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UNDERSTAND

***Titanic* and the iron-eating bacteria**

Spring 2018 | Issue 43

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EIROforum

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DECODING DNA WITH A POCKET-SIZED SEQUENCER 17

USB-powered sequencers smaller than your smartphone could revolutionise the way we decode DNA – in hospitals, in remote locations and even in space.

ESA/Stephane Corvaja, 2017

BECOMING AN ASTRONAUT: INTERVIEW WITH MATTHIAS MAURER 26

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Challenge your students to save the Earth from an asteroid collision, using calculations based on the Hollywood sci-fi fantasy film Armageddon.

UNDERSTAND

INSPIRE

TEACH

EDITORIAL

Eleanor Hayes
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Welcome to the spring issue of *Science in School*. Traditionally, spring is the season of renewal and a time to freshen things up. So while you might be thinking about decluttering your classroom, now might also be a good time to 'spring clean' your lesson plans and introduce some new activities into your teaching.

In this issue, there are plenty of fun activities to engage your students, including a colourful chemistry demonstration exploring redox reactions (page 41). In a Hollywood-themed physics lesson, students investigate whether events in the sci-fi action film Armageddon could really happen (page 46). We also bring you the latest article in the 'Fantastic feats' series (page 37).

For those who are keen to get planting this season, we have an activity involving growing an unusual species of dandelion (page 31). With a high proportion of rubber in its roots, this plant offers a potentially sustainable way to meet the increasing global demand for rubber. We also investigate the science behind the environmentally controversial technology known as fracking, which is used to extract shale gas from rocks deep underground (page 12).

This issue's coverage of new discoveries and developments in science includes a species of bacterium that is accelerating the decay of the *Titanic* shipwreck (page 8), and a pocket-sized DNA sequencer that was recently used to identify microbes in space (page 17). For more space-related reading, astronaut Matthias Maurer shares his story of becoming the European Space Agency's newest space recruit in this issue's scientist profile (page 26).

Finally, what do you say when a student asks whether we should believe what science tells us? We share some real responses from teachers to such challenging questions, followed by a philosopher of science's expert opinion on each response (page 21). We would love to hear what you think of these opinions – and how you deal with any similar challenges in your own classrooms.

Eleanor Hayes

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

Dinosaur discovery, self-sufficient space flight and structural biology for students

CERN

The past, present and future of the Large Hadron Collider

In March 1992, CERN launched the Large Hadron Collider (LHC) experimental programme, revealing to the public its initial ideas for building the world's largest particle accelerator.

Last year marked the 25th anniversary of this debut, and to celebrate, CERN hosted a commemorative symposium. As well as looking back at the history of the LHC, the event reflected on the bold decisions that led to the development of this remarkable facility and its collaborative experiments. The symposium concluded with a review of recent experimental results from the four large LHC experiments: ALICE, ATLAS, CMS and LHCb.

It was a particularly successful year for the LHC in 2017, as the accelerator produced 5 million billion (10^{15}) proton-proton collisions – exceeding its target, and collecting huge amounts of data that scientists will continue to analyse this year.

2018 will be the final year of data collection for the LHC before a 'technical stop', set to last from 2018 to early 2021. This will allow CERN's technicians, engineers and physicists to renovate and improve the accelerator, and to prepare the detectors to fully exploit the improved performance of the machine.

Based in Geneva, Switzerland, CERN is the world's largest particle physics laboratory. See: www.cern.ch

Julien Ordan/CERN

To celebrate the 25th anniversary of the LHC experimental programme, CERN hosted a commemorative symposium.

EMBL

'Seeing is believing' Insight Lecture attended by students worldwide

EMBL

Students listening to the EMBL Insight Lecture by Dr Thomas Schneider

Around 1500 students from 18 countries participated in the 2017 European Molecular Biology Laboratory (EMBL) Insight Lecture, an annual talk aimed at 15–19-year-old students that highlights cutting-edge developments in life sciences research.

The interactive event, entitled 'Seeing is believing – how technology enables structural biology', took place at EMBL Heidelberg, Germany, in December and was live-streamed to schools worldwide. EMBL senior scientist Dr Thomas Schneider took the students on a journey to learn about the basic principles of macromolecular crystallography and synchrotron radiation. Throughout the event, students and teachers put questions to the speaker via Twitter, which were answered at the end of the lecture.

EMBL extends a warm invitation to anyone interested in taking part in the 2018 Insight Lecture.

To stay informed, subscribe to receive updates from the European Learning Laboratory for the Life Sciences (ELLS) website. See: http://emblog.embl.de/ells/subscribe-to-emblog

Recordings of all EMBL Insight lectures produced between 2010 and 2017 can be viewed on the EMBL website. See: http://emblog.embl.de/ells/eil

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

A microscope image of *Arthrospira*, commonly known as spirulina

ESA
Recycling oxygen for self-sufficient space flight

In the harsh environment of space, resources are limited. To live on-board the International Space Station (ISS), supplies must be regularly restocked by cargo vessels. Self-sufficient space flight is a possibility for the future, but it will require precious resources, such as oxygen, to be recycled and reused. Astronauts on the ISS are now investigating how to do just that, with help from a single-celled microalga called *Arthrospira*, commonly known as spirulina.

In December 2017, samples of the bacteria were delivered to the ISS by the Space-X Dragon cargo vessel and loaded into a photobioreactor – a cylindrical container bathed in light. When the algae photosynthesise, carbon dioxide is used up, producing oxygen and edible biomass. The experiment will run for one month to measure the amount of oxygen produced, before the microalgae samples return to Earth in April. The algae's genetic information will then be analysed to build a clearer picture of the effects of weightlessness and radiation on the plant cell.

The experiment is part of an initiative named MELiSSA (Micro-ecological Life Support System Alternative), which is developing regenerative technologies for life support. To learn more, visit the ESA website. See: www.esa.int/Our_Activities/Space_Engineering_Technology/Melissa

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

ESA

ESO
Planetarium and visitor centre to open in April

On 26 April 2018, a new attraction will open at the headquarters of the European Southern Observatory (ESO) in Garching, Germany. The ESO Supernova Planetarium and Visitor Centre will provide visitors with an immersive experience to learn about our Universe, as well as presenting them with ESO-specific scientific results, projects and technological breakthroughs.

At the heart of the new ESO centre is a digital planetarium with state-of-the-art projection technology and a scientifically accurate three-dimensional astronomical database that allows you to fly to the stars and even to the edge of the Universe. The programme of shows is displayed on a 360° dome that is 14 m in diameter, and an interactive exhibition space hosts a variety of permanent and temporary exhibitions.

The centre also offers a variety of opportunities for teachers and schools. Teachers can participate in teacher training sessions and access free educational material. Curriculum-centred visits for school groups include workshops for a variety of ages, learning-focused planetarium shows and inspirational guided tours.

To keep informed about the developments of the ESO Supernova Planetarium and Visitor Centre, visit the ESO website. See: https://supernova.eso.org

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

The ESO Supernova Planetarium and Visitor Centre

ESO

ESRF

Synchrotron sheds light on the lifestyle of a new dinosaur

A study of an exceptionally well-preserved fossil skeleton from Mongolia has led to the discovery of a new species of bird-like dinosaur related to *Velociraptor*. With a neck similar to a swan's, and flipper-like forelimbs, the new dinosaur species (which also represents a new genus) combines an unexpected mix of features. These demonstrate that some predatory dinosaurs adopted a semi-aquatic lifestyle.

The fossil was first smuggled out of Halszka, Mongolia, and kept in private collections around the world before it was offered to palaeontologists for study. Since the skeleton is largely covered by stone and thus much of it cannot be seen directly, an international team of researchers at the European Synchrotron Radiation Facility (ESRF) used synchrotron analysis to visualise and reconstruct the bizarre 75-million-year-old predator, named *Halszkaraptor escuilliei,* in three dimensions.

The experiments revealed that this amphibious dinosaur walked on two legs on land, but used its flipper-like forelimbs to manoeuvre itself in water (similar to how penguins and other aquatic birds move), while relying on its long neck for foraging and ambush hunting.

For more information on the study, read the original research paper published in *Nature*. See:

Cau A et al. (2017) Synchrotron scanning reveals amphibious ecomorphology in a new clade of bird-like dinosaurs. *Nature* **552:** 395–399. doi: 10.1038/nature24679

Download the article free of charge on the *Science in School* website. See: www.scienceinschool.org/2018/issue43/eironews, or subscribe to *Nature* today: www.nature.com/subscribe

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

Illustrative reconstruction of Halszkaraptor escuilliei

L Panzarin

EUROfusion

World's largest fusion experiment reaches halfway point

Fusion is the process that powers the Sun and stars, but replicating the process on Earth to meet our energy needs has proven to be one of the greatest scientific and engineering challenges. The key to overcoming these challenges, as shown by the world's largest fusion experiment, ITER, is collaboration on a global scale.

With its seven member states (the European Union, India, Japan, China, Russia, South Korea and the United States), the ITER organisation is building the world's biggest fusion device in Cadarache, France. And, at the end of 2017, the project announced that it had reached an important milestone: ITER is now halfway towards completion, when it will be able to begin its first experiments.

This is a significant step, not only for ITER but for the entire fusion community. Once operational, ITER will prove that fusion electricity is feasible and not just a vision. This aim lies at the heart of EUROfusion's roadmap, which outlines how the European fusion community will reach the goal of obtaining fusion power.

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

Aerial view of ITER, which is currently under construction in Cadarache, France

ITER

European XFEL

Impressions from the first users of new X-ray laser facility

Matthias Vogt's organic LED experiment at the FXE instrument

European XFEL

From mid-September to early December 2017, the first external scientific researchers from across the world visited the European X-ray Free-electron Laser (European XFEL). They were there to carry out experiments at the first two operational instruments: FXE, which studies chemical reactions on extremely short timescales, and SPB/SFX, which has a strong focus on structural biology and the imaging of tiny particles.

Alexandra Ros from Arizona State University, USA, was excited to have the chance to work at the brand-new facility as one of the first user groups. "I was really amazed that we got accepted. We didn't know what to expect before coming – every day has been a steep learning process", she said.

For Matthias Vogt, a researcher from the University of Bremen, Germany, working with the scientists at European XFEL will be crucial for developing his group's luminescence compound into a material applicable in organic LEDs. "We're very grateful for the outstanding support of the FXE scientists on site; their expertise is key to the success of our experiment", he said.

European XFEL is looking forward to welcoming the second round of users in May 2018.

To read stories from the first users of the facility, visit the European XFEL website. See: www.xfel.eu/news_and_events/news/index_eng.html?openDirectAnchor=1344 or use the direct link https://tinyurl.com/ycm74xo2

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

ILL

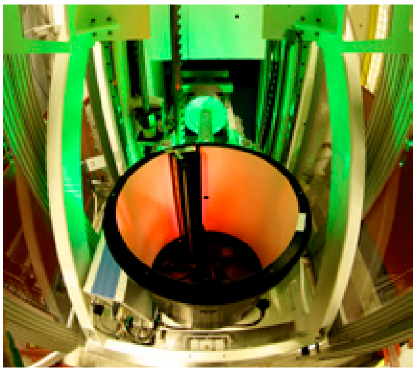
New insight into enzyme useful for drug development

A recent study has used neutrons to successfully visualise the structure of aspartate aminotransferase, an enzyme vital to the metabolism of certain amino acids. This could open avenues for new antibiotics and drugs to battle diseases such as drug-resistant tuberculosis, malaria and diabetes.

Aspartate aminotransferase is one of a group of vitamin B6-dependent proteins – a diverse group of enzymes that conduct over a hundred different chemical reactions in cells. Carried out at the Institut Laue-Langevin (ILL), the study used neutron crystallography on the ILL LADI instrument to study a vitamin B6-dependent protein for the first time. By exposing delicate protein crystals to neutrons using the ILL beamline, scientists determined the location of hydrogen atoms in the enzyme. Knowing the precise location of hydrogen atoms can help to explain why the behaviour of B6-dependent enzymes is so specific.

This study highlights how neutrons are an unrivalled probe for identifying the location of hydrogen atoms in biological systems, providing us with an unprecedented level of structural detail for this important enzyme.

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



LADI instrument at the Institut Laue-Langevin

R Cubitt

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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

Titanic and the iron-eating bacteria

A species of bacterium discovered on the decaying wreck of the *Titanic* is providing new insights into how to protect living cells from damage.

By Giuseppe Zaccai

The wreck of *Titanic* lies on the ocean floor, nearly 4 km below the surface of the dark, salty water of the North Atlantic. Divers on expeditions to the site have noticed 'rusticles' – icicle-like growths rich in rust – covering parts of the damaged and corroded hull. In 2010, scientists investigating rusticles taken from the *Titanic* site discovered a new species of bacteria within these growths[w1]. They named the new species *Halomonas titanicae*.

The scientists have also discovered that *Halomonas titanicae* bacteria are involved in the rusting process and are accelerating the wreck's decay. The decay is happening at quite a rapid rate: estimates suggest that the wreck may have disappeared completely by 2030. These bacteria could thus pose a significant threat to oil rigs and other iron structures located in the deep sea. However, these organisms have now become the focus of scientific research for another reason: to find out how they manage to thrive in conditions with high and varying salt concentrations.

Salts and the living cell

The term *halo-* means 'salt' in Greek. Bacteria of the genus *Halomonas* live in salty environments, such as sea water or salt marshes, where salt concentrations vary over a wide range. All members of the genus are strongly 'halotolerant': they have evolved ways of coping with wildly fluctuating salt concentrations outside the cell, surviving over a huge range of salinity from 0.5% (w/w) sodium chloride right up to 25%. This may seem like a trivial issue, but it is not.

The RMS Titanic *at the docks at Southampton, UK in April 1912*

Wikimedia Commons (public domain)

Image courtesy of Lori Johnston, RMS Titanic Expedition 2003, NOAA-OE

A view of the bathtub in the captain of the Titanic's *bathroom. Rusticles can be seen growing over most of the pipes and fixtures in the room.*

Cells are protected from the outside world by very thin membranes that control traffic in and out of the cell, creating and supporting huge differences in composition between the inside and outside of the cell. For example, cells maintain an electrical potential of about 100 millivolts across the membrane, which is typically just 10 nanometres thick. For all types of cell, sodium chloride (NaCl) is the dominant salt outside the cell (for example, in blood serum), whereas potassium chloride (KCl) is dominant inside the cell. Yet, while the salt types are different, the total salt concentration on either side of the cell membrane should match exactly. The reason for this is osmosis: if two solutions of different concentration are separated by a membrane that is permeable to water but not to solutes, water will flow from the more dilute side to the more concentrated side.

> **"All *Halomonas* bacteria have evolved ways of coping with wildly fluctuating salt concentrations outside the cell."**

Cell membranes cannot cope with osmotic pressure differences. Red blood cells will burst when placed in pure water, illustrating the effect of osmotic pressure – and the fragility of cell membranes. Clearly, to keep their membranes intact, *Halomonas* bacteria must be able to regulate the concentration of solutes in the cytoplasm in response to changing external salt concentrations, without disrupting the biochemistry within the cell (see Zaccai, 2009). How do they do this?

Halomonas bacteria produce large amounts of a substance called ectoine (see figure 1). To counterbalance the external salt concentrations, they adjust the concentration of this soluble compound within their cells. This keeps the cell's fluids in osmotic balance with the outside, protecting the cell against shrivelling up or bursting even in extreme conditions. Remarkably, ectoine appears to act differently from most salts and solutes, which can interfere with the role of water in metabolic processes. Ectoine is a 'compatible solute', and so preserves the normal biochemistry within the cell. It also increases the stability of proteins and membranes. So how does this unusual solute achieve these results?

REVIEW

- ✓ Microbiology
- ✓ Chemistry
- ✓ Biochemistry
- ✓ Archaeology
- ✓ Ecology
- ✓ Ages 16–19

The wreck of the *Titanic* is very well known, so this article can be used to excite students about science. It can also act as an incentive to delve deeper into the world of bacteria and their usefulness to human beings – despite their normally negative associations.

The article would be useful in biology teaching to explore how prokaryotic organisms can survive in extreme environments, and how substances are transferred across the cell membrane. It could also be used in chemistry teaching about hydrogen bonds and the interactions between water and other molecules.

Finally, recycling using *Halomonas titanicae* is relevant to ecology and the study of the energy balance within ecosystems.

Alina Giantsiou-Kyriakou,
biology teacher,
Livadia High School,
Cyprus

Ectoine and the hydrogen-bond network

Clues as to exactly how ectoine works on the molecular level have recently been discovered using the advanced experimental technique of neutron scattering (see text box). Carried out by an international collaboration[w2] involving the Institut Laue-Langevin (ILL)[w3], the experiments showed how ectoine influences the layer of water around protein molecules and on membrane surfaces (Zaccai et al., 2016). Normally, water molecules interact with each other through a network of hydrogen bonds. The atoms in a water molecule interact with neighbouring molecules, with each oxygen atom acting as a receiver of two hydrogen bonds and each hydrogen atom as a donor of one bond. This results in a highly dynamic network of intramolecular bonding, with the molecules changing partners a billion (10^9) times a second.

The attraction between water molecules is also the basis of the 'hydrophobic effect', which makes oil and water separate. The hydrophobic effect is important in many biological processes, including the three-dimensional folding of protein molecules and the formation of membranes. Hydrogen bond dynamics are thus an essential factor in how living cells are organised.

> "Hydrogen-bond dynamics are an essential factor in how living cells are organised."

Other substances in the water, such as salts, can interfere with this organisation. But, as the neutron experiments have revealed, ectoine seems to enhance hydrogen-bond dynamics – at least in part – rather than hindering it. This molecule contains a positively charged group (shown in blue in figure 1) and a negatively charged group (shown in red). These charged groups interact with water molecules, making the hydrogen bond network nearby a little less dynamic – but also creating a more dynamic network of water molecules further away.

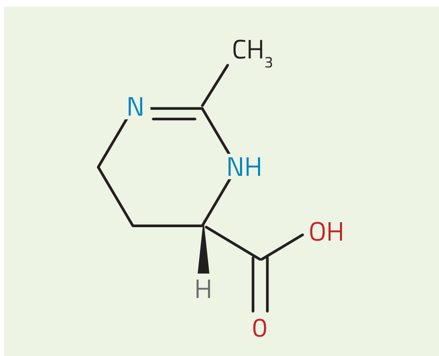


Figure 1: The chemical structure of ectoine. In water, the red group becomes negatively charged (by losing one H^+ ion) and the blue group becomes positively charged (by gaining one H^+ ion). The charged groups then form hydrogen bonds with adjacent water molecules.

BACKGROUND

Neutron scattering

Neutron scattering is a powerful method for studying the structure of materials, including water and its interactions with other compounds.

The nucleus of a hydrogen atom is a single proton. Neutrons and protons are very similar particles (apart from their electric charge), and neutrons strongly scatter off protons, rather like snooker balls bouncing off each other. The neutron scattering pattern provides information on the location of oxygen and hydrogen atoms in nearby water molecules, and thus on the dynamic network of hydrogen bonds that links them.

Another useful trick is used in neutron scattering. The nuclei of deuterium atoms (an isotope of hydrogen with one proton and one neutron in its nucleus) scatter neutrons in a very different way from normal hydrogen nuclei. Replacing the hydrogen in a specific compound (ectoine, for example) with deuterium makes it possible to see the contribution of only this compound to the scattering signal, distinct from that of the surrounding water molecules. This in turn helps to reveal the details of their interaction.

Neutron scattering with deuterium labelling has provided a rich crop of results in structural biology. These include insights into the complex interactions between protein molecules, and those between proteins and nucleic acids (DNA, RNA).

©ILL/L. Thion

The D22 instrument at ILL, which revealed how water and ectoine interact with protein surfaces. The door of the apparatus has been opened to show a view of the neutron detector.

Outside the bacterial context, ectoine is proving to be a useful ingredient in cosmetics and clinical treatments, because it can reduce inflammation in mammalian cells. The likely reason for this is that by stabilising proteins and membranes, ectoine protects human cells from damage, thus reducing inflammation and providing remedies for conditions such as allergies, eczema, and cough and cold symptoms.

Return to the *Titanic*

Although the neutron experiments have helped scientists to understand how *Halomonas* bacteria thrive in the potentially hostile environment around the sunken *Titanic*, the exact role of *Halomonas titanicae* in rust formation remains unclear. But there is some good news here: these iron-eating bacteria could have a role in future waste management, speeding up the decomposition of metallic litter – aside from historic wrecks – on the ocean floor.

