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August 2025

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The women at the forefront of quantum science in India

Island science Tales from Helgoland both now and then

Unique minds How to support neurodiverse people at work

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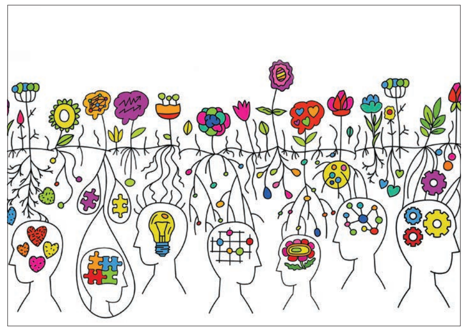

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(Alison Tovey, IOP Publishing)

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IYQ 2025

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News & Analysis

Tensions rise in US science

The Trump administration's policies are putting pressure on the country's scientific agencies and staff members are beginning to take action, as **Peter Gwynne** reports

A total of 139 employees at the US Environmental Protection Agency (EPA) have been suspended after signing a "declaration of dissent" accusing Donald Trump's administration of "undermining" the agency's mission. The letter, dated 1 July, stated that the signatories "stand together against the current administration's focus on harmful deregulation, mischaracterization of previous EPA activities, and disregard for scientific expertise".

Addressed to EPA administrator Lee Zeldin, the letter was signed by a total of more than 400 EPA workers, of whom 170 put their names to the document, with the rest choosing to remain anonymous. Zeldin suspended the employees on 3 July, with EPA officials telling them to provide contact information so the agency could be in touch with them while they are on leave.

Copied to leaders of the US Senate and House of Representatives, the letter was organized by the Stand Up For Science pressure group. The letter states that "EPA employees join in solidarity with employees across the Federal government in opposing this administration's policies, including those that undermine the EPA mission of protecting human health and the environment."

The document lists five "primary concerns", including the scientific consensus being ignored to benefit polluters, and undermining public trust by EPA workers being distracted from protecting public health and the environment through objective science-based policy. The letter adds that the EPA's progress in the US's most vulnerable communities is being reversed through the cancellation of environmental justice programmes, while budget cuts to the Office of Research and Development, which helps support the agency's rules on environmental protection and human health, mean it cannot meet the EPA's science needs. The letter also points to a culture of fear at the EPA, with staff being forced to choose between their livelihood and well-being.

Stormy times Hundreds of staff at the National Science Foundation marked the agency's 75th birthday in May with a group photo.

In response to the letter, Zeldin said he had a "ZERO tolerance policy for agency bureaucrats unlawfully undermining, sabotaging and undercutting the agenda of this administration". An EPA statement, sent to *Physics World*, notes that the letter "contains information that misleads the public about agency business", adding that the letter's signatories "represent a small fraction of the thousands of [agency] employees". On 18 July Zeldin then announced a plan to eliminate the EPA's Office of Research and Development, which could lead to more than 1000 agency scientists being sacked.

Climate concerns

In late July, more than 280 NASA employees signed a similar declaration of dissent protesting against staff cuts at the agency as well as calling on the acting head of NASA not to make the budget cuts Trump proposed. Another example of the tension in US science took place in May when hundreds of staff from the National Science Foundation (NSF) gathered in front of NSF headquarters for a photo marking the agency's 75th birthday. NSF officials, who had been criticized for seeking to cut the agency's budget and staff, and slash the proportion of scientific grants' costs allowed for ancillary expenses, refused to support the event with an official photographer.

Staff then used their own photographer, but they could only take a shot from a public space at the side of the building. In late June, the administration announced that the NSF will have to quit the building, which it has occupied since 2017. No new location for the headquarters has been announced, with NSF spokesperson Michelle Negrón declining to comment on the issue. The new tenant will be the Department of Housing and Urban Development.

The Department of Energy, meanwhile, has announced that it will hire three scientists who have expressed doubts about the scientific consensus on climate change – although details of the trio's job descriptions remain unknown. They are Steven Koonin, a physicist at Stanford University's Hoover Institution, along with atmospheric scientist John Christy, director of the Earth System Science Center at the University of Alabama in Huntsville, and Alabama meteorologist Roy Spencer.

The appointments come as the administration is taking steps to de-emphasize government research on climate and weather science. The proposed budget for financial year 2026 would close 10 labs belonging to the National Oceanic and Atmospheric Administration (NOAA). The NOAA's National Weather Service has already lost 600 of its 4200 employees this year, while NASA has announced that it will no longer host the National Climate Assessment website globalchange.gov.

Peter Gwynne is *Physics World*'s North America correspondent

People

Norwegian-US Nobel laureate Ivar Giaever dies at 96

AIP Emilio Segrè Visual Archives, W F Meggers Gallery of Nobel Laureates Collection

Nobel life
Ivar Giaever made pioneering progress in the late 1950s on electron tunnelling in superconductors.

The Norwegian-born condensed-matter physicist Ivar Giaever, who shared the Nobel Prize for Physics in 1973, died on 20 June at the age of 96. In the late 1950s Giaever made pioneering progress in electron tunnelling in superconductors, as well as providing a crucial verification of the Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity.

Born in Bergen, Norway, on 5 April 1929, Giaever graduated with a degree in mechanical engineering in 1952 from the Norwegian Institute of Technology. Following a year of military service, he worked as a patent examiner for the Norwegian government before moving to Canada in 1954 where he began working at General Electric (GE).

Two years later Giaever moved to GE's research laboratory in New York, where he continued to study the company's engineering courses. In 1958 he joined GE's R&D centre as a researcher. At the same time, Giaever began to study physics at Rensselaer Polytechnic Institute in New York where he obtained a PhD in 1964 working in tunnelling and superconductivity. That year he also became a naturalized US citizen.

It was his work in the early 1960s that led to his Nobel prize. Following the Japanese physicist Leo Esaki's discovery of electron tunnelling in semiconductors in 1958, Giaever showed that tunnelling also happens in superconductors, in this case a thin layer of oxide surrounded by a metal in a superconducting state.

Using his tunnelling apparatus, Giaever also measured the energy gap near the Fermi level when a metal becomes superconducting, providing crucial verification of the BCS theory of superconductivity. At the age of 44, Giaever shared half of the 1973 Nobel Prize for Physics with Esaki "for their experimental discoveries regarding tunnelling phenomena in semiconductors and superconductors, respectively". The other half went to Brian Josephson "for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects".

Josephson told *Physics World* that Giaever's experiments were the source of his interest in tunnelling supercurrents. "An interesting point is that none of the [physics] laureates that year were professors at the time," adds Josephson. "[Giaever] and I were too junior, while Esaki was in industry."

In 1988 Giaever left GE and moved to Rensselaer where he continued to work in biophysics. In 1993 he founded the New York-based company Applied BioPhysics. As well as the Nobel prize, Giaever also won the Oliver E Buckley Prize from the American Physical Society (APS) in 1965 as well as the Golden Plate Award from the American Academy of Achievement in 1966.

Giaever's career was not without controversy. In 2011 he resigned from the APS in protest after the organization called the evidence of damaging global warming "incontrovertible". In 2016 he published his autobiography *I am the Smartest Man I Know*, in which he details his journey from relatively humble beginnings in Norway to a Nobel prize and beyond.

Michael Banks

Astronomy

Vera C Rubin Observatory reveals its first spectacular images

A series of exquisitely detailed images showing millions of galaxies and Milky Way stars and thousands of asteroids have been released by astronomers at the Vera C Rubin Observatory.

Based in Cerro Pachón in the Andes, the observatory contains the Legacy Survey of Space and Time (LSST) – the largest camera ever built. Taking almost two decades to build, the 3200-megapixel instrument forms the heart of the observatory's 8.4 m Simonyi Survey Telescope.

The new images, which took just 10 hours of observations, are a small preview of the observatory's upcoming 10-year scientific mission. The image above is of the Trifid and Lagoon nebulas. This picture combines 678 separate images taken by the observatory in just over seven hours of observing time. It reveals otherwise faint or invisible details, such as the clouds of gas and dust that comprise the Trifid nebula (top right) and the Lagoon nebula, which are several thousand light-years away from Earth. Another image released shows a small section of the Virgo cluster, featuring two spiral galaxies, three merging galaxies and several groups of distant galaxies.

NSF–DOE Vera C Rubin Observatory

Blue lagoon
This image released by the Vera C Rubin Observatory shows the Trifid (top right) and Lagoon nebulas.

Later this year, the Vera C Rubin Observatory, which is funded by the US National Science Foundation and the US Department of Energy's Office of Science, will begin a decade-long survey of the southern hemisphere sky. The LSST will take a complete picture of the southern night sky every three or four nights. It will then replicate this process over a decade to produce almost 1000 full images of sky. These will be used to plot the positions and measure the brightness of objects in the sky to help improve our understanding of dark matter and dark energy. It will examine 20 billion galaxies as well as produce the most detailed star map of the Milky Way, imaging 17 billion stars and cataloguing some six million small objects within our solar system including asteroids.

