



Science in School

The European journal for science teachers

Take a deep breath?

Investigating indoor air pollution



INSPIRE

Behind the scenes at the laboratory

TEACH

Making connections: an online exchange with EIROforum scientists

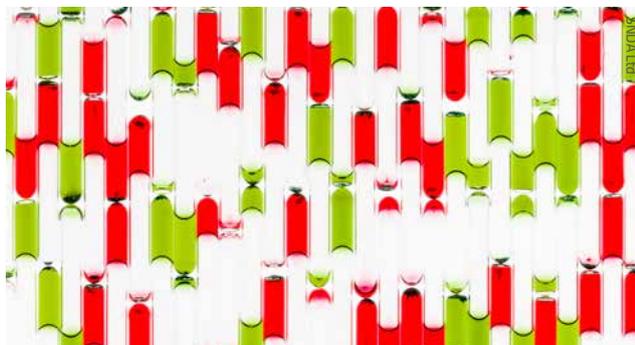


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EDITORIAL



Hannah Voak
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Science in School
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Shorter days and cooler weather signal that it's time to turn back the clocks, marking the end of daylight saving time. The darker evenings can knock our body clocks out of sync, taking a few days to readjust. Plants, too, suffer consequences to changing light conditions, so in this issue a biologist reveals the latest research into plant circadian clocks, by answering the curious question 'Do plants get jet lag?' (page 8).

With falling temperatures, we will soon be spending more time indoors. But after reading a chemist's account of the air pollution inside our homes (page 16), perhaps you will reconsider. Elsewhere in this issue, find out what a study of the Italian liqueur limoncello can tell us about emulsions (page 12), investigate the science behind sunscreens (page 37), and discover a visually exciting alternative to the standard experiments for finding an empirical formula (page 26).

As you might have seen, we are currently conducting our own research of sorts. Over the summer, we invited you – our readers – to take part in a survey about *Science in School*, on behalf of our publisher EIROforum. Thank you to everyone who shared their views to help shape the future directions of the journal. Look out for an update in the next issue.

And, finally, are your students curious about careers in science? For inspiration, we have a variety of career-focused articles to highlight the vast range of possibilities that are open to them. Go behind the scenes at one of Europe's largest laboratories to explore some of the less visible roles that make science happen (page 23), find out about an interactive project that bridges the gap between classroom science and research scientists (page 31), and read about the collaborative career path of a synchrotron scientist, who is using powerful techniques to study ancient works of art (page 20).

We hope these resources will help your students to explore rewarding careers in science – and perhaps join the next generation of STEM professionals.

Hannah Voak

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

Magnetism in the Earth's mantle, impressive asteroid observations, and insights into influenza

CERN

Students investigate fundamental physics with beamline competition

Earlier this year, CERN invited high-school students from across the world to submit proposals for their sixth Beamline for Schools competition, which gives students the opportunity to run their own experiment using a fully equipped beamline. More than 60 experts from CERN and the Deutsches Elektronen-Synchrotron (DESY) research centre evaluated the 178 proposals. The two winning teams – one from Groningen, Netherlands, and one from Salt Lake City, USA – were announced in June.

There are currently no beamlines in use at CERN, due to the shutdown of CERN's particle accelerators for maintenance and upgrades, so instead the two teams were invited to DESY in Hamburg, Germany. They will carry out their experiments, both of which involve investigating the fundamental differences between matter and antimatter, on the DESY beamline.



Kara Budge/Martin Mug/CERN

The 2019 Beamline for Schools winning teams from Salt Lake City, USA (left), and Groningen, Netherlands (right)

Learn more about the 2019 winning teams and their experiment proposals on the CERN website. See: <https://home.cern/news/press-release/cern/dutch-and-us-students-win-2019-cern-beamline-schools-competition> or use the direct link <https://tinyurl.com/y4bect2h>

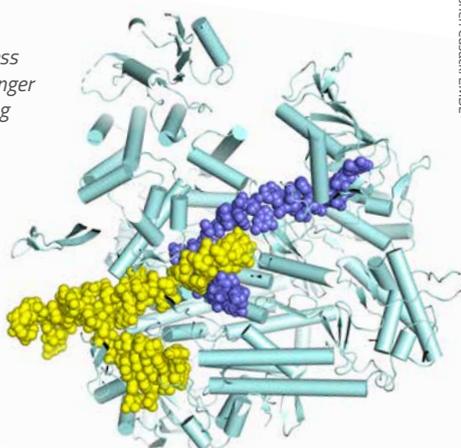
The CERN laboratory sits astride the Franco-Swiss border near Geneva, Switzerland. It is the world's largest particle physics laboratory. See: www.cern.ch

EMBL

Paving the way for new flu drugs

Up to 500 000 people worldwide die from influenza each year, and mortality rates are potentially much higher when a new pandemic flu strain emerges. Vaccination is not always effective, and anti-influenza drugs are needed as a complementary treatment option.

Influenza polymerase (light blue) in the process of synthesising messenger RNA (purple) by copying the viral RNA (yellow)



Stephen Casadev/EMBL



To design the next generation of anti-influenza drugs, scientists must understand the genetic processes of transcription and replication of the viral genome. These processes are carried out by an enzyme called a polymerase. Such enzymes are crucial to the propagation of the virus, as they allow the host cell to be tricked into making viral proteins and copies of the viral genome, thus producing more viruses to infect new hosts.

For the first time, scientists at the European Molecular Biology Laboratory (EMBL) in Grenoble, France, have observed the different states of the influenza virus polymerase in action. A drug that stops the polymerase from functioning would be much less likely to be affected by mutations of the virus, which is a problem for existing drugs.

Learn more about the study by visiting the EMBL website. See: <https://news.embl.de/science/paving-the-way-for-new-flu-drugs>

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

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

ESA

Space science challenges for the new school year

Each academic year, the European Space Agency (ESA) launches a series of exciting challenges for schools. The challenges cover a range of school subjects and are suitable for a variety of age groups. In the 2019/2020 academic year, ESA will offer five challenges for students to get involved in.

Among these projects are the European CanSat Competition and Mission X. The CanSat Competition invites students to build and test a CanSat – a simulation of a real satellite that is no larger than a soft-drink can and is launched to an altitude of a few hundred metres using a rocket or balloon. Mission X is an international educational challenge focusing on health and nutrition that encourages students to train like an astronaut. Students practice scientific reasoning and teamwork whilst participating in hands-on training missions.

Also on offer are the European Astro Pi Challenge, Moon Camp Challenge and Climate Detectives. You can find out more about all the challenges and how your students can participate by visiting the ESA Education webpage.

Information for all ESA Education programmes can be found on the ESA website. See: www.esa.int/Education

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



ESA will offer five challenges for the 2019/2020 academic year.

ESO

Tracking asteroids with the Very Large Telescope



The biggest telescopes on Earth usually observe astronomical objects millions of light years away. But on 25 May 2019, the Very Large Telescope (VLT) of the European Southern Observatory (ESO) focused on an object much closer to Earth: a double asteroid flying only 17 light seconds away, some 5.2 million kilometres from Earth (about 7% of the minimum distance between Earth and Mars).

The images from the VLT are the sharpest ever obtained of a double asteroid. This is thanks to the unique capabilities of the VLT's powerful detector, which uses an adaptive optics system to correct for the distortion effects caused by Earth's turbulent atmosphere.

Although the double asteroid, named 1999 KW4, did not pose a threat to Earth, scientists used this opportunity to test the VLT's capability in tracking such an object travelling at a speed of 70 000 km/h. The success of this test shows that ground-based telescopes equipped with sophisticated detectors could be critical in tracking nearby asteroids in the future, to keep Earth safe.

Learn more about the observation of 1999 KW4 by visiting the ESO website. See: www.eso.org/public/news/eso1910

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



Side by side comparison of the observation (left) and an artist's impression (right) of asteroid 1999 KW4

ESRF

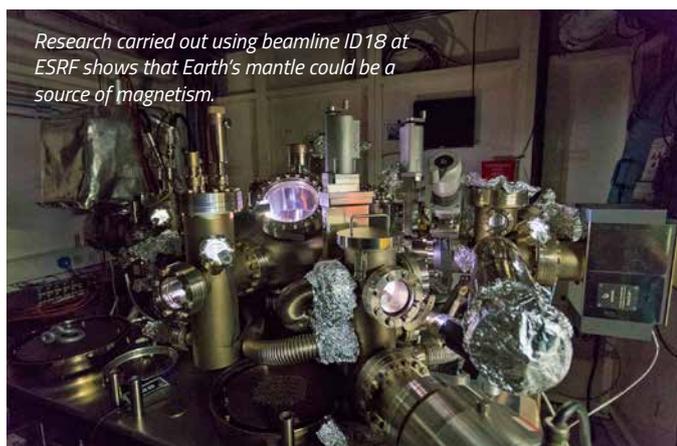
Scientists discover magnetism in Earth's mantle



We know that the Earth's magnetic field is derived from its core and crust, but it was also thought that the Earth's mantle (50–2500 m below the surface) was non-magnetic. This is because the conditions of extreme heat and pressure within the mantle were thought to cause the mineral haematite (a common iron oxide found in the mantle) to lose its

magnetism. However, recent magnetic satellite data suggests that parts of the mantle are magnetic, particularly around cooler areas such as tectonic plate boundaries.

Now, a team of researchers has helped to explain these magnetic anomalies by exposing a sample of haematite to conditions similar to those in the mantle itself. Using the beamline ID18 at the European Synchrotron Radiation Facility (ESRF), the researchers were surprised to find that the haematite remained magnetic up to the temperatures and pressures found at the transition zone between the upper and lower mantle. Scientists are now considering whether the magnetic anomalies, particularly those found beneath the Western Pacific Ocean, could be due to the presence of magnetic iron oxide in the mantle in such locations.



Research carried out using beamline ID18 at ESRF shows that Earth's mantle could be a source of magnetism.

Pierre Jayet/ESRF

To learn more about the study, visit the ESRF website: www.esrf.eu/home/news/general/content-news/general/earths-mantle-could-be-more-magnetic-than-once-thought.html or use the direct link <https://tinyurl.com/y2onq6dr>

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

EUROfusion

Fusion spin-off for cancer diagnosis



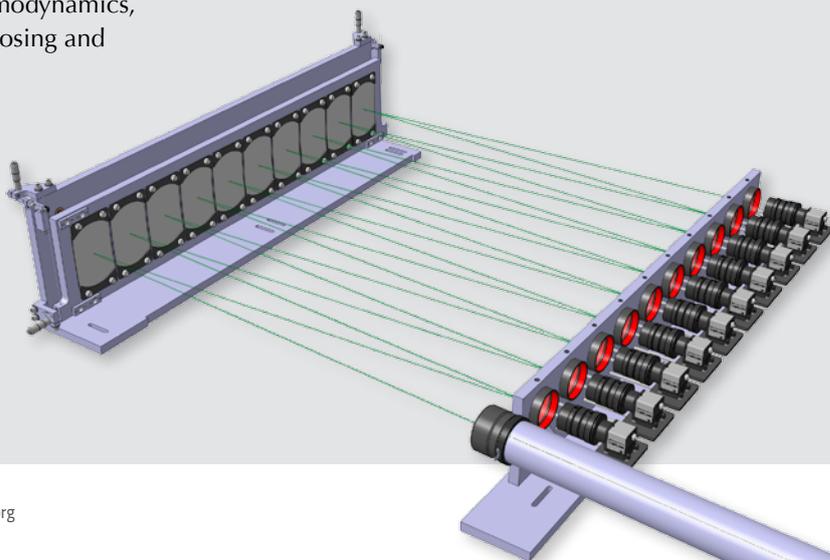
When it comes to cancer, improving early diagnosis is key to saving lives. To help achieve this goal, a former fusion researcher recently founded a spin-off company to explore the potential of multispectral imaging in cancer diagnosis.

The imaging technique is based on the research of the company's founder and CEO, Wouter Vijvers, at two EUROfusion consortium members: the Dutch Institute for Fundamental Energy Research (DIFFER) and the Swiss Plasma Center (SPC). Wouter developed his novel multispectral imaging and diagnostic system to study parts of fusion plasmas. Now, he aims to adapt this technique for medical and industrial applications. One of the main long-term goals of the new company, Chromodynamics, is to provide a single step solution for diagnosing and removing cancerous tumours.

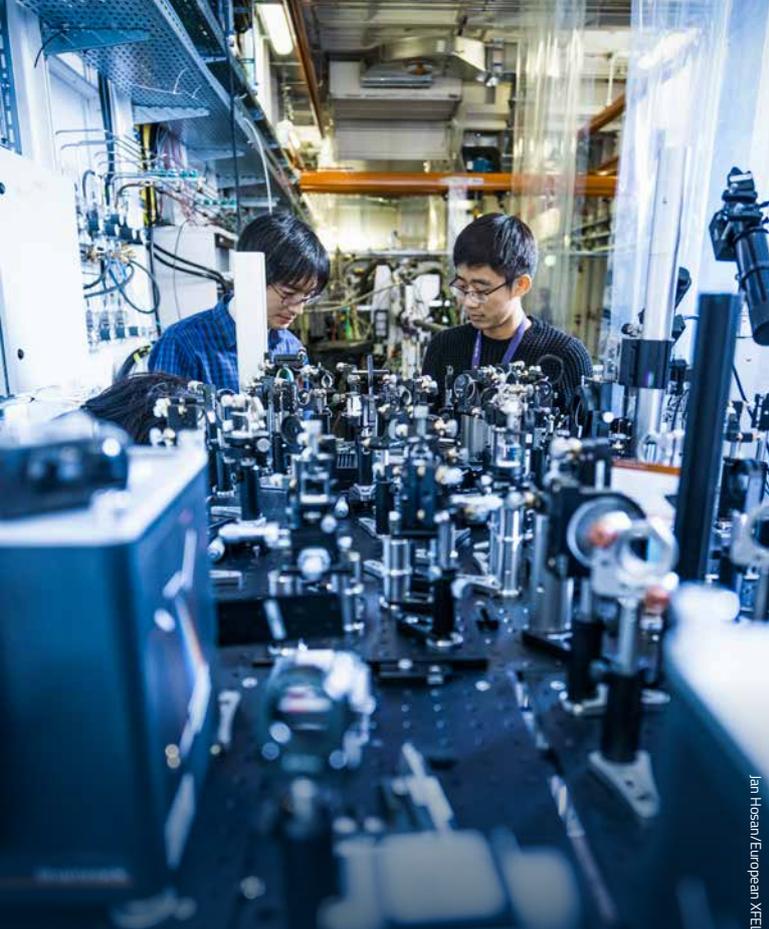
Healthy and malignant tissues have different chemical profiles, and multispectral imaging will be able to capture this difference in real time. Surgeons will thus be able to use the multispectral image while operating to ensure that a tumour is completely removed.

Learn more about the multispectral imaging system on the EUROfusion website. See: www.euro-fusion.org/news/2019/april/imagine-imaging-from-fusion-to-healthcare-and-more
EUROfusion manages and funds European fusion research activities, with the aim of realising fusion electricity. The consortium comprises 30 members from 26 European Union countries as well as Switzerland and Ukraine. See: www.euro-fusion.org

Illustration of the imaging system developed by Dr Wouter Vijvers at DIFFER, which will be adapted by Chromodynamics to diagnose and remove cancerous tumours



DIFFER



Jan Hoan/European XFEL

Scientists measuring the jitter of the SPB/SFX experiment station at European XFEL

European XFEL Getting the timing right for molecular movies



Chemical reactions are extremely fast. To watch them happen, scientists use intense pulses of laser light at X-ray facilities such as the European X-ray Free-Electron Laser (European XFEL). Researchers kick-start the reaction by shining an optical laser on the sample, before using the ultrashort X-ray laser pulses to take a sequence of images showing the molecular process. The images are then stitched together to create a movie.