References

Zaccai G (2009) The intracellular environment: not so muddy waters. *Science in School* **13**: 19-23. www.scienceinschool.org/2009/issue13/water

Zaccai G et al. (2016) Neutrons describe ectoine effects on water H-bonding and hydration around a soluble protein and a cell membrane. *Scientific Reports* **6**: 31434. doi:10.1038/srep31434

Web references

w1 *Halomonas titanicae* bacteria were discovered by scientists from universities in Seville, Spain, and Toronto and Halifax, Canada. Read a scientific account of the discovery on the UNESCO website. See: www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/CLT/pdf/Henrietta_Mann_Paper.pdf

w2 The collaborating organisations included the Institut Laue-Langevin (ILL) and Institut de Biologie Structurale in Grenoble, France, and the Max Planck Institute of Biochemistry and biotechnology company Bitop in Munich, Germany. See the online supplementary information section in Zaccai et al. (2016) for more information.

w3 The Institut Laue-Langevin (ILL) is an international research centre at the leading edge of neutron science and technology, based in Grenoble, France. See: www.ill.eu

Resource

Find out more about microbes that live on shipwrecks and the role of ectoine in an accessible article on the BBC website. See: www.bbc.com/earth/story/20170310-the-wreck-of-the-titanic-is-being-eaten-and-may-soon-vanish

Joe (Giuseppe) Zaccai is Emeritus Director of Research at the National Centre for Scientific Research (Centre National de la Recherche Scientifique, CNRS) in France. He spent his research career based at ILL, where he developed neutron scattering methods and applied them to the structural biology of adaptation to extreme environments.

Deepsea Delta *oil drilling rig in the North Sea. Like the wreck of the* Titanic, *oil rigs are at risk of damage from rust-eating bacteria.*

Erik Christensen/Wikimedia Commons

Ten things you might not know about fracking

Fracking is a hugely controversial technology, so it's worth taking a closer look at the science behind the headlines.

By Rosemary Wilson

In the USA, fracking is big business. A surge in fracking over the last few years means that it now accounts for more than 50% of all US gas production – but as levels of fracking have risen, so too have public opposition and concern. In Europe, governments and communities are currently weighing up the costs and benefits of fracking, and some governments have already banned it. But what exactly is fracking, and how does it work? Here we explore some of the science behind the current discussions.

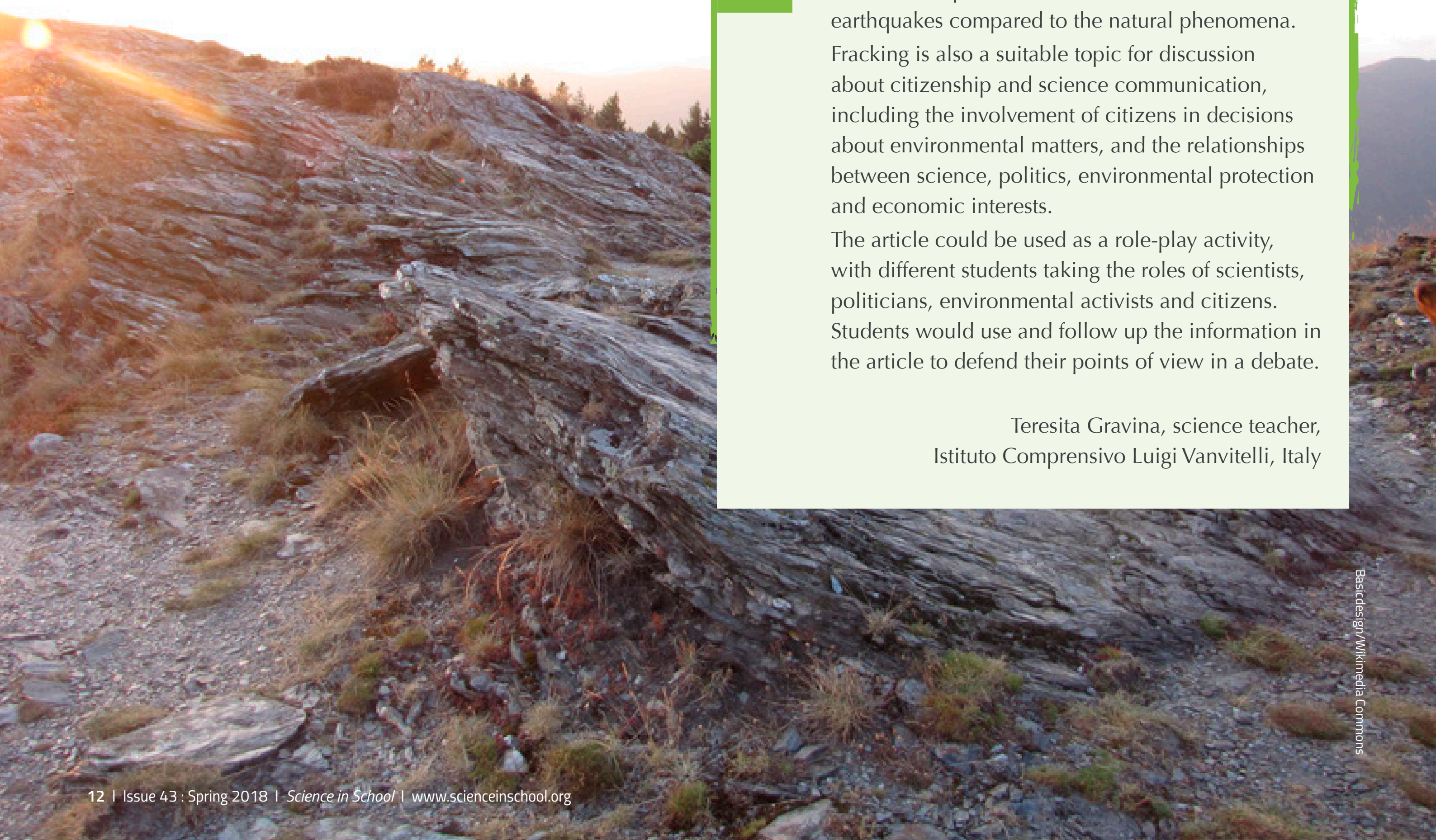
REVIEW

- ✓ Oil resources
- ✓ Earth science
- ✓ Earthquakes
- ✓ Environmental impacts
- ✓ Citizenship
- ✓ Ages 14–19

This article provides an interesting way to introduce the topic of fracking into lessons in different subjects. For example, it could be used in earth science to explore the idea of human-induced earthquakes compared to the natural phenomena. Fracking is also a suitable topic for discussion about citizenship and science communication, including the involvement of citizens in decisions about environmental matters, and the relationships between science, politics, environmental protection and economic interests.

The article could be used as a role-play activity, with different students taking the roles of scientists, politicians, environmental activists and citizens. Students would use and follow up the information in the article to defend their points of view in a debate.

Teresita Gravina, science teacher,
Istituto Comprensivo Luigi Vanvitelli, Italy



Shale landscape in the Languedoc-Roussillon region, France

Basicdesign/Wikimedia Commons

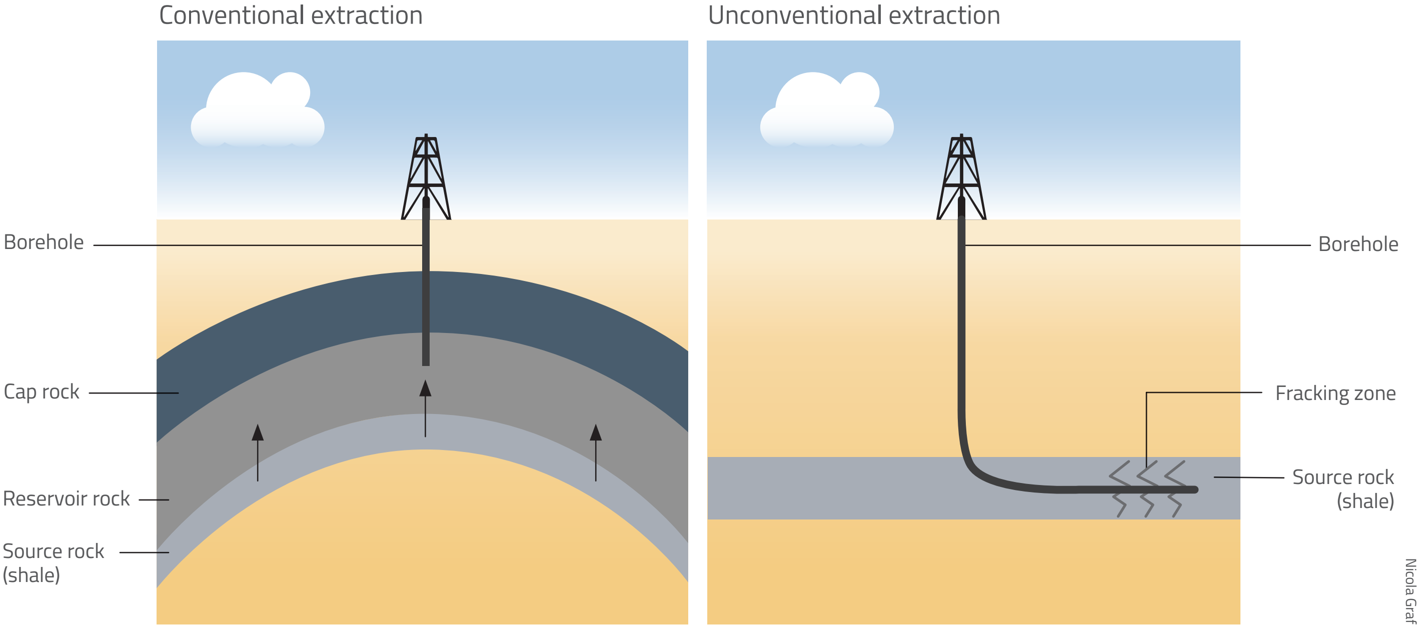


Figure 1: Comparison between conventional and unconventional gas extraction. In conventional extraction (left), gas moves upwards until it reaches an impermeable layer (cap rock). It collects within the reservoir rock, from where it is extracted by drilling. In unconventional extraction (right), the gas is extracted directly from the source rock, which must be fractured to obtain the gas. (Source: Hans-Martin Schulz, GFZ Potsdam)

1. Fracking means 'hydraulic fracturing'.

Fracking is an example of unconventional gas extraction. In this process, water (mixed with sand and chemicals) is injected into rocks under very high pressure to fracture them – hence the name hydraulic fracturing, or fracking.

In conventional extraction of natural gas reserves, such as those under the North Sea, the gas migrates upwards from the source rocks where it was formed and collects under an impermeable rock layer, from where it can be pumped out by drilling (see figure 1). Unconventional gas resources are trapped in the source rocks themselves, which have to be broken to release the gas. Sand particles are used to prevent the fractures from closing again, allowing the gas to escape and migrate to the surface.

2. Fracking is used to extract shale gas.

Currently, fracking is mainly used to extract the gas found in fine-grained sedimentary rocks called shales. As sediments of sand and mud were converted into rocks over millions of years under high temperature and pressure, the plant and animal remains associated with the sediments were converted into shale gas, which consists predominantly of methane.

Shale deposits are located all over the world, but the shales that contain the most gas formed in marine environments, particularly in slow-moving, poorly oxygenated water such as ancient sea basins. Here, the plants and animals could not decay before they were buried, providing organic material that was later converted into fossil fuel.

Anti-fracking demonstration in New York, USA (October 2012)

There are potential shale gas reserves across Europe, including the Posidonia Shale in Germany (see 4 on the map, figure 2), and the Bowland Shale in the north of England (see 8, figure 2). The Posidonia Shale was formed about 200 million years ago, at the bottom of the ancient Tethys Sea. Fossils of molluscs are common in these rocks, and those of larger animals such as dinosaurs have also been found here.

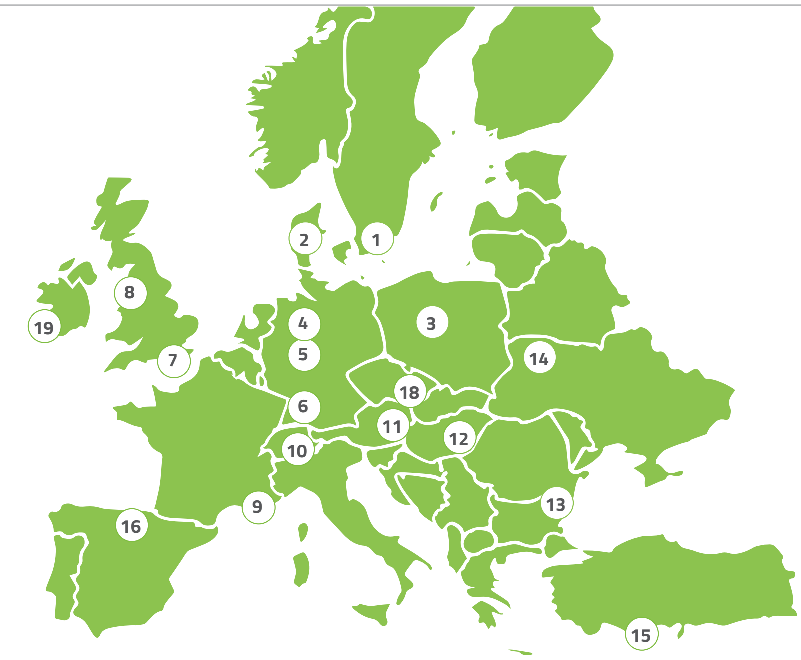
3. Fracking has been used for decades.

Fracking is not a new method of extraction: it has been used since the 1940s, but mostly in conventional extraction as a way of obtaining any last remaining gas. The type of fracking used to extract shale gas is more challenging, as shales are found at shallower depths closer to groundwater supplies and require greater volumes of fluid injection than conventional reserves.

More recently, engineers have worked out how to drill sideways into shale deposits, thereby fracking more rocks with only one borehole. In the USA, this development has led to a rapid increase in shale gas production over the last decade. In Europe, however, while there are a few test sites, fracking for shale gas is very limited.

4. Fracking needs a lot of water...

Some states in the USA have run dangerously low on drinking water, due to fracking. A single fracking borehole can use as much as 43 000 m³ of water – enough to supply a small town for about a month. Some boreholes use only a tiny percentage of this amount, but in the USA a large percentage of fracking boreholes are in areas prone to drought, such as Texas and California. In addition, fracking uses drinking water taken from reservoirs and groundwater aquifers, which must be disposed of afterwards rather than returned to the water cycle. This puts added strains on local water resources and is causing a lot of concern.



1. **Sweden**
   Alum shale
2. **Denmark**
   Alum shale
3. **Poland**
   Paleozoic shales
4. **Germany**
   Mesozoic shales including Posidonia shale, Lower Saxony Basin
5. **Germany**
   Namurian shales
6. **Germany**
   Permocarboniferous shales, Bodensee-Trog
7. **England**
   Weald Basin
8. **England**
   Namurian shales, including Bowland shale
9. **France**
   Mesozoic shales, Southeast Basin
10. **Switzerland**
    Lower Jurassic shales, Fribourg, Vaud
11. **Austria**
    Upper Jurassic shales, Vienna Basin
12. **Hungary**
    Cenozoic shales, Mako Trough
13. **Bulgaria**
    Mesozoic shales, northeast Bulgaria
14. **Ukraine**
    Lower Carboniferous shales, Dnepr Donets Basin
15. **Turkey**
    Silurian shales, southeast Turkey
16. **Spain**
    Lower Jurassic shales, Basque-Cantabrian Basin
17. **Italy**
    Tertiary shales, Ribolla Basin
18. **Czech Republic**
    Tertiary shales, Western Carpathian Basin
19. **Ireland**
    Clare shales, Upper Carboniferous, Clare Basin

Nicola Graf

Figure 2: Map showing location of potential shale gas reserves across Europe. (Source: Hans-Martin Schulz, GFZ Potsdam)

5. ...and a lot of sand.

Fracking uses vast amounts of sand – up to 8000 tonnes per borehole. In fact, fracking now accounts for approximately 60% of the sand used industrially in the USA. The sand needed is quite special: it is carefully sorted to select grains with a particular shape and size, and also with a high quartz content to withstand high pressures.

6. Fracking can cause earthquakes.

While fracking can cause earth tremors, these are generally too small to notice. However, there is evidence that the disposal of fracking fluids causes more problems and larger earthquakes than fracking itself. For example, in Oklahoma, USA, which has a large number of disposal sites, there were just a few tremors every year until

2008, increasing to 20 in 2009 and 105 in 2013. The largest tremor had a magnitude of 5.6 on the Richter scale and destroyed several homes.

Scientists at the US Geological Survey have worked out that the strength of these earthquakes depends on the amount of liquid pumped into the rocks. They calculated that injecting a volume of some 10 000 m^3 (enough to fill about four Olympic-sized swimming pools) could result in an earthquake with a maximum magnitude of 3.3. However, this is no prediction as to whether an earthquake will occur or not.

7. It takes a lot of pressure to fracture the rocks.

Shale deposits that can yield gas are usually found at depths of between 1000 m and 5000 m. After the borehole has been drilled down to the rocks, it has to be carefully encased with concrete to protect the surrounding environment before fracking can begin. Holes are then made in the borehole casing near the shales, and the fracking fluid is forced through these holes into the rocks under extremely high pressures – some 680 atm (69 million Pa). As a comparison, professional racing bike tyres have pressures of about 10 atm, or 1 million Pa.

8. In Europe, many potential fracking sites are near cities.

In the north of England, the shale gas reserves are beneath the large cities of Manchester and Leeds. In Germany, the Posidonia shale deposits are located near the city of Hanover, which has a population of over half a million. A couple of bore holes would require an area about the size of a football field, including space for drilling rigs, equipment and trucks; somewhere to store and dispose of water and waste; as well as gas storage and cabins for the workers. Setting up these sites and the associated infrastructure, such as transport routes, near or around any bustling European metropolis would not be easy.

9. Beer brewers in Germany are opposed to fracking.

The German beer purity law states that German beer should be brewed using only hops, yeast, malt and water. Pure, clean water is therefore a crucial ingredient of beer brewing, and many breweries in Germany obtain the water they use from their own wells. Any contamination of water supplies with methane or fracking fluids would be a threat to this important industry, and beer brewers in Germany have publicly declared their anti-fracking position.

Fracking advocates argue, however, that there are thick, impermeable layers of rock above shale deposits, which would act as a protective barrier during fracking, protecting shallow groundwater supplies from potential contamination. In addition, fracking must always take place at a defined distance away from

Annie and Andrew/Flickr

Beer drinkers at the Oktoberfest in Munich, Germany. German beer producers have voiced concerns about the effect fracking could have on the purity of their products.

groundwater. Another safety factor is that if any fracking fluids were to escape, they would sink downwards, rather than migrating upwards

> **"Beer brewers in Germany have publicly declared their anti-fracking position."**

towards the groundwater level. But while groundwater supplies might be protected from any contamination occurring at depth, there have been cases of groundwater contamination caused by spills on the surface, so careful handling of extraction chemicals and waste around the fracking site is also needed.

10. Scientists are using a similar technique to produce geothermal energy.

A method known as enhanced geothermal systems (EGS) exploits naturally occurring fractures in rocks, and uses high-pressure water to create even more fractures deep down, where the rocks are naturally hot. This creates a geothermal reservoir, which heats up water pumped down into the rocks, and the resulting steam is used to generate electricity. Once the water has cooled, it is then pumped back down into the rocks to be heated again.

Unlike in fracking for shale gas, no sand or other chemicals are needed for this process. The process is still controversial, however: an EGS project in Basel, Switzerland, was cancelled after it caused significant tremors, leading to insurance claims totalling millions of euros. But development and research continue: in Europe, there are EGS test facilities in Portugal, France and Germany, and projects are planned in Cornwall, UK that are expected to be operational by around 2020.

Acknowledgement

The author would like to thank Professor Dr Ernst Huenges and Dr Hans-Martin Schulz from the German Research Centre for Geosciences (GFZ), and Dr Clement Uguna from the University of Nottingham, UK, for their helpful input and comments on this article.