Michael Banks

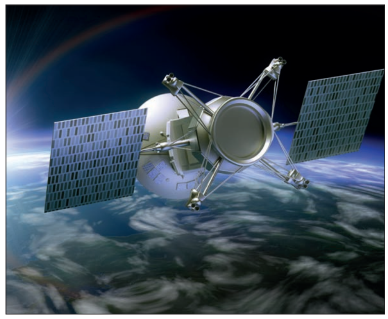
Space

UK 'well positioned' for space manufacturing

The UK should focus on being a "responsible, intelligent and independent leader" in space sustainability and can make a "major contribution" to the area. That's the verdict of a new report from the Institute of Physics (IOP), which warns, however, that such a move is possible only with significant investment and government backing.

The report, published together with the Frazer-Nash Consultancy, examines the physics that underpins the space science and technology sector. It also looks at several companies that work on services such as position, navigation and timing (PNT), Earth observation and satellite communications. In 2021/22 PNT services contributed over 12%, or about £280bn, to the UK's gross domestic product – and without them many critical national infrastructures would collapse.

The report warns, however, that a reliance on global navigation satellite systems (GNSS) exposes the country to its weaknesses. "The scale and sophistication of current and potential PNT attacks has grown (such as increased GPS signal jamming on aeroplanes) and GNSS outages could become commonplace," the report notes. "Countries and industries that address the issue of resilience in PNT will win the time advantage."



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Above and beyond A new Institute of Physics report highlights "in-space manufacturing" as a future growth opportunity with companies seeing "huge advantages" through in-orbit production lines.

Telecommunication satellite services contributed £116bn to the UK in 2021/22, while Earth observation and meteorological satellite services supported industries made up an estimated £304bn. The report calls the future of Earth observation "bold and ambitious", with satellite data resolving "the disparities with the quality and availability of on-the-ground data, exacerbated by irregular dataset updates by governments or international agencies".

As for future opportunities, the report highlights in-space manufacturing, with companies seeing "huge advantages" in making drugs, harvesting stem cells and growing crystals through in-orbit production lines. The report says that in-orbit servicing and manufacturing could be worth £2.7bn per year to the UK economy but central to that vision is the need for space sustainability. The report adds that the UK is well positioned to lead in sustainable space practices due to its strengths in science, safety and sustainability, which could lead to the creation of many high-value jobs. Yet this move, the report warns, demands an investment of time, money and expertise.

Particle physicist Tara Shears from the University of Liverpool, who is IOP vice-president for science and innovation, told *Physics World* that future space tech applications are exciting and important. "With the right investment, and continued collaboration between scientists, engineers, industry and government, the potential of space can be unlocked for everyone's benefit," she says. "The report shows how physics hides in plain sight; driving advances in space science and technology and shaping our lives in ways we're often unaware of but completely rely on."

Michael Banks

Astronomers capture spectacular 'thousand colour' image of the Sculptor Galaxy

ESO/E Congiu *et al.*

Astronomers at the European Southern Observatory's Very Large Telescope (VLT) have created a thousand-colour image of the nearby Sculptor Galaxy. First discovered by Caroline Herschel in 1783 the spiral galaxy lies 11 million light-years away and is one of the brightest galaxies in the sky. While conventional images contain only a handful of colours, this new map contains thousands, which helps astronomers to understand the age, composition and motion of the stars, gas and dust within it. To create the image, researchers observed the galaxy for over 50 hours with the Multi Unit Spectroscopic Explorer instrument on the VLT, which is based at the Paranal Observatory in Chile's Atacama Desert. The team then stitched together over 100 exposures to cover an area of the galaxy about 65 000 light-years wide. The image reveals around 500 planetary nebulae that can be used as distance markers to their host galaxies. Future work will involve understanding how gas flows, changes its composition, and forms stars in the galaxy.

Michael Banks

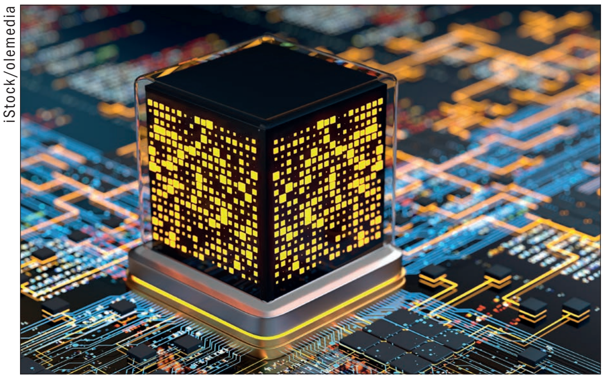
Quantum

Large-scale commercial quantum computing ‘far off’

Quantum technology is rapidly growing, with job demand tripling in the US along with venture capital bringing in billions of dollars into the field. That is according to the inaugural Massachusetts Institute of Technology (MIT) *Quantum Index Report 2025*, which finds, however, that large-scale commercial applications for quantum computing still remain “far off”.

Carried out by the Initiative on the Digital Economy (IDE) at MIT, the report examines data from academia, industry and policy sources to track trends across several areas such as education, funding, research and development.

One aim of the report is to reduce the complexity of quantum technology and to make the field more accessible and inclusive for entrepreneurs, investors, designers, teachers and decision makers. This in turn, the report says, can help to shape how the technology is developed, commercialized and governed.



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Growing demand The Massachusetts Institute of Technology (MIT) *Quantum Index Report 2025* finds that jobs in the quantum sector have tripled in the US since 2018.

The inaugural edition focuses on quantum computing and networks, due to their higher potential impact compared with quantum sensing and simulation. The report says that $1.6bn has been raised by quantum-computing firms in 2024 compared with $621m by quantum-software companies.

The report also finds that jobs in the quantum sector are rising, with demand tripling in the US since 2018. This has led to a higher number of education initiatives, with Germany having the most master’s degrees that include “quantum” in the name. When it comes to academic research, the report finds that while China produces the most papers in quantum computing, US research tends to have a greater impact and influence.

The report also analyses published data on over 200 quantum processing units (QPUs) from 17 countries to provide insight into how the performance of different types of quantum computers can be verified. The report finds that despite QPUs making impressive progress in performance, they remain far from meeting the requirements for running large-scale commercial applications.

Principal investigator Jonathan Ruane from MIT Sloan calls the report a “community-led project” and encourages people to contribute additional data. He says that while a report will be published annually, data on its website will be updated “as often as input is given”.

Martijn Boerkamp

Research

Diversity declining in UK astronomy and geophysics

Women and people of colour are still significantly under-represented in UK astronomy and geophysics, with the fields becoming more white. That is according to the latest demographic survey conducted by the Royal Astronomical Society (RAS), which concludes that decades of initiatives to improve representation have “failed”.

Based on data collected in 2023, the survey reveals more people working in astronomy and solar-system science than ever before, although the geophysics community has shrunk since 2016. According to university admissions data acquired by the RAS, about 80% of students who started undergraduate astronomy and geophysics courses in 2022 were white, slightly less than the 83% overall proportion of white people in the UK.

However, among permanent astronomy and geophysics staff, 97% of British respondents to the RAS survey are white, up from 95% in 2016. The makeup of postgraduate students was similar, with 92% of British students – who accounted for 70% of postgraduate respondents – stating they are white, up from 87% in 2016.

Shutterstock/Natalia Sheinkin

Open for all? A recent report finds that diversity in UK astronomy and geophysics has reduced in recent years, with the fields becoming more white.

The survey also finds that the proportion of women in professor, senior lecturer or reader roles increased from 2010 to 2023 in astronomy and solar-system science, but has stagnated at lecturer level in astronomy since 2016 and dropped in solid-Earth geophysics to 19%. The picture is better at more junior levels, with women making up 28% of postdocs in astronomy and solar-system science and 34% in solid-Earth geophysics.

“I very much want to see far more women and people from minority ethnic groups working as astronomers and geophysicists, and we have to redouble our efforts to make that happen,” says Robert Massey, deputy executive director of the RAS, who co-authored the survey and presented its results at the National Astronomy Meeting 2025 in Durham last month.

RAS president Mike Lockwood agrees, stating that effective policies and strategies are now needed. “Talent can, has, and does come from absolutely anywhere in society, and our concern is that astronomy and geophysics in the UK is missing out on some of the best natural talent available to us,” Lockwood adds.

Michael Allen

Business and innovation

Diversity in UK tech must improve, says report

The UK technology industry is struggling with persistent challenges around diversity and inclusion. That is according to a new report by the Department for Science, Innovation and Technology, which concludes that despite some modest recent progress, women and all minority groups still remain significantly under-represented in the technology sector.

The tech start-up ecosystem is valued at over $1.1 trillion worldwide, with the technology sector employing more than 1.8 million people in the UK. Women and people from ethnic-minority groups, however, account for only around a quarter of the technology workforce. People from ethnic-minority groups also hold only 14% of senior roles.

Based on surveys and reviews of existing research on the sector, the report finds that recent diversity gains diminish at mid-career and leadership levels. In the last year, female representation in senior technology positions increased by only 1%, while one in three women are planning to quit their jobs due to a lack of career progression, poor work–life balance and an unsupportive culture.

This persistent "leaky pipeline" is linked to structural and cultural barriers that result in poor retention and promotion of under-represented people. Cultural attitudes reinforce gender bias, the report says, with one recent study finding that 20% of men in technology believe that women are "naturally less suited" to technical work. Indeed, a previous national study found that under-represented groups were nearly twice as likely to leave a technology job because of unfair treatment than for a better role.