To get the timing of the individual snapshots of the movie just right, scientists need to understand the timing variation, or 'jitter', of the two laser beams used to take the images. Even the slightest timing delay or variation in the experiment set-up can counteract the benefits of using the ultrashort X-ray pulses in the first place.

In a recent experiment, scientists at European XFEL measured the jitter at the SPB/SFX instrument and found a value of 308 femtoseconds (10^{-15} s) for this undesirable effect. Scientists now expect to significantly reduce the delay as upgrades are made to the facility.

Read more about this measurement at the European XFEL website. See: www.xfel.eu/news_and_events/news/index_eng.html?openDirectAnchor=1675 or use the direct link <https://tinyurl.com/y69qrxg5>

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



EIROforum combines the resources, facilities and expertise of its member organisations to support European science in reaching its full potential. See: www.eiroforum.org

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

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

ILL

Ionisation potential of promethium determined after 75 years



An important characteristic of any chemical element is its ionisation potential, which represents the energy required to remove one electron from a neutral atom. Over the years, the ionisation potentials of all chemical elements from hydrogen (element 1) to lawrencium (element 103) have been experimentally determined, with one exception: promethium (element 61).

Now, nearly 75 years after its discovery, a European collaboration of chemists and physicists have published the ionisation potential for this element, thus closing the last remaining gap in the periodic table for this fundamental property.

One of the reasons why this task was particularly difficult is that promethium is a very rare element with no stable isotopes. To tackle this challenge, scientists used the high-flux reactor at the Institut Laue-Langevin (ILL) to artificially produce a long-lived isotope of promethium, Pm-147. Using atomic spectroscopy, the scientists determined that the ionisation potential of promethium is 5.58188 electron volts (eV).

Read more about this study on the ILL website. See: www.ill.eu/news-press-events/news/scientific-news/closing-the-last-gap-for-the-periodic-tables-150th-birthday/ or use the direct link <https://tinyurl.com/y3yrj9q4>

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



The high-flux reactor at ILL was used to artificially produce Pm-147, a long-lived isotope of promethium.

Jean-Luc Baudez/ILL





How plants beat jet lag

New research is shedding light on the internal 'clocks' that help plants respond to changing day-night cycles.

By Katharine Hubbard

Have you ever experienced the disorientating feeling of jet lag after a long-haul flight? The reason it feels so awful is a result of the mismatch between the environment and our internal body clock: sunlight tells us it's the middle of the afternoon, but our internal clock tells us it's time to sleep. This clock – also known as the body's circadian clock, or circadian oscillator – controls our body's biological rhythm. It is an evolutionary adaptation to living on a rotating planet where light and temperature levels fluctuate over a 24-hour period, and it affects our sleep cycle, our metabolism and other

aspects of our physiology. The word 'circadian' comes from the Latin 'circa', meaning around, and 'dies', meaning day.

Circadian rhythms were first observed in plants, with the earliest account made in the 4th century BCE when an admiral of Alexander the Great's fleet described the daily rhythms of tamarind leaves. Charles Darwin described leaf 'sleep movements' in his 1880 book *The Power of Movement in Plants*, after observing that the leaves of *Medicago* plants fold up at night. So if plants have body clocks, does this mean that a plant could suffer from jet lag?

Plants keep track of time

We now know that the circadian clock controls almost all aspects of plant biology, including growth, flowering, photosynthesis, and the opening and closing of leaf stomata. In most plants, the stomata open just before dawn so the plants can start photosynthesising as soon as light is available. Plants also use their internal clocks to 'measure' day length, which determines a plant's flowering time. For example, some short-day plants (e.g. rice, chrysanthemums) only flower when the daylight is shorter than a critical length. Chrysanthemums, for instance, will start to flower if the day is shorter than their critical day length of 15 hours, so tend to flower in the spring or autumn. Long-day plants (e.g. lettuce, spinach) have the opposite response, so will only flower when the day exceeds a critical length during the summer. In contrast, day-neutral plants are not sensitive to the number of hours of light. Short-day and long-day plants with a faulty circadian clock flower earlier or later than they would do normally, as they are unable to determine the day length. Non-functioning clocks can even affect plants' defence mechanisms, preventing them from synthesising defence compounds at the right time of day, making them more prone to attack by insects.

Circadian clocks thus have important implications for agricultural productivity. Experiments using the model plant *Arabidopsis* demonstrate that, in controlled laboratory conditions, plants with a non-functional circadian clock grow less well than plants with a functioning clock. This is because plants with a non-functional clock make less chlorophyll and have lower photosynthetic rates (Dodd et al., 2005).

As the clock controls flowering time, it also dictates harvest time for crop species. For example, the barley that is grown in southern Europe is sensitive to day length, so it flowers early in the spring and is harvested in early summer before it gets too hot. In northern Europe, however, the climate is much cooler; the barley grown there has a natural mutation that affects the



- ✓ Genetics
- ✓ Environment
- ✓ Ages 11–19

Have you ever wondered why some plant species flower in the winter and others flower in the summer? Or why we sleep at night and stay awake during the day? The answers to these questions lie in the circadian rhythm, a process that occurs in both animals and plants and is also responsible for jet lag. This article explores the biology of the circadian rhythm in a clear and precise manner, and considers the role of genes and hormones in regulating our daily rhythms. In addition to exploring the comprehension questions below, the article could be used to more broadly discuss the effects of environmental conditions on plant productivity, and the impacts of climate change and environmental disturbances on circadian rhythms.

Possible comprehension questions could include:

- What is the difference between circadian and diurnal rhythms?
- Why do different plants flower in different seasons?
- How can genetic mutations influence agricultural productivity?
- Why can plants correct their circadian rhythm more quickly than humans can?

Monica Menesini, science teacher, Italy

REVIEW

Fig. 139.



Medicago marina : A. leaves during the day ; B, leaves asleep at night.

Illustrations of 'sleep movements' of *Medicago* leaves from Charles Darwin's book *The Power of Movement in Plants*

way that the clock regulates genes controlling flowering time, making the plant less sensitive to day length. This mutation allows the plant to take advantage of the longer summer days

so it can be harvested in the autumn. As a result, there is increasing interest in the circadian clock from biotechnology companies hoping to increase crop yields by manipulating the circadian clock.



Stanpeisen/pixabay.com

Research into plant circadian clocks has important implications for agricultural productivity.

Genetics of circadian rhythms

So how does circadian regulation work? The answer lies in the plant's genetics. The clock consists of many genes that control each other in a type of self-regulating system known as a negative feedback loop. Figure 1 illustrates how this genetic regulation works using a circadian clock with two genes. Gene A is switched on (e.g. through a light-dependent process) and produces protein A. Protein A then activates gene B, resulting in the production of protein B. Protein B represses the expression of gene A, which means that levels of protein B decrease, allowing gene A to be expressed again. This results in a cycle where protein A is produced at the opposite time to protein B. If each of these regulatory steps takes 12 hours,

“The plant circadian clock comprises a network of over 20 genes and their related proteins.”

the result is a 24-hour rhythm that can sustain itself in constant conditions (e.g. 24 hours of continuous light).

In reality, the mechanism behind circadian rhythms is much more complicated than this: the plant

circadian clock comprises a network of over 20 genes and their related proteins (McClung, 2019). The clock is so complex that biologists are struggling to understand all of the connections and make predictions about what will happen if the network is disturbed. So to get to grips with the problem, biologists have teamed up with mathematicians to create computational models of the circadian clock, which are now being used to help with the design of experiments. For example, models have been built that integrate information about light levels, CO₂ availability and temperature with models of circadian gene expression, which are then used to predict the growth rate of the plant under different day lengths.

Avoiding jet lag

One of the major differences between plant and human circadian clocks is the degree of central control. Our circadian clock is coordinated by an area of the brain called the suprachiasmatic nucleus (SCN), which is located in the hypothalamus. During the evening, the SCN tells the pineal gland in the brain to produce melatonin, which then travels through the body preparing other organs, such as the stomach and liver, for sleep. Since our circadian clock largely relies on hormones circulating through the bloodstream, any circadian responses are relatively slow. When someone is jet lagged, different parts of their body end up being set to different time zones. It can take a few days after a flight for all areas of the body to adopt the same time again.

This is quite different to a plant's circadian clock, which is thought to function at the level of individual cells. Each cell in the plant has its own light receptors and circadian clock, so unlike in humans, individual cells can respond to light. If you cover up parts of a plant with tin foil, you can train one part of the leaf to think it is daytime and another part to think it is night-time. This difference in clock architecture means that plants can more easily correct their circadian rhythms, so if a plant were to be flown halfway around the world, it would be much better at

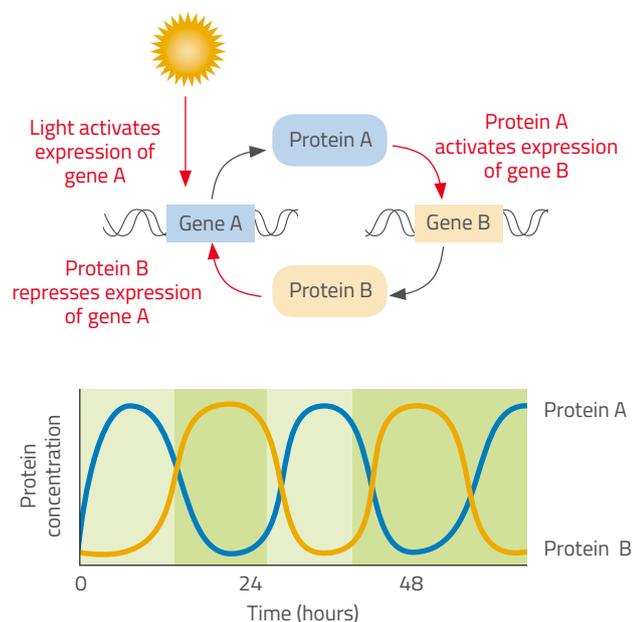


Figure 1: Negative feedback loop for a simple circadian clock

Katherine Hubbard



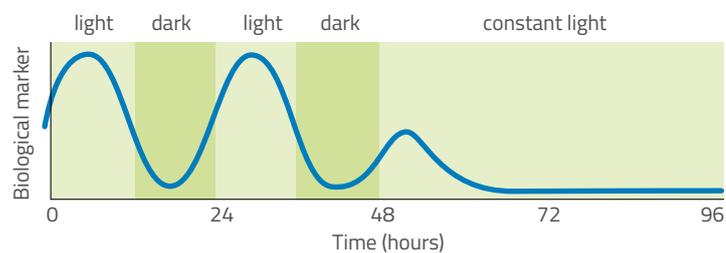
Testing for circadian rhythms

Since our circadian rhythms are controlled by an internal clock, the rhythms persist even when the external conditions (such as light) are constant. This makes them more complex than diurnal rhythms, which are simple responses to external conditions that no longer occur when the conditions are constant. Most daily rhythms are in fact circadian rhythms, but there is a simple test to check whether a biological process is a genuine circadian rhythm or not. Scientists first expose an organism (either plant or animal) to 24-hour cycles of stimuli (e.g. 12 hours

of light, followed by 12 hours of darkness). Then, the organism is put into continuous conditions (e.g. constant light) and the process is measured for several days. If the rhythm (such as the sleep-wake cycle or body-temperature cycle) persists even though the conditions are constant, it is controlled by an internal body clock and is not just a response to fluctuating environmental conditions (figure 2). This test has been performed in many different organisms, so we now know that mammals, insects, plants and even some bacteria have genuine circadian clocks.

Diurnal rhythm

24-hour rhythm ends in constant conditions, indicating a direct response to light/dark



Circadian rhythm

24-hour rhythm persists in constant conditions, indicating that it is controlled by an internal clock

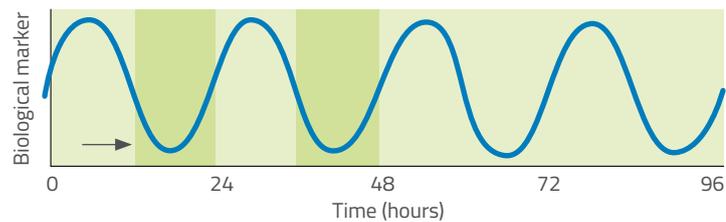


Figure 2: Experimental test to identify a diurnal or circadian rhythm

coping with the time difference than we would and, overall, jet lag wouldn't be a major issue. Unlike in humans, plants could combat jet lag in a matter of hours rather than days.

Whether plants can adjust to new time zones might be an interesting biological curiosity, but understanding the underlying biology of plant circadian rhythms has taught us a lot about how genetic networks are regulated – which ultimately could help improve agricultural yields in the future.

References

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- McClung CR (2019) The plant circadian oscillator. *Biology* **8**: 14. doi: 10.3390/biology8010014

Resources

For time-lapse videos showing plant circadian rhythms in various species, visit the Plants in Motion website. See: <http://plantsinmotion.bio.indiana.edu/plantmotion/movements/leafmovements/clocks.html> or use the direct link <https://tinyurl.com/2upbs9>

Read a short textbook introducing circadian rhythms in humans and their impact on our wellbeing. See:

Foster R, Kreitzman L (2017) *Circadian Rhythms: A Very Short Introduction*. Oxford, UK: Oxford University Press. ISBN: 9780198717683

The American Society for Plant Biology has published teaching resources on circadian rhythms. Although intended for undergraduate students, the resources could complement school-level classes or form inspiration for projects. See: Hubbard KE, Dodd AN (2016) Rhythms of life: the plant circadian clock. *The Plant Cell* **28**. doi: 10.1105/tpc.116.tt0416

Read a special issue of the journal *Biology* that celebrates the 2017 Nobel Prize in Physiology and Medicine, which was awarded to three biologists for their discoveries of the molecular mechanisms that control circadian rhythms. See: www.mdpi.com/journal/biology/special_issues/Biological_Clocks

Katharine Hubbard is a lecturer in biology at the University of Hull, UK. Her scientific background is in plant sciences, with a focus on circadian rhythms, plant signalling pathways and responses of plants to their environment. She currently teaches cell biology and plant biology to undergraduates, and is passionate about including students in modern plant biology research.



The peel of lemons contains essential oils, which are extracted in the production of limoncello.

Limoncello and the science of emulsions

How can you make oil and water stay mixed? A scientist's curiosity about a lemon liqueur has revealed how to do this – with some promising industrial applications.

By Leonardo Chiappisi

Limoncello, the fragrant Italian liqueur made from lemons, is becoming increasingly popular around the world. This sweet and citrus digestif is an iconic item of Italian food culture – but it is also a complex colloidal system made of essential oils, ethanol, sucrose and water.

As an Italian chemist working at the Institut Laue-Langevin (ILL)^{w1}, I was curious to find out what ILL's advanced technology might reveal about this complex system. So, earlier this year, my colleagues and I applied for beamline time to conduct a small study, and it turns out that – as well as being delicious – limoncello has some rather special scientific characteristics.

What is limoncello?

In the traditional limoncello recipe, the citrus zest (obtained by scraping the outer part of the lemon peel) is macerated in alcohol (ethanol) for several weeks. The zest contains most of the essential oils in lemons, producing the characteristic taste and colour of the liqueur. The ethanol and lemon extract is

then mixed with a sugar syrup. Limoncello typically contains approximately 30% alcohol and around 20% sucrose (sugar) by volume, but as limoncello is often home made, the preparation method and final composition vary from family to family.

The essential oils so important to the flavour of limoncello are found in small pockets in the peel of citrus fruits, which burst and deliver the typical strong scent we notice when peeling such fruit. These essential oils have a very complex composition: more than 60 different molecules have been identified, with a class of organic molecules called monoterpenes being the main components. In lemons, the most abundant compound is limonene (figure 1).

