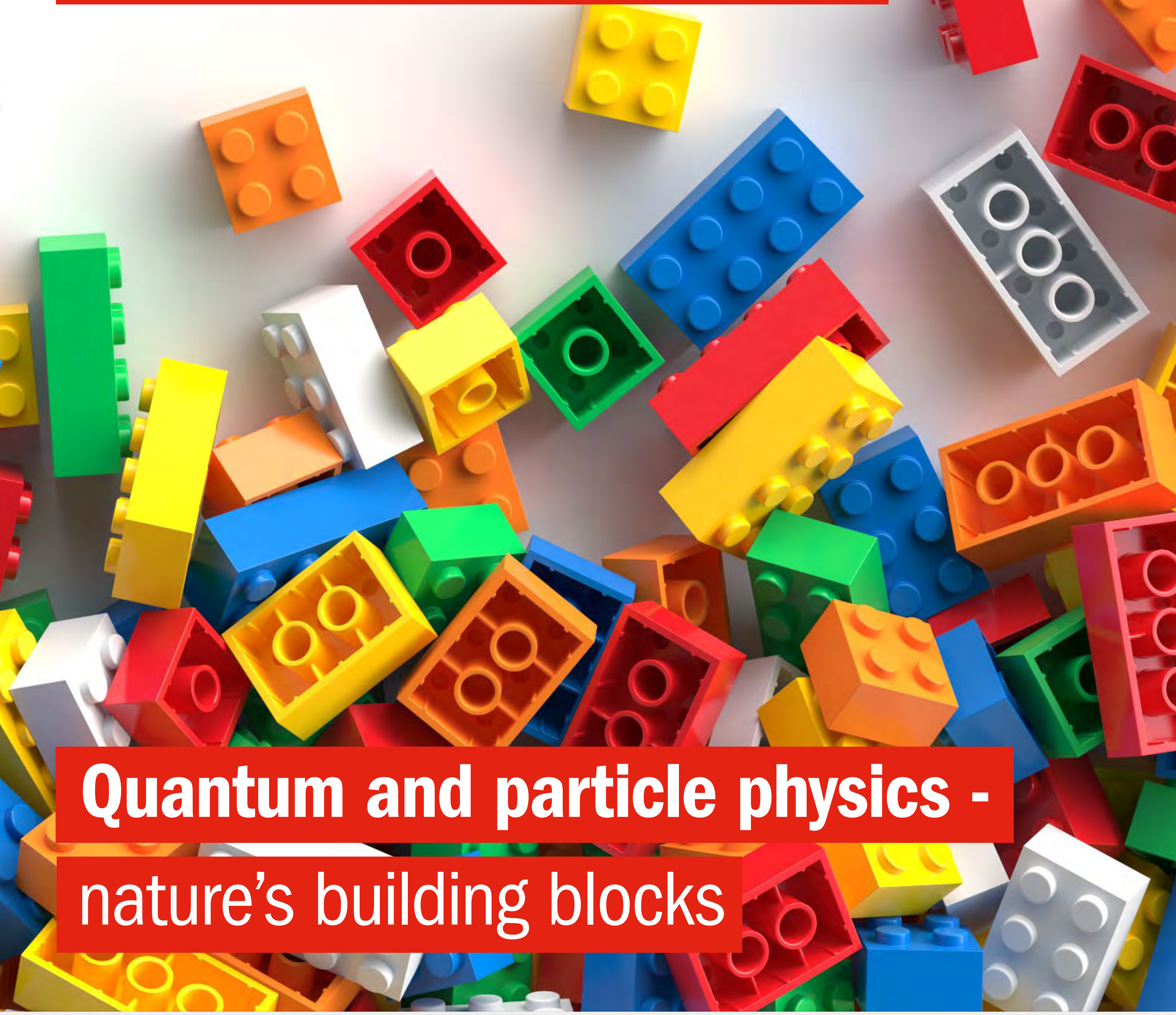
December 2021 | Issue 59

Classroom physics

The magazine for IOP affiliated schools



Quantum and particle physics - nature's building blocks

Get behind our manifesto for change in schools

Exploring the photoelectric effect

Join our award-winning teacher CPD

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Credit: Cerian Angharad

Congratulations to IOP Wales physics coach Cerian Angharad who recently collected an MBE for services to science promotion and engagement with young people

Quantum theory

Richard Feynman famously said, “I think I can safely say that nobody understands quantum mechanics.” *

Whether or not this is true, quantum mechanics has led to revolutionary technological advances. At the same time, its perceived complexity has captured the public imagination - tell your students they will be having a lesson on quantum theory and watch their reactions. But it is possible to introduce quantum concepts at all ages and this edition of Classroom Physics offers ideas for how to do so.

Artist and physicist Geraladine Cox starts us off by getting students to explore the nature of the atom via the medium of dance (page 5), while teacher and researcher Ben Still offers a class in LEGO (page 7). Education researchers James de Winter and Richard Brock offer an intriguing model using a beach ball (page 8).

Our pull-out is devoted to the particle model of light. Einstein used the idea of a photon to explain the photoelectric effect, work for which he won his Nobel Prize exactly 100 years ago.

Finally, we are delighted to share with you the final booklet in our Stories from Physics series. We hope you have enjoyed collecting all the booklets. We are also celebrating by including a 2022 Stories From Physics calendar, with new stories for each month. All the stories – and more – are available online at **spark.iop.org/stories-physics**

Caroline Davis
Classroom Physics editor

**Clip from the BBC archive of Richard Feynman's lecture The Character of Physical Law: Probability and Uncertainty - the Quantum Mechanical View of Nature recorded at Cornell University in 1964 twitter.com/bbcarchive/status/1025372232892198912*

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With this issue...

Stories from Physics
The final booklet in our series is on *Quantum, Nuclear and Particle Physics.* Plus the *2022 Stories from Physics Calendar*

Quantum City poster
An example poster from Quantum City's new series exploring the applications of quantum technologies (see page 18 for more info)

Follow the IOP Education Department on Twitter @IOPTeaching

Read Classroom Physics online and access previous editions at **spark.iop.org/classroom-physics**

Whole school equity plans lead to positive change – but more work needs to be done

A fifth of teachers across the UK and Ireland say their school does not have a whole school equity plan in place, or that they are not aware of them, according to a survey conducted for the IOP. This is of particular concern as three-quarters of those teachers in schools that do have them believe that implementation of the plan has led to positive changes in their school.

Currently, these plans are not mandatory and are not benchmarked or inspected. The Institute of Physics believes they should be and that a whole school equity plan should be a living document, embedded across the school, not a policy that remains unseen or unused on the school website.

Mandatory whole school equity plans are part of our Limit Less campaign's *Manifesto for Change Across the UK and Ireland.* Schools have begun to sign up to the manifesto, launched in October, showing their support for the changes we are calling for. We hope you will sign up your school too.

"A whole school equity plan is ensuring that the school (our community – so that's the parents, the students and the teachers) are all involved in coming up with a common vision: that every child in the community is entitled to that inclusivity and diversity of the curriculum that allows them to see beyond, not only what they have right now in front of them in terms of their own community but the wider picture, and they can then build upon when they go into society."

Jamie Drake, Curriculum Director of Science and Social Science, Noel-Baker Academy, Derby

We need as many teachers, school leaders and schools as possible to support our call for change. Please add your name and ask your SLT to do the same at:

campaign.iop.org/manifesto

Limit Less

Teaching without Limits - the current situation in our colleges, schools and early years centres

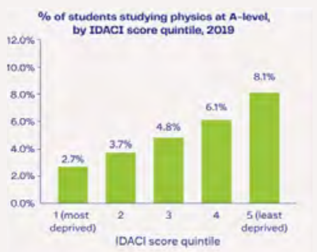
To accompany this manifesto, we have published six reports entitled Teaching without Limits. They discuss the issue of inequity in physics and the education sector, look at how whole school change can be implemented, and contain statistics and lived experiences from young people and the physics community. We cover each of the nations and each stage of school: early years, primary and secondary.

While writing the reports, it became clear there are issues in comparing data across the UK and Ireland. All nations track the gender-split of subjects, but only England provides further breakdowns by ethnic group, special educational needs and disadvantage (free school meals). So as well as lobbying governments on the ten points in our manifesto, we will also call for better data collection and access to that data, so inequities can be better understood and tracked.

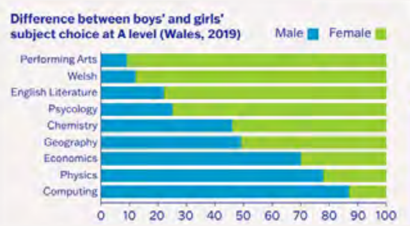
more...