Resources

Read a study about how earthquakes can be induced by fracking. See:
Ellsworth WL (2013) Injection-induced earthquakes. *Science* **341(6142)**: 1225942-1–7 doi: 10.1126/science.1225942

Information and an interactive map of induced earthquakes can be found on HiQuake, a database of human-induced earthquakes. See: http://inducedearthquakes.org

The US Geological Survey recently published a study on water consumption used by fracking. Find out more in this article from *Scientific American*. See: www.scientificamerican.com/article/water-use-rises-as-fracking-expands

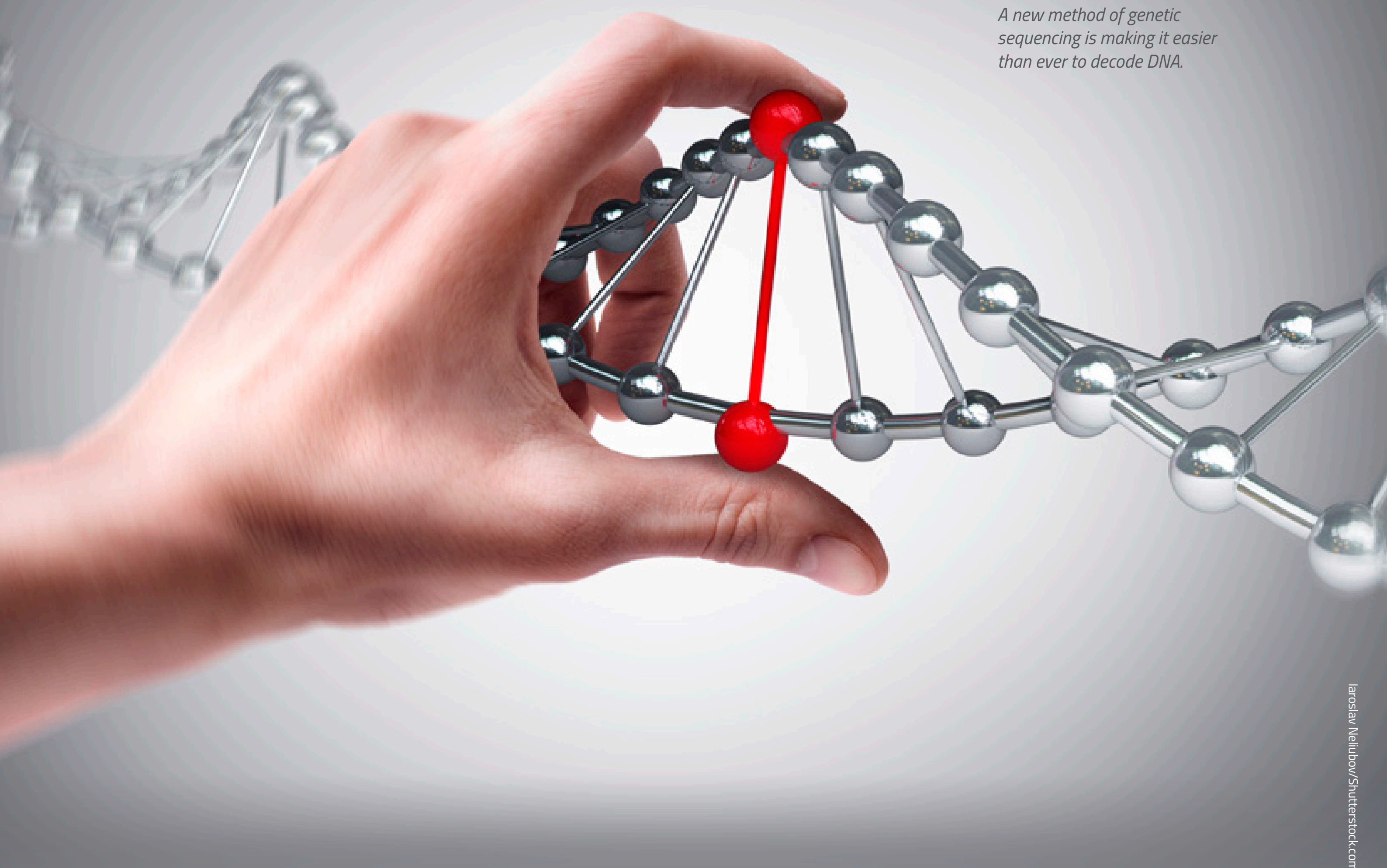
To learn about the current state of shale gas production in Germany, visit the Shale Gas Information Platform website. See: www.shale-gas-information-platform.org/areas/the-debate/shale-gas-in-germany-the-current-status.html

Information about shale gas geology, resources and production in the UK are available on the British Geological Survey website. See: www.bgs.ac.uk/shalegas

Learn more about fracking and current public opinion in the UK with this article published by *The Guardian*. See: www.theguardian.com/environment/2017/dec/25/fracking-start-2018-shale-gas-uk-industry-protests

Watch a TEDed lesson entitled 'How does fracking work?' to learn about the technology behind fracking, and why it is so controversial. See: https://ed.ted.com/lessons/how-does-fracking-work-mia-nacamulli

Rosemary Wilson is a science communicator and writer based in North Germany.



A new method of genetic sequencing is making it easier than ever to decode DNA.

Iaroslav Neliubov/Shutterstock.com

Decoding DNA with a pocket-sized sequencer

USB-powered sequencers smaller than your smartphone could revolutionise the way we decode DNA – in hospitals, in remote locations and even in space.

By Kerstin Göpfrich and Kim Judge

What were the biggest technological developments of the 20th century? Computers may be the first thing that comes to mind: early computers for military and commercial use took up a whole room before they were transformed into smaller, affordable consumer products in the 1980s. Computing power has advanced at such a rate that the smartphones we use today can perform tasks that even the most powerful computers could not achieve decades ago.

Now, another technology is being revolutionised in a similar way: the DNA sequencer.

DNA stores the genetic information that is passed down between generations. Similar to the way computers store information as a string of zeros and ones, the information in DNA is stored as a code of four bases: A, T, C and G (adenine, thymine, cytosine and guanine).

In 2003, the first human genome – the complete set of genetic information – was sequenced. It took seven years, 150 scientists and 3 billion US dollars (2.5 billion euros) to complete the mammoth project. Today, the same task can be achieved in just over a day for around 1000 dollars (850 euros). What's more, decoding the DNA doesn't need to take place in a large-scale laboratory: it can be done with a portable sequencer that fits in your pocket. This remarkable reduction in cost and size is thanks to a new technique called nanopore sequencing.

How does nanopore sequencing work?

Portable DNA sequencers have been on the market since 2015. The sequencing process is straightforward and, unlike earlier methods of DNA sequencing, scientists do not need to make millions of extra copies of the DNA or to label the DNA with fluorescent or radioactive tags. First, the DNA is extracted – for example, from a swab or blood sample – and mixed with an ionic solution to prepare it for sequencing. This DNA liquid is then pipetted directly into the nanopore sequencer, which is plugged into a laptop via a standard USB cable (figure 1).

Inside the nanopore sequencer, an enzyme unwinds the DNA double helix and passes one of the strands through a nanopore – a microscopic channel in the centre of a protein molecule sited in a membrane. A voltage is applied across the nanopore, causing ions in the solution to move through the pore and generate an ionic current. The channel is just the right size for the DNA strand to pass through. Since each of the four DNA bases is different in size, it blocks a different proportion of the nanopore as it passes through. This means there is more or less space for ions to pass through the nanopore, and so more or less current can flow across the gap (figure 2). The ionic current is measured and the data is transferred to the computer and analysed by specialist software that converts the measurements in real time into the DNA sequence – a text file with the letters A, T, C and G.

Depending on how much DNA sequence data you want to generate, the sequencer can run for minutes or days. One way to analyse the data is to upload it to an online DNA database and compare it to known sequences. This way, you can find out which species the DNA belongs to, whether there were pathogens in the sample, and what genes are present. Nanopore sequencing is remarkably fast, but typically generates a smaller amount of

REVIEW

- ✓ Biology
- ✓ Biochemistry
- ✓ Biotechnology
- ✓ Health
- ✓ Ages 16–19

This interesting article addresses one of the main topics in biology: the DNA molecule. In particular, it focuses on a new technique that allows faster and cheaper sequencing of DNA using a powerful but small device.

This new tool, called nanopore sequencing, has the potential to open doors to a variety of applications. In the near feature, it could be as simple to use as smartphones are today. However, the ease with which the public's DNA could be sequenced raises important ethical issues.

Together with images and graphics, the article could be used to explain the molecular biology techniques involved in reading and sequencing the DNA double helix, and how nanopore sequencing could replace earlier sequencing methods. It could also be used for discussions on the ethical issues and problems of privacy regarding genetic profiles.

Comprehension questions could include:

- Why does each nucleotide cause a different ionic signal in the nanopore sequencing device?
- What types of molecule could help to move the DNA through the nanopore?
- How does the DNA nanopore sequencer work?
- Explain two or three novel applications for the nanopore sequencer.
- What are the ethical issues surrounding the use of DNA sequencers?

Ana Molina, natural science teacher,
IES Gil y Carrasco High School, Spain

Oxford Nanopore Technologies

Figure 1: A nanopore sequencer connected to a laptop via USB. The DNA solution (yellow) is added with a pipette.

data than other sequencing methods. Sequencing centres will therefore remain important for obtaining large amounts of data.

Applications of nanopore sequencing

Nanopore sequencers are opening up many new possibilities for DNA sequencing. They have already been used to identify viruses, bacteria and parasites in a hospital environment. Most notably, in 2015 a team of scientists took the first sequencing field kit to West Africa and sequenced blood samples from 142 patients during the Ebola outbreak to track the emergence of new strains (see Bryk, 2017). Scientists identified the viral DNA in each sample after just 15 minutes of sequencing, showcasing the potential of the new technology to monitor epidemics and to help identify drug and vaccine targets to instantly inform control measures. In the future, nanopore sequencing could also speed up the identification of cancers, which is particularly important for aggressive tumours; currently, it can take weeks from collecting a patient's DNA sample to receiving the result from a laboratory.

Portable DNA sequencers have also been used to identify unknown species in remote areas, such as on high mountains and in the deep sea. Even further afield, it was announced at the start of 2018 that NASA astronauts had successfully identified microbes found on board the International Space Station using nanopore DNA sequencing. This means that astronauts could potentially diagnose infections using a sequencer to identify viral or bacterial DNA from their own mouth swabs. One day, nanopore sequencers may even be used to analyse DNA on other planets.

Using the same technology, DNA sequencing can now be carried out by students in the classroom[w1] – for example, sequencing the DNA of fruits in a smoothie[w2]. While the cost of portable DNA sequencers may still be prohibitive for widespread use, this technology opens up many new opportunities for citizen science projects and education.

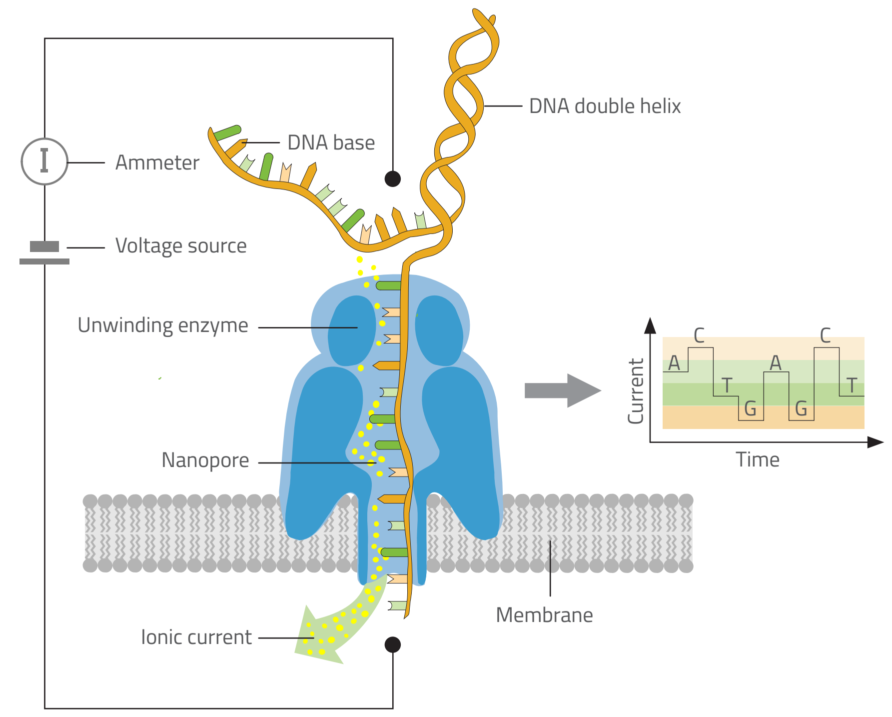
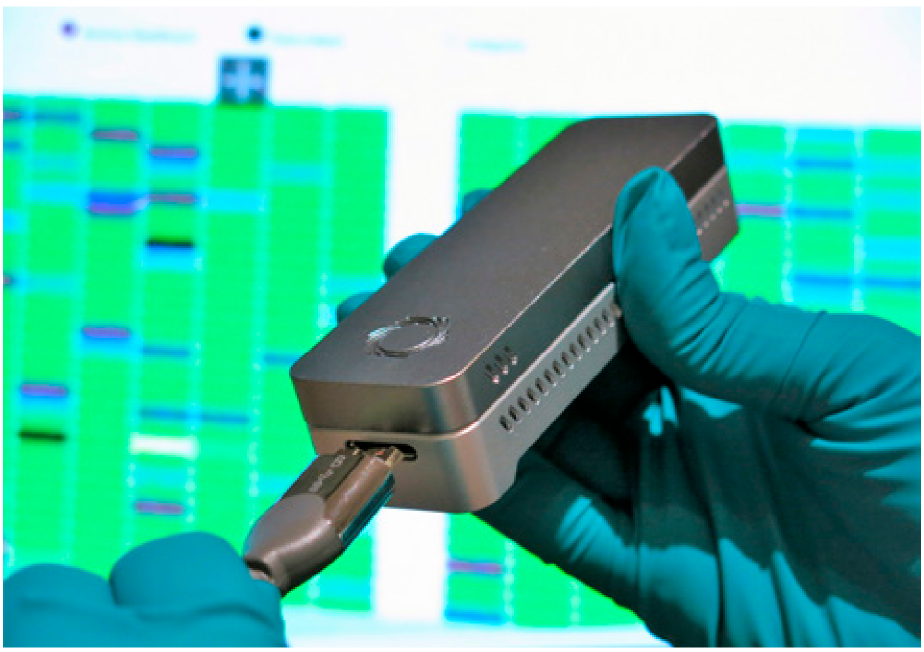


Figure 2: Illustration of the working principle of a nanopore DNA sequencer. A strand of DNA is passed through a nanopore, and an ionic current is measured and translated into the DNA sequence.



A portable nanopore sequencer

Ethics of DNA sequencing

Nanopore sequencing is the only technology to enable portable DNA sequencing of use genomes. Currently, anyone can use a home genetic-testing kit for less than 150 euros. But unlike nanopore sequencing, which can provide a base-by-base result, these kits analyse only specific genes, and the results are sometimes questionable.

As whole-genome DNA sequencing becomes increasingly accessible due to nanopore sequencing, it will be crucial to consider the ethical questions. The more DNA we sequence, the better we will understand the health implications

University of Birmingham

Portable DNA sequencers are being used to monitor epidemics, as shown here during the Zika outbreak in Brazil

of genetic predispositions. But while genes may predict the probability of certain diseases, lifestyle factors often decide the outcome. Private companies are already marketing dubious 'health horoscopes' based on DNA testing – often neglecting the complexity and probabilistic nature of genomic data.

> **"In principle anyone could own such a device and sequence DNA as they choose."**

The data may also be misused for new kinds of discrimination. For example, will health insurance companies pick their customers depending on genetic profiles? Could DNA records be available to the police? In light of the sudden miniaturisation of DNA sequencers, in principle anyone could own such a device and sequence DNA as they choose – in fact, a smartphone DNA sequencer is already under development[w3]. We all leave traces of DNA everywhere we go, so privacy is now an increasing concern.

Like computers and smartphones, DNA sequencers have the power to change our lives – but we must work together across society to ensure that we maximise the opportunities, while also mitigating the risks of DNA sequencing.

Reference

Byrk J (2017) Evolution in action: pathogens. *Science in School* **42**: 8–13. www.scienceinschool.org/content/evolution-action-pathogens

Web references

w1 For a podcast on DNA sequencing in the classroom involving both authors of this article, visit the Naked Scientists website. See: www.thenakedscientists.com/sites/default/files/media/Naked_Scientists_Show_16.11.29_1006003_1.mp3 or use the direct link https://tinyurl.com/ycrwge5t

w2 Learn more about an interactive DNA sequencing challenge set up by the authors, titled 'DNA my smoothie'. See: www.thenakedscientists.com/articles/features/dna-my-smoothie

w3 Visit the Oxford Nanopore Technologies website to read about the latest DNA sequencer under development. See: https://nanoporetech.com/products/smidgeon

Resources

Schedule a discussion between the authors and your students by making an appointment via the Ring-a-Scientist website – a project supported by Wikimedia Deutschland, Stifterverband and the Volkswagen Foundation within the Open Science Fellows Program. The authors can take you through sequencing experiments live via a video conference. See: www.ring-a-scientist.org

To learn more about nanopore sequencing, visit the Oxford Nanopore Technologies website. See: https://nanoporetech.com/how-it-works

For up-to-date information about the NASA project on DNA sequencing in space, visit the Oxford Nanopore Technologies blog, or listen to an interview with Dr Aaron Burton. See: https://dna.space and www.thenakedscientists.com/sites/default/files/media/Naked_Scientists_Show_16.11.29_1006004_1.mp3 or use the direct link https://tinyurl.com/y9qwng3q

The Wellcome Genome Campus provides detailed information, including classroom resources, about everything related to DNA. See: www.yourgenome.org

Dr Kerstin Göpfrich is a science communicator and a postdoctoral researcher at the Max Planck Institute for Medical Research in Heidelberg, Germany, with experience in nanopore technologies. She established the Ring-a-Scientist platform to connect scientists and teachers using video conferencing.

Dr Kim Judge is a senior staff scientist at the Sanger Institute in Cambridge, UK, working on DNA sequencing using nanopores and other sequencing technologies.

vexworldwide/Shutterstock.com

A relative view of truth deprives people of a shared platform for communication – as suggested in this illustration, based on the drawing entitled 'Relativity' by artist MC Escher.

Is science true?

Should we believe what science tells us? A philosopher of science comments on teachers' responses to this challenging question.

By Thomas Uebel and Susan Watt

As a science teacher, do your students sometimes put you on the spot – not just about the details of what you are teaching, but about the value of scientific knowledge itself? Compared to previous generations, people are now more sceptical about institutions and expert opinions in all fields of knowledge – young people perhaps even more so. And we can all think of examples where scientific advice has changed based on new evidence.

So how should educators respond to the question, 'Is science true?' Which responses support the validity of science – and which could undermine it?

Teachers' responses in defence of science

In this article, we look at some responses used by actual science teachers in the classroom as they attempt to defend scientific knowledge against challenges from students, such as 'Why should we believe what science tells us?' These responses are followed by comments and suggestions from a philosopher of science to add an expert's view on the issue.

Response 1: "Truth is relative: your truth isn't my truth."

This type of response is often tempting to use against challenges to any knowledge claims, not just in science. The aim is to sidestep the question of truth entirely – but does this work?

The problem with seeing truth as relative is that, without a notion of truth as something objective, it becomes impossible to understand how learning about the world around us is even possible. If what we hold to be true can only be true for us individually, could we ever agree or disagree with each other? I would always be right, and so would you – or rather, there would no longer be any 'being right'.

> "Without a notion of truth as something objective, it becomes impossible to understand how learning about the world around us is even possible."

Imagine two people are sitting in a room, which one says feels cold and the other thinks feels warm. This is understandable: one person may simply feel cold more easily than the other. But what if one person says that, based on a thermometer reading, the temperature of the room is 19 °C, and the other says that it is 22 °C? If they are both right, they would then have no common reference on which to base any decisions (for example, whether to turn the heating on or off). Having no disagreements sounds nice, but in reality, no one could rely on what anyone else said, and there would be no way of telling how things actually are.

There is one aspect of truth relativism that appeals to many people, because it seems to fulfil our wish to avoid claiming too much. This is even more so if we put the contrast in terms of 'relative vs. absolute truth' – after all, who wants to be an absolutist anymore? But to say that there is a truth on a given matter is not to say that we know what the truth is. If we want to be modest in making knowledge claims, then we should just be very careful about the claims that we make, and the uncertainty associated with them. Denying that there can be objective truth does not express modesty about our knowledge: it just makes knowledge of the world impossible.

Response 2: "Science is about models – it's not about reality."

It's certainly true that science provides models of what the world is like. But it's a misunderstanding to think that because science provides models, it's not about reality.

Whenever we think about anything, we do so by means of a medium – whether this is words in a language or images that are drawn or imagined. Either way, we always need a means of representation. Scientific thought is no different: it provides models of reality that are meant to represent just those aspects that are under investigation.

Obviously, models cannot be reality itself: they are merely representations of it. Reality itself is what we bump our heads on or burn our fingers

REVIEW

✓ Nature of science

✓ Science and society

✓ Ages 14–19

In this 21st century, the age of technology, is such an article necessary? Unfortunately, yes. Many European science curricula at secondary-school level do not pay much attention to the construction of scientific knowledge.

