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November 2025

Powering up

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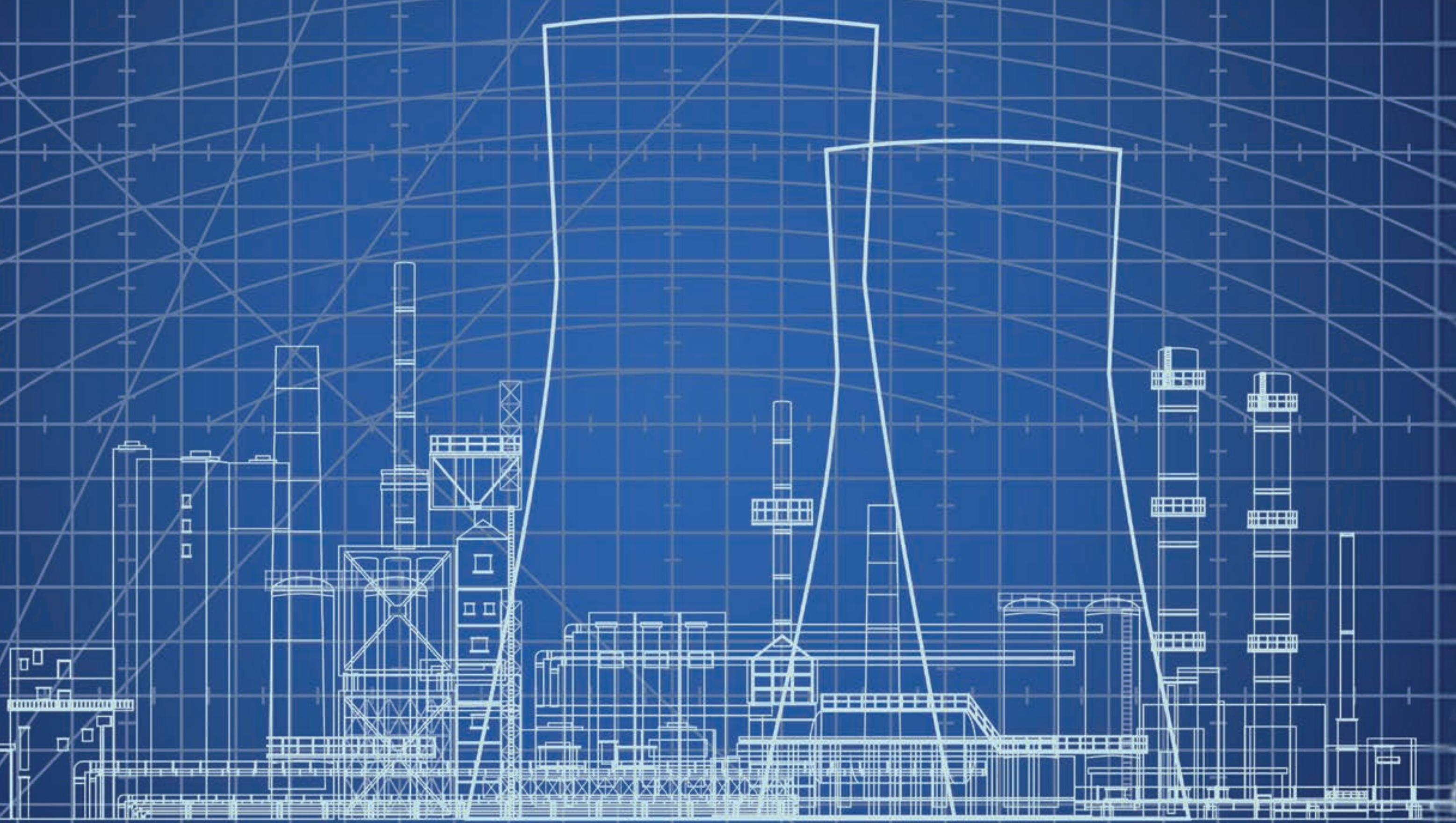
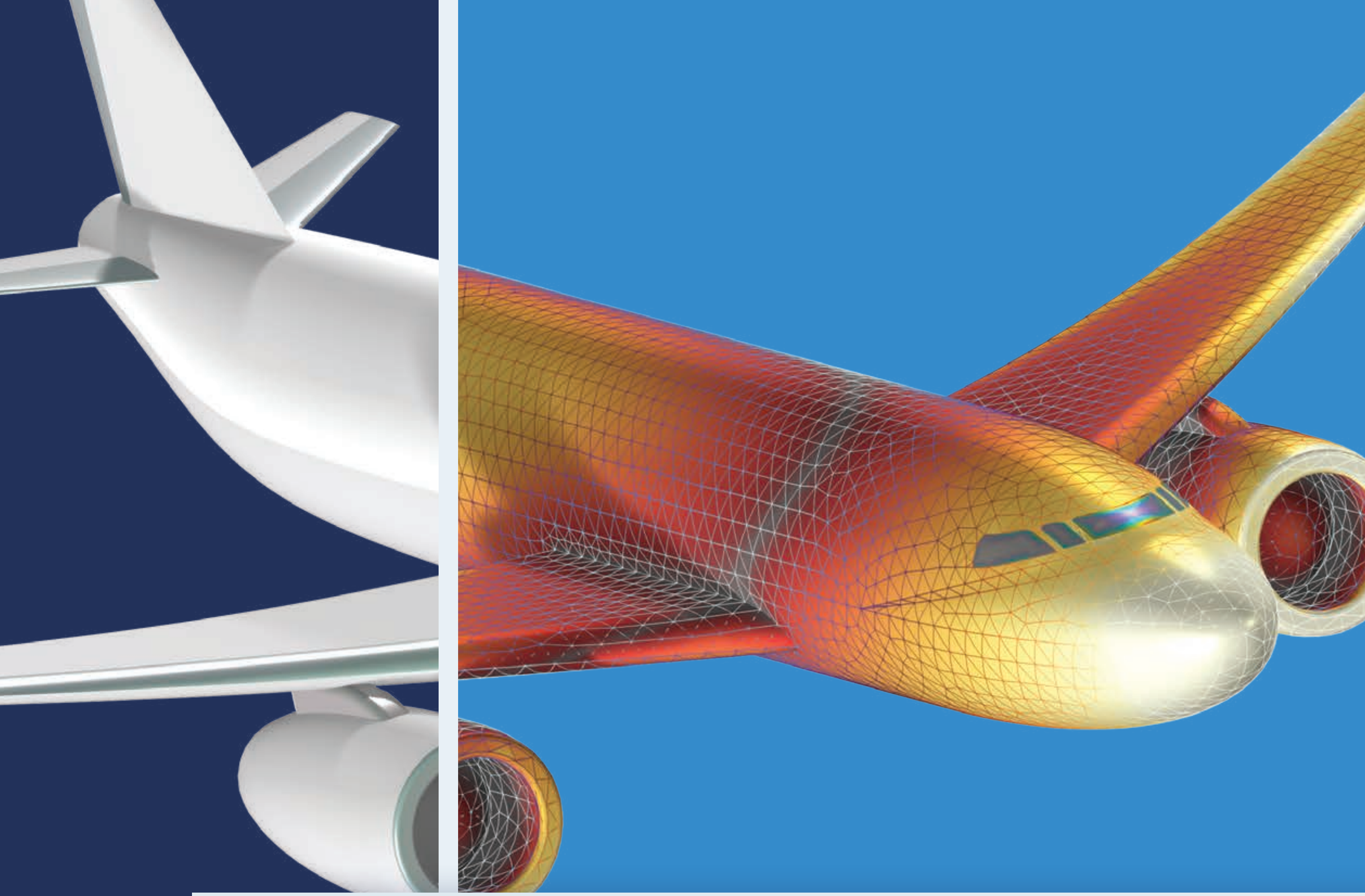


Materials science The new alchemy for the 21st century

Entangled business Surveying the quantum tech landscape

Forgotten heroes Nobel laureates you've never heard of



physicsworld

Volume 38 No 11

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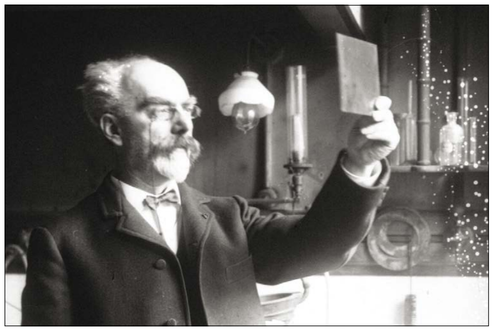

AUDIO The *Physics World* editorial team introduces the highlights of the November issue

Physics World is published monthly as 12 issues per annual volume by IOP Publishing Ltd, No.2 The Distillery, Glassfields, Avon Street, Bristol, BS2 0GR, UK

Printed in the UK by Warners (Midlands) plc, The Maltings, West Street, Bourne, Lincolnshire PE10 9PH

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Cover image
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News & Analysis

Quantum tunnelling bags Nobel prize

The 2025 Nobel Prize for Physics has gone to John Clarke, Michel Devoret and John Martinis for the discovery of macroscopic tunnelling, as **Hamish Johnston** and **Michael Banks** report

John Clarke, Michel Devoret and John Martinis last month won the 2025 Nobel Prize for Physics "for the discovery of macroscopic quantum mechanical tunnelling and energy quantization in an electric circuit". The award includes a SEK 11m prize (£0.87m), which is shared equally by the winners. The prize will be presented at a ceremony in Stockholm on 10 December.

The trio carried out their prizewinning work in the mid-1980s at the University of California, Berkeley. At the time Devoret was a postdoc and Martinis was a graduate student – both working for Clarke, who is a Fellow of the Institute of Physics (IOP). They were looking for evidence of macroscopic quantum tunnelling (MQT) in a Josephson junction, which comprises two pieces of superconductor separated by an insulating barrier. In 1962 the British physicist Brian Josephson predicted how the Cooper pairs of electrons that carry current in a superconductor can tunnel across the barrier unscathed. This Josephson effect was confirmed experimentally in 1963.

The lowest-energy (ground) state of a superconductor is a macroscopic quantum state in which all Cooper pairs are described by a single quantum-mechanical wavefunction. In the late 1970s, the British-American physicist Anthony Leggett proposed that the tunnelling of this entire macroscopic state could be observed in a Josephson junction. The idea is to put the system into a metastable state in which electrical current flows without resistance across the junction – resulting in zero voltage across the junction. If the system is indeed a macroscopic quantum state, then it should be able to occasionally tunnel out of this metastable state, resulting in a voltage across the junction.

This tunnelling can be observed by increasing the current through the junction and measuring the current at which a voltage occurs – obtaining an average value over many such measurements. As the temperature of the device is reduced, this average current increases – something that is expected regardless of whether the system is in a macroscopic quantum state. However, at very low temperatures the average current becomes independent of temperature, which is the signature of macroscopic quantum tunnelling that Martinis, Devoret and Clarke were seeking.

UC Berkeley; Yale University; UC Santa Barbara

Quantum pioneers (from left to right) John Clarke, Michel H Devoret and John M Martinis.

As well as observing the signature of tunnelling, they were also able to show that the macroscopic quantum state exists in several different energy states. Such a multilevel system is essentially a macroscopic version of an atom or nucleus, with its own spectroscopic structure. Their challenge was to reduce the noise in their experimental apparatus, because noise has a similar effect as tunnelling on their measurements. The noise-control techniques developed by the trio to observe MQT and the fact that a Josephson junction can function as a macroscopic multilevel quantum system have led to the development of superconducting quantum bits (qubits) that form the basis of some nascent quantum computers.

During a press conference announcing the prize, Clarke noted that he was "stunned" upon hearing the news. "To put it mildly, it was the surprise of my life," noted Clarke. "It had never occurred to me that this might be the basis of a Nobel prize." As well as acknowledging the contributions of Devoret and Martinis, Clarke also said that their work was made possible by the work of Leggett and Josephson – previous Nobel winners themselves – who laid the groundwork for their work on tunnelling in superconducting circuits. At a Berkeley press conference later that day, Clarke noted that he was afforded time and resources such as lab space, students and equipment to carry out the work. He warned that current cuts to US science are an "immensely serious problem" that will cripple US science. "It is going to be disastrous if this continues," Clarke added.

This year's prize is also timely given that physicists are celebrating the International Year for Quantum Science and Technology. "It is wonderful in the International Year of Quantum to see this area of physics being recognized," says IOP chief executive Tom Grinyer. "The IOP is doubly proud to see one of our own celebrated by the Nobel committee and our congratulations extend to Michel Devoret and John Martinis for their important and remarkable work."

From the lab to industry

As well as having scientific significance, the trio's work has led to the development of nascent commercial quantum computers that employ superconducting circuits. Physicist and tech entrepreneur Ilana Wisby, who co-founded Oxford Quantum Circuits, told *Physics World* "It's such a brilliant and well-deserved recognition for the community," while Izhar Medalsy, co-founder and chief executive officer of the US-based Quantum Elements, added it is "remarkable that experiments performed four decades ago to probe fundamental questions about quantum mechanics at the macroscopic scale have become the basis for one of the leading platforms in the quest for practical quantum computing today".

Michael Hush, chief scientist of Q-CTRL based in Sydney, Australia, also offered his congratulations. "By proving that engineered superconducting systems could act as controllable 'artificial atoms', their work laid the essential foundation for the development of superconducting qubits, one of the leading platform for today's quantum computers," Hush notes. "This recognition not only honours their groundbreaking contributions to fundamental physics, but also highlights their profound impact on the technologies that are shaping the future of quantum information science."

AUDIO

Listen to Ilana Wisby and *Physics World*'s Hamish Johnston discuss this year's Nobel Prize for Physics

Lives in science

Clarke was born in 1942 in Cambridge, UK. He received his BA in physics from the University of Cambridge in 1964, staying on there to do a PhD, which he completed in 1968. He then moved to the University of California, Berkeley, to carry out a postdoc before joining the physics faculty in 1969 where he has remained since.

Devoret was born in Paris, France in 1953. He graduated from Ecole Nationale Superieure des Telecommunications in Paris in 1975 before earning a PhD from the University of Paris, Orsay, in 1982. He then moved to the University of California, Berkeley, to work in Clarke's group collaborating with Martinis who was a graduate student at the time. In 1984 Devoret returned to France to start his own research group at the Commissariat à l'Energie Atomique in Saclay (CEA-Saclay) before heading to the US to Yale University in 2002. In 2024 he moved to the University of California, Santa Barbara, and also became chief scientist at Google Quantum AI.

Martinis was born in the US in 1958. He received a BS in physics in 1980 and a PhD in physics both from the University of California, Berkeley. He then carried out postdocs at CEA-Saclay and the National Institute of Standards and Technology in Boulder, Colorado, before moving to the University of California, Santa Barbara, in 2004. In 2014 Martinis and his team joined Google with the aim of building the first useful quantum computer before he moved to Australia in 2020 to join the start-up Silicon Quantum Computing. In 2022 he co-founded the company Qolab, of which he is currently the chief technology officer.

Hamish Johnston is an online editor of *Physics World*. **Michael Banks** is news editor of *Physics World*

Awards

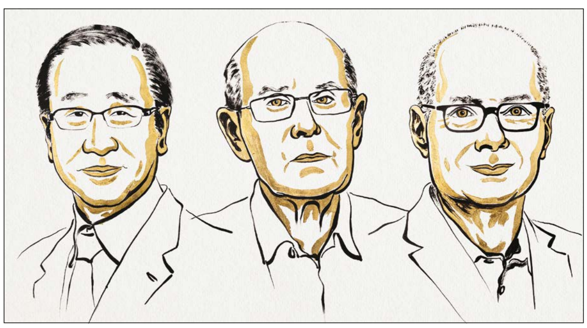
Chemistry Nobel goes to work on metal-organic frameworks

Susumu Kitagawa, Richard Robson and Omar Yaghi have been awarded the 2025 Nobel Prize for Chemistry "for developing metal-organic frameworks" (MOFs). The SEK 11m (£0.87m) prize money is shared equally by the winners.

Beginning in the late 1980s and for the next couple of decades, the trio, who are all trained chemists, developed a new form of molecular architecture in which metal ions function as cornerstones that are linked by long organic carbon-based molecules. Together, the metal ions and molecules form crystals that contain large cavities through which gases and other chemicals can flow.

Yet this year's laureates had to overcome several challenges before they could be used such as making them stable and flexible, which Kitagawa noted "was very tough" during a press conference announcing the prize. By varying the building blocks used in the MOFs, researchers can design them to capture and store specific substances as well as drive chemical reactions or conduct electricity. Following the laureates' work, chemists have built tens of thousands of different MOFs. Indeed, 3D MOFs are now an important class of materials that could be used in applications as diverse as sensing, gas storage, catalysis and optoelectronics.

MOFs can capture water from air in the desert, sequester carbon dioxide from industry effluents, store hydrogen gas, recover rare-earth metals from waste, break down oil contamination as well as extract "forever chemicals" such as PFAS from water. Their 2D versions might even be used as flexible material platforms to realize exotic quantum phases, such as topological and anomalous quantum Hall insulators. "My dream is to capture air and to separate air into CO_2, oxygen and water and convert them to usable materials using renewable energy," noted Kitagawa, who added that he was "deeply honoured and delighted" that his research had been recognized.



Niklas Elmehed for Nobel Prize Outreach

Material focus Susumu Kitagawa, Richard Robson and Omar Yaghi are honoured for their work on metal-organic frameworks.

Kitagawa was born in 1951 in Kyoto, Japan. He obtained a PhD from Kyoto University in 1979 and then held positions at Kindai University and Tokyo Metropolitan University, before joining Kyoto University in 1998 where he is currently based. Robson was born in 1937 in Glusburn, UK. He obtained a PhD from University of Oxford in 1962. He has been based at the University of Melbourne since 1966. Yaghi was born in 1965 in Amman, Jordan. He obtained a PhD from University of Illinois Urbana-Champaign, US, in 1990. He then held positions at Arizona State University, the University of Michigan and the University of California, Los Angeles, before joining the University of California, Berkeley, in 2012 where he is currently based.

Michael Banks

People

Cosmology pioneer George Smoot dies aged 80

George Smoot, who shared the Nobel Prize for Physics in 2006 for his studies of the cosmic microwave background (CMB), died on 18 September at the age of 80. Smoot's work on the blackbody form and anisotropy of the CMB radiation provided strong evidence that the universe was created in a massive explosion called the Big Bang.

Born in Yukon, Florida on 20 February 1945, Smoot studied mathematics and physics at the Massachusetts Institute of Technology (MIT). He completed a PhD in particle physics at MIT in 1970. Smoot then moved to the University of California, Berkeley, and the Lawrence Berkeley National Laboratory, where he began working on the NASA-funded High Altitude Particle Physics Experiment.

After devising other balloon-borne detectors to search for antimatter, in 1973 Smoot switched to studying the CMB, which had been discovered by Arno Penzias and Robert Wilson in 1964. Smoot and colleagues conceived several experiments to detect possible variations in the CMB, which at the time was thought to be isotropic.

CERN

Cosmic explorer Smoot led efforts to measure the tiny variations in the cosmic microwave background.

This included using a differential microwave radiometer (DMR) aboard a Lockheed U-2 plane that could measure differences in temperature as small as one-thousandth of a degree in the microwave radiation between two points.

Smoot proposed a space-based mission to measure possible anisotropies in the CMB. The probe eventually became NASA's Cosmic Background Explorer (COBE) satellite, which went into space in 1989 containing a DMR instrument that Smoot led. Following two years of observations, in April 1992 the COBE team announced that the CMB still bore the black-body signature, albeit at a much lower temperature (2.7 K) due to the ongoing expansion of the universe. The COBE researchers also announced that they had detected tiny temperature fluctuations – as small as one part in 100 000 – in the CMB.

For the work, Smoot together with John Mather who worked on another instrument aboard COBE, shared the 2006 Nobel Prize for Physics "for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation". In 2007 he became founding director of the Berkeley Center for Cosmological Physics, for which he used the money from his Nobel prize as seed cash. Two years later he joined Université Paris-Diderot VII (now known as the Université Paris-Cité) where he founded the Paris Center for Cosmological Physics.

Smoot made several media appearances throughout his career including playing himself on the hit TV show *The Big Bang Theory*. He also appeared in the TV show *Are You Smarter Than a 5th Grader?* where he took the top $1m prize.

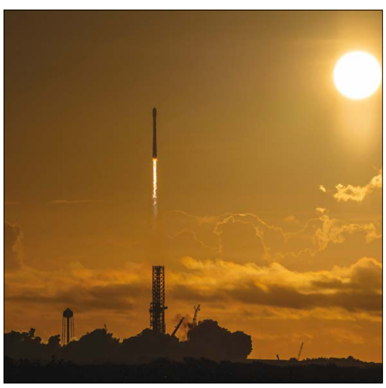
Michael Banks

Space

NASA launches IMAP to upgrade space weather forecasts

NASA has launched a two-year mission to study the boundary of the heliosphere, a huge protective bubble in space created by the Sun. The Interstellar Mapping and Acceleration Probe (IMAP) took off on 24 September aboard a SpaceX Falcon 9 rocket from the Kennedy Space Center at Cape Canaveral in Florida. The mission is now on a four-month journey to Lagrange point 1 (L1) – a point in space about 1.6 million kilometres from the Earth towards the Sun.

The solar wind is a stream of charged particles emitted by the Sun into space that helps to form the heliosphere. IMAP will study the solar wind and its interaction with the interstellar medium to better understand the heliosphere and its boundaries, which begin about 14 billion kilometres from Earth. This boundary offers protection from the harsh radiation from space and is key to creating and maintaining a habitable solar system.



SpaceX

Gone with the wind The Interstellar Mapping and Acceleration Probe will spend two years studying the solar wind and its interaction with the interstellar medium.

IMAP, which is 2.4 m in diameter and almost 1 m high, will also support real-time observations of the solar wind and energetic particles that can harm satellites as well as disrupt global communications and electrical grids on Earth. From L1, IMAP will provide a 30-minute warning to astronauts and spacecraft near Earth of harmful radiation.

IMAP contains 10 instruments that capture data on energetic neutral atoms, the solar wind and interstellar dust. They include a high-energy ion telescope, an electron instrument as well as a magnetometer that has been developed by Imperial College London. It will measure the strength and direction of magnetic fields in space, providing crucial data to improve our understanding of space weather.

"Our magnetic field instrument will help us understand how particles are accelerated at shock waves and travel through the solar system," notes Imperial's Timothy Horbury.

