to modern astronomy. In particular, Kepler's third law allows scientists to estimate the masses of supermassive black holes, while deviations from Kepler's laws exhibited by galaxy rotation curves led to the discovery of dark matter.

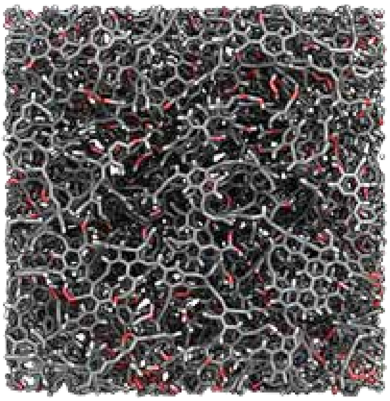
The ESO Supernova Planetarium & Visitor Centre itself is currently under construction. This April the impressive star-roof was installed and the centre is due to open to the public next year.

For more information, visit: www.eso.org/public/announcements/ann16022/

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

## ESRF:
## An insight into hydrocarbon research



*Molecular model of a sample of the Marcellus kerogen*

Image courtesy of Colin Bousige (CNRS)

Until recently, little was known about kerogen, the hydrocarbons from decomposed organic matter found in shale. With the help of the European Synchrotron Radiation Facility (ESRF) however, researchers from the French National Centre for Scientific Research (CNRS), the Massachusetts Institute of Technology (MIT) in the USA and the University of Upper Alsace, France, have been developing molecular models of kerogen to establish more environmentally friendly extraction methods as alternatives to controversial fracking.

To collect data about the chemical composition, texture and density of kerogen, four samples were selected and studied using the ESRF. The international group of scientists combined synchrotron and neutron experiments with molecular simulations to develop the models, which Benoît Coasne, director of research at CNRS and visiting scientist at MIT, says “are a fundamental building block for unravelling the adsorption, mechanical and transport properties of kerogen”.

See the press release here and the research paper at:
www.esrf.eu/home/news/general/content-news/general/kerogen-in-gas-shale.html

Bousige C et al. (2016) Realistic molecular model of kerogen’s nanostructure. *Nature Materials* doi: 10.1038/nmat4541

Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe.

To learn more about ESRF, see: www.esrf.eu

## EUROfusion:
## Fusion twists and turns

Housed at the Max Planck Institute for Plasma Physics (IPP) in Greifswald, Germany, is a rather complex-looking fusion device named Wendelstein 7-X. Wendelstein 7-X is a stellarator – a fusion device that, like its better-studied cousin the tokamak, works on the principle of magnetic confinement. But there is a twist.

Both the stellarator and the tokamak use magnetic fields to contain plasmas at $10^8$ °C, and this hot plasma is where fusion reactions can occur. But while a tokamak has a comparatively simple, symmetrical design, like that of a doughnut, a stellarator is shaped much more intricately. One easy way to describe a stellarator is to compare it to a doughnut that has been twisted many times over with numerous coils and cables protruding from it.

Some fusion researchers believe that although stellarators are complicated to design, they might be better at holding the hot plasma in place long enough for fusion reactions to occur. Wendelstein 7-X is an engineering and modelling feat, not only because it is the world’s largest stellarator with a diameter of around 16 metres but also because it is expected to be able to confine the plasma discharges for up to 30 minutes.

On 3 February 2016, Wendelstein 7-X began its first experiments with hydrogen plasmas. The important milestone was marked by the visit of German Chancellor Angela Merkel; she was at IPP Greifswald to push the button that kick-started the experiments with hydrogen plasma.

EUROfusion, which comprises 29 member institutes and laboratories, including IPP, congratulates IPP for the achievement and is looking forward to the progress and results that come from Wendelstein 7-X.

For more details, see www.euro-fusion.org/2016/02/wendelstein-7-x-ready-for-centre-stage-again/ and www.euro-fusion.org/2015/12/wendelstein-7-x-begins-fusion-journey/

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 https://www.euro-fusion.org/

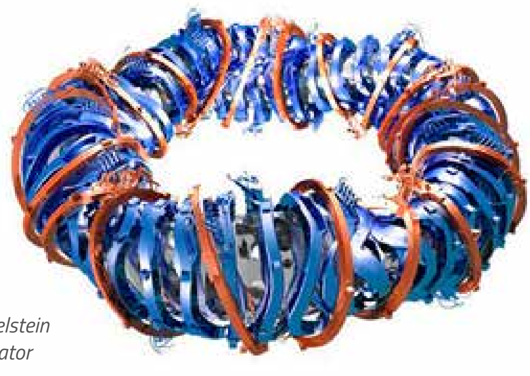


Image courtesy of Eurofusion

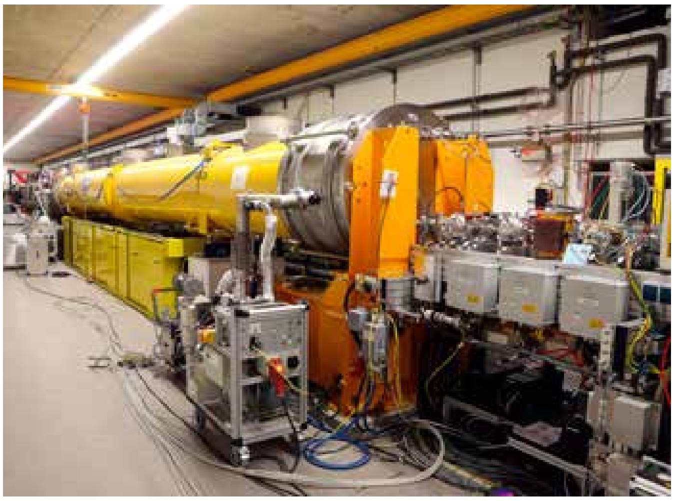
*The Wendelstein 7-X stellarator*

*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*

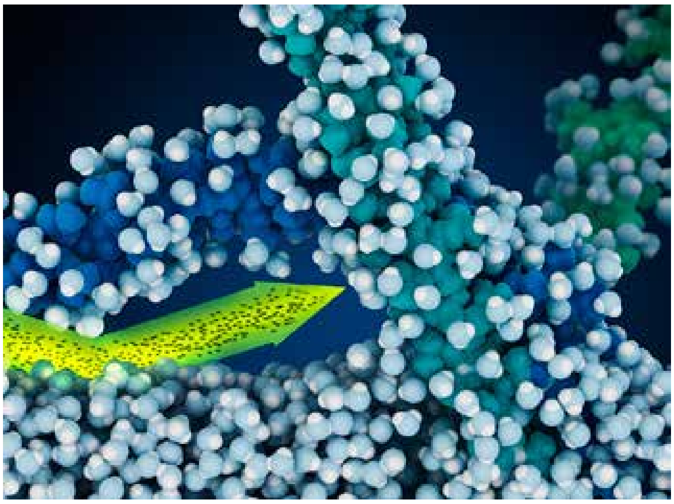
*To browse the other EIRO news articles, see: www.scienceinschool.org/eironews*

Image courtesy of European XFEL



*The 'injector'*

Image courtesy of ILL



## European XFEL: **First electrons accelerated in European XFEL**

A crucial component of European XFEL has begun operation: the so-called 'injector'. This 45-metre long injector beamline, which forms the first part of the superconducting particle accelerator, accelerated its first electrons in December 2015. The electrons reached the end of the injector in 0.15 microseconds, achieving near light speed. This is the first beam ever accelerated at the European XFEL and represents a major advancement toward the completion of the facility.

The injector shapes highly charged electron bunches and gives them their initial energy, which is gradually increased across a 2 kilometre linear accelerator that is still being assembled. Once energised, the electrons are ready to generate the facility's X-ray flashes, which will be used for researching matter at the atomic scale.

DESY, European XFEL's largest shareholder and close partner, is responsible for the construction and operation of the electron injector and the remainder of the linear accelerator. Components for the injector were produced across Europe by the 17-institute European XFEL Accelerator Consortium, which is led by DESY. The injector will continue to undergo rigorous testing while the rest of the linear accelerator is installed. The next major milestone, which is expected in late 2016, will be accelerating electrons using the full accelerator length.

See the press release here: www.xfel.eu/news/2015/first_electrons_accelerated_in_european_xfel/

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

## ILL: **Delivering drugs with smart nanogels**

Gels are found in many everyday products, from shampoos and sunscreens to foods. Different gels have various properties and applications, but they are fundamentally composed of large amounts of liquid, usually water, confined within a flexible network of polymer chains or colloidal particles.

One type of gel with an attractive application within pharmaceuticals are nanogels, composed of nanosized networks of cross-linked polymers that can carry or incorporate macromolecules in their network structure. As 'smart', 'switchable' materials, nanogels can respond to changes in temperature, and so they can be used as an intelligent drug delivery method. Recent experiments carried out at the ILL have provided important missing information on the behaviour of nanogels at interfaces, which may lead to a more patient- and user-friendly drug administration route than current methods.

See the press release and the research paper at:

www.ill.eu/press-and-news/press-room/press-releases/structure-of-smart-nanogels-at-airwater-interface-revealed-28012016/

Zielińska K et al. (2016) Smart nanogels at the air/water interface: structural study using neutron reflectivity. *Nanoscale* **8**: 4951-4960. doi: 10.1039/C5NR07538F

ILL is an international research centre at the leading edge of neutron science and technology.

To learn more about ILL, see: www.ill.eu


Image courtesy of Roman Miramontes; image source: Flickr

*Photoreceptors in our eyes are linked to the central body clock in the brain.*

# How plankton gets jet-lagged

## One of the world's largest migrations is probably driven by a hormone that governs our sleep patterns.

By Isabelle Kling

Melatonin is an essential hormone for maintaining daily rhythm and sleep in humans. Scientists at the European Molecular Biology Laboratory (EMBL) in Heidelberg, Germany, have now discovered that it also governs the nightly migration of a plankton species from the surface to deeper waters (Tosches et al 2016).

In vertebrates, melatonin has key roles in controlling the body's activity patterns and in ensuring it has a regular rhythm across the alternating of day and night over 24 hours. When we fly across time zones and this alternation is disrupted, our usual patterns slip out of sync and we feel jet-lagged.

Virtually all animals have melatonin, and it plays a similar role in all species, including some micro-organisms that scientists think are similar to our very distant ancestors. Understanding the role of melatonin in these primitive organisms may hold some clues to how our nervous system evolved.

### How humans get in sync

Although similar mechanisms exist in other species, humans are actually one of the most studied animals when it comes to understanding circadian rhythm. The circadian rhythm depends only on light and is mostly controlled via the eyes. The human retina not only is useful for us to consciously see things, but also plays a role as a light sensor, allowing us to adapt our body's functions to the quantity of light in our environment. It contains a small percentage (approximately 1 %) of very specific photoreceptors called intrinsically photosensitive retinal ganglion cells (ipRGCs), which are directly linked to the central body clock in the brain and produce a molecule called melanopsin.

The ipRGCs sense only the intensity of the light: they are activated and produce melanopsin when there is a lot of light, more specifically blue light, and they stop their production at night, when the intensity of light is lower. Melanopsin is


*Travelling over several time zones disrupts our body's rhythm resulting in jet-lag.*

Image courtesy of Slack12; image source: Flickr

released directly into the central body clock of the brain, situated just above where the two optical nerves cross – its scientific name is the suprachiasmatic nucleus (SCN), the nucleus above the crossing.

Via a cascade of reactions, melanopsin inhibits the production of melatonin in the pineal gland, another region of the brain. As a consequence, melatonin is only produced during dark hours – at night. Melatonin plays a major role in almost all of the body's functions[w1], such as sleep pattern or temperature; body temperature drops by approximately 1 °C from day to night.

To ensure that all functions are performed properly, every day, regardless of the weather, the body doesn't only adapt to the intensity of the light it currently sees, but also to its recent history of light exposure. In a way that is not yet fully understood, melanopsin keeps a memory of recent exposure. When this pattern of exposure changes, for example during travel over several time-zones, its rhythm is

## REVIEW

- ✓ General biology
- ✓ Neurology
- ✓ Behavioural science
- ✓ Health education
- ✓ Physics
- ✓ Evolution
- ✓ Ages 11–19

Every student changes their sleeping pattern as they grow up. They have to navigate schedule requirements, sometimes against their circadian rhythm. This article invites students to understand the basics of their own best performance time. Comprehending the biological facts behind circadian rhythms makes it easier to change patterns and gives students a feeling of empowerment. This topic may have a life-changing impact on their future.

The article could be used to do the following exercises in class:

- Melatonin as a 'cure' for jet lag: explain under what circumstances this makes sense (while travelling west or east), taking the time of the day into account.
- Draw a graph relating day / night to melanopsin / melatonin expression in the brain.
- Use the internet to define the light-sensitive areas on the human body.

Friedlinde Krotscheck, Austria

Image courtesy of EMBL/MA Tosches

Platynereis dumerilii *larvae's cilia pause less during the day when no melatonin is produced.*

disrupted and it takes several days to go back in sync, causing jet-lag.

## Planktonic migration

Melatonin is also present in other species, even microscopic ones that don't have as many different functions as humans: what is its role for them? To find out, Detlev Arendt and his colleagues at EMBL turned to the marine ragworm *Platynereis dumerilii*, a tiny creature that is thought to be very similar to the first animals with a brain and nervous system that appeared on Earth.

This worm's larvae take part in what has been described as the planet's biggest migration in terms of biomass: the daily vertical movement of plankton in the ocean. By beating a set of microscopic 'flippers' – cilia – arranged in a belt around its midline, the worm larvae are able to migrate toward the sea's surface every day. They reach the surface at dusk, and then throughout the night they settle back down to deeper waters, where they are sheltered from damaging UV rays at the height of day.

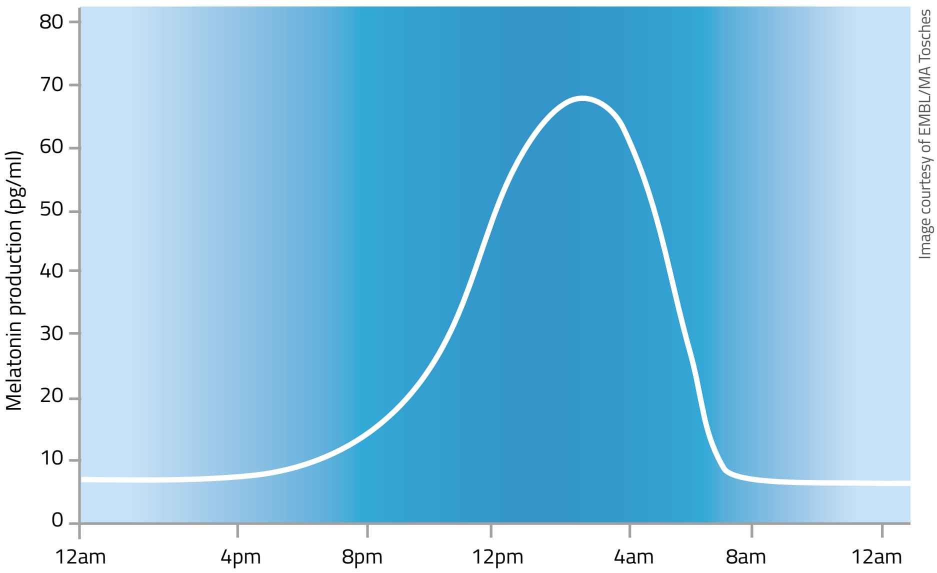
"We found that a group of multitasking cells in the brains of these larvae both sense light and run an internal clock that makes melatonin at night," says Detlev. "So we think that melatonin is the message these cells produce at night to regulate the activity of other neurons that ultimately drive day–night rhythmic behaviour."

Maria Antonietta Tosches, a postdoctoral researcher in Arendt's lab, discovered a group of specialised motor neurons that respond to melatonin. Using modern molecular sensors, she was able to visualise the activity of these neurons in the larva's brain, and found that it changes radically from day to night. The night-time production of melatonin drives changes in these neurons' activity, which in turn cause the larva's cilia to take long pauses from beating. Thanks to these extended pauses, the larva slowly sinks down. During the day, no melatonin is produced, the cilia pause less, and the larva swims upwards. "When we exposed the larvae to melatonin during the day, they switched towards night-time behaviour," says Tosches. "It's as if they were jet-lagged."

## From *Platynereis* to the human brain

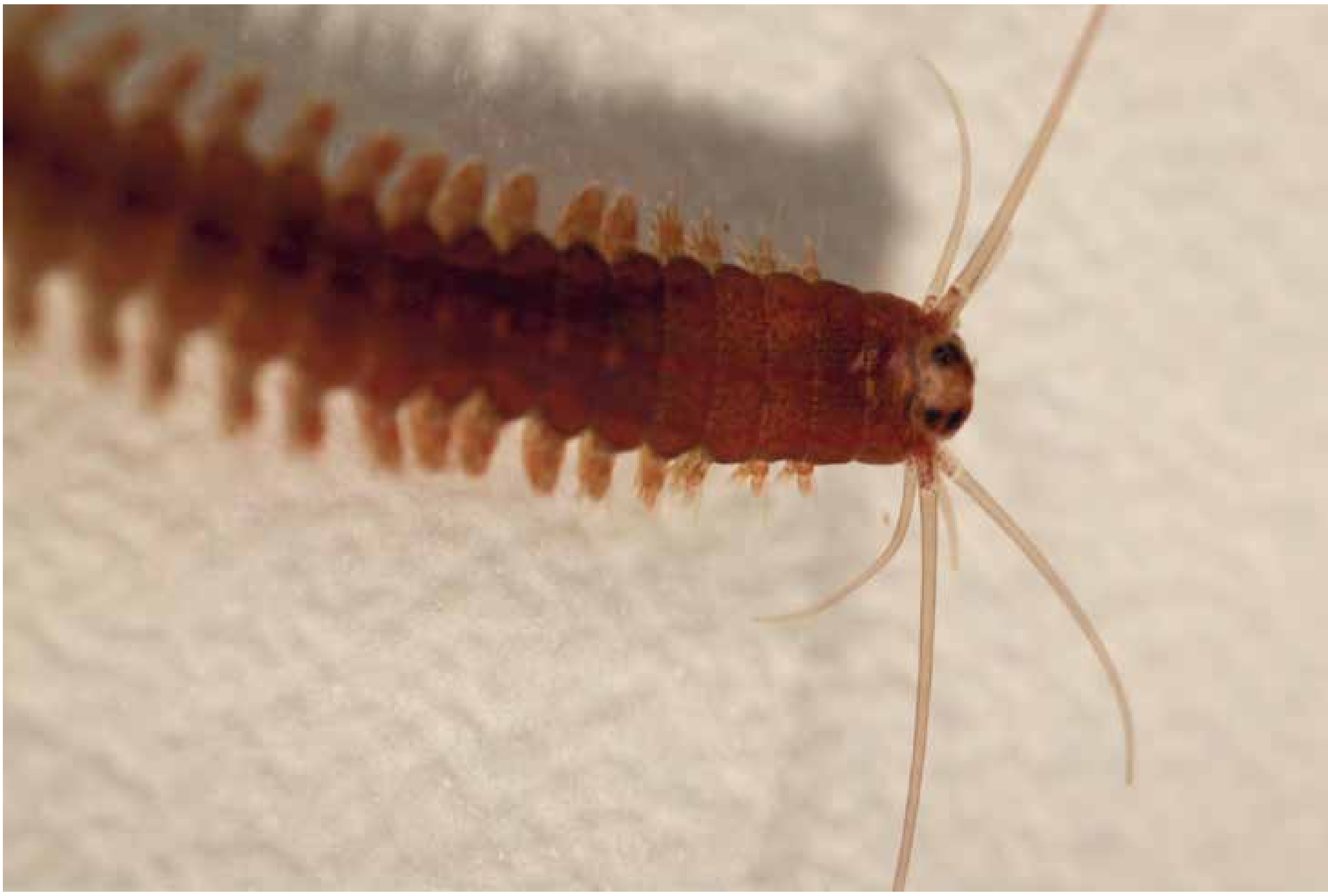
Research strongly suggests that the light-sensing, melatonin-producing cells at the heart of this larva's nightly migration have evolutionary relatives in the human brain. This implies that the cells that control our rhythms of sleep and wakefulness may have first evolved in the ocean, hundreds of millions of years ago, in response to pressure to move away from the Sun.

"Step by step, we can elucidate the evolutionary origin of key functions of our brain. The fascinating picture emerges that human biology finds its roots in some deeply conserved, fundamental aspects of ocean ecology that dominated life on Earth since ancient evolutionary times," Detlev concludes.




*Every night, an increase in melatonin levels in this larva's brain makes it move away from the sea's surface.*

Image courtesy of EMBL/Detlev Arendt



Platynereis dumerilii

BACKGROUND

## Circadian rhythm

Have you ever heard about the 'circadian rhythm'? The word 'circadian' comes from Latin: *circa* means nearly, and *dien* means day – so, nearly one day. It refers to the regular 24-hour cycle that most of the functions in our bodies (such as body temperature, blood pressure and hormonal production) follow. Having a regular and balanced circadian rhythm is very important, because its disruption can cause health problems that range from inconvenient, like jet-lag, to very serious, like depression.