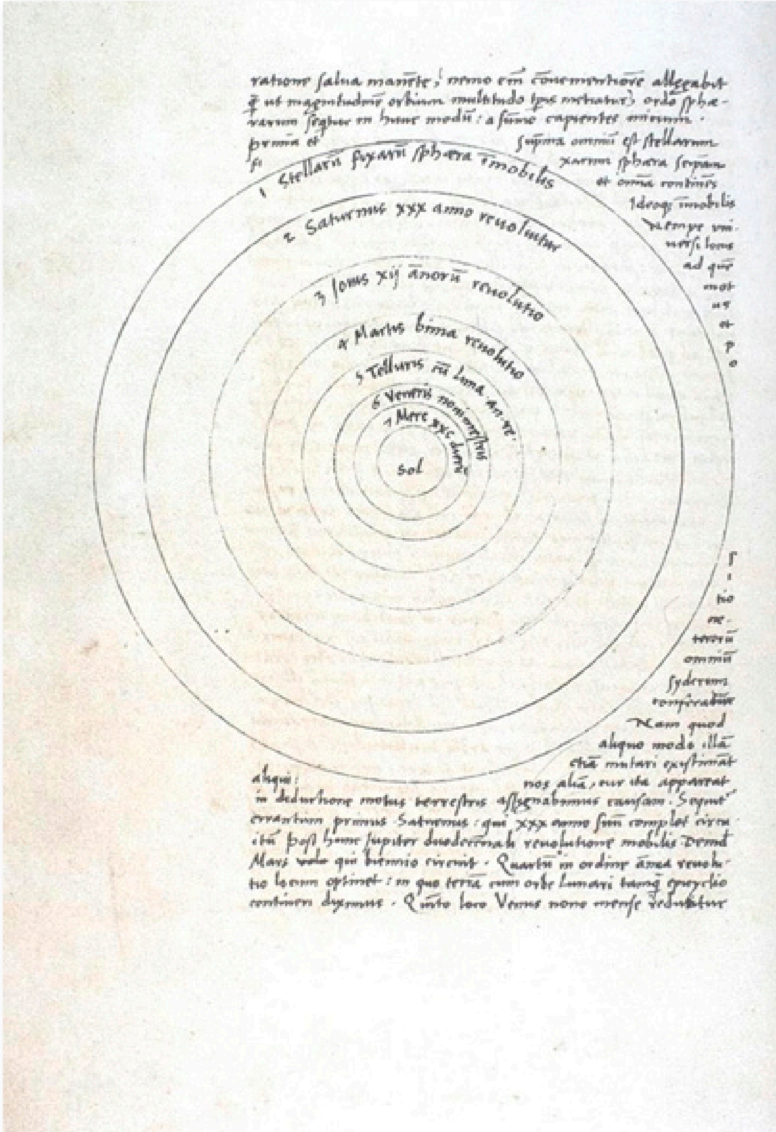
This very interesting article leads us to reflect on two crucial dimensions of science: the link to factual reality, and the search for reliable and testable patterns in our comprehension of the cosmos. After a discussion of the central ideas in this text, science teachers could involve their students in a semi-structured inquiry around a question from the recent history of science, as illustrated in the article.

Whatever approach science teachers take, I believe that this article will help them to consider the most important questions here: is the scientific endeavor well understood by science students in secondary education? Probably not. Can the misunderstanding of its goals and methods put a truly democratic and open society at risk? Definitely, yes.

Luis M Aires, biology teacher, Antonio Gedeao Secondary School, Portugal

Enzymlogic/Flickr

Model of the DNA molecule. Once Crick and Watson had built the first model of DNA structure, the double-helical form rapidly led to new theories about DNA's role in heredity.



Nicolas Copernicus (www.bj.uj.edu.pl; public domain)/Wikimedia Commons

Page from the manuscript of De Revolutionibus Orbium Coelestium *(1543) by Nicolaus Copernicus, showing the Sun at the centre of the planetary orbits*

with. Given that scientific models and theories are representations, all that we can ever ask of them is to predict and explain phenomena as precisely as possible.

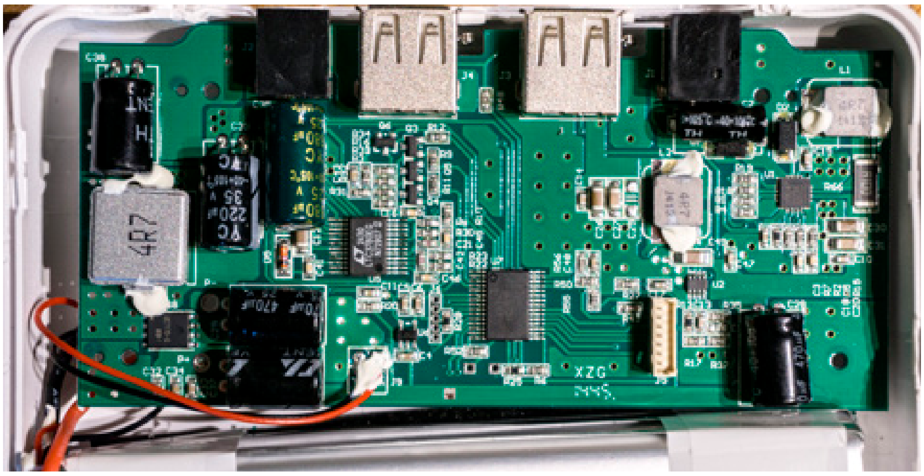
So is the criticism here that science uses bad models? Certainly, scientists argue over whether a model makes the right assumptions, uses the correct parameters, has included all the relevant features, and so on. Thus, the criticism cannot be of science itself, because science makes it its business to deal with such problems. Models can be tested and their results compared, leading to gradual refinements.

Response 3: "Scientific theories are just a way of fitting the data: all we have is observations."

This is an interesting thought that has a long history. In the century when the geocentric view of our Solar System was being replaced by the heliocentric one, it was often useful (for reasons to do with society at the time) to say that all that mattered was 'saving appearances'. In the book in which Copernicus put forward his heliocentric account, the preface warns readers not to assume any claims about reality from the descriptions of the Earth circling the Sun: the descriptions are merely there to account for the observations. And in more recent times, the 'instrumental' view of scientific theories – in which their only role is to make observable predictions – has been influential, although it is no longer very popular among philosophers of science.

> **"It's a misunderstanding to think that because science provides models, it's not about reality."**

In any case, in science as in everyday life, observations very rarely stand on their own, but are part of networks of related observations, generalisations and expectations – in other words, theories. And the beauty is that just as theories lead to predictions of new observations, so observations help to confirm or disconfirm theories. Both of these elements of science correct each other, and together they make scientific knowledge possible.



Larry Qian/Flickr

Electronics inside a mobile phone. The complex technology has been developed over many decades, based on robust scientific theories and new technological developments.

Response 4: "If science is just a theory, why does your mobile phone work?"

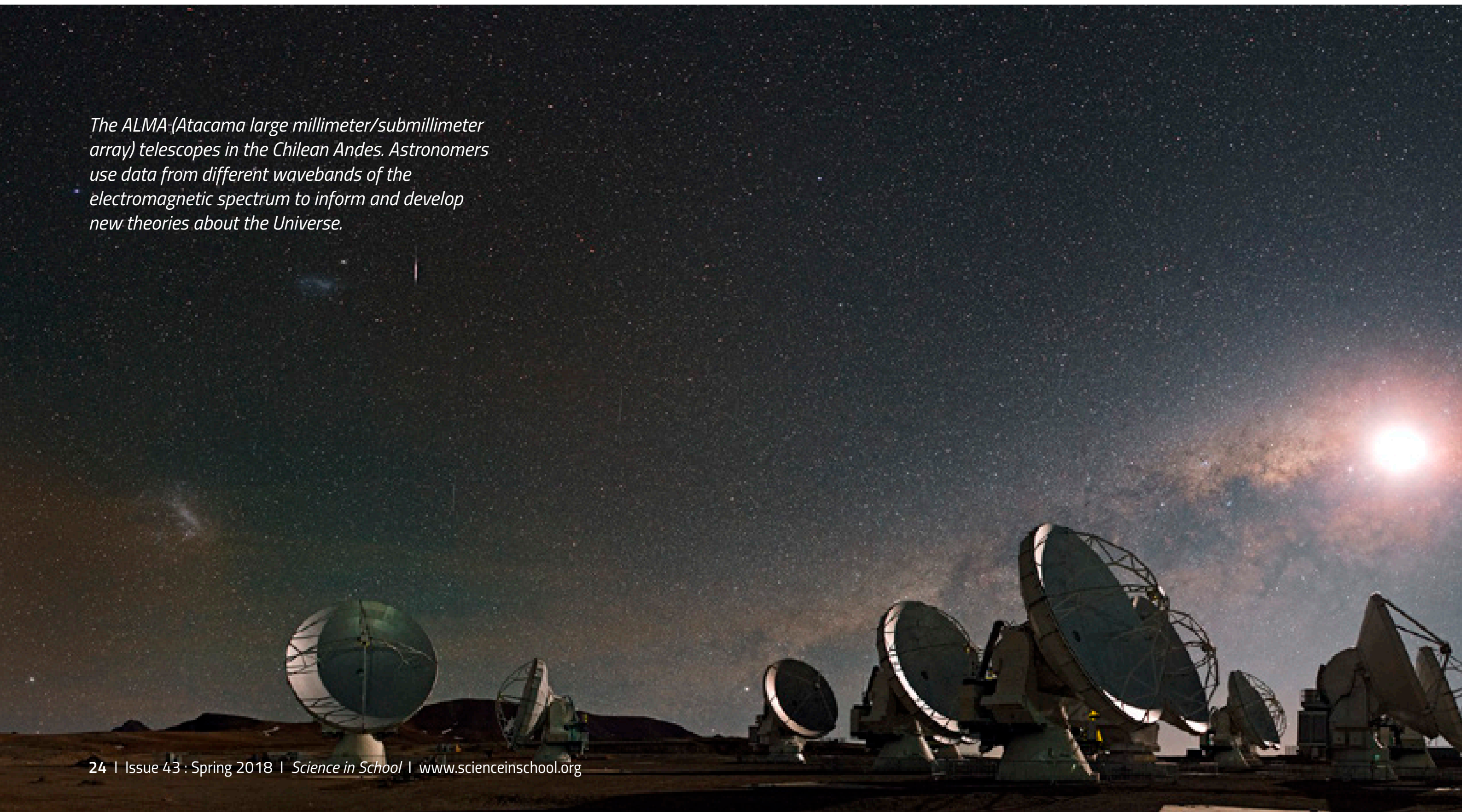
It is difficult to respond directly to the challenge that "science is just a theory", as it's not entirely clear what the complaint is. Science provides descriptions that allow us to explain what happens, and to make correct predictions. What more could be expected of these explanatory descriptions that we call theories?

What we call scientific knowledge are theories that are confirmed to the highest degree that it seems reasonable to demand. But certainty is not required throughout: within science we have many different degrees of acceptance – from theories that are extremely well confirmed, to models that have a more hypothetical status, or are even just speculative. Typically, scientists would only count the first category here as reliable knowledge.

Furthermore, most scientific theories are very complex, and they undergo stringent testing – not only from advocates, but also from opponents. It is because of these internal dynamics that we can regard science as a self-correcting enterprise. For this reason, it's quite persuasive to point to the practical successes of science (in terms of the technology we use) to demonstrate that science is an integrated and robust system of knowledge.

What lies behind this success is that, in principle, every scientific knowledge claim can be questioned – and certainly will have been in the past. If a theory survives at all, there is likely to be a good deal of truth about it. Even old theories are rarely discarded in their entirety. While Newtonian physics was superseded by relativistic physics,

> **"Even old scientific theories are rarely discarded in their entirety."**



The ALMA (Atacama large millimeter/submillimeter array) telescopes in the Chilean Andes. Astronomers use data from different wavebands of the electromagnetic spectrum to inform and develop new theories about the Universe.

the older theory continues to apply to objects within our ordinary experience, with degrees of deviation so tiny they are mostly undetectable. So there is discontinuity in scientific progress, but also continuity.

Eric Erbe, Chris Pooley (public domain)/Wikimedia Commons

Scanning electron micrograph of a yellow mite, Lorryia formosa, *magnification about 850 x. The wave-particle theory regards particles such as electrons as also having wave properties. This theory has led to the development of electron microscopy, with exquisitely high resolution.*

Resources

Read a classic introduction to the philosophy of science, see:

Chalmers A (2013) *What is this Thing Called Science?* 4th edition. Indianapolis, USA: Hackett Publishing Company. ISBN: 162466038X

For a recent and accessible introduction to philosophy of science, see:

Okasha S (2016) *Philosophy of Science. A Very Short Introduction*. 2nd edition. Oxford, UK: Oxford University Press. ISBN: 0198745583

For a comprehensive and up-to-date online resource on philosophy, look for various articles under 'science' and 'scientific' in The Stanford Encyclopaedia of Philosophy. See: https://plato.stanford.edu/contents.html

Thomas Uebel is a professor in the Department of Philosophy at the University of Manchester, UK. He teaches and researches philosophy of science and its history, and is the author of several books and numerous journal articles.

Susan Watt is a science writer and editor for *Science in School*. She holds a degree in natural sciences from the University of Cambridge, UK, and postgraduate degrees in philosophy and psychology.

S. Guisard/ESO

Becoming an astronaut: interview with Matthias Maurer

The European Space Agency's newest astronaut recruit talks about his exhilarating experiences in astronaut training and what the future has in store for space flight.

Wearing a training spacesuit, Matthias Maurer is submerged in a water tank at the Neutral Buoyancy Laboratory in Houston, Texas, USA.

ESA/Stephane Corvaja 2017

ESA/Sabine Grothues

Matthias Maurer at the European Astronaut Centre in Cologne, Germany

By Hannah Voak

After a challenging year-long selection process to become one of the European Space Agency's newest astronaut recruits, Matthias Maurer made it to the final group of ten candidates. But, with only six places available to fly to space, his aspiration to become an astronaut was put on hold at the final hurdle. *Science in School* spoke to Matthias about his unforeseen path to becoming an astronaut, and what he can expect if he ultimately travels to space.

How did you first become interested in science?

From an early age, I was fascinated by engineering. My uncle is an engineer, so I was always interested in the stories he told me about his job. As a very small kid, I wanted to become a pilot, or a Formula One racing driver – so there was a technical interest right from the start.

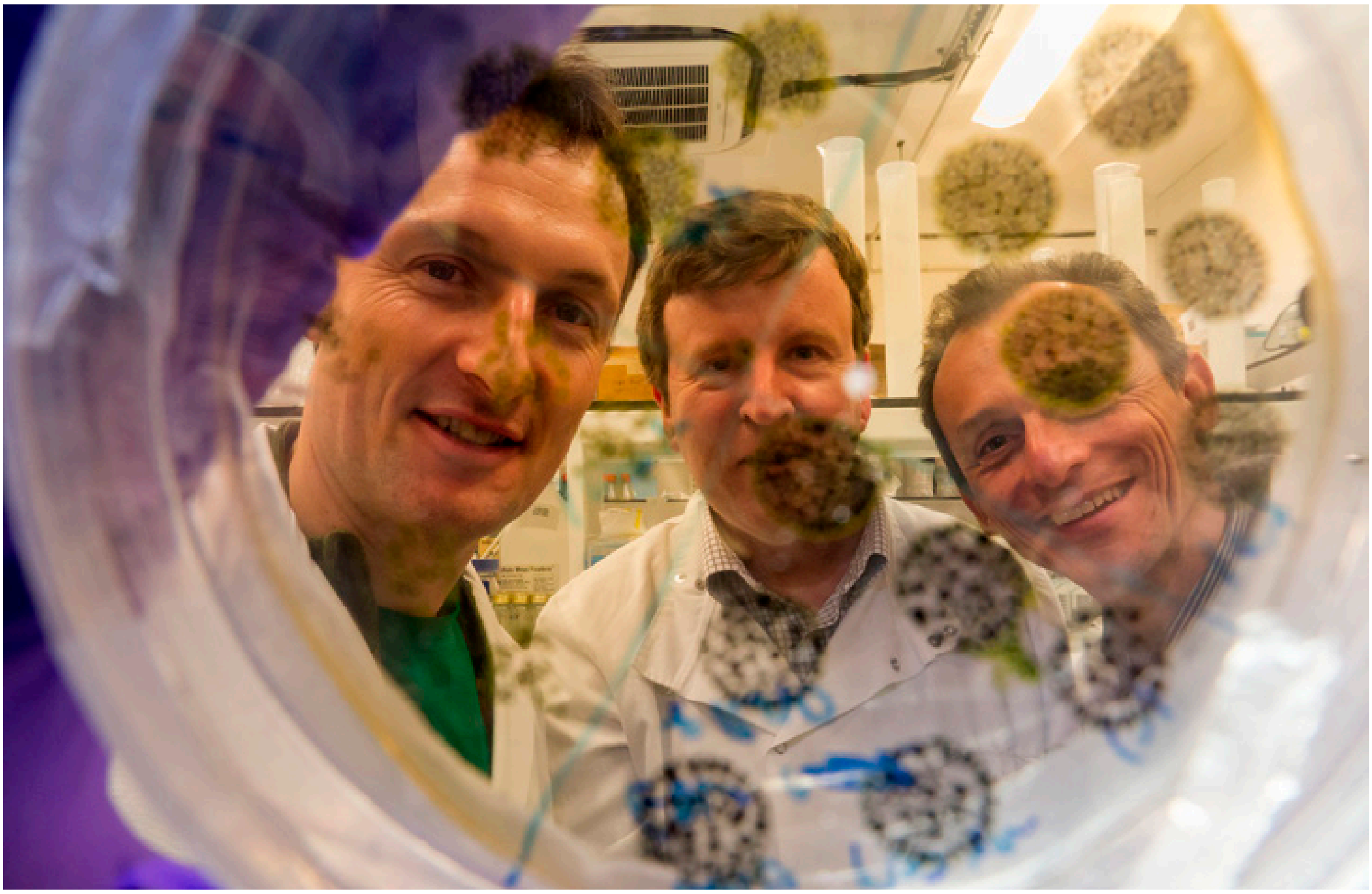
My initial plan was to study aerospace engineering, but I guess my career path was triggered partly by coincidence. I was completing my military service as an ambulance driver when the Berlin wall came down in Germany. So, in the summer of 1990, I received a letter informing me that I was relieved of my service ahead of time – I could start my studies a year earlier than planned. But the deadlines for applying to study aerospace engineering had closed six months before. Only a few universities in Germany reopened applications for special cases like mine, so I decided to study the next best thing – material science engineering.

My plan was to change to aerospace engineering later, but after one year of studying at my home university in Saarbrücken, Germany, I discovered that material science engineering was so rich and interesting that I wanted to continue. In the years that followed, I studied in the UK, France and Spain, and completed my PhD in material science engineering in 2004.

When did you decide that you wanted to become an astronaut?

When I left school at the age of 19, I did not have a clear plan for my career. When the European Space Agency (ESA) announced in 2008 that it would begin the selection for a new class of astronauts, I immediately realised that it was exactly what I wanted to do.

The preferred age range for an astronaut is between 27 and 37. By that time, you have finished studying and have at least three years' experience as an engineer, scientist or doctor, or a certain number of flight hours as a pilot. When I applied for the selection process, I was already 37. That said, Italian ESA astronaut Paolo Nespoli has just returned from space, and he is 60 years old. We now understand that space flight is not so hard on the body, so the health requirements for flying to space are changing, too.



Practical courses, which include learning about microorganisms and where best to look for signs of life, prepare astronauts for assisting with scientific studies on the ISS (Matthias Maurer, left).

“You would find hundreds of people who have the foundation to become a good astronaut – then it’s down to luck whether there is a selection process at the right time.”

What advice would you give to someone who wants to become an astronaut?

One of the biggest problems is that you can’t plan your life around becoming an astronaut. Even if you have all the right experience, the limiting factor is the number of available spots to fly to space – but this could change in the next 20 years, thanks to commercial space flight.

In Europe, you would find hundreds of people who have the foundation to become a good astronaut – then it’s down to luck whether there is a selection process at the right time. Don’t let anyone tell you that you can’t do it, though. Astronauts aren’t unique in the sense that we are smarter; we are just unique in that we were a bit luckier than others.

Lastly, always have fun, pursue the subjects you like best, and maybe it will add up, as it did in my case.

Tell us about how you got to be an astronaut.

The selection process took one year. The more I progressed, the more I believed I could actually do it. We went from 8500 candidates to only ten. But, at the final stage, we were told there was room for only six of us to fly to space. I was not among the six, and instead, I was put on a reserve list. It was a massive disappointment – a bit like at Christmas when you receive your dream present, only for your parents to tell you the next day that it wasn’t actually for you.

After the selection process, I joined ESA in 2010 as a member of their ground personnel, communicating between the control centre on Earth and the astronauts in space. But a couple of years ago, ESA had the capacity for more space flights and astronauts. They immediately came to me and asked ‘Do you still want to become an astronaut?’ I said yes.

You began astronaut training in 2015. What did it involve?

We currently fly on Russian Soyuz spacecraft, so the training began with intensive language courses in Russian. Since then, I have also started learning Chinese in anticipation of our cooperation with China. In basic astronaut training, you learn all the skills to become an astronaut, from knowing how to react quickly to failures on the International Space Station (ISS), to collecting valuable samples for scientific studies. We are trained as paramedics and we can also pull out teeth and do fillings. Survival training is also a big part – recently I was in China practising an emergency capsule landing in the open sea. I was hoisted out of the water by a helicopter hovering above me – I felt like I was in a James Bond movie!

When will you fly to space?

I am now ready to be assigned to a space mission at any time. There are currently six astronauts on board the ISS, but in future there will always be seven. ESA usually has only one space flight per year to the ISS and the next free spot is in 2020. I'm really hoping to be on that flight and to represent Europe in space.

What do you think will be the hardest part about living and working in space?

Physically, the most difficult part will be the spacewalk – working six hours in a space suit is really tough. It is difficult being away from your family, but it is only for half a year and I will be able to call them every day. Another thing that I will miss will be the fresh air – jogging in the forest or along the beach.