Michael Banks

Space

NASA criticized over Dragonfly

An internal audit has slammed NASA over its handling of the Dragonfly mission to Saturn's largest moon, Titan. The drone-like rotorcraft, which is designed to land on and gather samples from Titan, has been hit by a two-year delay, with costs surging by $1bn to $3.3bn. NASA now envisions a launch date of July 2028, with Dragonfly arriving at Titan in 2034.

NASA chose Dragonfly in June 2019 as the next mission under its New Frontiers programme. Managed by the Johns Hopkins University Applied Physics Laboratory, it is a nuclear-powered, car-sized craft with eight rotors. Dragonfly will spend over three years studying potential landing sites before collecting data on Titan's unique liquid environment and looking for signs that it could support life.

The audit, carried out by the NASA Office of Inspector General, took no issue with NASA's simulations of the rotors' performance. Indeed, the mission team is already planning formal testing of the system to start in January. But the audit criticized NASA for letting Dragonfly's development "proceed under less than ideal circumstances", including with "lower than optimum project cost reserves".

The report aims to avoid those problems affecting future New Horizon missions. Specifically, it calls on Nicky Fox, NASA's head of science, to document lessons learned from NASA's decision to start work on the project before establishing a baseline commitment.

It also says that NASA should maintain adequate levels of "unallocated future expenses" for the project and make sure that "the science community is informed of updates to the expected scope and cadence for future New Frontier missions". A NASA spokesperson told *Physics World* that NASA management agrees with the recommendations in the report, and that it "will use existing resources to address [them]".

Peter Gwynne
Boston, MA

UK universities

Physics departments at risk, warns IOP

More than a quarter of UK university physics departments could be shut down within the next couple of years, according to a survey carried out by the Institute of Physics (IOP). It also reveals that almost 60% of departmental heads expect physics degree courses to close within that time, while more than 80% of those questioned say they expect to see job losses.

The survey findings are published in a new report – *Physics Matters: Funding the Foundations of Growth* – that says UK university physics is a "major strength" of the UK university system and vital to "national security and technological sovereignty". The UK currently has about 17 000 physics undergraduates and more than 6000 physics department staff, with about 1 in 20 jobs in the UK using physics-related knowledge and skills.

However, the report adds that this strength cannot be taken for granted and points to "worrying signs" that university physics has started to "punch below its weight". This is compounded, the IOP says, by a drop in the number of students studying physics at UK universities and flat grant funding for UK physics departments over the past decade. In addition, UK universities are being hit by financial challenges and funding shortfalls caused by inflationary pressure and a drop in international student numbers. Given that physics comes with high teaching costs, the report states this threatens a "perfect storm" for university physics departments.

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Under threat
The Institute of Physics wants the UK government to commit extra cash for university science and engineering departments.

The survey of 31 departmental heads, which was carried out in August, found that three unnamed departments face imminent closure, with a further 11 anticipating shutting courses. When asked to look ahead over the next two years, eight say they expect to face closure, with 18 anticipating course closures. One head of physics at a UK university told the IOP that they are concerned they are "close to breaking point". "Our university has a £30m deficit," the anonymous head said. "Staff recruitment is frozen, morale is low. Yet colleagues in our school continue to deliver with less and less and under increasing pressure."

Jonte Hance, a quantum physicist at Newcastle University, told *Physics World* that the threat of closures is "horrifying". In 2004 Newcastle closed its physics department before reopening it over a decade later. "Worryingly, this approach – ignoring, or even cutting, any departments that don't make a massive short-term profit – doesn't just seem to be a panicked knee-jerk response on the part of vice-chancellors, but part of a concerted and planned strategy, aiming to turn universities into business incubators," adds Hance.

The IOP is now calling on the UK government to commit additional funding for science and engineering departments to help with the operation, maintenance, refurbishment and building of labs and technical facilities. It also wants an "early-warning system" created for departments at risk as well as changes to visa policy to remove international students from net migration figures, retain the graduate visa in its current form, and make "global talent and skilled worker" visas more affordable.

In addition, the IOP wants the UK government to develop a decade-long plan that includes reform of higher-education funding so universities can fund the cost of teaching "important subjects such as physics". Keith Burnett, the outgoing IOP president, warns that without such action, the UK is "walking towards a cliff edge", although he believes there is still time to "avert a crisis".

"While we understand the pressures on public finances, it would be negligent not to sound the alarm for a national capability fundamental to our wellbeing, competitiveness and the defence of the realm," says Burnett.

Michael Banks

Awards

Michael Berry wins 2025 Isaac Newton Medal

The theoretical physicist Michael Berry from the University of Bristol, UK, has won the 2025 Isaac Newton Medal and Prize for his "profound contributions across mathematical and theoretical physics in a career spanning over 60 years". Presented by the Institute of Physics (IOP), the international award is given annually for "world-leading contributions to physics by an individual of any nationality".

Born in 1941 in Surrey, UK, Berry earned a BSc in physics from the University of Exeter in 1962 and a PhD from the University of St Andrews in 1965. He then moved to Bristol, where he has remained for the rest of his career. Berry is best known for his work in the 1980s in which he showed that, under certain conditions, quantum systems can acquire what is known as a geometric phase. He was studying quantum systems in which the Hamiltonian describing the system is slowly changed so that it eventually returns to its initial form.

Berry showed that the adiabatic theorem widely used to describe such systems was incomplete and that a system acquires a phase factor that depends on the path followed, but not on the rate at which the Hamiltonian is changed. This geometric phase factor is now known as the Berry phase. Over his career Berry has written some 500 papers across a wide number of topics. In physics, Berry's ideas have applications in condensed matter, quantum information and high-energy physics, as well as optics, nonlinear dynamics, and atomic and molecular physics. In mathematics, meanwhile, his work forms the basis for research in analysis, geometry and number theory.

Michael Berry

Quantum pioneer Michael Berry is best known for his work in the 1980s on the Berry Phase.

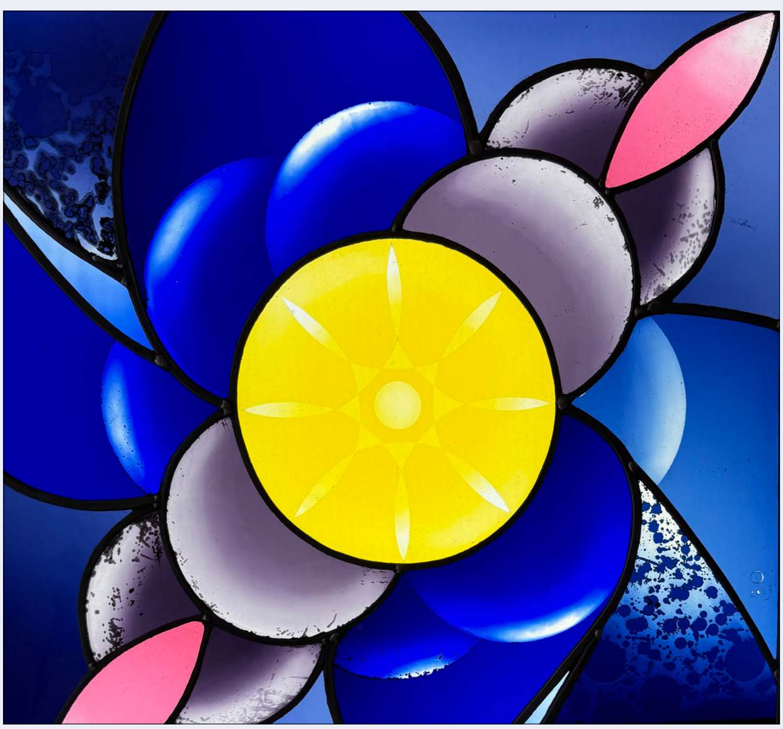
Over the years, Berry has won a number of other honours, including the IOP's Dirac Medal and the Royal Medal from the Royal Society, both awarded in 1990. He was also given the Wolf Prize for Physics in 1998 and the 2014 Lorentz Medal from the Royal Netherlands Academy of Arts and Sciences. In 1996 he received a knighthood for his services to science.

Berry's latest honour forms part of the IOP's wider 2025 awards, which recognize everyone from early-career scientists and teachers to technicians and subject specialists. Other winners include Julia Yeomans, who receives the Dirac Medal and Prize for her work highlighting the relevance of active physics to living matter. In a statement, IOP president Michele Dougherty congratulated all the winners. "It is becoming more obvious that the opportunities generated by a career in physics are many and varied – and the potential our science has to transform our society and economy in the modern world is huge," says Dougherty.

● For a full list of 2025 award winners, see: tinyurl.com/3b8jemhf

Michael Banks

Discovery of the Higgs boson at CERN inspires new stained-glass artwork



Oksana Kondratyeva

London-based artist Oksana Kondratyeva has created a new stained-glass artwork – entitled *Discovery* – that is inspired by the detection of the Higgs boson at CERN's Large Hadron Collider (LHC) in 2012. Born in Ukraine, Kondratyeva has a PhD in the theory of architecture and has an artist residency at the Romont Glass Museum (Vitromusée Romont) in Switzerland, where *Discovery* is currently exhibited. In 2023 Kondratyeva travelled to visit the LHC at CERN, which she says is "more than a laboratory [but] a gateway to the unknown". Kondratyeva says that the focal point of the artwork – a circle structured with geometric precision – represents the collision of two high-energy protons. The surrounding lead lines in the panel trace the trajectories of particle decays as they move through a magnetic field: right-curved lines represent positively charged particles, left-curved lines indicate negatively charged ones, while straight lines signify neutral particles unaffected by the magnetic field. The geometric composition within the central circle reflects the hidden symmetries of physical laws – patterns that only emerge when studying the behaviour of particle interactions. "Through glass, light and colour I sought to express the invisible forces and delicate symmetries that define our universe – ideas born in the realm of physics, yet deeply resonant in artistic expression," notes Kondratyeva.

Michael Banks

Research

US societies blast Trump order to politicize grants

Almost 60 US scientific societies have signed a letter calling on the US government to "safeguard the integrity" of the peer-review process when distributing grants. The move is in response to an executive order issued by the Trump administration in August that places accountability for reviewing and awarding new government grants in the hands of agency heads.

The executive order – *Improving Oversight of Federal Grantmaking* – calls on each agency head to "designate a senior appointee" to review new funding announcements and to "review discretionary grants to ensure that they are consistent with agency priorities and the national interest". The order outlines several previous grants that it says have not aligned with the Trump administration's current policies, claiming that in 2024 more than a quarter of new National Science Foundation (NSF) grants went to diversity, equity and inclusion and what it calls "other far-left initiatives".

iStock/uschools

Controversial move An executive order issued by the Trump administration in August places accountability for reviewing and awarding new government grants in the hands of agency heads.

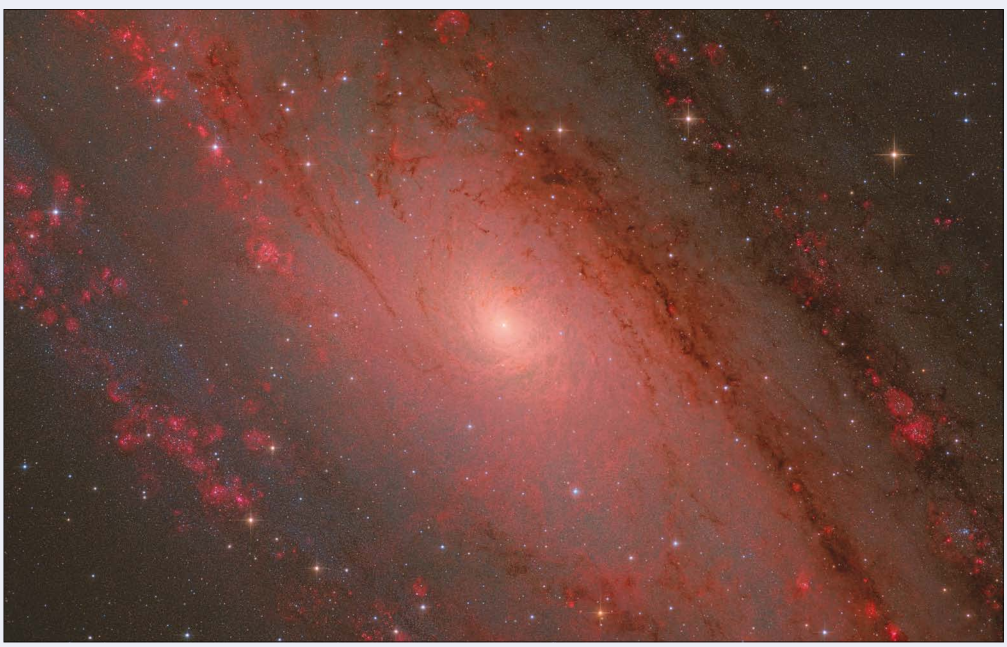
"These NSF grants included those to educators that promoted Marxism, class warfare propaganda, and other anti-American ideologies in the classroom, masked as rigorous and thoughtful investigation," the order states. "There is a strong need to strengthen oversight and coordination of, and to streamline, agency grantmaking to address these problems, prevent them from recurring, and ensure greater accountability for use of public funds more broadly."

In response, the 58 agencies – including the American Physical Society, the American Astronomical Society, the Biophysical Society, the American Geophysical Union and SPIE – have written to the majority and minority leaders of the US Senate and House of Representatives, to voice their concerns that the order "raises the possibility of politicization" in federally funded research.

"Our nation's federal grantmaking ecosystem serves as the gold standard for supporting cutting-edge research and driving technological innovation worldwide," the letter states. "Without the oversight traditionally applied by appropriators and committees of jurisdiction, this [order] will significantly increase administrative burdens on both researchers and agencies, slowing, and sometimes stopping altogether, vital scientific research that our country needs." The letter says more review and oversight is required by the US Congress before the order should go into effect, adding that the scientific community "is eager" to work with congress and the Trump administration "to strengthen our scientific enterprise".

Peter Gwynne
Boston, MA

Andromeda image wins Royal Observatory Greenwich prize



Weitang Liang, Qi Yang, Chuhong Yu

Photographers Weitang Liang, Qi Yang and Chuhong Yu have beaten thousands of amateur and professional photographers from around the world to receive the 2025 Royal Observatory Greenwich's ZWO Astronomy Photographer of the Year. Their image – *The Andromeda Core* – showcases the core of the Andromeda galaxy (M31) in exceptional detail, revealing the intricate structure of the galaxy's central region and its surrounding stellar population. The image was taken with a long-focal-length telescope from the AstroCamp Observatory in Nerpio, Spain. "Not to show it all – this is one of the greatest virtues of this photo. The Andromeda galaxy has been photographed in so many different ways and so many times with telescopes that it is hard to imagine a new photo would ever add to what we've already seen," notes astrophotographer László Francsics who was a judge for this year's competition. As well as winning the £10 000 top prize, the image has gone on display along with other selected pictures from the competition at an exhibition at the National Maritime Museum observatory. The award – now in its 17th year – is run by the Royal Observatory Greenwich in association with the astrophotography firm ZWO and *BBC Sky at Night Magazine*.

Michael Banks

Research updates

Quantum gas keeps its cool

New measurements on Bose–Einstein condensates could help us to understand how objects go from being quantum and ordered to classical and chaotic, as **Isabelle Dumé** explains

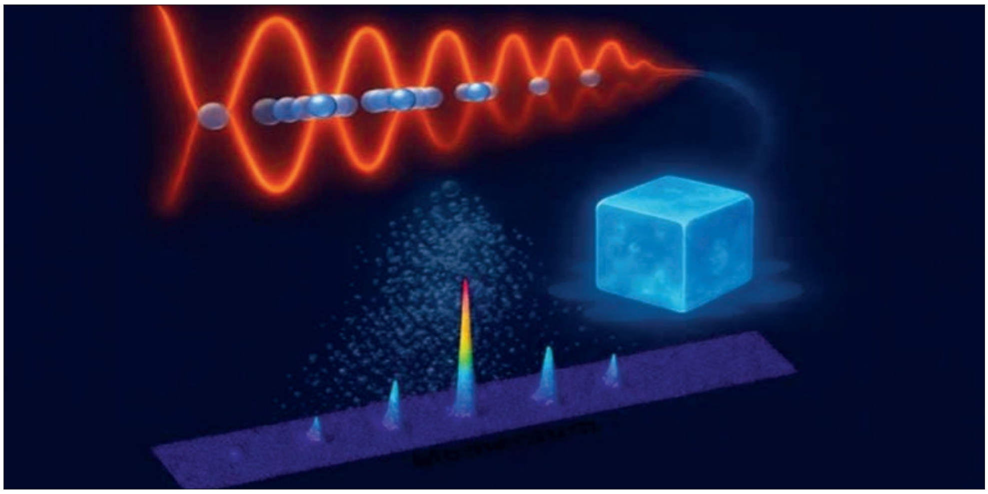
Adding energy to a system usually heats it up, but physicists at the University of Innsbruck in Austria have now discovered a scenario in which this is not the case. Their new platform – a 1D fluid of strongly interacting atoms cooled to just a few nanokelvin above absolute zero – could be used to study how objects transition from being quantum and ordered to classical and chaotic (*Science* **389** 716).

Chaos plays a crucial and often useful role in many areas of science – from nonlinear complex systems in mathematics, physics and biology to ecology, meteorology and economics. While we know how chaos emerges in classical systems, how it does so in quantum materials is still little understood as when this happens, the quantum system reverts to being classical.

Researchers have traditionally studied chaotic behaviour in driven systems – that is, rotating objects periodically kicked by an external force. The quantum version of these is the quantum kicked rotor (QKR). Here, quantum coherence effects can prevent the system from absorbing external energy, meaning that, in contrast to its classical counterpart, it doesn't heat up – even if a lot of energy is applied. This "dynamical localization" effect has already been seen in dilute ultracold atomic gases.

Real-world systems, however, contain many particles that interact with each other – something that can destroy dynamical localization. Recent theoretical work has suggested that this localization may persist in some types of interacting, even strongly interacting, many-body quantum systems – for example, in 1D bosonic gases.

In the new work, Hanns-Christoph Nägerl and colleagues made a QKR by subjecting samples of ultracold caesium atoms to periodic kicks by means of a "flashed-on lattice potential". They did this by loading a Bose–Einstein condensate of these atoms into an array of narrow 1D tubes created by a 2D optical lattice formed by laser beams propagating in the x–y plane at right angles to each other. They then increased the power of the beams to heat up the atoms.



Universität Innsbruck

Chaos theory Researchers at the University of Innsbruck have used ultracold caesium atoms to study chaos in the quantum realm.

The researchers expected the atoms to collectively absorb energy over the course of the experiment. Instead, when they recorded how their momentum distribution evolved, they found that it actually stopped spreading and that the system's energy reached a plateau. "Despite being continually kicked and strongly interacting, it no longer absorbed energy," says Nägerl. "We say that it had localized in momentum space – known as many-body dynamical localization (MBDL)."

In this state, quantum coherence and many-body interactions prevent the system from heating up. "The momentum distribution essentially freezes and retains whatever structure it has," adds Nägerl. The team repeated the experiment by varying the interaction between the atoms – from zero (non-interacting) to strongly interacting. They found that the system always localizes.

The MBDL is fragile, however – something the researchers proved by introducing randomness into the laser pulses. A small amount of disorder is enough the destroy the localization effect and restore diffusion. Nägerl explains that the momentum distribution smears out and the kinetic energy of the system rises sharply, meaning that it is absorbing energy. "This test highlights that quantum coherence is crucial for preventing thermalization in such driven many-body systems," he adds.

Simulating such a system on classical computers is only possible for two or three particles, but the one studied in this work contains 20 or more. "Our new experiments now provide precious data to which we can compare the QKR model system, which is a paradigmatic one in quantum physics," says Nägerl. "In our present work, we report on MBDL in 1D, but would it happen in a 2D or a 3D system?" asks Nägerl. The researchers say they would like to find out how stable MBDL is to various external perturbations. "Generally speaking, we would like to measure the 'phase diagram' for MBDL, where the axes of the graph would quantify the strength of the various perturbations we apply," adds Nägerl.

Condensed-matter physics

Space–time crystal emerges in a liquid crystal

The first-ever "space–time crystal" has been created by researchers in the US. The system is patterned in both space and time and comprises a rigid lattice of topological solitons that are sustained by steady oscillations in the orientations of liquid crystal molecules (*Nat. Mater.* doi:10.1038/s41563-025-02344-1).

In an ordinary crystal, atomic or molecular structures repeat at periodic intervals in space. In 2012 Frank Wilczek suggested that systems might also exist with quantum states that repeat at perfectly periodic intervals in time – even as they remain in their lowest-energy state. First observed experimentally in 2017, these time crystals are puzzling because they spontaneously break time–translation symmetry. A space–time crystal, however, is even more bizarre. In addition to breaking time–translation symmetry, such a system would also break spatial symmetry, just like the repeating molecular patterns of an ordinary crystal.

Hanqing Zhao and Ivan Smalyukh at the University of Colorado, Boulder, have now created a space–time crystal in the nematic phase of a liquid crystal, in which the crystal's rod-like molecules align parallel to each other and flow like a liquid. Building on computer simulations, they confined the liquid crystal between two glass plates coated with a light-sensitive dye. When the researchers illuminated the top plate with linearly polarized light at constant intensity, the dye molecules rotate to align perpendicular to the direction of polarization. This reorients nearby liquid crystal molecules, and the effect propagates deeper into the bulk.

Zhao & Smalyukh, 2025, *Nature Materials*

Ripples in space–time A "space–time crystal "not only breaks time–translation symmetry, but spatial symmetry too.

However, the influence weakens with depth, so that molecules farther from the top plate are progressively less aligned. As light travels through this gradually twisting structure, its linear polarization is transformed, becoming elliptically polarized by the time it reaches the bottom plate. The dye molecules there become aligned with this new polarization, altering the liquid crystal alignment near the bottom plate. These changes propagate back upward, influencing molecules near the top plate again.

This is a feedback loop, with the top and bottom plates continuously influencing each other via the polarized light passing through the liquid crystal. In this environment, particle-like topological solitons emerge as stable, localized twists in the liquid crystal's orientation that do not decay over time. Like particles, the solitons move and interact with each other while remaining intact. Once the feedback loop is established, these solitons emerge in a repeating lattice-like pattern. This arrangement not only persists as the feedback loop continued, but is sustained by it. This is a clear sign that the system exhibits crystalline order in time and space simultaneously. The duo now hope to broaden the scope of time-crystal research beyond a purely theoretical and experimental curiosity.