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Tech support
A new report by the UK government says that flexible-working options as well as diversity, equity and inclusion reporting could help more people from under-represented groups enter the tech industry.

Under-representation is particularly stark for Black technologists, who make up only 5% of workers, and just 0.07% of technology employees are Black women. Socioeconomic diversity is also lacking, with only 9% of technology employees coming from poorer backgrounds, compared with 29% in finance and 23% in law. Data show that individuals from working-class backgrounds in technology earn almost £5000 less per year, on average, than their peers from more affluent backgrounds.

There is also a lack of diversity when it comes to technology funding, with the report showing that 92% of angel investments in 2022 went to all-white teams, while female and ethnic-minority-led start-ups secured just 2% of venture capital funding. On average, female-founded technology businesses receive £1.1m, figures show, while male-owned start-ups receive £6.2m.

The report also points to one analysis that found that about 14% of technologists identify as disabled, while another put the figure as low as 6%, suggesting a reluctance to disclose disabilities. The latter survey also suggests that 53% of technology employees identify as neurodivergent, yet employers claim that just 3% of their staff are neurodivergent.

To improve diversity and inclusion in the technology sector, the report calls for improvements in flexible-working options; diversity, equity and inclusion reporting; improved governance structures; and socioeconomic-mobility initiatives.

Sarah Bakewell, head of diversity and inclusion at the Institute of Physics, describes the report's conclusions as "concerning" as "it reveals the lack of diversity in the sector and who funding is allocated to". Even more worrying, she says, is the lack of progress in boosting the diversity of people in UK tech. "To unleash a new wave of UK innovation, we must attract, develop and retain people from all backgrounds."

Michael Allen

Meteorology

Construction begins on £93m European weather-forecasting HQ

Work has begun on the new headquarters of the European Centre for Medium-Range Weather Forecasts (ECMWF). Based at the University of Reading, UK, the new £93m centre will provide cutting-edge meteorological research and forecasting.

The ECMWF is an independent intergovernmental organization with 35 member and co-operating states. Established in 1975, the centre employs around 500 staff from more than 30 countries at its existing headquarters at Shinfield Park in Reading and sites in Bologna, Italy, and Bonn, Germany. As a research institute and 24/7 operational service, the ECMWF produces global numerical weather predictions four times per day and other data for its member/co-operating states and the broader meteorological community.

University of Reading

Shovel ready
Officials marked the start of construction of the new headquarters of the European Centre for Medium-Range Weather Forecasts last month.

The new centre, built by construction firm Mace, is funded by the UK's Department for Science, Innovation and Technology. When it opens in 2027, it will accommodate up to 300 scientists and staff who will relocate from Shinfield Park. The centre will carry out work on all aspects of weather prediction, forecast production and research into climate change.

"This state-of-the-art facility places the UK at the heart of international efforts that are helping us to make better sense of our weather and climate," says UK science minister Patrick Vallance. "By improving our weather predictions we can optimize our energy consumption estimates – helping people and businesses to save money, cut energy use and stay safe."

Michael Banks

Research updates

Bohmian mechanics challenged

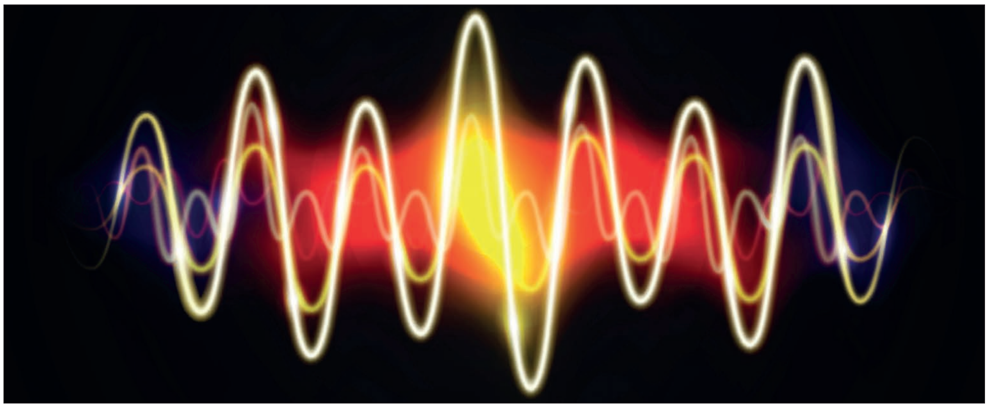
Alternative deterministic interpretation of quantum mechanics generally predicts the same results as standard theories – but a new experiment challenges that view, as **Tim Wogan** reports

A new experiment that measures the quantum tunnelling of photons between two waveguides has produced results that are hard to reconcile with certain deterministic interpretations of quantum mechanics. According to the researchers, their experiment is a long-sought-after test of theories that were previously regarded as empirically indistinguishable from conventional quantum mechanics (*Nature* **643** 67).

In the widely-held Copenhagen interpretation of quantum mechanics developed by physicists such as Werner Heisenberg and Niels Bohr in the 1920s, particles do not have definite properties (such as behaving like a particle or a wave) until they are measured. Instead, a particle's properties are defined only by its wavefunction, the square of which dictates the probability of the particle being in a particular state when measured.

An alternative interpretation, favoured by physicists such as David Bohm and Louis de Broglie, is that the properties of the particle are everywhere defined by a non-local "guiding equation". In the famous quantum double-slit experiment, therefore, the particle does not pass through both slits and interfere with itself. Instead, it passes through one slit or the other, but the probability of it passing through each slit is dictated by the value of the guiding equation. Closing or moving one of the slits alters this equation.

Though most physicists today reject Bohmian mechanics, the differences between it and the Copenhagen interpretation are largely conceptual, being empirically equivalent giving the same predictions, the same probabilities, for all possible experiments. In the new work, however, Jan Klärs and colleagues at the University of Twente in the Netherlands claim to have devised a test in which the two interpretations predict different results – and Copenhagen wins.



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Alternative realities
Physicists claim to have devised a test in which two interpretations of quantum mechanics – Copenhagen and Bohmian mechanics – predict different results.

To perform this test, the researchers set up two waveguides side by side. When they sent pulses of light down one of the waveguides, light leaked into the other waveguide by quantum tunnelling. By knowing the strength of the coupling and measuring the quantum tunnelling as a function of distance, they could infer the speed of the photons.

The researchers also introduced a potential step into the first waveguide. As this step was too large for photons to tunnel through, they were largely reflected, but with an exponentially decaying evanescent field inside the step. Bohmian mechanics agrees completely with standard quantum mechanics on the expected density of particles in this field. However, the guiding equation predicts that the velocity of these particles – which can never be measured directly – is zero.

The researchers therefore used the energy of the photons to calculate their expected speeds inside the potential step, and compared this to the tunnelling rate between the two waveguides. They found that particles that were expected to have higher velocity travelled further before tunnelling into the other waveguide. "We interpret this as a speed measurement," says Klärs. "When you interpret this as a speed measurement, it gives you a speed that is different from the fundamental guiding equation."

Yet mathematical physicist Sheldon Goldstein of Rutgers University in New Jersey, US, who was not involved in the research, is unconvinced. "There is a theory in Bohmian mechanics where the particles [inside the potential step] are at rest, but for the experiment they give, the Bohmian velocity is not especially relevant to a correct analysis," he says. "Whatever analysis they're doing, if they claim that it correctly predicts the analysis based on Schrödinger's equation, then that would be the conclusion of Bohmian mechanics, and the real thing for them to look at is why was the Bohmian velocity not the thing that corresponds to the result?"

Experimental physicist Aephraim Steinberg of the University of Toronto, Canada is equally sceptical that the work refutes Bohmian mechanics but credits their ingenuity. "This particular experiment gave a result that, even after 20 years thinking about tunnelling times, I did not know the answer to," he says. "There are things in quantum mechanics like 'how long does a particle spend in a region?' that sound to our classical ears like they should only have one answer, but that can in fact have multiple answers."

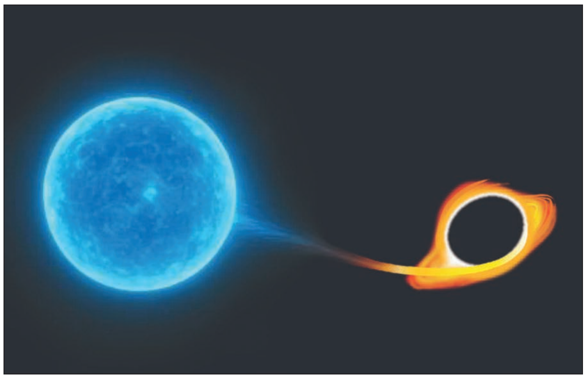
Astronomy

Astronomers observe the biggest booms since the Big Bang

Scientists at the University of Hawai'i's Institute for Astronomy (IfA) in the US have detected what they say are the most energetic cosmic explosions known to have occurred since the universe began. These colossal events, dubbed extreme nuclear transients (ENTs), emit at least 10 times as much energy as the previous record holders, and could open a new window into physical processes that take place at very high energies (*Sci. Adv.* **11** eadt0074).