Limoncello is made by mixing two solutions: the ethanolic extract containing the oils, and the aqueous sucrose solution. Each of these starting solutions is completely transparent; limoncello itself, however, is 'turbid', with a cloudy, opaque appearance. Turbid systems pervade everyday life: other



- ✓ Surfactants
- ✓ Phase diagrams

Most students will recognise that oil and water do not mix, and they may have heard the word 'emulsion' when helping a family member paint a room – but despite these real-world examples, very few will have questioned the chemistry behind such experiences. By encouraging students to question what is happening on a macro level and inspiring them with the chemistry occurring on a micro level, this article provides an accessible gateway to some key concepts.

In addition, there is an opportunity to interpret a three-fold phase diagram, which allows students to use their mathematical skills to derive conclusions about physical characteristics, demonstrating that such skills are essential for scientific research.

- ✓ Neutron scattering
- ✓ Ages 16–19

Comprehension questions that could be used in class include:

- The limonene molecule has two possible enantiomers. Identify the chiral carbon atom.
- What volume of ethanol would you expect 5 litres of limoncello to contain?
- Turbid systems contain particles at a scale comparable to the wavelength of visible light. What is the wavelength range of visible light?
- Why could the science of limoncello prove useful for designing self-emulsifying systems?
- The phase diagram contains a 'metastable ouzo region'. What is meant by the term 'metastable'?

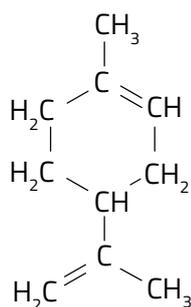
Caroline Evans, Head of Chemistry,
Wellington College, UK

REVIEW

examples include ice crystals in clouds, fat droplets in milk, and algae in a pond. These different systems all contain particles or droplets at the scale of hundreds of nanometres, which is comparable to the wavelength of visible light. It is these 'heterogeneities' – tiny amounts of solid or liquid suspended in a fluid medium – that give these systems their turbid appearance.

The 'ouzo effect'

So where does the turbidity of limoncello come from? Water and ethanol are fully miscible (soluble in each other), as are limonene and ethanol – but limonene and water are barely miscible. In limoncello, this combination of three liquids spontaneously produces an 'emulsion':



Nicola Graf

a suspension of tiny droplets of one liquid in another. However, this only happens at some specific ranges of composition (see phase diagram text box).

This phenomenon of spontaneous emulsion formation is called the 'ouzo effect', after the famous Mediterranean drink called ouzo that immediately becomes turbid when mixed with water, forming an emulsion. Indeed, ouzo is, from a scientific perspective, quite similar to limoncello, as it is made from water, ethanol and the flavour component anethole, which – like limonene – is highly soluble in ethanol but only slightly soluble in water.

In contrast to these ouzo systems, typical emulsions require a very high energetic input – such as the shaking and stirring required to make the emulsion we call mayonnaise. Another very important difference between ouzo systems and classical emulsions is the absence of any stabilising agents. For example, mayonnaise is prepared by emulsifying a vegetable oil with the water contained in egg yolk. The process is long and tedious, and it requires a substantial amount of energy – provided by vigorous shaking and stirring – to make the two liquids mix

to form the emulsion. Lecithin and proteins contained in the egg yolk are also needed to stabilise the emulsion. So why are ouzo systems important outside the kitchen? Some important industrial processes take place in emulsions – for example, polymerisation, where small molecules (monomers) combine to form large macromolecules, or polymers. Here, emulsions are often created to bring the reagents into close proximity so the reaction can proceed quickly. If such



Limoncello bottles for sale in Capri, Italy

Figure 1: The structure of limonene



The ouzo effect: the Mediterranean drink ouzo (centre) immediately turns cloudy (right) when water (left) is added to it.



Making mayonnaise requires not only the right ingredients to create the emulsion, but also quite a lot of energy.

emulsions form spontaneously (as in limoncello), requiring very little energy input, if any, this obviously makes the process more efficient and sustainable. In addition, the polymer product needs to be recovered from the reaction medium at the end of the reaction, which is often the most challenging step of the entire process. However, if the system contains no stabilisers, the extraction of the polymer and catalysts is much simpler, as the components can easily separate once the emulsion-forming composition no longer exists. Another widely used application of emulsions is in pesticides, to enable these water-insoluble products to be diluted and spread onto fields. Using an ouzo-type emulsion would avoid also spreading unnecessary surfactants, which are often harmful to the environment.

Limoncello at the micro level

As mentioned, the way limoncello scatters light is quite revealing about the liquid's structure at the microscopic level. Using radiation of shorter wavelength, X-rays or neutron beams allow us to look in more detail at structures and interactions within this liquid, and at an even smaller scale.

We hoped to use the neutron scattering facilities at ILL to see what they could tell us about limoncello – and, luckily, we were allocated time on the small-angle neutron scattering (SANS) beamline. The aim of our research was to find out where the extraordinary stability of limoncello comes from. With this aim, we studied the liqueur

under different conditions: when water is added to the ethanolic extract; at different temperatures; and at different sucrose concentrations (Chiappisi & Grillo, 2018). Neutrons are sensitive to the isotopic composition of the system, and they interact very differently with

“Limoncello can be kept in the bottle for years: not bad for a metastable system!”

the two stable isotopes of hydrogen: protium, ^1H (normal hydrogen), and the much rarer deuterium, ^2H . In the research, the essential oil was extracted from a lemon bought in the local market (thus containing mostly protium nuclei), while the ethanol and water were highly enriched with deuterium nuclei, as a contrast.

The analysis revealed that, in limoncello, the size of the oil-rich domains is always around



The SANS instrument D11 at ILL, which was used for the limoncello study

100 nanometres in diameter, regardless of water content, sugar content or temperature. These results are surprising: the typical size of the oil-rich domains in ouzo systems is normally much larger, at several hundreds or even thousands of nanometres in size (Grillo, 2003). In addition, their size is usually very sensitive to the composition or the temperature of the system – unlike in limoncello.

This makes limoncello a very interesting liquid, scientifically. The small size of the oil droplets seems to provide its exceptional stability in relation to changes of temperature and composition, and also over time. In fact, limoncello can be kept in the bottle for years: not bad for a metastable system! In contrast, drinks like pastis or ouzo tend to phase separate within a few hours of preparation (which is why a pastis is always diluted with water in the glass, just before consumption). So while we don't yet fully understand why limoncello behaves so differently to other ouzo-type drinks, we now have a better understanding of the science of self-emulsifying systems – and how to design them for use in future products and processes.

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Phase diagrams and the stability of limoncello

Phase diagrams are a convenient way of representing the changing physical states of systems of two or more components under different conditions. A common type of phase diagram shows how a single substance (water, for example) will change state between solid, liquid and gas at different combinations of temperature and pressure (figure 2).

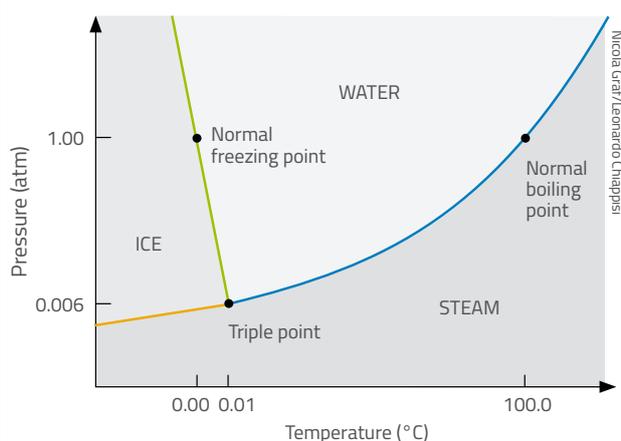


Figure 2: Diagram showing the phases of water (ice, water, steam) at different temperature and pressure combinations. The three phases can only coexist at the triple point.

In systems like limoncello, which is itself made up of three components (water, ethanol and essential oil), phase diagrams allow us to represent the possible compositions within the system, and the physical characteristics (such as solubility and stability) associated with each composition. A typical three-fold phase diagram is shown in figure 3. Here, each of the pure components is represented by a vertex of the main triangle, where the adjoining scales read 100% and 0% for two different components.

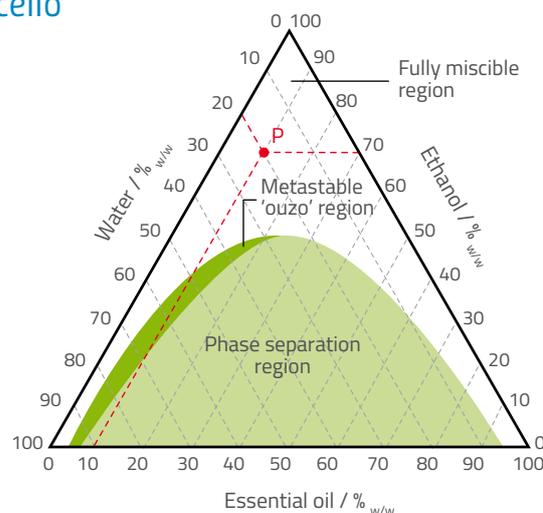


Figure 3: Three-component phase diagram representing an ouzo system

As the example illustrates, the composition of a point within the phase diagram can be read by drawing three lines starting from the point and ending at each axis (note the triangular grid used to draw the lines). In this case, a sample represented by the red point P will have a composition of 20% water, 70% ethanol and 10% essential oil (w/w).

From this phase diagram, we can see that water and ethanol are fully miscible, as are ethanol and the essential oil. However, the solubility of the essential oil in water is only 5% w/w, and the solubility of water in the essential oil is less than 10%. The diagram also shows an area in which the components separate into at least two phases and don't mix (the phase separation region). The small 'metastable ouzo region' is where the composition enables spontaneous emulsion formation – as found in ouzo systems. Phase separation will occur eventually in this region, but the timescale can be very long because the metastable state requires energy to overcome.

Web reference

w1 Based in Grenoble, France, ILL is an international research centre at the leading edge of neutron science and technology. See: www.ill.eu

Resources

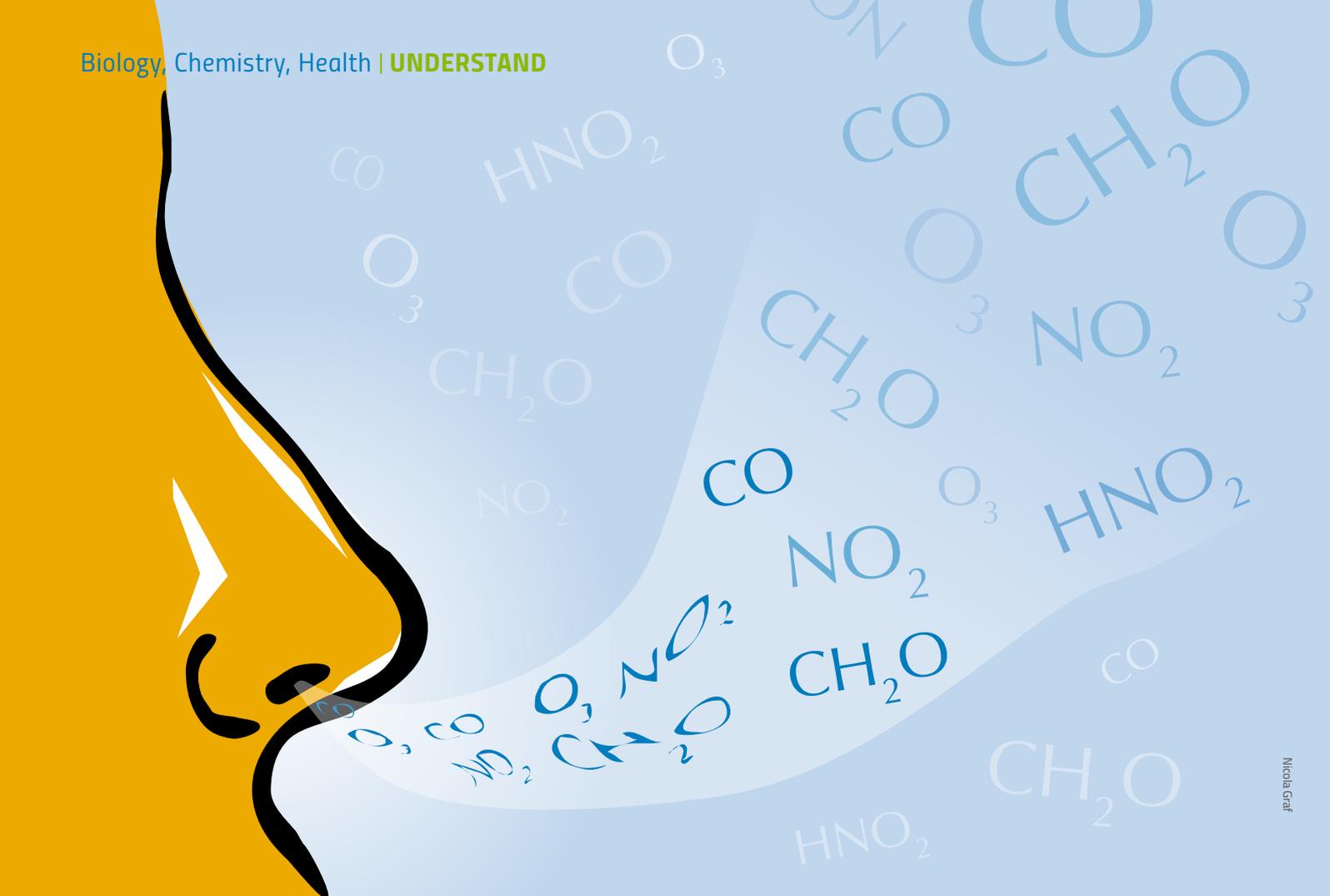
The study of the microscopic structure of limoncello was carried out using the SANS instrument D11 at the ILL. Learn how this instrument works on the ILL website. See: www.ill.eu/users/instruments/instruments-list/d11/how-it-works/d11-simulated-experiment/

Find out more about how neutron scattering works from an article from ILL about a study of how some bacteria can live in salty sea environments. See: Zaccai G (2018) Titanic and the iron-eating bacteria. *Science in School* **43**: 8-11. www.scienceinschool.org/2018/issue43/titanic

Read about how SANS was used to develop a new, recoverable surfactant at the ILL. See: Eastoe J et al. (2012) Magnetic science: developing a new surfactant. *Science in School* **25**: 22-27. www.scienceinschool.org/2012/issue25/soap

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Nicola Graf

Take a deep breath? Investigating indoor air pollution

New studies are uncovering how emissions from daily household activities pollute the air we breathe at home.

By Nicola Carlslaw and Nina Notman

In many towns and cities around the world, air quality is now continually monitored, and laws exist to help keep air pollution to acceptable levels. In some major cities, policies such as banning cars in central zones are helping to reduce the public's exposure to harmful pollutants. This is, of course, great progress, but when you consider that people in developed countries are estimated to spend around 90% of their time indoors, it is perhaps surprising that our knowledge of indoor air quality lags considerably behind that of outdoor air. In the past few years, however, scientists have started to investigate the quality of indoor air, and the chemistry that creates indoor air pollution, in more detail.

Sources of indoor pollutants

The majority of indoor air pollutants originate from things we use and do indoors. This means that the composition of indoor air is usually very different to that of outdoor air. Sources of indoor pollution include gas hobs and wood-burning stoves, which emit a mixture of potentially harmful gases including nitrogen dioxide (NO₂) and carbon monoxide (CO). Candles are another significant offender: perhaps surprisingly, burning a candle for just one hour can produce enough NO₂ to increase the indoor concentration close to the World Health Organization's (WHO) limit (hourly mean) of 200 micrograms per cubic metre (µg/m³)^{w1} (Uhde & Shulz,



Wood-burning stoves emit a mixture of potentially harmful gases.

vinyl floorings and soft furnishings, as well as personal care products, cleaning agents and air fresheners. These release potentially dangerous volatile organic compounds (VOCs) into the surrounding air. One of the most common VOCs is formaldehyde (methanal, CH_2O), a colourless – but smelly – gas that is a respiratory irritant and carcinogen.