Sam Jarman

Materials

Kirigami-inspired parachute achieves perfect landing

Researchers in Canada and France have designed a kirigami-inspired parachute that can safely and accurately deliver its payloads when dropped directly above its target. Tested in realistic outdoor conditions, the parachute's deformable design stabilizes the airflow around its porous structure, removing the need to drift as it falls (*Nature* 646 88).

When a conventional parachute is deployed, it cannot simply fall vertically towards its target. To protect itself from turbulence, which can cause its canopy to collapse, it glides at an angle that breaks the symmetry of the airflow around it, stabilizing the parachute against small perturbations. But this necessity comes at a cost. When dropping a payload from a drone or aircraft, this gliding angle means parachutes will often drift far from their intended targets. This can be especially frustrating and potentially dangerous for operations such as humanitarian aid delivery, where precisely targeted airdrops are often vital to success.

Frédérick Gosselin

Hitting the target A Kirigami-inspired parachute could have applications such as delivering humanitarian aid.

To address this challenge, researchers led by David Mélançon at Polytechnique Montréal looked to kirigami and drew inspiration from nature such as how the feathery bristles of dandelion seeds stabilize the airflow around them. For their design, Mélançon's team created a parachute that can deform into a shape pre-programmed by a pattern of kirigami cuts, etched into a flexible disc using a laser cutter. "Our parachutes are simple flat discs, with circumferential slits inspired by a kirigami motif called a closed loop," says Mélançon. "Instead of attaching the payload with strings at the outer edge of the disk, we directly mount it its centre."

When dropped, a combination of air resistance and the weight of the free-falling payload deformed the parachute into an inverted, porous bell shape. "This ensures that the air flows in an orderly manner without any major chaotic turbulence, resulting in a predictable trajectory," adds Mélançon. The researchers tested their parachute via simulations and wind tunnel experiments and outdoor tests, where they used the parachute to drop a water bottle from a hovering drone. In this case, the parachute delivered its payload safely to the ground from a height of 60 m directly above its target. With its simple and affordable design, the parachute could have uses in areas including drone delivery and humanitarian aid.

Sam Jarman

Cosmology

Dark energy solution compatible with observed neutrino masses

An unconventional approach to solving the dark energy problem appears to be compatible with the observed masses of neutrinos. This new finding, from researchers working at the Dark Energy Spectroscopic Instrument (DESI), suggests that black holes may represent little Big Bangs played in reverse and could be used as a laboratory to study the birth and infancy of our universe (*Phys. Rev. Lett.* 135 081003).

According to standard theories of cosmology, matter is thought to comprise cold dark matter (CDM) and normal matter (mostly baryons and neutrinos). DESI can observe baryonic acoustic oscillations (BAOs), which are density fluctuations that were created after the Big Bang in the hot plasma of baryons and electrons that prevailed then. BAOs expand with the growth of the universe and represent a sort of "standard ruler" that allows cosmologists to map the universe's expansion.

To search for evidence of matter converting into dark energy, researchers combined their BAO measurements with cosmic microwave background (CMB) datasets. They did this by focusing on a new hypothesis known as the cosmologically coupled black hole (CCBH), which builds on a mathematical description – introduced over 50 years ago – of black holes as bubbles of dark energy in space. CCBH describes a scenario in which massive stars exhaust their nuclear fuel and collapse to produce black holes filled with dark energy that then grows as the universe expands. The rate of dark energy production is therefore determined by the rate at which stars form.

KPNO/NOIRLab/NSF/AURA/B Tafreshi

Eye on the sky
To search for evidence of matter converting into dark energy, researchers combined baryonic acoustic oscillations measurements with cosmic microwave background data.

Previous analyses by DESI scientists suggested that there is less matter in the universe today compared to when it was much younger. When they then added the additional, known, matter source from neutrinos, there appeared to be no "room" and the masses of these particles therefore appeared negative in their calculations. When the researchers re-interpreted the new set of data with the CCBH model, they were able to resolve this issue.

Since stars are made of baryons and black holes convert exhausted matter from stars into dark energy, the number of baryons today has decreased in comparison to the CMB measurements. This means that neutrinos can indeed contribute to the universe's mass, slowing down the expansion of the universe as the dark energy produced sped it up. The researchers say they studied the CCBH scenario in its simplest form in this work, and found that it performs well.

"The next big observational test will involve a new layer of complexity, where consistency with the large-scale features of the Big Bang relic radiation, or CMB, and the statistical properties of the distribution of galaxies in space will make or break the model," says Gregory Tarlé from the University of Michigan.

Isabelle Dumé

Biophysics

Protein qubit could be used inside cells as a quantum biosensor

A new optically addressable quantum bit (qubit) encoded in a fluorescent protein could be used as a sensor that can be directly produced inside living cells. The device could open up a new era for fluorescence microscopy to monitor biological processes (*Nature* **645** 73).

Qubits can be manipulated and measured with high precision, and in quantum sensing they can detect minute changes in their environment with exquisite sensitivity. Many of today's quantum sensors are based on nitrogen-vacancy (NV) centres, which are crystallographic defects in diamond but these are difficult to position at well-defined sites inside living cells. The researchers at the University of Chicago Pritzker School of Molecular Engineering got around this issue by utilising fluorescent proteins. Just 3 nm in diameter, they can be genetically encoded, allowing cells to produce these sensors directly at the desired location with atomic precision.

"We recognized that these proteins possess optical and spin properties that are strikingly similar to those of qubits formed by crystallographic defects in diamond – namely that they have a metastable triplet state," explains Peter Maurer, who co-led the study with David Awschalom. "Building on this insight, we combined techniques from fluorescence microscopy with methods of quantum control to encode and manipulate protein-based qubits." The researchers used a near-infrared laser pulse to optically address a yellow fluorescent protein known as EYFP and read out its triplet spin state with up to 20% "spin contrast" – measured using optically detected magnetic resonance (ODMR) spectroscopy. To test the technique, the team genetically modified the protein so that it was expressed in human embryonic kidney cells and *E. coli* cells.

UChicago Pritzker School of Molecular Engineering/Jason Smith

Body signatures
Researchers in the US have designed protein qubits that can be produced directly inside living cells.

The measured OMDR signals exhibited a contrast of up to 8% and while this performance is not as good as NV quantum sensors, the fluorescent proteins open the door to magnetic resonance measurements directly inside living cells – something that NV centres cannot do. "They could thus transform medical and biochemical studies by probing protein folding, monitoring redox states or detecting drug binding at the molecular scale," adds Maurer.

Beyond sensing, Awschalom adds that the unique quantum resonance "signatures" offer a new dimension for fluorescence microscopy, paving the way for highly multiplexed imaging far beyond today's colour palette.

Isabelle Dumé

Opinion

physicsworld

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Bibliographic codes ISSN 0953-8585 (print)
ISSN 2058-7058 (online) CODEN PHWOEW

Institute of Physics
37 Caledonian Road, London N1 9BU, UK
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E-mail membership@iop.org
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Nobel pioneers

Celebrating this year's Nobel laureates – and others you might not have heard of

Every year we have fun at *Physics World* trying to predict who might win the Nobel Prize for Physics. Quantum physics topped our list this time round – specifically quantum information and algorithms – although we did hedge our bets by also going with metamaterials. Turns out, we were (almost) right, with John Clarke, Michel Devoret and John Martinis winning "for the discovery of macroscopic quantum mechanical tunnelling and energy quantization in an electric circuit".

Nobel Foundation

The work, which the trio originally did in the 1980s, saw them create a macroscopic quantum system that opened the door to the superconducting quantum bits used in some of today's nascent quantum computers. You can find out more in our news story (pp3–4) or the *Physics World Weekly* podcast of 9 October, where we talk to quantum-technology entrepreneur Ilana Wisby.

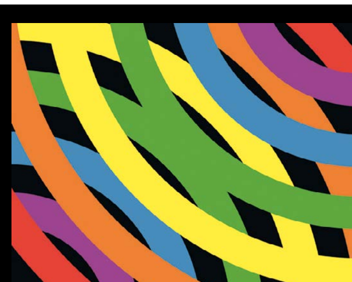
Over the 125 years since the physics Nobel was first awarded, almost every seminal finding in physics has been honoured – from quantum mechanics to high-temperature superconductivity. Members of the Nobel Committee for Physics work long and hard, guided by Alfred Nobel's wish that the prize should go to "the person who made the most important discovery or invention in the field of physics during the preceding year".

Very occasionally, however, the committee comes up with a frankly bizarre choice. Fresh from honouring J J Thompson in 1906 for discovering the electron and Albert Michelson in 1907 for his precision optical measurements, in 1908 the committee gave the prize to Gabriel Lippmann for a curious and cumbersome way of making colour photos. Then in 1912 – after a run of prizes to Guglielmo Marconi (wireless communication), Johannes van der Waals (fluids) and Wilhelm Wien (blackbody radiation) – we find Nils Gustaf Dalén winning for his work on lighthouses.

So why were these two prizes recognized with Nobel awards, who nominated the winners, and what happened next? Margaret Harris explores those questions in her feature "The physics Nobels you've never heard of" (pp28–32), which reminds us that physics is, like any endeavour, a human activity, subject to biases, rivalries and emotions. For Dalén, there's also an unmissable ending.

This year's prize will certainly be remembered for all the right reasons. But if you're wondering what are the five most significant Nobel physics prizes of the 21st century, do check out my blog post at tinyurl.com/bdhkdtbb – and let me know if you agree or disagree with my picks.

Matin Durrani, editor-in-chief, *Physics World*



Critical Point Particle afterglow

The 1980s and 1990s were a unique time for particle physics in the aftermath of the Standard Model, says **Robert P Crease**

CERN

Tunnel vision The successful consolidation of particle physics in the 1980s and 1990s, typified by work at the Large Electron–Positron collider, is the theme of a symposium held at CERN this month.

Call it millennial, generation Y or *fin de siècle*, high-energy physics during the last two decades of the 20th century had a special flavour. The principal pieces of the Standard Model of particle physics had come together remarkably tightly – so tightly, in fact, that physicists had to rethink what instruments to build, what experiments to plan, and what theories to develop to move forward. But it was also an era when the hub of particle physics moved from the US to Europe.

The momentous events of the 1980s and 1990s will be the focus of the 4th International Symposium on the History of Particle Physics, which is being held on 10–13 November at CERN. The meeting will take place more than four decades after the first symposium in the series was held at Fermilab near Chicago in 1980. Entitled The Birth of Particle Physics, that initial meeting covered the years 1930 to 1950.

Speakers back then included trailblazers such as Paul Dirac, Julian Schwinger and Victor Weisskopf. They reviewed discoveries such as the neutron and the positron and the development of relativistic quantum field theory. Those two decades before 1950 were a time when particle physicists "constructed the room", so to speak, in which the discipline would be based.

The second symposium – Pions to Quarks – was also held at Fermilab and covered the 1950s. Accelerators could now create particles seen in cosmic-ray collisions, populating what Robert Oppenheimer called the "particle zoo". Certain discoveries of this era, such as parity violation in the weak interaction, were so shocking that C N Yang likened it to having a blackout and not knowing if the room would look the same when the lights came back on. Speakers at that 1985 event included Luis Alvarez, Val Fitch, Abdus Salam, Robert Wilson and Yang himself.

The third symposium, The Rise of the Standard Model, was held in Stanford, California, in 1992 and covered the 1960s and 1970s. It was a time not of blackouts but of disruptions that dimmed the lights. Charge-parity violation and the existence of two types of neutrino were found in the 1960s, followed in the 1970s by deep inelastic electron scattering and quarks, neutral currents, a fourth quark and gluon jets.

These discoveries decimated alternative approaches to quantum field theory, which was duly established for good as the skeleton of high-energy physics. The era culminated with Sheldon Glashow, Abdus Salam and Steven Weinberg winning the 1979 Nobel Prize for Physics for their part in establishing the Standard Model. Speakers at that third symposium included Murray Gell-Mann, Leon Lederman and Weinberg himself.

Changing times

The upcoming CERN event, on whose programme committee I serve, will start exactly where the previous symposium ended. "1980 is a natural historical break," says conference co-organizer Michael Riordan, who won the 2025 Abraham Pais Prize for History of Physics. "It begins a period of the consolidation of the Standard Model. Colliders became the main instruments, and were built with specific standard-model targets in mind. And the centre of gravity of the discipline moved across the Atlantic to Europe."

The conference will address physics that took place at CERN's Super Proton Synchrotron (SPS), where the W and Z particles were discovered in 1983. It will also examines the SPS's successor – the Large Electron–Positron (LEP) collider. Opened in 1989, it was used to make precise measurements of these and other implications of the Standard Model until being controversially shut down in 2000 to make way for the Large Hadron Collider (LHC).

Speakers at the meeting will also discuss Fermilab's Tevatron, where the top quark – another Standard Model component – was found in 1995. Work at the Stanford Linear Accelerator Center, DESY in Germany, and Tsukuba, Japan, will be tackled too. There will be coverage as well of failed accelerator projects, which – perhaps perversely – can be equally interesting and revealing as successful facilities.

In particular, I will speak about ISABELLE, a planned and partially built proton–proton collider at Brookhaven National Laboratory, which was terminated in 1983 to make way for the far more ambitious Superconducting Super Collider (SSC). ISABELLE was then transformed into the Relativistic Heavy Ion Collider (RHIC), which was completed in 1999 and took nuclear physics into the high-energy regime.

Riordan will talk about the fate of the SSC, which was supposed to discover the Higgs boson or whatever else plays its mass-generating role. But in 1993 the US Congress terminated that project, a traumatic episode for US physics, about which Riordan

Public Domain

Inspiring stuff The 1990s also saw the blossoming of the World Wide Web – shown here with its historical logo, created by Robert Cailliau in 1990.

co-authored the book *Tunnel Visions*. Its cancellation signalled the end of the glory years for US particle physics and the realization of the need for international collaborations in ever-costlier accelerator projects.

The CERN meeting will also explore more positive developments such as the growing convergence of particle physics and cosmology during the 1980s and 1990s. During that time, researchers stepped up their studies of dark matter, neutrino oscillations and supernovas. It was a period that saw the construction of underground detectors at Gran Sasso in Italy and Kamiokande in Japan.

Other themes to be explored include the development of the Web – which transformed the world – and the impact of globalization, the end of the Cold War, and the rise of high-energy physics in China, and physics in Russia, former Soviet Union republics and former Eastern Bloc countries. While particle physics became more global, it also grew more dependent on, and vulnerable to, changing political ambitions, economic realities and international collaborations. The growing importance of diversity, communication and knowledge transfer will be looked at too.

The critical point

The years between 1980 and 2000 were a distinct period in the history of particle physics. It took place in the afterglow of the triumph of the Standard Model. The lights in high energy physics did not go out or even dim, to use Yang's metaphor. Instead, the Standard Model shed so much light on high-energy physics that the effort and excitement focused around consolidating the model.

Particle physics, during those years, was all about finding the deeply hidden outstanding pieces, developing the theory, and connecting with other areas of physics. The triumph was so complete that physicists began to wonder what bigger and more comprehensive structure the Standard Model's "room" might be embedded in – what was "beyond the Standard Model". A quarter of a century on, our attempt to make out that structure is still an ongoing task.

Robert P Crease is a professor in the Department of Philosophy, Stony Brook University, US; e-mail robert.crease@stonybrook.edu; www.robertpcrease.com; his latest book is *The Leak* (2022 MIT Press)

Physics for the environment

As climate change intensifies, it is crucial that environmental physics is taught to every physics undergraduate, explains **Peter Hughes**

The world is changing rapidly – economically, geopolitically, technologically, militarily and environmentally. But when it comes to the environment, many people feel the world is on the cusp of catastrophe. That's especially true for anyone directly affected by endemic environmental disasters, such as drought or flooding, where mass outmigration is the only option possible.

The challenges are considerable and the crisis is urgent. But we know that physics has already contributed enormously to society – and I believe that environmental physics can make a huge difference by identifying, addressing and alleviating the problems at stake. However, physicists will only be able to make a difference if we put environmental physics at the centre of our university teaching.

iStock/Daniel Stein

Damaging effects We now live in an increasingly urban world, with cities expanding into megacities that are inflicting terrible damage to the environment.

Grounded in physics

Environmental physics is defined as the response of living organisms to their environment within the framework of the physics principles and processes. It examines the interactions within and between the biosphere, the hydrosphere, the cryosphere, the lithosphere, the geosphere and the atmosphere. Stretching from geophysics, meteorology and climate change to renewable energy and remote sensing, it also covers soils and vegetation, the urban and built environment, and the survival of humans and animals in extreme environments.

Environmental physics was pioneered in the UK in the 1950s by the physicists Howard Penman and John Monteith, who were based at the Rothamsted Experimental Station, which is one of the oldest agricultural research institutions in the world. In recent decades, environmental physics has become more prevalent in universities across the world.

Some UK universities either teach environmental physics in their undergraduate physics degrees or have elements of it within environmental science degrees. That's the approach taken, for example, by University College London as well as well as the universities of Cambridge, Leicester, Manchester, Oxford, Reading, Strathclyde and Warwick.

When it comes to master's degrees in environmental physics, there are 17 related courses in the UK, including nuclear and environmental physics at Glasgow and radiation and environmental protection at Surrey. Even the London School of Economics has elements of environmental physics in some of its business, geography and economics degrees via a "physics of climate" course.

But we need to do more. The interdisciplinary nature of environmental physics means it overlaps with not just physics and maths but agriculture, biology, chemistry, computing, engineering, geology and health science too.

Indeed, recent developments in machine learning, digital technology and artificial intelligence (AI) have had an impact on environmental physics – for example, through the use of drones in environmental monitoring and simulations – while AI algorithms can catalyse modelling and weather forecasting. AI could also in future be used to predict natural disasters, such as earthquakes, tsunamis, hurricanes and volcanic eruptions, and to assess the health implications of environmental pollution.

Environmental physics is exciting and challenging, has solid foundations in mathematics and the sciences via experiments both in the lab and field. Environmental measurements are a great way to learn about the use of uncertainties, monitoring and modelling, while providing scope for project and teamwork. A grounding in environmental physics can also open the door to lots of exciting career opportunities, with ongoing environmental change meaning lots of ongoing environmental research will be vital.

Solving major regional and global environmental problems is a key part of sociopolitics and so environmental physics has a special role to play in the public arena. It gives students the chance to develop presentational and interpersonal skills that can be used to influence decision makers at local and national government level.

Taken together, I believe a module on environmental physics should be a component of every undergraduate degree as a minimum, ideally having the same weight as quantum or statistical physics or optics. Students of environmental physics have the potential to be enabled, engaged and, ultimately, to be empowered to meet the demands that the future holds.

Peter Hughes is the first chair of the IOP's Environmental Physics Group education committee, which aims to advance environmental physics in schools, colleges and universities

Transactions Materials science: our century's new alchemy?

Stuff that matters Whether it's metals, ceramics, bioplastics or the auxetic materials in this Nike running shoe, the world is being transformed thanks to materials science.

With the 2025 Fall Meeting of the Materials Research Society starting in Boston at the end of this month, **Honor Powrie** believes the field is the most rewarding and challenging in all of science, with its practitioners striving to create "new gold"

For many years, I've been a judge for awards and prizes linked to research and innovation in engineering and physics. It's often said that it's better to give than to receive, and it's certainly true in this case. But another highlight of my involvement with awards is learning about cutting-edge innovations I either hadn't heard of or didn't know much about.

One area that never fails to fascinate me is the development of new and advanced materials. I'm not a materials scientist – my expertise lies in creating monitoring systems for engineering – so I apologize for any over-simplification in what follows. But I do want to give you a sense of just how impressive, challenging and rewarding the field of materials science is.

It's all too easy to take advanced materials for granted. We are in constant contact with them in everyday life, whether it's through applications in healthcare, electronics and computing or energy, transport, construction and process engineering. But what are the most important materials innovations right now – and what kinds of novel materials can we expect in future?

Drivers of innovation

There are several – and all equally important – drivers when it comes to materials development. One is the desire to improve the performance of products we're already familiar with. A second is the need to develop more sustainable materials, whether that means replacing less environmentally friendly solutions or enabling new technology. Third, there's the drive for novel developments, which is where some of the most ground-breaking work is occurring.

On the environmental front, we know that there are many products with components that could, in principle, be recycled. However, the reality is that many products end up in landfill because of how they've been constructed. I was recently reminded of this conundrum when I heard a research presentation about the difficulties of recycling solar panels.

Photovoltaic cells become increasingly inefficient with time and most solar panels aren't expected to last more than about 30 years. Trouble is, solar panels are so robustly built that recycling them requires specialized equipment and processes. More often than not, solar panels just get thrown away despite mostly containing reusable materials such as glass, plastic and metals – including aluminium and silver.

It seems ironic that solar panels, which enable sustainable living, could also contribute significantly to landfill. In fact, the problem could escalate significantly if left unaddressed. There are already an estimated 1.8 million solar panels in use the UK, and potentially billions around the world, with a rapidly increasing install base. Making solar panels more sustainable is surely a grand challenge in materials science.

The soybean car: fact or fiction?

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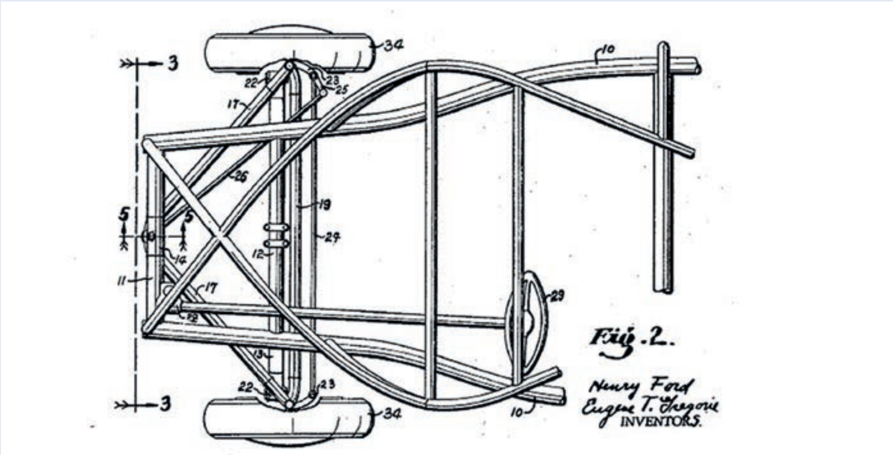

Crazy or credible? Soybean car frame patent signed by Henry Ford and Eugene Turenne Gregorie.