## Reference

Tosches MA, Bucher D, Vopalensky P, Arendt D (2014) Melatonin signaling controls circadian swimming behavior in marine zooplankton. *Cell* **159**: 46–57. doi: 10.1016/j.cell.2014.07.042

## Web reference

w1 Some of the main roles of melatonin in the body are explained in this article from *Medical News Today*: www.medicalnewstoday.com/articles/232138.php

## Resource

This article is based on a full report of the Arendt group's discovery on the EMBL website, which you can read at:

Furtado Neves S (2014) How plankton gets jet lagged. 25 Sep, http://news.embl.de/science/1409_plankton-jetlag/


Isabelle Kling trained as a biochemist and a science communicator, then went on to set up various science communication projects in Canada and Europe. She is now one of the editors of *Science in School* at EMBL.

Image courtesy of Velmc, Flickr

# Making laser flashes meet their mark

*A flat lake still has the same curvature as the planet and might have waves that are too small to see.*

## Take a closer look at the construction of European XFEL.

By Joseph W Piergrossi

In the German city of Hamburg, scientists and engineers are assembling a subterranean super microscope capable of seeing matter in motion using X-ray laser flashes. Smaller structures, faster movements, more intense light: European XFEL will open up areas of research that were previously inaccessible[w1]. But scientists have to make sure these flashes, travelling down a kilometres-long path, can accurately meet a tiny object such as a biomolecule or a living cell as precisely as possible several thousand times per second. Look inside two of the myriad technical advances making this possible.

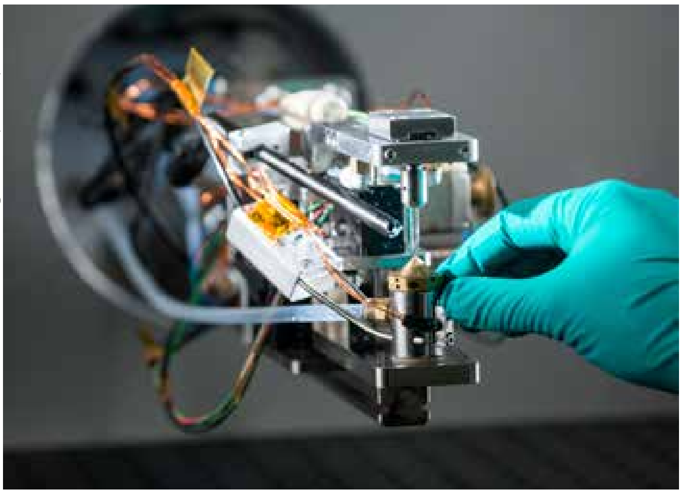


Image courtesy of European XFEL

*An example liquid jet setup*

European XFEL will use X-ray laser flashes that last for a few femtoseconds ($10^{-15}$ s) to investigate matter down to the atomic level, at a rate of 27 000 flashes per second. Scientists will use European XFEL to map the atomic details of viruses, decipher the molecular composition of cells, take 3D images of the nanoworld, film chemical reactions, and study processes such as those occurring deep inside planets. But before the first such molecular movie can be shot, scientists and engineers have to make sure the flashes and the things they want to study meet in the right place at the right time. This requires technological developments in two key areas:

1. To direct the X-rays to their targets while preserving their special laser properties, scientists need the flattest mirrors ever made.

*Close-up of the nozzle, showing the thin liquid jet*

Image courtesy of European XFEL

2. To study nanostructures, they need a sample delivery system that is not only ultrafast but also able to easily isolate objects ranging in size from cells to biomolecules.

To attain these extremes of size and speed, scientists need to advance technology beyond the current state of the art.

## Unimaginably flat

From where they first originate, the X-ray laser flashes of European XFEL have a long journey to the facility's experiment hall. To generate the X-rays, scientists accelerate electrons to very high energies. They do this by getting the electrons to move at nearly the speed of light in a 2 km long superconducting accelerator that has been cooled to 2 Kelvin, just two degrees above absolute zero. The electrons then pass through a series of alternating magnets called undulators. With each change of direction, the electrons emit X-ray light as they zigzag along between the magnets.

The interaction of the electrons with the generated light causes that light to be laser-like, or coherent, with all of its photons having the same wavelength and being in phase with one another.

Redirecting X-ray laser light that has such specific properties isn't easy: you need mirrors that are flatter than we might consider flat. A still lake with no disturbances in its surface may appear to be a perfectly flat mirror, but it has the same curvature as the planet and may have waves that are too small to see. The same applies to everyday mirrors that you'd find in your house. Using a mirror of such curvature and roughness would increase the fuzziness of the beam beyond its useful limit. Even the roughness of superflat mirrors used for telescopes (which are within a few micrometres of flatness) is still enough to negatively affect the X-ray laser light. X-ray free-electron lasers need mirrors roughly fifty times smoother than those used for telescopes.

To solve the problem, European XFEL scientists designed a mirror made from a 1 m long block of silicon, polished to within approximately 2 nanometres of perfect flatness. That's the same as a road being 28 km long and going up or down by only the width of a human hair for its entire length. Additionally, scientists will be able to alter the shape of the beam using an ultrafine responsive motor system that will flex the mirror by nanometres.

"With the advancements we've made with mirror polishing and metrology, I have a good feeling," says Maurizio Vannoni, one of the scientists involved with the development of European XFEL's optical components. "We wanted something dependable for our first light [experiment] in 2017, and I'm confident we will have it."

## Special delivery

More technological advancements are underway to make sure that the samples for study meet the laser flashes as accurately as possible.

Scientists from around the world will be using European XFEL's six scientific instruments to study everything from viruses and tiny crystals of biomolecules to nanoparticles and plasmas. With the X-ray laser's 27 000 flashes per second,

**REVIEW**

✓ Physics

✓ Ages 14–19

This article is most useful as a news article about current work in a research lab and could allow the teacher to start a discussion on modern research topics and how European XFEL will be used.

Stuart Farmer, Robert Gordon's College, Scotland, UK

Image courtesy of European XFEL / Heiner Mueller-Elsner

Image courtesy of European XFEL

*Prototype of the mirror*

scientists have to ensure their samples are at the exact right spot at the exact right time without any prior treatment.

To acquire data, the scientists will scatter X-ray flashes off an isolated sample and into a detector. For example, if studying a virus, each viral particle would have to reliably pass a tiny target area at a rate that allows it to be hit with several of the incoming X-ray flashes.

By using a stream of liquid only a micrometre in diameter, scientists at European XFEL are aiming to place these samples directly into the path of the flashes. This liquid jet is pushed through a specially designed nozzle so that the crystals are delivered at a consistent rate. A separate, more complicated setup is also in development and would deliver uncrystallised biological cells or viral particles. In this instance, the liquid around the samples would be removed using differential pressures and the particles would be steered into position by an electrical field, so that nothing would come between the sample material and the X-ray flashes.

"The challenge is to replace the sample rapidly to get fresh sample with every shot," says Joachim Schultz, the scientist who leads the sample environment group at European XFEL. "At the same time, we cannot waste too much sample between the shots. There is a lot of effort going into optimising this delivery process."

These developments are only two of the very many needed to build the European XFEL. Big leaps are being made in other sample delivery methods, ultrafast detector technology, optical laser systems, data acquisition, control software, and many other aspects of this facility of superlatives, which continues to push current technical boundaries so we can see the nanocosmos more clearly than ever.

## Web reference

w1 For more information about European XFEL, see: www.xfel.eu

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.

Joseph W Piergrossi is a science writer at European XFEL and a former science teacher.

# Cellular redox – living chemistry

## Learn how fluorescent biosensors can monitor the chemistry inside living cells.

By Prince Saforo Amponsah

We tend to think about reduction and oxidation (redox) reactions as pure chemistry. In living cells, however, reduction is just a gain in electrons and oxidation is a loss of electrons. Redox reactions have important roles in a wide range of biochemical processes. Unbalanced cellular redox reactions are involved in several diseases, so maintaining a balance in these reactions is critical for our health.

Consider the following two half reactions:

$$C \rightleftharpoons C^{4+} + 4e^-$$

$$O_2 + 4e^- \rightleftharpoons 2O^{2-}$$

In one, the carbon is oxidised, and in the other, the oxygen in reduced. Together, the two equations describe a redox reaction that looks like simple chemistry. However, this reaction is happening in our bodies all the time.

## A typical redox reaction

In redox reactions, electrons are transferred between chemical species. For example, in the explosive thermite reaction, which is sometimes used to weld railways, electrons are passed from metallic aluminium to ferric oxide:

$$Fe_2O_3(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2Fe(l)$$

This change becomes clearer if we remove the oxygen atoms from the equation:

$$2Fe^{3+} + 2Al \rightarrow 2Al^{3+} + 2Fe$$

We can see that the aluminium atoms lose electrons (become oxidised) and that the electrons pass to the iron ions in ferric oxide, reducing them. In principle, every redox reaction consists of two halves: the oxidation half (in this case, the Al/$Al^{3+}$ couple) and the reduction half (here the $Fe^{3+}$/Fe couple).

**REVIEW**

- ✓ Chemistry
- ✓ Biology
- ✓ Redox reactions
- ✓ Cell metabolism
- ✓ Cancer
- ✓ Ages 14–19

Knowing the redox reactions taking place in living cells is important to understand many cellular mechanisms such as ageing, inflammation, apoptosis and cancer.

This article describes how biosensors, some of which are based on GFP, can be used to detect the level of the chemical species participating in a redox reaction and therefore to understand the dynamics of our cells.

The article could be used to explain lab techniques used in molecular biology as well to form the basis for discussions around the role of antioxidants and the use of GFP in biology. Comprehension questions around the article could include:

- In cellular respiration, which element is oxidised and which element is reduced?
- Demonstrate how 48 electrons are exchanged in cellular respiration.
- What are reactive oxygen species?
- Describe the roles of superoxide, hydrogen peroxide and nitric oxide in the cell.
- Describe how reactive oxygen species could be used in cancer therapy.

*Monica Menesini, Liceo Scientifico A Vallisneri, Italy*

## Biological redox

### Metabolism

The thermite reaction demonstrates that spontaneous redox reactions release energy, which can be useful in the body. The two half equations at the beginning of the article are actually just a different way of describing cellular metabolism. When you eat, food is broken down into sugars such as glucose. Inside the cell, these sugars are oxidised, transferring electrons to $O_2$. An alternative way of writing the equation is:

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) + \text{energy}$$

In this equation, 48 electrons move from the carbon atoms in the sugar to the oxygen atoms, releasing energy to drive even more redox reactions along the way. Maintaining a balance in these reactions is critical for normal cellular function; if the equilibrium moves too far to either side of the reaction, there can be unwelcome consequences such as disease.

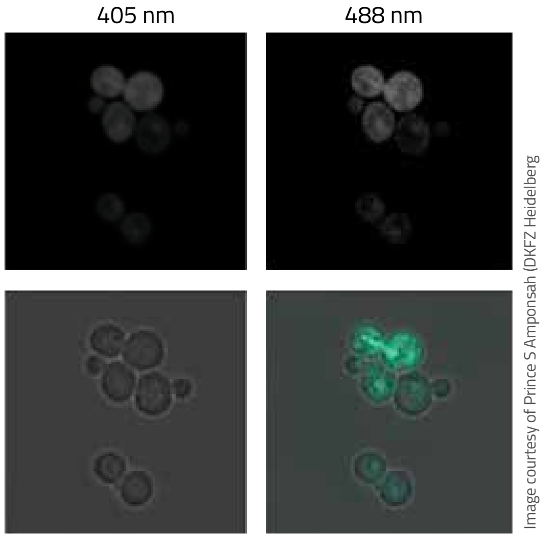



*Figure 1. Wild type (top) and probe-containing cells (bottom). The probe is targeted to the cytosol in yeast and fluoresces green when excited by light at 488 nm.*

### Cellular communication

For a long time, chemically reactive molecules containing oxygen, known as reactive oxygen species (ROS), which can alter the redox state of a cell, have been regarded as unwanted and damaging by-products of cellular metabolism. Normally, the cytoplasm in cells is kept in a reduced state; a shift to a more oxidised state has been implicated in several diseases, including cancer[w1].

However, some ROS also have important beneficial roles as signalling molecules and are thus essential to organismal health. Thousands of different ROS molecules are used as messenger signals to enable cells to communicate. Examples include superoxide ($O_2^-$), hydrogen peroxide ($H_2O_2$) and nitric oxide ($NO\cdot$), which are normally produced in a controlled manner and have roles in processes such as wound healing, ageing, inflammation and programmed cell death (apoptosis).

## Redox and cancer

In cancer, cells divide uncontrollably and proteins behave oddly, such as appearing or disappearing unexpectedly. Redox reactions have been implicated in the formation of cancer, for example by damaging our DNA, and ROS have been reported to either activate the expression of genes whose proteins promote cancer (oncogenes) or deactivate tumour suppressor genes, whose proteins do the opposite. ROS can also oxidise proteins, directly altering their structure and therefore function. If these proteins are important to the division or movement of cells, then cancer might appear.

Once a tumour has developed, redox mechanisms can also be exploited in treatment. Many anti-cancer drugs attack tumours by increasing the production of ROS inside malignant cells, which eventually kills them. However, cancer cells typically increase the production of their anti-oxidant defence systems, counteracting such an effect.

Redox mechanisms may also be responsible for resistance to therapy, when available drug treatments don't

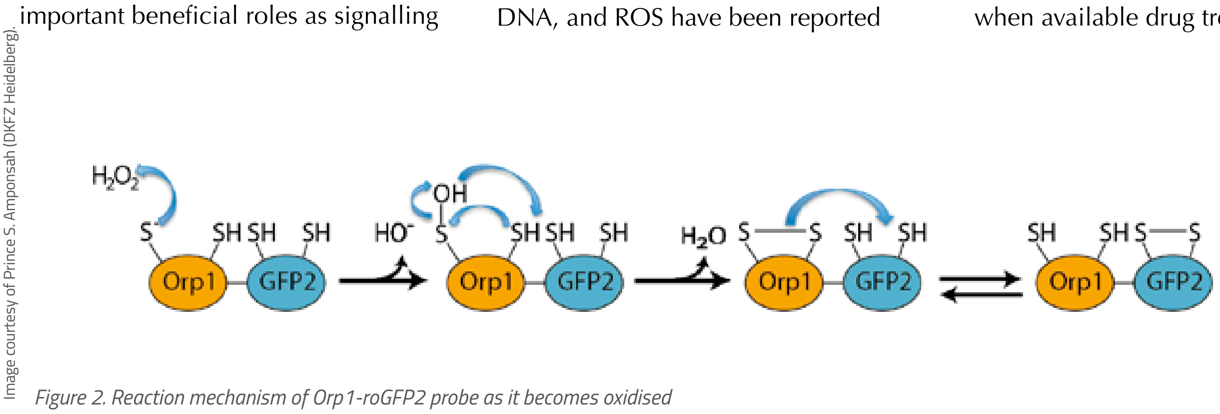



*Figure 2. Reaction mechanism of Orp1-roGFP2 probe as it becomes oxidised*

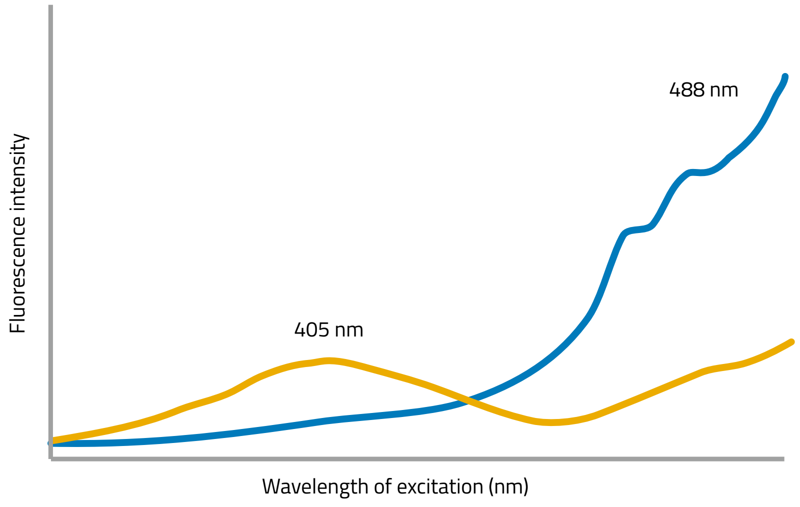



*Figure 3. The fluorescence response of the reduced (yellow) and oxidised (blue) probe*

work. To attack tumours efficiently, these drugs use the body's transport proteins to reach their target location (for example, where malignant cells are). However, redox reactions could alter these proteins, rendering them non-functional and interfering with the therapy.

These are just some of the reasons why understanding biological redox reactions and how cells achieve redox balance may help in the fight against cancer.

## Shining a light on redox reactions

To understand how different factors interact in healthy and diseased cells, we visualise the redox processes in cells using versions of a fluorescent jellyfish protein known as green fluorescent protein (GFP). In the 1960s and 1970s, researchers discovered GFP in the jellyfish *Aequorea victoria* and modified it to produce different colours. This work was later awarded the Nobel Prize in Chemistry[w2].

Using some genetics, we can now make cells produce fluorescent biosensors based on GFP for use in monitoring cells' redox states. One such biosensor is a variant of GFP called roGFP2, which can be modified with different protein segments to achieve specific goals. For example, it can be targeted to specific locations in the cell (e.g. cytosol or mitochondria) by adding trafficking sequences (figure 1). Alternatively, a specialised biosensor for a particular redox molecule can be generated by adding a specific protein segment that reacts with that redox species.

To measure $H_2O_2$ levels in cells, we use the Orp1-roGFP2 sensor (figure 2). The sulfur of the Orp1 part of the biosensor reacts with the peroxide and the protein becomes oxidised, creating disulfide bridges that change the shape of the protein and thus reduce its fluorescence in the measured range (figure 3).

By using these modified GFP proteins, we can see in real time where the redox species travel in cells and how they influence or maintain the redox state, both in healthy individuals and in cancer patients. This can help us understand the dynamics of our cells when we are healthy and if we develop cancer. Perhaps one day we can use our findings to suggest new treatments for the disease.

## Web references

w1 The group of Professor Tobias Dick at the German Cancer Research Center (DKFZ) investigates redox regulation in normal and cancer cells. To read more about their research, see: www.dkfz.de/en/redoxregulation/index.php

w2 More information on the 2008 Nobel Prize in Chemistry for the discovery and development of GFP is available from the Nobel Prize website. See: http://tinyurl.com/7y8df4s

## Resources

To learn more about chemical redox reactions, visit: http://tinyurl.com/d65vdx6

More on GFP can be found at:

Furtado S (2009) Painting life green: GFP. *Science in School* **12**: 19–23. www.scienceinschool.org/2009/issue12/gfp

For an activity about the genes involved in cancer, see:

Communication and Public Engagement team (2010) Can you spot a cancer mutation? *Science in School* **16**: 39-44. www.scienceinschool.org/2010/issue16/cancer

Prince S Amponsah is a masters student at the University of Heidelberg, Germany. He graduated with a BSc in biochemistry from the University of Ghana and joined the molecular biosciences programme of the University of Heidelberg and the German Cancer Research Center (DKFZ) in Heidelberg in October 2013, majoring in cancer biology. Prince also worked as a student assistant for *Science in School* between February and August 2014.

Image courtesy of Thomas Leth-Olsen; image source: Flickr

# On track: technology for runners

When we watch elite runners breaking world records, we rarely think about the chemistry and physics of the running tracks.

By João AS Bomfim

This year, the Olympic Games will give the world's top athletes another chance to prove themselves and smash records at the events in Rio de Janeiro, Brazil. Along with their training, fitness and sheer talent, the competitors have another factor to help them succeed: technology.

For the runners, it's principally the latest track surfaces that will enable them to do their best. Perhaps surprisingly, whereas leisure runners exercising in streets and parks rely on their sports shoes to provide the cushioning and spring needed for each step, for professional runners it's the track itself that fulfils this role. This fact reflects the gap in performance levels between school or amateur sports practised for fun or fitness, and top-level competitive sports. The energies involved in accelerating, decelerating, jumping and so on are markedly different: an Olympic sprinter running at full speed would probably injure herself on a hard track because of the high impact on her joints. In contrast, a jogger or school student wearing cushioned shoes might find athletic tracks too soft.

Image courtesy of Andrew Hecker; image source: Wikimedia Commons


*Figure 1: Olympic stadium João Havelange in Rio de Janeiro, which will be used in the 2016 Olympics*

Image courtesy of Mondo SpA


*Figure 2: An athlete positioning herself at the start gate. Note the shoes without any cushioning: in top-level competitions, it is the track that absorbs the impacts during running, not the shoes.*

REVIEW

- ✓ Chemistry
- ✓ Physics
- ✓ Biology
- ✓ Environmental science
- ✓ Ages 11–19

Before beginning a traditional lesson about polymers or Newton's laws, wait a moment and read this article on the technological secrets of modern sports tracks. This concise and simple text contains plenty of interesting information and lots of inspiring ideas for teaching organic chemistry, physics, biology and environmental science. The author appeals to students' curiosity and interest in sport in the run-up to the 2016 Olympic Games, using clear examples from everyday life.