Insights into air chemistry

One of the first in-depth studies into indoor air chemistry began in June 2018, when 65 scientists took over a three-bedroom test house in Texas, USA, to begin a project called 'HOMEChem'^{w2} (Farmer et al., 2019). Bringing with them \$4.5 million worth of equipment, they spent a month cooking, cleaning and performing other everyday tasks, while analytical instruments measured the mixture of indoor chemicals being emitted. The project

culminated in the researchers preparing a typical Thanksgiving dinner with roast turkey and all the trimmings. While cooking this meal, NO_2 concentrations peaked at approximately $200 \mu\text{g}/\text{m}^3$ as a result of emissions from the gas hob.

But much simpler meals ultimately proved to be a bigger threat: cooking a stir-fry resulted in the highest concentration of PM_{10} (particles that measure less than $10 \mu\text{m}$ in diameter) of around $350 \mu\text{g}/\text{m}^3$, as a result of particles from both the cooking oil and the food. To put this in perspective, the WHO limit (24-hour mean) for PM_{10} is $50 \mu\text{g}/\text{m}^3$. Frying eggs, sausages and tomatoes (in addition to cooking toast for breakfast) produced the highest concentration of fine particles (those measuring less than $2.5 \mu\text{m}$ in diameter, known as $\text{PM}_{2.5}$) at approximately $200 \mu\text{g}/\text{m}^3$ (Farmer et al., 2019), for which the WHO limit is $25 \mu\text{g}/\text{m}^3$. What's more, these smaller particles are

2015). These combustion sources also release minute specks of inhalable particles known as particulate matter (PM). At high enough concentrations, NO_2 and PM can lead to respiratory and cardiovascular problems, while exposure to high concentrations of CO can be fatal.

Other contributors to indoor pollution are household materials such as paint,



- ✓ Inorganic and organic chemistry
- ✓ Chemical reactions
- ✓ Human physiology
- ✓ Health and disease
- ✓ Environmental sciences
- ✓ Atmospheric chemistry
- ✓ Ages 11–19

While the study of outdoor air pollution and its presence in the media date back many decades, the study of indoor air pollution is a more novel topic. This article, written in a concise and clear style, introduces readers to the complexities of this issue, keeping it as simple as possible without compromising its scientific details.

The article is aimed at secondary school teachers and students, and sparks the readers' interest with the broader topic of air pollution before addressing theoretical topics in chemistry. The direct link between indoor air pollution and human health offers further teaching opportunities, and the additional web references and resources provide more ways to explore the topic.

The article can also be used as a comprehension exercise, for learning assessments, and for a discussion on the safety of indoor environments and ways of improving air quality through our own habits and behaviours.

Possible comprehension questions include:

- On average, how much time do people in developed countries spend indoors every day?
- Is the composition of indoor air usually similar or different to outdoor air?
- Name two chemicals produced by combustion in gas hobs and wood-burning stoves.
- What is the difference between PM_{10} and $\text{PM}_{2.5}$? Which type of particle can travel deeper into the lungs?
- Name four household materials that release VOCs.
- Which compounds are produced by the splitting of formaldehyde due to light?
- What is third-hand smoke?
- List three actions that can be taken to reduce indoor air pollution.
- Indoor air pollution is a bigger problem now than it was 50 years ago. Why is this?

Giulia Realdon, natural sciences teacher and education researcher, Italy

REVIEW

likely to be more harmful to our health than PM_{10} , as they can travel further into the respiratory system.

Reactions in the air

Once these molecules are released into the air, they don't hang around in their original form for long. Instead, they can react with other chemicals to form new products. The reaction rates are often different indoors and outdoors. Light-driven reactions, for example, happen more slowly indoors. This is because glass cuts out much of the ultraviolet light that splits molecules apart outdoors. Indoor lights also tend to have low ultraviolet levels. However, these reactions can still happen. For instance, there is sufficient light indoors for formaldehyde to react with oxygen and split to form two hydroperoxy (HO_2) radicals and a CO molecule. The HO_2 radicals can then form other oxidants that react with the indoor VOCs – and before you know it, there are hundreds of different reactions forming myriad different compounds, some of which are harmful to health.

A more significant driver of indoor reactions, however, is the amount of available surface area. Surfaces play a more important role in indoor chemistry than outdoor chemistry, since the ratios of surface area to volume are much greater indoors than outdoors. This is because the fibres in fleecy surfaces such as carpets and soft furnishings increase the surface area beyond the



Calle Richmond/Calle Richmond Galleries

Stir-fry experiments resulted in a spike in the concentration of particulate matter inside the HOMEChem house.

nominal footprint that such an item occupies in a room. As a result, there are more opportunities for pollutants to settle on surfaces and react with other chemicals deposited there (Weschler & Carslaw, 2018).

Here, tobacco smoke and e-cigarette vapour are a particular concern. Nicotine and other chemicals in exhaled smoke or vapour linger in the air and stick to surfaces such as those of furniture or fabrics. This residue, which is known as third-hand smoke^{w3}, can later react with indoor pollutants such as nitrous acid (HNO_2) to form new and often harmful products, such as carcinogenic nitrosamines. Third-hand

smoke is currently an area of very active research, given the potentially adverse health effects that arise from exposure to it.

Perhaps the most interesting surface that scientists are exploring, however, is the human body. When ozone in the air comes into contact with the many oils and fatty acids on our skin, they can react to produce a range of secondary pollutants. As we go about our daily indoor lives, we are removing ozone (O_3) from the air and releasing other chemicals. For instance, if you use bleach to clean your home, mixing the bleach with water releases chlorine gas (Cl_2), hypochlorous acid ($HOCl$)

Scientists of the HOMEChem project carried out everyday activities in this three-bedroom test house in Texas, USA, to measure indoor air pollution.



Calle Richmond/Calle Richmond Galleries

and other chlorine compounds into the surrounding air. The oils on our skin contain unsaturated compounds with carbon-carbon double bonds, such as squalene ($C_{30}H_{50}$). The HOCl reacts with the double bonds to form chlorinated compounds, which could explain why our skin becomes irritated without even coming into direct contact with the bleach itself.

Cleaning up pollutants

As a result of these new scientific studies, our once foggy understanding of indoor air pollution is now starting to clear. Evidently, spending so much of our time indoors means that we are exposed to a concoction of chemicals and indoor air pollutants – especially as energy-efficient measures mean that our homes and buildings are increasingly airtight, making it easier for pollutants to build up inside. Minimising our

“Energy-efficient measures mean that our homes and buildings are increasingly airtight, making it easier for pollutants to build up inside.”

exposure to these pollutants is more important than ever, so remember to ventilate often, especially when you cook and clean, and consider the frequency with which you use air fresheners or scented candles. And judging from the HOMEChem project results, it's a sensible idea to use a cooker hood whenever you're using a hob – especially when cooking a breakfast fry-up.

Acknowledgement

The authors acknowledge the support of the Alfred P Sloan Foundation^{w4} under grant number G-2018-10083 to write this article.



We spend the majority of our time inside, but little is known about the indoor air pollutants we inhale every day.

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- w2 Learn more about the 'HOMEChem' project in the article 'Large scale experiment probes chemistry inside our homes' published in *Chemistry World*. See: www.chemistryworld.com/news/large-scale-experiment-probes-chemistry-inside-our-homes/3009228. article
- w3 Watch a short video about third-hand smoke on the 'Indoor Chem' YouTube channel. See: www.youtube.com/watch?v=qQvllEbQ3tU&t=3s or use the direct link <https://tinyurl.com/yxpupd5n>
- w4 The Chemistry of Indoor Environments webpage on the Sloan Foundation website

provides more information about the programme, as well as links to further resources and videos. See: <https://sloan.org/programs/research/chemistry-of-indoor-environments>

Resources

- Read about the health impacts of various air pollutants in a factsheet published by WHO. See: [www.who.int/en/news-room/factsheets/detail/ambient-\(outdoor\)-air-quality-and-health](http://www.who.int/en/news-room/factsheets/detail/ambient-(outdoor)-air-quality-and-health)
- The 'Indoor Chem' YouTube channel publishes a range of videos on the topic of indoor air pollution. See: www.youtube.com/channel/UCXFu3yNKZvgkWrzq6irGzUw or use the direct link <https://tinyurl.com/y49v2jj5>

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Wall fresco from Pompeii, showing some blackening of the natural red pigment cinnabar



Rembrandt self-portrait (1659)

Art and science from Pompeii to Rembrandt

Applying high-tech science to the study of ancient art and famous paintings has been a rewarding career choice for synchrotron scientist Marine Cotte.

By Montserrat Capellas Espuny

We sometimes think of art and science as two quite different areas of endeavour. But one person whose career challenges this view is Dr Marine Cotte, a scientist at the European Synchrotron Radiation Facility (ESRF)^{w1} in Grenoble, France. Marine has always been fascinated not only by science but also by cultural heritage, and this has influenced her career from the very start. After studying chemistry at the prestigious Ecole Normale Supérieure de Lyon, for her PhD research she moved not to a university but instead to the Louvre Museum in Paris. In 2001, at the Centre of Research and Restoration of French Museums, situated in the basement of the Louvre, she began her research studies.

Ancient materials

As part of her thesis, Marine used advanced scientific techniques to study tiny fragments of ancient materials in some of the Louvre's collections. "Surprisingly, many of the antique cosmetics pots which are stored and exhibited at the Louvre Museum are made of lead compounds", she says. While today people would not like to find lead in their make-up, in earlier periods it was a common practice to use lead-based ingredients to prepare cosmetics – and also in pharmaceutical products. For example, the black eye make-up used by ancient Egyptians was generally made of galena (a lead sulfide mineral). And until the beginning of the 20th



Chantal Argoud/ESRF

Synchrotron scientist and art conservation researcher Marine Cotte

century, pastes used to treat burns or wounds were made by mixing fat or oil with a lead compound and various additional ingredients.

One technique Marine brought to her research at the Louvre was a new type of X-ray microscopy, carried out using the high-powered beam produced by a synchrotron – a very narrow, intense light beam ranging from infrared to X-ray wavelengths, produced in a dedicated research facility. Using synchrotron microscopes to study ancient materials was a rare approach

in those days, but one Marine has carried on using with great success. She continued to study ancient arts for her postdoctoral research, moving to ESRF in 2004. While she has been based at ESRF ever since, her research has been truly international.

In one of her first research projects at ESRF, Marine joined forces with researchers from Paris and Pisa, Italy, to study the degradation of wall paintings in a house near the ancient city of Pompeii, which was buried when the volcano Vesuvius erupted in 79 AD. Scientists have been wondering for many years why the red paintings on the walls of Pompeii, made using the natural pigment cinnabar, turned black. This colour change was familiar even to the ancients: they attempted to prevent the problem by applying a protective varnish based on a substance called ‘punic wax’.

Until Marine’s research, the most widely accepted explanation was that, when exposed to light, cinnabar undergoes a change in crystal structure into metacinnabar, which is black. However, the experiments – performed on an X-ray microscopy beamline

at ESRF – showed that this structural change did not happen: instead, the team found that two chemical reactions (one involving chlorine) were the cause of the blackening (Cotte et al., 2006). Ironically, the punic wax varnish may

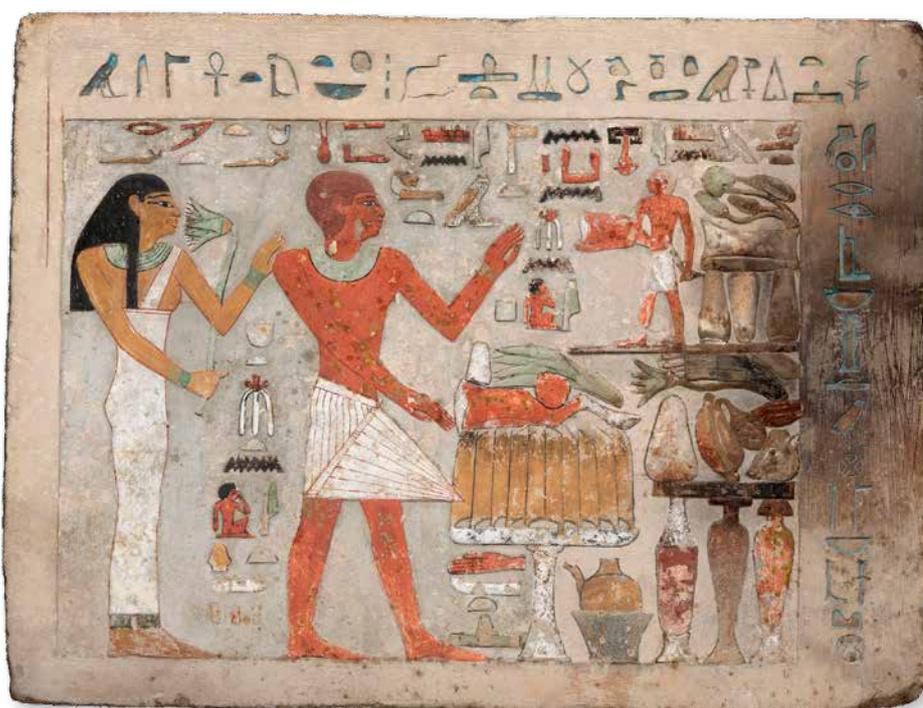
“Rembrandt revolutionised painting with a technique called *impasto*, where thick paint makes parts of a painting protrude from the surface.”

have hastened this change. “Chlorine probably comes from the neighbouring Mediterranean Sea and might even have been applied by painters, since punic wax was made using sea water”, explains Marine.

Fine art investigations

The quest for what makes old and valuable paintings degrade has always been at the top of Marine’s goals in her research. Such a question is fundamental if we want to preserve our artistic heritage in the best state for future generations, because understanding the chemistry involved can help conservators to minimise degradation. In 2010, Marine joined a collaboration with researchers at the University of Antwerp, the University of Perugia and the Van Gogh Museum in Amsterdam to study how the chrome yellow pigment has changed in van Gogh’s paintings, especially in the *Sunflowers* series^{w2} (Dik et al., 2008).

The Dutch connection did not stop there. In 2018, Marine began working on the paintings of the ‘old master’ painter Rembrandt, who epitomised the Dutch Golden Age of painting. Rembrandt revolutionised painting with a technique called *impasto*, where thick paint makes parts of a painting protrude



Museum Purchase Fund/Art Institute of Chicago, CCO 1.0

Amenemhat and his wife Hemet, c. 1900 BCE. Both the male and female figures depicted in this ancient Egyptian painting wear striking lead-based eye make-up.



Rijksmuseum / Musée du Louvre, public domain

Portrait of Marten Soolmans (1634). Samples from this Rembrandt painting were used to study Rembrandt's impasto technique.

from the surface, creating a three-dimensional effect and increasing the light-reflecting and textural properties of the painting. Rembrandt achieved the *impasto* effect by using materials traditionally available on the 17th century Dutch colour market – namely, the lead white pigment (a mixture of hydrocerussite, $\text{Pb}_3(\text{CO}_3)_2 \cdot (\text{OH})_2$, and cerussite, PbCO_3) and organic media (mainly linseed oil). However, the precise recipe of his *impasto* was unknown.