Henry Ford's 1941 "soybean" car, which was built entirely of a plant-based plastic, was apparently motivated by a need to make vehicles lighter (and therefore more fuel efficient), less reliant on steel (which was in high demand during the Second World War) and safer too. The exact ingredients of the plastic are, however, not known since there were no records kept.

Speculation is that it was a combination of soybeans, wheat, hemp, flax and ramie (a kind of flowering nettle). Lowell Overly, a Ford designer who had major involvement in creating the car, said it was "soybean fibre in a phenolic resin with formaldehyde used in the impregnation". Despite being a mix of natural and synthetic materials – and not entirely made of soybeans – the car was nonetheless a significant advancement for the automotive industry more than eight decades ago.

We have to create an environmentally sustainable economic system that's based on the reuse and regeneration of materials or products – what some dub the "circular economy"

iStock/Dmitriy Sidor

Sustainable challenge Material scientists will need to find practical bio-based alternatives to conventional plastics to avoid polluting microplastics entering the seas and oceans.

Waste not, want not

Another vital issue concerns our addiction to new tech, which means we rarely hang on to objects until the end of their life; I mean, who hasn't been tempted by a shiny new smartphone even though the old one is perfectly adequate? That urge for new objects means we need more materials and designs that can be readily re-used or recycled, thereby reducing waste and resource depletion.

As someone who works in the aerospace industry, I know first-hand how companies are trying to make planes more fuel efficient by developing composite materials that are stronger and can survive higher temperatures and pressures – for example carbon fibre and composite matrix ceramics. The industry also uses "additive manufacturing" to enable more intricate component design with less resultant waste.

Plastics are another key area of development. Many products are made from single type, recyclable materials, such as polyethylene or polypropylene, which benefit from being light, durable and capable of withstanding chemicals and heat. Trouble is, while polyethene and polypropene can be recycled, they both create the tiny "microplastics" that, as we know all too well, are not good news for the environment.

Bio-based materials are becoming more common for everyday items. Think about polylactic acid (PLA), which is a plant-based polymer derived from renewable resources such as cornstarch or sugar cane. Typically used for food or medical packaging, it's usually said to be "compostable", although this is a term we need to view with caution.

Sadly, PLA does not degrade readily in natural environments or landfill. To break it down, you need high-temperature, high-moisture industrial composting facilities. So whilst PLAs come from natural plants, they are not straightforward to recycle, which is why single-use disposable items, such as plastic cutlery, drinking straws and plates, are no longer permitted to be made from it.

Thankfully, we're also seeing greater use of more sustainable, natural fibre composites, such as flax, hemp and bamboo (have you tried bamboo socks or cutlery?). All of which brings me to an interesting urban myth, which is that in 1941 legendary US car manufacturer Henry Ford built a car

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Medical marvels Wearable electronic materials are starting to transform how we monitor human health.

apparently made entirely of a plant-based plastic – dubbed the "soybean" car (see box "The soybean car: fact or fiction?" opposite).

Avoiding the "solar-panel trap"

So what technology developments do we need to take materials to the next level? The key will be to avoid what I coin the "solar-panel trap" and find materials that are sustainable from cradle to grave. We have to create an environmentally sustainable economic system that's based on the reuse and regeneration of materials or products – what some dub the "circular economy".

Sustainable composites will be essential. We'll need composites that can be easily separated, such as adhesives that dissolve in water or a specific solvent, so that we can cleanly, quickly and cheaply recover valuable materials from complex products. We'll also need recycled composites, using recycled carbon fibre, or plastic combined with bio-based resins made from renewable sources like plant-based oils, starches and agricultural waste (rather than fossil fuels).

Vital too will be eco-friendly composites that combine sustainable composite materials (such as natural fibres) with bio-based resins. In principle, these could be used to replace traditional composite materials and to reduce waste and environmental impact.

Another important trend is developing novel metals and complex alloys. As well as enhancing traditional applications, these are addressing future requirements for what may become commonplace applications, such as wide-scale hydrogen manufacture, transportation and distribution.

Materials science is an amazing cauldron of ideas where physics, chemistry and engineering work hand in hand to deliver groundbreaking solutions

Soft and stretchy

Then there are "soft composites". These are advanced, often biocompatible materials that combine softer, rubbery polymers with reinforcing fibres or nanoparticles to create flexible, durable and functional materials that can be used for soft robotics, medical implants, prosthetics and wearable sensors. These materials can be engineered for properties like stretchability, self-healing, magnetic actuation and tissue integration, enabling innovative and patient-friendly healthcare solutions.

And have you heard of e-textiles, which integrate electronic components into everyday fabrics? These materials could be game-changing for healthcare applications by offering wearable, non-invasive monitoring of physiological information such as heart rate and respiration.

Further applications could include advanced personal protective equipment (PPE), smart bandages and garments for long-term rehabilitation and remote patient care. Smart textiles could revolutionize medical diagnostics, therapy delivery and treatment by providing personalized digital healthcare solutions.

Towards "new gold"

I realize I have only scratched the surface of materials science – an amazing cauldron of ideas where physics, chemistry and engineering work hand in hand to deliver groundbreaking solutions. It's a hugely and truly important discipline. With far greater success than the original alchemists, materials scientists are adept at creating the "new gold".

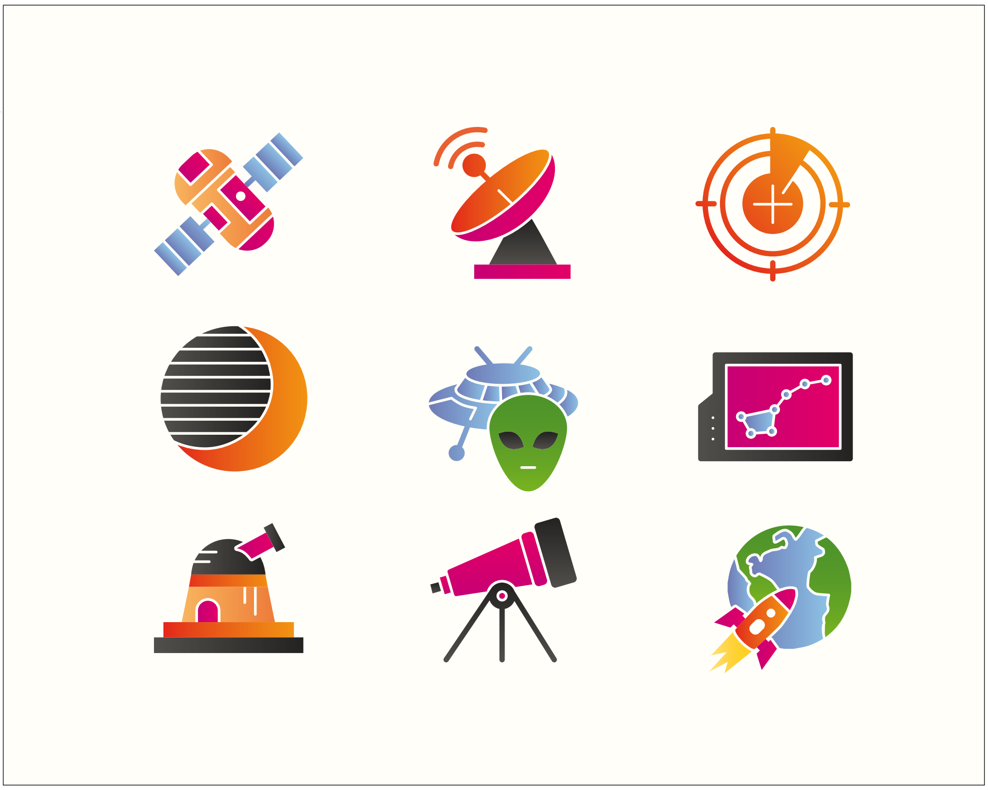
Their discoveries and inventions are making major contributions to our planet's sustainable economy from the design, deployment and decommission of everyday items, as well as finding novel solutions that will positively impact the way we live today. Surely it's an area we should celebrate and, as physicists, become more closely involved in.

Honor Powrie is an engineer who is now senior director for data science and analytics at GE in Southampton, UK. She is writing here in a personal capacity

Reviews

Talking with aliens

Hamish Johnston reviews *Do Aliens Speak Physics?* by Daniel Whiteson and Andy Warner



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Weird assumption Would an alien even know what it means to do science?

Do Aliens Speak Physics?
Daniel Whiteson and Andy Warner
4 November 2025 WW Norton & Company 272pp £23.00 hb; £21.84 ebook

"Imagine the day the aliens arrive." So begins *Do Aliens Speak Physics?* by the US particle physicist Daniel Whiteson and the cartoonist and author Andy Warner. From that starting point, if you believe the plots of many works of science fiction, it wouldn't be long before we're communicating with emissaries of an extraterrestrial civilization. Quickly, we'd be marvelling at their advanced science and technology.

But is this a reasonable assumption? Would we really be able to communicate with aliens? Even if we could, would their way of doing science have any meaning to us? What if an advanced alien civilization had no science at all? These are some of the questions tackled by Whiteson and Warner in their entertaining and thought-provoking book.

While *Do Aliens Speak Physics?* focuses on the possible differences between human and alien science, it made me think about what science means to humans – and the role of science in our civilization. Indeed, when I spoke to Whiteson for a future episode of the *Physics World Weekly* podcast, he told me that his original plan for the book was to examine if physics is universal or shaped by human perspective.

But when he pitched the idea to his teenage son, Whiteson realized that approach was a bit boring and decided to spice things up using an alien landing. At the heart of the book is a new equation for estimating the number of alien civilizations that scientists could potentially communicate with – ideally, when the aliens arrive on Earth.

The authors aren't the first people to do such a calculation. In 1961 the US astrophysicist Frank Drake famously did so by estimating how many habitable planets might exist and whether they could harbour life that's evolved so far that it could communicate with us. Whiteson and Warner's "extended Drake equation" adds four extra terms related to alien science.

The first is the probability that a civilization has developed science. The second is the likelihood that we would be able to communicate with the civilization, with the third being the probability that an alien civilization would ask scientific questions that are meaningful to us. The final term is whether human science would benefit from the answers to those questions.

A question of perception

One of Whiteson and Warner's more interesting ideas is that aliens could perceive science and technology in very different ways to us. After all, an alien civilization could be completely focused on developing technology and not be at all interested in the underlying science. Technology without science might seem deeply foreign to us today, but for most of history humans have focused on how things work – not why.

Blacksmiths of the past, for example, developed impressive swords and other metal implements without any understanding of how the materials they worked with behaved at a microscopic level. So perhaps our alien visitors will come from a planet of blacksmiths rather than materials scientists.

Mind you, communicating with alien scientists could be a massive challenge given that we do so mainly using sound and visual symbols, whereas an alien might use smells or subatomic particles to get their point across. As the authors point out, it's difficult even translating the Danish/Norwegian word *hygge* into English, despite the concept's apparent popularity in the English-speaking world. Imagine how much harder things would be if we used a different form

AUDIO Hamish Johnston talks to Daniel Whiteson about his new book *Do Aliens Speak Physics?*

of communication altogether.

But could physics function as a kind of Rosetta Stone, offering a universal way of translating one language into another? We could then get the aliens to explain various physical processes – such as how a mass falls under the influence of gravity – and compare their reasoning to our understanding of the same phenomena.

Of course, an alien scientist's questions might depend on how they perceive the universe. In a chapter titled "Can aliens taste electrons?", the authors explore what might happen if aliens were so small that they experience quantum effects such as entanglement in their daily lives. What if an organism were so big that it feels the gravitational tug of dark matter? Or what if an intelligent alien could exist in an ultracold environment where everything moves so slowly that their perception of physics is completely different to ours?

The final term in the authors' extended Drake equation looks at whether the answers to the questions of alien physics would be meaningful to humans. We naturally assume there are deep truths about nature that can be explored using experimental and mathematical tools. But what if there are no deep truths out there – and what if our alien friends are already aware of that fact?

Could physics function as a kind of Rosetta Stone, offering a universal way of translating one language into another?

When Drake proposed his equation, humans did not know of any planets beyond the solar system. Today, however, we have discovered nearly 6000 such exoplanets, and it is possible that there are billions of habitable, Earth-like exoplanets in the Milky Way. So it does not seem at all fanciful that we could soon be communicating with an alien civilization.

But when I asked Whiteson if he's worried that visiting aliens could be hostile towards humans, he said he hoped for a "peaceful" visit. In fact, Whiteson is unable to think of a good reason why an advanced civilization would be hostile to Earth – pointing out that there is probably nothing of material value here for them. Fingers crossed, any visit will be driven by curiosity, peace and goodwill.

Hamish Johnston is an online editor of *Physics World*

Feedback

Letters and comments that appear here may have been edited, and do not necessarily reflect the views of *Physics World*.

Please send us your feedback by e-mail to pwld@ioppublishing.org

Musing on metaphors

In reply to Robert P Crease's Critical Point article about scientific metaphors that can be experimentally verified (September pp17–18).

Crease's article led me to ponder the UK's Spherical Tokamak for Energy Production (STEP) fusion reactor project, which stands to benefit from an additional £2.5bn in funding from the UK government that was announced last year. STEP has been described by insiders as a "moonshot" project – so does that make it a world-beating test of a metaphor?

In one sense, I can see why the "moonshot" metaphor has been used for STEP. Just as NASA's Apollo programme was a risky, complex and costly mission of no direct commercial value, so STEP is a high-risk mission to generate a small net output of electricity from a complex and highly costly nuclear plant. In both cases, potential spin-offs seem to provide the only realistic commercial justification.

But ultimately, the "moonshot" metaphor is not appropriate for STEP because every key stage of the Apollo mission was rigorously tested at scale before the Moon landing was attempted. In contrast, the STEP fusion reactor moonshot is based on one giant leap from the record results obtained by the Joint European Torus (JET) with no testing at reactor scale. The JET results are equivalent to brief firings of a small rocket engine at low-thrust.

So is it possible for a metaphor to be true and false at the same time? Perhaps fusion is in some kind of superposition of both "moonshot" and "moonshine"?

Guy Matthews
Oxfordshire, UK

Is it possible for a metaphor to be true and false at the same time? Perhaps fusion is in some kind of superposition

Crease mentions Einstein's metaphor regarding an observer in a windowless spacecraft, towed by an invisible being, who cannot differentiate whether they are in a gravitational field or being accelerated. Einstein was convinced he would be unable to test this metaphor, but imagine fitting two pendulums one metre apart, on the ceiling above the observer's head and measuring the distance between the bottom centres of the pendulums.

If the observer now replaced the tow rope with a dense massive object (such as a black hole) below the spacecraft – at a distance that would provide the same force as the tow – they wouldn't notice any difference in their weight. However, the pendulums would be closer together as they would point to the centre of mass of the black hole. So does this place the metaphor in the verifiable or non-verifiable category?

Laurence Rothwell
Paignton, Devon, UK

Anybody who has spent an evening propping beer mats under the legs of a four-legged table to stabilize it might take issue with Crease's claim that a "scientific metaphor...is as stable as a four-legged table". It is well known that a three-legged table, or stool, is stable regardless of the topology upon which it sits.

Chris Atkins
Exmouth, Devon, UK

India outnumbered

In response to the article about women quantum scientists in India by Tanusri Saha-Dasgupta and Rupamanjari Ghosh (August pp25–29).

"India's women of quantum" is a fascinating article – and the fact that 43% of STEM graduates in the country are female is impressive. That figure is higher than every country in Europe, apart from Romania. However, it is not "the highest percentage...in the world", as the authors claim, even though the number of female STEM graduates may be the highest in absolute terms. According to World Bank Gender Statistics (tinyurl.com/yfhfscmb), India ranked 18th in the world, with women in seven nations, including Tunisia, Algeria and Syria, making up more than 50% of STEM graduates.

I remember visiting a collaborator at the University of Wasit in Iraq in 2016, where about 70% of physicists were women, including the head of physics there. I was told that engineering had the worst representation at Wasit, with only about one in three staff being women – but even that was about twice what we had in the UK at the time. In fact, my colleagues in the West are often surprised when they realize a scientific result has come from a Middle Eastern or African nation, being unaware of the depth of scientific expertise in such places. It is our loss if we in the UK make life hard for visitors or immigrants from these countries.

Anita Richards
University of Manchester, UK

Video fears

In response to the interview with Emanual Wallace, whose educational science videos have become a huge hit online (September pp33–35).

Over the years, I have made several YouTube science videos, including one showing how to measure gravity with a yo-yo. But I had concerns about posting another video I made, which involved drawing a large current from a battery. If left running for long enough, there would be a very small risk of the battery exploding or catching fire. Such risks would be greater if other types of battery, such as lithium-ion, were used.

I decided not to post the video to YouTube because of the risk of someone injuring themselves by copying my experiments and then suing me. I enquired about insurance but could find only companies that would cover me for legal action taken against me in the UK. Trouble is, online videos can be viewed anywhere in the world.

I was reminded of an incident in 2019 when a Chinese woman called Ms Yeah – real name Zhou Xiao Hui – settled out of court after two girls allegedly copied something in one of her online videos that involved an unconventional cooking technique; one of the girls sadly died, while the other got badly burnt.

Of course, one can add disclaimers to videos, as I have done, but I'm not sure they give absolute protection. What's more, anyone can bring about a frivolous lawsuit, which would be expensive to defend. I'm all for science videos as a way of getting youngsters interested in physics – but I just worry about the legal risks.

Alex McDowell
South Ruislip, Middlesex, UK

Mathematical reawakening

In two previous letters of mine, I reflected on the overconfidence of youth (June 2017 p20) and on the rightful place of mathematics as the *lingua franca* of the sciences (October 2021 p25). Now, rather improbably, after taking a degree in mathematics at the Open University almost 40 years after my degree in physics, I find myself beginning a new life as a mathematician. Some 18 months ago, the idea that I might use self-directed study to learn analytical mechanics and functional analysis would have seemed unthinkable.

Yet here I am, working alongside patient and generous colleagues who judge me not by past missteps but by present curiosity. The journey back to academia has been long and uneven, but it feels like a homecoming. I have had staging posts along the way – experiences that kept the dream alive – and now I am on the verge of publishing a paper with one of the professors in my mathematics department.

Although I began – but did not complete – a PhD in physics back in the 1980s, I am now applying to do a PhD in mathematics, keenly aware that I must approach the task with realism as well as enthusiasm. So for others who may feel left behind, take heart: there are good, warm, generous people out there who are willing to help and want to see others, like me, happy and fulfilled, sometimes with a second or even a third chance at life.

Martin Reynolds
University of Birmingham, UK

Ice-cream science

In response to the interview with Douglas Goff (April pp23–26) about the physics of ice cream.

I recently discovered a new shop near where I live called Tracy's Artisan Gelato & Ices. I showed the owner this article and commented on the importance of ice-crystal size. If the small crystals are

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allowed to warm up and are then refrozen, I pointed out, they grow into larger crystals that impair the quality of the ice cream.

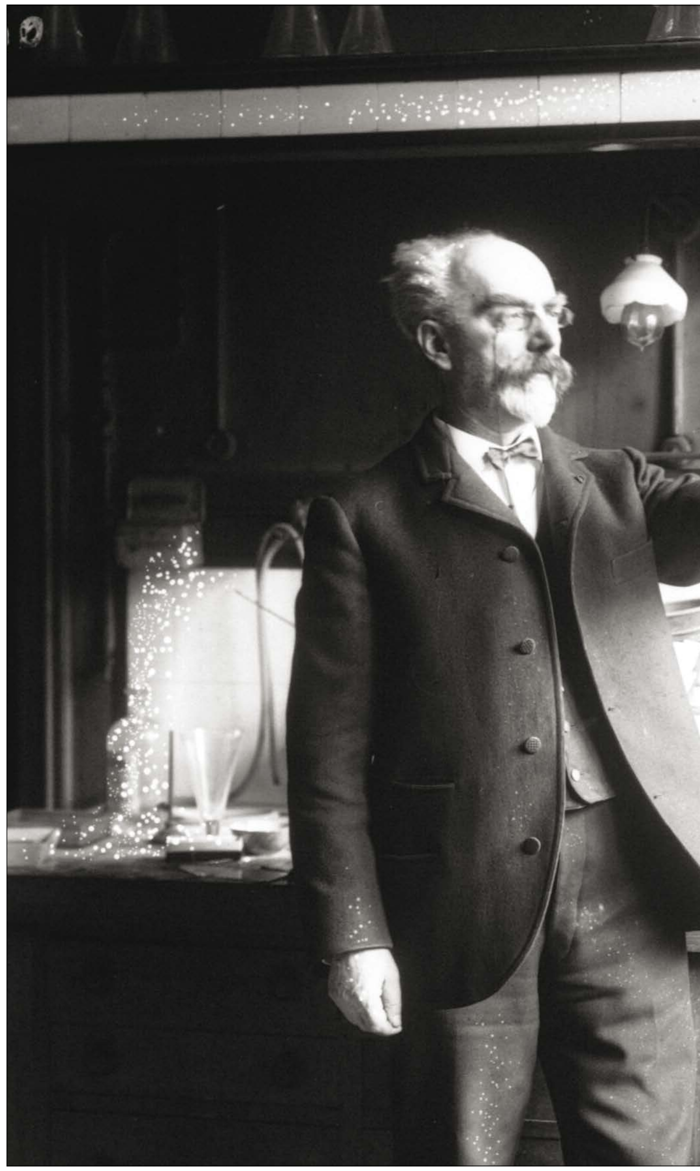
The owner was, in fact, aware of this issue and uses a blast freezer when making ice cream to keep the crystal size small. He was impressed by the electron microscopy images in the article, which showed the ice crystals, oil drops and air bubbles, and now plans to find out more about Goff's research.

David Murnaghan
Dublin, Ireland

The physics Nobel prizes you've never heard of

Gabriel Lippmann received the 1908 Nobel Prize for Physics for a version of colour photography that never took off. Four years later, Gustaf Dalén was honoured for inventing, of all things, a valve used in lighthouses. **Margaret Harris** uncovers the stories behind these lesser-known laureates

Margaret Harris is an online editor of *Physics World*



The early years of the Nobel prize read like a Who's Who in modern physics. The inaugural physics prize, in 1901, went to Wilhelm Röntgen for discovering X-rays. Subsequent recipients included Henri Becquerel, Marie and Pierre Curie, Lord Rayleigh and several others who likewise lent their names to scientific units and physical phenomena.