The article is suitable for science teachers and students at secondary school. It could be used for a warm-up activity before introducing organic chemistry (polymers, chemical structure of natural and synthetic rubber, chemical bonds, vulcanisation, rubber chemical properties and industrial use). It could also be used as a starting point for a lesson on physics (Newton's second and third laws, elasticity, viscosity, or human body levers), biology (anatomy, muscular contraction, or biomechanics) or environmental science (the use of rubber, rubber production, manufacturing, natural and synthetic rubber, rubber life cycle, disposal and recycling). Another interesting discussion topic could be the technology of facilities for professional and amateur sports. It could also be used as a starting point for an investigation into the technical details of sports equipment such as shoes, balls, swimsuits or helmets.

Possible comprehension questions include:

1. Which body parts are NOT commonly injured by the impact with the ground when running?
   a) Ankles
   b) Toes
   c) Ligaments
   d) Knees.
2. Compared to tracks for amateur sporting events, professional running tracks are:
   a) Softer
   e) Harder
   f) More elastic
   g) Similar.
3. Which of the following statements about rubber molecules is false?
   a) They are huge polymers
   h) They are physically entangled
   i) They have a free volume
   j) They line up with each other.

Giulia Realdon, Italy

## Forces in action

Running is in effect a series of controlled impacts on the ground, so the ideal surface should provide enough shock absorption to avoid injury (especially to the ankles, knees and ligaments) at the same time as offering a strong, stable base to allow an athlete to push forward.

Let's think about the forces between the athlete and the running surface that are involved in running. At each step, the athlete uses her leg muscles (and the friction between the track and the sole of her shoes) to push against the ground. Newton's third law of motion tells us that:

> For every action [force], there is an equal and opposite reaction [force].

Image courtesy of tableatny; image source: Wikimedia Commons

*Figure 3: A sprinter about to begin a race*

This means that as the athlete pushes against the track, the track exerts an equal and opposite force on the athlete, pushing her forward. This is often called the **ground reaction force**.

Newton's second law of motion tells us that:

> Force = mass x acceleration.

Image courtesy of Mondo SpA

*Figure 4: London Olympic Stadium with rubber polymer surface for track and field events*

So for the athlete, the greater the force pushing her forward, the greater her acceleration.

Newton's second law also helps to explain what happens every time an athlete lands during running. When the foot hits the track, it will decelerate to a stop before leaving the track again. The faster the deceleration, the greater the force of impact on the foot. So the track needs to ensure that the deceleration is slow enough to make the impact bearable, but fast enough to sustain running speed. It is here that specialist materials are needed to produce a track that is neither too soft nor too hard.

## Hard and soft materials

In everyday life, we encounter materials of varied consistency: from hard, solid metals to soft, flowing liquids. Let's think about these characteristics in more detail.

- As well as being hard, metals are **elastic** materials. Like a spring, a metal wire will stretch when a force is applied and will then return to its original length when the force is removed. (If the force is too strong and stretches the metal past its elastic limit, the wire will be stretched permanently.) Energy is stored by the material when it is stretched and is then quickly released when it springs back.
- Liquids are soft, non-elastic materials. They will flow freely if a force (such as gravity) is applied and will not keep their shape. The mechanical energy is dissipated, rather than stored in the material. Materials of this kind are described as **viscous**.

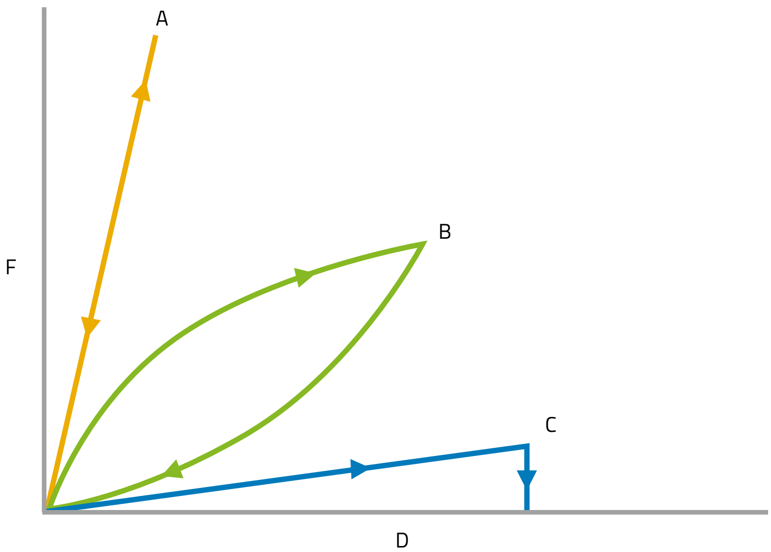



Image courtesy of Joao Bomfim

*Figure 5: Force (F) against deformation (D) graphs showing how plastic (A), viscoelastic (B) and viscous (C) materials respond to applied forces*

As figure 5 illustrates, a purely elastic material (e.g. metal or concrete) will store all the energy of impact and return it instantly. However, this produces ground reaction forces that are not safe for runners: some energy needs to be absorbed by the track material. Viscous surfaces, on the other hand, will absorb the energy of the foot impact but will not give anything back.

Between these two extremes are **viscoelastic** materials. These can dissipate part of the energy of impact – enough to protect the athlete's ligaments – while also conserving enough to provide a suitable reaction force to propel the athlete forward.

## Why polymers might be the answer

So where can we find a material with the right viscoelastic characteristics? An important group of viscoelastic materials are polymers – the family of materials that includes plastics, rubbers and glues. Polymers are made up of huge molecules comprising hundreds or even thousands of atoms. Because of their size, polymer molecules can interact with each other by lining up and becoming physically entangled. Rubber molecules are special because although they entangle, they do not normally line up with each other, remaining somewhat 'loose'; they have what polymer scientists call free volume. This means that the molecules can bend and move, sliding away from or towards each other, allowing the material to stretch.

Besides physical interactions, chemical (covalent) bonds called crosslinks can form between polymer molecules. Polymer materials with many crosslinks are usually hard: epoxy glue is an example of this. In contrast, most rubbers have a relatively small number of crosslinks, so they are softer. Rubber can be hardened by a process called vulcanisation, in which sulfur atoms form additional crosslinks between molecules (figure 6).

Image courtesy of Rolfe Kolbe; image source: Flickr

*Figure 7: Discarded tyres waiting to be recycled or incinerated*

If the free volume allows rubber to be stretched, the forces and entanglements between the polymer molecules, especially the crosslinks, will pull them back to their original position, giving rubber its elasticity.

The job of the polymer chemist is to know how to choose the right materials and processing conditions for a given use, such as running tracks. Beyond choosing the right rubber with the appropriate number of crosslinks, a polymer chemist must also pay attention to the right antioxidants, so the tracks will not degrade. The heat and UV light from exposure to sunlight and outdoor weather are known to promote chemical reactions. This is because the process of rubber hardening (from vulcanisation, ageing or weathering) never actually stops. Without proper antioxidants to prevent more and more crosslinks forming, a running track would become hard and lose its shock-absorbing properties, behaving more and more like a purely elastic material, until the runners feel as though they are running on concrete.

Another important contribution of science to running tracks is linked to environmental concerns and recycling. Indeed, many tracks use recycled rubber in their composition. It is a clever way of reducing the waste that ends up in landfill or is incinerated. Tyres are strong and flexible – they have to support the weight of a car and must not break even if they hit the curb or a hole in the road. Old tyres can be ground into crumbs, cleaned and incorporated into the bottom layer of the track, which is not visible and does not come into contact with the athletes. Tyre rubber has excellent viscoelastic properties and, when combined with new rubber material on the track surface which protects it from oxidation, it can give a safe and fast running track. Indeed, tyre crumb rubber is already used in many playgrounds as a safe, cushioning flooring to protect children when they fall. In much the same way, it protects top athletes while they do their best to break world records. So when you're watching athletes competing at the Olympic Games this summer, you can appreciate the science behind those gold medals.

Image courtesy of Joao Bomfim

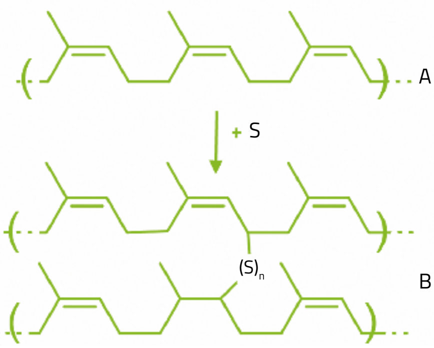



*Figure 6: Natural rubber (A) reacts with sulfur (S), resulting in vulcanised rubber (B)*

Image courtesy of Oxyman; image source: Wikimedia Commons

*Figure 8: A playground surface composed of recycled rubber*

## Resources

To learn more about the history of running-track technology, see:

Lovett RA (2008) The technology of athletics tracks. *Cosmos* 15 Aug. http://archive.cosmosmagazine.com or use the direct link: http://tinyurl.com/zxhkt9x

For a video about athletic speed increases and sports technology, see:

Epstein D (2014) Are athletes really getting faster, better, stronger? *TED2014*, filmed March. www.ted.com or use the direct link: http://tinyurl.com/mgkpo7g

João AS Bomfim is a chemist by training and holds a PhD in polymer science from Rio de Janeiro Federal University, Brazil. He worked as a research scientist in both academia and industry, developing new plastic and rubbery materials before joining the Luxembourg branch of Mondo Group as a research and development expert in charge of developing new sports surfaces.

# Bruno Pin: a lifetime of sharing knowledge

Bruno Pin can go a long way to find new methods of making science meaningful to his students.

*Grenoble*

By Montserrat Capellas

Solving mysteries, revealing insights into medicines or attempting some trendy molecular cooking are examples of what Bruno Pin and his students get up to in his science lessons. Obviously his classroom is not always like this, but Bruno likes to find new ways to make science meaningful to his students.

A secondary school teacher for the past 27 years, Bruno Pin always knew he wanted to teach. He loved teaching tennis in the summer as a teenager and went on to study physics. He wasn't persuaded by a career in research (unlike his wife, whom he met at university), so he took the exams to become a teacher straight after completing his degree. Exchanging views, sharing knowledge and interacting with youngsters drive Bruno in his job. He claims that "the difficulty and, funnily enough, also the charm of this job is that you don't have two days that are the same".

Bruno has always used a creative approach to teaching. He has been involved in setting up local programmes in Grenoble such as Nano@School and, more recently, Synchrotron@School, the ESRF's outreach programme for secondary school students. These initiatives often started with an informal conversation with researchers from the different labs in the area and from visits to his school, the Lycée des Eaux Claires. With time these programmes became properly established under the umbrella of the Academie de Grenoble, the local representative for the Minister of Education. The focus of these initiatives is to give students the opportunity to get out of the routine of the classroom and experiment with science at the same time.

"Ultimately," Bruno says, "I want to share knowledge with the students. These programmes are a different take on teaching; we are trying to transmit concepts and ideas to show them how science can be applied to everyday life."

## Evolution of teaching throughout the years

Like many teachers, at the age of 54 Bruno Pin has seen first-hand the evolution in different generations of students. "Maybe it is because there is a bigger gap in age between me and the 17–18-year-olds that I am teaching today, but I also feel there is a change in how they learn," he explains. "Take, for example, maths. For me it is a tool to use every day, not just a subject in school, but students don't understand this and therefore can't make calculations in their heads. And they don't even know how to use a calculator properly, so there is

Image courtesy of Olivier Duquesne; image source: Flickr

Image courtesy of ESRF

*Bruno Pin*

Image courtesy of ESRF

*Bruno Pin working with a group of students at ESRF*

a learning gap compared to some years ago."

The fact that kids today have fast access to communication means they are more "awake", as Bruno calls it. They ask many questions, have a lot of curiosity and are more experimental than previous generations. On the other hand, he claims that students "need answers straight away" and "don't think things through as much as in the past".

## Science path by default

Going down the scientific route in France has always been seen as the 'prestigious' pathway. At the age of 16, children have to choose what subjects they want to specialise in for the last two years of school. Many students are unsure about their choice, and parents sometimes orientate them towards the scientific option because it is taken for granted that they will find a job later on. Bruno points out that a scientific option involves many years of studying (especially if the student does a PhD) and it is very demanding, so you need to be committed: if you make the wrong choice at 16, then you might fail later on if you can't keep up with the workload. Bruno has witnessed some people failing, but others – most of them, in fact – have gone on to become professionals in their field. He says this proudly and explains that he often asks former students who are now doctors or engineers to visit his school to show youngsters how far you can go with science. And their journey invariably started in a classroom with Bruno at the teacher's desk.

REVIEW

- ✓ Biology
- ✓ Chemistry
- ✓ Physics
- ✓ All ages

Atomic physics is for the most part theoretical in high school because the experimental part requires too much expensive support and equipment. Instead, Bruno Pin goes with students in a research centre, where the experiments can be done and so the students become researchers for a day.

Corina Toma, "Tiberiu Popoviciu" Computer Science High School, Romania

## Synchrotron@School: making science tangible

While bringing scientists into the classroom is a good way to demystify scientific careers, Bruno also knows that changing students' views on research in general takes a bit more work, for example, by changing the educational setting and taking them into research facilities. He was nominated by the Academie to direct school outreach activities at the ESRF, together with Yannick Lacaze, an outreach officer at ESRF.

The concept of the synchrotron may not mean much to many students in secondary schools in Grenoble. In an attempt to explain how a synchrotron works, to present the various fields of research conducted in an international facility such as the ESRF, and to show the diversity of jobs available (such as scientists, engineers and technicians), the ESRF has organised, along with the Academie de Grenoble, a series of one-day stays at the facility since 2013.

The day starts with a challenge for each group of students. Throughout the day they need to find the solution to a question based on the science curriculum and the work done at the ESRF. Currently most questions revolve around diffraction, fluorescence and heat transfer. For example, students need to identify a fluorescent molecule in a test tube. They use everyday objects, such as bank notes or reflective vests, to learn about the emission spectrum of different fluorescent and phosphorescent powders. Then they calculate the energy emitted by the unknown molecule and compare it with supplied data to find its name. At the end of the day the students present a poster and a slideshow highlighting their conclusions. The day also includes a visit to the beamlines and informal chats with staff to allow relaxed exchanges of views and advice.

Image courtesy of DKdIV; image source: Flickr

*European Synchrotron Radiation Facility*

Image courtesy of Garry Knight; image source: Flickr


*High-visibility jackets*

**Background**

### Synchrotron@ School

Launched in 2013, Synchrotron@School is now well established among local schools and has also welcomed secondary school girls from abroad, namely the UK and Sweden, with the aim of promoting careers for Women in Science. The programme is for students in the last two years of school before university. If you would like to apply, please contact Yannick Lacaze: yannick.lacaze@esrf.fr

### Resource

Visit the Nano@School website to learn more: www.nanoatschool.org/reperes/nanoschool-en

Montserrat Capellas is a senior science communicator at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France.

*A native bee visits a manuka flower (*Leptospermum scoparium*)*

Image courtesy of Avenue; Image source: Wikimedia commons

# The sweet taste of science

## As a 'scientist / inventor in residence' at a primary school, teacher Carole Kenrick inspires children and is inspired by them

By Laura Howes

In the summer of 2015, children at Gillespie Primary School in north London, UK, made international news with a double-blind controlled trial that concluded that manuka honey is not effective in preventing colds and minor illnesses. The trial, funded by the British Pharmacological Society, was conducted by children aged between 7 and 11 at the school's Lab_13, a dedicated space in the school, where small groups of children investigate their questions and turn their ideas for inventions into reality.

The lab is overseen by Carole Kenrick, the project's 'Scientist / Inventor in Residence'. After studying physics at university, Carole became a secondary-school physics teacher and head of physics for a school in London. Then she saw the job advert for the part time position at Gillespie. "This seemed like my dream job – an opportunity to teach beyond the curriculum, pursuing children's own questions and ideas," she explains. "Really getting them to think for themselves, like scientists and inventors."

Image courtesy of Carole Kenrick

*Carole Kendrick*

Part of her job there is to facilitate the work of a committee of children in Years 5 and 6 (9–11 years old) to engage the rest of the school in science, technology, engineering and maths (STEM). When I asked the children how involved they get, they answer: "A lot! We basically take charge of everything except filling in the forms." The management committee meets weekly to plan events, competitions and science assemblies. Sessions with Carole are inspired by the students' own questions, which she then uses to plan a session. "The idea being," says Carole, "that they think like scientists/inventors and work out as much for themselves as they can." The idea of the lab is to increase what some people call 'science capital' – exposure to science as a cultural activity that can have a positive benefit.

The idea behind the manuka honey project, says Carole, came from a question asked by a parent, who wondered whether claims about the honey's benefits to health could be substantiated. Manuka honey is a honey produced in Australia and New Zealand from the nectar of the manuka tree. The honey is commonly sold as an alternative medicine and a component found in manuka honey has demonstrated antibacterial properties in vitro.

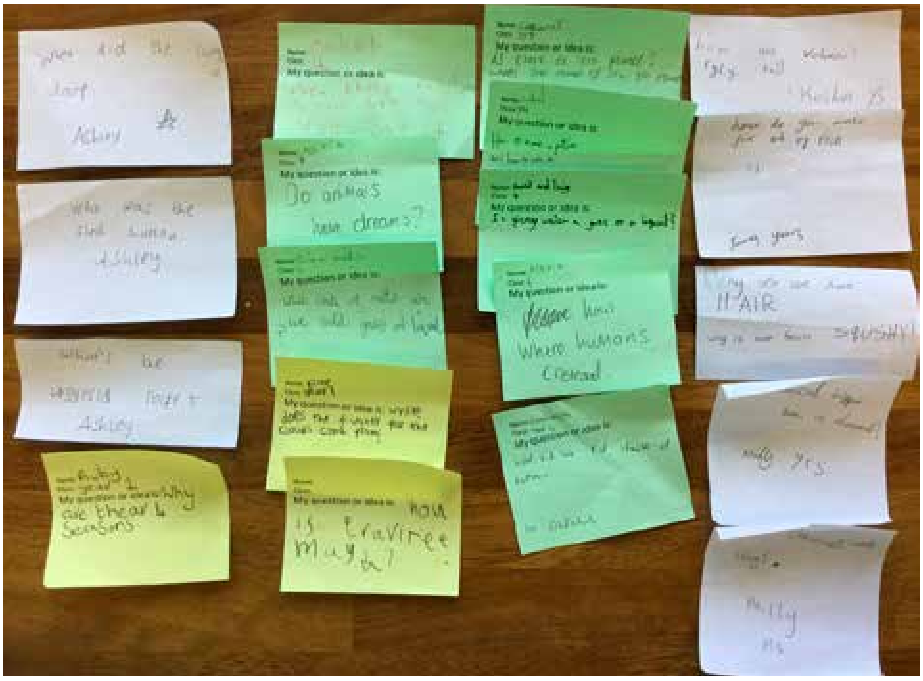
## Preparing a protocol

After the question was raised, Carole worked with students to design a protocol for a double-blind trial with a control group, which was reviewed by Dr Robert Dickinson at Imperial College London, UK. Volunteers from the school community took part in the trial, either eating manuka honey, a normal honey, or no honey, and then reported how they felt each day. Children from across the school helped with data input and analysis and the results showed that children taking manuka honey reported feeling very well on 54% of the days of the study. For those on other honey or not taking honey at all, the figure was over 70%.

Of course the size of the school does limit the number of participants, which means that the results cannot be seen as very scientifically reliable. According to Carole, 10 children ate manuka honey; 10 children ate non-manuka honey and 14 ate no honey at all. Looking over the results however, it is clear that the children take scientific reproducibility very seriously. In a poster of their results the children also conclude that they are not confident that their results are entirely accurate. 'We would like child-led research groups in other schools to double check our results by trying this out in their school,' they conclude in their poster. And indeed the students themselves seemed upset that one online newspaper reported that their results 'prove' that manuka honey doesn't impact health while the children themselves were careful to say that

Image courtesy of Sage Ross; Image source: Wikimedia Commons

Image courtesy of Carole Kenrick




*Carole's question wall in her lab, full of children's questions*

their results 'suggested' this might be the case. Carole says that the children were surprised that their research was respected by so many people – from being interviewed for the newspapers to presenting at the Cheltenham Science Festival in the UK. "They felt that they were being taken seriously, and recognised as scientists."

But the benefits of the trial have spread even further. "The eight 'Beesearchers' grew tremendously in confidence," she adds "And children across the school make reference to the trial when discussing other investigations." Furthermore, Carole's pupil surveys tell her that they want to be involved in more long-term research projects. The trial included no fancy demos or special pieces of equipment, and by Carole's own admission involved "some pretty repetitive, and frankly dull work, the children experienced the satisfaction that only a long hard slog can provide."

Background

## What is a Lab_13?

Lab_13 laboratories are based within schools, but external from the curriculum and managed entirely by the students of the school.