Marine assisted Victor Gonzalez, a researcher from the Rijksmuseum and the Delft University of Technology, to analyse tiny fragments from three of Rembrandt's masterpieces: *Portrait of Marten Soolmans*, *Bathsheba* and *Susanna*. Using ESRF's beamlines, they investigated the structure and composition of the *impasto* material on the micron scale. The outcome was the discovery that the *impasto* layers contained plumbonacrite, $\text{Pb}_5(\text{CO}_3)_3\text{O}(\text{OH})_2$ – a lead compound that is extremely rare in historical paints, thus providing a distinctive chemical 'signature' of the material that Rembrandt used (Gonzalez et al., 2019).

"This was a real surprise because, before starting the experiments, we had absolutely no clue that our technique would detect any particular signature in the *impasto*", says Marine.

Prizewinning research

Beyond such important results for the art world, Marine's extensive international research has paid further dividends: in November 2018, she was awarded the Descartes-Huygens Prize, an award created in 1995 by the French and Dutch governments to strengthen Franco-Dutch scientific cooperation. The prize is awarded each year to two researchers – one in France, the other in the Netherlands – for their outstanding work and contribution to the two countries' bilateral relationship.

This award now allows Marine to travel regularly to the Netherlands – which is excellent timing, due to the current temporary shutdown of ESRF for an upgrade. "2019 is the perfect year to organise stays in the Netherlands and strengthen our collaborations there", says Marine. In addition to her ongoing

"The outcome was the discovery of a distinctive chemical 'signature' of the material that Rembrandt used."

research on painting techniques, she will be involved in the design and construction of a small, transportable 'table-top' synchrotron currently being built for use in the Netherlands.

Marine is also on a mission to convince members of the art world of what synchrotron science can do for them. "With my collaborators from Amsterdam and Delft, we hope to raise the awareness of Dutch cultural heritage actors – academics, museum scientists, curators, conservators, art historians – about the assets of

synchrotron radiation techniques to study works of art", she says. As well as following up the research on Rembrandt and plumbonacrite, Marine and her colleagues hope to reveal the material secrets of other master painters – including the enigmatic Leonardo da Vinci – in their future research.

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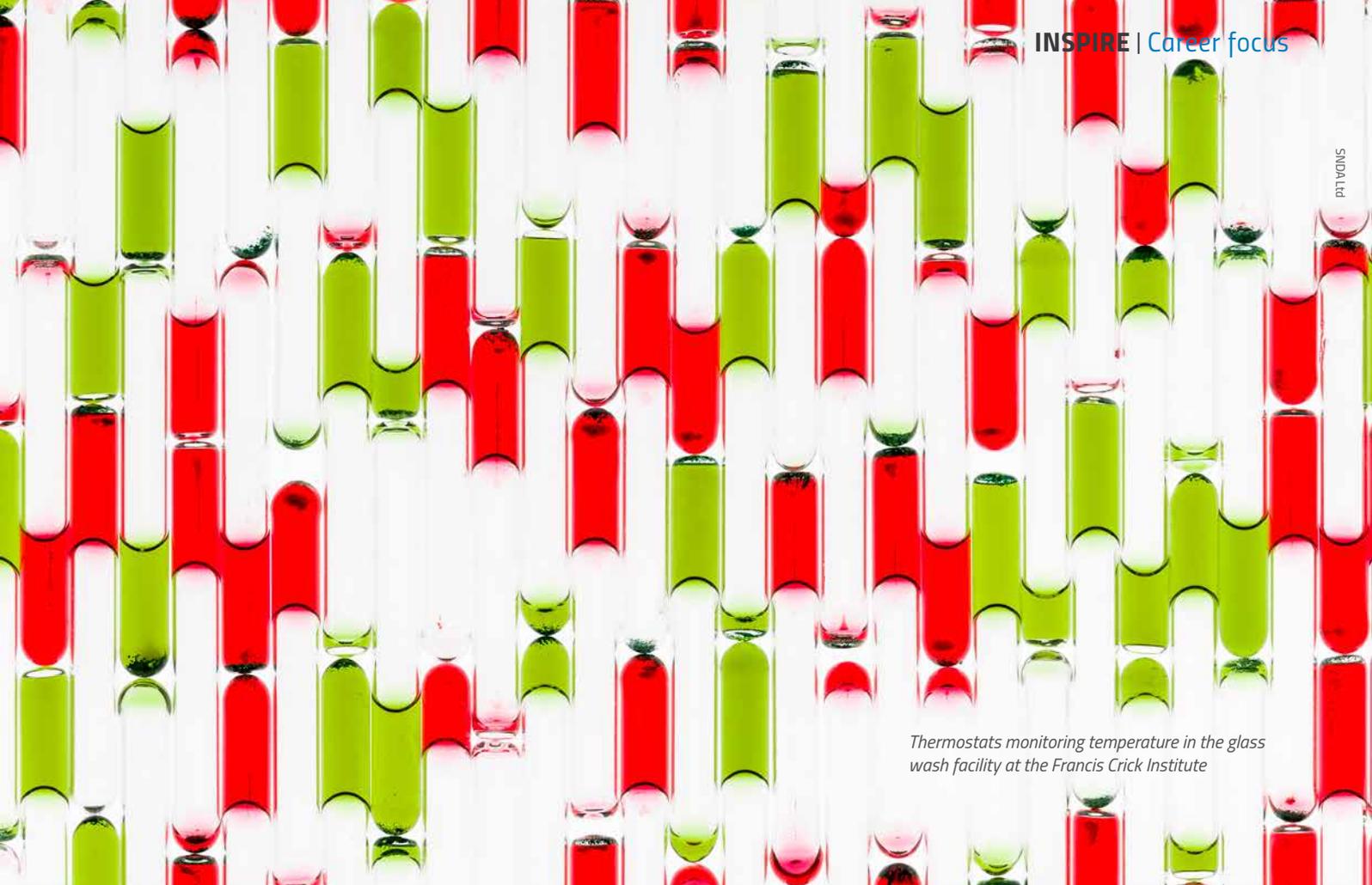
- w1 Situated in Grenoble, France, ESRF operates the most powerful synchrotron radiation source in Europe. See: www.esrf.eu
- w2 Learn how the X-ray techniques of ESRF explain the darkening of rich yellow in van Gogh's paintings. See: Brown A (2011) Van Gogh's darkening legacy. *Science in School* **19**: 19-25. www.scienceinschool.org/2011/issue19/vangogh

Resources

- Find out more about the study that revealed the secret of Rembrandt's *impasto* in this article on the Phys.org website. See: <https://phys.org/news/2019-01-secret-rembrandt-impasto-unveiled.html>
- Read a press release announcing Marine Cotte as a recipient of the 2018 Descartes-Huygens Prize on the Koninklijke Nederlandse Akademie van Wetenschappen website. See: www.knaw.nl/en/news/news/descartes-huygens-prize-for-art-conservation-researcher-and-literary-scholar

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Thermostats monitoring temperature in the glass wash facility at the Francis Crick Institute

Behind the scenes at the laboratory

You don't have to be a researcher to take part in worthwhile scientific research. Find out about some of the less visible roles that keep the science happening.

By Susan Watt

Although many students are enthusiastic about studying science at school, it's not a universal sentiment: some less-enamoured students sometimes question why they need to learn about science when they are not ultimately aiming for a career as a researcher. One answer, of course, is that scientific knowledge helps us to understand key issues facing society – from future energy sources to regulating gene technology – as well as to make more evidence-based choices in our own lives.

But there is another reason, which is sometimes overlooked: science can offer great job opportunities, even for those who are not aiming for a future as a research scientist.

A current exhibition at one of Europe's biggest and newest laboratories aims to remind people of this fact. 'Craft and

Graft'^{w1} takes a look behind the scenes at the many different teams that support the biomedical research carried out at the Francis Crick Institute in London – from bottle-washing to breeding flies. Each of these teams employs staff who need to be 100% reliable in what they do, because the research absolutely requires this: a non-sterile flask, for example, could ruin a year's work.

The curator of the exhibition, Emily Scott-Dearing, worked for a year to create 'Craft and Graft' and spoke to members of some 20 different technician teams who maintain the vital services needed for the laboratory's research. "You certainly don't have to be a scientist to play a part in



Flasks and record-keeping diary in cell services

life-changing scientific research. There are so many routes into this world”, Emily says.

More than washing up

Among the technicians that support the science are the glass wash team, who provide fresh glassware throughout the building. Each member of the team is responsible for collecting, cleaning and returning glassware to a particular group of laboratories. This means running some 20 loads through industrial dishwashers every day, oven-baking or autoclaving the items to sterilise them

– and clocking up a lot of steps to pick them up and return them. Over a year, the team cleans around 750 000 flasks, test tubes and beakers.

Attention to detail is essential throughout – perhaps even more than when looking after crystal glasses in a fine-dining restaurant. And, as Emily says, “Would you rather wash glasses in a restaurant or wash the flasks and bottles crucial for cancer research and understanding how our brains work?” Like many members of the team, Nick Sherwood trained on the job. With school-level science qualifications and

a background in practical work, Nick has been a glass wash technician since 2006. “Our roles are so different from the scientists’”, he says. “But when you see the work they’re doing, you feel part of a whole.”

Cells – fresh and frozen

In a biomedical laboratory, cells are the living systems that many scientists use as biological models for their experiments. These ‘cell lines’ – cells that can reproduce indefinitely – have to be cultured and then frozen for storage in the cell line repository.

Technicians in the cell services team look after around 100 different cell types at any one time – with another 6000 types hibernating in basement freezers. This amounts to culturing billions of cells each year for use in cancer studies and other biomedical research, as the researchers require.

Cell services team member Fatemeh Abolverdi arrived at her post as a laboratory research apprentice after studying science at school, followed by a college diploma in applied science. As well as culturing cells and retrieving them from liquid nitrogen, she needs to observe correct laboratory procedure at all times in her role. As Fatemeh says, “The quality of cells that



Technicians use cotton gloves to handle freshly washed glassware.



Technician selecting a vial containing frozen cells

cell services provides to scientists can have far-reaching effects and impacts on experiments.” The work often entails multitasking and working under pressure, while maintaining meticulous records. But Fatemeh takes this in her stride: “I enjoy everything in cell services”, she says.

Fruitful flies

As biomedical research advances, the tiny fruit fly *Drosophila* remains a key model organism used by biomedical researchers – not least because 70% of genes linked to human disease have a fruit-fly equivalent. The fly facility at the Francis Crick Institute looks after 1.5 million flies from 8000 different strains of *Drosophila*. Feeding these flies consumes some 10 000 litres of food per year – but the fly facility team

“Staff are skilled in providing the technical services researchers need, including the delicate task of identifying the sex of individual flies.”

does a great deal more than provide bed and board for their insect residents. Staff are also skilled in providing the technical services researchers need, including performing microinjection procedures to create transgenic flies,



Fly incubation room (top) and incubation shelf (above) in the fly facility

carrying out genetic crosses, and setting up fly cages to run experiments – as well as undertaking the delicate task of identifying the sex of individual flies.

Like her colleagues in other teams, fly facility technician Grace Davis is inspired by the ultimate aim of the laboratory’s work, which she shares with the researchers. “The most satisfying aspect of working at the Crick is knowing what I do could help researchers now, or in the future, discover cures for disease”, she says.

All in a career

All this hard work does not go unnoticed by the laboratory’s high-profile director, Nobel prizewinner Sir Paul Nurse. “Engineers, technicians and other research specialists make up a significant part of our workforce, and without them the science we do here would be impossible”, he says. And this view comes not only from his current position, but from much earlier personal experience: “I began my scientific

career as a 17-year-old laboratory technician, so I really understand what technical staff contribute to research”, he says.

Web reference

w1 Find out more about the Craft and Graft exhibition at the Francis Crick Institute in London, which runs until 30 November 2019. See: www.crick.ac.uk/whats-on/exhibitions/craft-and-graft

Resource

Read the *Science in School* interview with Sir Paul Nurse. See:

Gristwood A (2017) The importance of failure: interview with Paul Nurse. *Science in School* **40**: 31–33. www.scienceinschool.org/2017/issue40/failure

Susan Watt is a science writer and staff editor with *Science in School*.



*Purple vapour of
elemental iodine*

Classic chemistry: finding the empirical formula

Witness a spectacular chemical reaction and take some careful measurements to work out the empirical formula of a compound.

By Caroline Evans

Every chemical compound has a chemical formula. In fact, there are several different types of chemical formula for any one compound (figure 1). Perhaps the most familiar type is the molecular formula – such as H_2O for water and CO_2 for carbon dioxide – which tells us the number of different atoms in each molecule. Structural formulae go a step further by showing how the atoms are linked together within the molecule, which is especially important for organic compounds.

The simplest type of formula – called the empirical formula – shows just the ratio of different atoms. For example, while the molecular formula for glucose is $\text{C}_6\text{H}_{12}\text{O}_6$, its empirical formula is CH_2O – showing that there are twice as many hydrogen atoms as carbon or oxygen atoms, but not the actual numbers of atoms in a single molecule or how they are arranged. These simple, ratio-based formulae were developed by early chemists in the 18th century. They are known as

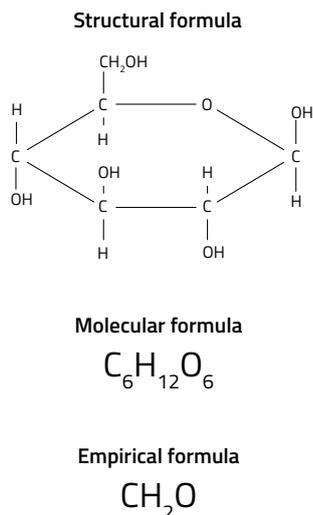


Figure 1: The structural, molecular and empirical formulae for glucose

'empirical' formulae because the ratio between the numbers of atoms in a compound can be found by traditional methods of chemical analysis by experiment.

Today, working out an empirical formula experimentally is an important feature of chemistry courses all over the world. It is also the first step in working out the chemical formula of an unidentified compound, making it a useful tool in chemical analysis. The classic school demonstration involves heating magnesium in a crucible to make magnesium oxide – a dull white powder. In this article, a much more exciting alternative is described: a dramatic reaction between tin and iodine, producing a bold purple vapour and bright orange crystals as the reaction progresses.

The aim of the experiment is to calculate the ratio between tin and iodine atoms in tin iodide. This is done by synthesising this compound and accurately measuring the mass of the reagents at the start of the experiment and the leftover tin at the end. The experiment involves a range of techniques, including setting up and using a reflux condenser and using organic solvents for extraction. As well as covering the practical exercise of deriving the empirical formula, the experiment links to more theoretical chemistry topics, such as the benefits of using a reagent in excess, the synthesis of compounds from their elements, and

Nicola Graf

how bonding can be linked to solubility. It's also a very clear application of the law of conservation of mass, which is a fundamental principle throughout chemistry (and science generally).

Depending on the number of fume cupboards available in your classroom, students can carry out the experiment themselves, but it is also suitable as a teacher demonstration. The experiment takes about two hours and works best in a double lesson, but it is also possible to split it between two single lessons. It is most suitable for students aged 16–18, but it could also be used as an extension activity for those aged 14–16.

Materials

The teacher (or each group of students) will need the following:

- 3 g iodine
- 5 g tin metal, in pieces no larger than about 1 cm square
- 60 ml cyclohexane
- Propanone
- 250 ml round-bottomed flask (for example Quickfit®)
- 100 ml measuring cylinder



The reagents needed for the experiment

- 250 ml beaker
- Clamps
- Electric heating mantle
- Reflux condenser
- Water supply
- 2 large pieces of filter paper
- Accurate weighing balance
- Lab jack (optional)

Safety note: Students should wear a lab coat, gloves and safety goggles. Solid iodine is corrosive and can stain



- ✓ Stoichiometry
- ✓ Analytical chemistry
- ✓ Ages 14–19

This article describes a spectacular experiment to work out the empirical formula of a compound produced from its elements. This practical exercise gives students an opportunity to go beyond numerical exercises when working out chemical formulae.