Look a little further down the list of laureates, though, and you'll find two names that stand out not because they're famous, but because they aren't. The first is Gabriel Lippmann, who received the 1908 Nobel Prize for Physics "for his method of reproducing colours photographically based on the phenomenon of interference". The second is Gustaf Dalén, who got the 1912 Nobel "for his invention of automatic valves designed to be used in combination with gas accumulators in lighthouses and buoys".

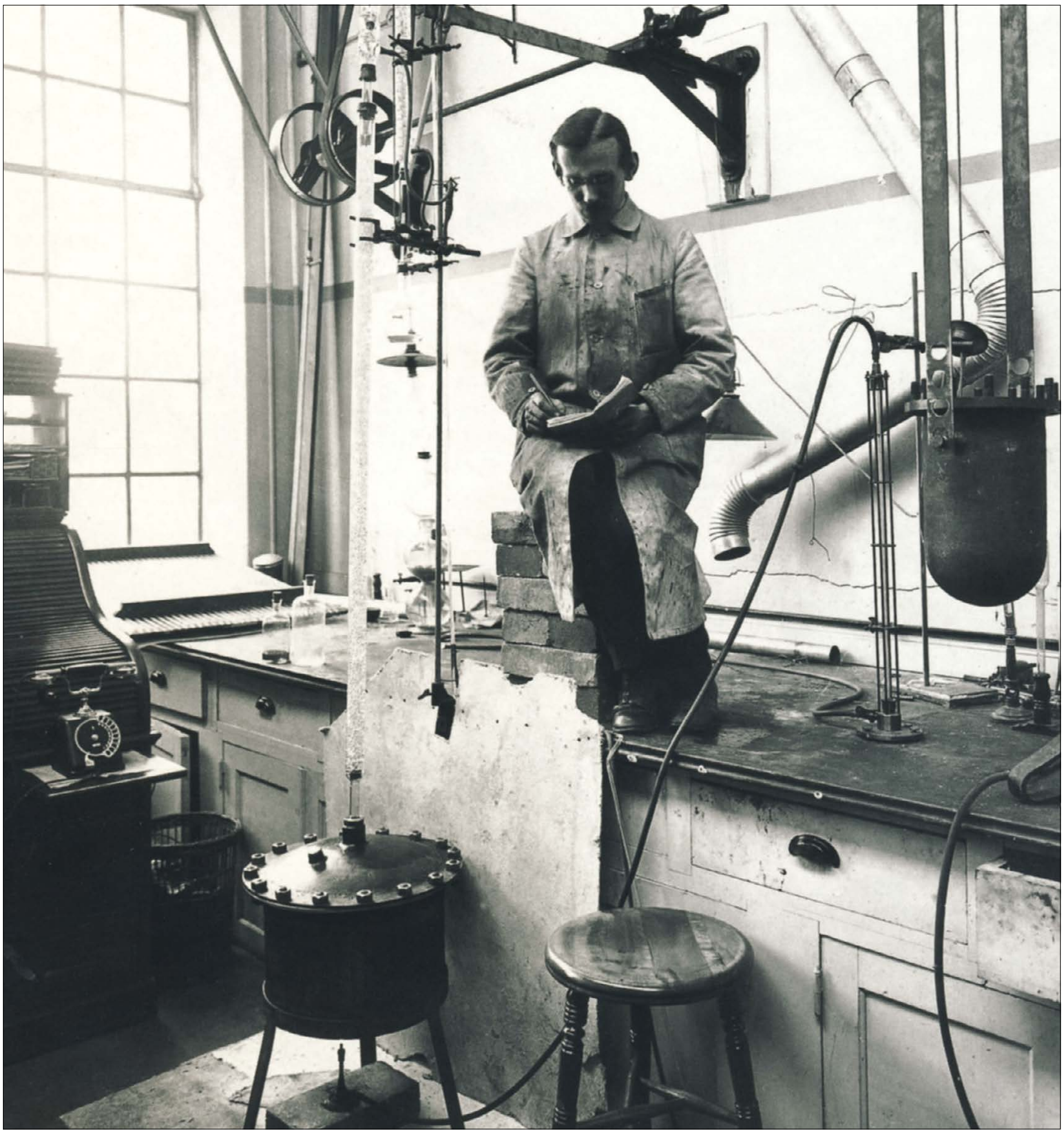
If you've never heard of Lippmann photographs or Dalén valves – if their names do not trip off your tongue like Lorentz contractions or Zeeman shifts – you're in good company. Lippmann's invention was never commercially successful. Dalén's was, but it faded from use around 50 years ago, and in physics terms it is undeniably much less important than contemporaneous advances in quantum mechanics and relativity. Why, then, did the Royal Swedish Academy of Sciences deem these inventions worthy of the most prestigious prize in physics?

> If technical merit can't explain Gabriel Lippmann's Nobel, was it perhaps due to politics?

A colourful but puzzling prize

The strangest thing about Lippmann's prize is that by the time he received it, his version of colour photography was already obsolete – and he knew it. Four days after picking up his award in Stockholm, Lippmann, a Frenchman with a waxed moustache that would shame a silent film villain, ended his Nobel lecture with the verbal equivalent of a Gallic shrug. Despite nearly 20 years of work, he acknowledged that the minimum exposure time for his photographs – one minute in full sunlight – was still "too long for the portrait". Though further improvements were possible, he concluded, "Life is short and progress is slow."

To understand why the Academy bestowed its physics prize on a method of colour photography that not even its inventor seemed to believe in, let's begin with the method itself. Unlike other imaging processes, Lippmann photography directly records the entire colour spectrum of an object. It does this by using standing waves of light to produce interference fringes in a light-sensitive emulsion backed by a mirrored surface. The longer the wavelength



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Inventive laureates (Left) Gabriel Lippmann in his laboratory at Sorbonne University in 1908. (Right) Gustaf Dalén in his lab at Aktiebolaget Gasaccumulator.

of light given off by the object, the larger the separation between the fringes. It's an elegant application of classical wave theory. It's easy to see why Edwardian-era physicists loved it.

Lippmann's method also has an important practical advantage. Because his photographs don't require pigments, they retain their colour over time. Consequently, the images Lippmann showed off in his Nobel lecture look as brilliant today as they did in 1908.

The method's disadvantages, though, are numerous. As well as needing long exposure times, the colours in Lippmann photographs are hard to see. Because they are virtual, like a hologram, they are only accurate when viewed face-on, in perpendicular light. Lippmann's original method also required highly toxic liquid mercury to make the mirrored back surface of each photographic plate. Though modern versions have eliminated this, it's not surprising that Lippmann's method is now largely the domain of artists and hobbyists.

A French connection

If technical merit can't explain Lippmann's Nobel, was it perhaps due to politics? The easiest way to find out is to look in the Nobel archives. Although the names of Nobel prize nominees and the people who nominated them are initially secret, this secrecy is lifted after 50 years. The nomination records for Lippmann's era are therefore very much available, and they show that he was a popular candidate. Between 1901 and 1908, he received 23 nominations from 12 different people – including previous laureates, foreign members of the Academy, and scientists from prestigious universities invited to make nominations in specific years.

Funnily enough, though, all of them were French.

Faced with this apparent conspiracy to stamp the French tricolour on the Nobel medal, Karl Grandin, who directs the Academy's Center for History of Science, concedes that such nationalistic campaigns were "quite common in the first years". However, this doesn't mean they were successful: "Sometimes when all the members of the French Academy have signed a nomination, it might be impressive at one point, but it might also be working in the opposite way," he says.

A clash of personalities

Because Nobel Foundation statutes stipulate that discussions and vote numbers from the prize-awarding meeting of the Academy are not recorded, Grandin can't say

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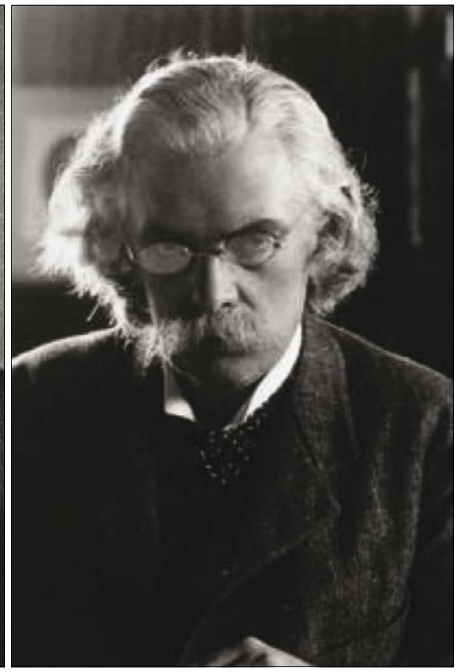
Capturing colour A still life photograph taken by Lippmann using his method between 1890 and 1910. By the latter part of this period, the method had fallen out of favour, superseded by the simpler Autochrome process.

Images in public domain



Double trouble The feuding between Svante Arrhenius (left) and Gustaf Mittag-Leffler played a major role in Gabriel Lippmann winning the Nobel Prize for Physics.

exactly how Lippmann came out on top in 1908. He does, however, have access to an illuminating article written in 1981 by a theoretical physicist, Bengt Nagel.

Drawing on the private letters and diaries of Academy members as well as the Nobel archives, Nagel showed that personal biases played a significant role in the awarding of the 1908 prize. It's a complicated story, but the most important strand of it centres on Svante Arrhenius, the Swedish physical chemist who'd won the Nobel Prize for Chemistry five years earlier.

Today, Arrhenius is best known for predicting that putting carbon dioxide in the Earth's atmosphere will affect the climate. In his own lifetime, though, Arrhenius was also known for having a long-running personality conflict with a Swedish mathematician called Gustaf Mittag-Leffler.

"Stockholm at the time was a small place," Grandin explains. "Everyone knew each other, and it wasn't big enough to host both Arrhenius and Mittag-Leffler."

Arrhenius wasn't the chair of the Nobel physics committee in 1908. That honour fell to Knut Angstrom, son of the Angstrom the unit is named after. Still, Arrhenius' prestige and outsized personality gave him considerable influence. After much debate, the committee agreed to recommend his preferred choice for the prize, Max Planck, to the full Academy.

This choice, however, was not problem-free. Planck's theory of the quantization of matter was still relatively new in 1908, and his work was not demonstrably guiding experiments. If anything, it was the other way around. In principle, the committee could have dealt with this by recommending that Planck share the prize with a quantum experimentalist. Unfortunately, no such person had been nominated.

That was awkward, and it gave Mittag-Leffler the opening he needed. When the matter went to the Academy for a vote, he used members' doubts about quantum theory to argue against Arrhenius' choice. It worked. In Mittag-Leffler's telling, Planck got only 13 votes. Lippmann, the committee's second choice, got 46.

A consensus laureate

Afterwards, Mittag-Leffler boasted about his victory. "Arrhenius wanted to give it to Planck…but his report, which he had nevertheless managed to have unanimously accepted by the committee, was so stupid that I could easily have crushed it," he wrote to a French colleague. "Two members even declared that after hearing me, they changed their opinion and voted for Lippmann. I would have had nothing against sharing the prize between [quantum theorist Wilhelm] Wien and Planck," Mittag-Leffler added, "but to give it to Planck alone would have been to reward ideas that are still very obscure and require verification by mathematics and experimentation."

Lippmann's work posed no such difficulties, and that seems to have swung it for him. In a letter to a colleague after the dust had settled, Angstrom called Lippmann "obviously a prizeworthy candidate who did not give rise to any objections". However, Angstrom added, he "could not deny that the radiation laws constitute a more important advance in physical science than Lippmann's colour photography".

Much has been written about excellent scientists getting overlooked for prizes because of biases against them. The flip side of this – that merely good scientists sometimes win prizes because of biases in their favour – is usually left unacknowledged. Nevertheless, it happens, and in 1908 it happened to Gabriel Lippmann – a good scientist who won a Nobel prize not because he did the most important work, but because his friends clubbed together to support him; because Academy members were wary of his quantum rivals; and above all because a grudge-holding mathematician and an egotistical chemist had a massive beef with each other.

And then, four years later, it happened again, to Gustaf Dalén.

The unlikeliest laureate

Dalén was, by some margin, history's unlikeliest physics Nobel laureate. He wasn't a physicist, for starters. He wasn't even a chemist. He was an inventor, and the invention that won him the prize was closely connected – in more ways than one – to an industrial accident that almost cost him his life.

Like Alfred Nobel, Dalén was Swedish, born in 1869 in the small farming community of Stenstorp. Located around 140 km north-east of Gothenburg, Stenstorp is now home to a museum in Dalén's honour. As a young man, though, he did not seem like museum material. On the contrary, he was incredibly lazy – so lazy, in fact, that he invented a machine to make coffee and turn the light on for him in the mornings.

This ingenious device brought Dalén some local notoriety, but his big break came when Sweden's most famous inventor at the time, Gustaf de Laval, saw him demonstrate a device for measuring milk fat content. Encouraged by de Laval to attend university, Dalén sold his family's farm and enrolled at what is now the Chalmers University of Technology. After spending an additional year at ETH Zürich in Switzerland, he returned to Sweden to set up his first engineering firm.

A light in the darkness

The engineering challenge that set Dalén on the path to the Nobel was hugely important in a country like Sweden with a long, complex coastline. Years before the advent of GPS, or even reliable radio communications, lighthouses were the main way of warning ships away from danger. However, they were extremely expensive and hard to maintain. As well as needing 24-hour attention from skilled and hardy humans, they required huge amounts of propane fuel, necessitating frequent (and frequently dangerous) resupply trips.

The obvious way of reducing these costs was to make lighthouses burn something else. Acetylene was attractive because it could be manufactured in industrial quantities, and it produced a bright light when burned. Unfortunately, it was also highly explosive, meaning it couldn't be safely bottled or shipped.

To tame the acetylene dragon, Dalén developed three separate inventions. The first was a combination of asbestos and diatomaceous earth that he called "agamassan" after his company (Aktiebolaget Gasaccumulator) and the Swedish word for compound, *massan*. By filling a container with agamassan, wetting it with acetone and then forcing acetylene into the container under pressure, Dalén showed that the acetylene would dissolve in the acetone and become trapped within the agamassan like water in a sponge. Under these conditions, it could be shipped, stored and even dropped without exploding.

Having made acetylene safe to use, Dalén turned to making it economical. His second invention was a device that automatically turned the acetylene supply on and off. This saved fuel and enabled the light to flash (distinguishing it from other light sources on the shore) without the need for cumbersome rotation mechanisms.

Dalén's third invention enabled even greater automation. Rather than relying on lighthouse keepers to switch acetylene burners on at night and off in the morning, Dalén developed a valve that could do it automatically. This valve worked by means of a set of metal rods, one of which was blackened while the others were polished. When the blackened rod absorbed enough heat from the Sun, it expanded and closed the valve. At dusk, or in foggy conditions, the blackened rod returned to the temperature of the others, contracted, and opened the valve.

Let there be light The first lighthouse designed to use Gustaf Dalén's technology is located near Djurgården in Stockholm, Sweden. It has since been converted to run on electricity.

The committee's call

While Dalén was perfecting the use of acetylene gas for lighthouses, the Nobel physics committee was getting on with its usual business of recommending candidates for the prize. In 1909 the committee suggested the radio pioneer Guglielmo Marconi and his academic counterpart Karl Ferdinand Braun. The wider Academy accepted this choice. In 1910 the committee recommended Johannes Diderik van der Waals, the father of modern molecular science. He also won the Academy's approval. In 1911 Wien, whose joint nomination with Planck in 1908 provoked such bitter disputes that neither of them got the prize, finally got the nod from both the committee and the Academy (Planck's prize would have to wait until 1918).

By the early autumn of 1912, there was every indication that the Academy would again accept the committee's recommendation: Heike Kammerlingh Onnes, who had liquefied helium for the first time in 1908 and subsequently used it to discover superconductivity. Although Dalén had also been nominated, Mats Larsson, a physicist at Stockholm University who served on the committee between 2016 and 2023, says he wasn't a serious contender.

"It's clear from the report from the Nobel committee to the Academy that they recognize there is an importance to Dalén's inventions, but it doesn't reach the standard for a Nobel prize," says Larsson. With only a single nomination from a member of the Academy's technical section, Larsson adds, "Dalén is not even on the shortlist."

An industrial accident

Then, before the Academy could vote, tragedy struck. On 27 September 1912, during an experiment so risky it was performed in a quarry rather than in Aktiebolaget Gasaccumulator's Stockholm factory, an explosion left Dalén seriously injured. The next day, Sweden's national paper of record, *Dagens Nyheter*, put the accident on its front page, describing Dalén's face as "unrecognizable" and his

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A devoted couple Gustaf Dalén and his wife Elma outside their home in 1937.

Gustaf Dalén may be the least likely physics Nobel laureate in history, but it would be facile to dismiss him as unworthy

right side as "horribly massacred and burned". Though conscious and talking when taken to hospital, he was not expected to survive.

Nobel prizes cannot be awarded posthumously. If Dalén had died of his injuries, it is unlikely that his colleagues would have voted to honour him. But though Dalén's doctors could not save his eyesight, they did save his life. By the time the Academy convened a few weeks later to vote on the 1912 Nobel prizes, he was recovering in the care of his family and very much on the minds of his sympathetic colleagues.

We don't know exactly what happened next. "The material [in the Nobel archives] is very meagre," Larsson explains. "It just says there was a vote and Dalén won the prize."

Still, it's easy to imagine that someone in the Academy must have pled Dalén's cause. "This is our national hero who fought the war against ignorance and against darkness," agrees Grandin. "And he loses his sight in the purpose of bringing light to the world. It was a symbolic thing."

Warmth as well as light

Dalén was too unwell to attend the usual Nobel prize celebrations in Stockholm. Instead, he sent his brother, a physician, to accept the prize on his behalf. Eventually, though, he recovered enough to resume his duties at Aktiebolaget Gasaccumulator. In time, he even returned to inventing. And herein lies the final twist in his story.

During his convalescence, the blind Dalén noticed something that had apparently escaped his attention when he could see. His wife, Elma, worked very hard around the house, and cooking for him and their four children was especially tiresome. It would be much easier, Dalén decided, if she had a device that could cook several dishes at once, at different temperatures.

In 1922, ten years after losing his sight and winning the Nobel prize, Dalén unveiled the invention that would become his most enduring. Named, like agamassan, after the initials of his company, the AGA cooker is still sold today, bringing warmth to kitchens just as its inventor brought safe and economical illumination to lighthouses. Dalén may be the least likely physics Nobel laureate in history, but it would be facile to dismiss him as unworthy. After all, how many other physics laureates saved hundreds of thousands of lives at sea, while also relieving the drudgery of hundreds of thousands back home?

The verdict of history

Lippmann and Dalén received their Nobel prizes more than a century ago, but many of the factors that contributed to them remain relevant today. Though Larsson is tight-lipped when asked if there have been any recent dust-ups like the one in 1908, or sympathy votes like the one in 1912, he acknowledges that Nobel's request that the prize go to "the person who made the most important discovery or invention in the field of physics during the preceding year" still creates some conflict.

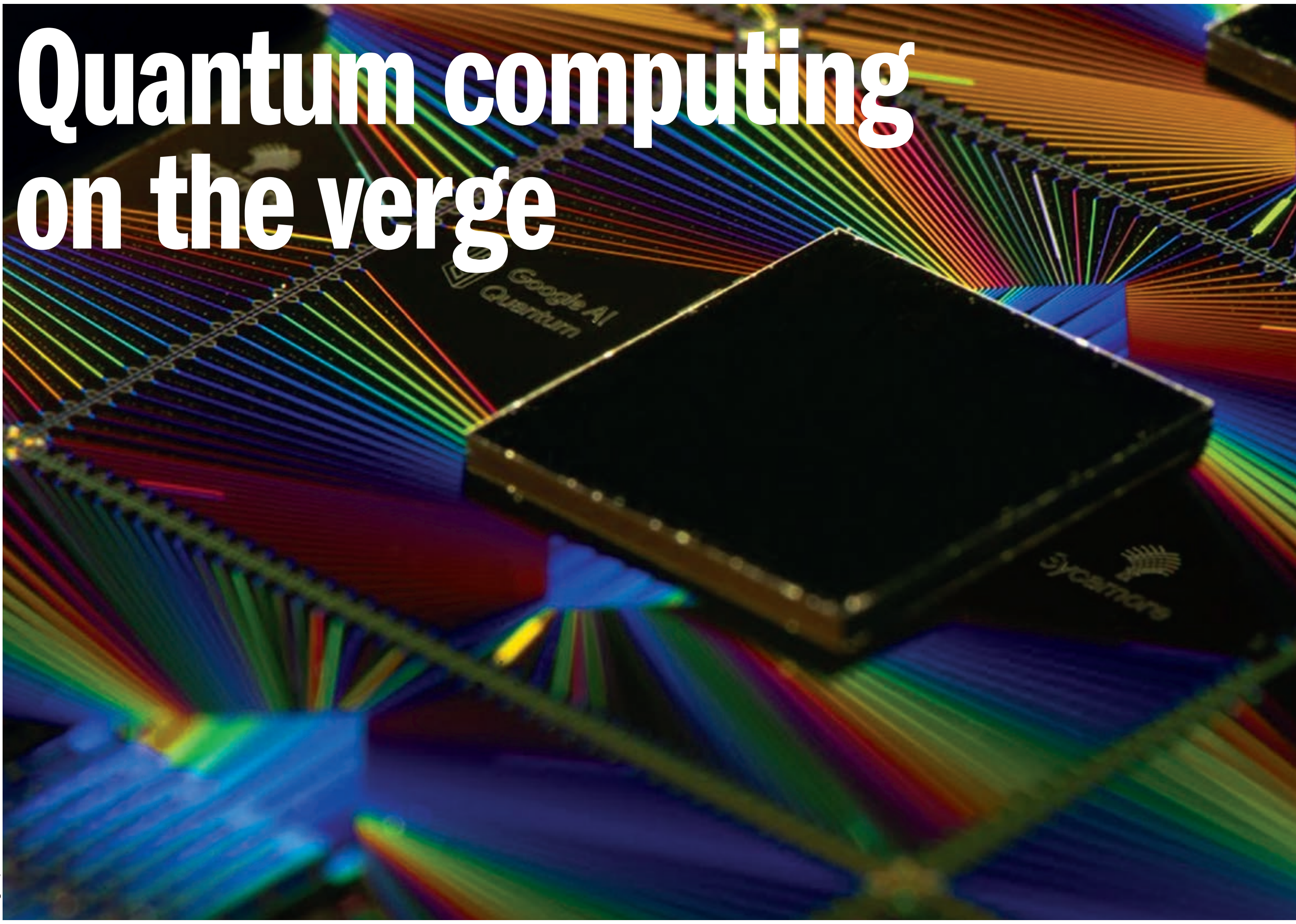
There is, he says, frequently a debate between honouring discoveries (which can, in principle, endure forever) and recognizing inventions (most of which eventually become obsolete). "If we award a discovery prize, there are people who think, 'Oh, there should be more invention prizes,'" he says. "There is always a little bit of this tension."