ENTs occur when stars that are at least three times as massive as the Sun pass so close to a supermassive black hole that its colossal gravity shreds them to pieces. The resulting string of matter then spirals into the black hole in a phenomenon known as accretion. Such events are extremely rare, but when they do happen, they release huge amounts of energy, producing long-lasting flares that can then be detected on Earth.

Optical transient surveys have spotted several classes of accretion-powered flares over the past decade or so. Yet the new ENTs released $0.5–2.5 \times 10^{46}$ J, making them at least twice as energetic as any other known transient. "They are also 10 times as bright and remain luminous for years, far surpassing the energy output of even the brightest known supernova explosions," notes Jason Hinkle, who led the study as part of his PhD research at the IfA.



University of Hawai'i

Record breaker Researchers have discovered extreme nuclear transients that are at least twice as energetic as any previous detections.

Sifting through data from the European Space Agency's Gaia mission, Hinkle's search for smooth, high-amplitude, long-lived signals revealed two possible sources. Designated Gaia16aaw (AT2016dbs) and Gaia18cdj (AT2018fbb), each comes from the centre of a distant galaxy.

In 2020, astronomers began observing these sources with space-based UV/X-ray missions and ground-based facilities. The data show that the brightness of the light emitted from ENTs increases for more than 100 days, peaks, and then slowly declines over a period of more than 150 days. ENTs also produce infrared light, which suggests that circumnuclear dust is being heated up and re-emitted at longer wavelengths.

The fact that Gaia16aaw and Gaia18cdj are located relatively close to the centres of their host galaxies confirms their status as nuclear transients, adds Hinkle. Their long timescales and high peak luminosities also suggest that they originate from accretion onto a supermassive black hole. "The way they accrete is very different from normal black hole accretion, however, which typically shows irregular and unpredictable changes in brightness," Hinkle explains. "Instead, the smooth and long-lived flares of ENTs imply a distinct physical process – the gradual accretion of a tidally disrupted star by a supermassive black hole."

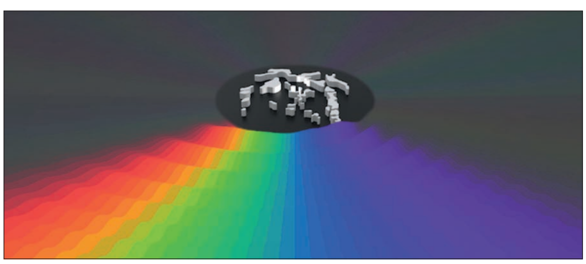
Isabelle Dumé

Optics

Acoustic rainbows emerge from novel sound-scattering structure

Researchers have produced the acoustic equivalent of a rainbow, creating a structure that spatially decomposes sound into its component frequencies in free space. The team at Technical University of Denmark (DTU) did this using an advanced structural design technique that could also be used to make devices tailored to emit or receive certain frequencies of sound (*Sci. Adv.* 11 eads7497).

Acoustic rainbows follow the same principle as optical rainbows, being the spatial decomposition of sound in free space where waves oscillating at different frequencies propagate in different directions. They have previously been created in confined media using arrays of resonant structures that "trap" sound at different positions in space depending on their frequency. Acoustic spectral decomposition also occurs in the outer ear structures, or pinnae, of mammals such as bats, cetaceans and primates. But previous attempts to imitate such biological designs did not really succeed.



Christiansen *et al.*, *Sci. Adv.* **11** eads7497

Sounds fantastic Acoustic rainbows are the spatial decomposition of sound in free space in which waves oscillating at different frequencies propagate in different directions.

Rasmus Ellebæk Christiansen and Efren Fernandez-Grande at the DTU and colleagues have now used a new technique known as computational morphogenesis, or topology optimization. Using an iterative process, the team spatially redistributed sound-reflecting material in an air background inside a specified region of space. This enabled them to tailor the sound field emitted from the created structure to match a predefined target emission pattern across a specified frequency band, mimicking naturally-occurring "sound shaping" structures.

The geometry and topology of the metamaterial the team created has several features reminiscent of structures present in the pinnae. However, Ellebæk Christiansen told *Physics World* that the technique may also enable them to develop unique structures/geometries. One option, Fernandez-Grande suggests, would be to design acoustic materials that reflect different frequencies of sound in different ways – for example, by scattering high frequencies diffusely and redirecting low frequencies towards an absorbing surface.

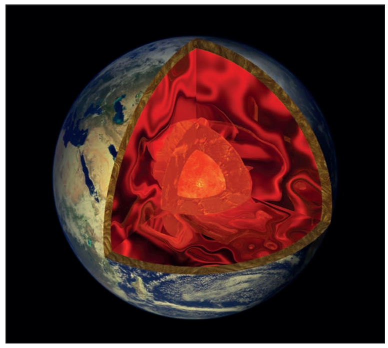
Isabelle Dumé

Geology

Mysterious seismic wave speed-up in Earth's mantle explained

Scientists in Switzerland and Japan have uncovered what they say is the first direct evidence that materials at the bottom of the Earth's mantle flow like a massive river. The finding, made by comparing seismic data with laboratory studies of materials at high pressures and temperatures, could reshape our understanding of the dynamics at play deep within our planet's interior (*Commun. Earth Environ.* 6 406).

One of the biggest unresolved mysteries in geosciences is what occurs just above the boundary where the Earth's solid mantle meets its liquid core. Within this so-called D" layer, the velocity of seismic waves passing through the mantle abruptly increases, known as the D" discontinuity, possibly caused by a change in the material the waves are travelling through. Previous work found that perovskite – the main mineral present in the Earth's lower mantle – transforms into a different substance known as post-perovskite under the extreme pressures and temperatures characteristic of the D" layer and this phase change could explain the jump in the speed of seismic waves.



Mantle mystery Researchers have offered an explanation for why the velocity of seismic waves passing through the Earth's mantle abruptly increases, known as the D" discontinuity.

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Subsequent computer modelling, however, revealed that the hardness of post-perovskite materials is not fixed. Instead, it depends on the direction of the material's crystals – and seismic waves through the material will only speed up when all the crystals point in the same direction.

Motohiko Murakami, a geophysicist at ETH Zurich, and colleagues at Tohoku University and the Japan Synchrotron Radiation Research Institute have now confirmed this notion experimentally for the first time. They placed crystals of the post-perovskite with the chemical formula $MgGeO_3$ in a special apparatus designed to replicate the extreme pressures (around 1 million atmospheres) and temperatures (around 2500 K) found at the D" depth nearly 3000 km below the Earth's surface. They then measured the velocity of lab-produced seismic waves sent through this material.

These measurements show that while randomly-oriented crystal samples do not reproduce the shear wave velocity jump at the D" discontinuity, crystals oriented along the (001) slip plane of the material's lattice do. Murakami says that the slow, convective motions that cause the lower mantle to move at a rate of several centimetres per year could make these crystals line up.

Murakami adds that the post-perovskite mineral is rigid in one direction while being softer in others. "Since it naturally aligns its harder axis with the mantle flow, it effectively creates a structured arrangement at the base of the mantle," he says. According to Murakami, the discovery that solid (and not liquid) rock flows at this depth does more than just solve the D" layer mystery. It could also become a critical tool for identifying the locations at which large-scale mantle upwellings, or superplumes, originate. This, in turn, could provide new insights into Earth's internal dynamics.

Isabelle Dumé

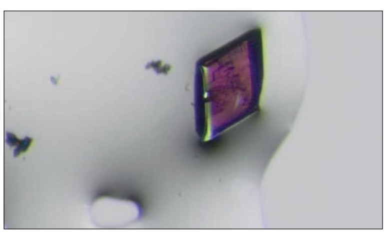
Materials

Symmetric crystals found to absorb light asymmetrically

Scientists have discovered a centrosymmetric crystal that behaves as though it is chiral – absorbing left- and right-handed circularly polarized light differently. This counterintuitive finding could lead to new technologies that control light including brighter optical displays and improved sensors (*Science* **388** 1194).

Centrosymmetric crystals are those that look identical when reflected through a central point. Until now, only non-centrosymmetric crystals were thought to exhibit differential absorption of circularly polarized light, owing to their chirality – a property that describes how an object differs from its mirror image.

In the new work, a team led by chemist Roel Tempelaar from Northwestern University studied how a centrosymmetric crystal made from lithium, cobalt and selenium oxide ($Li_2Co_3(SeO_3)_4$,) interacts with circularly polarized light. They found it absorbs circularly polarized light more when the light is polarized in one direction than in the other. This property, they say, stems from a photophysical process involving strong chiroptical signals that invert when the sample is flipped. Such a mechanism is different to conventional chiroptical response to circularly polarized light and has not been seen before in single centrosymmetric crystals.



One direction A centrosymmetric crystal made from lithium, cobalt and selenium absorbs circularly polarized light more when the light is polarized in one direction than in the other.

Kendall Kamp/Northwestern University

Not only does the discovery challenge long-held assumptions about crystals and chiroptical responses, it opens up opportunities for engineering new optical materials that control light, says Tempelaar. Potential applications could include brighter optical displays, polarization-dependent optical diodes, chiral lasing, more sensitive sensors and new types of faster, more secure light-based communication.

"This crystal is the first candidate material that we resorted to in order to test our prediction," says Tempelaar. "The fact that it behaved the way it does could just be a great stroke of luck, but it is more likely that $Li_2Co_3(SeO_3)_4$ is just the tip of the iceberg spanning many centrosymmetric materials for circularly polarized light absorption."