The experiment is suitable for senior chemistry students studying analytical chemistry. It involves a wide range of experimental techniques and could be used as a starting point for discussing different sources of error in experimental measurements. It can also provide a basis for other key topics, including how bonding is linked to solubility.

All the materials required can be easily obtained and the instructions are easy to follow, making the activities suitable for students to perform in groups.

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

REVIEW



Weighing the iodine (step 1)



Tin and iodine in the flask (step 2)



Flask with cyclohexane added to the tin and iodine (step 3)

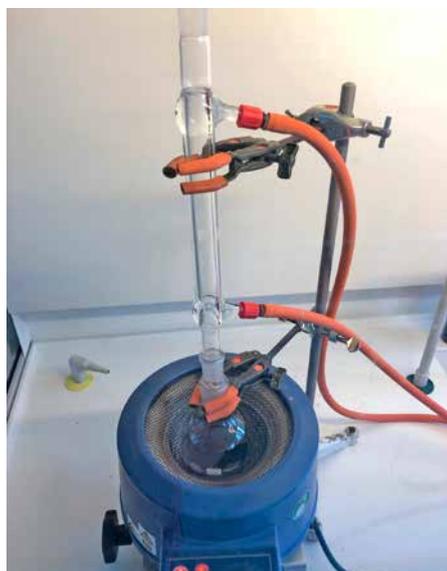
the skin, which is why gloves should be worn. The experiment should be carried out in a fume cupboard. As iodine vapour is toxic, ensure that the purple vapour does not rise more than one-third of the way up the reflux condenser when heating. Cyclohexane and propanone are highly flammable, so a heating mantle is required, and care should also be taken to keep both these solvents away from naked flames. Propanone should be disposed of in a solvent residues bottle. In addition, teachers should follow their local health and safety rules.

Procedure

1. Place the 250 ml round-bottomed flask on weighing scales. Place about 3 g of solid iodine in the flask, and record accurately the mass added.
2. Add about 5 g of tin metal to the flask and record accurately the mass of tin used.
3. Clamp the flask by the neck and add 60 ml of cyclohexane.
4. Lower the flask into an electric heating mantle. You may wish to use a lab jack to allow you to

raise and lower the heater when required.

5. Attach a reflux condenser vertically into the neck of the flask, then clamp and connect this to the water supply.
6. Heat the mixture gently in the flask until it starts to boil.
7. Now reduce the heat so that the mixture boils steadily and the purple iodine vapour rises no more than one-third of the way up the condenser.
8. Continue heating until there is no longer any trace of purple, and the



Flask, reflux condenser and heating mantle setup (steps 4–5)



Iodine vapour rising as the mixture is heated (step 7)



Orange liquid formed (step 8)

liquid dripping back into the flask from the condenser is colourless. The liquid in the flask should be orange. This may take up to an hour to complete.

9. Allow the mixture in the flask to cool.
10. In a fume cupboard, pour the orange liquid from the flask into a beaker, taking care not to tip out any of the residual tin metal.
11. Pour a small amount of propanone into the round-bottomed flask and swirl this around to dissolve any remaining tin iodide that could still be in the flask with the excess solid tin. Carefully decant the propanone washings into the beaker. Repeat this process of swirling with propanone until the propanone poured from the flask into the beaker is colourless. This step ensures the leftover solid tin does not contain any of the orange tin iodide.
12. Leave the beaker in the fume cupboard overnight so that the solvent evaporates, allowing beautiful orange tin iodide crystals to form. (You can look at these in the next lesson.)
13. Transfer the unreacted tin left in the flask at the end of the experiment onto two large pieces of filter paper. Allow the filter paper and tin to dry in the air, then weigh and record the mass of leftover tin.



End of the reaction: orange liquid and residual tin (step 10)



Tin iodide crystals formed (step 12)



Leftover tin, dried on filter paper (step 13)

Determining the empirical formula

This experiment involves reacting two substances – tin and iodine – in their elemental form to produce the compound tin iodide. Tin has more than one possible oxidation state, so the reaction could produce either tin(II) iodide (SnI_2) or tin(IV) iodide (SnI_4). Using the experimental data, we can derive the empirical formula for the product, which will tell us the ratio between tin and iodine. From this, we can work out the identity of the tin compound produced.

14. The first step is to work out the masses of the iodine and tin used in the reaction. The iodine is all used in the reaction (as it is the limiting reagent, while tin is in excess), so we can use the accurate mass of iodine weighed in step 1.

15. To calculate the mass of tin used in the reaction, we need to subtract the mass of tin left over once the reaction has finished from the initial mass. Tin used in the reaction = initial mass (step 2) minus the leftover mass (step 13)

16. Now we need to convert masses into moles, to find the amount of tin and iodine atoms used in the reaction. To do this, we divide each mass value (from steps 14 and 15) by the relative atomic mass (A_r) of the element. The resulting answers will tell us the number of moles of each element used in the reaction (and thus in the final compound).

17. To find the empirical formula of tin iodide, we need to find the number of moles of iodine used for one mole of tin. Here, we divide both answers in step 16 by the number of moles of tin used (as this will tell us how many moles of iodine combine with one mole of tin). You may need to round this ratio slightly to form simple whole numbers: for example, a ratio of tin to iodine of 1:3.6 can be rounded to 1:4.

18. Finally, you can write the empirical formula: for example, a ratio of 1:4 means that the empirical formula is SnI_4 . What empirical formula did you find?

Error	Effect on: mass of tin left over	Effect on: mass of tin reacted (initial mass minus leftover mass)	Effect on: value of x (in SnI _x)
Incomplete reaction of iodine	Increases, as not all the tin reacts	Decreases	Increases
Loss of leftover tin while washing with propanone	Decreases	Increases	Decreases
Incomplete drying of leftover tin	Increases, by adding extra mass from the solvent	Decreases	Increases
Poor washing of leftover tin	Increases, as some tin iodide is included in the leftover tin mass	Decreases	Increases
Loss of iodine vapour from condenser	Increases, as not all the tin was able to react	Decreases	Increases

Table 1: Sources of experimental error and their effects



Caroline Evans

Sources of error in experimental measurements

After the experiment, ask all students to think about possible sources of error. What effect might each of the following have on the final results?

- Accuracy of the balance used
- Incomplete reaction of iodine
- Loss of iodine vapour from the condenser
- Poor washing of the residual tin
- Loss of tin while washing with propanone
- Incomplete drying of the tin before recording the mass

Table 1 summarises the effect of each of these sources of error in the experiment and on the final result – that is, how each changes the value of x in the empirical formula SnI_x.

Extension discussion: solubility and bonding

This experiment also offers an opportunity to discuss how bonding is linked to solubility. Iodine and tin iodide both dissolve in non-polar solvents (cyclohexane and propanone) but not in water, whereas tin is a metal and is insoluble in cyclohexane, propanone and water. Using this information, can your students draw

conclusions about the likely bonding in these substances?

Acknowledgement

The author would like to thank Alan Carter, who was the Head of Chemistry at Wellington College (Berkshire, UK) until 2004, and who created the initial resource that inspired this article.

Resources

Find out more about the oxidation states of tin. See: www.chemguide.co.uk/inorganic/group4/oxstates.html

Learn about an alternative experiment for deducing an empirical formula, this time for copper(II) oxide. See: www.rsc.org/learn-chemistry/resource/res00000727/finding-the-formula-of-copper-ii-oxide or use the direct link: <https://tinyurl.com/y2tcg2xs>

Iodine vapour in the reflux condenser

Discussion

This activity can produce good results if carried out carefully, with values that should quite closely round to 1:4 (as the ratio of tin to iodine). This leads to SnI₄ as the empirical formula for tin iodide.

In general, values ranging between 1:3.2 and 1:3.8 are often obtained. As the common oxidation states for tin are +2 and +4, an experimental outcome giving a ratio close to 1:3 would not be in agreement. However, such values can open up a discussion about sources of experimental error and the importance of precision.

Caroline Evans is the Head of Chemistry at Wellington College, Berkshire, UK. She is a reviewer for *Science in School* and has reviewed numerous textbooks linked to A-level and International Baccalaureate courses. Caroline is also an examiner for both GCSE and A-level chemistry.



Making connections: an online exchange with EIROforum scientists

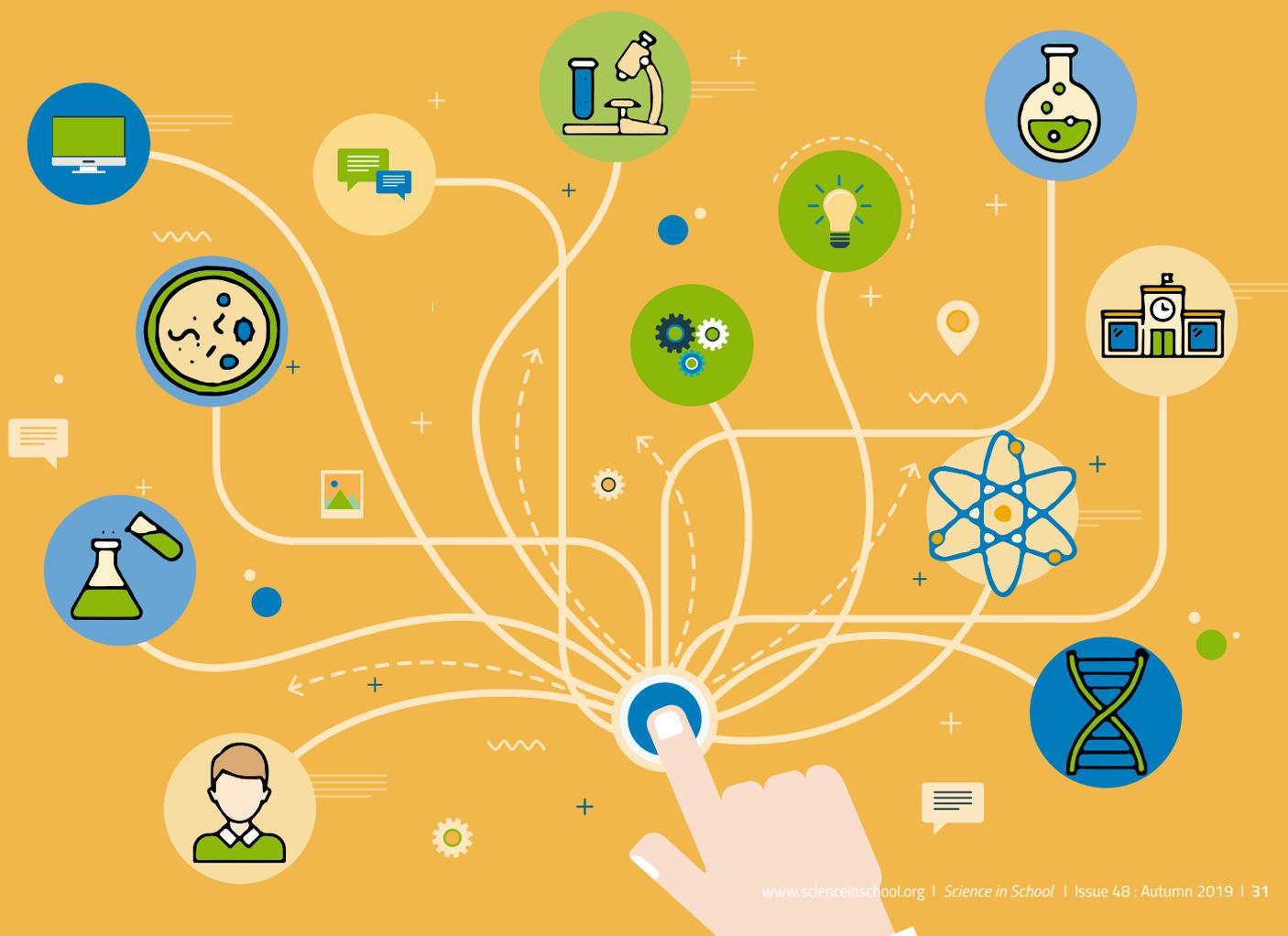
Connect your class with scientists across Europe in a video-conference exchange – and find out about life as a scientific researcher.

By Sevasti Malamou

Do your students ever complain about the mismatch between school subjects and real life? And do you wonder what science teachers can do to show that there's more to science than laws and theories? These thoughts often come to mind, so two years ago, while I was reading the EIROforum news

section of *Science in School*, I was inspired to start a new school project with the aim of connecting school science with science in practice.

My idea was to set up video conferences for my students to interact with working scientists and learn about research





✓ Careers in science

✓ Ages 14–19

REVIEW

This article outlines an interesting project that enables students to learn about science careers in different research institutes. The article describes a Greek science teacher’s own experiences, and provides a structured, interactive approach for a project that will be more engaging for the students than just reading or watching films about careers. The whole premise of the project is useful internationally, so it would need very little modification to be relevant and applicable to different countries.

Marie Walsh, science lecturer, Ireland



happening now – without even leaving the classroom. I chose to collaborate with scientists working at the intergovernmental organisations of EIROforum^{w1}, which cover research across the sciences, from fundamental physics at CERN, to life sciences at the European Molecular Biology Laboratory (EMBL) and space science at the European Space Agency (ESA).

After successfully completing the project with my students in the 2017–2018 school year, I am pleased to share some guidelines outlining the main steps that we took, in the hope of inspiring other teachers to initiate a similar project in their own schools. I

began thinking about the project during the preceding academic year, so that I was ready to start running it with my students in September.

1. Choose the students

Select a particular class or age group for the project. The scientists provide valuable insights into careers in science, so the project is particularly useful for older students.

I implemented the project with students aged 17 at the Senior High School of Parga in western Greece. The students were studying a science-oriented curriculum, and they were advanced enough in their studies to identify links between the school subjects and the science happening at the different organisations.

2. Select some scientific organisations

Choose 6–8 organisations to potentially collaborate with. Provide your students with a simple worksheet to see how much your students already know about these organisations.

1. Choose the students

2. Select some scientific organisations

4. Find the scientists

5. Arrange an initial meeting



3. Learn about the scientific organisations

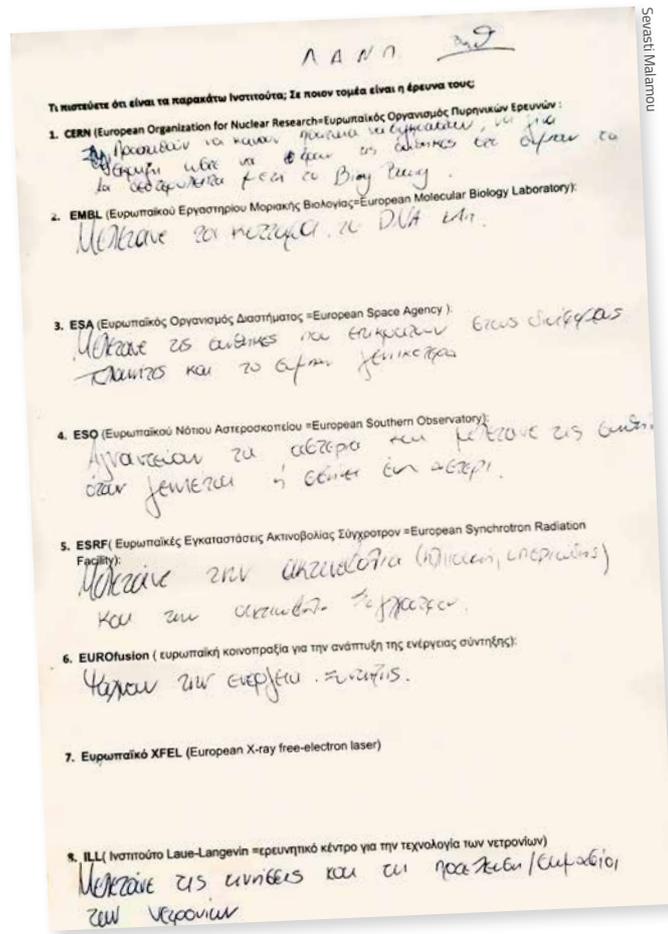
Since this project was inspired by the EIROforum news, I used the EIROforum organisations as our starting point. However, you could find other organisations that are of interest to you and your students, within Europe or specifically in your home country.