A more troubling continuity concerns the role of bias. Despite measures to diversify the pool of Nobel nominators, Grandin says that getting broad perspectives remains a challenge. "How on Earth should this small community of physicists and chemists in this small country, Sweden, be able to make this decision every year?" he asks. It is, he adds, "a big, big task".

For the record, Larsson says that Nobel committee members take their task very seriously, with many "long and intense discussions" before recommending new laureates. Even so, he and his colleagues are human, and humans are, on our worst days, prone to all sorts of biases: good at avoiding tough decisions; suspicious of new facts that don't fit our worldviews; and inclined to favour people who remind us of ourselves. In Dalén's case, these biases got refracted through a lens of humanitarian spirit rather than partisan spite, but even so, Grandin says that his prize and Lippmann's demonstrate the importance of keeping the Nobels in perspective.

"Sometimes I have to say, it's just a prize," he says. "It's not the correct answers to all questions in physics." ■

Quantum computing on the verge



Google Quantum AI

Quantum computing is booming in the world of business, with about 400 competing companies, lots of rival qubit platforms and varying measures of merit. **Philip Ball** explores how the quantum tech landscape is developing

"I'd be amazed if quantum computing produces anything technologically useful in ten years, twenty years, even longer." So wrote University of Oxford physicist David Deutsch – often considered the father of the theory of quantum computing – in 2004. But, as he added in a caveat, "I've been amazed before."

We don't know how amazed Deutsch, a pioneer of quantum computing, would have been had he attended a meeting at the Royal Society in London in February on "the future of quantum information". But it was tempting to conclude from the event that quantum computing has now well and truly arrived, with working machines that harness quantum mechanics to perform computations being commercially produced and shipped to clients. Serving as the UK launch of the International Year of Quantum Science and Technology (IYQ) 2025, it brought together some of the key figures of the field to spend two days discussing quantum computing as something like a mature industry, even if one in its early days.

Werner Heisenberg – who worked out the first proper theory of quantum mechanics 100 years ago – would surely have been amazed to find that the formalism he and his peers developed to understand the fundamental behaviour of tiny particles had generated new ways of manipulating information to solve real-world problems in computation. So far, quantum computing – which exploits phenomena such as superposition and entanglement to potentially achieve greater computational power than the best classical computers can muster – hasn't tackled any practical problems that can't be solved classically.

Although the fundamental quantum principles are well-established and proven to work, there remain many hurdles that quantum information technologies have to clear before this industry can routinely deliver resources with transformative capabilities. But many researchers think that moment of "practical quantum advantage" is fast approaching, and an entire industry is readying itself for that day.

Entangled marketplace

So what are the current capabilities and near-term prospects for quantum computing?

The first thing to acknowledge is that a booming quantum-computing market exists. Devices are being

INTERNATIONAL YEAR OF
Quantum Science and Technology

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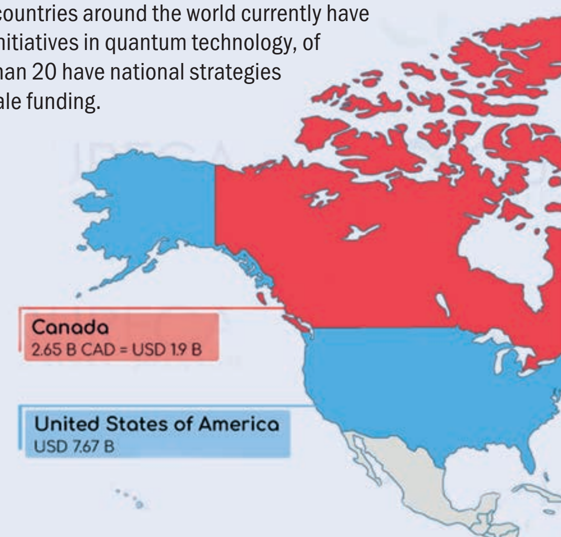
> Many researchers believe that no single qubit type will ever dominate

The global quantum ecosystem

We are on the cusp of a second quantum revolution, with quantum science and technologies growing rapidly across the globe. This includes quantum computers; quantum sensing (ultra-high precision clocks, sensors for medical diagnostics); as well as quantum communications (a quantum internet). Indeed, according to the *State of Quantum 2024* report, a total of 33 countries around the world currently have government initiatives in quantum technology, of which more than 20 have national strategies with large-scale funding.



As of this year, worldwide investments in quantum tech – by governments and industry – exceed $55.7 billion, and the market is projected to reach $106 billion by 2040. With the multitude of ground-breaking capabilities that quantum technologies bring globally, it's unsurprising that governments all over the world are eager to invest in the industry.

With data from a number of international reports and studies, quantum education and skills firm QURECA has summarized key programmes and efforts around the world. These include total government funding spent through 2025, as well as future commitments spanning 2–10 year programmes, varying by country. These initiatives generally represent government agencies' funding announcements, related to their countries' advancements in quantum technologies, excluding any private investments and revenues.

produced for commercial use by a number of tech firms, from the likes of IBM, Google, Canada-based D-Wave, and Rigetti who have been in the field for a decade or more; to relative newcomers like Nord Quantique (Canada), IQM (Finland), Quantinuum (UK and US), Orca (UK) and PsiQuantum (US), Silicon Quantum Computing (Australia). See box, "The global quantum ecosystem".

A supply chain is also organically developing, which includes manufacturers of specific hardware components, such as Oxford Instruments and Quantum Machines and software developers like Riverlane, based in Cambridge, UK, and QC Ware in Palo Alto, California. Supplying the last link in this chain are a range of eager end-users, from finance companies such as J P Morgan and Goldman Sachs to pharmaceutical companies such as AstraZeneca and engineering firms like Airbus. Quantum computing is already big business, with around 400 active companies and current global investment estimated at around $2 billion.

But the immediate future of all this buzz is hard to assess. When the chief executive of computer giant Nvidia announced at the start of 2025 that "truly useful" quantum computers were still two decades away, the previously burgeoning share prices of some leading quantum-computing companies plummeted. They have since recovered somewhat, but such volatility reflects the fact that quantum computing has yet to prove its commercial worth.

The field is still new and firms need to manage expectations and avoid hype while also promoting an optimistic enough picture to keep investment flowing in. "Really amazing breakthroughs are being made," says physicist Winfried Hensinger of the University of Sussex, "but we need to get away from the expectancy that [truly useful] quantum computers will be available tomorrow."

The current state of play is often called the "noisy intermediate-scale quantum" (NISQ) era. That's because the "noisy" quantum bits (qubits) in today's devices are prone to errors for which no general and simple correction process exists. Current quantum computers can't therefore carry out practically useful computations that could not be done on classical high-performance computing (HPC) machines. It's not just a matter of better engineering either; the basic science is far from done.

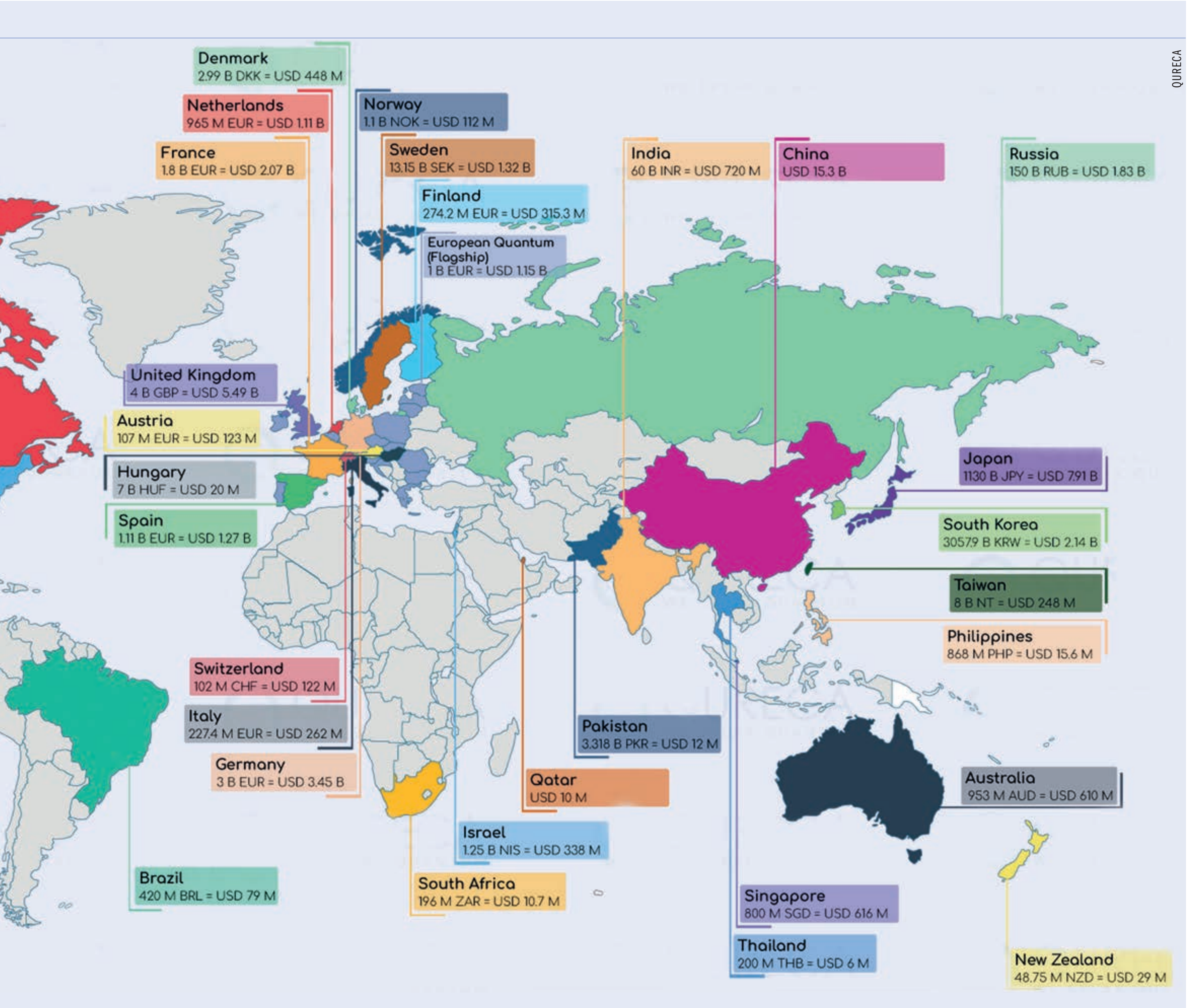
"We are right on the cusp of scientific quantum advantage – solving certain scientific problems better than the world's best classical methods can," says Ashley Montanaro, a physicist at the University of Bristol who co-founded the quantum software company Phasecraft. "But we haven't yet got to the stage of practical quantum advantage, where quantum computers solve commercially important and practically relevant problems such as discovering the next lithium-ion battery." It's no longer if or how, but when that will happen.

Pick your platform

As the quantum-computing business is such an emerging area, today's devices use wildly different types of physical systems for their qubits, see the box on p38, "Comparing computing modalities: from qubits to architectures". There is still no clear sign as to which of these platforms, if any, will emerge as the winner.

Indeed many researchers believe that no single qubit type will ever dominate. The top-performing quantum computers, like those made by Google (with its 105-qubit Willow chip) and IBM (which has made the 121-qubit Condor), use qubits in which information is encoded in the wavefunction of a superconducting material. Until recently, the strongest competing platform seemed to be trapped ions, where the qubits are individual ions held in electromagnetic traps – a technology being developed into working devices by the US company IonQ, spun out from the University of Maryland, among others.

But over the past few years, neutral trapped atoms have emerged as a major contender, thanks to advances in controlling the positions and states of these qubits. Here the atoms are prepared in highly excited electronic states called Rydberg atoms, which can be entangled with one another over a few microns. A Harvard start-up called QuEra is developing this technology, as is the French start-up Pasqal. In September a team from the California Institute of Technology announced a



6100-qubit array made from neutral atoms. “Ten years ago I would not have included [neutral-atom] methods if I were hedging bets on the future of quantum computing,” says Deutsch’s Oxford colleague, the quantum information theorist Andrew Steane. But like many, he thinks differently now.

Some researchers believe that optical quantum computing, using photons as qubits, will also be an important platform. One advantage here is that there is no need for complex conversion of photonic signals in existing telecommunications networks going to or from the processing units, which is also handy for photonic interconnections between chips. What’s more, photonic circuits can work at room temperature, whereas trapped ions and superconducting qubits need to be cooled. Photonic quantum computing is being developed by firms like PsiQuantum, Orca and Xanadu.

Other efforts, for example at Intel and Silicon Quantum Computing in Australia, make qubits from either quantum dots (Intel) or precision-placed phosphorus atoms (SQC), both in good old silicon, which benefits from a very mature manufacturing base. “Small qubits based on ions and atoms yield the highest quality processors”, says Michelle Simmons of the University of New South Wales, who is the founder and CEO of SQC. “But only atom-based systems in silicon combine this quality with manufacturability.”

And it’s not impossible that entirely new quantum computing platforms might yet arrive. At the start of 2025, researchers at Microsoft’s laboratories in Washington State caused a stir when they announced that they had made topological qubits from semiconducting and superconducting devices, which are less error-prone than those currently in use. The announcement left some scientists disgruntled because it was not accompanied by a peer-reviewed paper providing the evidence for these long-sought entities. But in any event, most researchers think it would take a decade or more

Comparing computing modalities: from qubits to architectures

PatentVest

Modality	How it works	Key advantages	Key limitations	Representative companies
Superconducting qubits	Electrical circuits made from superconducting materials, operated at millikelvin temperatures, where current flows without resistance. Qubits are formed using Josephson junctions	Fast gate speeds, mature nanofabrication, strong ecosystem	Short coherence times, complex cryogenic wiring	IBM, Google, Rigetti, IQM
Trapped ions	Individual charged atoms suspended in electromagnetic traps, manipulated by lasers	Exceptional fidelity, long coherence, all-to-all connectivity	Slow operation, complex optical set-ups	IonQ, Quantinuum, Alpine
Neutral atoms	Neutral atoms held in optical tweezers and excited to Rydberg states for interaction	Naturally identical qubits, scalable arrays, parallel gates	Precision laser control needed, electronics scaling challenge	QuEra, Pasqal, Infleqtion
Photonic qubits	Single photons in optical circuits or fibres, encoded in polarization, time, or path	Room-temperature operation, easy networking	Photon loss, probabilistic entanglement	PsiQuantum, Xanadu, ORCA
Silicon spin qubits	Electron or nuclear spins in semiconductor quantum dots, controlled electrically or magnetically	CMOS-compatible fabrication, small footprint	Extreme cryogenics, coherence challenges	Diraq, Quantum Motion
Annealing	Superconducting flux qubits arranged to find low-energy solutions to optimization problems	Only modality with commercial revenue today (optimization)	Not universal computing	D-Wave

Much like classical computers, quantum computers have a core processor and a control stack – the difference being that the core depends on the type of qubit being used. Currently, quantum computing is not based on a single platform, but rather a set of competing hardware approaches, each with its own physical basis for creating and controlling qubits and keeping them stable.

The data above – taken from the August 2025 report *Quantum Computing at the Inflection Point: Who's Leading, What They Own, and Why IP Decides Quantum's Future* by US firm PatentVest – shows the key "quantum modalities", which refers to the different types of qubits and architectures used to build these quantum systems. Differing qubits each have their own pros and cons, with varying factors including the temperature at which they operate, coherence time, gate speed, and how easy they might be to scale up.

One important issue is how amenable the platforms are to making larger quantum circuits

for topological quantum computing to catch up with the platforms already out there.

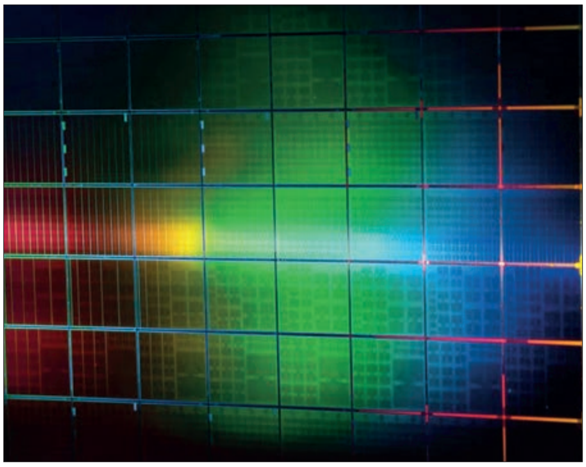
Each of these quantum technologies has its own strengths and weaknesses. "My personal view is that there will not be a single architecture that 'wins', certainly not in the foreseeable future," says Michael Cuthbert, founding director of the UK's National Quantum Computing Centre (NQCC), which aims to facilitate the transition of quantum computing from basic research to an industrial concern. Cuthbert thinks the best platform will differ for different types of computation: cold neutral atoms might be good for quantum simulations of molecules, materials and exotic quantum states, say, while superconducting and trapped-ion qubits might be best for problems involving machine learning or optimization.

Measures and metrics

Given these pros and cons of different hardware platforms, one difficulty in assessing their merits is finding meaningful metrics for making comparisons. Should we be comparing error rates, coherence times (basically how long qubits remain entangled), gate speeds (how fast a single computational step can be conducted), circuit depth (how many steps a single computation can sustain), number of qubits in a processor, or what? "The metrics and measures that have been put forward so far tend to suit one or other platform more than others," says Cuthbert, "such that it becomes almost a marketing exercise rather than a scientific benchmarking exercise as to which quantum computer is better."

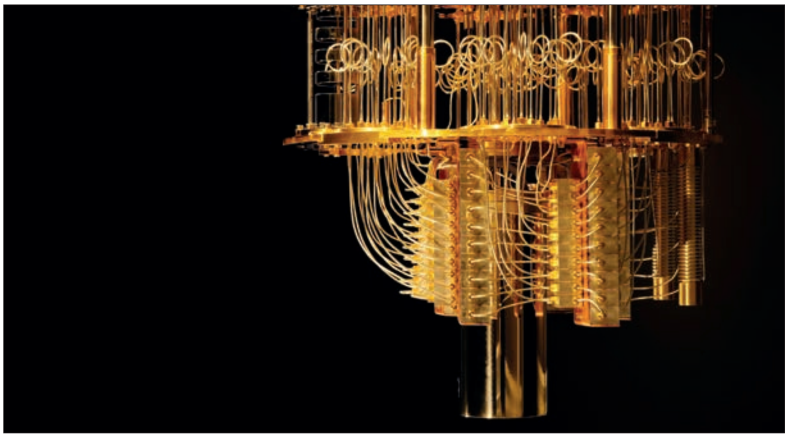
The NQCC evaluates the performance of devices using a factor known as the "quantum operation" (QuOp). This is simply the number of quantum operations that can be carried out in a single computation, before the qubits lose their coherence and the computation dissolves into noise. "If you want to run a computation, the number of coherent operations you can run consecutively is an objective measure," Cuthbert says. If we want to get beyond the NISQ era, he adds, "we need to progress to the point where we can do about a million coherent operations in a single computation. We're now at the level of maybe a few thousand. So we've got a long way to go before we can run large-scale computations."

One important issue is how amenable the platforms are to making larger quantum circuits. Cuthbert contrasts the issue of scaling up – putting more qubits on a chip – with "scaling out", whereby chips of a given size are linked in modular fashion. Many researchers think it unlikely that individual quantum chips will have millions of qubits like the silicon chips of today's machines. Rather, they will be modular arrays of relatively small chips linked at their edges by quantum interconnects.



Intel Corporation

Spinning around Intel’s silicon spin qubits are now being manufactured on an industrial scale.



IBM

Building up Quantum computing behemoth IBM says that by 2029, its fault-tolerant system should accurately run 100 million gates on 200 logical qubits, thereby truly achieving quantum advantage.

Having made the Condor, IBM now plans to focus on modular architectures (scaling out) – a necessity anyway, since superconducting qubits are micron-sized, so a chip with millions of them would be “bigger than your dining room table”, says Cuthbert. But superconducting qubits are not easy to scale out because microwave frequencies that control and read out the qubits have to be converted into optical frequencies for photonic interconnects. Cold atoms are easier to scale up, as the qubits are small, while photonic quantum computing is easiest to scale out because it already speaks the same language as the interconnects.

To be able to build up so called “fault tolerant” quantum computers, quantum platforms must solve the issue of error correction, which will enable more extensive computations without the results becoming degraded into mere noise.

In part two of this feature, we will explore how this is being achieved and meet the various firms developing quantum software. We will also look into the potential high-value commercial uses for robust quantum computers – once such devices exist. ■

Bridging the gap between the lab and policy

With the quantum sector quickly evolving, governments are getting scientific policies and regulations in place to ensure the new technology will benefit our society. During their PhDs, **Elizabeth Pasatembou** and **Dimitrie Cielecki** took part in policy engagement to understand the process and how scientists can get involved

When we started our PhDs in physics at Imperial College London, our paths seemed conventional: a lot of lab work, conferences and a bit of teaching on the side. What we did not expect was that within a couple of years we would be talking with MPs in the House of Commons, civil servants in Whitehall and business leaders in industry. We found ourselves contributing to policy reports and organizing roundtable discussions alongside policy-makers, scientists and investors; focusing on quantum technology and its impact on the economy and society.

Our journey into science policy engagement started almost by chance. Back in 2022 we received an e-mail from Imperial‘s Centre for Quantum Engineering Science and Technology (QuEST) advertising positions for PhD students to support evidence-based policy-making. Seeing it as an opportunity to contribute beyond the lab, we both took up the challenge. It became an integral part of our PhD experience. What started as a part-time role alongside our PhDs turned into something much more than that.