Read the reports at **iop.org/WholeSchool**

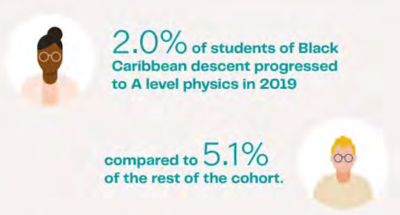
Credit: IOP



All state schools in England, 2019. Source: Improving Gender Balance and Drayson Foundation Pilot Project Evaluation Report



Source: JCQ, GCE A Level Results Summer 2019 (Wales only)



Source: Improving Gender Balance and Drayson Foundation Pilot Project Evaluation Report (England only)

An invitation to our new Teacher Forum

Credit: Boivin Nicolas at Shutterstock

We are excited to announce the launch of the IOP Teacher Forum, giving participants the opportunity to inform the work of the Institute, working in partnership with the IOP's education department. This will ensure that what we do at the IOP remains relevant to and beneficial to all teachers of physics. Registrations are welcome from all teachers of physics at any stage of their career, located across the UK and Ireland. Teacher Forum members will be given the opportunity to preview and contribute to the development of innovative new projects. Upcoming projects include:

Spaced learning: we are exploring the potential for this methodology with '*Download Learning*' to boost teaching physics to students and teacher CPD. Download applies the neuroscience of long-term memory formation to digital learning to improve the speed of learning and boost knowledge acquisition, retention and application. We have agreed to run a pre-pilot to test out teacher and student reaction. We will develop a student-focused module to deliver the cognitive input for atomic structure and nuclear for 14-16s, and seek teachers to trial the module in their schools and give initial feedback.

Lesson Toolkits project: the Best Evidence Science Teaching (BEST) team at the University of York have developed excellent research-informed teaching resources. The Lesson Toolkits project aims to bring together BEST's sequencing of topics, accompanying diagnostic questions and IOP activities to give teachers a full package of resources needed to teach a given topic. Initially we will be developing lessons for 11-14s, starting with an exemplar topic of Seasons. We are looking for feedback around usability, possible improvements and what topics should be prioritised.

more...

To register your interest in joining the IOP's Teacher Forum visit **spark.iop.org/teacher-forum**

Limit Less Careers Week

7-11th March 2022

Visit **iop.org/careersweek** for more information.

Limit Less

Discovering elemental dance

Geraldine Cox has an unusual role, working as an artist at Imperial College London with scientists. She has just completed a project with them alongside dance artists from The Place, the centre for contemporary dance in London. Together, they have created a series of inspiring dance videos about atoms and molecules. Geraldine explains, "Nature is dynamic, full of movement and change, and much of science is about studying the way things change. Scientists are always discussing dynamics, transitions, processes,reactions, emergence, evolution. It seems natural to use dance to express these ideas."

Each 20–30-minute film begins with a question introduced by a physicist such as 'How big is an atom?', 'Where do atoms come from?' and 'Why do we think they exist?'. The scientific theories and ideas are then explored in a fun dance segment with a dance artist.

Geraldine's unusual career began with degrees in physics and then fine art painting. She works to bring the two together: "My aim is to find new forms of expression for some of the beautiful things we've discovered. I want to encourage everyone to express their understanding in their own way."

more...

theplace.org.uk/elemental-dances

findingpatterns.info

Dance artist Akeim Toussaint Buck, by Alice Underwood

0 SIZE
How big is an atom? 2:02

1 CLUES
Why do we think atoms exist? 24:44

2 WORLD INGREDIENTS
What are the atoms that make the world? 22.42

3 ATOM LIGHT
How do atoms colour the world? 31:16

4 THE WATER MOLECULE
How do atoms behave when they combine to make a water molecule? 26:51

5 ICE, WATER, STEAM
How does water change its character so dramatically? 17:34

6 ATOM FACTORIES
Where do atoms come from? 23:49

Imperial College London
THE PLACE

Reforming teacher training: developing subject knowledge for teaching

Credit: IOP

Subject knowledge should be at the heart of teacher training and CPD throughout a teacher's career

Subject expertise should be at the heart of any new reforms, ensuring that sufficient time is provided in the curriculum with a coherent system for developing teachers' subject and teaching knowledge "from the moment they start training to the time they leave the classroom".

This is the recommendation of the IOP's head of education, Charles Tracy, in an essay which forms part of a collection addressing the future of Initial Teacher Training (ITT).

Charles describes the different types of subject knowledge required for teaching and makes the case for putting subject expertise at the heart of any new reforms, with emphasis on the importance of subject-specific mentoring. He also proposes that trainees and new teachers are allowed to focus on their home subject during their early career to prevent them being overloaded with new material to learn and prepare to teach.

Published by the Gatsby Foundation, Reforming Teacher Training: Expert Perspectives, is a set of responses to the current debate in England as part of the government's ITT Market Review. Gatsby asked nine education experts from a range of institutions and backgrounds to write an essay covering their thoughts on aspects of teacher training, and to reflect on the new proposals, which controversially included the suggestion that every provider should go through a re-accreditation process.

Gatsby has worked with government and other partners over the last 20 years to improve the quality and quantity of specialist teachers. It has particularly focused on physics teachers, where the number of new teachers still falls short of what is needed.

The Gatsby publication comes just months after the launch of the IOP-led Subjects Matter report, the result of a collaboration between over 50 educational organisations, subject-specific societies and individual specialists. It described how a national system of subject-specific CPD for all teachers could help to increase the quality of teaching in schools and improve educational outcomes for all students.

Gatsby recommends that the uncertainty around how to shape the future of ITT is reason to slow down and assess in detail the options and their implications, before identifying the long-term solution.

more...

The Gatsby Trust's *Reforming Teacher Training: Expert Perspectives* is available at **bit.ly/ITTreformGatsby**

Subjects matter

Charles has also written an article for the journal of the Chartered College of Teaching entitled Towards a national system of subject-specific CPD, available at **impact.chartered.college/article/towards-a-national-system-of-subject-specific-cpd**

More about the IOP Subjects Matter project at **iop.org/subjects-matter**

Early Career Professional Learning

As a newly qualified teacher, you may have missed out on several weeks of school placement experience during your training year due to COVID-19 and may be finding that your current school environment is bringing new unexpected challenges. In response, the IOP is providing targeted support for early career physics teachers.

Watch videos at **spark.iop.org/early-career-teaching-cpd-videos**

More about the mentoring and networking aspects of the programme at **iop.org/ecpl**

IOP ITT Scholarships 2022/3

We will have 175 scholarships each worth £26,000 with professional development support for talented individuals who have the potential to become inspirational teachers. We will support your trainee teacher with online CPD workshops and they will benefit from being part of a community of scholars. They will also become members of the IOP for the year (England only).

More info at **iop.org/scholarships**

The Association for Science Education

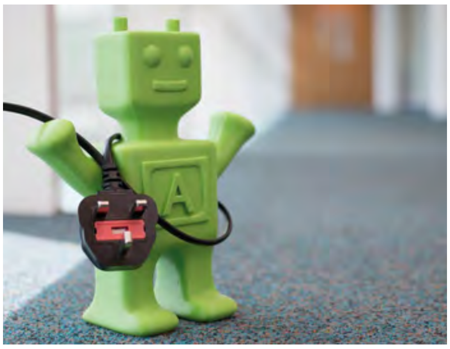
Inclusion in Schools project

The Association for Science Education is partnering with the IOP and the Department for Education (England) to increase the number of students from under-represented groups progressing to physics-based routes (A-level physics, vocational or technical) post the age of 16. Inclusion in Schools works with secondary schools to address barriers to inclusion at a whole-school level.

Read more at **ase.org.uk/news/inclusion-project-delivery-subcontracted-institute-of-physics-ase**

These themes will be explored in the Talking Science session at the ASE Annual Conference.

Register at **ase.org.uk/aseconf2022**



The Quantum Ampere

Quantum effects and constants now underpin all SI units, ready for exciting future challenges of science and technology, write Andrew Hanson, Nick Fletcher and Masaya Kataoka of the National Physical Laboratory (NPL)

NPL uses the science of measurement (metrology) to develop some of the most accurate global measurement standards. Quantum phenomena appear both in the definitions of SI base units and, more importantly for us, in realisation - practical instrumentation to export measurement scales.

In 2019 the ampere was redefined - hopefully for the final time. The finality stems from our faith that the quantum phenomena it anchors to are constant over time and the same everywhere in the universe. When you tell your class that current is a measure of the number of electrons passing a point, that is now exactly how the ampere is defined.