A management team is established in each school; a small group of students who have the responsibility of the management of the laboratory. Every aspect of the laboratory, from recruitment to resources, is decided on by this team (which recruits replacement members each year, in most cases).

Each management team recruits a 'scientist-in-residence', with either a scientific, engineering or inventing background to assist with investigations, ensure the children are conducting experiments safely, and lend a hand where needed. Carole says she is very lucky at Gillespie that one of the parent governors involved at the school is chemistry professor Andrea Sella. "Whilst support from universities isn't necessary to the day-to-day running of the lab," she explains, "It does make it easier to find scientists to work with."

The project began in the UK, but the network has now moved into Ghana as a first step to see how internationally applicable the project could be.

All the scientists/inventors in residence keep in contact over email and the different Lab_13 all contribute to a shared blog[w2]. Pupils at Carole's school have also taken part in competitions set by their peers in Ghana and had online chats. "I think it's so important for the children to learn about the experiences of children in other parts of the world," Carole adds.


## Keeping busy

Even though the trial is over, Carole, who works at the school on a part-time basis and also as a teacher trainer at Canterbury Christ Church University in Kent, is still being kept busy with a growing pile of submitted questions for investigation. She also helps the Lab_13 management committee run school-wide competitions (including science art, science baking and logo designing) and events.

As with all schools, however, budgets are tight. The children have been heavily involved in raising money to ensure the survival of their Lab_13 and above all, Carole's post as resident scientist[w1]. However, the financial requirements of the project are small apart from Carole's salary. "We do have a few bits of special kit, like a microscope and a telescope," admits Carole, "but to be honest, it's more about the approach than the equipment." However there is one piece of equipment that Carole does think helps: lab coats. "It helps them feel like scientists," she explains.

The project has only been going for two years, so its long-term impact cannot yet be measured. However, the positive replies to Carole's latest pupil survey suggests the benefit of the project is clear: "It allows children to share their ideas and have fun whilst still learning", one replies. Another is even more inspired, the best thing, they say, "is that we can discover anything."

## Web references

w1 Donate money for the project at http://tinyurl.com/5tbg4jj

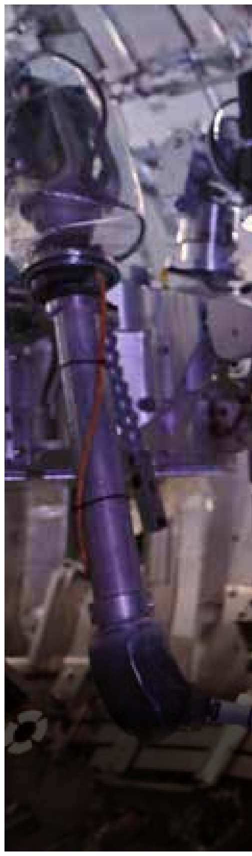
w2 The Lab_13 blog can be found at https://lab13network.wordpress.com/

## Resources

You can learn more about the work that Carole does with the students at https://youtu.be/HXeRg7YfVDE

Images courtesy of EUROfusion, Olivier Sauter and Haydn Denman





# Destination fusion

## Five young researchers are working to create a star on Earth.

By Misha Kidambi

What does it take to become a fusion researcher? A fascinating and multidisciplinary field, fusion needs people with a variety of expertise and skills. From physics and material sciences to engineering and management, there's a lot that goes into getting a fusion experiment running.

Fusion is the process that powers stars, including our Sun. To replicate the fusion process on Earth, researchers have to use heavy hydrogen isotopes – deuterium, which is readily available from water, and tritium – and temperatures almost six times hotter than the core of the Sun. It may be fair to say that generating energy from fusion is one of the greatest challenges for humankind. But fusion researchers have accepted this challenge because, once harnessed, fusion provides nearly unlimited, safe and clean energy.

EUROfusion, the consortium of fusion research institutes across the European Union and Switzerland, promotes education and training in fusion by supporting young fusion researchers. Talking to holders of EUROfusion grants can give us a glimpse into the world of fusion research. For Llion Marc Evans, Mélanie Preynas, Gergely (Geri) Papp, Mike Dunne and Matthias Willensdorfer, it is about more than just physics and engineering. It is the excitement of working in a multidisciplinary field, the drive to see fusion power light up homes across the globe, and the thrill of being part of a future energy solution.

Background

### EUROfusion

The European Consortium for the Development of Fusion Energy (EUROfusion[w1]) comprises representations of 28 European member states as well as Switzerland, and manages fusion research activities on behalf of Euratom. More than 40 European fusion laboratories collectively use the Joint European Torus (JET), which has remained the world's largest magnetic fusion device since it was built in 1983. Smaller national experiments in Germany, Switzerland and the United Kingdom complement the experimental programme. The aim is to realise fusion electricity by 2050.

## Llion Marc Evans

Image courtesy of Haydn Denman

*Llion Marc Evans at the Joint European Torus*

Armed with a masters degree in aeronautics, Welsh physicist Llion Marc Evans was on track for a career in the fast-paced world of Formula 1 racing before he made a pit-stop. After hearing stories about sustainable energy and fusion power, Llion changed tracks and drove straight into fusion research.

Back in 2008, when Llion was considering his options for a PhD, reports about climate change kept taking his interest. "I watched a BBC Horizon episode on fusion energy, which convinced me that research in fusion would be exciting and that I could contribute towards fighting climate change," he says.

In November 2014, after Llion completed his PhD on materials used in fusion reactors, EUROfusion awarded him a Researcher Grant, and in August 2015, Llion began working as the EUROfusion Fellow at the Culham Centre for Fusion Energy in Oxfordshire, UK. Currently, he is working on a method to convert 3D X-ray images of components for the planned demonstration power plant DEMO into high-resolution computer models. "By creating a 'digital twin' you model real parts instead of idealised designs," he explains. "Achieving better accuracy helps the design process and improves our predictions of the power plant's performance."

The blurred lines between physics, engineering and materials science, and foundations in experimental, computational and theoretical fields are what makes fusion research exciting for Llion. Other than many cups of coffee, he says, nothing in the day of a fusion researcher is typical. "One day, I might be using a facility such as the neutron source ISIS, another day it might be one of the world's most powerful computers like ARCHER or I may just be sitting in the library reading journal papers," he adds.

But ultimately, it is the potential that fusion research has to bring about a positive change at a global scale that is most appealing to Llion. "My hope is that I'll see the first fusion power plant put electricity onto the grid before I retire and that I'll have played a part in that moment."

## Mélanie Preynas

Image courtesy of Olivier Sauter

*Mélanie Preynas at the TCV tokamak of the Swiss Plasma Center*

When it comes to states of matter, the fourth state, plasma, is not as widely known as solids, liquids and gases. However, it is the most abundant form of matter in the Universe, and is crucial to nuclear fusion. One ingredient for a successful fusion experiment in a tokamak, currently the most advanced fusion device, is a well-behaved and stable plasma, but achieving good behaviour and stability is not trivial. This challenge is one of the things that physicist Mélanie Preynas tackles. Her work aims to control, in real time, what are known as 'magnetohydrodynamic' instabilities in plasma.

Simply put, magnetohydrodynamics refers to studying the magnetic properties of electrically conducting fields such as plasma. Magnetic fields induce currents in the conductive fluid, which in turn modifies the geometry and strength of the magnetic fields themselves. "To achieve stability and good performance of the plasma, we have to control it in real time," says Mélanie. "One possibility is to launch microwaves into the vessel of the tokamak to generate heat and drive the current," she explains.

Mélanie, who is currently working at the Swiss Plasma Center of the *École Polytechnique Fédérale de Lausanne*, discovered the world of fusion research during her PhD at the Institute of Magnetic Fusion Research in France. The idea of developing a new energy source is what initially drew Mélanie to fusion research. Once in, she was excited by the multidisciplinary nature of this field. "It's a mix of theoreticians and experimentalists working with technicians and engineers to obtain and understand experimental results of the fusion device," she says.

The life of a young researcher in fusion can be exciting, fun and competitive. Melanie's work is also varied, and about more than just working on tokamaks. "I may spend time in my office analysing experimental data, or an entire day in the control room of the fusion device during an experimental campaign or making some calibration of a measurement system on the machine," she points out. Mélanie is looking ahead and hopes to continue working for fusion research in the future.

## Gergely (Geri) Papp

Image courtesy of EUROfusion

*Geri Papp at ASDEX Upgrade*

How far can childhood fantasies take you? In the case of EUROfusion fellow Gergely (Geri) Papp, they paved the way for his career as a fusion researcher. Geri, who was (and still is) a great fan of science fiction, learnt that there is nothing fictional about the fusion reactors that he came across so often in the pages of science fiction. "Part of the reason why I became a physicist is that I wanted to work with fusion," says Geri, who initially studied physics in his home country of Hungary before completing his PhD.

Geri currently works at the Max Planck Institute for Plasma Physics in Garching, Germany, which houses the tokamak ASDEX Upgrade. "It's a fantastic machine to work with because it allows you to plan and execute experiments on a relatively shorter time-scale as compared to larger experiments, and at the same time gives results that are crucial," he explains.

One of the projects that Geri works on involves runaway electrons. Within the fusion reactor a mixture of hot electrons and positive ions moves in random directions. Most particles move around harmlessly, colliding with each other, but some fast-moving electrons, known as runaway electrons, collide with the walls of the fusion experiment vessel. "Our goal is to better understand the formation process of such electrons and to design a safety system to eliminate or mitigate them," Geri explains.

From carrying out experiments to developing theoretical models, implementing numerical codes, teaching, publishing scientific papers and giving talks, the life of a fusion researcher is exciting. But the ultimate motivator for Geri is the vision of realising fusion energy. "When achieved, fusion will be as close as possible to an ideal energy source: clean, safe, abundant, accessible and controllable." The fact that power from fusion might be decades away does little to dampen Geri's enthusiasm. "It took humankind more than 6000 years to learn how to fly or build computers; even if it takes an extra 50 years to realise fusion power, I can live with that."

## Matthias Willensdorfer

Image courtesy of EUROfusion

*Matthias Willensdorfer at ASDEX Upgrade*

When experiments are running at ASDEX Upgrade, you can find Matthias Willensdorfer in the control room. Sitting between 30 other scientists, his task is to ensure that the electron temperatures measured inside the tokamak, the device responsible for producing controlled fusion reactions, are correct.

Whenever there is a failure in the complex setup of his diagnostics, Matthias has to rush to resolve it. It could be a power supply breaking down in one of the components or a device deep in the signal chain not working correctly. And he has all of twenty minutes to do this before the next cycle of the experiment starts. "It can be exciting… and stressful," he says with a smile.

Matthias joined the Max Planck Institute for Plasma Physics in Garching, Germany, as a EUROfusion fellow after completing his PhD and working as a guest scientist at ASDEX Upgrade. He says that running experiments is just one facet of his job. "You can spend anything from a few months to a few years developing and building new diagnostics or planning new experiments," Matthias explains. Experimental work and the anticipation of the results make fusion research exciting for him. "Fusion science combines several fields such as fluid dynamics, electrodynamics and plasma physics… it never gets boring."

By delving into physics, data analysis and programming, Matthias is striving to understand the response of the plasma to external magnetic perturbations produced by additional coils. Fusion plasmas can develop various kinds of instabilities and some of them, such as the edge localised modes (ELMs), have the potential to damage the inner lining of the wall of a tokamak. "External magnetic perturbations, though small, can be used to mitigate such ELMs," explains Matthias. "In theory, the plasma can weaken or amplify these perturbations and can therefore change the behaviour of these edge instabilities. My task is to measure and characterise this response and compare it with different theories."

The experiments, data analysis and programming aside, Matthias says that there was also some idealism behind his decision to pursue fusion research. "The energy problem is huge, and I want to do something about it." And fusion research it was.

## Mike Dunne

Image courtesy of EUROfusion

*Mike Dunne at ASDEX Upgrade*

Mike Dunne's decision to take up fusion research was rather accidental. Having completed a bachelor's degree in astrophysics and physics, Mike was on the hunt for suitable PhD options when his professor informed him about a position in plasma physics. "Since I was planning on studying some kind of fluid or plasma physics anyway, it wasn't such a big jump," says Mike, who went on to obtain his PhD before taking up his current position as a EUROfusion fellow at the Max Planck Institute for Plasma Physics in Garching, Germany.

For Mike, now is perhaps the most exciting time to be involved in fusion research. "You're right on the edge of everything … the subject is growing rapidly around you as ITER [the next-generation fusion experiment] is being built, as plans for demonstration reactors are being made, and [it is exciting] knowing that you're right in the middle of it, trying to figure out some of the key issues and understand what's going on."

Being part of a potential game-changer in the energy landscape is exciting in itself, but for a physicist, fusion research is truly fascinating. Mike works on what is known as boundary physics: what happens at the plasma edge in a fusion experiment. "There are two separate parts here," he explains, "one of which is inside the confined plasma, and one which is outside. The inside layer is quite narrow, only 2 cm over a 50 cm plasma radius, but separates a tremendous amount of heat from the inside, where fusion will happen, and the colder outside, where the machine walls are. The layer outside of the confined plasma is where particles and heat are 'exhausted' from the plasma and pumped away."

The heat within the inner layer is directly proportional to the fusion power that can be extracted from an eventual power plant. "What I've been working on lately is how these two [layers] interact with each other," he adds. Understanding this interaction will influence the design and operational conditions of future fusion power plants.

Because of growing anticipation and excitement about fusion power and technology, Mike says that the fusion community in Europe has become vibrant and integrated. "There are more opportunities for communication, for discussing your results and ideas with other people," he explains. "Science is based on collaboration and communication so, apart from data analysis, setting up experiments and programming, reading other people's papers, listening to talks and lectures, preparing posters and talks for conferences are all part of a typical day," he says. "All that and coffee… coffee is definitely involved."

### Web reference

w1 To learn more about Eurofusion visit https://www.euro-fusion.org/. For a list of EUROfusion articles in *Science in School*, see www.scienceinschool.org/EUROfusion

Misha Kidambi is a communications officer for EUROfusion based at the EUROfusion programme management unit in Garching, Germany.

# Student competition: the search for the strangest species on Earth

## Encourage your students to enter our writing competition – and see their work published.

Image courtesy of John Hann; image source: Flickr

By Eleanor Hayes

We know that evolution has come up with some bizarre adaptations to life on Earth. Carnivorous plants, stick insects and some seriously smelly mushrooms are just some of the more familiar examples. However, it is not only animals, plants and fungi that can amaze and delight us with their variety - if you look down the microscope, you might be astonished too.

In this competition, we invite you to do your own research – to investigate the weird and wonderful life on Earth and to choose the species you think is strangest.

What makes that species the strangest? Is it how it looks? What it eats? How it moves? Where it lives? How it reproduces? Can it perform amazing feats – dive deep, fly high, survive extreme conditions? Do you know *how* it can do these things? In your explanation, can you apply what you have learned in lessons other than biology? What physical principles is the organism exploiting? What chemical reactions?

A panel of scientists and science editors will judge the entries. If you can convince us that your choice really is the strangest organism on Earth, we'll publish your entry in *Science in School*. For each of the three winning entries, a scientist working on that type of organism will write a short comment on the entry.

## General rules

1. Entries are welcomed from students at primary or secondary schools (or other educational institutions with students up to the age of 19) anywhere in Europe.
2. There will be one winner for each category, according to the author's age on the date of submission: 4- to 10-year-olds, 11- to 15-year-olds, and 16 and over.
3. Entries may be submitted individually or by groups of students (only one entry per individual or group). Group entries will be judged in the category of the oldest group member.
4. In writing and *in your own words*, explain why you think this is the strangest organism on Earth.
5. Don't forget to include the scientific name (e.g. *Homo sapiens* or *Lucilia sericata*).

6. Only real species (living or extinct; animals, plants, fungi, micro-organisms or viruses) may be chosen. Mythical species (e.g. unicorns) or individual organisms (e.g. Paul the octopus) will not be considered.
7. Hand-written entries will not be accepted.
8. Include your name and date of birth, school address, and your teacher's name and contact details (postal and email addresses).
9. The deadline for submissions is 31 January 2017 (midnight CET).
10. Entries should be submitted electronically via the *Science in School* website: www.scienceinschool.org/2016/issue36/entry

## Additional rules for students aged 11 and over

11. Maximum word count (excluding sources and image information): 750 words.
12. All written submissions must be in English.
13. At the end of your text, list *all* the sources of your information (websites, books, TV documentaries, your teacher, etc; provide enough details for other people to find the sources).
14. Optionally, you may include *one* picture or video of the organism, in addition to the text.
    a) You may want to draw, photograph or video the organism yourself, in which case you should state that it is your own work.
    b) If you submit a picture or video you found elsewhere, specify exactly where you found it (e.g. Internet address or full reference, detailed enough for other people to find it).
    c) If you submit a video, do *not* send the video file to us – just provide the web link to the video (e.g. uploaded on YouTube or available on another website). Videos should be no more than two minutes long.

## Additional rules for pupils aged 4–10

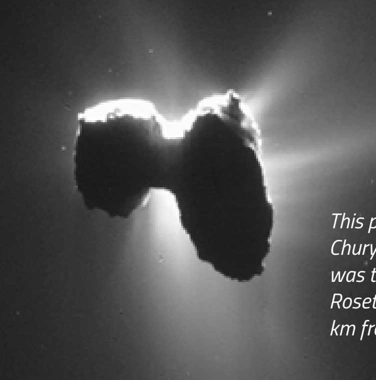
11. All entries must be accompanied by a picture of your chosen organism. You may use paints, pencils, pens, crayons, pasta, beans, fabric or other materials for your picture, but Photoshop and other computer software should not be used. You may either submit the original picture or a photograph of it.
12. Maximum word count: 50 words.
13. Written submissions may be made in the language of instruction at your school.

Entries that do not comply with the rules will not be considered for the competition.

Image courtesy of Bernard Dupont; image source: Flickr

Image courtesy of Kalle Gustafsson; image source: Flickr

# Teaching with Rosetta and Philae



*This photo of comet 67P / Churyumov-Gerasimenko was taken when the Rosetta spacecraft was 329 km from the nucleus.*

Image courtesy of ESA

## How a great achievement of the European Space Agency can become an inspiration for your students

By Maria Eleftheriou

On 12 November 2014, after ten years of travelling together in space, the small robot Philae left the spacecraft Rosetta to land on comet 67P / Churyumov-Gerasimenko (67P). It was the first time in history that an expedition successfully landed on a comet.

The adventurous landing of Philae on comet 67P can be used to study Newton's Laws, and students can use real data to work out the acceleration of gravity on the comet. I developed this project for students aged 15–18 who have already been taught Newton's first and second laws of motion and who understand the theory of an object in free fall. You will need three teaching hours. In the first hour, introduce the problem and ask students to find useful information from the web. In the second hour, students find the acceleration of gravity on the comet using the laws of physics that they already know. In the third hour, students use simulations to find the acceleration of gravity on the comet. Finally, they compare the two different methods.

## Hour 1: Introduction and data collection

1. Show your students *Ambition*, a short video from ESA[w1], and then present Rosetta and Philae's latest achievement using videos and images from the ESA's websites[w2,w3]. Ask your students why they think this expedition is so important and what ESA wants to learn about comets.
2. Present the simulation video[w4] showing how Philae suffered a malfunction to two anchoring harpoons and so bounced twice before reaching its final destination on the comet 67P. Those two bounces are very important in this project to work out the gravitational constant of the comet.
3. Organise the class into teams and ask them to search the web for information such as the mass of Philae, the velocity of its descent, and the height and duration of the two bounces. Your students should find that Philae left Rosetta 22.5 km above the surface of 67P. Philae reached 67P with a velocity ($v$) of 1 $m\ s^{-1}$ and then bounced for 1 hour and 50 minutes, reaching 1 km in height with a velocity of 0.38 $m\ s^{-1}$. The second bounce lasted 7 minutes with an initial velocity of 0.03 $m\ s^{-1}$.