We joined QuEST and the Imperial Policy Forum – the university's policy engagement programme – in 2022 and were soon sitting at the table with leading voices in the nascent quantum technology field. We had many productive conversations with senior figures from most quantum technology start-ups in the UK. We also found ourselves talking to leaders of the National Quantum Technology Programme (including its chair, Sir Peter Knight); to civil servants from the Office for Quantum in the Department of Science, Innovation and Technology (DSIT); and to members of both the House of Commons and the House of Lords.

Elizabeth Pasatembou is a postdoctoral fellow in the Cyprus Quantum Communications Infrastructure group at Cyprus University of Technology. **Dimitrie Cielecki** is a researcher at the Institute for Deep Tech Entrepreneurship at Imperial College London

Elizabeth Pasatembou

Getting started Imperial College London encourages its researchers – established and early-career – to get involved in shaping policy. From left: Dimitrie Cielecki, Michael Ho, Louis Chen, Elizabeth Pasatembou.

Sometimes we would carry out tasks such as identifying the relevant stakeholders for an event or a roundtable discussion with policy implications. Other times we would do desk research and contribute to reports used in the policy-making process. For example, we responded to the House of Commons written evidence inquiry on *Commercialising Quantum Technologies* (2023) and provided analysis and insights for the Regulatory Horizons Council report *Regulating Quantum Technology Applications* (2024). We also moderated a day of roundtable discussions with quantum specialists for the Parliamentary Office of Science and Technology's briefing note *Quantum Computing, Sensing and Communications* (2025).

A two-way street

When studying science, we tend to think of it as a purely intellectual exercise, divorced from the real world. But we know that the field is applied to many areas of life, which is why countries, governments and institutions need policies to decide how science should be regulated, taught, governed and so on.

Science policy has two complimentary sides. First, it's about how governments and institutions support and shape the practice of science through, for example, how funding is allocated. Second, science policy looks at how scientific knowledge informs and guides policy decisions in society, which also links to the increasingly important area of evidence-informed policy-making. These two dimensions are of course linked – science policy connects the science and its applications to regulation, economics, strategy and public value.

iStock/wavebreakmedia

Up for discussion Quantum topics being debated as national policy include quantum cryptography and security.

Quantum policy specifically focuses on the frameworks, strategies and regulations that shape how governments, industries and research institutions develop and deploy quantum technologies. Many countries have published national quantum strategies, which include technology roadmaps tied to government investments. These outline the infrastructure needed to speed up the adoption of quantum technology – such as facilities, supply chains and a skilled workforce.

In the UK, the National Quantum Technology Programme (NQTP) – a government-led initiative that brings together industry, academia and government – has pioneered the idea of co-ordinated national efforts for the development of quantum technologies. Set up in 2014, the programme has influenced other countries to adopt a similar approach. The NQTP has been immensely successful in bringing together different groups from both the public and private sectors to create a productive environment that advances quantum science and technology. Co-operation and communication have been at the core of this programme, which has led to the UK's 10-year National Quantum Strategy. Launched in 2023, this details specific projects to help accelerate technological progress and make the country a leading quantum-enabled economy. But that won't happen unless we have mechanisms to help translate science into innovation, resilient supply chains, industry-led standardization, stable regulatory frameworks and a trained workforce.

Quantum technologies can bring benefits for national security, from advanced sensing to secure communications. But their dual-use nature also poses potential threats as the technology matures, particularly with the prospect of cryptographically relevant quantum computers – machines powerful enough to break encryption. To mitigate these risks in a complex geopolitical landscape, governments need tailored regulations, whether that's preparing for the transition to post-quantum cryptography (making communication safe from powerful code-cracking quantum computers) or controlling exports of sensitive products that could compromise security.

Like artificial intelligence (AI) and other emerging technologies, there are also ethical considerations to take into account when developing quantum technologies. In particular, we need policies to ensure transparency, inclusivity and equitable access. International organizations such as UNESCO and the World Economic Forum have already started integrating quantum into their policy agendas. But as quantum technology is such a rapidly evolving new field, we need to strike a balance between innovation and regulation. Too many rules can stifle innovation but, on the other hand, policy needs to keep up with innovation to avoid any future serious incidents.

Language barriers

Policy engagement involves collaborating with three sets of stakeholders – academia; industry and investors; and policy-makers. But as we started to work with these groups, we noticed each had a different way of communicating, creating a kind of language barrier. Scientists love throwing around equations, data and figures, often using highly technical terminology. Industry leaders and investors, on the other hand, talk in terms of how innovations could affect business performance and profitability, and what the risk for their investments could be. As for policy-makers, they focus more on how to distinguish between reality and hype, and look at budgets and regulations.

We found ourselves acting as cross-sector translators, seeking to bridge the gap between the three groups. We had to listen to each stakeholder's requirements and understand what they needed to know. We then had to reframe technical insights and communicate them in a relevant and useful way – without simplifying the science. Once we grasped everyone's needs and expectations, we offered relevant information, putting it into context for

Mixing PhDs and policy

Elizabeth Pasatembou
Elizabeth Pasatembou started her PhD in 2021, working with the particle-physics group and Centre for Cold Matter at Imperial College London. Her research focused on quantum sensing for fundamental physics as part of the Atom Interferometer Observatory and Network (AION) project. She is now a postdoctoral fellow working on quantum communications with the Cyprus Quantum Communications Infrastructure (CyQCI) team at the Cyprus University of Technology, which is part of the pan-European Quantum Communication Infrastructure (EuroQCI) project.

Her interest in science policy engagement started out of curiosity and the desire to make a more immediate impact during her PhD. "Research can feel slow," she says. "Taking up this role and getting involved in policy gave me the chance to use my expertise in a way that felt directly relevant, and develop new skills along the way. I also saw this as an opportunity to challenge myself and try something new."

Pasatembou also worked on a collaborative project between the Imperial Deep Tech Entrepreneurship and QuEST, conducting interviews with investors to inform the design of a tailored curriculum on quantum technologies for the investors community.

Craig Whittall

Getting involved From left: Dimitrie Cielecki, Elizabeth Pasatembou and Michael Ho in the UK Houses of Parliament.

Dimitrie Cielecki
Dimitrie Cielecki joined Imperial's Complex Nanophotonics group as a PhD candidate in 2021. The opportunity to work in science policy came at a time when his research was evolving in new directions. "The first year of my PhD was not straightforward, with my project taking unexpected, yet exciting, turns in the realm of photonics, but shifting away from quantum," explains Cielecki, whose PhD topic was spatio-temporal light shaping for metamaterials.

After seeing an advert for a quantum-related policy fellowship, he decided to jump in. "I didn't even know what supporting policy-making meant at that point," he says. "But I quickly became driven by the idea that my actions and opinions could have a quick impact in this field."

Cielecki is now a quantum innovation researcher at the Institute for Deep Tech Entrepreneurship in the Imperial Business School, where he is conducting research on the correlations between technical progress, investors' confidence and commercial success in the emerging quantum sector.

each group so everyone was on the same page.

To help us do this, we considered the stakeholders as "inventor", "funder", "innovator" or "regulator". As quantum technology is such a rapidly growing sector, the groupings of academia, industry and policy-makers are so entangled that the roles are often blurred. This alternative framework helped us to identify the needs and objectives of the people we were working with and to effectively communicate our science or evidence-backed messages.

Finding the right people

During our time as policy fellows, we were lucky to have mentors to teach us how to navigate this quantum landscape. In terms of policy, Craig Whittall from the Imperial Policy Forum was our guide on protocol and policy scoping. We worked closely with QuEST management – Peter Haynes and Jess Wade – to organize discussions, collect evidence from researchers, generate policy leads, and formulate insights or recommendations. We also had the pleasure of working with other PhD students, including Michael Ho, Louis Chen and Victor Lovic, who shared the same passion for bridging quantum research and policy.

Having access to world-leading scientists and a large pool of early-career researchers spread across all departments and faculties, facilitated by the network in QuEST, made it easier for us to respond to policy inquiries. Early on, we mapped out what quantum-related research is going on at Imperial and created a database of the researchers involved. This helped inform the university's strategy regarding quantum research, and let us identify who should contribute to the various calls for evidence by government or parliament offices.

PhD students are often treated as learners rather than contributors. But our experience showed that with the right support and guidance, early-career researchers (ECRs) such as ourselves can make real impact by offering fresh perspectives and expertise. We are the scientists, innovators or funders of the future so there is value in training people like us to understand the bigger picture as we embark on our careers.

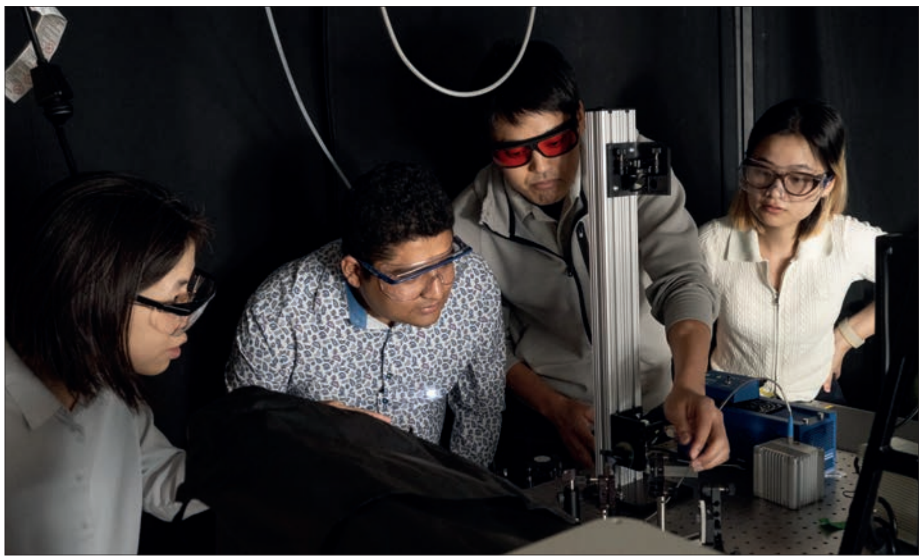
To encourage young researchers to get involved in policy, QuEST and DSIT recently organized two policy workshops for ECR quantum tech specialists. Civil servants from the Office for Quantum explained their efforts and priorities, while we answered questions about our experience – the aim being to help ECRs to engage in policy-making, or choose it as a career option.

In April 2025 QuEST also launched an eight-week quantum primer for policy-makers. The course was modelled on a highly successful equivalent for AI, and looked to help policy-makers make more technically informed policy discussions. The first cohort welcomed civil servants from across government, and it was so highly reviewed a second course will be running from October 2025.

Our experience with QuEST has shown us the importance of scientists taking an active role in policy-making. With the quantum sector evolving at a formidable rate, it is vital that a framework is in place to take research from the lab to society. Scientists, industry, investors and policy-makers need to work together to create regulations and policies that will ensure the responsible use of quantum technologies that will benefit us all. ■

Shengxi Huang: how defects can boost 2D materials as single-photon emitters

Shengxi Huang explains why Picoquant's instruments are helping her to develop 2D materials that are highly efficient sources of single photons



Jeff Fitlow

Hidden depths Shengxi Huang (left) with members of her lab at Rice University in the US, where she studies 2D materials as single-photon sources.

Everyday life is three dimensional, with even a sheet of paper having a finite thickness. Shengxi Huang from Rice University in the US, however, is attracted by 2D materials, which are usually just one atomic layer thick. Graphene is perhaps the most famous example – a single layer of carbon atoms arranged in a hexagonal lattice. But since it was first created in 2004, all sorts of other 2D materials, notably boron nitride, have been createds.

An electrical engineer by training, Huang did a PhD at the Massachusetts Institute of Technology and postdoctoral research at Stanford University before spending five years as an assistant professor at the Pennsylvania State University. Huang has been at Rice since 2022, where she is now an associate professor in the Department of Electrical and Computer Engineering, the Department of Material Science and NanoEngineering, and the Department of Bioengineering.

Her group at Rice currently has 12 people, including eight graduate students and four postdocs. Some are physicists, some are engineers, while others have backgrounds in material science or chemistry. But they all share an interest in understanding the optical and electronic properties of quantum materials and seeing how they can be used, for example, as biochemical sensors. Lab equipment from Picoquant is vital in helping in that quest, as Huang explains in an interview with *Physics World*.

Why are you fascinated by 2D materials?

I'm an electrical engineer by training, which is a very broad field. Some electrical engineers focus on things like communication and computing, but others, like myself, are more interested in how we can use fundamental physics to build useful devices, such as semiconductor chips. I'm particularly interested in using 2D materials for optoelectronic devices and as single-photon emitters.

What kinds of 2D materials do you study?

The materials I am particularly interested in are transition metal dichalcogenides, which consist of a layer of transition-metal atoms sandwiched between two layers of chalcogen atoms – sulphur, selenium or tellurium. One of the most common examples is molybdenum disulphide, which in its monolayer form has a layer of sulphur on either side of a layer of molybdenum. In multi-layer molybdenum disulphide, the van der Waals forces between the tri-layers are relatively weak, meaning that the material is widely used as a lubricant – just like graphite, which is a many-layer version of graphene.

Why do you find transition metal dichalcogenides interesting?

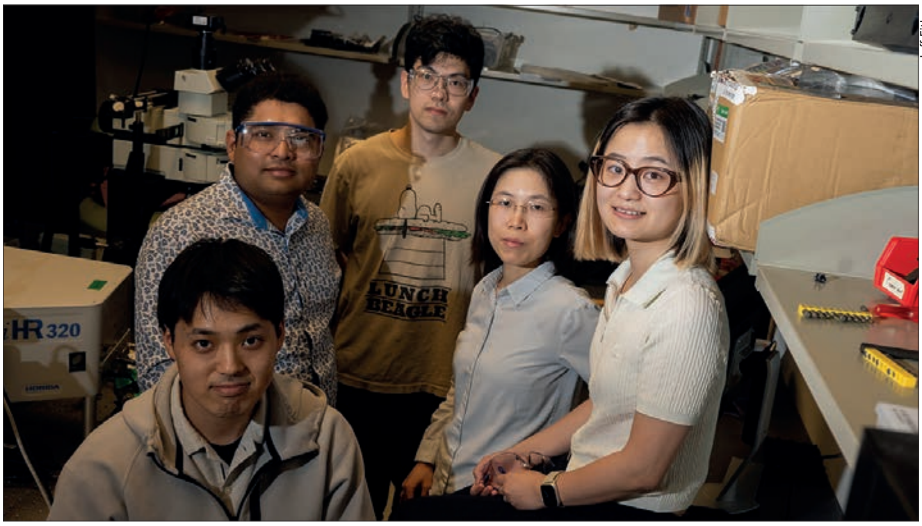
Transition metal dichalcogenides have some very useful optoelectronic properties. In particular, they emit light whenever the electron and hole that make up an "exciton" recombine. Now because these dichalcogenides are so thin, most of the light they emit can be used. In a 3D material, in contrast, most light is generated deep in the bulk of the material and doesn't penetrate beyond the surface. Such 2D materials are therefore very efficient and, what's more, can be easily integrated onto chip-based devices such as waveguides and cavities.

Transition metal dichalcogenide materials also have promising electronic applications, particularly as the active material in transistors. Over the years, we've seen silicon-based transistors get smaller and smaller as we've followed Moore's law, but we're rapidly reaching a limit where we can't shrink them any further, partly because the electrons in very thin layers of silicon move so slowly. In 2D transition metal dichalcogenides, in contrast, the electron mobility can actually be higher than in silicon of the same thickness, making them a promising material for future transistor applications.

What can such sources of single photons be used for?

Single photons are useful for quantum communication and quantum cryptography. Carrying information as zero and one, they basically function as a qubit, providing a very secure communication channel. Single photons are also interesting for quantum sensing and even quantum computing. But it's vital that you have a highly pure source of photons. You don't want them mixed up with "classical photons", which – like those from the Sun – are emitted in bunches as otherwise the tasks you're trying to perform cannot be completed

What approaches are you taking to improve 2D materials as single-photon emitters?
What we do is introduce atomic defects into a 2D material to give it optical properties that are different to what you'd get in the bulk. There are several ways of doing this. One is to irradiate a sample with ions or electrons, which can bombard individual atoms out to generate "vacancy defects". Another option is to use plasmas, whereby atoms in the sample get replaced by atoms from the plasma.



Jeff Fitlow

Beyond the surface Shengxi Huang (second right) uses equipment from PicoQuant to probe 2D materials.

So how do you study the samples?
Se can probe defect emission using a technique called photoluminescence, which basically involves shining a laser beam onto the material. The laser excites electrons from the ground state to an excited state, prompting them to emit light. As the laser beam is about 500-1000 nm in diameter, we can see single photon emission from an individual defect if the defect density is suitable.

What sort of experiments do you do in your lab?
We start by engineering our materials at the atomic level to introduce the correct type of defect. We also try to strain the material, which can increase how many single photons are emitted at a time. Once we've confirmed we've got the correct defects in the correct location, we check the material is emitting single photons by carrying out optical measurements, such as photoluminescence. Finally, we characterize the purity of our single photons – ideally, they shouldn't be mixed up with classical photons but in reality, you never have a 100% pure source. As single photons are emitted one at a time, they have different statistical characteristics to classical light. We also check the brightness and lifetime of the source, the efficiency, how stable it is, and if the photons are polarized. In fact, we have a feedback loop: what improvements can we do at the atomic level to get the properties we're after?

Is it difficult adding defects to a sample?
It's pretty challenging. You want to add just one defect to an area that might be just one micron square so you have to control the atomic structure very finely. It's made harder because 2D materials are atomically thin and very fragile. So if you don't do the engineering correctly, you may accidentally introduce other types of defects that you don't want, which will alter the defects' emission.

What techniques do you use to confirm the defects are in the right place?
Because the defect concentration is so low, we cannot use methods that are typically used to characterise materials, such as X-ray photo-emission spectroscopy or scanning electron microscopy. Instead, the best and most practical way is to see if the defects generate the correct type of optical emission predicted by theory. But even that is challenging because our calculations, which we work on with computational groups, might not be completely accurate.

How do your PicoQuant instruments help in that regard?
We have two main pieces of equipment – a MicroTime 100 photoluminescence microscope and a FluoTime 300 spectrometer. These have been customized to form a Hanbury Brown Twiss interferometer, which measures the purity of a single photon source. We also use the microscope and spectrometer to characterise photoluminescence spectrum and lifetime. Essentially, if the material emits light, we can then work out how long it takes before the emission dies down.

Did you buy the equipment off-the-shelf?
It's more of a customised instrument with different components – lasers, microscopes, detectors and so on – connected together so we can do multiple types of measurement. I put in a request to Picoquant, who discussed my requirements with me to work out how to meet my needs. The equipment has been very important for our studies as we can carry out high-throughput measurements over and over again. We've tailored it for our own research purposes basically.

So how good are your samples?
The best single-photon source that we currently work with is boron nitride, which has a single-photon purity of 98.5% at room temperature. In other words, for every 200 photons only three are classical. With transition-metal dichalcogenides, we get a purity of 98.3% at cryogenic temperatures.

What are your next steps?
There's still lots to explore in terms of making better single-photon emitters and learning how to control them at different wavelengths. We also want to see if these materials can be used as high-quality quantum sensors. In some cases, if we have the right types of atomic defects, we get a high-quality source of single photons, which we can then entangle with their spin. The emitters can therefore monitor the local magnetic environment with better performance than is possible with classical sensing methods.

More information about the author's work can be found in Sci. Adv. (**11** 2899)*, Nano. Lett.* (**25** 10263)*, ACS Nano* (**16** 7428) *and J. Phys. Chem. Lett.* (**14** 3274).

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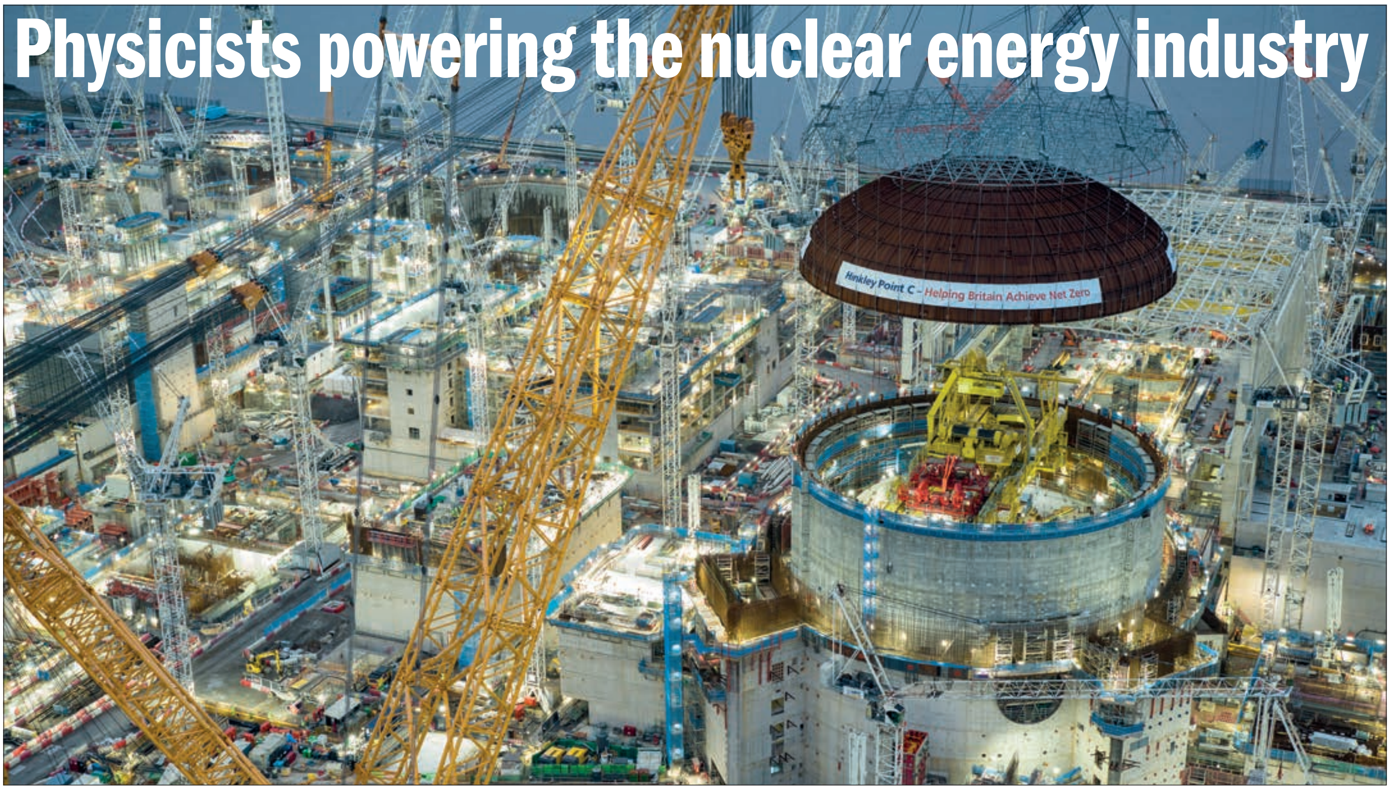
This article was written by *Physics World* on behalf of PicoQuant. Read more on *physicsworld.com*.