> **"The ampere is defined by taking the fixed numerical value of the elementary charge *e* to be 1.602 176 634 × 10^{-19} when expressed in the unit C, which is equal to A·s, where the second is defined in terms of $\Delta\nu_{Cs}$, the unperturbed ground state hyperfine transition frequency of the caesium-133 atom."**
>
> 2019 definition of the ampere

The 'size' of the new ampere is unchanged, just defined with 21st century technology in mind. Previous definitions involved silver deposited in electroplating, or an electromagnetic force resulting from two parallel current-carrying cables. These both involved measurable effects rather than relate to what electric current is - the flow of charged particles.

The new definition includes two quantum phenomena:

1. Electrons (and protons) are quantum 'anchors', accessible to all and stable with time, unlike a certain metal cylinder that until recently defined the mass scale.
2. The definition of the second relates to the quantum phenomena of atomic energy levels.

For realisation, we could take the direct approach - creating a known current by controlling or counting the number of electrons flowing through a circuit with time. An 'electron pump' has been made to work but the challenge is scaling up to typical electronic device currents (1 mA ≈ 6×10^{15} electrons/s). Fortunately, two other quantum phenomena enable practical electrical measurements for science and industry:

1. A resistance experiment uses the *quantum Hall effect,* where a magnetic field perpendicular to a '2D surface' containing ultra-cold electrons leads to exact resistance values.
2. A voltage experiment uses a *Josephson junction* comprising two superconducting, electrodes separated by an insulating barrier. In superconductors, current flows without resistance (or voltage drop). Exposing the junction to microwaves causes electron pairs to cross the barrier in a way that gives discrete 'quantised' steps in voltage across it.

more...

Read a fuller version of this article at **spark.iop.org/ampere**

Read about the redefinition of the SI units at **npl.co.uk/si-units**

Einstein's not-so-famous Nobel-winning discovery

Albert Einstein is synonymous with relativity, E = mc² and mad hair. But few people realise that his 1921 Nobel Prize was mainly for work done on the photoelectric effect. And its impact cannot be understated. A revolution in our understanding of the universe – from tiny invisible particles to the entire cosmos – happened in part thanks to our need to understand the photoelectric effect.

The photoelectric effect dates back to 1887 when Heinrich Hertz was exploring light and electricity. He showed that ultraviolet light can change the electrical behaviour of metal surfaces. Later, it was defined more clearly as the emission of electrons from a material when light hits it.

Up to then, there was no doubt light was a wave. This explained how light behaves perfectly. Experiments on the photoelectric effect should have been no exception: shining bright light on a material should have spat out higher energy electrons than electrons ejected when only dim light was used. But instead, electron energy was related to the light's colour (frequency). No waves behaved like that!

In March 1905, Einstein – just 26 years old and scrabbling a humble wage in a Swiss patent office – proposed a radical solution. Using Max Planck's idea that in certain circumstances energy comes in discrete packets (or 'quanta'), he reasoned light came in quanta too: tiny particles later named 'photons'. Photon energy was directly related to the light's frequency, creating the observed photoelectric effect.

This did not mean discarding the old description of light as a wave. For Einstein, both were true. As a particle, light carried energy proportional to the wave's frequency. As a wave, light's frequency was determined by the particle's energy.

Though Einstein would use the traditional wave description of light months later to complete his special theory of relativity and eventually explain the very fabric of the universe in his general theory of relativity, being able to see light as both wave and particle came in handy elsewhere. In fact, the wave–particle duality of light would go on to form a central pillar of quantum mechanics: that all particles can be described as either a particle or a wave.

Dr Benjamin Skuse
Freelance science writer

Credit: Ben Still

The standard model: Building understanding with LEGO

The standard model of particle physics sorts elementary particles according to their respective charges and describes how they interact through fundamental interactions. It is, like any theory, an analogy of nature. The mathematical models we construct to explain what is seen in experiments draw upon analogies outside of maths. Using LEGO to teach this topic provides a tangible way for students to understand what is probably one of the most abstract parts of the 16-19 curriculum: which combinations of colour-charge are stable

Forces are exchanged between particles which have properties known as charge, and each force has its own associated charge. Most familiar is that of electric charges. All electric charges are given either a positive or negative number with charges of the same sign repelling each other while charges of opposite sign attract. These positive and negative numbers are themselves just an analogy to explain electric charge and the electrostatic force that acts on particles. There is no deeper meaning to a positive or negative charge other than this number line analogy - posing much frustration when teaching conventional current!

There is also an analogy to explain the way quarks and antiquarks combine to form baryons and mesons. The analogy here is more complex than a single number line due to the underlying force. It is the strong force that dictates how quarks must group together. The associated charge is not explained through numbers but instead the primary colours of light of human vision: red, green and blue. Strong force is experienced only by quarks and antiquarks who all possess this strong colour charge.

For electrically charged particles, positive and negative charges combine to form more stable structures (atoms) because together they have a lower potential energy than when separated. The same idea is true for the strong force - something with no overall colour-charge has a lower potential energy and therefore is more stable.

Colour neutrality can occur in three different ways and this leads to three types of particles: baryons, antibaryons and mesons. My favourite way to introduce this idea is to combine light mixing demos with LEGO (see above).

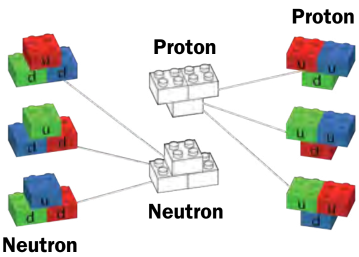
And once your students understand additive mixing they can construct various particles and so go beyond the curriculum by reasoning through which combinations of quark and antiquark we will see in nature.

Building colour-neutral particles

The primary colours of light are used as an analogy for the strong charges of quarks while the secondary colours can be used as examples of anticolours for antiquarks. Mix three primary or secondary colours together and you get colourless white light.

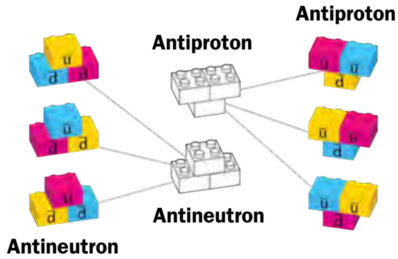
1. Baryons

A combination of three quarks: one with red charge, one green and one blue. In human vision, equal parts red, green and blue would yield white light, not an overall discernible colour. Particles constructed from three quarks in this way are called baryons. Protons and neutrons are both examples of baryons.



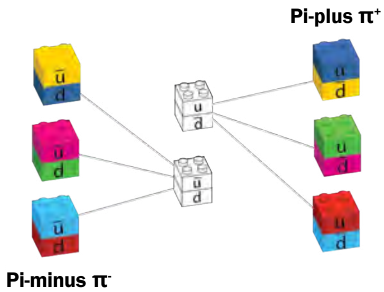
2. Antibaryons

Colourless particles which are a mirrored combination of not three quarks but three antiquarks. Mirroring the colour charges but bringing all three antiquarks together does not change the fact that this creates a white colourless antibaryon.



3. Mesons

The final way of creating colourless particles is to negate any colour of one quark by pairing it with an antiquark of opposing colour. Pairs of quark and antiquark form metastable particles called mesons.



more...

For videos and resources on using LEGO to explain particle and nuclear physics, visit **bit.ly/LEGOPhysics**

Dr Ben Still is a teacher and Head of STEM Partnerships at St Paul's School, Visiting Research Associate at the School of Physics and Astronomy Queen Mary University of London, and author.

Physics education research

In this column, **James de Winter** (University of Uppsala and University of Cambridge) and **Richard Brock** (King's College London) highlight accessible and usable resources based on research into physics education.

Get involved with physics education research discussions by joining the **Physics Education Research** group on Talk Physics at **talkphysics.org/groups/physics-education-research-per** or email **research@teachphysics.co.uk**

Credit: hxdbzxy and irin-k at Shutterstock

Deciding where a beach ball is without using their eyes is a good way for students to start thinking about quantum physics

Observe, measure or interact?

The extent to which quantum physics can be meaningfully taught at secondary level can be a point of contention. Views can range from "don't, it's just too hard and weird, they'll get confused" to "we HAVE to, it's what modern physics is about". Like most debates in education there is not a clear answer but research from a team in Norway suggests that how we interpret the everyday concept of *observation* may be a good starting point.

The ReleQuant project has developed digital, research-based learning resources in general relativity and quantum physics for upper secondary physics. Although based in Norway, the resources and some of the messages from the associated research, are of use and value to secondary teachers elsewhere.

Based on research with students using the ReleQuant resources across seven schools, Anders Huseby and Berit Bungum noted that challenges can arise if students do not discriminate clearly between **passive looking, observation** and **measurement.** The authors found that some students did not appreciate that to measure, you will also need to interact with the thing you are measuring. Many students interpret observation as if it were the same as passive looking where there is no interaction at all between the looker and the object being looked at. While this may be correct when it comes to vision, this made it harder for them to realise that the measurement process interacts with the system it is measuring. This finding suggests that reinforcement of a precise use of the term 'measurement' with an emphasis that the process requires an interaction, is important. As in many physics teaching situations, an insistence on the precise use of concepts is not pedantry, but conveys important meanings needed to support understanding.