The space station is more or less the size of a football pitch so you can easily go the entire day without seeing another astronaut. But your sleeping quarter is as small as a cupboard, so that's all you have for privacy.

The astronaut training means we are well prepared for living in space. However, I can imagine that losing sight of Earth, for example in the case of flying to Mars, would be difficult psychologically.

Would you fly to Mars?

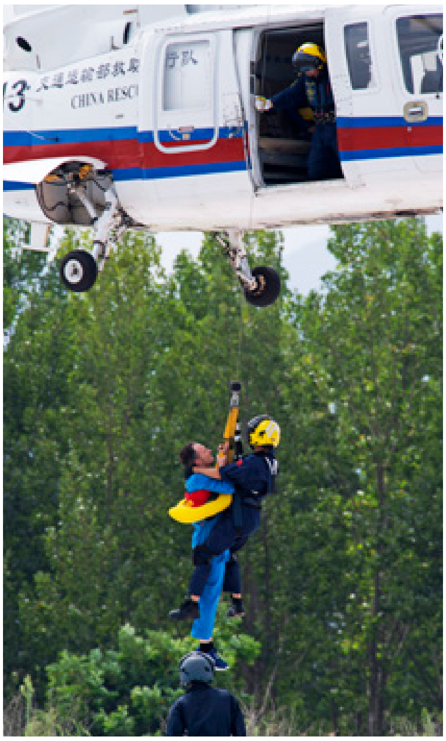
I would do it if I had the confidence that it would be safe for me to return. I would never do it on a one-way mission.

What would teachers find most interesting about your job?

Often, the most fascinating part about space is how things differ from Earth. For example, how does a candle burn in space? When a flame burns on Earth, heated gases rise from the flame, forming the elongated shape we are

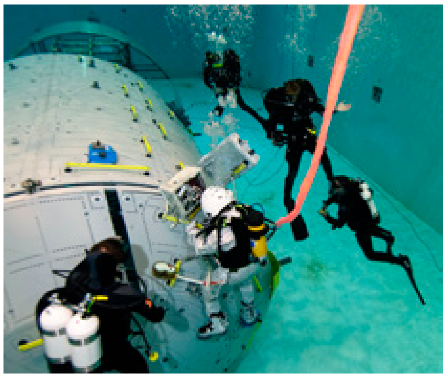
Matthias Maurer jumping from a Chinese Shenzou capsule during sea survival training in 2017

ESA/Stephane Corvaja, 2017



ESA/Stephane Corvaja, 2017

Matthias Maurer is lifted out of the sea during survival training in Yantai, China



ESA/Helmut Rueb

To prepare for work on the exterior of the ISS, Matthias Maurer performs tasks wearing a training spacesuit at the ESA Neutral Buoyancy Facility in Cologne, Germany.

ESA/Anneke Le Floc'h

ESA astronauts Matthias Maurer (centre) and Samantha Cristoforetti (left) during a parabolic flight, which allows astronauts to experience weightlessness for 20 seconds at a time

used to seeing. In space, hot air doesn't rise, so the flame is like a ball. We can then investigate why this happens.

In that sense, astronauts act as facilitators for scientists. One of my favourite projects was developing new alloys in space for the next generation of aeroplane turbine engines, so they can fly further with less petrol. Protein crystallisation in space is also fascinating – the weightlessness means that the crystals grow perfectly, so scientists fly proteins to space to be crystallised, before they are brought back to Earth for X-ray analysis. Space research also has applications for medicine, for example testing medication to slow down or stop osteoporosis. And we also address fundamental questions such as where life comes from, whether we are unique on Earth, and what organisms can survive in space.

Finally, what is the future of space flight?

It is an exciting time for space flight – lots of changes are happening. The ISS will operate for a few more years, and ESA is already studying potential space platforms for the post-ISS period. The Chinese space station will be ready by 2023, and the Americans are talking about a commercial space station that could replace the ISS. We also have long-term international plans to return to the Moon and eventually – in the next few decades – put the first people on Mars. Space flight is a truly international endeavour, and it is essential that we have people from different countries, different backgrounds and different fields, working together.

Resources

Watch a video showing Matthias Maurer in astronaut training. See: www.esa.int/spaceinvideos/Videos/2017/01/Introducing_ESA_s_new_astronaut_Matthias_Maurer

Visit the ESA education website for classroom resources, hands-on projects for pupils, and information about teacher training. See: www.esa.int/Education

Learn more about human space flight and exploration by visiting the ESA website. See: www.esa.int/Our_Activities/Human_Spaceflight/Astronauts

Hannah Voak is an editor of *Science in School*. With a bachelor's degree in biology and an enthusiasm for science communication, she moved to Germany in 2016 to join *Science in School* at the European Molecular Biology Laboratory.

Turning dandelions into rubber: the road to a sustainable future

A species of dandelion is leading the way towards sustainable rubber. Find out how, by growing this unusual plant yourself and extracting the rubber from the roots.

Russian dandelion,
Taraxacum kok-saghyz

Mareike Göbel

By Mareike Göbel and Martin Gröger

Look around you: what objects can you see that are made from rubber? You might spot an elastic band, a pencil eraser, or perhaps one of the biggest users of rubber – car tyres. In fact, over 40 000 everyday products are produced from natural and synthetic rubber. With this material in such high demand, scientists are exploring an alternative source of rubber from a particular species of the familiar, but underestimated, dandelion: *Taraxacum kok-saghyz*, commonly known as the Russian dandelion.

To help students understand more about sustainability and this unusual source of rubber, we developed two simple methods to extract the rubber from the dried roots of the Russian dandelion. In the first method, students grind the roots into a powder to extract the rubber particles and create


The roots of the Russian dandelion contain a high proportion of rubber.

Mareike Göbel

their own eraser. In the second method, sodium hydroxide is used to erode the woody parts of the root, and students can stretch out the fine strands of rubber that remain. The activities can be carried out by students aged 11–14 or older, in small groups of three or four, and will take about two hours.

Rubber: sources and structure

The majority of the world's natural rubber comes from plantations of the tropical rubber tree *Hevea brasiliensis* – over 90% of which are cultivated in Southeast Asia. Natural rubber production is responsible for widespread deforestation, and most of this rubber is used to make tyres. Relying on natural rubber to meet rising demands is not only unsustainable, but also risky: yields of natural rubber are falling due to a decline in prices, which has resulted in farmers switching to more profitable plantations such as palm oil. Climate change and crop

REVIEW

- ✓ Chemistry
- ✓ Biology
- ✓ Environmental sciences
- ✓ Design technology
- ✓ History
- ✓ Ages 11–19

We live in a time when we must reconsider our habits and how we use natural resources. This article, which provides information on how rubber can be made using a species of dandelion, can be used for chemistry, biology and environmental sciences lessons. It is particularly suitable for discussing sustainability issues related to technological development, and for considering global questions regarding biodiversity.

The article also describes a novel activity using the roots of the dandelion. The *Taraxacum* species must be grown well in advance, but teachers could grow the plants with students in the spring, and complete the experiment in autumn. It would be interesting to follow the whole process, from seeds to rubber.

Ingela Bursjöö, science teacher and science education researcher, Johannebergsskolan Elementary School, Sweden diseases pose additional threats. These challenges make the future of natural rubber production uncertain. Producing rubber synthetically can help, but it requires the use of crude oil – so it is important to find an environmentally friendly and sustainable alternative.

The discovery of Russian dandelion

The Russian dandelion, *Taraxacum kok-saghyz*, was discovered in Eastern Kazakhstan in 1931. The plant has the yellow flowers characteristic of the dandelion genus, but the roots contain a higher percentage of rubber than the familiar species of dandelion found in Europe. Soon after its discovery, the Soviet Union began large-scale cultivation of *T. kok-saghyz* to extract the rubber and end the country's dependence on imports (see Göbel & Gröger, 2016). When the Japanese seized rubber plantations in Southeast Asia during World War II, other countries, including the USA and Germany, started farming the dandelion as an alternative. When the war ended and supplies from the rubber tree, *H. brasiliensis,* became available again, research on the Russian dandelion ceased – until recently.

> **"Compared to tree-sourced rubber, the Russian dandelion is extremely resilient and can be grown in moderate climates on poor soils."**

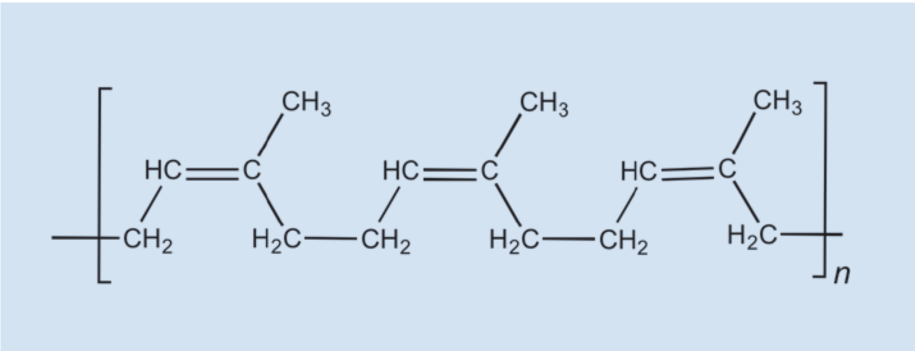
A replacement for natural rubber

Today, research into the Russian dandelion is growing. The Fraunhofer Institute for Molecular Biology and Applied Ecology[w1], based at the University of Münster, and the tyre company Continental[w2] are just two of the organisations working on using Russian dandelion as an alternative source of rubber.

Compared to tree-sourced rubber, the Russian dandelion is extremely resilient and can be grown in moderate climates on poor soils. This means that it can be grown locally, reducing dependence on imports. It is also much quicker to grow dandelions than trees – Russian dandelions can be harvested twice a year, whereas natural rubber trees take 7–10 years to mature before the sap, which is processed into rubber, can first be collected. What's more, the Russian dandelion produces inulin (a sugar substitute and potential biofuel) as a by-product.

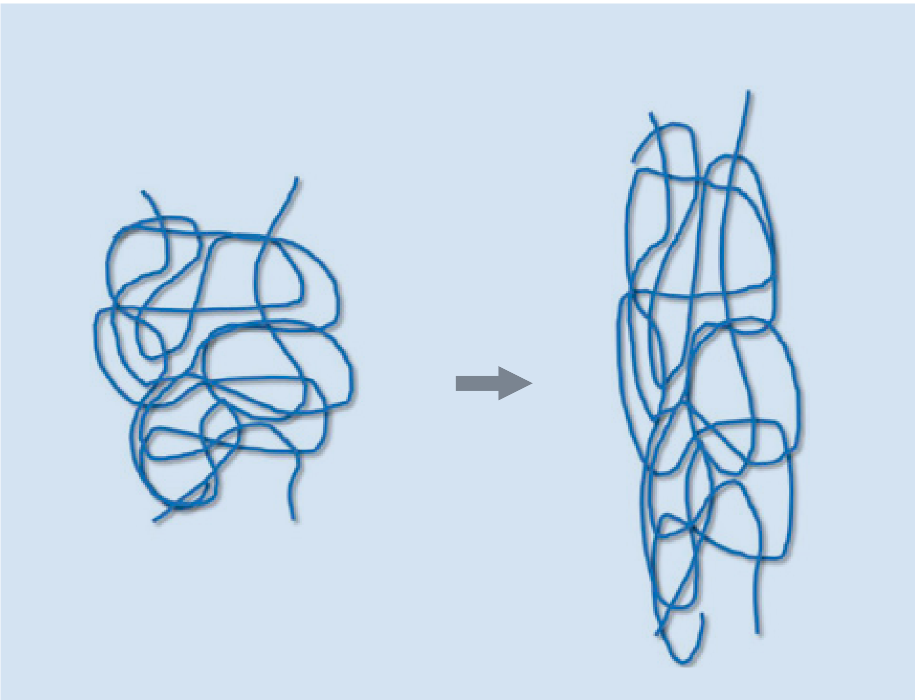
Structure and properties of rubber

Rubber is used in so many products because of its unique chemical and physical characteristics. An elastomer (a polymer with elastic properties, such as rubber) can be stretched to over 100% of its original length without breaking. Natural rubber consists of long chains of *cis*-1,4-polyisoprene (figure 1), each comprising up to 30 000 isoprene monomers. The chains are interwoven with one another like a plate of cooked spaghetti. When you stretch rubber, the chains are pulled apart but do not break, due to the linkages between the entangled chains (figure 2).



Smokefoot/Wikimedia Commons

Figure 1: Chemical structure of cis*-1,4-polyisoprene, the main constituent of natural rubber*



Mareike Göbel

Figure 2: Model showing the structure of rubber when relaxed (left) and stretched (right)

David Edelstein/Unsplash

The tyre industry is the biggest consumer of natural rubber.

Preparing the plant material

In preparation for the following activities, you will need to grow the Russian dandelion plant and harvest the roots to dry. The whole preparation process will take approximately seven months from February to September, but teachers could use this opportunity to teach students about plants and the requirements for growing them. Seeds can be purchased online[w3] and should be sown in February in a window-sill greenhouse. After two months, transfer the plants into flower boxes. You can harvest the roots from August onwards. To dry them, place the roots on paper towels and leave them at room temperature for 3–4 weeks.

Introductory activity

Before carrying out the two main activities, spark your students' interest with this starter activity introducing the topic of rubber and the Russian dandelion.

Procedure

1. Ask your students to list rubber products that they use in their everyday lives.
2. Show students a photo of the Russian dandelion and ask them to find the connection between the dandelion and the rubber products. To prompt them, ask where natural rubber usually comes from.
3. Give each student one dried Russian dandelion root. Instruct them to carefully break the root in half so they can see the very fine elastic rubber threads within the root (figure 3). Note that these threads can rip easily if the root is broken too forcefully.

Mareike Göbel

Figure 3: Breaking the Russian dandelion root reveals the net of white rubber threads.

Activity 1: Making a dandelion root eraser

In this activity, students physically extract rubber from dried Russian dandelion roots to produce a small eraser.

Materials

Each group of 3–4 students will need:

- 3–4 pieces of dried Russian dandelion root. Note: you should choose roots with a diameter of about 1 mm, and break them into pieces of about 2–3 cm in length.
- Pestle and mortar
- Tweezers
- Watch glass
- Water

Procedure

1. Place the dried dandelion roots into the mortar (figure 4). The greater the number of roots you have, the more time and effort is required to grind them.
2. Using the pestle, grind the roots for 5–10 minutes until they become a homogeneous powder (figure 5).
3. As you grind the roots, remove any small, globular brown particles in the mortar using tweezers, and place aside on the watch glass. These are the rubber particles.
4. Continue grinding the roots until no further brown particles are formed in the powder.
5. Wash out the mortar with some water to remove the woody powder. Place the rubber particles back into the mortar, which should still be slightly wet (figure 6).
6. Grind the rubber particles until they stick together (figure 7) and form a piece of rubber about 0.5–1 cm in length (figure 8).
7. You can now test the piece of rubber as an eraser. Students can merge the rubber from multiple groups to create a bigger eraser.

Mareike Göbel

Figure 4: Dried dandelion roots in the mortar

Figure 5: Dried roots are ground until they become a powder.

Mareike Göbel

Figure 6: Individual rubber particles

Figure 7: Individual rubber particles come together to form one piece of rubber.

Mareike Göbel

Figure 8: Grinding three pieces of dried rubber produces an eraser roughly 1 cm in length.

Activity 2: Refining the rubber threads

The rubber from fresh dandelion roots is an emulsion of polymer micro-particles, similar to the sap from a rubber tree. In the dried roots, however, the rubber is a solid aggregate. In this activity, students dissolve the outer, woody material of the dried roots to gain access to the inner net of rubber.

Materials

Each group of 3–4 students will need:

- 1–2 pieces of dried Russian dandelion root. Note: you should choose roots with a diameter of about 0.5 cm, and break them into pieces of about 3–4 cm in length.
- 5 ml of sodium hydroxide (NaOH) solution (3%)
- Test tube
- Water bath set to approximately 90 °C
- Tweezers

Safety note:

This procedure involves the use of sodium hydroxide solution. Students should wear lab coats and safety goggles. See also the general safety note on the *Science in School* website and at the end of this print issue.

Procedure

1. Place a piece of dandelion root in a test tube.
2. Cover the root with the sodium hydroxide solution.
3. Place the test tube in the water bath for about one hour. The colour of the sodium hydroxide solution will change from clear to brown, but the solution will remain transparent.
4. After one hour, remove the root from the test tube using tweezers. The root will now be soft.
5. Using tweezers, carefully wash the root by dipping it into the water from the water bath. The woody material of the root will wash away, but if needed, you should remove any remaining tissue using the tweezers until you are left with only the bright white net of fine rubber threads.
6. Gently extend the threads by pulling them apart (figure 9).

Mareike Göbel

Figure 9: Gently pulling the net of rubber threads apart highlights the elastic properties of rubber.

Discussion questions

Alongside the activities, discuss the following questions with your students to teach them about different types of rubber, the properties of rubber, and the importance of sustainability.

- What are the advantages and disadvantages of rubber from *Hevea brasiliensis* and synthetic rubber?
- Why is it important to look for alternative sources of rubber like the Russian dandelion?
- When you break a dandelion root in half, what can you see?
- What form does the rubber take in dried dandelion roots?
- What are the advantages and disadvantages of dandelion rubber?
- What are the properties of rubber? Explain its elasticity.

Extension activity

Seeing and experiencing the elasticity of rubber from the Russian dandelion is sufficient proof of natural rubber. To extend the activities, however, you could chemically detect the double bonds in polyisoprene, for example using bromine, potassium permanganate (Baeyer test) or the Burchfield colour reaction (see Göbel & Gröger, 2017).

References

Göbel M, Gröger M (2016) Kautschukforschung am russischen Löwenzahn in der Zeit um den Zweiten Weltkrieg. *Praxis der Naturwissenschaften – Chemie in der Schule* **8(65):** 19–22

Göbel M, Gröger M (2017) Alternative Kautschukquellen am Beispiel des russischen Löwenzahns experimentell erschließen. *Praxis der Naturwissenschaften – Chemie in der Schule* **2(66):** 26–30

Web references

w1 Understand how researchers are using Russian dandelion rubber as an environmentally friendly alternative to the natural rubber tree in this video from the Fraunhofer Institute. See: www.youtube.com/watch?v=bvVJL2GYRHY

w2 Learn how rubber from the Russian dandelion can be used to produce tyres in this video from the tyre company Continental. See: www.youtube.com/watch?v=H8XODAJAmmg

w3 Seeds of Russian dandelion, *Taraxacum kok-saghyz*, can be purchased from the All Good Things Organic Seeds website. See: www.plantgoodseed.com

Resources

Understand more about rubber and inulin production from the Russian dandelion in an article from Owlcation. See: https://owlcation.com/stem/Natural-Latex-and-Rubber-From-Common-and-Russian-Dandelions

Read about the European DRIVE4EU project, which is working to make Russian dandelion rubber a serious alternative to natural rubber. See: www.wur.nl/nl/nieuws/Rubber-from-Russian-dandelions-a-serious-European-alternative-to-rubber-tree-plantations.htm

The gene editing technique CRISPR-Cas9 has been used to increase the rubber content of Russian dandelion plants. Read more in an article from Chemical & Engineering News. See: https://cen.acs.org/articles/94/i30/Dandelions-scourge-lawns-fount-rubber.html

Mareike Göbel is a PhD student in Professor Dr Martin Gröger's Chemistry Didactics group at the University of Siegen, Germany. In her thesis, she develops experimental approaches for extracting rubber and inulin from the roots of Russian dandelion and tests and evaluates them with students.