To gauge their knowledge of the different organisations before we began the project, the students completed a worksheet^{w2} to outline any facts they already knew, such as where each of the institutes is located, and what their main research aims are. I kept the responses to compare after the project.

3. Learn about the scientific organisations

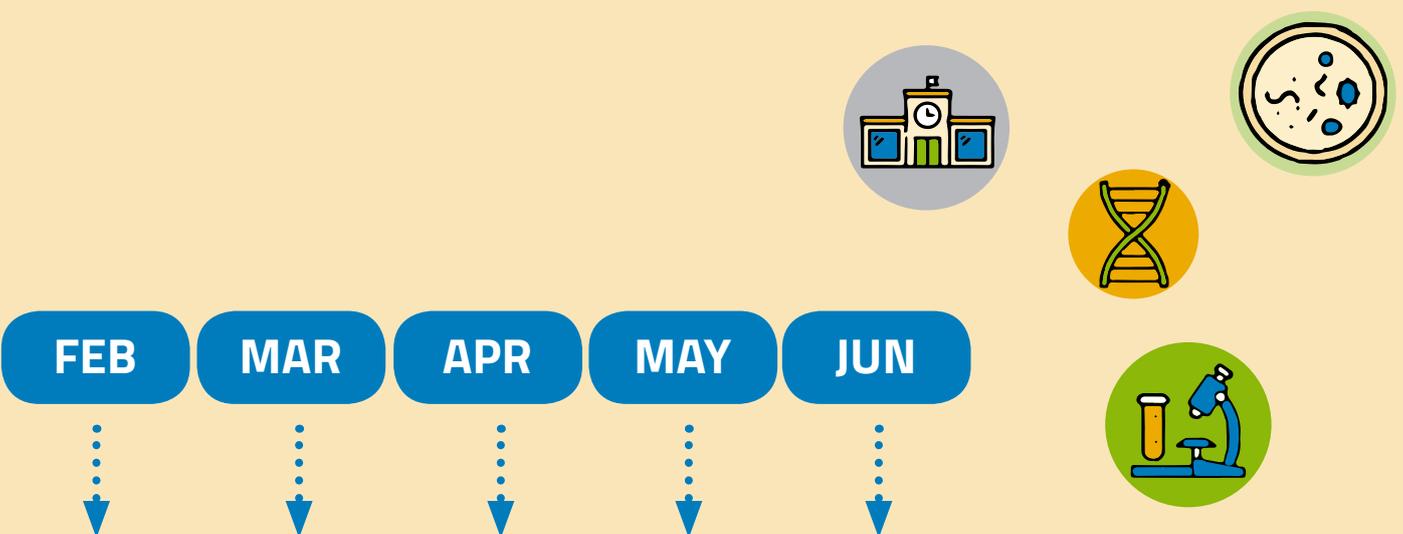
Divide your class into groups of 2–3 students. Ask each group to conduct some basic research into one of the scientific organisations and present the key information to the rest of the class.

I assigned each group a different organisation (from step 2) so that all of the organisations were researched. We allocated four physics lessons (i.e. 4 hours) over a period of 2 months for



Sevasti Malinou

Completed worksheet (in Greek) recording one student's knowledge of the EIROforum organisations before the project



6. Prepare questions for the scientists

7. Conduct the video conferences

8. Evaluate the project



Pantelis Poulakis, an ExoMars rover engineer at ESA. Here, Pantelis introduces a group of visitors to the 'Mars yard' that is used to test rovers.

students to work on their presentations. Any further work was completed at home.

Questions that students considered included:

- What is the full name of the research organisation?
- Where is the organisation based?
- What area of science does the organisation research?
- How many scientists or employees work at the organisation?
- What is an example of a recent piece of scientific research published by the organisation?
- What are their future research plans?

Students in each group presented their research to the class in the form of a talk. After the presentation, the other students asked questions to the group about the institute. My students uploaded their research to an online bulletin board called Padlet, for the rest of the class to see.

4. Find the scientists

Choose a final list of 4–5 organisations to work with. Contact each organisation

and invite scientists to participate in a video conference with your students.

We created the shortlist based on the students' presentations and their reactions to the organisations. My students were keen to talk to CERN, EMBL, ESA and the European Southern Observatory (ESO), so I contacted those organisations to explain the aim of the project

“The scientists were keen to spread science to their home country, and were particularly happy to work with students.”

and outline what the scientists would be asked to do. We also chose to reach out to Greek scientists in particular. This was for two reasons: first, so that our students could talk more freely to the scientists without any language barriers; and second, because this showed the students that science operates without

borders – scientists, even from small countries, can work in research centres across Europe and beyond.

After I sent emails to those four organisations, three of them put me in touch with Greek scientists: an ESO astrophysicist, an EMBL geneticist, and an ESA space engineer. We arranged for these three scientists to take part in the project. The scientists were keen to spread science to their home country, and were particularly happy to work with students.

5. Arrange an initial meeting

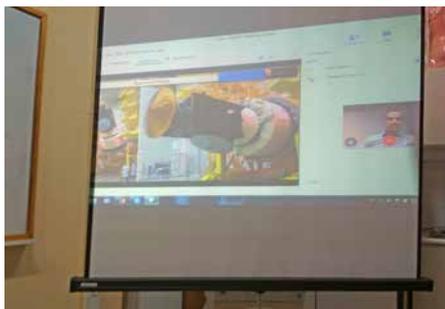
Organise an initial video conference to meet the individual scientists and discuss the logistics of the whole-class conference.

Once a scientist agreed to participate in our whole-class conference call, I set up a one-to-one video conference (via Skype) with them to discuss further details. During the call, we arranged a suitable date and time to hold the whole-class conference. We organised one video conference per month in February, March and May with ESO, EMBL and ESA, respectively. We found this to be a suitable schedule, giving students enough time to prepare, and subsequently evaluate each session.

We also agreed on the style of their video conference. For example, the meeting could follow a simple conversation between the students and the scientist, or it could be more formal, with the scientist giving a brief presentation (e.g. about their organisation, their role and their academic studies and current research) before opening up the session for questions.

6. Prepare questions for the scientists

Before each video conference, ask your students to write down questions that they would like to ask each scientist.



Pantelis Poulakis describes his work as a space engineer at ESA in the Netherlands.



Students in the classroom talking to Evanthia Hatziminaoglou, a Greek astrophysicist calling from ESO in Germany

Students might like to know how the scientist came to be working at that organisation, what their day-to-day work involves, or what area of science they are currently researching. Our students exceeded our expectations by coming up with many interesting questions, for example:

- What are the necessary studies to become a researcher at EMBL?
- What is it like working in a biology laboratory?
- Did you always want to become an astrophysicist?
- What was your career path from university to your institute?
- Why is ESA working hard to explore Mars?
- How do you balance family life and demanding laboratory schedules?
- What are the advantages and disadvantages of working with people from all over Europe or the whole world?

For the video conferences, we chose to leave the conversations open to all students, so they could all ask questions as the discussions evolved. You could, however, work with the students to create a list of final questions for each video conference, and assign the questions to nominated students to ask during the conference.

7. Conduct the video conferences

Carry out the video conference in your classroom, school hall, computer lab or science lab. How the conversation evolves is in the hands of you and your students!

All you need is a computer with the correct software installed (such as Skype), a good internet connection, a projector and speakers. On average,

our video conferences lasted for around 90 minutes. We were delighted by how much the students learned about the different scientific organisations and the scientists' research. Talking face-to-face (although via the internet) to a 'real' scientist was a valuable experience for them all, and the scientists were very willing to answer questions and provide career advice.



ESO astrophysicist Evanthia Hatziminaoglou

Panagiotis Mantas



EMBL geneticist
Panagiotis Mantas



Don't forget to thank the scientists for being part of the project by following up with them after the video conference. Why not keep in touch with them for a future project, if they are happy to do so?

8. Evaluate the project

After each video conference, ask students to give their feedback and share their experiences of speaking to the scientist. This can be done in small groups or as a whole-class discussion.

“We anticipate that students, irrespective of their future careers, will remember this unique experience from their school studies.”

Encourage students to say what interested them the most, and if there was anything that surprised them. In our project, many students were surprised by how young the scientists were, as they had preconceptions that scientists at these organisations were older. Meeting the different scientists gave students a new perspective. I recall one student saying, “Before the conference, I thought that scientists worked in the lab day and night.” The students soon appreciated that the scientists led ordinary lives too, including spending time with family and enjoying music.

Finally, I asked my students to fill out the same worksheet from step 2, and they compared their new answers to their answers from the start of the project. They were pleased to see their newly acquired knowledge.

We anticipate that the students, irrespective of their future careers, will remember this unique experience from their school studies. We hope this article is a useful starting guide if

you are interested in implementing a similar project at your school. For more information, do not hesitate to e-mail smalamou@gmail.com.

Web references

- w1 EIROforum is a collaboration between eight of Europe's largest intergovernmental scientific research organisations. See: www.eiroforum.org
- w2 The simple worksheet used in the project is available to download from the *Science in School* website. See: www.scienceinschool.org/2019/issue48/eiroforumexchange

Sevasti Malamou is a secondary school physics teacher in Greece. She also teaches chemistry, biology and geography, and enjoys using innovative methods to teach science. Sevasti holds master's degrees in both electronics and telecommunications, and secondary education.





How effective is your sunscreen?

Encourage students to stay safe in the sun with a collection of activities to discover the science behind sunscreen.

By Fina Guitart and Silvia Lope

Whether it's enjoying a summer's day on the beach, skiing down the slopes in winter, or simply going outside for some fresh air during a lunch break, any time spent outdoors leaves our skin vulnerable to the Sun's ultraviolet (UV) rays. Applying sunscreen is key to protecting ourselves from the damaging effects of sunlight, but have you ever stopped to consider how your sunscreen works – and ultimately, how effective it is?

To find out, we devised the following activities for students aged 14–17 to explore the science behind sunscreen and to investigate its effectiveness for UV protection. In the process, students will appreciate the importance of protecting themselves from sunlight, and will be more able to make informed decisions regarding their use of sunscreens. We

recommend that students work in small groups (e.g. 2–3 students per group) throughout.

Activity 1: An introduction to UV protection

This activity introduces students to the key ingredients in sunscreens, and explores the difference between organic and inorganic UV filters. In small groups, students study the labels of various store-bought sunscreens to determine the key ingredients and types of UV filters that are commonly used. We recommend placing the sunscreen bottles around the classroom, with each group working their way around the different sunscreen products. You could collect your own

selection of sunscreen products, or ask your students to bring in products from home. This activity (including a class discussion) takes approximately 50 minutes, and it is helpful to complete it before the main activities.

Materials

To have a diverse collection of sunscreens, try and find the following:

- One sunscreen with low protection (SPF 15 or below)
- One sunscreen with medium–high protection (SPF 30–50)
- One sunscreen with very high protection (SPF 50+)
- One sunscreen formulated for babies/children
- One sunscreen for water sports (high water-resistance)
- One sunscreen with titanium dioxide or zinc oxide (inorganic active ingredients)

Procedure

Ask your students to work through the following steps:

1. In your group, begin by examining the label of the first sunscreen. Consider the following questions, and record your observations in a table (see table 1):
 - What are the key pieces of information that are included on the front of the packaging?
 - Does the sunscreen provide UVA protection, UVB protection, or both (broad spectrum)?
 - What are the SPF number (e.g. 10, 15, 30) and SPF category (e.g. low, medium, high)?
 - Looking at the ingredients list, what active ingredients are found in the sunscreen?^{w1}
 - What are the first 5 inactive ingredients listed on the label?
2. Repeat the previous step for the different sunscreens around the classroom, and compare your findings.
3. In your group, discuss the different characteristics of the sunscreens and try to classify them, taking into account the type of UV filter (UVA,



- ✓ Electromagnetic radiation
- ✓ Organic and inorganic compounds
- ✓ Solubility
- ✓ Emulsifiers
- ✓ Ages 14–19

REVIEW

This article is a great example of a cross-curricular project that offers learning in an active way. The activities provide the perfect mix of discussion, analysis and experiment on the topic of sunscreens and their UV protection – something that is highly relevant to teenagers.

The experiments and discussions can be used to explore a variety of topics that are central to most science curricula, and they also provide the opportunity to learn about the scientific method. The time needed for all three activities is approximately 3 hours, which – from my point of view as a teacher of chemistry, physics and biology – is time well spent.

Dr Ingela Bursjö, science teacher, Montessori school Elyseum, Gothenburg, Sweden



Sunscreens vary depending on the type of UV filter, their active ingredients, and the SPF.

UVB or broad spectrum), their active ingredients, and the SPF. You will share your preliminary conclusions with the rest of the class in a follow-up discussion.

Discussion

Discuss the following questions with your students to explore the key concepts:

- Which substances are commonly used as UV filters (the active ingredients)?
- Are the active ingredients organic or inorganic substances?
- What are the main inactive ingredients found in sunscreens?
- How many of the sunscreens claimed UVA protection, UVB protection or both?

Station	Sunscreen type/brand	SPF value	SPF category	UVA/UVB/broad spectrum filters	Active ingredients	Inactive ingredients
1	Kids mineral sunscreen	50	High protection	Broad spectrum	Titanium dioxide	Water, Glycerin, Propylene Glycol, Diisopropyl Sebacate, Ethylhexyl Salicylate
2	High-protection gel sunscreen	50+	Very high protection	UVA/UVB	Avobenzone, Octocrylene	Water, Alcohol Denat., Ethylhexyl Salicylate, Dibutyl Adipate, 4-Methylbenzylidene Camphor
3	Hydrate and protect face sunscreen	15	Medium protection	UVA/UVB	Avobenzone, Octinoxate, Oxybenzone	Water, Cyclopentasiloxane, Glycerin, Butyloctyl Salicylate, Dimethicone

Table 1: Example table showing the key information students should record in activity 1

- What is the difference between UVA and UVB? What are their known health effects?
- What does 'SPF' mean? How is SPF calculated?
- What is the difference between a sunscreen with SPF 30 and a sunscreen with SPF 50?

Explanation

Sunscreens protect us from the Sun's harmful rays by blocking or absorbing UV radiation. There are two types of UV radiation that can damage our skin: UVA and UVB. They affect our skin in different ways (UVA, for example, is the dominant 'tanning' ray, while UVB causes sunburn), and both types increase the risk of skin cancer. UVA rays are also responsible for premature ageing effects such as wrinkling.

At sea level, UVA comprises approximately 95% of the UV energy reaching Earth's surface, and UVB comprises the remaining 5%. UVB rays have a wavelength of 280–320 nanometres (nm), while UVA rays are split into two categories: UVA1 (320–340 nm) and UVA2 (340–400 nm). SPF (sun protection factor) indicates a sunscreen's ability to protect skin from UVB damage^{w2}. It is a measure of how much radiation is required to cause sunburn on protected skin (i.e. with sunscreen) relative to the amount of

radiation required to produce sunburn on unprotected skin. The higher the SPF, the more UVB protection the sunscreen provides. In addition to the SPF, sunscreens are now categorised as providing low to very high protection, to ensure the labels are easy to understand.