The team developed a teaching approach to help students realise that measurement is connected to interaction: students were asked to decide where a big beach ball was in a room with their eyes closed. In order to find the ball, they have to stretch out their arms and legs. In doing so, as they **measured,** they interacted with the ball, almost certainly moving it from the position where it originally was. The researchers found that students understood this point quickly, making it easier to accept that we cannot just **look** at electrons since light will have to be reflected from them.

Studying quantum physics at secondary level may always present some challenges, but paying close attention to language and how everyday concepts may be incorrectly interpreted can help. Attention to language, and using research-informed resources such as those produced by ReleQuant, can make the wonders and beauty of quantum physics accessible to more students and open a deeper, richer understanding of the world.

more...

The Huseby and Bungum paper, Observation in quantum physics: challenges for upper secondary physics students in discussing electrons as waves, is at **bit.ly/PWobservation**

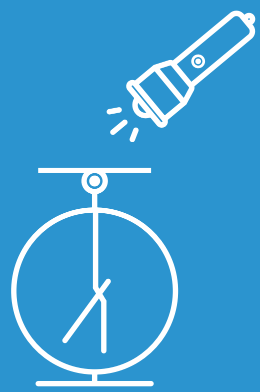
The ReleQuant resources, further details of the project and links to more research are at **mn.uio.no/fysikk/english/research/projects/relequant/**

Pull out and keep!

Photons

Inside this pull-out:

- **Activity 1:** Liquid photons
- **Activity 2:** LED photocell
- **Worksheet:** Photons multiple choice



Quantum physics suitable for the classroom

Quantum physics underpins so much of modern science, from some of the most abstract theories ever proposed through to revolutionary applications in modern electronics and biology. It is a subject many students are fascinated by, but one that can seem like the preserve of research institutions and university departments.

However, some fascinating quantum phenomena can be reproduced in a school laboratory. The photoelectric effect demonstrated using an electroscope is a great example of an easy school demonstration that provides results that a classical theory of light cannot explain. And demonstrating spectral lines from discharge tubes provide colourful evidence of the discrete nature of atomic energy levels. A simple class practical of finding the 'striking', or minimum, voltage required to activate different coloured LEDs provides a value of the Planck constant.

All of physics requires some form of model to explain observed phenomena, whether through words and images, or using formal mathematics. In the abstract world of the quantum universe, we rely on such models even more to enable us to attempt to 'see' the unseeable.

This pull-out focuses on the particle model of light – the photon - and includes:

Activity 1: Liquid photons
A model to introduce the idea that light arrives in chunks.

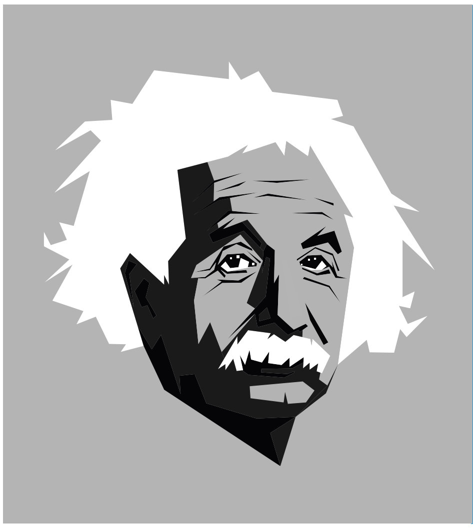
Activity 2: LED photocell
A demonstration that illustrates light behaving as a 'particle'.

Worksheet: Photons multiple choice
Questions to use in class or to set as homework.

more...

For our Nuffield Practical on spectral lines see **spark.iop.org/spectra-formed-gratings**

Credit: asnan_ad at Shutterstock



Einstein's explanation of the photelectric effect experiment was the first clear evidence of photons

Einstein's equation for the photoelectric effect

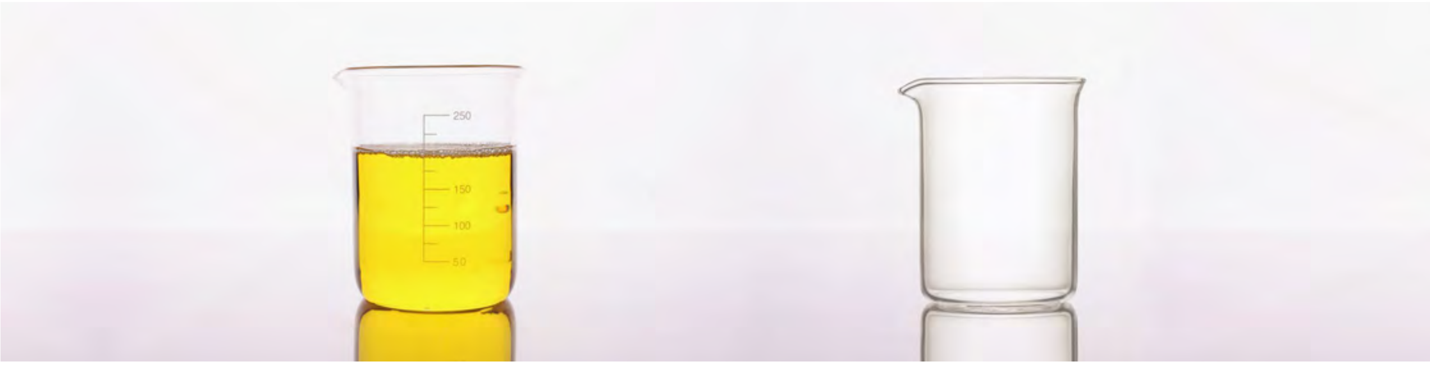
In 1905 Albert Einstein published a paper which would eventually gain him the 1921 Nobel Prize for the photoelectric effect. This contained the ground-breaking equation $E_{max} = hf - \phi$ which described how the maximum kinetic energy that an electron emitted from a metal's surface (E_{max}) was related to the frequency f of the light striking it. The work function ϕ of the metal is the minimum energy required to liberate an electron and its inclusion shows that there is a minimum frequency of light – known as the *threshold frequency* - needed for photoelectric effect to occur.

No matter how bright the light source, not a single electron will be liberated unless the frequency light is high enough. This result cannot be explained by a wave theory of light but can by a particle model if each light 'particle' interacts with one electron.

Activity 1:
Liquid photons

This demonstration introduces the idea that light arrives in chunks using a coloured liquid and beaker model

Credit: H_Ko at Shutterstock



Transferring coloured liquid between beakers can be used to model energy stores filling and emptying via photons

Equipment

- teaspoon
- dessert spoon
- tablespoon
- yellow food colouring
- two measuring beakers

Procedure

1. Explain that you will be modelling your skin warming up on a warm summer's day.

2. Fill one beaker with water and add food colouring. Label the beaker the **The Sun's nuclear energy store.** Label an empty beaker **Your skin's thermal energy store.**

3. Model a photon of red light arriving by filling the teaspoon from the full beaker and transferring the liquid to the empty beaker.

4. Repeat with dessert spoon to represent a green photon arriving.

5. Repeat with tablespoon to represent a blue photon arriving.

Teachers' notes

You may have already used coloured liquid and beakers to represent energy stores filling and emptying in your teaching. This demonstration uses this model to introduce the idea of a photon. Light arrives in chunks with an energy that is proportional to the frequency. The higher the frequency, the bigger the chunk.

Ask your students if it is possible to fill the beaker as quickly with red photons as it is with blue? (Yes, if more red photons are transferred per second.)

Discuss how blue/ultraviolet can give us sunburn, but red light cannot. Explain that this is because sunburn is due to damage to DNA in the upper layers of our skin cells and this is an interaction that happens at the microscopic level on a scale at which the size of the chunk of energy is important.

Photoelectric effect on IOPSpark

See **spark.iop.org/so-whats-new-about-chunks-energy** for more about light as continuous streams and discrete chunks. Search for 'photoelectric' for lesson plans, videos, misconceptions and more at **spark.iop.org**

Answers to worksheet on page 12

1. B. The energy of a photon is proportional to the frequency of the light ($E = hf$).
2. B. Red light has the lowest frequency and so the lowest energy.
3. C. Both beams are green so have the same frequency but the brighter laser produces more photons per second.
4. A. The blue laser beam has a higher frequency and so each photon has higher energy. For the intensity to be the same as a red laser, a blue laser must produce fewer photons per second.
5. C. At the microscopic level, the size of the chunk of energy arriving is important.
6. A. Threshold frequency $f_0 = \Phi/h$, where h, the Planck constant, is a universal constant and Φ, the work function, is a property of the metal.
7. B. One photon interacts with one electron and so the number of electrons emitted is proportional to the number of photons arriving.
8. C. The photoelectric effect removes negatively charged electrons. The only way the gold leaf can become uncharged is if the plate was negatively charged.
9. B. $E_k = hf - \Phi$ and so the gradient of a graph of E_k vs f is equal to the Planck constant h.