Isabelle Dumé

Nuclear physics

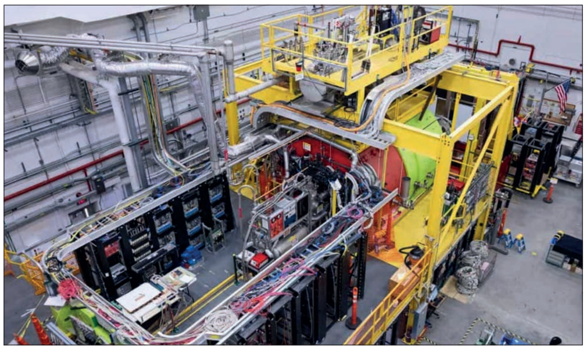
Photon collisions provide a glimpse of gluons inside nuclei

A new experiment has offered the clearest view yet of how gluons behave inside atomic nuclei. Conducted at the Thomas Jefferson National Accelerator Facility in the US, the research sheds light on how gluons are distributed in nuclear matter and is a crucial step toward understanding the nature of protons within nuclei (*Phys. Rev. Lett.* **134** 201903).

Gluons, which are massless, generate most of the visible mass in the universe, but their role inside nuclei remains poorly understood. Mediating the strong nuclear force, which binds quarks as well as protons and neutrons in nuclei, gluons carry no electric charge and cannot be directly detected. The theory that describes gluons – quantum chromodynamics (QCD) – is difficult to test, especially in the dense, strongly interacting environment of a nucleus. Precision experiments are therefore essential for revealing how matter is held together at the deepest level.

The Jefferson Lab experiment focused on photoproduction, in which a high-energy photon strikes a particle and creates something new, in this case, a J/Ψ meson. The J/Ψ comprises a charm quark and its antiquark and is especially useful for studying gluons. Charm quarks are much heavier than those found in ordinary matter and are not present in protons or neutrons. Therefore, they must be created entirely during the interaction, making the J/Ψ a particularly clean and sensitive probe of gluon behaviour inside nuclei.

Earlier studies had observed photoproduction using free protons. This new experiment extends the approach to protons confined in nuclei to see how that environment affects gluon behaviour. The researchers used Jefferson Lab's Experimental Hall D, which delivers an intense beam of high-energy photons and the GlueX spectrometer.


Jefferson Lab/Aileen Devlin

Holding it together Researchers used the Thomas Jefferson National Accelerator Facility in the US to study the behaviour of gluons within nuclei.

As well as being the first to measure J/Ψ photoproduction from nuclei in the "threshold" region – where the photon has just enough energy to produce a J/Ψ meson – particularly striking were observations in the so-called "sub-threshold". This is where the incoming photon does not carry enough energy to produce the J/Ψ on its own, so it must draw additional energy from the internal motion of protons or from the nuclear medium itself.

"The number of subthreshold J/Ψ exceeded expectations," notes Jackson Pybus, who is now a postdoc at Los Alamos National Laboratory and one of the experiment's collaborators. "That raises questions about how the photon is able to pick up so much energy from the nucleus." The results suggest that gluons may be modified inside nuclei in ways that are not described by existing models – suggesting a new frontier in nuclear physics.

Andrey Feldman

Condensed-matter physics

Odd behaviour of materials exhibiting giant magnetoresistance explained

Theorists have found that two distinctive features of quantum double-exchange ferromagnets are purely due to quantum spin effects and multi-orbital physics, with no need for the lattice vibrations previously invoked to explain them. Their finding suggests that some properties of these materials may arise from interactions hitherto regarded as less important (*Rep. Prog. Phys.* 88 068001).

Quantum double-exchange ferromagnets feature an electrical resistance that depends strongly on the magnitude of an external magnetic field – known as giant magnetoresistance (GMR). Such materials remain somewhat mysterious and one question is how Coulomb interactions between many individual electrons lead to the electron spins in these ferromagnets becoming aligned.

"Physicists broadly distinguish two mechanisms," says physicist Jacek Herbrych at Wrocław University of Science and Technology in Poland. "For insulating ferromagnets, the Goodenough–Kanamori rules – based on electron shell occupancy and geometrical arguments – can predict spin alignment. For metallic ferromagnets, the double-exchange mechanism is more appropriate."

In this latter case, Herbrych explains, the electrons' motion and the alignment of their spins are intrinsically linked, and the electrons often occupy multiple orbitals. This means they need to be modelled in a fundamentally different way.

The approach Herbrych and colleagues took, used the two-orbital Hubbard–Kanamori model and the Kondo lattice model with interactions. They then used these models to explore two distinctive features of quantum double-exchange ferromagnets. In basic "toy" models of ferromagnets, magnons exhibit a well-defined energy-momentum correspondence known as the dispersion relation.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In a spin New work challenges the notion that a classical spin model with phonons is responsible for some features of quantum double-exchange ferromagnets.

Quantum double-exchange ferromagnets, however, experience a phenomenon known as magnon mode softening: at short wavelengths, their magnons become nearly dispersionless, or momentum independent. They also exhibit magnon damping, which occurs when magnons lose coherence, meaning that the standard picture of spin flips propagating through the material's lattice breaks down.

"It was previously thought that a classical spin model with phonons would do," says Herbrych. "But our work shows that these phenomena can arise purely from quantum spin effects and multi-orbital physics."

Isabelle Dumé


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Opinion

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The joy of what-if

Enjoy a piece of "alt-history" fiction in this month's issue

If Archduke Franz Ferdinand hadn't been shot in Sarajevo, would the First World War have unfurled differently or not occurred at all? If Hitler and Stalin had maintained their non-aggression pact, would there have never been a divided Europe? More prosaically, if Football Association chair Burt Millichip hadn't agreed to set up the Premier League, would Alan Shearer have won a title with Blackburn Rovers?


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From time to time, it's fun to indulge in a bit of "alternate history" – contemplating how the world would have changed or evolved differently if a certain event hadn't taken place. In fact, there's an entire genre of fiction devoted to alt-history plus extensive online forums where you can burrow into all sorts of parallel universes to your heart's content. But alt-history also has its place in science.

If Henri Becquerel hadn't put his photographic plate and uranium salt in his drawer while waiting for sunny weather, would he have discovered radioactivity? Or would someone else have got there first? Would we have microwave ovens if Percy Lebaron Spencer, a physicist at Raytheon in the US, hadn't put a chocolate bar in his pocket and noticed his radar set melt it? Would the creation of nuclear weapons have been delayed or forestalled if Lise Meitner and Otto Frisch hadn't discovered the principles of fission on their 1939 skiing trip?

This month *Physics World* brings you our own piece of alt-history surrounding Werner Heisenberg's famous 1925 trip to the tiny North Sea island of Helgoland, where he discovered the principles of quantum mechanics a century ago. Heisenberg had gone to the island to counter a bad bout of hay fever, taking leave of absence from his postdoc with Max Born in Göttingen. But what if Born had never let him go?

In a piece of "flash fiction" (pp40–41), Kevlin Henney imagines what Heisenberg might have put in his diary on the island – and what he might have written if he had remained in Göttingen. Without the quiet time to think alone on Helgoland, would Heisenberg have failed to develop quantum mechanics? Or would his thoughts have emerged in the same form just slightly later? Or would Paul Dirac or Niels Bohr have got there first?

It's just a bit of fun so don't take Henney's article too seriously. But do let us know if you have your own imaginary alt-physics worlds.

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

Critical Point

The Trump uncertainty principle

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Uncertain times Researchers in the US find themselves unable to plan ahead following the Trump administration's attacks on science and its deep budget cuts.

Robert P Crease believes the Trump administration isn't just punishing US science – it's destroying it

The Heisenberg uncertainty principle holds things together. Articulated by the German physicist Werner Heisenberg almost a century ago, it remains the foundation of the physical world. Its name suggests the rule of the vague and temporary. But the principle is quantitative. A high uncertainty about the position of, say, an electron is compensated by a low uncertainty in its momentum. The principle is vital in helping us to understand chemical bonding, which is what holds matter together.

The Trump uncertainty principle, which I hereby coin, does the opposite; it tears things apart. Having taken effect on the US president's inauguration day back in January, it almost immediately began damaging scientific culture. Researchers can no longer be sure if their grants will be delayed or axed – or if new proposals are even in the ballpark of the potentially fundable. Work is being stalled, erased or doomed, especially in the medical and environmental sciences.

The Trump uncertainty principle, or TUP for short, is implemented in several ways. One is through new policies at funding agencies like the National Science Foundation (NSF) and the National Institutes of Health (NIH). Those new policies, the administration claims, are designed to promote "science, national health, prosperity, and defense". Despite being exactly the same as the old policies, they've been used to justify the cancellation of 400 grants at the NSF alone and hollow out the NSF, NIH and other key US science funding agencies.

The Trump administration has sought to terminate billions of dollars worth of grants at Harvard University alone. It wants to ban US universities from recruiting international students and has even been cancelling the visas of current students, many of whom are enrolled in the sciences. It also wants to vet what prospective students have posted on social media, despite Trump's supposed support for free speech. Harvard is already suing the Administration over these actions.