## Hour 2: Working with the physical laws

1. Ask your students about the motion of Philae as it descends towards the comet. Is it possible to divide the motion into steps? For example, students can think first of the free fall of Philae, then the first bounce as a constant deceleration, and then free fall again. The second bounce can be thought of in a similar way.
2. Ask your students to calculate the acceleration of gravity on the comet using the data that they found in the previous teaching hour. If the students use the equation $v = v_0 - gt$ and assume deceleration with constant $g$ (a homogeneous gravity field) then when $v = 0$, $v_0 = 0.38$ $m\ s^{-1}$ and t = 55 min (the total bounce time of 110 minutes divided by two), the acceleration of gravity on the comet will be approximately $10^{-4}$ $m\ s^{-2}$.
3. Ask your students to perform the same calculation using the second bounce of Philae. Their result should be of the same order of magnitude but not exactly the same value because the comet has an anomalous shape and its gravity field is not homogeneous (Sierks et al., 2015).
4. Finally, ask your students what would have happened if Philae had fallen to Earth instead of the comet. What



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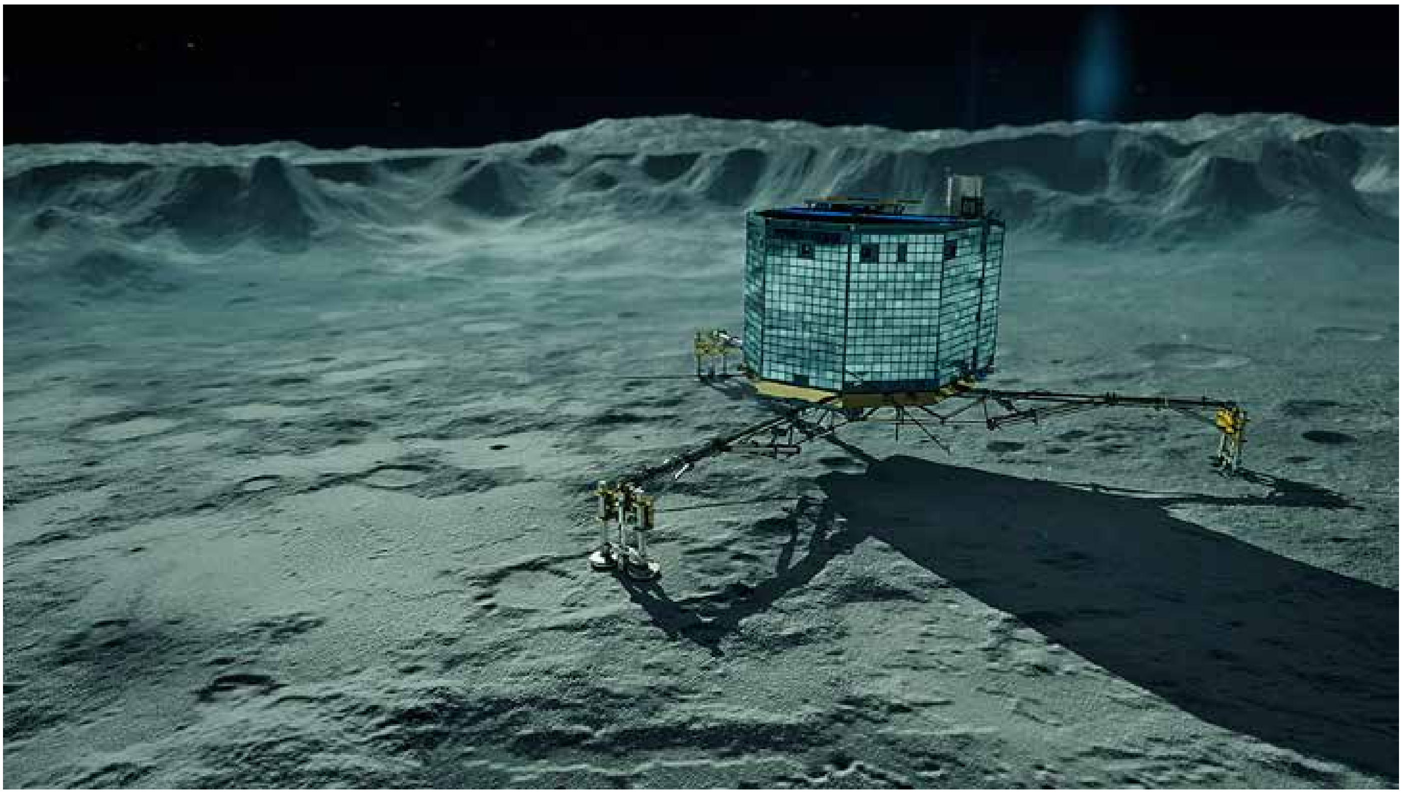
Image courtesy of DLR German Aerospace Centre; image source: Flickr



*Artistic rendering of Philae on comet 67P / Churyumov-Gerasimenko*

would be the duration of the bounces?

## Hour 3: Simulating the fall

The next step requires physics simulation software such as the Interactive Physics (IP) software, which is free for schools in Greece. If you cannot download this software or it is not freely available in your country, you can use the free Step[w5] software as an alternative. Whichever simulation software you use, we assume that your students are already familiar with it. If they are not, you should first spend an hour helping them understand how the software can be used.

1. Ask your students to use the software to simulate Philae's landing. They will need a small object to play the role of Philae and a bigger object to play the role of the comet. They can then play with the shape, dimension and mass of both objects.
2. The students should start by modelling the comet as a sphere with a radius of 1 km (the largest dimension of the comet is 4 km).
3. Ask your students to perform a simulation with a homogeneous gravity field of $g$ = 9.81 m $s^{-2}$ as on Earth.
4. Tell the students to reduce the value of the acceleration due to gravity and to run the simulation again.
5. The students should continue with the simulations after adjusting different variables. Eventually they should use the real mass for Philae and 67P as well as the comet's true dimensions.
6. In the final stage, the students should deactivate the homogeneous field and activate planetary interaction between the two objects. The force on Philae can be calculated as 0.066 N on the surface of the comet, giving an acceleration of gravity on the surface of 6.6 $10^{-4}$ m $s^{-2}$, because

REVIEW

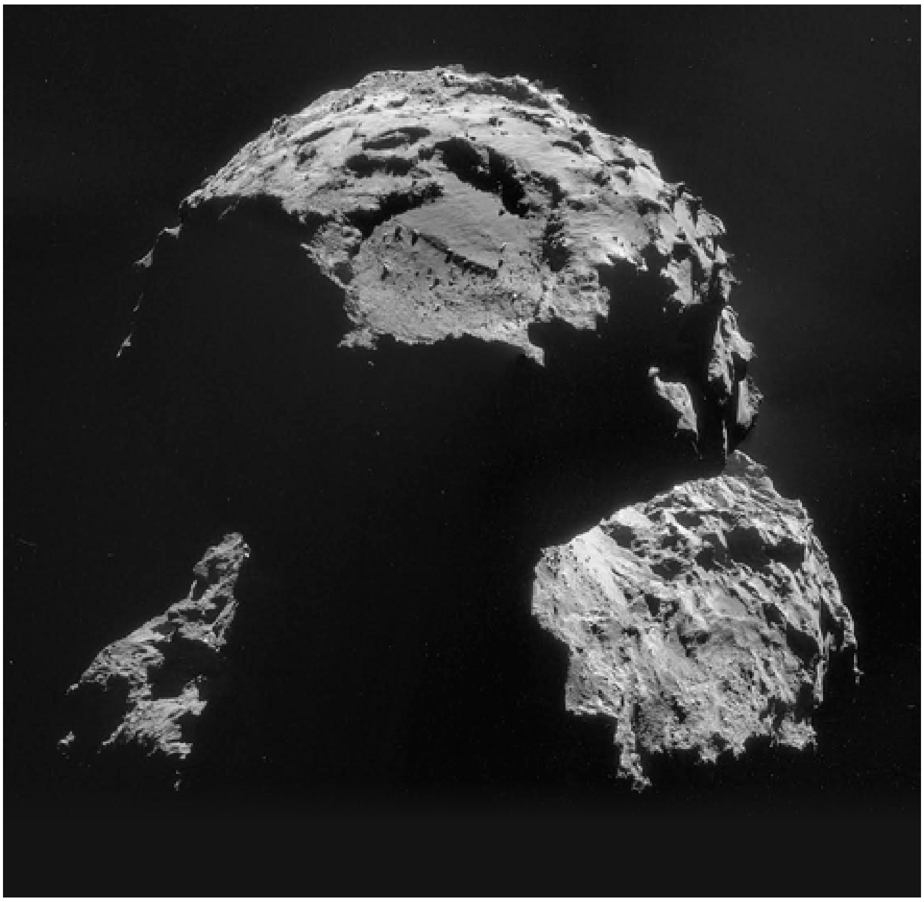
### ✓ Ages 16–19

Space exploration is a very rich subject and this article can be used in many different ways. For instance, the orbit and periodicity of 67P can be used to study the evolution of human knowledge about the motion of space objects, from Kepler and Galileo to Newton and Halley.

The article can be used for further insight into the concept of escape velocity and for discussions regarding the enormous distances involved in space travel, the inherent difficulty associated with human space travel, and ultimately, our position in the Universe and our loneliness in space – subjects that go well beyond science.

Duarte Nuno Januário, Portugal

Image courtesy of ESA.



*The Agilkia landing site on comet 67P / Churyumov-Gerasimenko*

the mass of Philae is 100 kg. This value should be of the same order of magnitude as the results of the previous method and also very near to reality[w6].

In my experience, students are enthusiastic about the project: two totally different methods give similar answers that coincide. The results are also very close to the real value of the acceleration of gravity. Students work as researchers, finding the necessary data from reliable websites as well as testing the parameters of the problem to find the acceleration of gravity on comet 67P using theory and simulations. Space science is very attractive but unfortunately is not included in the Greek physics curriculum in lyceum (for ages 15–18). This project is an opportunity to learn about ESA's important achievement while still following the regular curriculum. Students use Newton's first and second laws as well as the equations of motion for the free fall of an object before using Rosetta's expedition, and more specifically the trajectory of Philae, to demonstrate a real-life example of the equations of motion. Students can also use their ICT skills to perform the simulations. In general, such a challenging problem gives inspiration to students.

It is possible to reduce the three teaching hours to two if you don't have enough time. For example, you can skip the section where students search the web and instead give them the data directly. You can also adjust the project to work with students aged 12–14, for example by spending more time on the introduction and skipping the simulations.

## Acknowledgement

Part of this article comprised the main issue in an educational scenario that I submitted to the 2014–2015 Open Discovery Space Contest for the best learning scenario. My scenario received the pan-European prize[w7].

## Reference

Sierks H et al. (2015) On the nucleus structure and activity of the comet 67P/Churyumov-Gerasimenko. *Science* **347**: aaa1044. doi: 10.1126/science.aaa1044

## Web references

w1 To watch *Ambition*, a short video from ESA, visit: https://youtu.be/H08tGjXNHO4

w2 For more information about the Rosetta mission, visit the ESA's dedicated Rosetta website: http://rosetta.esa.int

w3 Even more information on Rosetta and Philae can be found on the ESA's education website: www.esa.int/education

w4 To watch a short video simulating Philae's two bounces before landing on 67P, see: https://youtu.be/bpAH3DtRBjo w5 – Detailed information about the Rosetta mission can be found on Quora, a crowd-sourced question-and-answer website. See: http://tinyurl.com/h9f7sf2

w5 Interactive Physics is free for schools in Greece. If this is not true in your country you can purchase the software from https://www.design-simulation.com/IP/index.php. To download the free Step physics simulator and the accompanying user documentation, visit: https://userbase.kde.org/Step

w6 For a news report of Philae's successful descent onto 67P, see: http://tinyurl.com/hgya3ex

w7 The Open Discovery Space Contest 2014–2015 sought to develop innovative learning scenarios, foster new knowledge and create awareness in the education community. For more information about the contest and its participants, read: http://issuu.com/signosis/docs/ods-contest-brochure

## Resource

A version of this article that deals with the same topic, but is not a direct translation, has been published in the Greek-language magazine Φυσικές Επιστήμες στην Εκπαίδευσ (Physical Sciences in Education). For more information, see: http://physcool.web.auth.gr/ or use the direct link: http://tinyurl.com/z8ljedw

Maria Eleftheriou is a science teacher in the Lyceum of Tzermiadon, Lassithi Plateau, Crete, Greece. A physicist with a master's degree in condensed matter physics and a PhD in computational physics, she is trying to bring real research into the school.

# Smart measurements of the heavens

## Get your students to use their smartphones for some hands-on astronomy.

Image courtesy of iStockphoto

By Gerhard Rath, Philippe Jeanjacquot, Eleanor Hayes

Exactly where are you at this moment? One way to find out would be to use the satellite positioning function (often known as GPS) of your mobile phone. In the past, though, you might have relied on the stars to tell you where you were – especially if you were a sailor at sea in a largely featureless landscape.

In this article, we describe some of the early developments in navigation based on the stars, and show how these traditional techniques can be reproduced in the classroom using simple apps on a smartphone. Your students can then use the GPS

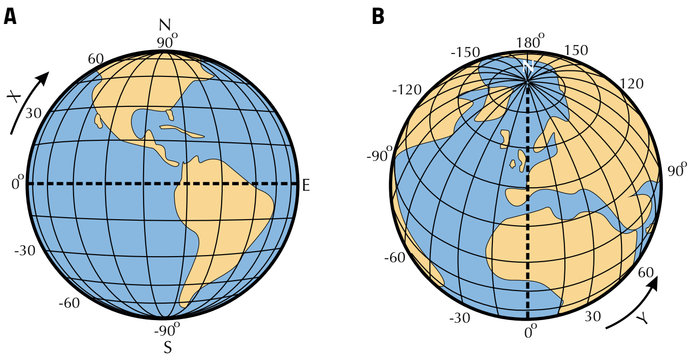



Image courtesy of Djexplo; image source: Wikimedia Commons

*Figure 1A: Lines of latitude run parallel to the equator (E), beginning at 0° at the equator and reaching maxima of 90° at the North Pole (N) and -90° at the South Pole.*

*Figure 1B: Lines of longitude run from pole to pole (N and S), starting at 0° at the Royal Observatory, Greenwich, in London, UK.*

REVIEW

- ✓ Physics
- ✓ Maths
- ✓ Astrophysics
- ✓ Space
- ✓ History
- ✓ Ages 14–16

Ever wanted to know where you are? Use the Sun or the stars to calculate your latitude using just your smartphone, some sticky tape and a drinking straw. These activities could be used not only for a physics lessons on astrophysics or space, but also in an interdisciplinary lesson on history and early navigation, or mathematics and the uses of trigonometry.

The article also provides an interesting pan-European project idea, whereby schools at different latitudes do the same experiment and use their results to calculate the circumference of Earth.

Graham Armstrong, UK

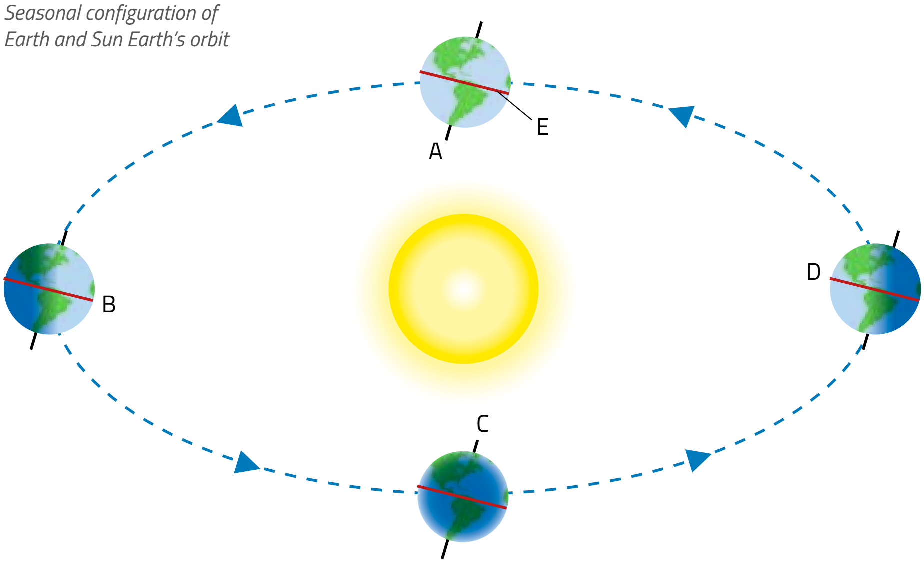



Image courtesy of Nicola Graf

*Figure 2. At the March and September equinoxes (A and C, respectively), the equator (E) is the closest part of Earth to the Sun. At other times of year, the tilt of Earth's axis of rotation means that either the northern or the southern hemisphere is closer to the Sun (B and D, respectively).*

function on their smartphones to check the accuracy of their work before considering potential sources of error.

Suitable for students aged 14–18, the two activities link history, astronomy, geography and mathematics: determining your latitude (figure 1) using the Sun, and determining your latitude using the star Polaris. Details of a collaborative activity between schools, to calculate the circumference of Earth, can be downloaded from the *Science in School* website[w1]. The three activities require little more than a smartphone and take no more than an hour each.

## Determining your latitude using the altitude of the Sun

'What is noon?' may seem like an odd question. Surely noon is 12 o'clock midday? Strictly speaking, though, solar noon is the moment when the Sun crosses your meridian, or line of longitude, and will usually appear to be either due north or due south. This is when the Sun is at its highest point in the sky and shadows are at their shortest. It is at this moment that the position of the Sun can be used to determine your latitude, or angular distance from the equator.

How does this work? Let us consider the situation at one of the equinoxes (approximately 20 March and 23 September each year), when the plane of the equator runs through the centre of the Sun (figure

- A: Imagine you are standing on the equator, latitude 0°, at noon: the Sun is directly overhead. If you measured the altitude of the Sun (its angle of elevation above the horizon), you would find it to be 90° (figure 3A). Subtracting this number from 90° gives 0°, which is your latitude. (We stated that at noon, the Sun is *usually* either due north or due south. At the equinoxes, it is directly overhead.)
- B: A friend of yours is standing at the North or South Pole (latitudes 90° N or 90° S, respectively). At that same moment, she would see the Sun lying directly on the horizon: an altitude of 0° (figure 3B). Subtracting that from 90° gives 90°, which is her latitude.
- C: Another friend is on the same meridian as you are, but at a latitude of 30° N. Because he is on the same meridian, it is also noon for him, but he would observe the Sun at an altitude of 60° above the horizon (figure 3C). Subtracting that from 90° gives 30°: his latitude.

*Latitude = 90° - altitude of the Sun at noon at the equinox*
*(Equation 1)*

How can we use this knowledge in practice? In the 15th and early 16th

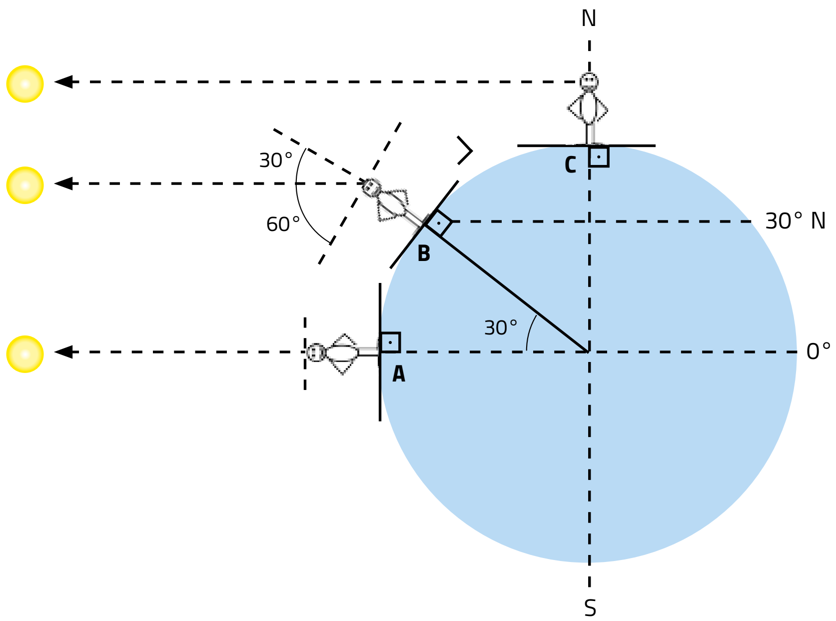



Image courtesy of Gerhard Rath

*Figure 3. At the equinoxes, latitude can be calculated by subtracting the Sun's noon altitude from 90°.*
*A: At the equator, the Sun is directly overhead (altitude = 90°; latitude = 0°).*
*B: At the poles, the Sun lies on the horizon (altitude = 0°; latitude = 90°).*
*C: At a latitude of 30°, the Sun's altitude is 60°.*

centuries, many navigators used mariner's astrolabes to measure the Sun's altitude and thus calculate their ship's latitude. The mariner's astrolabe was essentially an inclinometer: suspended in the vertical plane, it was pointed at a celestial body, for example the Sun. A rotating alidade was used to read the altitude of the celestial body from the scale around the outer ring (figure 4).

While a mariner's astrolabe is comparatively simple to build[w2], it is also easy to use a smartphone to measure the altitude of the Sun with the aid of an inclinometer app. Before we do this, however, we need to introduce a refinement so that our calculations work all year round.

Due to the tilt of Earth's rotational axis (23.45°) and the fact that Earth orbits the Sun, it is only at the equinoxes that the Sun appears directly above the equator. Starting at the March equinox, the position of the Sun at noon appears to move north of the equator, reaching a maximum angle of +23.45° at the June solstice, returning to 0° at the September equinox, and moving south of the equator to reach -23.45° at the December solstice. This angle is known as the Sun's declination (figure 5).

Thus the Sun's noon altitude, which early navigators measured with a mariner's astrolabe and which we can measure with a smartphone, depends on both the time of year – and therefore the Sun's declination – and our latitude (figure 6):

*Altitude of the Sun at noon = 90° + declination - latitude*
*(Equation 2)*

Or, rearranged:

*Latitude = 90° - altitude of the Sun at noon + declination*
*(Equation 3)*

To determine the declination of the Sun, early navigators used tables of data or sophisticated mariner's astrolabes with the declination of the Sun marked on the rotating disc. We can obtain the same information from a planetarium app, after which we can measure the Sun's elevation to determine our latitude.