Activity 2

LED photocell

In this demonstration, students see that only certain colours of light produce a voltage when shone onto an LED: an example of light behaving as a 'particle'

Equipment set up for LED photocell activity

Equipment

Each group of students will need:

- Green LED (clear without a coating)
- Torch (or other white light source)
- Red and green laser pointers (Class 2 from reputable suppliers)
- Digital voltmeter, internal resistance 10 MΩ or greater
- 2 connecting leads and crocodile clips
- Card (enough to mount the LED and make a tube to shield it)

Procedure

1. Use a pencil to make a hole in a small piece of card, push the LED through and mount the card in a clamp stand.
2. Connect a voltmeter across the LED. Use a cardboard tube to block any ambient light so the voltmeter reads zero.
3. Mount the torch in a clamp stand and aim it directly onto the domed end of the LED. The voltmeter should show a small reading.
4. Remove the torch and mount the red laser in the clamp stand. The voltmeter should read zero.
5. Remove the red laser and mount the green laser pointer. The voltmeter should now show a non-zero reading.

Preparation & safety

Any sunlight or room lighting which falls on the LED will produce a reading. Carry out the demonstration in a darkened room and/or shield the LED using a cardboard tube.

The voltmeter needs a resistance of 10 MΩ or greater, otherwise the small current produced when light is shone onto it will leak away too rapidly to give a reading.

Fix lasers firmly in a clamp and direct them away from students.

Teachers' notes

Ask your class why they think we get a reading with white and green light, but not red.

Students may suggest the red light does not produce a reading because the red laser is not bright enough. Emphasise that both lasers produce a much more intense beam than the torch. The results cannot be explained in terms of wave amplitude. It is the frequency of the light that is important.

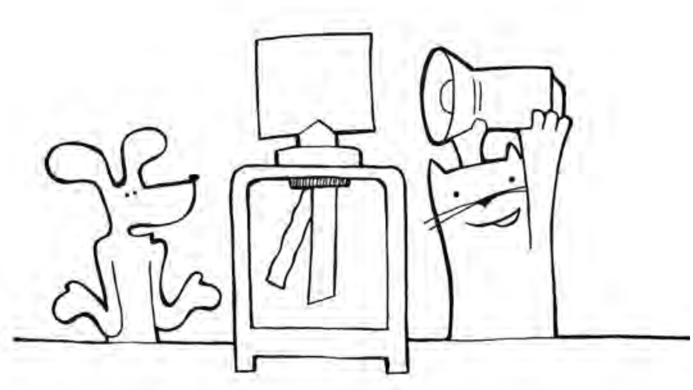
Now ask them whether, in this experiment, light is behaving as a wave or a particle and why.

Discuss how a particle model of light can be used to explain the results. When a 'particle' (photon) strikes the LED it is absorbed. Each photon has an energy directly proportional to its frequency so only those with a high enough energy will release an electron. Red photons are ineffective because they have the lowest frequency and so least energy. Green photons are more energetic. White light is made up of all visible frequencies and so will contain some photons with high enough energy.

more...

spark.iop.org/led-photocell

Worksheet:
Photons multiple choice



Which of A, B, C or D either completes the sentences correctly or answers the question?

1. The energy of a photon is proportional to:

A. the wavelength of the light
B. the frequency of the light
C. the intensity of the light
D. the amplitude of the light

2. Which colour of light has photons of the lowest energy?

A. yellow
B. red
C. blue
D. green

3. Two lasers both produce beams of the same wavelength of green light. One is brighter than the other. Each second, the laser with the brighter beam gives out:

A. the same number of photons, but of higher frequency
B. more photons of higher frequency
C. more photons of the same frequency
D. more photons of lower frequency

4. Two lasers have the same power output. One produces red light, the other blue. Compared to the red laser, each second the blue laser produces:

A. fewer photons
B. more photons
C. the same numbers of photons
D. it is impossible to tell

5. Ultraviolet light causes sunburn of the skin whereas infrared light does not. This is because:

A. infrared light needs more time to build up sufficient energy to cause sunburn
B. infrared photons have more energy than the ultraviolet photons
C. ultraviolet photons have more energy than the red photons
D. the intensity of infrared light is too low

6. In the photoelectric effect, the threshold frequency is the minimum frequency of radiation required to eject an electron from a metal. Threshold frequency is a property of the:

A. metal
B. light
C. electrons
D. electroscopes

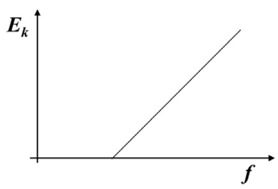
7. If light with a frequency above the threshold frequency is shone onto a metal, the number of electrons emitted is proportional to the:

A. kinetic energy of the electrons
B. number of photons arriving
C. work function of the metal
D. frequency of the light

8. The photoelectric effect can be demonstrated with a gold leaf electroscope connected to a zinc plate. The gold leaf drops when UV light is shone onto the plate. To set up the experiment, the zinc plate must be:

A. uncharged
B. positively charged
C. negatively charged
D. charged either positively or negatively

9. The graph below shows how the maximum kinetic energy of the electrons (E_k) varies with the frequency of the light (f) in the photoelectric effect.



The gradient of the graph is equal to:

A. the charge on an electron
B. the Planck constant
C. the work function of the metal
D. the wavelength of the light

The nuclear seagull freezer

Many of us have mysterious items lurking in the backs of our home freezers – but your forgotten Tupperware containers are unlikely to rival the surprises in Sellafield's freezer. *The Independent* newspaper reported that the Sellafield nuclear site has a store of frozen radioactive seagulls. These and other birds would land at the site and potentially pick up traces of radioactive material which could be transferred when they flew to other areas. Safety managers implemented a policy of employing sharpshooters to kill the unfortunate animals. Given the potential risk of contamination, the birds' carcasses were classified as low-level nuclear waste. Moreover, unlike other waste, because the material was organic, the birds were categorised as 'putrescent', meaning they would decay. Freezers, like those used by supermarkets to store food, were installed to preserve the carcasses. A spokesperson for the site commented on the number of seagulls in their freezer: "We are adding to the store all the time so we do not count them. But given the size I'd say it was in the hundreds."

It's all Greek to Millikan

When teaching the photoelectric effect, it is worth a detour into Robert Millikan's biography. Millikan carried out significant experimental work on the phenomenon, but his undergraduate degree was in classics. He then went on to be the first person to graduate with a PhD in physics from Columbia University. Millikan reported that:

> At the close of my sophomore year […] my Greek professor […] asked me to teach the course in elementary physics in the preparatory department during the next year. To my reply that I did not know any physics at all, his answer was, "Anyone who can do well in my Greek can teach physics." "All right," said I, "you will have to take the consequences, but I will try and see what I can do with it."

Millikan was founding president of the California Institute of Technology (Caltech). But, in his later life, he became interested in eugenics and his involvement with the Human Betterment Foundation has led to Caltech removing his name from their buildings.