FURTHER FANTASTIC FEATS

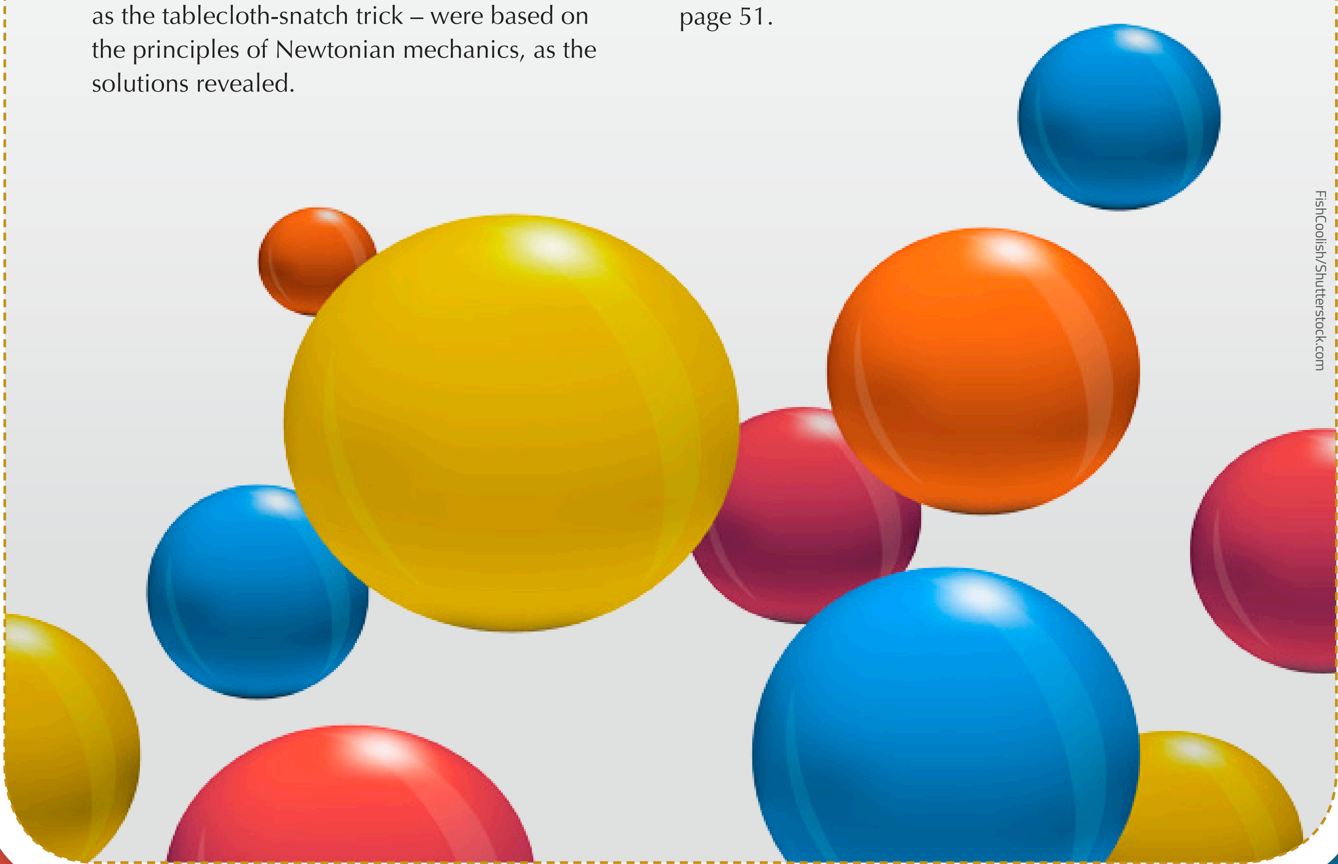
FALLING & BOUNCING

Roll up, roll up! We bring you some more fantastic feats to challenge and entertain – and to showcase some physics, too.

By David Featonby

In a previous article, I presented some intriguing tricks to try at home or in the classroom (Featonby, 2016). All the tricks – even familiar ones, such as the tablecloth-snatch trick – were based on the principles of Newtonian mechanics, as the solutions revealed.

Here, I present another selection of challenges that you'll be able to solve by applying some simple physics principles, as revealed in the solutions on page 51.



FishCoolish/Shutterstock.com

Feat 1: Tunnel ball

The challenge here – to make a ball bounce through a tunnel – may seem easy, but it's more difficult than it appears at first.

Materials

- One high-bounce rubber ball
- One heavy, large-format hardback book
- Two tall drinking glasses (or other similar-sized supports for the book)
- A table or other level surface

Procedure

Make a tunnel with the book lying across the drinking glasses (or other supports), as shown in figure 1.

The challenge is to try to make the ball bounce in the following way, forming a W-shaped path (figure 2):

- First bounce: in front of the tunnel
- Second bounce: on the underside of the tunnel (book)
- Third bounce: outside the tunnel

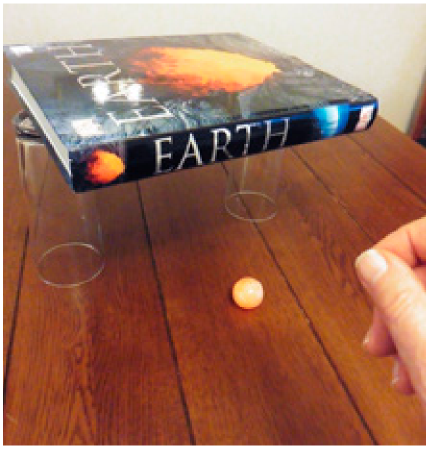
It comes as a surprise to most people that the ball does not follow a W-shaped path, but usually returns to the sender as if it has struck a reflecting wall in the tunnel.

So how can you make the ball pass through the tunnel as required? And can you explain what's going on?

This feat can be performed using different-sized tunnels – for example, a table with a flat underside (with the floor as the lower surface).

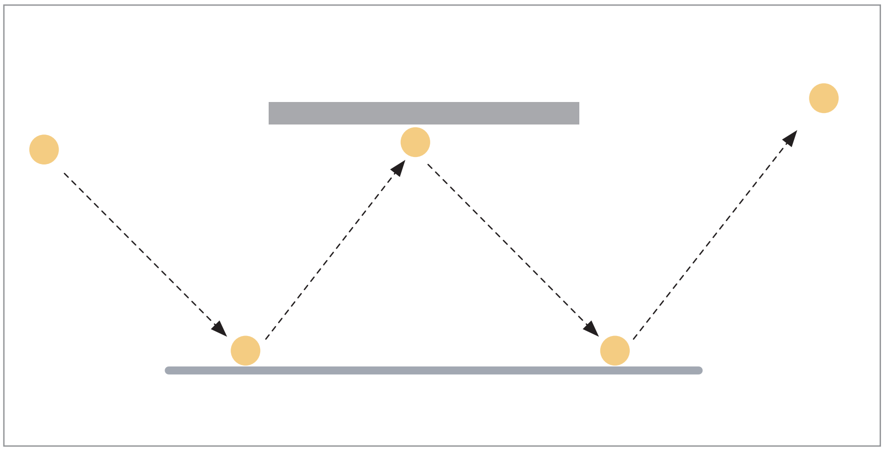
Feat 2: Cork bounce

Here, the trick is quite easy to do; the challenge is to explain why it works.



David Featonby

Figure 1: Tunnel arrangement formed by a book and two glasses



David Featonby/Nicola Graf

Figure 2: How the ball should bounce through the tunnel: the challenge is to make it follow this path.

REVIEW

- ✓ Physics
- ✓ Engineering
- ✓ Mechanics
- ✓ Dynamics
- ✓ Ages 11–16

This article describes some simple but enjoyable experiments that illustrate important principles of mechanics and dynamics. It shows how bouncing balls or cylindrical objects move, depending on their spin or applied forces, and how this movement depends on friction and other factors. These experiments are simple to perform, and show interesting effects.

The article could also be used as a comprehension exercise.

Questions could include:

- How does spin affect the movement of a ball?
- Does spin depend on the type of surface?
- How do spin and friction depend on each other?
- What applications are connected to the experiments described in the article?

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

Materials

- One standard wine-bottle cork, preferably made from real cork
- A table or other level surface

Procedure

1. Hold the cork about 10 cm above the table.
2. Try to drop the cork so that it lands standing on one end (figure 3). How should you hold the cork before you drop it to achieve this result? And can you explain why?

Once you've mastered this feat and worked out how best to drop the cork to make it bounce upright, you can try it with other cylindrical objects – such as the cardboard inner tube of a toilet roll, or any slightly flexible tube.

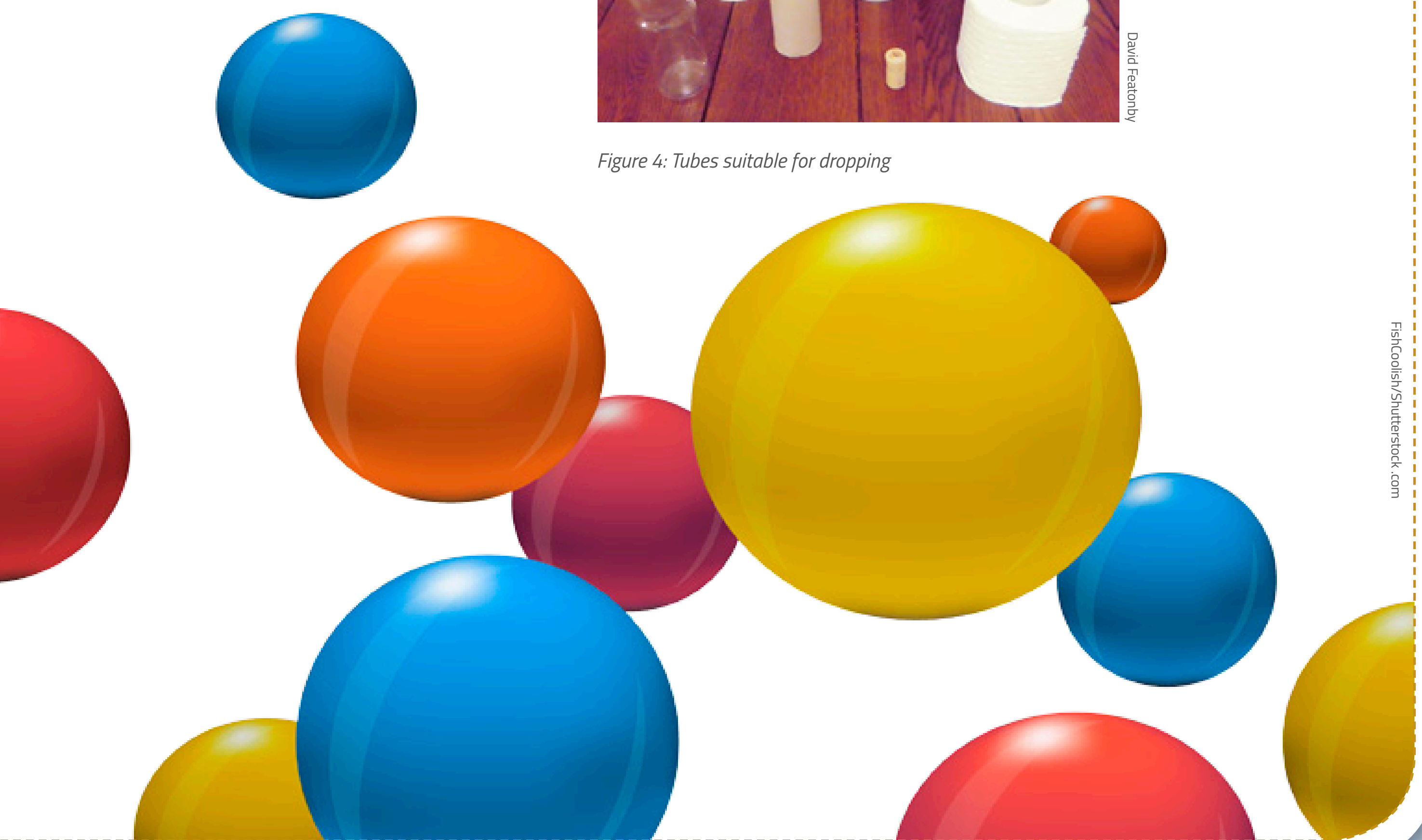
In fact, this challenge is easier with the toilet roll tube than with the cork. And there are plenty more tube-shaped items you can try this with: all the objects shown in figure 4 were successfully bounced into a vertical standing position.

David Featonby

Figure 3: Cork standing upright after being dropped

David Featonby

Figure 4: Tubes suitable for dropping



FishCoolish/Shutterstock.com

Feat 3: Card drop

The aim of this challenge is to find a reliable way to drop a playing card into a hat, from a height of about 1.5 m.

Materials

- Some standard-sized playing cards
- A hat with a crown that keeps its shape when placed upside down, or a similar-sized bowl, box or other open container
- A table or other level surface

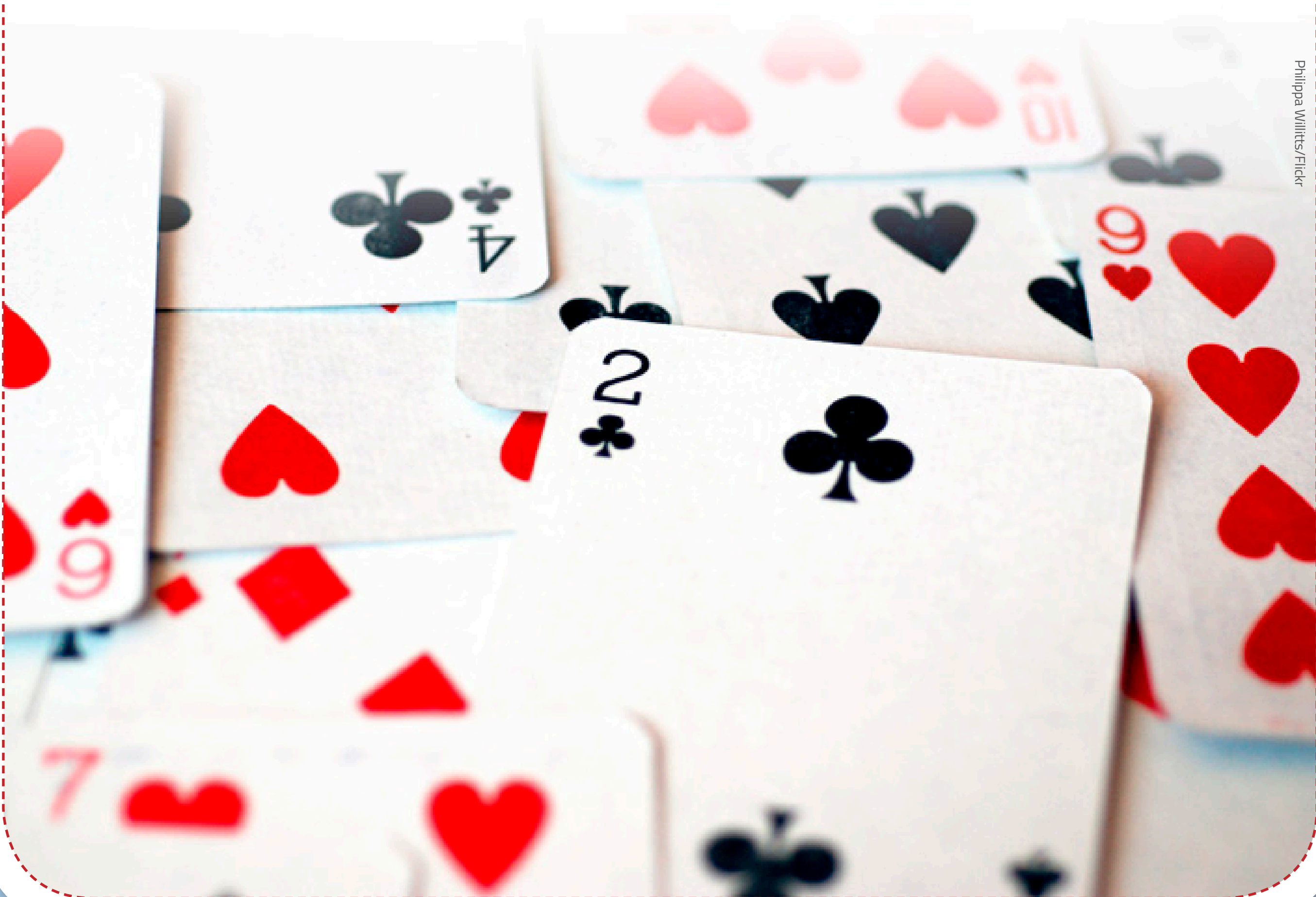
Procedure

1. Place the hat upside down on the table.
2. Take a card and hold it about 1.5 m above the hat (figure 5).
3. Try to drop the card so that it lands inside the hat. How should you hold the card before you drop it to achieve this result? And can you explain why?

David Featonby

Figure 5: Attempting to drop a playing card into an upturned hat. As you can see from the photograph, this is not as simple as it seems.

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



Philippa Willitts/Flickr

The chemical chameleon demonstration produces vivid colour changes as a result of redox reactions.

IanRedding/Shutterstock.com

Colourful chemistry: redox reactions with lollipops

Use a lollipop to activate colour-changing redox reactions in this simple but eye-catching activity.

By Marisa Prolongo and Gabriel Pinto

Teaching oxidation-reduction (redox) reactions is part of all secondary-school chemistry curricula. In this article, we describe a vivid colour-changing demonstration to illustrate a chain of redox reactions, whereby electrons are transferred between different compounds and ions. The activity is suitable as a teacher demonstration, or older students could carry out the experiment themselves.

Oxidising and reducing agents

A redox reaction is any chemical reaction in which a molecule, atom or ion loses or gains electrons, altering its oxidation state. An oxidising agent gains electrons (and is reduced in the reaction) and a reducing agent loses electrons (and is oxidised in the reaction). In this experiment, glucose from a lollipop is used as the reducing agent. When glucose is added to a solution containing OH^- ions, the alcohol groups in the glucose donate electrons, giving rise to ketone groups:

$$\underset{\text{(secondary alcohol)}}{-C(H)(OH)- + 2OH^-} \rightarrow \underset{\text{(ketone group)}}{-C(=O)-} + 2H_2O + 2e^-$$

In our experiment, glucose is added to a permanganate solution together with sodium hydroxide (NaOH), so electrons from glucose ($C_6H_{12}O_6$) are first donated to permanganate ions (MnO_4^-). The oxidation products of the reducing sugar are mainly glucuronic acid ($C_6H_{10}O_7$), plus some arabinonic acid ($C_5H_{10}O_6$) and formic acid (CH_2O_2). If the lollipop is made from fructose, which is an isomer of glucose, the main product is fructonic acid (also $C_6H_{10}O_7$).

In a series of redox reactions, electrons are donated continually from glucose to successive compounds of manganese. At each step in the chain, a colour change is visible. Manganese is ideal for this experiment, as it has more stable oxidation states than any other transition metal (from +2 to +7), each of which has a different colour.

You may be familiar with the classic 'chemical chameleon' demonstration[w1], of which this experiment is an adaptation. In the original version, you begin with a potassium permanganate and glucose solution, which changes colour upon mixing with a spatula. By using a lollipop instead, the glucose is added more gradually to the solution, which makes it easier to follow the colour changes. Using a miniature electric whisk means the lollipop is stirred faster than by hand.

Marisa Prolongo

Figure 1: Materials required for the lollipop experiment

REVIEW

✓ Chemistry

✓ Redox reactions

✓ Ages 16–19

The redox chemistry of manganese is a fascinating aspect of transition metal chemistry. This simple practical exercise helps students to familiarise themselves with the variable oxidation states of manganese and their respective colours.

Observing the different colours will elicit discussion and will be a point of focus for understanding what is happening in the redox steps in the reaction.

Andrew Galea, chemistry lecturer, Giovanni Curmi Higher Secondary School, Malta

Materials

You will need the following materials (see figure 1):

- Potassium permanganate ($KMnO_4$) crystals
- Spherical lollipop containing glucose (or other reducing sugar, e.g. fructose)
- 3–4 sodium hydroxide (NaOH) pellets (approximately 0.5 g)
- 200 ml distilled water
- 250 ml conical flask or beaker (glass or plastic)
- Spoon and spatula
- Miniature electric whisk, e.g. hand-held milk frother
- Adhesive tape

Safety note:

A lab coat, gloves and safety goggles should be worn. Teachers should follow their local health and safety rules, in particular concerning the use of potassium permanganate and the disposal of the resulting solution. See also the general safety note on the *Science in School* website and at the end of this print issue.

Procedure

The activity is suitable for a single lesson. The experiment takes only about 15 minutes and can be followed up by a set of discussion questions.

The steps are as follows:

1. Fill the flask or beaker with 200 ml of distilled water.
2. Stir in the NaOH pellets with the spoon until they have dissolved completely.
3. Using the spatula, add a few potassium permanganate crystals (not too many, or the colour will be too dark to see the changes). When potassium permanganate ($KMnO_4$) is added to the alkaline NaOH solution, it dissolves into potassium (K^+) and permanganate (MnO_4^-) ions.
4. Attach the stick of the unwrapped lollipop to the mini electric whisk using adhesive tape (see figure 1).
5. Insert the lollipop into the solution and switch on the whisk to start mixing.

As the lollipop dissolves into the solution, you will observe colour changes for each redox reaction. The first two changes happen very rapidly (3–5 seconds), while further changes take a little longer. Students can take photos (e.g. with the camera of a mobile phone) at various time points to better compare and follow the changes in colour. A video from the authors demonstrating the experiment is available in Spanish[w2].

What happens in the experiment?

As the lollipop dissolves in the solution containing manganese ions, at least five different colours can be distinguished (as shown in figures 2–6), which correspond to different oxidation states of manganese.

1. The first colour (purple) corresponds to permanganate ions (MnO_4^-). Manganese has the oxidation state +7 (figure 2).
2. The permanganate ions (MnO_4^-) are then reduced to manganate ions (MnO_4^{2-}). The oxidation state of manganese changes from +7 to +6, and the colour changes from purple to green (figure 4).

   $MnO_4^-(aq)$ (purple) + e^-
   $\rightarrow MnO_4^{2-}(aq)$ (green)

   An intermediate blue stage occurs between steps 1 and 2 (figure 3). One explanation is that the mixture contains both the purple permanganate (MnO_4^-) and the green manganate ions (MnO_4^{2-}), which combine to produce a blue solution. Another explanation is that a part of permanganate is reduced to hypomanganate (MnO_4^{3-}), which has an oxidation state of +5 and a blue colour.