Careers

Physicists powering the nuclear energy industry



EDF energy

Big energy The 245-tonne domed roof has been lowered onto the first of two new reactors being built at Hinkley Point C.

With the push to move away from fossil fuels, the UK is turning to nuclear power. New reactors are being built and new technology is being developed, but there is a skills shortage. **Sarah Tesh** talks to six physicists working across the nuclear energy industry, highlighting how a background in physics can open many doors in this expanding sector

Nuclear power in the UK is on the rise – and so too are the job opportunities for physicists. Whether it's planning and designing new reactors, operating existing plants safely and reliably, or dealing with waste management and decommissioning, physicists play a key role in the burgeoning nuclear industry.

The UK currently has nine operational reactors across five power stations, which together provided 12% of the country's electricity in 2024. But the government wants that figure to reach 25% by 2050 as part of its goal to move away from fossil fuels and reach net zero. Some also think that nuclear energy will be vital for powering data centres for AI in a clean and efficient way.

While many see fusion as the future of nuclear power, it is still in the research and development stages, so fission remains where most job opportunities lie. Although eight of the current fleet of nuclear reactors are to be retired by the end of this decade, the first of the next generation are already in construction. At Hinkley Point C in Somerset, two new reactors are being built with costs estimated to reach £46bn; and in July 2025, Sizewell C in Suffolk got the final go-ahead. Rolls-Royce, meanwhile, has just won a government-funded bid to develop small modular reactors (SMR) in the UK. Although currently an unproven technology, the hope is that SMRs will be cheaper and quicker to build than traditional plants, with proponents saying that each reactor could produce enough affordable emission-free energy to power about 600,000 homes for at least 60 years.

The renaissance of the nuclear power industry has led to employment in the sector growing by 35% between 2021 and 2024, with the workforce reaching over 85 000. However – as highlighted in a 2025 members survey by the Nuclear Institute – there are concerns about a skills shortage. In fact, the Nuclear Skills Plan was detailed by the Nuclear Skills Delivery Group in 2024 with the aim to address this problem.

Supported by an investment of £763m by 2030 from the UK government and industry, the plan's objectives include quadrupling the number of PhDs in nuclear fission, and doubling the number of graduates entering the workforce. It also aims to provide opportunities for people to "upskill" and join the sector mid-career. The overall hope is to fill 40 000 new jobs by the end of the decade.

Having a degree in physics can open the door to any part of the nuclear-energy industry, from designing, operating or decommissioning a reactor, to training staff, overseeing safety or working as a consultant. We talk to six nuclear experts who all studied physics at university but now work across the sector, for a range of companies – including EDF Energy and Great British Energy – Nuclear. They give a quick snapshot of their "nuclear journeys", and offer advice to those thinking of following in their footsteps.

Design and construction

Michael Hodgson, lead engineer, Rolls-Royce SMR

My interest in nuclear power started when I did a project on energy at secondary school. I learnt that there were significant challenges around the world's future energy demands, resource security, and need for clean generation. Although at the time these were not topics commonly talked about, I could see they were vital to work on, and thought nuclear would play an important role.

I went on to study physics at the University of Surrey, with a year at Michigan State University in the US and another at CERN. After working for a couple of years, I returned to Surrey to do a part-time masters in radiation detection and instrumentation, followed a few years later by a PhD in radiation-hard semiconductor neutron detectors.

Up until recently, my professional work has mainly been in the supply chain for nuclear applications, working for Thermo Fisher Scientific, Centronic and Exosens. Nuclear power isn't made by one company, it's a combination of thousands of suppliers and sub-suppliers, the majority of which are small to medium-sized enterprises that need to operate across multiple industries. My job was primarily a technical design authority for manufacturers of radiation detectors and instruments, used in applications such as reactor power monitoring, health physics, industrial controls, and laboratory equipment, to name but a few. Now I work at Rolls-Royce SMR as a lead engineer for the control and instrumentation team. This role involves selecting and qualifying the thousands of different detectors and control instruments that will support the operation of small modular reactors.


Michael Hodgson

Logical, evidence-based problem solving is the cornerstone of science and a powerful tool in any work setting

Beyond the technical knowledge I've gained throughout my education, studying physics has also given me two important skills. Firstly, learning how to learn – this is critical in academia but it also helps you step into any professional role. The second skill is the logical, evidence-based problem solving that is the cornerstone of science, which is a powerful tool in any work setting.

A career in nuclear energy can take many forms. The industry is comprised of a range of sectors and thousands of organizations that altogether form a complex support structure. My advice for any role is that knowledge is important, but experience is critical. While studying, try to look for opportunities to gain professional experience – this may be industry placements, research projects, or even volunteering. And it doesn't have to be in your specific area of interest – cross-disciplinary experience breeds novel thinking. Utilizing these opportunities can guide your professional interests, set your CV apart from your peers, and bring pragmatism to your future roles.

Skills initiatives

Saralyn Thomas, skills lead, Great British Energy – Nuclear

During my physics degree at the University of Bristol, my interest in energy led me to write a dissertation on nuclear power. This inspired me to do a masters in nuclear science and technology at the University of Manchester under the Nuclear Technology Education Consortium. The course opened doors for me, such as a summer placement with the UK National Nuclear Laboratory, and my first role as a junior safety consultant with Orano.

I worked in nuclear safety for roughly 10 years, progressing to principal consultant with Abbott Risk Consulting, but decided that this wasn't where my strengths and passions lay. During my career, I volunteered for the Nuclear Institute (NI), and worked with the society's young members group – the Young Generation Network (YGN). I ended up becoming chair of the YGN and a trustee of the NI, which involved supporting skills initiatives including those feeding into the Nuclear Skills Plan. Having a strategic view of the sector and helping to solve its skills challenges energized me in a new way, so I chose to change career paths and moved to Great British Energy – Nuclear (GBE-N) as skills lead. In this role I plan for what skills the business and wider sector will need for a nuclear new build programme, as well as develop interventions to address skills gaps.


Great British Energy – Nuclear

The UK's nuclear sector is seeing significant government commitment, but there is a major skills gap

GBE-N's current remit is to deliver Europe's first fleet of small modular reactors, but there is relatively limited experience of building this technology. Problem-solving skills from my background in physics have been essential to understanding what assumptions we can put in place at this early stage, learning from other nuclear new builds and major infrastructure projects, to help set us up for the future.

To anyone interested in nuclear energy, my advice is to get involved now. The UK's nuclear sector is seeing significant government commitment, but there is a major skills gap. Nuclear offers a lifelong career with challenging, complex projects – ideal for physicists who enjoy solving problems and making a difference.

Reactor operation

Katie Barber, nuclear reactor operator and simulator instructor, Sizewell B, EDF

I studied physics at the University of Leicester simply because it was a subject I enjoyed – at the time I had no idea what I wanted to do for a career. I first became interested in nuclear energy when I was looking for graduate jobs. The British Energy (now EDF) graduate scheme caught my eye because it offered a good balance of training and on-the-job experience. I was able to spend time in multiple different departments at different power stations before I decided which career path was right for me.

At the end of my graduate scheme, I worked in nuclear safety for several years. This involved reactor physics testing and advising on safety issues concerning the core and fuel. It was during that time I became interested in the operational response to faults. I therefore applied for the company's reactor operator training programme – a two-year course that was a mixture of classroom and simulator training. I really enjoyed being a reactor operator, particularly during outages when the plant would be shutdown, cooled, depressurised and dissembled for refuelling before reversing the process to start up again. But after almost 10 years in the control room, I wanted a new challenge.


Katie Barber

A graduate training scheme is an excellent way to get an overview of the business, and gain experience across many different departments and disciplines

Now I develop and deliver the training for the control-room teams. My job, which includes simulator and classroom training, covers everything from operator fundamentals (such as reactor physics and thermodynamics) and normal operations (e.g. start up and shutdown), through to accident scenarios.

My background in physics gives me a solid foundation for understanding the reactor physics and thermodynamics of the plant. However, there are also a lot of softer skills essential for my role. Teaching others requires the ability to present and explain technical material; to facilitate a constructive debrief after a simulator scenario; and to deliver effective coaching and feedback. The training focuses as much on human performance as it does technical knowledge, highlighting the importance of effective teamwork, error prevention and clear communications.

With Hinkley Point C construction progressing well and the recent final investment decision for Sizewell C, now is an exciting time to join the nuclear industry. A graduate training scheme is an excellent way to get an overview of the business, and gain experience across many different departments and disciplines, before making the decision about which area is right for you.

Uranium enrichment

Mark Savage, nuclear licensing manager, Urenco UK

As a child, I remember going to the visitors' centre at the Sellafield nuclear site – a large nuclear facility in the north-west of England that's now the subject of a major clean-up and decommissioning operation. At the centre, there was a show about splitting the atom that really sparked my interest in physics and nuclear energy.

I went on to study physics at Durham University, and did two summer placements at Sellafield, working with radiometric instruments. I feel these placements helped me get a place on the Rolls-Royce nuclear engineering graduate scheme after university. From there I joined Urenco, an international supplier of uranium enrichment services and fuel cycle products for the civil nuclear industry.

While at Urenco, I have undertaken a range of interesting roles in nuclear safety and radiation physics, including criticality safety assessment and safety case management. Highlights have included being the licensing manager for a project looking to deploy a high-temperature gas-cooled reactor design, and presenting a paper at a nuclear industry conference in Japan. These roles have allowed me to directly apply my physics background – such as using Monte Carlo radiation transport codes to model nuclear systems and radiation sources – as well as develop broader knowledge and skills in safety, engineering and project management.

Mark Savage

I would always recommend anyone interested in working in nuclear energy to look for work experience

My current role is nuclear licensing manager at the Capenhurst site in Cheshire, where we operate a number of nuclear facilities including three uranium enrichment plants, a uranium chemical deconversion facility, and waste management facilities. I lead a team who ensure the site complies with regulations, and achieves the required approvals for our programme of activities. Key skills for this role include building relationships with internal and external stakeholders; being able to understand and explain complex technical issues to a range of audiences; and planning programmes of work.

Some form of relevant experience is always advantageous, so I would always recommend anyone interested in working in nuclear energy to look for work experience visits, summer placements or degree schemes that include working with industry.

Nuclear safety

Jacob Plummer, principal nuclear safety inspector, Office for Nuclear Regulation

I'd been generally interested in nuclear science throughout my undergraduate physics degree at the University of Manchester, but this really accelerated after studying modules in applied nuclear and reactor physics. The topic was engaging, and the nuclear industry offered a way to explore real-world implementation of physics concepts. This led me to do a masters in nuclear science and technology, also at Manchester (under the Nuclear Technology Education Consortium), to develop the skills the UK nuclear sector required.

My first job was as a graduate nuclear safety engineer at Atkins (now AtkinsRealis), an engineering consultancy. It opened my eyes to the breadth of physics-related opportunities in the industry. I worked on new and operational power station projects for Hitachi-GE and EDF, as well as a variety of defence new-build projects. I primarily worked in hazard analysis, using modelling and simulation tools to generate evidence on topics like fire, blast and flooding to support safety case claims and inform reactor designs. I was also able to gain experience in project management, business development, and other energy projects, such as offshore wind farms. The analytical and problem solving skills I had developed during my physics studies really helped me to adapt to all of these roles.

Jacob Plummer

Physics skills and experience are valued across the nuclear industry, from hazards and fault assessment to security, safeguards, project management and more

Currently I work as a principal nuclear safety inspector at the Office for Nuclear Regulation. My role is quite varied. Day to day I might be assessing safety case submissions from a prospective reactor vendor; planning and delivering inspections at fuel and waste sites; or managing fire research projects as part of an international programme. A physics background helps me to understand complex safety arguments and how they link to technical evidence; and to make reasoned and logical regulatory judgements as a result.

It's a great time to join the nuclear industry with a huge amount of activity and investment across the nuclear lifecycle. I'd advise early-career professionals to cast the net wide when looking for roles. There are some obvious physics-related areas such as health physics, fuel and core design, and criticality safety, but physics skills and experience are valued across the nuclear industry, from hazards and fault assessment to security, safeguards, project management and more. Don't be limited by the physicist label.

Waste and decommissioning

Becky Houghton, principal consultant, Galson Sciences Ltd

My interest in a career in nuclear energy sparked mid-way through my degree in physics and mathematics at the University of Sheffield, when I was researching "safer nuclear power" for an essay. Several rabbit holes later, I had discovered a myriad of opportunities in the sector that would allow me to use the skills and knowledge I'd gained through my degree in an industrial setting.

My first job in the field was as a technical support advisor on a graduate training scheme, where I supported plant operations on a nuclear licensed site. Next, I did a stint working in strategy development and delivery across the back end of the fuel cycle, before moving into consultancy. I now work as a principal consultant for Galson Sciences Ltd, part of the Egis group. Egis is an international multi-disciplinary consulting and engineering firm, within which Galson Sciences provides specialist nuclear decommissioning and waste management consultancy services to nuclear sector clients worldwide.

Ultimately, my role boils down to providing strategic and technical support to help clients make decisions. My focus these days tends to be around radioactive waste management, which can mean anything from analysing radioactive waste inventories to assessing the environmental safety of disposal facilities.

Egis

Whichever part of the nuclear fuel cycle you end up in, the work you do makes a difference

In terms of technical skills needed for the role, data analysis and the ability to provide high-quality reports on time and within budget are at the top of the list. Physics-wise, an understanding of radioactive decay, criticality mechanisms and the physico-chemical properties of different isotopes are fairly fundamental requirements. Meanwhile, as a consultant, some of the most important soft skills are being able to lead, teach and mentor less experienced colleagues; develop and maintain strong client relationships; and look after the well-being and deployment of my staff.

My advice to anyone looking to go into the nuclear energy is to go for it. There are lots of really interesting things happening right now across the industry, all the way from building new reactors and operating the current fleet, to decommissioning, site remediation and waste management activities. Whichever part of the nuclear fuel cycle you end up in, the work you do makes a difference, whether that's by cleaning up the legacy of years gone by or by helping to meet the UK's energy demands. Don't be afraid to say "yes" to opportunities even if they're outside your comfort zone, keep learning, and keep being curious about the world around you.

Ask me anything: Scott Bolton

Planetary scientist Scott Bolton is an assistant vice president at Southwest Research Institute in San Antonio, Texas, US, and the principal investigator of NASA's Juno mission, which has been exploring Jupiter since July 2016


Scott Bolton

What skills do you use every day in your job?

As a planetary scientist, I use mathematics, physics, geology and atmospheric science. But as the principal investigator of Juno, I also have to manage the Juno team, and interface with politicians, people at NASA headquarters and other administrators. In that capacity, I need to be able to talk about topics at various technical levels, because many of the people I'm speaking with are not actively researching planetary science. I need a broad range of skills, but one of the most important is to be able to recognize when I don't have the right expertise and need to find someone who can help.

What do you like best and least about your job?

I really love being part of a mission that's discovering new information and new ideas about how the universe works. It's exciting to be at the edge of something, where you are part of a team that's seeing an image or an aspect of how nature works for the first time. The discovery element is truly inspirational. I also love seeing how a mixture of scientists with different expertise, skills and backgrounds can come together to understand something new. Watching that process unfold is very exciting to me.

Some tasks I like least are related to budget exercises, administrative tasks and documentation. Some government rules and regulations can be quite taxing and require a lot of time to ensure forms and documents are completed correctly. Occasionally, an urgent action item will appear requiring an immediate response and having to drop current work to fit in a new task. As a result, my normal work gets delayed, and this can be frustrating. I consider one of my main jobs to shelter the team from these extraneous tasks so they can get their work done.

What do you know today, that you wish you knew when you were starting out in your career?

The most important thing I know now is that if you really believe in something, you should stick to it. You should not give up. You should keep trying, keep working at it, and find people who can collaborate with you to make it happen. Early on, I didn't realize how important it was to combine forces with people who complemented my skills in order to achieve goals.

The other thing I wish I had known is that taking time to figure out the best way to approach a challenge, question or problem is beneficial to achieving one's goals. That was a very valuable lesson to learn. We should resist the temptation to rush into finding the answer – instead, it's worthwhile to take the time to think about the question and develop an approach.

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Slow science, fast success

Stefan Hutzler and **Louise Bradley** on turning the pitch-drop experiment into an outreach activity

Nothing is really known about the origin of the world-famous "pitch-drop experiment" at the School of Physics, Trinity College Dublin. Discovered in the 1980s during a clear-out of dusty cupboards, this curious glass funnel contains a dark, black substance. All we do know is that it was prepared in October 1944 (assuming you trust the writing on it). We don't know who filled the funnel, with what exactly, or why.

Placed on a shelf at Trinity, the funnel was largely ignored by generations of students passing by. But anyone who looked closely would have seen a drop forming slowly at the bottom of the funnel, preparing to join older drops that had fallen roughly once a decade. Then, in 2013 this ultimate example of "slow science" went viral when a webcam recorded a video of a tear-drop blob of pitch falling into the beaker below.

The video attracted more than two million hits on YouTube and the story was covered on the main Irish evening TV news. We also had a visit from *Der Spiegel*, while *Discover* named it as a top 100 science story of 2013. As one of us (SH) described in *Physics World* (May 2014 pp25–29), the experiment became "the drop heard round the world".

Inspired by that interest, we decided to create custom-made replicas of the experiment to send to secondary schools across Ireland as an outreach initiative and to mark 300 years of physics at Trinity, which dates back to 1724 when the college established the Erasmus Smith's Professorship in Natural and Experimental Philosophy.

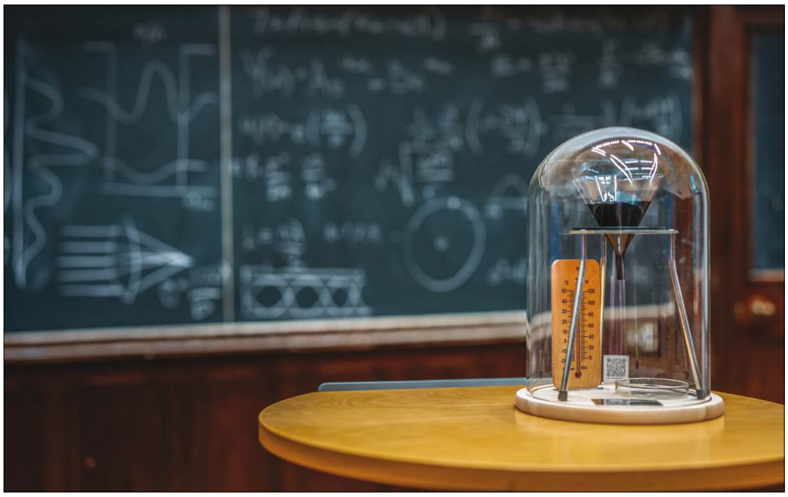
Now, an outreach activity that takes 10 years for anything to happen is obviously never going to work. Technical staff at Trinity's School of Physics, who initiated the project, therefore experimented for months with different tar samples. Their goal was a material that appears solid but will lead to a falling drop every few months – not every decade.

After hitting upon a special mix of two types of bitumen in just the right proportion, the staff also built a robust experimental set-up consisting of a stand, a funnel and flask to hold any fallen drops. Each was placed on a wooden base and contained inside a glass bell jar. There were also a thermometer and a ruler for data-taking along with a set of instructions.

Over 100 schools across Ireland applied for one of the set-ups, with a total of 37 selected to take part. Most kits were personally hand-delivered to schools, which were also given a video explaining how to unpack and assemble the set-ups. On 27 November 2024 we held a Zoom call with all participating schools, culminating in the official call to remove the funnel stopper. The race was on.

Each school was asked to record the temperature and length of the thread of pitch slowly emerging from the funnel. They were also given a guide to making a time-lapse video of the drop and provided with information about additional experiments to explore the viscosity of other materials.

To process incoming data, we set up a website, maintained by yet another one of our technical staff. It contained interactive graphs showing the increased in drop length for every school, together with the temperature when the measurement was taken. All data were shared between schools.



Karl Gaff, TCD School of Physics

Sticky challenge One of the 37 pitch-drop experiments sent by Trinity College Dublin's School of Physics to secondary schools all over Ireland.

After about four months, four schools had recorded a pitch drop and we decided to take stock at a half-day event at Trinity in March 2025. Attended by more than 80 pupils aged 12–18 and teachers from 17 schools, we were amazed by how much excitement our initiative had created. It spawned huge levels of engagement, with lots of colourful posters.

By the end of the school year, most had recorded a drop, showing our tar mix had worked well. Some schools had also done experiments testing other viscous materials, such as syrup, honey, ketchup and oil, examining the effect of temperature on flow rate. Others had studied the flow of granular materials, such as salt and seeds. One school had even captured on video the moment their drop fell, although sadly nobody was around to see it in person.

Some schools displayed the kits in their school entrance, others in their trophy cabinet. One group of students appeared on their local radio station; another streamed the set-up live on YouTube. The pitch-drop experiment has been a great way for students to learn basic scientific skills, such as observation, data-taking, data analysis and communication.

As for teachers, the experiment is an innovative way for them to introduce concepts such as viscosity and surface tension. It lets them explore the notion of multiple variables, measurement uncertainty and long-time-scale experiments. Some are now planning future projects on statistical analysis using the publicly available dataset or by observing the pitch drop in a more controlled environment.

Wouldn't it be great if other physics departments followed our lead?

Stefan Hutzler and **Louise Bradley** are in the School of Physics, Trinity College Dublin, Ireland