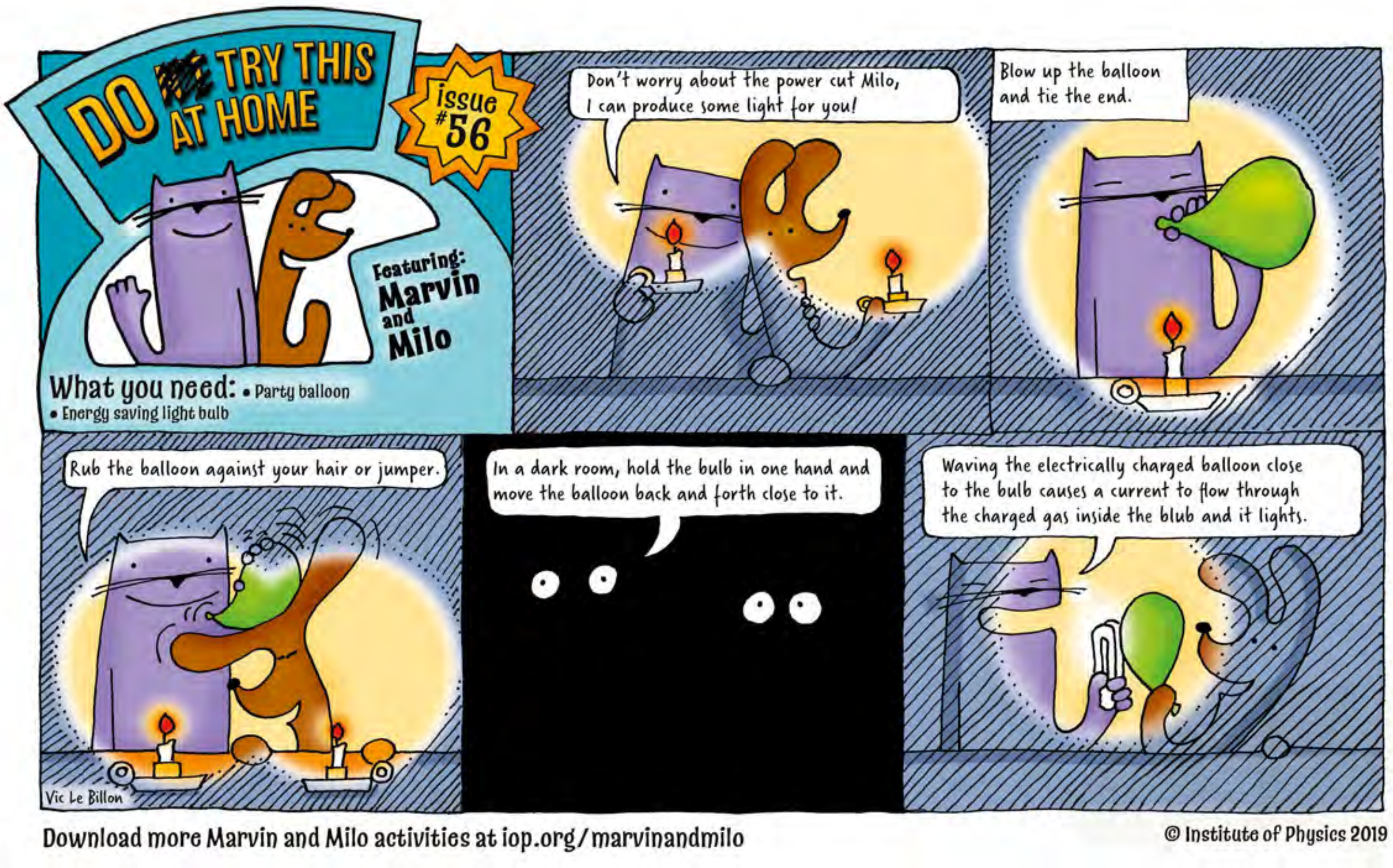
Bohr's brief betrothal

Niels Bohr cancelled his Norwegian honeymoon as he hadn't made enough progress on a paper on alpha particles. Instead, the Bohrs travelled round England and Scotland. They spent two weeks in Cambridge, where Bohr dictated the paper to his new wife, Margrethe, who helped with its composition. The honeymoon followed the briefest of weddings – the ceremony lasted only two minutes and, hearing of his mother-in-law's plans for a three-hour wedding breakfast, Bohr remarked: "How is it really possible to take three hours for a dinner?"

spark.iop.org/stories-physics

These stories were collected by Richard Brock, lecturer at King's College London and former physics teacher.

Follow him on Twitter **@RBrockPhysics**



Physics*education*

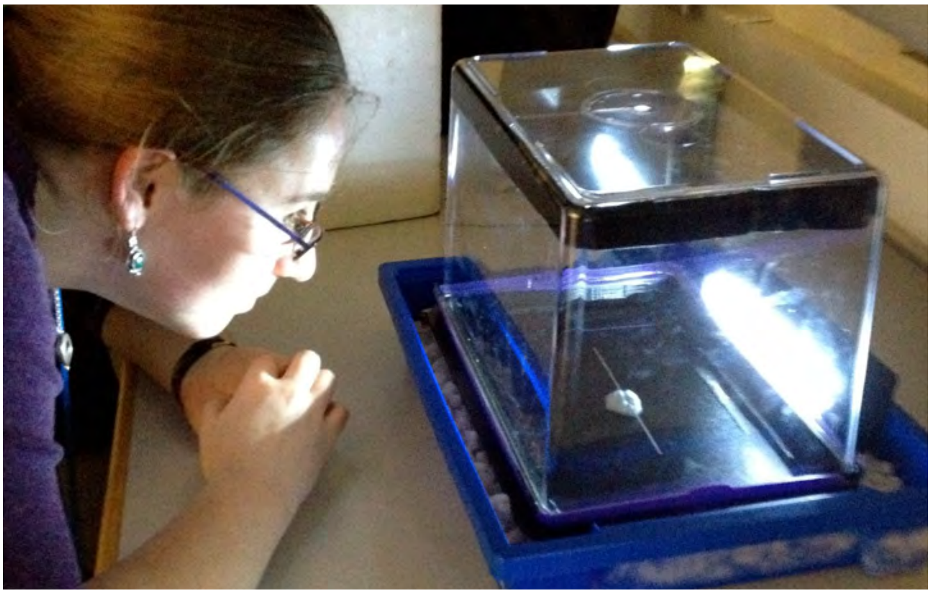
Physics Education is our international online journal for everyone involved with the teaching of physics in schools and colleges.

Editor-in-chief Gary Williams highlights his favourite papers on **particle physics** from the archive and the current volume. These papers should provide support for developing a topic for your scheme of work that could include environmental issues, mathematical modelling and hands-on experiments.

Access over 50 years of articles at **iopscience.org/physed**

Affiliated schools have free access – email **affiliation@iop.org** for a reminder of your log in details.

Fish-tank cloud chambers



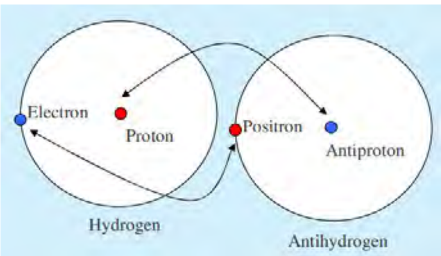
Credit: Physics Education

The fish-tank cloud chamber - lighting is important with these cloud chambers

If you are going to teach particle physics, then you really do have to show students a cloud chamber. There is just something magical about seeing the little vapour trails appear from nowhere as the ionising radiation leaves its tiny trail of condensation behind it. Searching the *Physics Education* archive, or looking online, will show many designs of cloud chamber, some using dry-ice, some Peltier effect modules as well as a few other ideas. My favourite is still the fish-tank cloud chamber, an idea that originally came from the USA. This 2012 paper describes how to make it, along with a video of Frances Green, the author of the paper, and wingman Richard Bonella putting one together. You will need dry ice for this design so make sure you plan lessons to make the most of this very cool material. Definitely an activity to generate some of those 'wow' moments.

Read the paper at **bit.ly/PEDfishtank**

Antimatter



The right comparison can help students' learning

The next recommendation is really for a pair of papers that were written to go together. *Antihydrogen* on tap by Michael Charlton in 2005 discusses the production of antihydrogen at CERN. The paper explains how and why this antimatter atom was made with its antiproton nucleus and orbiting (depending on how you imagine it!) positron. By making enough antihydrogen, techniques such as spectroscopy can be used to compare the antimatter with its equivalent matter. My paper of the same year, *Antimatter in the 21st Century,* describes the history of antimatter from the end of the 1800s up until around 2000, where the previously mentioned paper takes over. This paper is a fairly easy read and could be given to students in the 14-18 age range.

Read the papers at **bit.ly/PEDantihydrogen** and **bit.ly/PEDantimatter**

Quantum physics in the Netherlands

In this 2020 paper, *Designing inquiry-based learning environments for quantum physics education in secondary schools,* the authors describe how they created a digital, inquiry-based learning unit about the photoelectric effect. They discuss the framework behind the design and the findings of research into its effectiveness. The results of testing this unit in four high schools in the Netherlands showed that students could explain most aspects of the photoelectric effect after the inquiry activities used in this unit. However, the particle nature of light was still not fully understood, as many student explanations still built on previously studied classical physics concepts. This paper is well worth a read if you are considering improving your scheme of work.