   $MnO_4^-(aq)$ (purple) + $2e^-$
   $\rightarrow MnO_4^{3-}(aq)$ (blue)

3. The manganate ions (MnO_4^{2-}), which have an oxidation state of +6, are further reduced to manganese dioxide (MnO_2), with an oxidation state of +4, causing a colour change from green to yellow-brown (figure 5).

   $MnO_4^{2-}(aq)$ (green) + $2\ H_2O(l)$ + $2e^-$
   $\rightarrow\ MnO_2(s) + 4OH^-(aq)$
   (yellow-brown)

4. Finally, when even more glucose is incorporated into the solution, brown-black manganese dioxide (MnO_2) forms a colloidal suspension in alkaline solution, which (if fairly dilute) can appear orange (figure 6).

Figure 2: The first colour in the chain of redox reactions is purple, which corresponds to the permanganate ions.

Figure 3: Before the colour changes from purple to green, there is a blue intermediate stage.

Figure 4: Permanganate ions are reduced to manganate ions, resulting in a colour change to green.

Figure 5: Manganate ions are reduced to manganese dioxide, causing the colour to change from green to yellow-brown.

Figure 6: The final colour change is to orange, when manganese dioxide forms a colloidal suspension in the alkaline solution.

Marisa Prolongo

Variations in colour

The food colours used in lollipops do not have a big impact on the colours you see in this experiment, but some other factors do play a role. Once the reactions start, there are always mixtures of ions in the solution, resulting in mixtures of colours that are not always easy to interpret (see figure 7).

Another factor is that the colour of manganese ions in solution is generally different from the colour of their corresponding solid salts. This is because manganese ions form complexes with water due to the electron-accepting capacity of their atomic d-orbitals. In addition, the tendency for molecules to accept electrons varies with pH and temperature, so if you change these variables or the quantities of the chemicals, the colours will vary, and the colour changes will occur at different times between experiments.

Discussion

To link the lollipop demonstration to the chemistry of redox reactions, ask your students some of the following questions:

- In the experiment, what is the reducing agent that donates electrons in the redox reactions?

  This depends on which reducing sugar you use, but in our experiment, the reducing agent is glucose ($C_6H_{12}O_6$).
- What is the oxidising agent that accepts the electrons?

  The first oxidising agent in the reaction is the permanganate ions. After that, electrons are donated to manganate ions.
- Does potassium permanganate in solution absorb the part of visible light that corresponds to the colour we see (green) or to its complementary colour (red)?

  Potassium permanganate absorbs electromagnetic radiation from the red part of the visible spectrum, but what we see as the colour of manganate ions is the complementary colour, green.

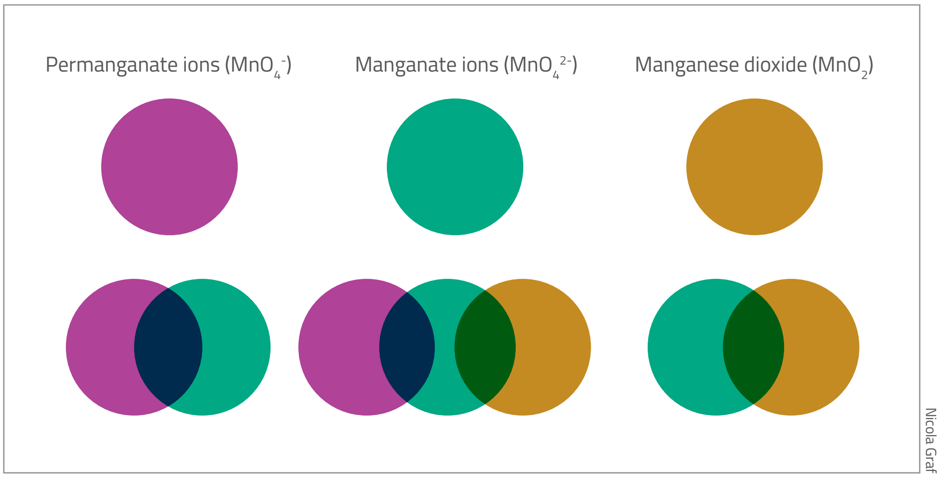


Figure 7: Colours of the three main manganese compounds (top row) and example mixtures of these compounds as the redox reactions proceed (bottom row)

BACKGROUND

Electron configuration and transition metals

Electrons are arranged in energy levels called shells. Each shell is divided into subshells, which are made up of orbitals. Transition metals have one or more electrons in their outermost d-orbital. The difference in energy between individual d-orbital electrons is relatively small, so all transition metal cations have a variety of ways of forming chemical bonds involving different numbers of d-orbital electrons. This is why transition metals have several oxidation states.

When electrons absorb certain frequencies of electromagnetic radiation, they jump to a higher energy level. In many transition metals, the difference in energy between d-orbitals corresponds to the energy of radiation of the visible light spectrum. For example, the d-orbital electrons of permanganate ions absorb electromagnetic radiation from the yellow part of the visible spectrum, but what we see as the colour of permanganate ions is the colour complementary to yellow – that is, purple. We see the colour of the remaining wavelengths that were not absorbed (figure 8).

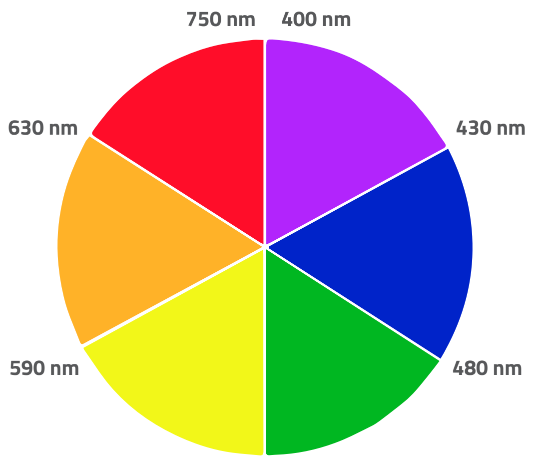


Figure 8: The colour of the solution is the colour that is complementary (i.e. opposite on the colour wheel) to the wavelength of light absorbed by d-orbital electrons.

- Do you know of any other chemical elements that show different colours in different oxidation states in solution?

  Examples include: chromium ($Cr_2O_7^{2-}$, orange; CrO_4^{2-}, yellow) and vanadium (V^{2+}, violet; V^{3+}, green; VO^{2+}, blue; VO_4^{3-}, yellow)
- What are the main uses of manganese, for example in biology or industry?

  Manganese compounds are used in stainless steels and batteries, and as fuel additives and pigments. Manganese is also an essential cofactor for many enzymes, such as photosystem II in chloroplasts. However, in large amounts it is toxic to humans.

Variations of the experiment

This experiment can be performed in a number of different ways. For example, rather than using a lollipop, you could use a chewing gum containing sugar as the reducing agent; or instead of adding the glucose to a flask, you could add it to a plastic bottle and shake it to observe the colour changes (see figure 9). Your students could use their creativity to think of alternative experiments.

Acknowledgements

This article is based on a presentation at the Spanish Science on Stage festival (Ciencia en Acción) in 2014. This work was first carried out by students at IES Manuel Romero Secondary School in Málaga, Spain. We are grateful for the support of the Technical University of Madrid (Universidad Politécnica de Madrid) for the projects 'Promotion of experimental learning of chemistry' and 'Chem-Innova', and of the Spanish Royal Society of Chemistry (Real Sociedad Española de Química, RSEQ).

Web references

w1 For variations of the experiment, visit the Science Brothers website and the Hobby Chemistry website. See: www.sciencebrothers.org/the-chemical-chameleon/ and https://hobbychemistry.wordpress.com/2015/03/31/chemical-chameleon/

w2 A video of the experiment is available in Spanish on YouTube and the IES Manuel Romero Secondary School website. See: www.youtube.com/watch?v=1pE3U7Uklqc or http://iesmanuelromero.es/index.php/es/noticias/132-noticias-curso-2013-14/519-experimentos-de-ciencias

Resources

For ideas on introducing redox reactions using everyday examples, see:

Voak H (2016) Redox resources. *Science in School* **36**. www.scienceinschool.org/content/redox-resources

To try a colour-change experiment involving pH-sensitive plant dyes, see:

Shimamoto GG, Vitorino Rossi A (2005) An artistic introduction to anthocyanin inks. *Science in School* **31**: 32–36. www.scienceinschool.org/content/artistic-introduction-anthocyanin-inks

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Marisa and Gabriel are Scientix ambassadors and have taken part in many national and international science festivals and workshops presenting experiments for STEM education.

Marisa Prolongo

Figure 9: An alternative experimental setup using chewing gum and a plastic bottle

Saving the Earth Hollywood-style

Challenge your students to save the Earth from an asteroid collision, using calculations based on the Hollywood sci-fi fantasy film Armageddon.

By Mike Follows

What would students prefer to discuss: Hollywood films or physics? In my physics classes, I try to combine these topics by using scenarios from Hollywood sci-fi films as a source of problem-solving exercises – in a similar way to using the adventures of superhero characters (see Follows, 2017). Even if students have not seen the films, they seem to enjoy engaging with the inventive and fantastical scenarios, which they can use as a basis for doing real science – as long as the ideas and assumptions are set out clearly.

In this article, I present some exercises based on the film Armageddon (1998) – a Hollywood movie about a heroic mission to save the Earth from a giant asteroid heading straight towards it. The film was criticised for being rather unrealistic, but it still offers an interesting plot to use as a basis for calculations.

Armageddon: the story

In the film, astronomers spot an asteroid the size of Texas heading towards Earth when it is only 18 days away from impact. A plan is devised to detonate a nuclear warhead beneath the surface of the asteroid, to split it into two equal halves along a fault line. The two halves would then move apart – and miss the Earth. To execute the plan, NASA flies oil-driller Harry Stamper (Bruce Willis) and his team to the asteroid on board two space shuttles, which perform a slingshot around the Moon and come up behind the asteroid. Once they reach the asteroid, to avert disaster they must detonate the bomb before the asteroid reaches 'zero barrier', a point reached eight hours after the asteroid passes the Moon.

geralt/pixabay.com

Creating a classroom activity

Students can carry out a variety of calculations based on the information in the film, supplemented by some reasonable assumptions. The fun lies in seeing whether the quantities and assumptions in the film make sense – or not.

From the film, we know that:

- The asteroid is 'the size of Texas'. Let's assume that this refers to the cross-sectional area through the centre of the approximately spherical asteroid.
- The asteroid is heading towards Earth at a speed of 22 000 miles per hour.
- Each half of the asteroid misses the Earth's surface by 400 miles (640 km).

The other information we need is as follows:

- Texas has an area of 696 200 km^2.
- The average density of the four largest known asteroids is 2760 kg m^{-3}. (For comparison, the Earth has a density of 5520 kg m^{-3}.)
- The distance of the Moon from Earth is 384 400 km.
- Earth has a radius of 6400 km.
- The energy of a nuclear warhead is up to 50 megatons of TNT. (This is the energy of the most powerful thermonuclear weapon known: the Soviet warhead called Big Ivan.)
- 1 megaton of TNT is 4.18×10^{15} J

Let's also assume that:

- The asteroid is heading for the centre of the Earth, so that both halves of the asteroid need to move 'sideways' by the same distance.

Student questions and worked calculations

Students are asked to investigate whether the plan is likely to succeed in saving Earth from the collision. This can be done as a sequence of calculations, as set out below. Students work in groups, and are encouraged to discuss the way forward with each other.

1. Show that the asteroid has a radius of 470.8 km.

We assume that the approximately circular cross-section of the asteroid has an area A equal to that of Texas, i.e. approximately 696 200 km^2.

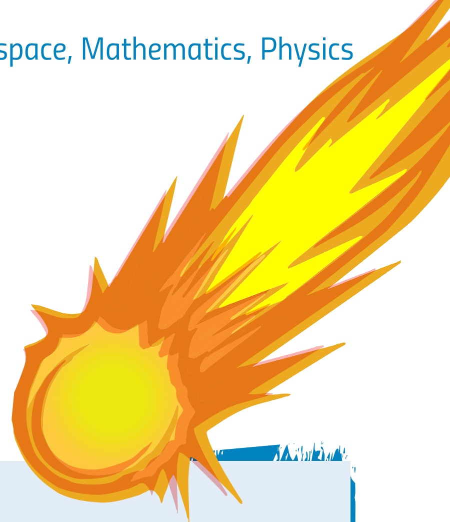
$A = \pi r^2$ where r = radius of asteroid.

So:

$$r = \sqrt{\frac{A}{\pi}}$$

$$= \sqrt{\frac{696\ 200\ \text{km}}{\pi}}$$

$$= 470.8\ \text{km}$$



REVIEW

✓ Astronomy

✓ Linear motion

✓ Ages 14–19

This activity is very interesting and fun for students. What better way to trigger students' curiosity and to prompt them to think creatively? Verifying or disproving facts derived from fictional films allows students to generate their own questions about them, and to think of how these questions can be answered by applying their knowledge of physics and mathematics. No matter how surreal some scenes in these films are, there will always be a scientific principle that can help explain their possibility or impossibility.

The use of science to explain fictional movies can also lead to some very elaborate discussions when students think about the facts stated in films and do not just take them for granted. Students can be motivated to expand their area of research as needed, and to back up their arguments with mathematical evidence.

This exercise can also make students aware that science facts are everywhere, in real life as well as in fiction.

Catherine Cutajar, physics lecturer, St Martin's College, Malta

2. At what speed is the asteroid travelling in metric units (i.e. in m s⁻¹)?

Encourage the students to perform the change of units formally:

22 000 miles per hour (mph)

$= 22000 \times \frac{1609 \text{ m}}{3600 \text{ s}}$

$= 9833 \text{ m s}^{-1}$

3. How far from Earth is 'zero barrier'?

To answer this question, we first need to work out how far the asteroid would travel in eight hours, as the 'zero barrier' is a distance equal to eight hours travel from the Moon:

Distance = speed x time

$= 9833 \text{ m s}^{-1} \times 8 \times 3600 \text{ s}$

$= 2.83 \times 10^8 \text{ m}$

Then, we subtract this distance from the overall Earth–Moon distance (3.84×10^8 m) to calculate how much further the asteroid would need to travel to collide with the Earth.

$3.84 \times 10^8 \text{ m} - 2.83 \times 10^8 \text{ m}$
$= 1.01 \times 10^8 \text{ m}$

4. How fast do the two pieces of the asteroid need to move apart to avoid impact with Earth?

The two halves of the asteroid must travel 1.01×10^8 m from the zero barrier to reach Earth. In the time this takes, each half-asteroid must also move in a direction perpendicular to the original direction of travel, far enough to miss the Earth by at least 640 km on each side (see figure 1).

Here:

D = distance between zero barrier and Earth

R = radius of the Earth plus the 640 km by which each half misses the Earth

v_1 = speed of the asteroid moving towards Earth

v_2 = perpendicular (sideways) speed of each half-asteroid needed to miss the Earth with a margin of 640 km

The speed v_2 can be calculated in two ways.

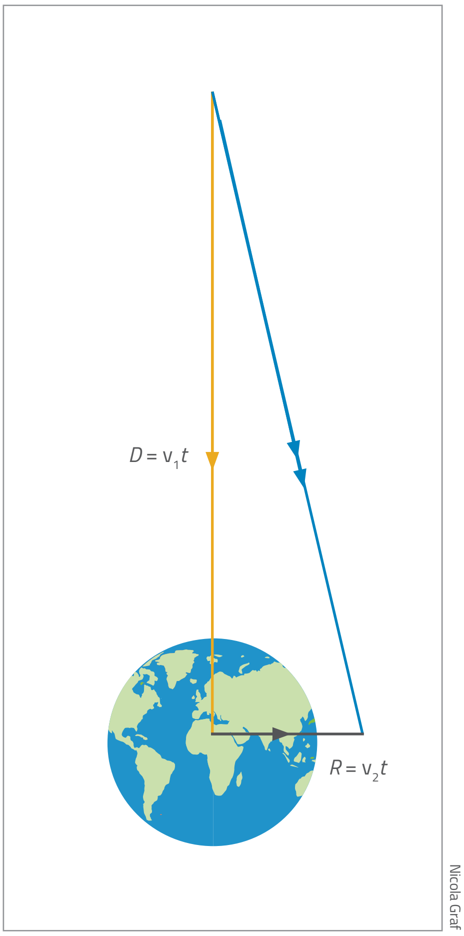


Figure 1 (not to scale): The yellow line shows the asteroid's original direction of travel. The black line shows how far one half of the asteroid has to move to miss the Earth by 640 km; the blue line shows the resultant path that the half-asteroid needs to take.

Method 1

First, we calculate how long it would take (time t) for the asteroid to travel from the zero barrier to Earth:

$t = \frac{D}{v_1}$

$= \frac{1.01 \times 10^8 \text{ m}}{9.83 \times 10^3 \text{ m s}^{-1}}$

$= 10\,274.7 \text{ s}$

$= 171.2$ min, or 2 h 51 min

We can now work out the speed that each half of the asteroid needs to move in a direction perpendicular to its original path to miss the Earth with a margin of 640 km.

$v_2 = \frac{R}{t}$

$= \frac{(6400 + 640) \times 10^3}{10\,274.7 \text{ s}}$

$= 685 \text{ m s}^{-1}$

Method 2

For those students who are more confident with maths, we can use proportionality. As in the method above, in the time t that it takes the asteroid to travel 101 000 km to Earth, the two pieces must move apart by a distance equivalent to the radius of the Earth plus 640 km, R. So using algebra:

$t = \frac{s}{u} = \frac{D}{v_1} = \frac{R}{v_2}$

so $v_2 = v_1 \frac{R}{D}$

$= \frac{9.83 \times 10^3 \text{ m s}^{-1} \times (6400 + 640) \times 10^3 \text{ m}}{1.01 \times 10^8 \text{ m}}$

$= 685 \text{ m s}^{-1}$

$\text{time} = \frac{\text{distance}}{\text{speed}}$

so $= \frac{D}{v_1} = \frac{R}{v_2}$

Rearranging for v_2 gives:

$v_2 = v_1 \frac{R}{D}$

$= \frac{9.83 \times 10^3 \text{ m s}^{-1} \times (6400 + 640) \times 10^3 \text{ m}}{1.01 \times 10^8 \text{ m}}$

$= 685 \text{ m s}^{-1}$

5. What is the mass of the asteroid (assuming it has a density typical of asteroids)?

The mass m is equal to density ρ times volume V, so $m = \rho \times V$

The asteroid is approximately spherical, so $V = \frac{4}{3} \pi R^3$

From question 1, R = 470.8 km

So $M = \rho \pi R^3$

$= 2760 \text{ kg m}^{-3} \times \frac{4}{3} \pi \times (4.71 \times 10^5 \text{ m})^3$

$= 1.21 \times 10^{21} \text{ kg}$

6. How much kinetic energy must be given to the two halves of the asteroid to prevent a collision with Earth?

Note: you will get the same answer whether the asteroid is treated as one lump or two separate pieces.

$E = \frac{1}{2} mv^2$

$= \frac{1}{2} \times 1.2 \times 10^{21} \text{ kg} \times (685 \text{ m s}^{-1})^2$

$= 2.84 \times 10^{26} \text{ J}$

7. How many nuclear weapons of the same size as Big Ivan would be needed to provide this energy?

One Big Ivan is equivalent to 50 megatons of TNT

$= 50 \times 4.18 \times 10^{15}$ J

$= 2.09 \times 10^{17}$ J

So the energy required to change the path of the asteroid sufficiently to miss the Earth is equivalent to:

$$\frac{2.84 \times 10^{26}\ \text{J}}{2.09 \times 10^{17}\ \text{J}} = 1.36 \times 10^{9}\ \text{Big Ivans}$$

8. How fast will the two halves of the asteroid move apart if only one Big Ivan bomb is used?

$$E = \frac{1}{2} mv^2$$

$$\text{so } v = \sqrt{\frac{2E}{m}}$$

$$= \sqrt{\frac{2 \times 2.09 \times 10^{17}}{1.21 \times 10^{21}}}$$

$= 1.85 \times 10^{2}$ m s^{-1}

= about 2 cm s^{-1}

9. How far apart will the two halves be when they collide with Earth, if only one Big Ivan bomb is used?

We have already shown (in question 4) that at the zero barrier, the asteroid is less than three hours away from impact. At a speed of 1.85×10^{2} m s^{-1} (question 8), in that time each half of the asteroid will have moved 190 m away from its original path, so that the two halves will have moved apart by less than 400 m – far too little to avoid a collision with Earth. In fact, under the circumstances described in the film, the team would need to intercept the asteroid when it was some 3.74×10^{12} km away – 25 times the distance of the Sun from Earth, out in space between Uranus and Neptune.

Which all goes to show that there are times when you need something even bigger than a nuclear explosion to make things happen.