Back in March the Office for Civil Rights of the US Department of Education sent letters to Harvard and 59 other universities, including Columbia, Cornell, Princeton, Stanford and Yale, accusing them of what it considers "discrimination and harassment". The office threatened "potential enforcement actions if institutions do not fulfil their obligations under Title VI of the Civil Rights Act", which "prohibits discrimination against or otherwise excluding individuals on the basis of race, color, or national origin".

"Saddening, traumatic and unnecessary"

But the impact of the Trump uncertainty principle reaches far beyond these 60 institutions because it is destroying the bonding of these institutions through its impact on the labs, institutions and companies that collaborate with them. It is also badly damaging the hiring of postdocs, the ability to attract undergraduates, the retention of skilled support staff, and laboratory maintenance. Most disruptively of all, the Trump uncertainty principle provides no explanation for why or where it shows up, or what it is going to be applied to.

Stony Brook University, where I teach, is a research incubator not on the list of 60 institutions of higher learning threatened by the Department of Education. But many of my colleagues have had their NIH, NSF or Department of Energy funding paused, left unrenewed, or suspended without explanation, and nobody could tell them whether or when it might be restored or why it was stopped in the first place.

Bomb-proof knowledge is what Trump fears the most, and he is undermining it by injecting uncertainty into the culture that produces it

Support for 11 graduate students at Stony Brook was terminated. Though it was later restored after months of uncertainty, nobody knows if it might happen again. I, too, had a grant stopped, though it was due to a crude error and the money started up again. Everyone in the sciences I've spoken to – faculty, staff and students – is affected in one way or another by the Trump uncertainty principle even if they haven't lost funding or jobs.

It is easy to sound hyperbolic. It is possible that Trump's draconian cuts may be reversed, that the threats won't be implemented, that they won't stand up in court, and that the Trump administration will actually respect the court decisions. But that's not the point. You can't plan ahead if you are unsure how much money you have, or even why you may be in the administration's cross-hairs. That's what is most destructive to US science. It's also saddening, traumatic and unnecessary.

Maintaining any culture, including an academic research one, requires supporting an active and ongoing dynamic between past, present and future. It consists of an inherited array of resources, a set of ideas about how to go forward, and existing habits and practices about how best to move from one to the other. The Trump administration targets all three. It has slashed budgets and staff of long-standing scientific institutions and redirected future-directed scientific programmes at its whim. The Trump uncertainty principle also comes into play by damaging the existing habits and practices in the present.

The critical point

In his 2016 book *The Invention of Science*, David Wootton – a historian at the University of York in the UK – defined scientific culture as being "innovative, combative, competitive, but at the same time obsessed with accuracy". Science isn't the only kind of culture, he admitted, but it's "a practical and effective one if your goal is the acquisition of new knowledge". It seeks to produce knowledge about the world that can withstand criticism – "bomb-proof", as Wootton put it.

Bomb-proof knowledge is what Trump fears the most, and he is undermining it by injecting uncertainty into the culture that produces it. The administration says that the Trump uncertainty principle is grounded in the fight against financial waste, fraud and discrimination. But proof of the principle is missing.

How do you save money by ending, say, a programme aimed at diagnosing tuberculosis? Why does a study of maternal health promote discrimination? What does research into Alzheimer's disease have to do with diversity? Has ending scientific study of climate change got anything to do with any of this?

The justifications are not credible, and their lack of credibility is a leading factor in damaging scientific culture. Quite simply, the Trump uncertainty principle is destroying the position and momentum of US science.

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)

Science needs more than solidarity

After attending the Helgoland 2025 meeting in June celebrating 100 years of quantum mechanics, **Gino Elia** leaves with concerns about the culture of science

INTERNATIONAL YEAR OF Quantum Science and Technology

Hundreds of physicists gathered on the island of Helgoland in June to celebrate the centennial anniversary of the invention of quantum mechanics by the physicist Werner Heisenberg. The event – Helgoland 2025 – is a centrepiece of the International Year of Quantum Science and Technology and it drew 300 quantum physicists with plenary talks and panel discussions ranging from philosophical puzzles like Wigner's friend to state-of-the-art experiments in quantum computing.

In 1925 Heisenberg travelled to the island, off the coast of Germany, to recover from hay fever. While there he put together a mathematical framework for quantum mechanics that gave up the "visualizability" of quantum phenomena and strictly focused on "observables". Heisenberg's mythical stay on Helgoland is traditionally celebrated as the birth of quantum mechanics.

Matin Durrani

Meeting of minds The Helgoland 2025 conference in June saw numerous participants cite the importance of international collaboration and inclusivity in quantum science. Alfred Douglas Stone of Yale University gave the opening talk.

I attended the event as a philosopher of science with a background in quantum mechanics, and I was keen to learn more about participants' views about the relationship between philosophy and physics. Quantum information theory lives at the intersection of philosophy and physics, as the field has been one of the primary drivers of renewed progress in the philosophy of quantum mechanics and its interpretations.

Renowned for being the financial powerhouse of quantum computing, quantum-information theory is flush with funding for building computers promising "quantum advantage". Isaac Chuang from Massachusetts Institute of Technology bluntly told the audience that these computers currently do not serve any important economic function. The theory behind the boom in quantum computing has been equally important for philosophers and physicists looking for a compelling list of axioms from quantum mechanics, akin to Einstein's postulates for relativity.

Questioning nature

Like most scientific pursuits, quantum information did not begin with practical ends in mind, but with honest questions about nature. In the 1990s it was closer to foundational issues about the meaning of quantum mechanics. The growth of this philosophical-physical discipline called "quantum foundations", while not a moneymaker, has made the field more introspective about concepts in desperate need of elucidation. Terms such as measurement, superposition, nonlocality and the metaphysics of quantum states are hotly debated in the community.

As has happened multiple times, Nobel laureates Alain Aspect and Anton Zeilinger sparred at Helgoland over the ontology of quantum states. Zeilinger defended the viewpoint that quantum states are states of knowledge, while Aspect defended nonlocality on pragmatic grounds. When Markus Aspelmeyer from the University of Vienna finished his talk on looking for gravitationally induced entanglement, he was asked what this phenomenon could mean if quantum states are only knowledge.

None of the talks attempted to fix a consensus about foundational questions. As the British philosopher Ludwig Wittgenstein wrote in his 1969 book *On Certainty*, "At the foundation of well-founded belief lies belief that is not founded." Talks by Christopher Fuchs from the University of Massachusetts Boston and Robert Spekkens from the Perimeter Institute for Theoretical Physics in Canada underscored that we must be willing to dissect the theory to find what makes quantum mechanics truly quantum, and this will reveal what is special about nature. This patience for not jumping the gun on quantum ontology has paid off.

Spekkens showed that many phenomena taken to be uniquely quantum – the uncertainty relations, interference and wave–particle duality – are not the root of the mystery and can be accounted for classically. He referred to remaining phenomena as the "thin film" of quantum mechanics, such as Bell inequality violations, that cannot be accounted for in any classical theory. The pedagogical strategy of making quantum theory look as classical as possible was picked up in a panel discussion on the last day. The panellists suggested that physics educators not sensationalize the theory and use the most intuitive, "classical" reasoning available.

While at Helgoland, I had a discussion with philosopher Elise Crull from City College of New York and IBM quantum physicist Charles Bennett about the philosophy of science. Crull said how physics and philosophy can support each other, as physics was once a branch of natural philosophy. In fact, in her classes, Crull says she shows students how philosophically engaged the pioneers of quantum mechanics were – for example, how Bohr and Einstein were broadly familiar with Kantian philosophy.

Bennett, meanwhile, told the story of how he built up the field of quantum information

Matin Durrani

Natural philosophy Back in 1925, the island of Helgoland provided Werner Heisenberg a peaceful location to walk and think. A century later, it hosted hundreds of physicists discussing and contemplating quantum mechanics.

theory by calculating the amount of energy necessary for computing with a quantum bit. He emphasized that one of a scientist's great virtues is the joy of being wrong. We do not have to back down from the truth and we can also believe it is important to humanize others. If we can admit that we're wrong, then non-scientists can too.

Renewed hope

Moral concerns surrounding the culture of science surfaced throughout the conference. It was lost on no-one, for instance, that the vast majority of participants at the conference were men. Crull made this explicit during the opening banquet, when she flashed a slide that slowly populated with the overlooked or outright forgotten voices of women in the invention of quantum mechanics. The slide was completely full by the end. The organization Diversity in Quantum noted that it is examining workplace diversity in quantum sciences and quantum technologies.

> I worry that scientists are still too confident that the acceptance of scientific truth is inevitable, as if the status quo will be easily restored in a few years

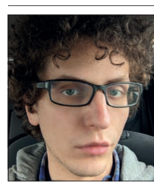
Through the celebration, the gravity of our current political environment crept into the otherwise momentous gathering. The invention of quantum mechanics converged with arguably the darkest moment in human history. Among its many moral atrocities, the political ascent of Nazism fractured the intellectual centres of Europe and severely damaged the reputation of German science. The conference saw numerous participants cite the importance of international collaboration and inclusivity in their talks. During the closing remarks of the conference, Časlav Brukner, who is scientific director of the Institute for Quantum Optics and Quantum Information in Vienna, told the crowd, "Love is wise. Hatred is foolish."