Read the paper at **bit.ly/PEDquantuminquiry**

Quick Links

Cockney acoustics: from how far away can you hear the sound of Bow bells?

bit.ly/PEDbowbells

Let's have a coffee with the Standard Model of particle physics! OPEN ACCESS

bit.ly/PEDcoffee

Using Arduino in physics experiments: determining the speed of sound in air

bit.ly/PEDsoundair

A 3D-printed model coupled to an Arduino emulates the Rutherford scattering experiment

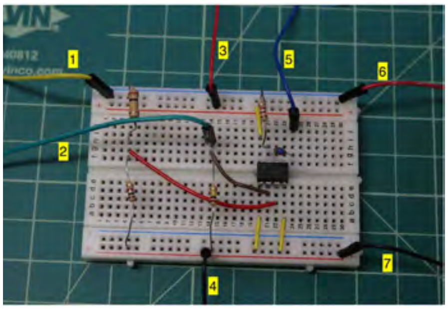
bit.ly/PEDrutherford

Practitioners' views on new teaching material for introducing quantum optics in secondary schools OPEN ACCESS

bit.ly/PEDquantumoptics

Using a siphon to supply spring water to a remote village

bit.ly/PEDsiphon



Credit: Physics Education

The circuit for the Zener diode can be made on a breadboard

Generating gamma-ray statistics without the gamma rays

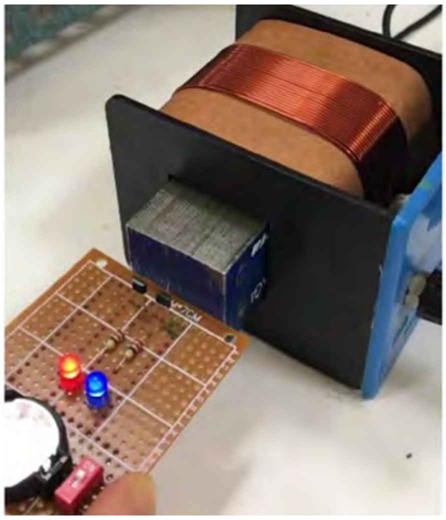
Students do need to have a genuine experience of physics and that means interacting with the physical universe rather than watching someone else do it or using simulations. There are times when providing the means to do that are challenging. In the paper, *The Zener diode: generating gamma-ray statistics without the gamma rays,* Tom Bensky describes how a Zener diode can be used in avalanche mode to give a series of spikes that mimic the random nature of gamma rays arriving at a Geiger-Muller tube. No radioactive sources are needed nor the equipment to detect them. An Arduino is used but these can be purchased at a low price. Some time and effort is required but once assembled the equipment can be used over and over again.

Read the paper at **bit.ly/PEDzener**

Magnets for younger students

Teaching students about magnets can be tricky because at younger ages much of the learning is limited to what magnets do rather than how they do it. Those curious students who want to know how the phenomena are happening may find themselves frustrated. *A magnetic polarity detector* is a paper which may help, describing a simple circuit that allows students to investigate magnets and electromagnets. The circuit uses two small sensors to detect the field and LEDs to show the polarity. While identifying which pole is which probably is not that useful, showing students that the same idea applies to coils could be. They might also investigate the distance over which the device works and hence whether it could be used to measure the strength of a magnetic field.

Read the paper at **bit.ly/PEDpolarity**



Credit: Physics Education

Magnetic pole indications for the magnetic field created by an alternating current coil

Neils Bohr and the barometer

Sixty-one ways to measure the height of a building: an introduction to experimental practices, written by F Bouquet et al, is about the well-known urban myth of Niels Bohr and the barometer. When asked how to measure the height of a building with a barometer, a young Niels Bohr invented a dozen or so experiments that answered the question while avoiding the solution expected by the teacher. The authors revisited this barometer question but changed it to: 'How many ways are there to measure the height of a building with a smartphone?' Unlike Bohr's story, they further asked their students to carry out the experiments they suggested and to evaluate how the results compared with one another. The students came up with 61 ideas and tested many of them. The paper contains a table showing how accurate each method was. There are plenty of ideas in this paper that could make your teaching even more engaging and help your students think about getting practical.

Read the paper at **bit.ly/PEDbohr61**

Measurement of the height of the building using free fall of a smartphone (left) and giant pendulum, using the smartphone's gyroscope

talkphysics

David Cotton, editor of our online discussion forum, chooses his favourite TalkPhysics discussion threads on **quantum and particle physics.**

Log in or register to join the conversation at **talkphysics.org**

Photoelectric effect

The photoelectric effect has been a popular discussion on TalkPhysics over the years. This thread has some alternative setups and ideas, including the one in the picture where you can see we took an aluminium can and sanded off the paint. We then stuck this on polystyrene cups to insulate. The thread includes hints on how to clean the zinc plate from the traditional set up.

bit.ly/TPphotocan

Demonstrating the photoelectric effect with an aluminium can and polystyrene cups

Multiple choice questions

David Keenahan, IOP coach in Ireland, created this thread with lots of multiple-choice questions. Topics include the photoelectric effect, the electron, fission and fusion.

bit.ly/TPmcq

Quantum question...

Mark wrote, “I understand that when an incoming electron has enough energy to cause excitation, it loses some of its KE to cause an orbital electron to excite. But I was asked why an electron which does not have the necessary quanta of energy to cause excitation that even after it collides with an orbital electron, no energy is transferred.” This thread attempts to answer the question.

bit.ly/TPelectronQ

physicsworld

Stories from our magazine for the global physics community. Visit **physicsworld.com**

Credit: Heide Pinkall at Shutterstock

The Bremen drop tower for weightlessness experiments

Bose–Einstein condensates hit record low temperature

A new way of controlling the expansion of matter in a freely falling Bose–Einstein condensate (BEC) has produced the coldest effective temperature ever measured: 38 pK (10^{-12} K) above absolute zero. The method, which allowed researchers in Germany and France to image the condensate’s evolution for more than two seconds, opens the door to enhanced measurements of the gravitational constant g and photon recoil, and could even offer an alternative means of detecting gravitational waves. BECs are clusters of particles in the same quantum ground state. Since they were first created experimentally in 1995, they have become a testbed for research on the quantum nature of matter. To test their technique, researchers led by Ernst Rasel of Leibniz University Hannover used the 110-metre drop tower in Bremen, Germany.

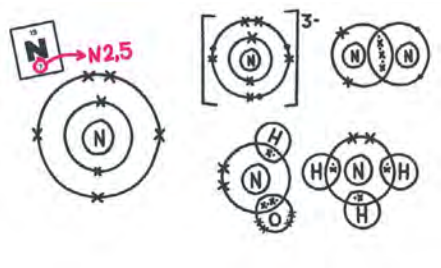
Full article: **bit.ly/PW-bec**

Wave–particle duality quantified for the first time

One of the most counterintuitive concepts in physics – the idea that quantum objects are complementary, behaving like waves in some situations and like particles in others – just got a new and more quantitative foundation. In a twist on the classic double-slit experiment, scientists at Korea’s Institute for Basic Sciences (IBS) used precisely controlled photon sources to measure a photon’s degree of wave-ness and particle-ness. Their results, published in Science Advances, show that the properties of the photon’s source influence its wave and particle character – a discovery that complicates and challenges the common understanding of complementarity. The double-slit experiment is the archetypal example of complementarity at work. The new study adds to this principle by showing that the properties of the slits also matter.

Full article: **bit.ly/PW-duality**

EiC is the Royal Society of Chemistry's magazine for teachers. Visit **edu.rsc.org/eic**



Credit: Dan Bright

How to draw electron configuration diagrams

Download a step-by-step guide to build your 14–16 students' confidence

The idea that electrons orbit the atom in fixed shells, or energy levels, was first suggested by Niels Bohr in 1913. As well as receiving a Nobel Prize for his work, he impressed fellow scientist Ernest Rutherford, who discovered the nucleus of the atom. He did not win over JJ Thomson though, whose plum pudding model was replaced first by Rutherford's and then by Bohr's. Now chemistry students learn the Bohr model as part of their 14–16 studies.

The Bohr model, or the solar system model as it is often called, uses dots or crosses to depict electrons in energy levels, or shells. *Education in Chemistry* has put together a 12-step guide to help students accurately draw electron configuration diagrams for the first 20 elements and boost their confidence. You can download the steps as a poster to display in your school or as a handout for students (or both). You can also download a fact sheet, worksheet and answer sheet. The worksheet asks students to assess diagrams for eight of the first 20 elements, giving them plenty of opportunity to develop their skills and gain confidence.

This is one topic covered by a set of infographic posters with associated classroom activities. So far EiC has looked at allotropes of carbon, thermodynamics, changes of state (using chocolate as an example!), evaporation and buffer solutions.

Find them all at **rsc.li/3DrSt4c**

more...

Get the poster and resources at **rsc.li/3ApaKxa**

Science and Technology Facilities Council

The Rutherford Appleton Laboratory is a national scientific research laboratory operated by the Science and Technology Facilities Council. RAL regularly hosts free events for teachers and school students. Email **visitRAL@stfc.ac.uk** for more information.

Stop press! The world's biggest particle physics experiment, the Large Hadron Collider, will be restarting in 2022, and we will be celebrating with a series of events, activities and resources for schools – find out more at ppd.stfc.ac.uk/Pages/LHC-Restart.aspx

Solving mysteries with muons

The muon and its wobble recently hit headlines, offering clues to a possible fifth fundamental force of nature. Elsewhere at the Rutherford Appleton Laboratory (RAL), muons are solving other mysteries, exploring the physics and chemistry of a huge range of materials, and helping to tackle the world's biggest challenges.