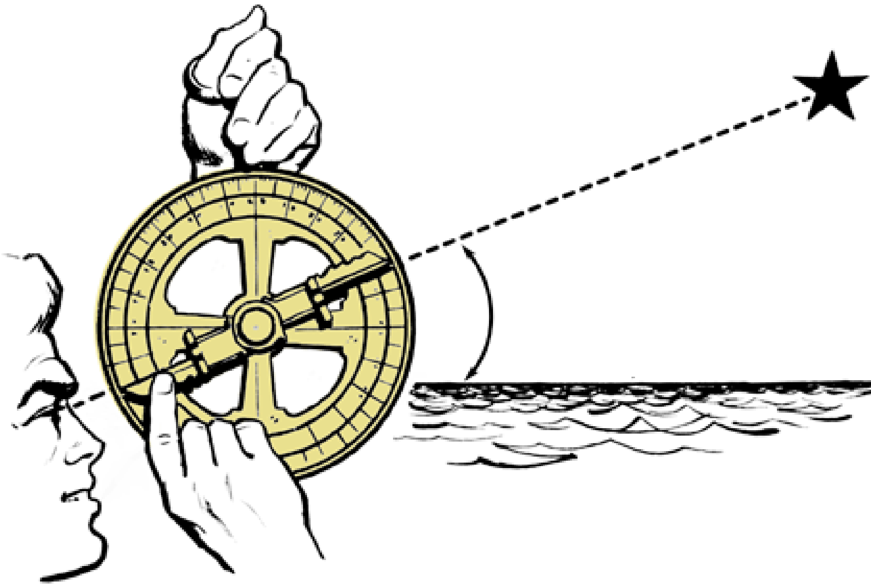


Image courtesy of Pearson Scott Foresman; image source: Wikimedia Commons

*Figure 4. Suspended from a ring, the marine astrolabe hangs in a vertical plane. The navigator would align the plane of the astrolabe to the direction of the object of interest, e.g. the Sun or another star. The alidade was rotated to point at the star and the altitude was read off the scale around the astrolabe.*

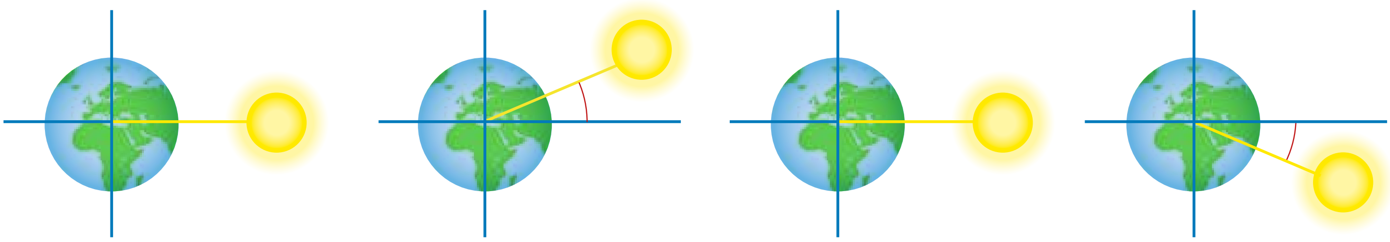


Image courtesy of Nicola Graf

*Figure 5. As Earth orbits the Sun, the position of the Sun at noon rises and sinks with respect to the equator. A: At the March equinox, the Sun lies directly above the equator (declination 0°); B: at the June solstice, it appears directly over the Tropic of Cancer (declination 23.45°); at the September equinox, the declination returns to 0°; and C: at the December solstice, the Sun lies directly above the Tropic of Capricorn (declination -23.45°).*

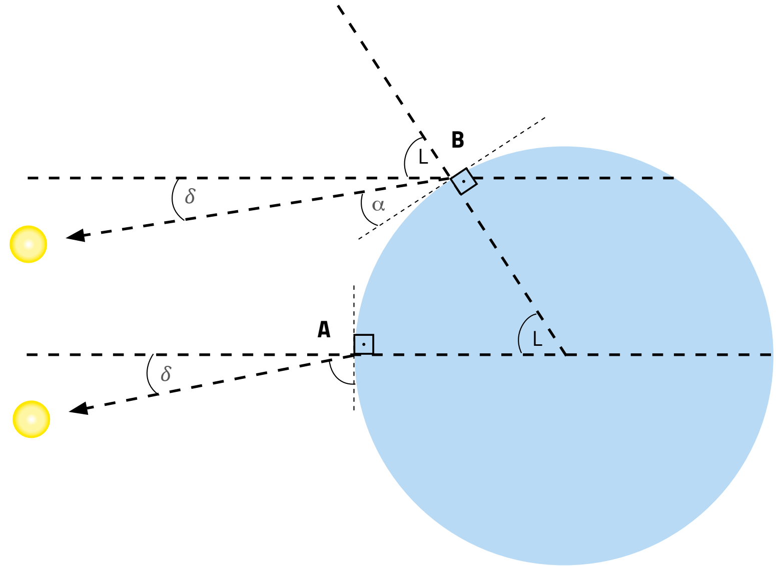



Image courtesy of Gerhard Rath

*Figure 6. The relationship between latitude, the Sun's altitude at noon, and its declination.*

*A: At the equator (latitude 0 °). Except at the equinoxes, the Sun is not directly overhead at noon but somewhat closer to the horizon. This angular difference determines the Sun's declination (δ): positive when the Sun lies due north or – as in this example – negative when it lies due south of the equator. The Sun's altitude (α) is its elevation above the horizon, thus 90 ° - α + δ = 0 °, the latitude of the equator.*

*B: At an unknown latitude (L). The Sun's declination (δ) is the same as at the equator and has a negative value. Using this figure and the measured elevation of the Sun above the horizon (α), we can calculate 90 ° - α + δ = L °, the latitude of our location.*

## Materials

Each group of students will need:

- Smartphone with an inclinometer app and a planetarium app installed
- Drinking straw
- Sticky tape
- Spirit level (optional)

## Procedure

To determine their latitude, your students will need to:

1. Use sticky tape to fasten the drinking straw along one side of the smartphone (figure 7). This is the alidade.
2. Use the planetarium app to determine the local time of solar noon and the Sun's declination.

   Depending on your location within your time zone, solar noon may be as early as 11.30 am, and because of daylight saving, it could be as late as 1.30 pm.
3. Holding the smartphone with the drinking straw on the upper edge, point the straw at the Sun. When the shadow of the straw is at its smallest, the smartphone is correctly aligned (figure 7).
4. Using the inclinometer app, read off the angle of elevation of the Sun.
5. Use equation 2 to estimate the latitude.

Alternatively, to enable the students to point their smartphones more precisely at the Sun and thus measure the elevation of the Sun more accurately, they could build a support that can be placed on a tripod. Full details of materials and construction are available online[w3].

Image courtesy of Gerhard Rath

*Figure 7. Measuring the Sun's elevation. When the shadow of the straw is at its smallest, the smartphone is correctly aligned.*

## Discussion

Ask your students to compare their results with the exact latitude given by the GPS function on their smartphone or by using the planetarium app. How accurate was their calculated value? What sources of error might there be?

Of course, the accuracy depends on the precision of the students' work, e.g. how exactly the straw was aligned with the edge of the phone or whether the shadow was really at its smallest. For maximum accuracy, the measurements should be taken at noon, but a few minutes either side will not affect the estimate much because when the Sun is at its highest, its change in altitude is slowest.

Smartphones are able to measure slope angles with a precision of 0.1°, which is not bad. It could be interesting, Image courtesy of Udo Kügel; image source: Wikimedia Commons

*Figure 8. A long-exposure photograph of Polaris (centre). While other stars appear to rotate around the poles, Polaris appears fixed.*

Image courtesy of Gerhard Rath, based on an image from Stellarium

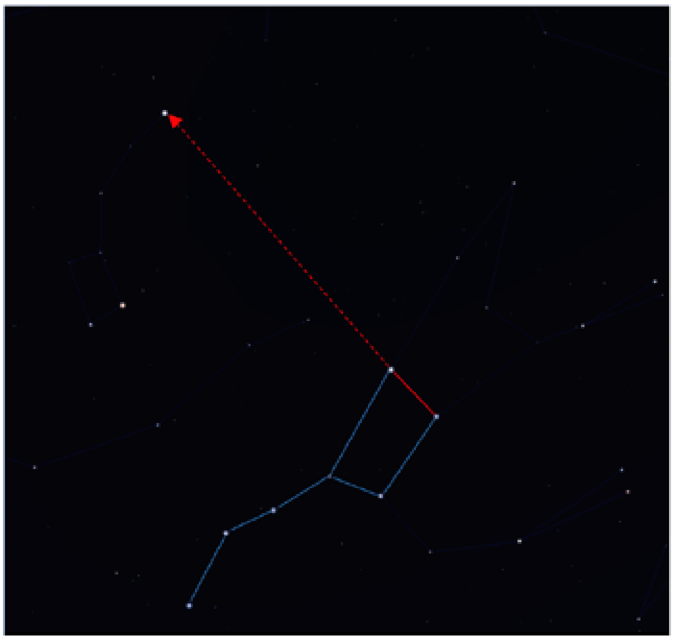


*Figure 9. Locate Ursa Major, then extend an imaginary line from the furthest two stars of the tetragon.*

however, to calibrate the inclinometer app with a spirit level to see if a reading of 0.0° truly is horizontal.

You could also ask your students why they think that although latitude could be determined in the ancient world, it was only in the 18th century that it became possible to measure longitude.

The answer lies with Earth's rotation: 360° in one day or about 15° every hour. Thus by comparing the local time with the time at a reference point of known longitude, it is possible to determine your longitude. Local time could be estimated from the Sun, but the difficulty was the time at the reference point: a clock that kept time accurately, even on board a moving ship, was only invented in 1759, by John Harrison.

## Determining your latitude using the altitude of Polaris

In the previous activity, we measured the altitude of the Sun at local noon: as the Sun crosses your meridian. It is at this moment – and only at this moment – that the Sun will appear to be either due south or due north. If your students were to calculate their latitude from the Sun at other times of day, their results could be wildly inaccurate. Fortunately, there is another method that is not so time critical – although it only works in the northern hemisphere and needs to be done after dark – relying on Polaris, the North Star.

While the positions of other stars seem to change during the night, Polaris appears to remain fixed in the north (figure 8), because its position is in line with Earth's rotational axis. If you were to stand at the North Pole (latitude 90° N), Polaris would appear to be directly above you, at an altitude of 90°. At the equator (latitude 0°), in contrast, Polaris would appear to be on the horizon, at an altitude of 0°. Thus the altitude of Polaris is equal to your latitude: if you were in Paris, at a latitude of around 49° N, you would measure the altitude of Polaris as about 49°.

*Latitude = altitude of Polaris*
*(Equation 4)*

Early navigators used a marine astrolabe to navigate by the stars, as they did when navigating by the Sun. Again, we can use a smartphone.

### Materials

- Smartphone with an inclinometer app and a planetarium app installed
- Binoculars (optional)
- Torch (optional)

### Procedure

It is simpler to calculate your latitude from Polaris than from the Sun: it is not necessary to consider the declination, because the position of Polaris remains unchanged throughout the year.

How can you find Polaris? Look for the constellation of Ursa Major, also known as the Big Dipper or the Plough (figure 9). Extend an imaginary line upwards from the furthest two stars of the tetragon, extending about seven times their distance. The first bright star along that line is Polaris, which is part of Ursa Minor, the Little Dipper. Alternatively, you can use the planetarium app and the search function.

Because it is much fainter than the Sun, observations of Polaris can be made directly, without an alidade, but its faintness also makes it rather difficult to locate. It can help to train your measuring skills by practising on brighter objects such as planets or the Moon.

Ask your students to:

1. Hold their smartphones with the long side uppermost, then point it

directly at Polaris, looking along the face of the phone.

They will need some ambient light for this, to recognise the edge of the phone in the dark.

6. Using the inclinometer app, read off the angle of elevation of Polaris. This is the estimate of your latitude.

Alternatively, working in pairs, they can use binoculars. One student should point the binoculars at Polaris so that the star is in the centre of the visual field (rest the binoculars on, for example a wall to keep them steady). Another student should rest the smartphone on the binoculars and determine the angle of elevation using the inclinometer app. If necessary, calibrate the binoculars: lay them on a horizontal surface, place the smartphone on top and check the angle on the inclinometer app.

## Discussion

Ask your students to look up the altitude of Polaris in the planetarium app. How accurate was their measurement? How does their estimated latitude compare to the exact latitude given by the planetarium app or the GPS function on the smartphone? What sources of error can they think of, in addition to the ones discussed in the previous activity?

Although Polaris is a bright star, it is considerably fainter than the Sun, which makes it harder to get an accurate reading of its altitude.

Another source of error is the position of Polaris. We said that Polaris would appear to be directly above you if you stood at the North Pole: at an elevation of 90°. In fact, its elevation would be 89.3°, which introduces an error of 0.7° into your students' calculations, corresponding to about 100 km.

This method works best at medium latitudes. Very far north, it is hard to point at the star, which appears above your head. Near the equator, Polaris appears close to the horizon, which means there are disturbances introduced by the atmosphere.


## Acknowledgements

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

At Science on Stage workshops in Vienna, Austria, and Berlin, Germany, as well as discussions over email and the open-source learning platform Moodle, 20 teachers from 14 European countries worked together to develop 11 teaching units that show how smartphones and apps can be used in maths, physics, chemistry or biology lessons. These units were then published in 2014 by Science on Stage Germany as iStage 2: Smartphones in Science Teaching[w4]. The project is supported by SAP.

In addition to Gerhard Rath and Philippe Jeanjacquot, Pere Compte from Spain and Immacolata Ercolino from Italy were very involved in the development of this project. Martin Pratl provided valuable assistance with the article text.


## Web references


w1 Download instructions for a collaborative activity between schools, to calculate the circumference of Earth, from the *Science in School* website. See: www.scienceinschool.org/2016/issue36/isky

w2 Build your own simple mariner's astrolabe using instructions from the US National Oceanic and Atmospheric Administration. See: http://oceanservice.noaa.gov or use the direct link: http://tinyurl.com/zybuewb

w3 Learn how to build a support to attach your smartphone to a tripod, and thus measure the elevation of the Sun or Polaris more accurately. See: http://usuaris.tinet.cat/pcompte/mobile

w4 The *iStage 2* publication can be found on the Science on Stage website. See: www.scienceonstage.de or use the direct link: http://tinyurl.com/q65zxuc


## Resources

The Instructables website offers step-by-step instructions for locating Polaris. See www.instructables.com or use the direct link: http://tinyurl.com/jyx4c9g

Several inclinometer apps for smartphones are available online:

For iOS: Angle Meter (free and easy to use). See https://itunes.apple.com/fr/app/angle-meter-free/id436775826

For iOS: Theodolite (€6; very accurate and has a 4X digital zoom). See: https://itunes.apple.com/us/app/theodolite/id339393884

For Android: Théodolite Droid (free and easy to use). See https://play.google.com or use the direct link: http://tinyurl.com/prf586o

Star Chart, a planetarium app for smartphones, is free and easy to use:

For iOS: https://itunes.apple.com/us/app/star-chart/id345542655

For Android: https://play.google.com or use the direct link: http://tinyurl.com/78gaf6g

Philippe Jeanjacquot's video explaining the Eratosthenes activity (in French) is available on Youtube. See: http://bit.ly/JEA-eratosthene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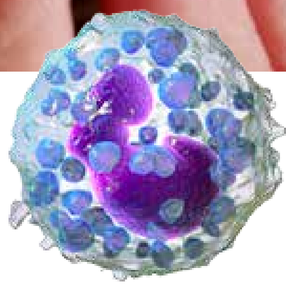
Eleanor Hayes is the editor-in-chief of *Science in School*. She studied zoology at the University of Oxford, UK, and completed a PhD in insect ecology. She then spent some time working in university administration before moving to Germany and into science publishing in 2001. In 2005, she moved to the European Molecular Biology Laboratory to launch *Science in School*.

Image courtesy of Anna gutermuth; image source: Flickr

# Ready, set, infect!

## Recreate the epic fight between pathogens and the immune system in your classroom.



*Basophil, a type of white blood that releases histamines*

Image courtesy of BruceBlaus; image source: Wikimedia Commons

By Emily Kang

Anyone who has seen live footage of a human white blood cell chasing and capturing a bacterium in the body would think he or she was witnessing a game of cops and robbers. The white blood cell indefatigably chases the invader until the cell reaches its goal of ingesting and then 'spitting out' the villain. Unfortunately, the excitement of the chase does not easily translate onto the written page of a science textbook.

'Ready, set, infect!' is a role-playing game for middle-school science classrooms (ages 11–14). It allows students to experience how dynamic the human immune system must be to protect the body against infection via three lines of defence: skin; white blood cells (through inflammation); and antibodies (via the immune response).

The game can be taught in one 45-minute lesson and can be played as an introduction to the immune system or as a follow-up lesson. Rather than learning through textbook diagrams and direct instruction, students actively engage in and develop a model of how each component interacts with the other to protect the body from invasion and illness. Students can also use their model to argue whether or not a hypothetical patient's blood test shows evidence of an immune response. Teaching through role-playing games allows students to engage in the messy nature of science.

REVIEW

- ✓ Biology
- ✓ Immune system
- ✓ Ages under 11–14

The article introduces the immune system using a role-playing game, in which students are either antigens, antibodies or white blood cells.

The game should make students aware that there are three lines of defence, the first two of which are non-specific and the third specific. The activity can be easily carried out but the teacher should make sure that students don't run around or push each other violently.

Monica Menesini, Liceo Scientifico A Vallisneri, Italy

Image courtesy of Pedro Dias; image source: Flickr

Image courtesy of Gavin White; image source: Flickr

### Antibody versus antigen competition

The immune system relies on three main lines of defence, two of which are non-specific to the pathogen, and one of which is specific to fighting one particular type of germ.

#### Non-specific defence

1) Skin (or mucus or cilia): skin is an effective barrier to the entry of micro-organisms, while cilia, tears, sweat, saliva, mucus and earwax trap or wash micro-organisms away.
2) Inflammatory response (white blood cells): various types of white blood cell either surround and engulf micro-organisms (e.g. neutrophils and microphages) or kill their targets by releasing damaging chemicals (e.g. natural killer cells or basophils). For example, histamines (released by basophils) promote the dilation of local blood vessels and the release of further white blood cells from the vessels to enter the infected tissue.

#### Specific defence

3) Immune response (antibodies): a type of white blood cells known as B cells produce antibodies against foreign antigens (which are no longer called pathogens, as they now elicit an antibody response), while further white blood cells, T cells, enhance the immune response and kill foreign cells directly.

The game is a competition between two teams, in which students on one team represent an invading source of infection (antigens), and students from the other team are members of the human immune system (skin, white blood cells and antibodies).

## Materials

- Role cards (figure 1)
  These can be downloaded from the article page on the *Science in School* website[w1].

## Procedure

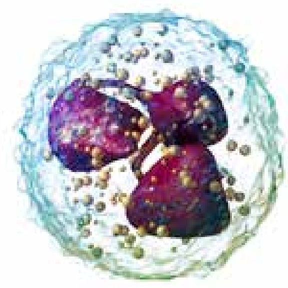
1. Before the lesson starts, you should cut the antigen–antibody cards along the dotted lines to separate the two roles. There are enough role cards for a class of 28 students, but extra cards can be copied for larger classes. The role cards can be enlarged or laminated for ease of use.
2. As part of a whole-class discussion, begin by asking students to share the last time they were ill and how long the illness lasted. You can ask follow-up questions such as "Have you ever wondered why your doctor checks the glands on the side of your neck?" and "How do you think you were eventually able to recover?".
   Students may mention the role of their immune system in the recovery process.
3. Store tables and chairs at the side of the classroom and clear enough space for students to walk quickly around the room. To ensure safety, no running is permitted during the activity. Tagging by touch must be gentle – no pushing.
4. Ask each student to pick a card with their eyes closed; it is important that students do not know who their matching antigen or antibody is before the start of the game. The cards will determine the roles of the participants as follows:
   a) Skin – this role is taken by the teacher, so that the rest of the class may participate in the game. The teacher is in charge of keeping the door of the classroom closed (the door remains unlocked but the teacher must keep the door from being opened by members of the opposite team, who are standing outside the classroom) until a cut or a breach in the body's mucus membrane is simulated. Then the teacher (or skin) opens the door and lets the antigens into the classroom.
   b) White blood cells (macrophages, neutrophils and natural killer cells) – these students are in charge of standing inside the classroom, by the door, to prevent invading antigens from proceeding further into the room. The macrophages and neutrophils must 'engulf' antigens by placing two hands on an antigen's shoulders. If only one hand

is touching the antigen, then it can escape and roam free. The natural killer cells should be provided with a plastic pipette filled with a small amount of water to simulate the release of damaging chemicals. Natural killer cells can only wet the right hand of an antigen to 'destroy' it.