I felt refreshed by the air of solidarity among participants after months of Donald Trump's cartoonish vitriol towards education and academic freedom. However, I worry that scientists are still too confident that the acceptance of scientific truth is inevitable, as if the status quo will be easily restored in a few years. I have taught physics classes in rural areas where a distrust in scientific institutions resonated with my students, who openly doubted not only the science of evolution and climate change, but also the seemingly exotic features of relativity, or whether human beings landed on the Moon.

I often found that explaining the facts does not change students' minds because the entire enterprise of science, the meaningfulness of scientific inquiry, often strikes non-scientists as alien and disconnected from the context in which they live. As suggested by Wittgenstein, many of our core beliefs go unexamined and end up in a blind spot. It is difficult to know what our common ground really is, but without it, facts are not salient to us.

They do not look like "facts" at all without a significant amount of education and preparation, not just in terms of technical background but also the culture of scientific inquiry. We require training and acculturation to know how a piece of information is supposed to count as "evidence" for a conclusion. Nothing inevitable follows from the possession or dissemination of facts. It takes a community of peers, not just experts, to recontextualize the facts in terms of our common ground.

I left the conference with renewed hope that quantum physics is thriving but also concerned that scientists are in for a long fight to depoliticize factual information. It is essential that this fight humanizes those who disagree with us as much as it draws a line in the sand against the spreading of falsehoods. Science is not really the default setting for how humans think about the world. As many historians of science point out, a belief in the possibility of science at all, over all its competitors in the history of the world, is quite extraordinary.



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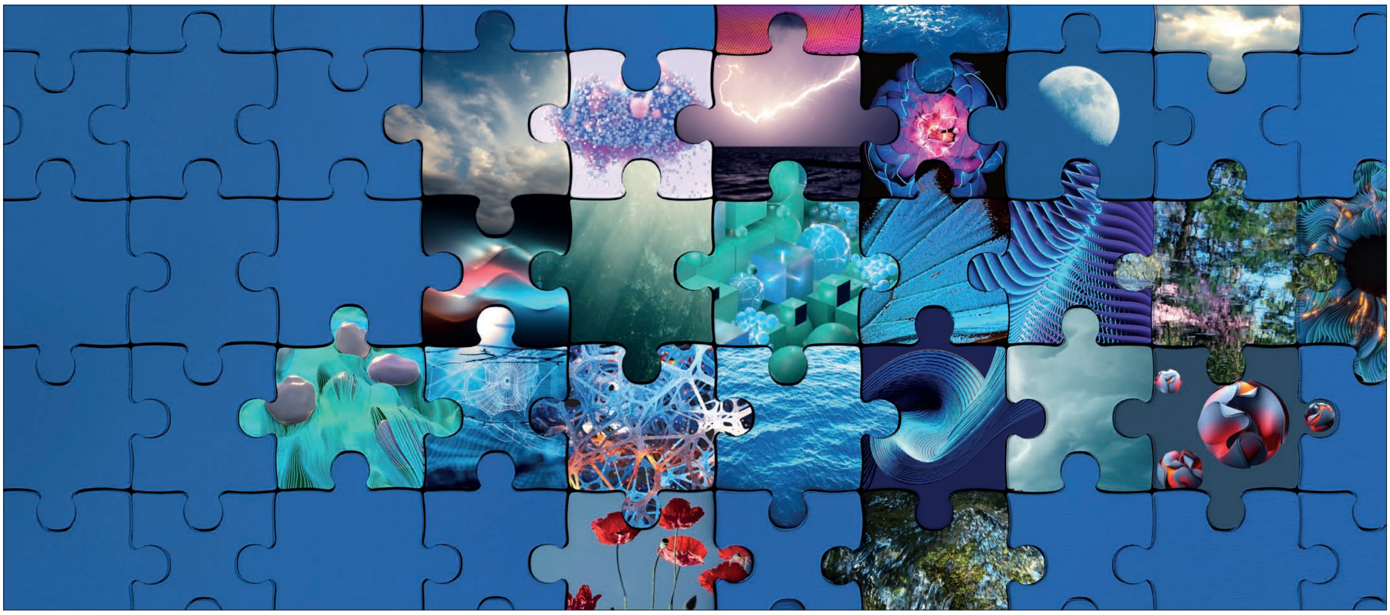
Transactions We are STEMM united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Piecing it together Connecting ideas and inspiration from a range of disciplines helps to increase the pace of scientific breakthrough.

Honor Powrie explains why physicists aren't superior to other scientists and must learn the art of collaborating with people from other disciplines

I recently heard a physicist jocularly remind us that "All science is either physics or stamp collecting". Widely attributed to the Nobel prize-winning nuclear physicist Ernest Rutherford, this quotation is often interpreted as the pre-eminence of physics over other scientific disciplines. While there is some doubt about whether Rutherford actually uttered that phrase, what's interesting for me is not its origins but why the statement has – or ought to have – little place in today's world.

In an era of rapid technological advancement and complex global challenges, it has never been more important for the scientific community to work together. From tackling climate change and dealing with the opportunities and risks of artificial intelligence to exploring space and ensuring everyone has advanced and accessible healthcare, we need experts from different disciplines to work together. No single domain can comprehensively address such challenges.

That's why all of us in Science, Technology, Engineering, Mathematics and Medicine (STEMM) need to work together collectively and with one voice. Fortunately, there are many examples of where this already occurs. Biomedical engineering, for example, has seen physicists, chemists, biologists, material scientists and medical experts develop many successful innovations, such as prosthetics, joint implants, artificial organs and advanced imaging technologies.

The development of machine learning algorithms for healthcare applications, meanwhile, requires computer scientists, statisticians and medical professionals. By embracing collaboration, the strengths of multiple disciplines can be exploited to drive innovation and create solutions that would be difficult – and sometimes even impossible – to achieve in isolation

Sharing knowledge

Without such collaboration, any solution would be incomplete and likely impractical. By working together, STEMM professionals are creating holistic solutions that address our technical, environmental and societal needs. However, it's vital that we share knowledge and expertise so that STEMM professionals can learn from one another and build on existing work.

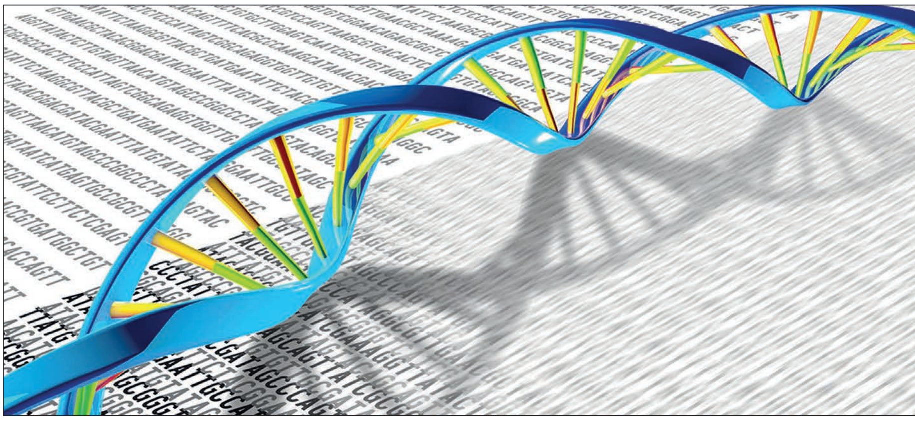
In today's ever-changing world, staying informed about the latest developments is critical. Collaborative efforts ensure that knowledge is disseminated quickly and efficiently, thereby reducing duplication of effort and speeding up progress. It also fosters creativity by encouraging individuals to think beyond the boundaries of their own expertise. Innovation often occurs at the intersection of disciplines.

When people from different fields collaborate, they bring unique perspectives and methodologies that can lead to ground-breaking discoveries. Just look at the Human Genome Project (HGP), which involved teams of researchers working together to achieve a common goal. The HGP was a voyage of biological discovery led by an international group of researchers looking to comprehensively study all the DNA of a select set of organisms.

Launched in October 1990 and completed in April 2003, the HGP's major accomplishment – generating the first sequence of the human genome – provided fundamental information about the human blueprint, which has since accelerated the study of human biology and improved the practice of medicine. What we need are more such projects where people work together towards a common goal.

Avoiding siloes

Competition and siloed thinking can, however, hinder progress. Individuals and companies may be reluctant to share knowledge or resources due to concerns about leaking intellectual property, not getting



National Human Genome Research Institute

Masterclass of collaboration The Human Genome Project set out to sequence the DNA of a number of organisms, including humans.

recognition or losing funding opportunities. But knowledge needs to be spread, not least because vesting know-how in a single individual is risky if that person leaves an organization. When you share knowledge, you never know what it can lead to.

Collaborative teams with people from different disciplines are better equipped to handle setbacks and challenges as, when faced with obstacles, team members can rely on each other for support and help seeking alternative solutions. Collective resilience is important in STEMM fields, where failure is often a stepping stone to success. Ultimately the progress and success of humanity depends on our ability to work together.

In practical terms, I am pleased to say that the Institute of Physics (IOP) Business Innovation Awards, which have been running for almost 15 years, embrace much of what I have been talking about. They recognize and celebrate small, medium and large companies that have excelled in innovation, delivering significant economic and/or societal impact through the application of physics.