A muon is an unstable fundamental particle, similar to an electron but 207 times heavier. They are very short lived, having an average lifetime of only 2.2 microseconds. Muons are produced on Earth when cosmic rays collide with its atmosphere, and thousands of muons pass through our bodies every minute without us noticing. However, to study materials using muons we need a particle accelerator.

The ISIS Neutron and Muon Source at RAL has a synchrotron that accelerates protons to 84% the speed of light and fires them into a graphite target to produce muons. These muons are used in a range of experiments, from investigating battery materials and superconductors to exploring historical and archaeological objects.

The ISIS facility produces both positive and negative muons to study materials. Positive muons (antimuons) are excellent probes of battery materials, allowing scientists to study ion diffusion during charge and discharge processes, and assess battery performance. The effect of different electrode and electrolyte materials on ion diffusion can also be explored.

Negative muons are particularly useful for studying cultural heritage objects. Recently, scientists from the universities of Oxford and Warwick have been using ISIS's negative muons to study the elemental composition of Roman coins dated 14 CE to 420 CE. Their results revealed clear differences in the composition of the coins, including varying proportions of gold, offering insight into the circulation of gold around the Roman Empire during this period in history.

more...

Find out more about these experiments and explore muon research at ISIS at **isis.stfc.ac.uk/Pages/ScienceStories.aspx**

Careers in particle physics postcards

STFC and NUSTEM's free set of careers postcards highlight the range of skills and applications of particle physics – from cloud architects to electronics apprentices - and include teacher guidance notes.

To download a free set of postcards, please visit **nustem.uk/careers-postcards**

A-level particle physics masterclasses

These will run online and, hopefully, in person. They involve talks by experts, tours of particle accelerators and facilities, interactive exercises using real particle accelerator data, and the chance to meet scientists and engineers.

Rutherford Appleton Laboratory masterclass (15-18 March 2022): **ppm2022.eventbrite.co.uk**

Daresbury Laboratory (date tbc): **daresburyappmc.co.uk**

diamond

nustem

UKRI Science and Technology Facilities Council

IOP Institute of Physics
Quantum Optics, Quantum Information and Quantum Control Group

COMPETITION FOR UK AND IRELAND STUDENTS IN THEIR FINAL 2 YEARS OF PRE-UNIVERSITY EDUCATION (A LEVEL (Y12 &13), SCOTTISH HIGHER & ADVANCED HIGHER (S5 & S6) AND IRISH SENIOR CYCLE, OR EQUIVALENT)

QUANTUM ON THE CLOCK

SCAN ME

Create a 3-minute video about any aspect of quantum science or technology!

Entries can be individual or in teams of up to 4, and you can be as creative as you like with the video.

Find out more at the IOP QQQ group website using the QR code above, or by visiting: www.iop.org/physics-community/special-interest-groups/qqq-group

Follow us on Twitter for latest updates: @qqq_iop

Quantum physics posters for schools

This edition of *Classroom Physics* came with a complimentary poster for all IOP Affiliated Schools from Quantum City, the public engagement arm of the UK National Quantum Technologies Programme. Their new series of six posters for schools shows the many exciting applications of quantum technologies, highlighting the various life changing and revolutionary applications of quantum computing, communications, imaging, measurement and sensing. You can request printed copies of the subsequent five posters to liven up your classroom for free by visiting:

quantumcity.org.uk/contact

UKRI National Quantum Computing Centre

On the 20th of September 2021 a breaking-ground ceremony was led by Professor Sir Peter Knight for the National Quantum Computing Centre's (NQCC) new facility at Harwell Campus in Oxfordshire.

An important purpose of the centre will be to train and educate skilled individuals and inspire the next generation of scientists and engineers by engaging them with quantum computing. The NQCC will raise awareness and make educational materials available for use by teachers across the UK, as well as organising dedicated workshops and events aimed at both teachers and pupils.

Get in touch: comms@nqcc.ac.uk

2021 IOP Awards

We would like to offer our warmest congratulations to the winners of the 2021 IOP Teachers of Physics Award.

Edward Male, Ysgol Harri Tudur, Pembroke
Dr Isabelle Parkes, The Arnewood School, New Milton
Lawrence Herklots, King Edward VI School, Southampton
Sarah Hookway, Reepham High School and College, Reepham
Dr Steve Essex, Ernesford Grange Community Academy, Binley
Steve Dempsey, Turriff Academy, Turriff
Tom Tierney, St Vincent's Castleknock College, Dublin

We would also like to extend our congratulations to **David Barclay Ferguson** at Uppingham School for winning the 2021 IOP Technician Award in the secondary schools category.

Nominations for our 2022 Awards are now open. Please feel free to nominate a teacher colleague, technician colleague or indeed yourself. To read more, visit **iop.org/about/awards/teachers-physics-award** and **iop.org/about/awards/technical-skills-awards/technician-award**

What would improve physics teacher retention?

Share your views via our survey

The shortage of physics teachers in schools is not a new problem. As we continue to analyse and communicate the issues, we need your help. As a part of a suite of initiatives, we are asking all secondary level physics teachers in the UK and Ireland to complete a confidential survey (we will not collect any data that could identify you).

smartsurvey.co.uk/s/IOP-Shareyourviews

The more physics teachers we hear from, the more compelling a case we can build to influence changes in policy. Please find 15 minutes to make sure your views are included.

Thank you!

IOP Institute of Physics

Engineering careers

neonfutures.org.uk

Funding opportunity: what will you investigate?

Through the Royal Society's Partnership Grants scheme, your school could receive up to £3,000 to run an investigative STEM project in partnership with a STEM professional from academia or industry. An extension to the Partnership Grants scheme called Tomorrow's Climate Scientists funds projects specifically researching into climate change and biodiversity. The next round of funding will open in early 2022 and will be available to primary and secondary schools and colleges.

To find out more and for support, contact the Society's Schools Engagement team via **education@royalsociety.org** or visit **royalsociety.org/partnership**

IOP DOMAINS CPD wins award

We are delighted to announce that IOP DOMAINS, the online teacher CPD programme that we launched during lockdown comprising videos and live workshops, has won the CPD category in the Teach Secondary awards.

The judges said:
"This is an impressively-featured, free resource that can build confidence, teacher expertise and knowledge, particularly among non-specialist teachers who may not have studied physics at degree level. The website is well-organised and easy to use, supporting both individual CPD and the ability for departments to learn together."

Congratulations to everyone involved. A great deal of work went into preparing and filming these videos in a very short time period while ensuring that the content was sound. The videos have already been viewed over 11,000 times – and there are plenty of online workshops still running.

teachawards.com/winners/

IOP DOMAINS live events iop.org/domains

Online workshops for everyone teaching physics. Watch our award winning online CPD videos before you join to prepare.

Energy Stores at 11-14
11 Jan | 5 - 6 pm

Energy Calculations at 14-16
18 Jan | 5 - 6 pm

Teaching Energy to Post-16 Students
20 Jan | 5:30 - 6:30 pm

Exploring the Particle Model at 11-14
25 Jan | 5 - 6 pm

Does it Matter!? at 14-16
1 Feb | 5 - 6 pm

Teaching Kinetic Theory to Post-16 Students
3 Feb | 5:30 - 6:30 pm

Radioactivity - from Macroscopic to Microscopic at 14-16
8 Feb | 5 - 6 pm

Radioactivity - Exploring Half-Life and Decay Equations at 14-16
15 Feb | 5 - 6 pm

Teaching Radioactivity to Post-16 Students
17 Feb | 5:30 - 6:30 pm

Teaching Nuclear Physics to Post-16 Students
10 Mar | 5:30 - 6:30 pm

IOP MATHS ON MONDAY 2022
10 & 24 Jan, 7 Feb, 7 & 21 Mar | 7-8pm

For all physics/science teachers to develop understanding of maths required at GCSE. Graphs, adding and resolving vectors, SUVAT: equations of motion and challenging GCSE questions.

talkphysics.org/groups/maths-on-monday

WINTER SCHOOLS
14-16 & 21-23 Feb | all day, online

For all teachers of physics, trainee science teachers, NQTs/ECTs and those new to or less confident with teaching physics. Nine sessions over three days: forces, electricity, energy, maths, inclusion and careers.

Booking will open in January at
talkphysics.org/events

EVERYONE COACHING PHYSICS
13 Jan, 10 Mar, 12 May, 30 Jun | 5-6 pm and 7-8pm

For CPD leaders, lone physics teachers supporting their department, mentors and supporters of early career teachers. We will discuss ideas and best practice in coaching physics plus recent education research.

talkphysics.org/events

Contact your IOP regional education manager to find out about teacher support in your area:

Scotland
Stuart Farmer
education-scotland@iop.org

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