Since the SPF only measures protection against UVB rays, it is important to choose a sunscreen that also has high UVA protection. According to EU recommendations, the UVA protection for a sunscreen should be equivalent to at least one-third of the labelled SPF. Products that achieve this requirement are labelled with the letters 'UVA' printed in a circle. Sunscreens that protect from both UVA and UVB do so by either combining UVA and UVB filters or by using a broad-spectrum filter.

In addition to being classified according to their SPF and UVA protection, sunscreens can be grouped depending on whether their active ingredients are organic or inorganic. Organic UV filters are a group of carbon-containing compounds that absorb UV radiation and convert it to heat energy. Inorganic filters, on the other hand, are a group of mineral oxides such as zinc oxide and titanium dioxide, which reflect UV radiation.

The active ingredients are combined with a 'base cream', which is made

up of various inactive ingredients. This forms a product that can be easily applied to skin.

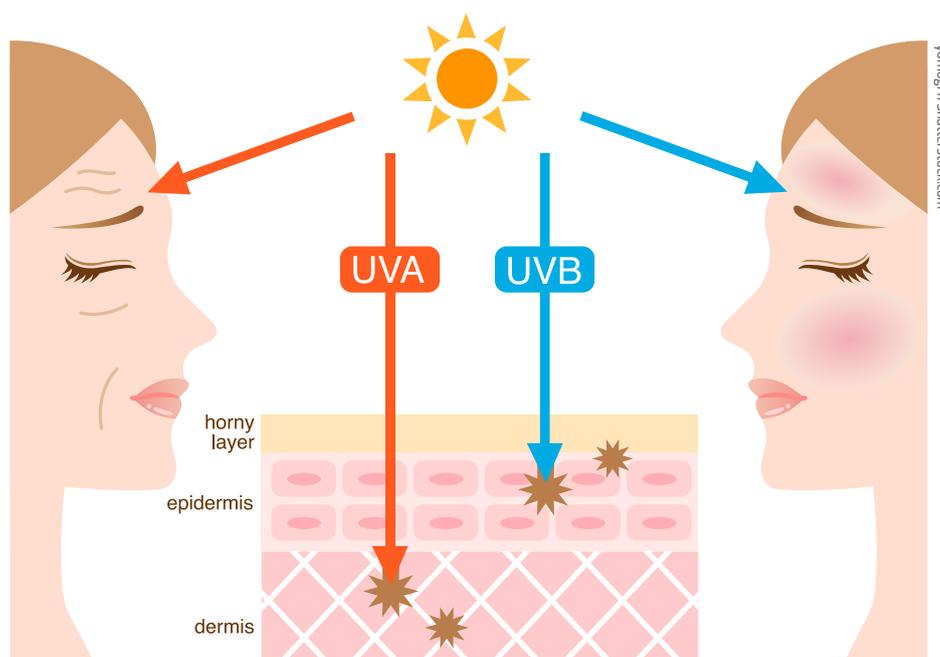
Activity 2: Formulating sunscreen

In this activity, students formulate their own inorganic sunscreen at two SPF values using zinc oxide. The aim is to learn more about the composition of sunscreens, while also exploring key concepts such as concentration, solubility, polarity and emulsions. This activity will take approximately 50 minutes.

Materials

To prepare one sample of sunscreen, each group requires:

- Lanette wax (contains a mixture of cetearyl alcohol and cetostearyl alcohol)
- Sweet almond oil
- Liquid paraffin
- Glycerine
- Distilled water
- Zinc oxide
- Water bath heated to 80 °C
- Two 250 ml beakers
- Three 50 ml beakers
- Two glass rods
- Magnetic stirrer
- Spatula
- Electronic balance



UVA rays penetrate deep into the skin's thickest layer (the dermis) resulting in skin ageing, while UVB rays damage the upper layers of the skin (the epidermis) causing sunburn.

Procedure

Ask your students to work through the following steps:

1. Begin by preparing an emulsion that will serve as the base cream of your sunscreen. Add the oily phase ingredients to a 250 ml beaker: 15 g lanette wax, 7 g sweet almond oil and 7 g liquid paraffin. Weigh out the ingredients using an electronic balance.
2. Place the beaker inside the water bath. Mix the ingredients using a glass rod or magnetic stirrer for 5 minutes until the mixture is well combined. Leave the beaker inside the water bath.
3. In a separate 250 ml beaker, add the aqueous phase ingredients: 5 g glycerine and 66 ml distilled water. Mix using a new glass rod or the magnetic stirrer.
4. Keeping the oily-phase beaker in the water bath, pour the aqueous-phase solution into the oily phase, stirring continuously for 5–10 minutes until you have a homogeneous mixture: this is the base cream. Leave the beaker inside the water bath.
5. In a 50 ml beaker, mix the zinc oxide with liquid paraffin in a ratio of 5:4, i.e. 2 g of zinc oxide to 2 ml (1.6 g) of paraffin.
6. In a separate 50 ml beaker, measure out 4.1 g of the base cream. Add 0.9 g of zinc oxide/paraffin paste and mix them with a glass rod until combined. This creates a sunscreen

that is 10% zinc oxide, which equates to an SPF of approximately 10.

7. In another 50 ml beaker, measure out 3.2 g of base cream and add 1.8 g of zinc oxide/paraffin paste. Mix them with a glass rod until combined. This creates a sunscreen that is 20% zinc oxide, which equates to an SPF of approximately 20. You will use these sunscreens in the next activity.

Discussion

Discuss the following questions with your students to explore the key concepts:

- Which base cream ingredients are soluble only in water? Which are soluble only in oil? Justify your answers in relation to the polarity of the substance.
- Why is lanette wax essential for your formulation?
- What are the characteristics of emulsions and emulsifiers?
- What is the difference between an oil-in-water and a water-in-oil emulsion?
- Find two emulsifiers in the ingredient lists of some sunscreens from activity 1.

Explanation

The base cream produced in the activity is an emulsion, since it has an oily phase and an aqueous phase. The emulsifier (which stabilises the emulsion) is lanette wax. Emulsifiers typically have a polar (or hydrophilic) head and a non-polar (or hydrophobic)



Oily phase ingredients are placed in a beaker inside a water bath and mixed using a magnetic stirrer or glass rod.

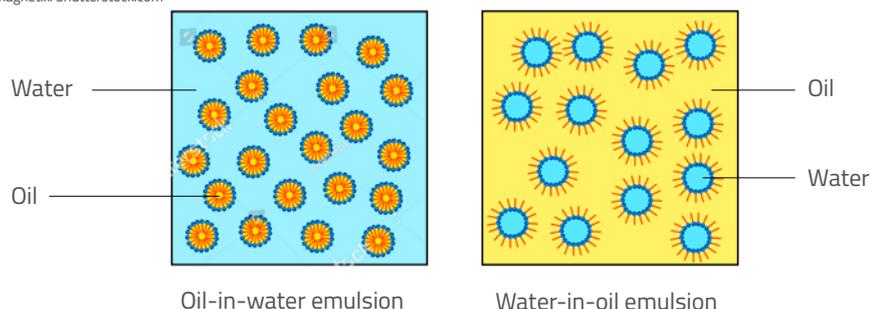


Mixing the aqueous phase solution with the oily phase solution produces the homogeneous base cream.



The end result: students produce their own zinc oxide sunscreen to test the effectiveness of sunscreen.

magnetix/Shutterstock.com



When an emulsifier is used to create a stable mixture of water and oil, the hydrophilic heads (blue) are attracted to water, while the hydrophobic tails (red) are attracted to oil.

tail, and they tend to have greater or less solubility in either water or oil. The lanette wax emulsifier is more soluble in oil, although also water-soluble. Emulsifiers that are more soluble in oil tend to form water-in-oil emulsions, whereas emulsifiers that are more soluble in water tend to form oil-in-water emulsions.

Activity 3: Investigating the effectiveness of UV protection

The aim of this activity is to investigate the effectiveness of the two sunscreens produced in activity 2. Using colour-changing craft beads that change colour in response to UV light (at 300–360 nm) to represent our skin, students can determine how well the two sunscreens shield the beads from UV radiation, and thus how well they protect. We found it was best to use purple or blue beads as they show changes in colour intensity best. Use the same colour beads for all experiments, i.e. all blue or all purple. Note that all UV beads start off white before they are exposed to light. The procedure takes approximately 50 minutes.

Once students have tested their own sunscreens, they should expand their investigations (see extension section) to compare a variety of other store-bought sunscreens.

Materials

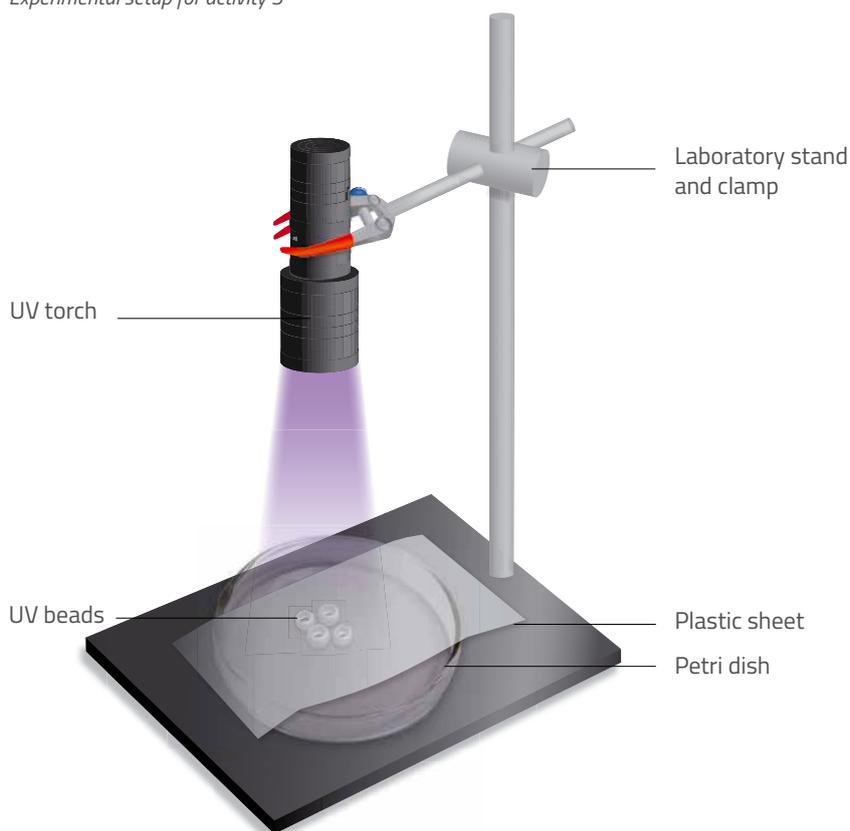
Each group requires:

- Sunscreens from activity 2
- 10–12 UV beads (kept in a light-impenetrable container)

- Small transparent plastic sheets (large enough to cover four UV beads)
- Petri dish or similar (to hold the UV beads)
- Colour chart^{w3} or smartphone with a colour detection app (such as 'Color Grab' or 'Drop – Colour Palette')
- UV light source, e.g. torch or black light
- Spatula
- Laboratory stand and clamps
- Stopwatch

Safety note: Do not look directly towards UV lamps. Turn on the UV lamps only when required, and after

Experimental setup for activity 3



Nicola Graf/FinaGuhart

safety instructions have been given by teachers.

Procedure

Ask your students to work through the following steps:

1. Place four UV beads in the centre of a petri dish. Position the UV lamp approximately 20 cm away from the dish, or clamp a UV torch to a stand positioned at the same distance. Ensure that the UV light source stays at the same distance throughout the experiment and that the light always illuminates downwards.
2. Collect a pea-sized amount of your first sunscreen from activity 2 (10% zinc oxide) using a spatula, and spread a thin layer of the sunscreen onto the centre of the plastic sheet to cover the UV beads (approximately 4 cm in diameter).
3. Place the plastic sheet on top of the beads, ensuring that the sunscreen covers the beads.
4. Turn on the UV light source for 5 seconds, keeping count with a stopwatch.
5. As soon as the time is up, turn off the lamp and use the colour chart or a



Colour intensities of UV beads exposed to UV light, from left to right: without sunscreen; with SPF 20; SPF 50; SPF 90.

colour detection app to record the colour of each bead. Alternatively, take a photo of the beads to compare their colours with those obtained in subsequent experiments. Ensure that you save your data and/or photos.

6. Move the UV beads into a dark container so that they are not exposed to light. Add four new, unexposed beads to the petri dish.
7. Repeat the procedure twice more for your first sunscreen so that you conduct the experiment three times in total.
8. Follow the same procedure for your second sunscreen (20% zinc oxide), and also for two controls: one using a clean plastic sheet without sunscreen, and another using no plastic sheet.
9. Compare the colour intensities of the UV beads for each sunscreen and the controls.

Discussion

Discuss the following questions with your students:

- What conclusions can you draw from your experiments?
- Are your experimental results consistent with the idea of SPF?
- What were the dependent, independent and fixed variables in your experiments?
- Why should UV beads be used only as a guide to compare the effectiveness of sunscreens? What are the main disadvantages of this experimental method?

Explanation

The experiment should show a clear difference in the colour of the beads in the presence and absence of the homemade sunscreens, and

students should be able to observe a small difference between the use of sunscreens of 10% zinc oxide and 20% zinc oxide. The darker the colour of the beads, the more UV radiation they have absorbed, and the less effective the sunscreen. This shows students that there is a difference in the amount of UV radiation that can be absorbed by the beads, depending on the SPF of the sunscreen. This was more evident when we tested store-bought sunscreens of the same brand and type (but different SPF) in our extension experiments.

We found there was no significant difference in outcomes between the two control experiments, which tested the UV beads with and without the plastic sheet. However, using a UV sensor (see extension section), students may detect a slight difference in the amount of UV radiation reaching the beads with and without the plastic sheet.

Extension activity

Students can devise their own investigations and create new hypotheses by expanding on the previous procedure to test other sunscreens. For example:

- Compare two store-bought sunscreens (choose among sunscreens of activity 1), one of SPF 15 and the other of SPF 30, keeping the brand and sunscreen type the same.
- Compare two sunscreens of the same SPF but from two different brands.
- Compare two sunscreens of the same SPF, brand and type, but with a difference in 'shelf life', e.g. using one sunscreen that has only just been opened, and one that has expired.

You can make further modifications to the experiments, for example:

- Test the UV beads in sunlight, rather than under a UV lamp or torch.

- Using the same procedure, test various pairs of sunglasses to investigate their effects against UV light.
- For a more sophisticated method, use a UV sensor to investigate the effectiveness of sunscreens by measuring the intensity of UV light. Place the plastic sunscreen sheet over the sensor, rather than the UV beads, and record the sensor's readings.

Web references

- w1 For a list of active ingredients used in sunscreens, visit the FDA website to download a poster that outlines their proposed changes to sunscreen regulations. See: www.fda.gov/media/124654/download
- w2 Learn more about SPF and the factors related to sun exposure on the US Food and Drug Administration (FDA) website. See: www.fda.gov/about-fda/center-drug-evaluation-and-research/sun-protection-factor-spf
- w3 For activity 3, students can use a colour chart such as this one created by the Royal Society of Chemistry. Note that students should ignore the 'UV Sun index' scale. See: www.rsc.org/learn-chemistry/resource/res00002073/starlight-a-global-experiment-on-uv-protection#!:cmpid=CMPO0007582 or use the direct link: <https://tinyurl.com/y3b3d3uq>

Resource

Visit the British Association of Dermatologists website for a factsheet on sunscreen, including details of how to apply sunscreen and tips for staying safe in the sun. See: www.bad.org.uk/for-the-public/skin-cancer/sunscreen-fact-sheet

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