If the antigens successfully make it past the white blood cells, then the white blood cells summon the third line of defence: the antibodies, who have been waiting until that stage.

c) Antibodies – these students are antigen-specific and should wait further inside the classroom. Their cards are uniquely shaped so that the students are allowed to capture only the student who carries the card with the complementary shape. This is why it is important that students do not know who their matching antigen or antibody is before the start of the game.

d) Antigens – these students remain outside the classroom door at the start of the game. When



*Neutrophil, a type of white blood cell that engulfs invading cells*

Image courtesy of BruceBlaus; image source: Wikimedia Commons

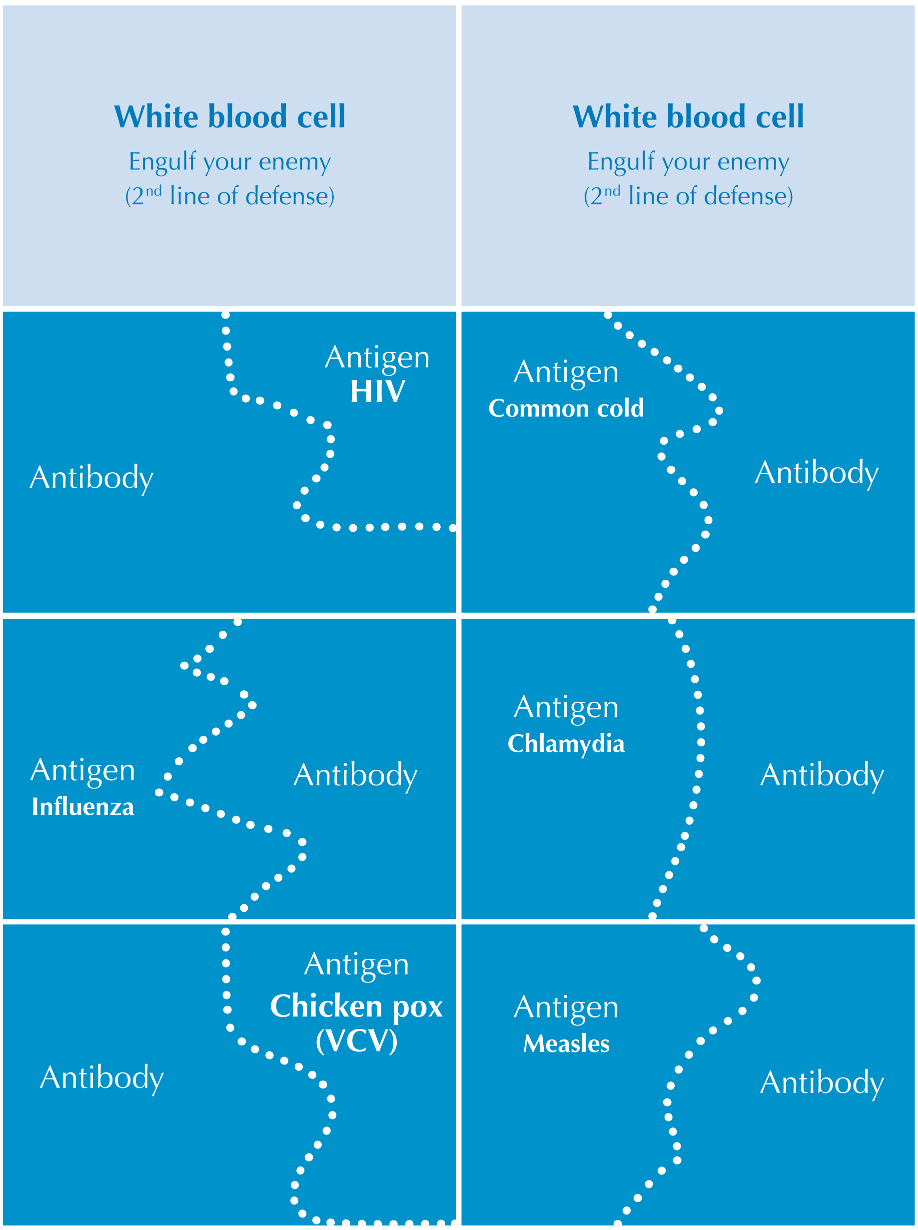



Image courtesy of Emily Kang

*Examples of 'Ready, set, infect!' role cards*

the teacher gives the signal, the antigens must try to enter the classroom (even though the skin prevents the antigens from entering). If the antigens are successful in passing through the first line of defence, then they must battle the second line (white blood cells), who will try to tag the antigens by touching the antigens' shoulders. If the antigens are successful in escaping the white blood cells, then it is up to the antibodies (the third line of defence) to tag the antigens. Once an antigen is tagged, it must present its card to the antibody. If the cards are a match, then the antibody and antigen sit down next to each other. If the cards do not match, the antibody must release the antigen and attempt to capture the next antigen until it finds and captures its match.

The teacher should act as the narrator, timekeeper and referee of the game. As the narrator, the teacher should commentate on the action (e.g. when the antigens pass each line of defence or how many antigens are still at large).

Note: although B cells have an important role in making antibodies and proliferating, their role in this game is eliminated to provide as many students as possible with an

Image courtesy of Sanofi Pasteur; image source: Flickr

*Our skin is the first line of defence against infection.*

active part in the chase as antibodies or antigens. Should the teacher wish to include B cells in the game, he or she can assign a student to play a B cell that is responsible for making additional role cards for B cells as quickly as possible.

5. Play the game as described above for about 4-5 minutes. If there is a single surviving antigen at the end of the game, then the class is infected with the disease named on the antigen's card and the body will become ill (e.g. catch a cold) as the antigen multiplies. If all the antigens are vanquished, then the immune system has successfully kept the body healthy.
6. Repeat the game at least twice, with the teams switching roles so that each student is allowed to play a role on both sides. Note that once the body has been infected, the immune system begins synthesising antibodies and additional white blood cells to defeat the invader. Then the system keeps a memory of the antigen as well as copies of the corresponding antibody should future infections occur. So if the class is 'infected' during the first game, then the corresponding antibodies should be present during the second game.
7. Once the game has finished, have a brief discussion with students to ascertain what they learned or observed as a result of playing the game. Encourage them to summarise the process by which the immune system defends the body against pathogens.
8. Ask the students to draw a model of the immune system (it can be a concept map, a comic strip, an animation or any other form of expression that is appropriate) to evaluate their ability to analyse data and construct an explanation based on their analysis. They should include terms from each of the three lines of defence in their diagrams.
9. As an extension to the game, students can research the viruses labelled on the antigen cards to discover more about their pathogenesis, diagnosis, treatment and epidemiology.

'Ready, set, infect!' allows teachers to present a challenging concept in an understandable way to many types of middle-school learners, particularly those who learn best through movement and social interaction. It also allows students to develop a more complex conceptual model of how cells, chemicals and infecting agents interact simultaneously in the immune system.

On a grander scale, the game gives them a deeper appreciation of their bodies.

## Web reference

w1 You can download the materials needed for the activity from: www.scienceinschool.org/2016/issue36/infect

## Resource

Watch a white blood cell chase bacteria: www.youtube.com/watch?v=JnlULOjUhSQ

Emily Kang is an assistant professor of science education at Adelphi University in New York, USA. She is a former middle-school science teacher and currently focuses on teaching future teachers and providing professional development for elementary and secondary-school science teachers.

# Cracking the genetic code: replicating a scientific discovery

Image courtesy of Caroline Davis2010; image source: flickr

By Jordi Domènech-Casal

In 1953, James Watson and Francis Crick discovered the structure of DNA, the molecule that carries our genetic information. In 1958, Crick postulated the central dogma of molecular biology: that the flow of information goes from DNA to RNA to protein. But the question remained: how did the four-letter alphabet of nucleotides in DNA (A, C, T and G) or its equivalent in RNA (A, C, U and G) encode the 20-letter alphabet of amino acids that build our proteins? What was the genetic code?

In 1961, Marshall W Nirenberg and Johann H Matthaei deciphered the first letter of the code, revealing that the RNA sequence UUU encodes the amino acid phenylalanine. Subsequently, Har Gobind Khorana showed that the repeating nucleotide sequence UCUCUCUCUCUC encodes a strand of amino acids reading serine-leucine-serine-leucine. By 1965, largely due to the work of Nirenberg and Khorana, the genetic code had been completely cracked. It revealed that each group of three nucleotides (known as codons) encodes a specific amino acid, and that the order of the codons determines the order of amino acids in (and, consequently, the chemical and biological properties of) the resulting protein.

REVIEW

- ✓ Biology
- ✓ Chemistry
- ✓ Maths
- ✓ Protein synthesis
- ✓ Ages 16–19

This article offers a strategy that helps teachers to explore, simply and accessibly, one of the most challenging aspects of science teaching: helping their students to appreciate and understand how science actually works. Acquiring knowledge requires scientists to ask good questions, design and carry out good experiments, and work together to address uncertainty. This is exactly what the students need to do in this activity to crack the genetic code.

I anticipate that teachers of disciplines other than biology (particularly maths and chemistry) would also find this article useful. It would also be a very good activity to use during a science fair.

Betina Lopes, Portugal

## Background

### How did Nirenberg and Khorana crack the genetic code?

Nirenberg and Khorana compared short sequences of the nucleic acid RNA and the resulting amino acid sequences (peptides). To do this, they followed the protocol that Nirenberg developed with Matthaei.

This involved artificially synthesising a specific sequence of RNA nucleotides and mixing it with extracts of *Escherichia coli* bacteria that contained ribosomes and other cellular machinery necessary for protein synthesis. The scientists then prepared 20 samples of the resulting mixture; to each sample, they added one radioactively labelled amino acid and 19 unlabelled amino acids, then allowed protein synthesis to occur. Each of the 20 samples contained a different radioactively labelled amino acid. If the resulting peptide was radioactive, it indicated that the radioactively labelled amino acid was included, confirming that the RNA nucleotide sequence coded for this amino acid at some point.

By repeating this experiment with different RNA sequences, more and more information could be gathered about the genetic code. After simple sequences such as UUUUUU and AAAAAA had been tested, further teams of scientists took up the challenge, analysing more complex RNA sequences, eventually allowing all 64 codons to be de-coded.

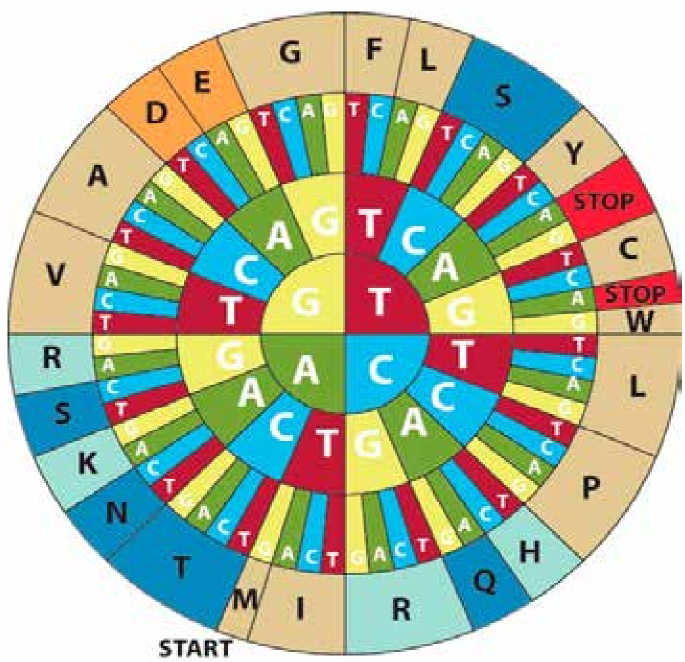



Image courtesy of Cath Brooksbank EMBL

**Amino acid code**

| | | | |
|---|---|---|---|
| A - Alanine | G - Glycine | M - Methionine | S - Serine |
| C - Cysteine | H - Hisitidine | N - Asparagine | T - Threonine |
| D - Aspartic Acid | I - Isoleucine | P - Proline | V - Valine |
| E - Glutamic acid | K - Lysine | Q - Glutamine | W - Tryptophan |
| F - Phenylalanine | L - Leucine | R - Arginine | Y - Tyrosine |

*Figure 1: The genetic code. To decode a DNA sense codon, find the first letter of your sequence in the inner circle and work outwards to identify the corresponding amino acid. For example, CAT codes for H (histidine).*

The genetic code itself is a crucial element of biology lessons, providing a molecular explanation of the actions of genes (for example, in mutation, evolution and gene expression). Furthermore, the way in which Nirenberg and Khorana cracked the genetic code – by comparing short sequences of RNA with the resulting amino acid sequences – can be re-run as an inquiry-based teaching activity at school. Using the sequences provided by the teacher, the students work in teams to:

- Identify patterns
- Construct hypotheses and explanatory models
- Design experiments
- Reach conclusions from partial data
- Establish the strength of their conclusions
- Communicate and justify their conclusions in a scientific manner.

The activity thus offers a model for teaching the nature of scientific knowledge: a provisory consensus constructed by the community with conclusions of diverse strength based on partial evidence.

## Cracking the code in the classroom

This activity is suitable for 14- to 18-year-old students working in teams of 3–4, and takes about two hours, divided into four steps plus a final discussion. It is designed as an introduction to molecular biology, before you explain anything about the genetic code or the central dogma of molecular biology.

Students are asked to crack a code composed of different sequences of letters (A, C, T, G) using the messages that those sequences encode (e.g. AspHisTrp…). In each of the first three steps, each team is given a different set of letter sequences and corresponding messages. At each step, they will need to re-evaluate their conclusions from the previous steps, and modify their solution to the code.

Explain that all the groups will be working to crack the same code, using different examples. Do not tell your students about the biological nature of the sequences (DNA and amino acids); they should focus on finding patterns and relationships.

Nirenberg and Khorana used RNA sequences to crack the code; in contrast, this activity uses DNA sequences (sense codons, 5¢ to 3¢). The crux of the activity is the existence of the code rather than the details of transcription and translation, which can be addressed in subsequent lessons.

After each step, you may ask one student from each team to join a different team. (This mimics the dynamics of how scientific knowledge is acquired and shared, for example at conferences or through publications.)

Otherwise, teams may exchange information only when they are told to do so. (If one team gets stuck and discouraged, it can be more motivating to ask another team to help them rather than the teacher.)

## Materials

- Worksheets 1-4 for each team, which can be downloaded from the *Science in School* website[w1]. The sequence sets are different for each team.
- Figure 1 or a smartphone app for easily converting DNA codons to amino acids[w2].

## Procedure

Allow at least 10-15 minutes for your students to discuss each step. When all the teams feel that they have obtained all the possible information from their sequences, move on to the next step.

1. **Detecting frames.** Give each team a copy of worksheet 1, which contains three sequences that do not contain synonym codons or stop codons. All the sequences begin with an ATG codon, encoding the amino acid methionine (Met).

   Using the three sequences, the students should be able to establish that the code is based on triplets of letters and to make their first hypotheses about the meaning of some of these triplets.

2. **Building a model.** Give each team a copy of worksheet 2, which contains three new sequences, some of which include synonym codons.

   The students should be able to confirm some of their hypotheses from step 1, while other hypotheses may be cast into doubt.

3. **Adjusting the model to new evidence.** Give each team a copy of worksheet 3, which contains new sequences presenting more complexity: some sequences lack the initial ATG codon, some have it further into the sequence, and some have a stop codon. These characteristics either result in messages that are shorter than the seven-amino-acid sequences in the previous steps, or produce no message at all.

   The worksheets for this step each contain two lists of sequences. You can choose whether to give your students all the sequences together (to make this step easier) or in two separate sub-steps (to make it harder).

   Besides confirming the triplets that encode some amino acids, these sequences allow the students to identify the key roles of the methionine (start) and stop codons.

4. **Testing hypotheses and designing experiments.** The students should now be able to propose a partial

| Sequence | Message | Students discover that... |
|---|---|---|
| ATGTTAGGTAGTAAAGATGCT | MetLeuGlySerLysAspAla | The code is based on triplets and each triplet represents one of the three-letter elements, e.g. Met. |
| ATGCATGAAGCTATTTATGAT | MetHisGluAlaIleTyrAsp | |
| ATGGGTAGTGATGAAGCTTAT | MetGlySerAspGluAlaTyr | |

*Table 1: An example of worksheet 1*

| Sequence | Message | Students discover that... |
|---|---|---|
| ATGGTTTCGTACACTGCGTCA | MetValSerTyrThrAlaSer | Some elements can be encoded by more than one triplet, e.g. Ser. |
| ATGCCGTACACATGTGTCACA | MetProTyrThrCysValThr | |
| ATGACGAGTGCGTTGTGCGAT | MetThrSerAlaLeuCysAsp | |

*Table 2: An example of one team's sequences for step 2*

| Sequence | Message | Students discover that... |
|---|---|---|
| TGTCATGCATCCGTCATCACTGAC | – | The ATG triplet determines the beginning of the message and the TGA triplet its end. |
| TGCGTGACTATGGACACAGTCGT | MetAspThrVal | |
| ATGTGTCGATGACTGATCATG | MetCysArg | |
| ATGTGCGTACACATTTGAGTC | MetCysValHisIle | |
| ATGCTGTACACATGATGCACAGT | MetLeuTyrThr | |

*Table 3: An example of one team's sequences for step 3*

solution to the code. To test their hypotheses, give each team a copy of worksheet 4 and ask them to design an experiment. They should propose changes to four specific sequences that they were given in the previous steps, and note any change that they would expect to the message. You then give them the correct message, using figure 1 if necessary. Was the result what they expected? If not, what does that tell them? This mimics a rapid process of hypothesising, designing experiments and analysing results.

As a conclusion to the activity, each team should present their partial solution for the code to the rest of the class, justifying their conclusions. Those parts of the code that are accepted by the rest of the group – representing the scientific community – should be written on the blackboard. Controversial or unclear parts should also be noted. The result will be a consensual, partial genetic code.

Avoid confirming immediately if the code that your students have constructed is correct. Explain that in science, there is no book to compare your results to, and the only way to find if something is correct is by asking good questions, designing good experiments, and sharing information and ideas with your peers to gain consensus.

## Discussion

Ask your students to consider the following questions:

- How did you discover what you now know?
- Did you discuss your ideas with anyone during the activity? What did you discuss?
- How did you confirm whether your hypotheses were accurate?
- Did you reject any of your initial hypotheses? Which ones?
- How did you resolve any contradictory conclusions within or between teams?
- Were all your conclusions equally strong?

Image courtesy of Jordi Domènech-Casal Adaptations

*Students comparing new data with their conclusions from previous steps*

After the discussion, explain to your students that the sequences were DNA and amino acid sequences, and that they have just reproduced a key experiment in molecular biology. Your students should now be motivated to learn more about the genetic code and the central dogma of molecular biology, including how similar their activity was to the way in which the genetic code was really cracked.

You could recap the activity, reminding your students what they discovered for themselves:

- In step 1, that the genetic code is based on triplets of nucleotides (codons).
- In step 2, that the genetic code is redundant but not ambiguous: each codon encodes a single element (e.g. an amino acid), but some elements are encoded by more than one codon.
- In step 3, that the code includes start and stop codons to specify the beginning and the end of the encoded amino acid sequences.

Image courtesy of Duncan Hull; image source: flickr

(Note that the activity could generate the misconception that proteins are usually composed of six or seven amino acids, so this may need to be addressed.)

Explain that the way your students have been working, in collaborative and / or competitive teams, with the membership of the teams changing, and information being shared with other teams, reflects the way that scientists work in real life.

To make the activity easier, you could give your students more sequences in each step (e.g. the sequence sets for two teams). Alternatively, you could leave out step 3, and simply explain the role of the start and stop codons after the activity.

## Acknowledgements

Pedagogic reflections on the activity described in this article are part of the work of the language and context in science education (llenguatge i contextos en educació científica, LICEC) research group at the Autonomous University of Barcelona (reference 2014SGR1492), financed by the Spanish Ministry of Economics and Competitiveness (reference EDU2015-66643-C2-1-P).