Jack W. Aeby (public domain)/Wikimedia Commons

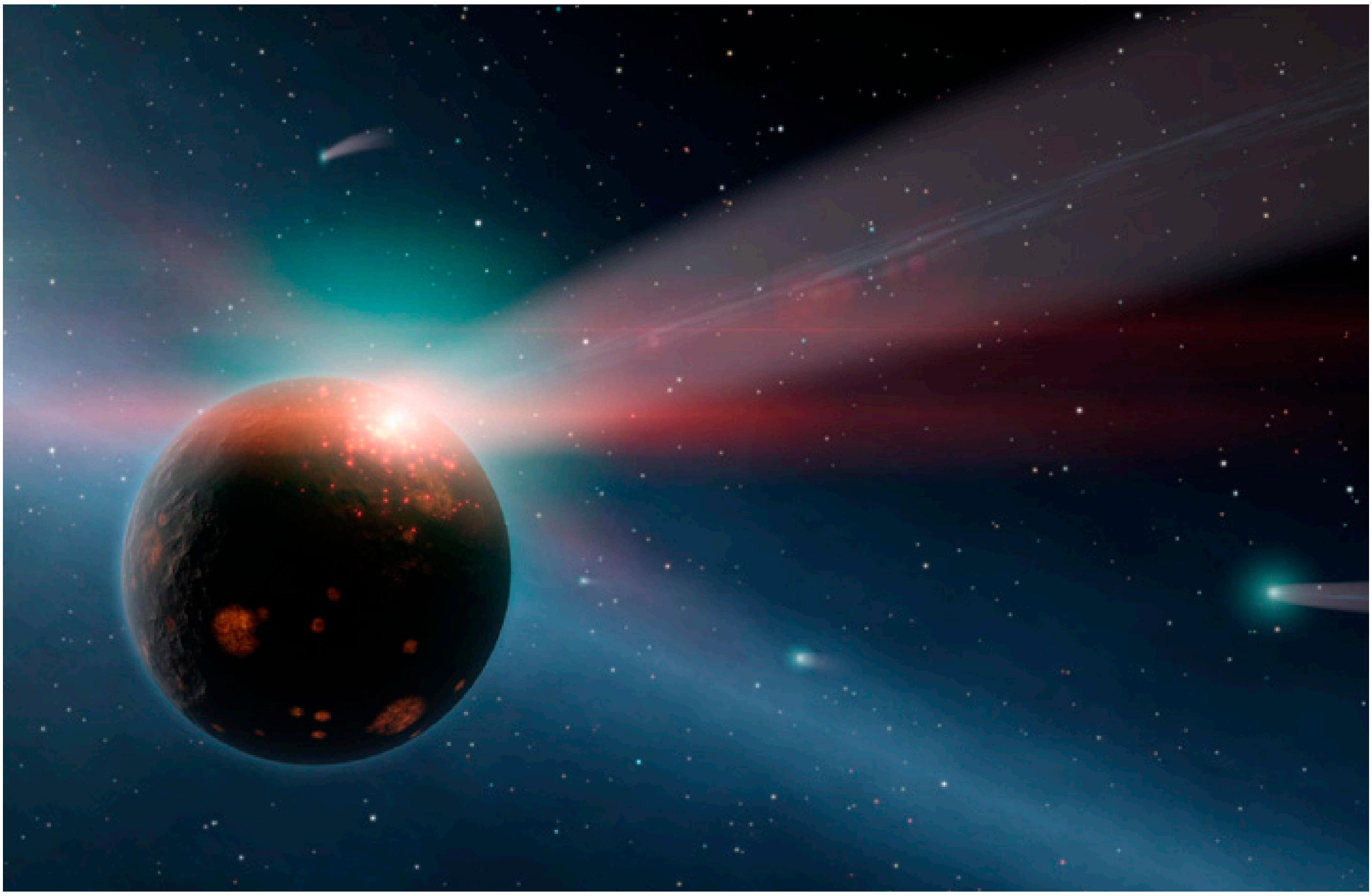
The first nuclear explosion: the Trinity test at Los Alamos, USA on 16 July 1945

Discussion

There is plenty more here to discuss with students, after or alongside the calculations. Students may well have their own thoughts on how to make the scenario more realistic – and on which outcomes or assumptions are the most absurd. For example, why did the scientists fail to spot the asteroid until it was so close? And despite this failure, how did they work out that it had a fault line running through it, exactly along the direction of travel?

Here are some suggestions of other points to consider:

- The calculations did not include the energy required to break the chemical bonds to split the asteroid in two: it included only the energy required to move the two halves apart, assuming that the asteroid was already conveniently fractured. If we added the energy needed to fracture the asteroid, by how much would this affect the calculations?
- If the asteroid were to hit the Earth, what would be the energy of the impact? Students can work this out from the kinetic energy of the asteroid. They will find that its impact with the Earth would release 5.8×10^{28} J – equivalent to 276 billion (2.76×10^{11}) Big Ivans. For comparison, the asteroid that marked the end of the Cretaceous (and the demise of the dinosaurs) 65 million years ago is estimated to have released only about 4×10^{23} J (2 million Big Ivans).
- Students can investigate real-life objects that might strike the Earth, and find out how typical the asteroid



Planet in peril? Imaginative image of a planet with nearby comets and asteroids

in Armageddon is for asteroids generally. At 9833 m s^{-1}, its speed is somewhat slower than asteroids on average, which have a mean velocity of 25 000 m s^{-1}. (For comparison, Halley's comet has a velocity of 53 600 m s^{-1} when it is closest to the Sun, at perihelion.) NASA's NEO[w1] (near-Earth object) programme searches for and tracks objects that might strike the Earth: one candidate is asteroid (29075) 1950 DA, which has a diameter of about 1 km. Its chances of hitting the Earth in 2880 is currently estimated to be 1 in 300.

Reference

Follows M (2017) Heroes and villains: the science of superheroes. *Science in School* **40**: 57-63. www.scienceinschool.org/content/heroes-and-villains-science-superheroes

Web reference

w1 To read the latest news stories from the Center for Near Earth Object Studies, visit the NASA website. See: https://cneos.jpl.nasa.gov

Resources

Read about the 'good' and 'bad' science in Armageddon by visiting the Bad Astronomy website. See: www.badastronomy.com/bad/movies/armpitageddon.html

For information on asteroids and comets, visit Bill Arnett's very comprehensive Nine Planets website. See: http://nineplanets.org/smallbodies.html

Watch a TED talk explaining how we could defend the Earth from asteroids on the TED website. See: www.ted.com/talks/phil_plait_how_to_defend_earth_from_asteroids

The Spaceguard Centre (located in Knighton, Powys, UK) provides information about the threat of asteroid and comet impacts, and the ways in which we can predict and deal with them. For more information, visit their website. See: https://spaceguardcentre.com

The Views of the Solar System website offers a catalogue of terrestrial impact craters. See: http://solarviews.com/eng/tercrate.htm

For other critiques and explorations of science in the movies, see the following books:

Rogers T (2007) *Insultingly Stupid Movie Physics*. Naperville, IL, USA: Sourcebooks Hysteria. ISBN: 1402210337

Perkowitz S (2010) *Hollywood Science: Movies, Science, and the End of the World.* New York, USA: Columbia University Press. ISBN: 0231142811

Weiner A (2007) *Don't Try This at Home! The Physics of Hollywood Movies.* New York, USA: Kaplan Publishing. ISBN: 1419594060

Edwards R, Brooks M (2017) *Science(ish): The Peculiar Science Behind the Movies*. London, UK: Atlantic Books. ISBN: 1786492210

Mike Follows is acting head of physics at King Edward's School in Birmingham, UK. He has a PhD in ultralow-temperature physics, and he enjoys developing interesting ways of teaching physics to students, including finding unusual contexts (such as science fiction movies). He is also drawn to global issues and how physics helps to explain them – and might help solve them.

FURTHER FANTASTIC FEATS

SOLUTIONS TO THE CHALLENGES ON PAGE 37

ON PAGE 37

Feat 1: Tunnel ball

The reason that the ball usually bounces back towards the thrower, rather than continuing forward, is explained by one word: spin.

The spin can be seen most easily using a ball with markings on it, such as a basketball. If you throw a basketball at an angle to the ground, after bouncing it immediately starts to spin. This is due to friction between the ball and the ground (see figure 1).

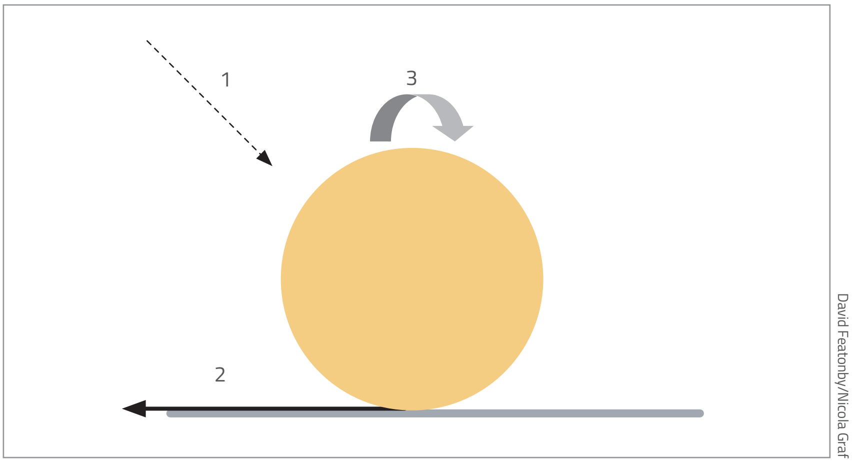


Figure 1: The ball's first bounce, showing the spin directions. 1: the ball's initial direction of travel; 2: friction acts on one side of the ball only, producing spin; 3: the resulting direction of spin

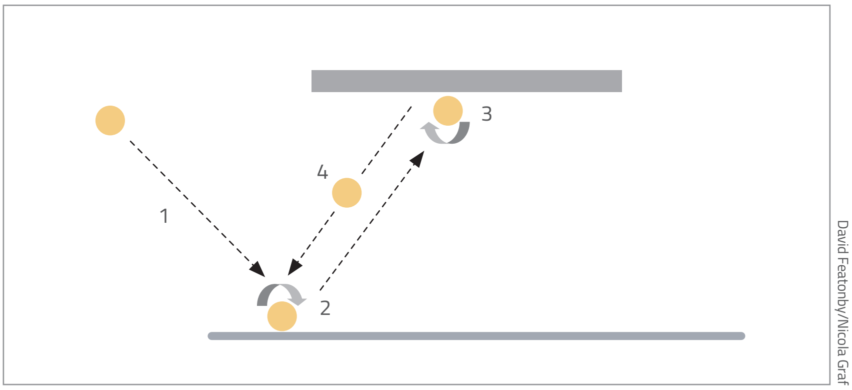


Figure 2: The ball hits the tunnel roof with backspin, which changes the ball's path. 1: the ball's initial direction of travel; 2: forward spin (relative to table) after the first bounce; 3: backward spin (relative to roof); 4: final direction of travel

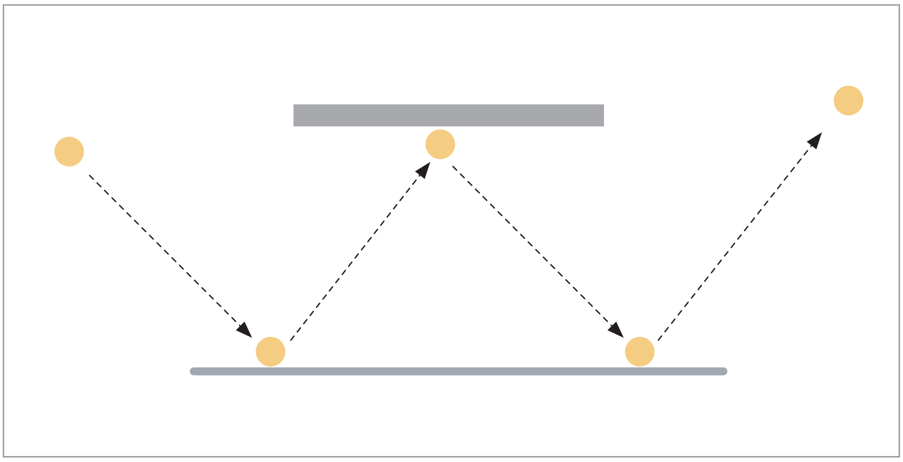


Figure 3: Path of the ball when friction is eliminated, so no spin is produced

In the challenge, friction between the ball and the table gives the ball a forward spin at the first bounce, in the same direction in which the ball is travelling. So when the ball hits the tunnel roof, it has a backwards spin relative to the underside of the roof (figure 2) – because the top part of a spinning ball must be turning in the opposite direction to the bottom part.
This backspin causes the ball to return along its original path, back towards the thrower. So, how can you overcome this spin and make the ball pass through the tunnel as intended?

For the ball to follow a W-shaped path through the tunnel, it must strike the table (and then the roof of the tunnel) without spin. The spin is caused by the friction at the point of contact, because friction opposes the motion between two surfaces in contact – so one side of the ball is slowed down, but not the other.

To minimise the spin, the friction also needs to be minimised. The easiest way to do this is to change the surface of the ball. If the ball is immersed in water for a second, its wet surface will then skid over the table and upper surface of the tunnel without spin, and the ball will follow a W-shaped path through the tunnel, as most people initially expect (figure 3).

A challenging extension of this feat is to work out the direction and size of the spin at different stages of the ball's motion. Taking a film of a large, patterned ball (such as a basketball) and watching it in slow motion is a good way to make this easier.

Feat 2: Cork bounce

The secret here is in how you hold the cork (or other cylinder) before you drop it.

1. Hold the cork horizontally but at a very slight angle (it's almost impossible not to do so), and at a height above the table of about 1.5 times the length of the cork (figure 4).

David Featonby

Figure 4: Cork at the ready

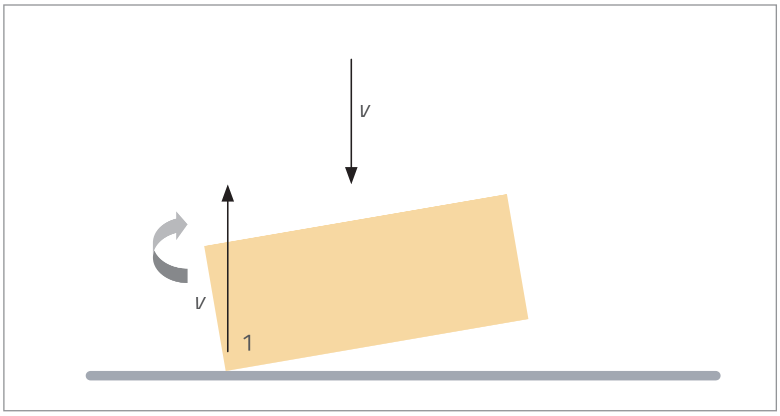


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Figure 5: Falling at speed v*, one end of the cork (1) hits the table and bounces up again at the same speed, making the cork rotate.*

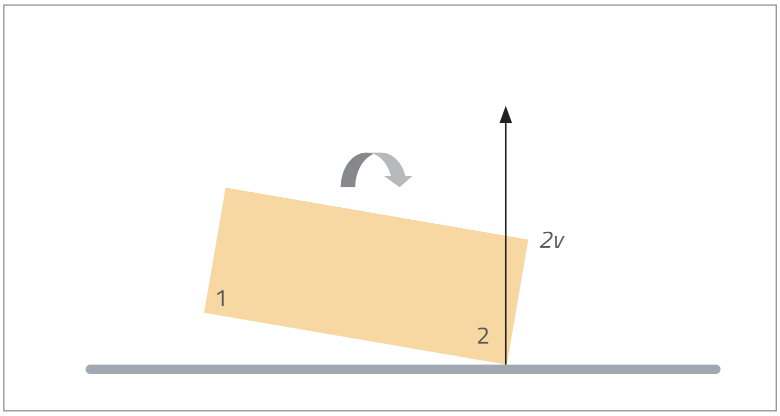

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Figure 6: The second end of the cork (2) hits the table at speed 2v *(falling plus rotation speed) and rebounds at the same speed, making the cork rotate in the opposite direction.*

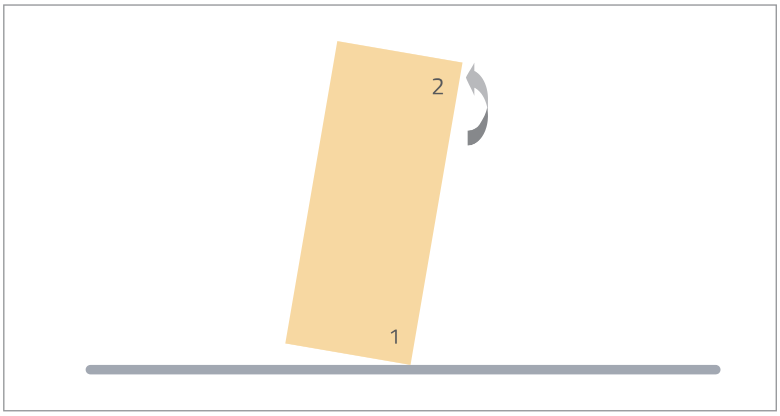

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Figure 7: The cork rotates to a vertical position – with luck!

2. Drop the cork. It should bounce and finish up standing on its end – at least 50% of the time.
3. Keep practicing to find the best height for your cork and table.

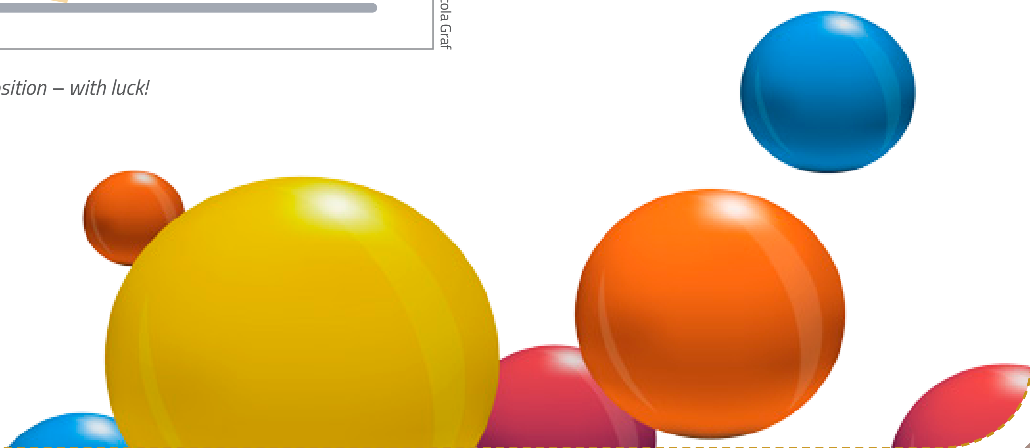
The basic explanation is that when the cork falls, one of its ends will strike the table before the rest of the cork. This results in a force applied to only one end of the cork, producing a turning effect. This makes the cork rotate enough to stand on its end.

However, videoing the fall and watching it in slow motion has revealed a more complex sequence than described above, as the diagrams here illustrate.

The cork is falling at speed *v* when the first end hits the table. Assuming this is an elastic collision, this end bounces back upwards at speed *v* (see figure 5).

This change in momentum at one end of the cork causes it to rotate about its centre of gravity, here as a clockwise movement. This rotation makes the opposite end (end 2) of the cork move at the same speed about its centre. But for end 2, the movement due to rotation will be in the same direction as its fall. So when end 2 of the cork hits the table, it is moving at speed 2*v* (*v* from its fall plus *v* from the rotation), and will also rebound at speed 2*v* (see figure 6).

The rebound momentum of 2*v* makes the cork rotate in the opposite direction (here anticlockwise), so that it rotates to a vertical position (see figure 7).



Finding the best height for the drop and getting the cork to stand upright is very much a trial-by-experiment process. There are many factors involved that will vary significantly from cork to cork, and between different surfaces.

All the other tubes can be made to stand on end in the same way. The ease with which this happens varies considerably – and the cork is probably the most difficult. What else could you bounce into a vertical position by producing a turning force?

Feat 3: Card drop

When trying this challenge, most people will hold the card vertically before dropping it. From this position the card will invariably move sideways during its fall, and it will usually miss the hat – even if dropped from directly above it.

This sideways shift is due to pressure from air movements caused by the falling card itself. Even though they are very slight, these movements will produce enough force on the side of the card to move it sideways, away from the hat.

The trick is to hold the card horizontally, as shown in figure 8. In this position, the area of the card that is exposed to sideways air movements is much smaller – just the edge of the card. This means there is much less chance of a significant sideways force, so the card's fall is almost vertical – directly into the hat below.

For even greater theatrical effect, try performing this feat with banknotes.

Resources

For a more detailed analysis of dropping cards from greater heights, read the explanation on the Naked Scientists website. See: www.thenakedscientists.com/get-naked/experiments/falling-cards

David Featonby

Figure 8: Holding the card horizontally before dropping it

Philippa Willitts/Flickr

About *Science in School*

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