## Web references

w1 Download the worksheets for the activity from the *Science in School* website. See: www.scienceinschool.org/2016/issue36/code

The worksheets are also available from the author's website: https://sites.google.com/a/xtec.cat/hacking-the-code

w2 The Nobel Prize website has a table to translate the codons into amino acids. See: www.nobelprize.org or use the direct link: http://tinyurl.com/jkqz9vz

## Resources

This activity is part of the C3 science education project, which develops inquiry problem-based learning activities to cover the science curriculum. See: https://sites.google.com/a/xtec.cat/c3/home

Other English-language activities in the project address plate tectonics, mitosis and cancer, human evolution, phylogeny, genetic heredity, gene expression and ecosystem

Image courtesy of Daniel; image source: Flickr


*Complementary nucleotide base pairs*

dynamics. See: https://sites.google.com/site/proyectandobiogeo

See also:

Domènech-Casal J (2013) Hacking the code: una aproximació indagadora a l'ensenyament del codi genètic, o seguint les passes de Nirenberg i Khorana. *Ciències: revista del professorat de ciències de primària i secundària* **25**: 20-25

Domènech-Casal J (in press) Proyectando BioGeo, un itinerario de trabajo por proyectos contextualizados basado en la indagación y la Naturaleza de la Ciencia. *Alambique, Didáctica de las Ciencias Experimentales*

Nirenberg M, et al (1965) RNA codewords and protein synthesis, VII. On the general nature of the RNA code. *Proceedings of the National Academy of Sciences of the USA* **53(5)**: 1161–1168

The article can be downloaded free of charge from the Pubmed Central website. See: www.ncbi.nlm.nih.gov/pmc or use the direct link: http://tinyurl.com/z8fyqx9

Read the story of 'How the code was cracked' on the Nobel Prize website. See: www.nobelprize.org or use the direct link: http://tinyurl.com/h4j9olf

Image courtesy of Francisco Gonzalez; image source: Flickr

In 1968, Marshall W Nirenberg, Har Gobind Khorana and Robert W Holley were awarded the Nobel Prize in Physiology or Medicine 'for their interpretation of the genetic code and its function in protein synthesis'. Details of their work are described in the presentation speech. See: www.nobelprize.org or use the direct link: http://tinyurl.com/z9vsyqs

Francis Crick, James Watson and Maurice Wilkins were awarded the 1962 Nobel Prize in Physiology or Medicine 'for their discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material'. See: www.nobelprize.org or use the direct link: http://tinyurl.com/hozaohv

In 1970, Francis Crick described how the central dogma of molecular biology was developed.

Crick F (1970) Central dogma of molecular biology. *Nature* **227**: 561-563. doi:10.1038/227561a0

Many papers by Crick are freely available on the *Nature* website. See: www.nature.com

Jordi Domènech-Casal has a PhD in biology and worked for eight years as a researcher in genetics and inorganic chemistry at the universities of Barcelona, Spain; Bologna, Italy; and Paris VII, France. He currently works as a science teacher at the Institut de Granollers, a secondary school in Barcelona, and as a teacher trainer and advisor in science education for the Catalonian government and on the European project 'Engaging science'. He is a member of the language and science education (*llenguatge i ensenyament de les ciències, LIEC*) research group at the Autonomous University of Barcelona, where his interests focus on the role of language and context in inquiry- and project-based learning activities in science education.

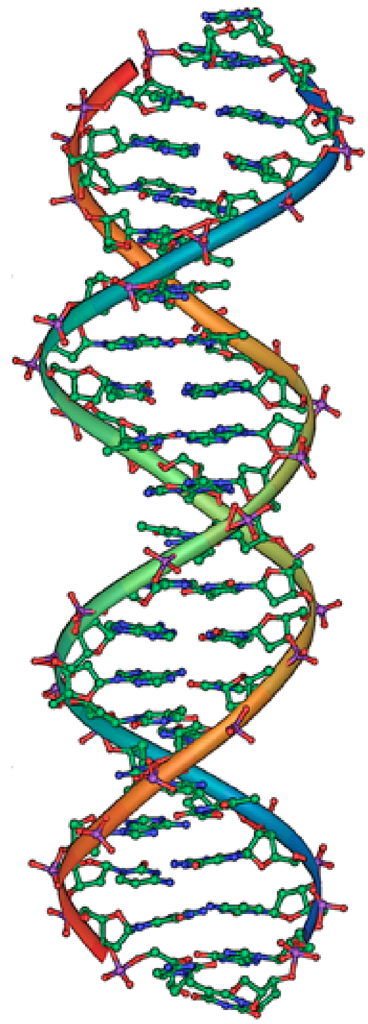


Image courtesy of mstroeck / Wikimedia Commons

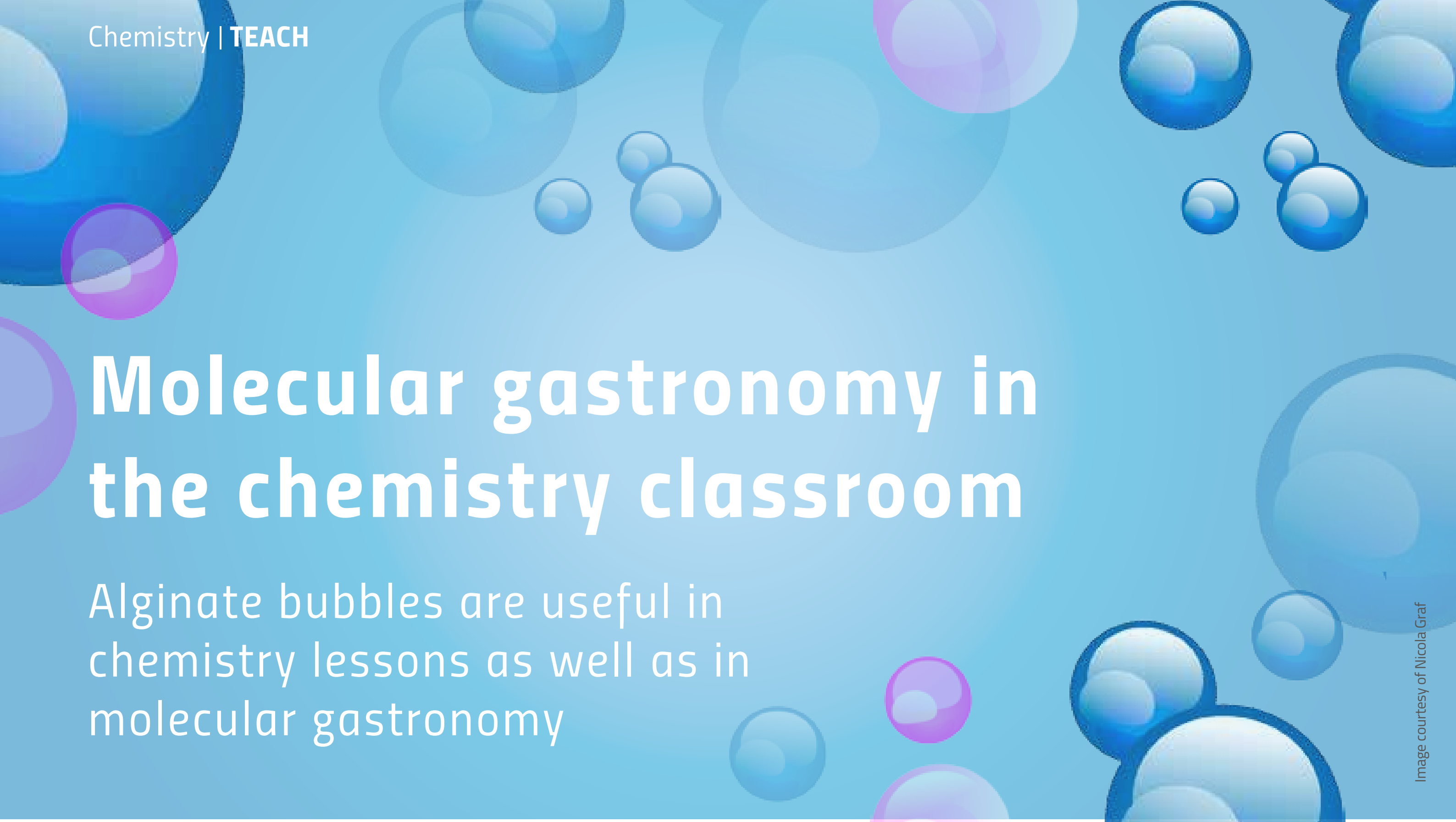


Image courtesy of Nicola Graf

# Molecular gastronomy in the chemistry classroom

## Alginate bubbles are useful in chemistry lessons as well as in molecular gastronomy

By Johanna Dittmar, Christian Zowada, Shuichi Yamashita, Ingo Eilks

Molecular gastronomy is a new trend in haute cuisine, with chefs providing their guests with novel and strange culinary experiences using liquid nitrogen, gels and foams. One of the techniques that is becoming more well known is the use of alginate spheres containing different fruit juices or flavours. Even if you don't frequent Michelin-starred restaurants, you may have come across these spheres in bubble tea.

Bubble tea, originally invented in Taiwan in the 1980s, spilled over from Eastern Asia to Western countries some years ago. It consists of a tea-based drink that also contains fruit jellies, tapioca or alginate spheres, filled with fruit juice or syrup.

Making and examining the behaviour of alginate bubbles can be fascinating and can be used in inquiry-based learning in the sciences.

In this article, we suggest how alginate bubbles can be used to teach various scientific concepts, presenting scientific phenomena in an aesthetic fashion. We introduce how to make alginate bubbles and present three example experiments, each of which can be performed in a one-hour lesson: an acid-base reaction, chemo luminescence with redox chemistry, and thermal convection with a thermochromic effect.

## Forming alginate bubbles

Alginate bubbles are formed when an aqueous alginate solution (figure 1) comes into contact with a solution containing calcium ions, creating a membrane of calcium alginate where the two solutions meet (figure 2). Alginate is a long polysaccharide that becomes cross-linked in the presence of a divalent cation, such as calcium, to make a water-insoluble gel.

REVIEW

- ✓ Biology
- ✓ Chemistry
- ✓ Physics
- ✓ Acid-base reactions
- ✓ Convection
- ✓ Luminescence
- ✓ Ages 11–19

Our curiosity is always attracted by changes of colour, position, shape and light. Using such changes in our teaching can help our students to enjoy science more. The first and second activities would be suitable for students aged 15–16, whereas the third activity, involving convection and luminescence, would also be suitable for younger students, aged 11–14.

After the activities, the teacher could ask why bubbles were used, leading to a discussion of the chemical and physical properties of matter.

Enrico Capaccio, Istituto Superiore S Bellarmino, Montepulciano (Siena), Italy

### Materials

- 2 g sodium alginate ($Na(C_6H_8O_6)$)
- 100 ml distilled water
- 10 ml 0.5% calcium chloride (CaCl) or 1% calcium lactate ($Ca(C_3H_5O_3)_2$ solution
- Two 250 ml beakers
- Dropper pipette or spoon
- Glass rod or other stirrer
- Sieve or spoon

### Procedure

1. Mix the alginate and water in one of the beakers.
2. Wait at least 15 minutes until all the alginate has dissolved.
3. Pour the calcium ion solution into the other beaker.
4. Add drops of the alginate solution to the calcium ion solution with a pipette or a spoon. Stir the calcium solution as you do this to prevent the alginate spheres sticking together.
5. The bubbles are stable and can be removed from the calcium ion solution with a spoon or sieve.

When the liquids come into contact, gelatinous calcium alginate is formed, encapsulating the alginate solution in spheres. If other compounds are also added to the alginate solution, such as flavours, colouring agents, or indicators, they are also encapsulated.

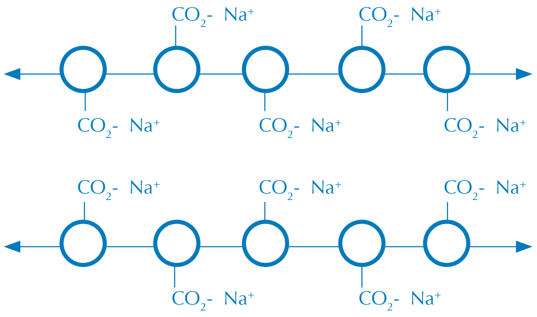



*Figure 1: Alginate polymer in NaCl solution (no crosslinking)*

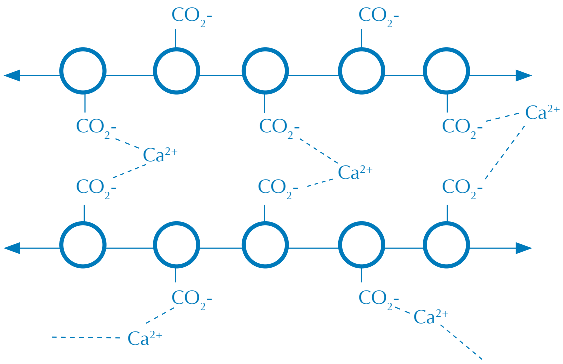



*Figure 2: Alginate polymer in $CaCl_2$ (crosslinking)*

## Acid–base bubbles

### Materials

- 2 g sodium alginate
- 500 ml distilled water
- 10 ml 0.5% calcium chloride or 1% calcium lactate solution
- Three 250 ml beakers
- Dropper pipette or spoon
- Glass rod or other stirrer
- Sieve (optional)
- Indicator solution
- Assorted acids and bases

### Procedure

1. Follow the procedure above for forming alginate bubbles but add an acid–base indicator to the alginate solution just before adding the alginate to the calcium solution.
2. Remove the bubbles and place them in a beaker containing the rest of the distilled water.
3. Note the colour of the spheres.
4. Systematically add different acids and bases to the water and note how the colour of the bubbles changes.

Although the indicator solution is inside the bubbles, the alginate membrane can exchange hydroxide or hydronium ions (hydrated protons) between the bubbles' contents and the surrounding liquid. Changing the pH value of the surrounding liquid by adding an acid or a base will therefore change the pH of the liquid inside the spheres, and so the indicator will change colour (figure 3).

While technical indicators can be used in the classroom, pH-sensitive extracts of red cabbage or garden radish peel could be used at home.

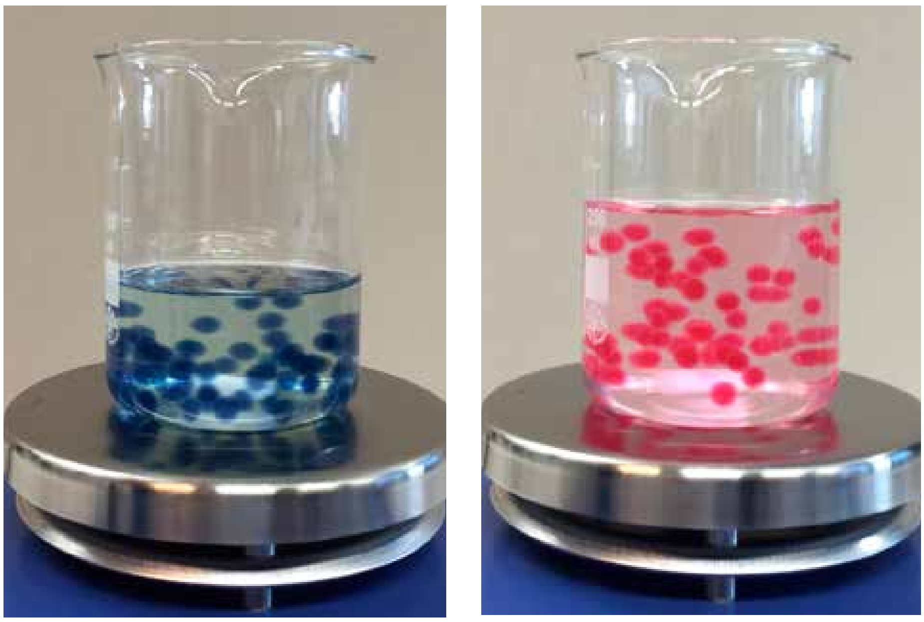


Image courtesy of Christian Zowada

*Figure 3: Indicator bubbles in acidic (left) and basic (right) environments*

## Luminescent bubbles

Alginate bubbles can be used to illustrate the phenomenon of luminescence by simply adding a luminescent compound to the alginate solution before the bubbles are formed. One easy way to do this is to use riboflavin (vitamin B2), which fluoresces under UV light. Although you can use pure riboflavin, you can also extract it from a food such as an instant custard powder that contains it.

### Materials

Extracting riboflavin (optional):

- One pack instant custard powder containing riboflavin (also known as E101)
- 200 ml distilled water
- Beaker
- Stirrer
- Funnel with filter paper

Making luminescent bubbles:

- Two spatula tips of riboflavin powder ($C_{17}H_{20}NaO_6$)
- 2 g sodium alginate
- 100 ml water
- 10 ml 0.5% calcium chloride or 1% calcium lactate solution
- Two 250 ml beakers
- Dropper pipette or spoon
- Glass rod or other stirrer
- Sieve (optional)
- UV source
- 15–20 ml saturated sodium dithionite ($Na_2S_2O_4$) solution
- 15–20 ml hydrogen peroxide

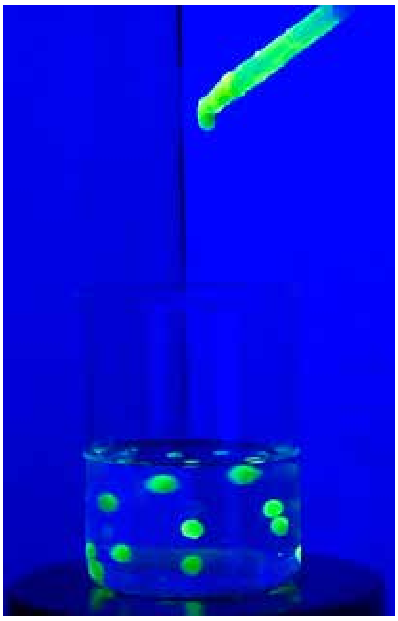


Image courtesy of Christian Zowada

*Figure 4: Luminescent bubbles under UV light*

### Procedure

1. To extract the riboflavin from the instant custard powder, place about 8 g of powder in a beaker with 200 ml water. Stir well for about 10 minutes and filter.
2. Follow the procedure for making alginate bubbles, but add the riboflavin to the alginate solution just before spherification.
3. Shine UV light on the bubbles that are formed. They should fluoresce, emitting a yellow-green light (figure 4).
4. Turn the UV light off and the bubbles will stop fluorescing.
5. Turn the light back on.
6. Add the sodium dithionite to the beaker containing the alginate bubbles. You should notice that the luminescence is turned off, because the sodium dithionate crosses the membrane around the alginate bubbles and reduces the riboflavin inside.
7. Add hydrogen peroxide to oxidise the riboflavin, turning the luminescence on again.

## Thermo bubbles

Adding a thermochromic ink to the alginate solution can help to illustrate the phenomenon of convection. In Japan, a special thermo ink based on a lactone of crystal violet (and not to be confused with the thermo inks used in thermo printers) is sold to illustrate heat-related phenomena in physics.

### Materials

- 2 g sodium alginate
- 100 ml distilled water
- 10 ml 0.5% calcium chloride or 1% calcium lactate solution
- Two 250 ml beakers

Images courtesy of Christian Zowada

*Thermo ink from Japan and thermo bubbles while heated*

- Dropper pipette or spoon
- Glass rod or other stirrer
- Sieve
- 3–5 ml thermochromic ink
- Heatproof beaker filled with water
- Heat source

### Procedure

1. Make the bubbles as described above, but add the ink to the alginate solution just before spherification.
2. Place the resulting bubbles in a heatproof beaker of water.
3. Heat the beaker until the bubbles start to rise.

The alginate bubbles will move to show convection: rising as they become less dense when heated, and then cooling and sinking back down as they become more dense again. At the same time, the alginate bubbles will change colour, showing that convection is associated with a change in temperature.

### Acknowledgements

Part of this work was funded by the Teaching Enquiry with Mysteries Incorporated (TEMI) project supported (Peleg et al., 2015), by the European Union under the 7th Framework Programme for Research Funding "Science in Society" under Grant Agreement No. 321403.

## Reference

Peleg R et al. (2015) The magic sand mystery. *Science in School* **32**: 37-40. www.scienceinschool.org/content/magic-sand-mystery

## Resources

To learn more about molecular gastronomy, see:

Davies E (2014) From methional to fried chicken. *Science in School* **30**: 44–48. www.scienceinschool.org/2014/issue**30**/HThis

To learn more about spherification in molecular gastronomy, see: www.molecularrecipes.com/spherification-class/basic-spherification

A video showing how to make an edible water 'bottle' from alginate can be found at: www.youtube.com/watch?v=YLjzsfgk198

Videos of all the experiments described here can be found on the TEMI Youtube channel. See: www.youtube.com/channel/UC62-j3UpwF-Z5yh84umnxIQ

For a podcast about sodium alginate, see the Chemistry World website www.rsc.org/chemistryworld or use the direct link: http://tinyurl.com/go95nk2

A German-language description of using bubbles for inquiry-based learning, following the TEMI philosophy, can be downloaded from the website of the TEMI team at the University of Bremen, Germany. See: www.chemiedidaktik.uni-bremen.de/temi/index.html. An English translation will soon be published in the *Book of Science Mysteries* on the TEMI website: www.teachingmysteries.eu

Spherification can be used in many other experiments. For an activity in which 'algal balls' are used to explore photosynthesis, for example, see www.saps.org.uk or use the direct link: http://tinyurl.com/qxwcafa

Most of the chemicals and equipment you will need for these investigations are easily sourced from standard school science suppliers. If you cannot find a supplier of the Japanese thermochromic ink, you should be able to buy thermochromic slurries for aqueous use from specialist dye manufacturers such as SpecialFX & Coatings in the UK. See: www.sfxc.co.uk

Johanna Dittmar, Christian Zowada and Professor Ingo Eilks are from the chemistry education research group based at the University of Bremen, Germany. Professor Shuichi Yamashita is a science educator in Chiba, Japan. Each of the authors developed a different activity using alginate bubbles.

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