Whilst the award-winning product innovations recognized by the IOP need to have some link to physics, they almost always involve some other fundamental science. What's more, the innovations invariably need input from engineering design and manufacture, from software development, and from expertise in, say, medicine, aerospace, nuclear power or food science. Successful winners demonstrate strong multidisciplinary collaboration within their teams.

The bottom line is that it's vital for STEMM professionals to stick together and not try to trump each other with statements like Rutherford's. For collaboration to work effectively, it requires mutual respect across all contributors. And by working well together, we will drive innovation, help solve complex problems, and shape a better future for the world. As a physicist by training, I naturally have a certain loyalty to the subject. But I'm hugely grateful for what I've learnt and achieved by working with people from other disciplines.

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

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

Distinguished dissenters

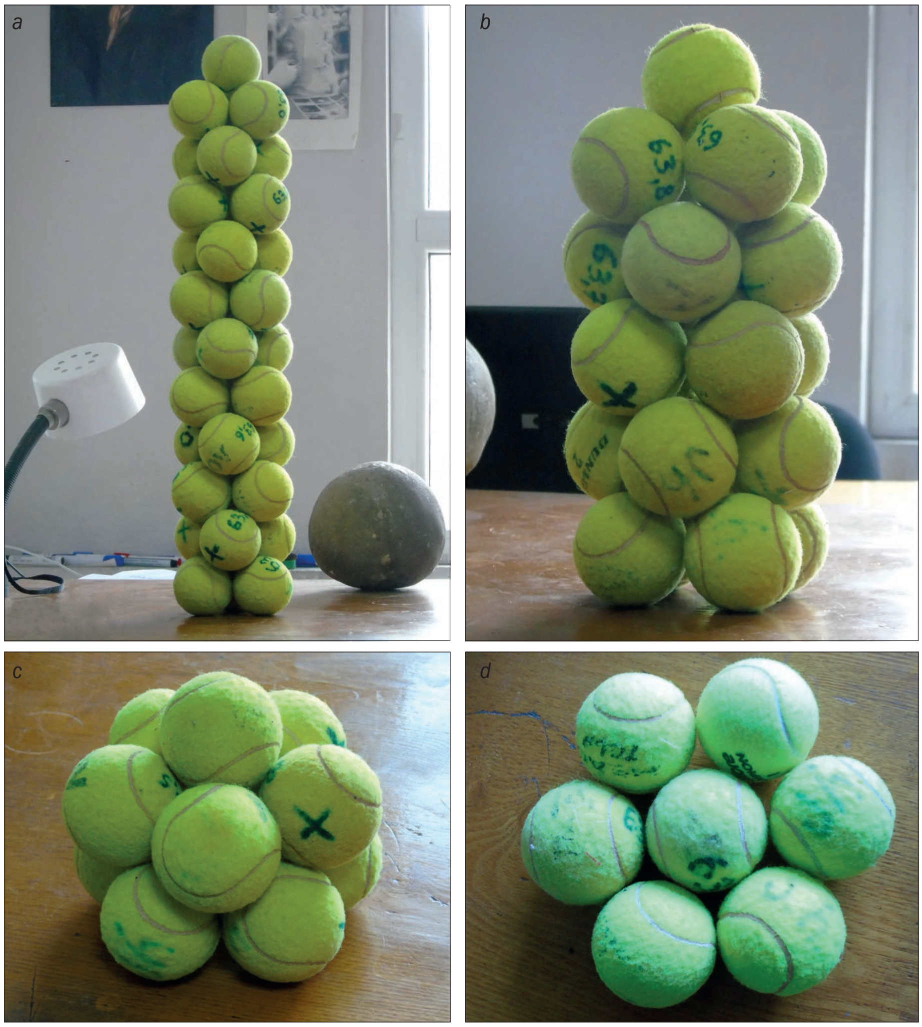
In response to the letter by David Tyler about the need for scientists to discuss their differences and let dissenters have a voice (May p24).

I agree with Tyler – so long as the dissenters understand the science before voicing their dissent. In arguing that the climate-science consensus fails to acknowledge distinguished scientists who see problems with the messages being given to politicians and the public, Tyler quotes members of the advisory council of the Global Warming Policy Foundation. It does contain many distinguished scientists – but few of them are climate scientists.

The dissent Tyler refers to has all taken place among the climate scientists who have deep knowledge of the climate. The arguments for and against have all been rehearsed before the conclusions were expressed in the assessment reports of the Intergovernmental Panel on Climate Change. Politicians must heed the stark warnings in these reports rather than listen to the instincts of people of whatever level of distinction.

Terry Sloan
Keswick, Cumbria, UK

The return of the tennis-ball towers



Andria Rogava

New balls, please A record-breaking 34-ball, 12-storey tower with three balls per layer (*a*); a 21-ball six-storey tower with four balls per layer (*b*); an 11-ball, three-storey tower with five balls per layers (*c*); and why a tower with six balls per layer would be impossible as the "locker" ball sits in the middle (*d*).

A few years ago I wrote to *Physics World* about various bizarre structures I'd built from tennis balls, the most peculiar of which I termed "tennis-ball towers" (May 2019 p25). They consisted of a series of three-ball layers topped by a single ball ("the locker") that keeps the whole tower intact. Each tower had $(3n+1)$ balls, where n is the number of triangular layers. The tallest tower I made was a seven-storey, 19-ball structure ($n=6$). Shortly after my letter was published, I made an even bigger, nine-storey, 25-ball structure ($n=8$).

Now, in the latest exciting development, I have built an even bigger tower with 34 balls ($n=11$), in which all 30 balls from the second to the tenth layer are kept in equilibrium by the locker on the top. The three balls in the bottom layer aren't influenced by the locker as they stay in place by virtue of being on the horizontal surface of a table.

I tried going higher still but failed to build a structure that would stay intact without supporting "scaffolds". In case you think I've just glued the balls together, I made a video to show the 34-ball structure collapsing spontaneously, which you can watch on the *Physics World* blog (tinyurl.com/munsckvh).

Even more unexpectedly, I have been able to make tennis-ball towers consisting of layers of four balls $(4n+1)$ and five balls too $(5n+1)$. Their equilibria are more delicate and so far I have only managed to build a 21-ball $(4n+1)$ tower ($n=5$).

The $(5n+1)$ towers are even trickier to make and I've only got up to a three-storey structure with 11 balls ($n=2$), which has two lots of five balls with a sixth single ball on top. Towers with six balls in each layer ($n=6$) are physically impossible to build because the balls form a regular hexagon. You can't just use another ball as a locker because it would simply sit between the other six.

Andria Rogava
Institute of Theoretical Physics, Ilia State University, Georgia

Noether's genius

In response to Isabel Rabey's review of *Einstein's Tutor: the story of Emmy Noether and the Invention of Modern Physics* by Lee Phillips (June pp34–35).

Rabey may have been exceptionally generous in not mentioning what seems to be a major omission from the book: Noether's seminal contributions to the invention of modern mathematics and specifically abstract algebra. Arguably that is the most significant legacy of Noether's remarkably productive life.

Alan Shore
School of Electronic Engineering, Bangor University, UK

Salty solution?

In response to Michael Allen's feature on burying – rather than burning – waste biomass to stop its carbon entering the atmosphere (July pp25–29).

Allen's article is a useful survey but overlooks the work of Eli Yablonovitch and Harry Deckman, who have argued that we can cut carbon dioxide from plant decay by preserving agricultural biomass just as we do with food – by the age-old methods of drying and salting. As they say, the method could be cheap as wind is free and salt is superabundant (*Proc. Natl Acad. Sci.* **120** e2217695120).

From the saline badlands of the American west to the salt ranges of Eurasia, there are literally mountains of it. Halite is a mineral so abundant that it's tempting to speak of Earth having a "halosphere". The salt in the oceans outweighs Earth's atmosphere 10 to one, and millions of square kilometres of continental surface are mantled in "evaporite" layers left behind by oceans past.

> The method could be cheap as wind is free and salt is superabundant

Climate policy proposals should generally be taken with a grain of salt, but this one has archaeology on its side. Drying out or pickling biomass to levels bacteria can't cope with can, as with prosciutto, forestall decay almost indefinitely. The Austrian Alps are riddled with tunnels stuffed with the un-decayed detritus of 3000 years of salt mining, from timber props and half-burned torches, to unfortunate Iron Age miners mummified by rock salt falls.

Waste plastics currently being buried in landfill could be put to better use in sealing cellulosic crops in plastic to exclude moisture over the millennia. The avid absorption of moisture from the air that has preserved artworks secreted in salt mines from the hazards of war suggests salting biomass away could also retard its decay.

To get a handle on the scale of the carbon-capture problem, consider that each of us effectively has 700 000 tonnes of air (Earth's total air mass divided by the global population) and the greenhouse gases in it. Our individual "share" of the problem roughly equals a 100 tonne pile of dry ice, which makes burying enough wood and crop waste to offset your carbon footprint a task on the same scale as building a house. All it takes is a mortgage.

Salt mines are ubiquitous, and some, thanks to our heroic use of salt to clear snowy roads, have empty vaults waiting to be filled.

Russell Seitz
Department of Physics, Harvard University, US

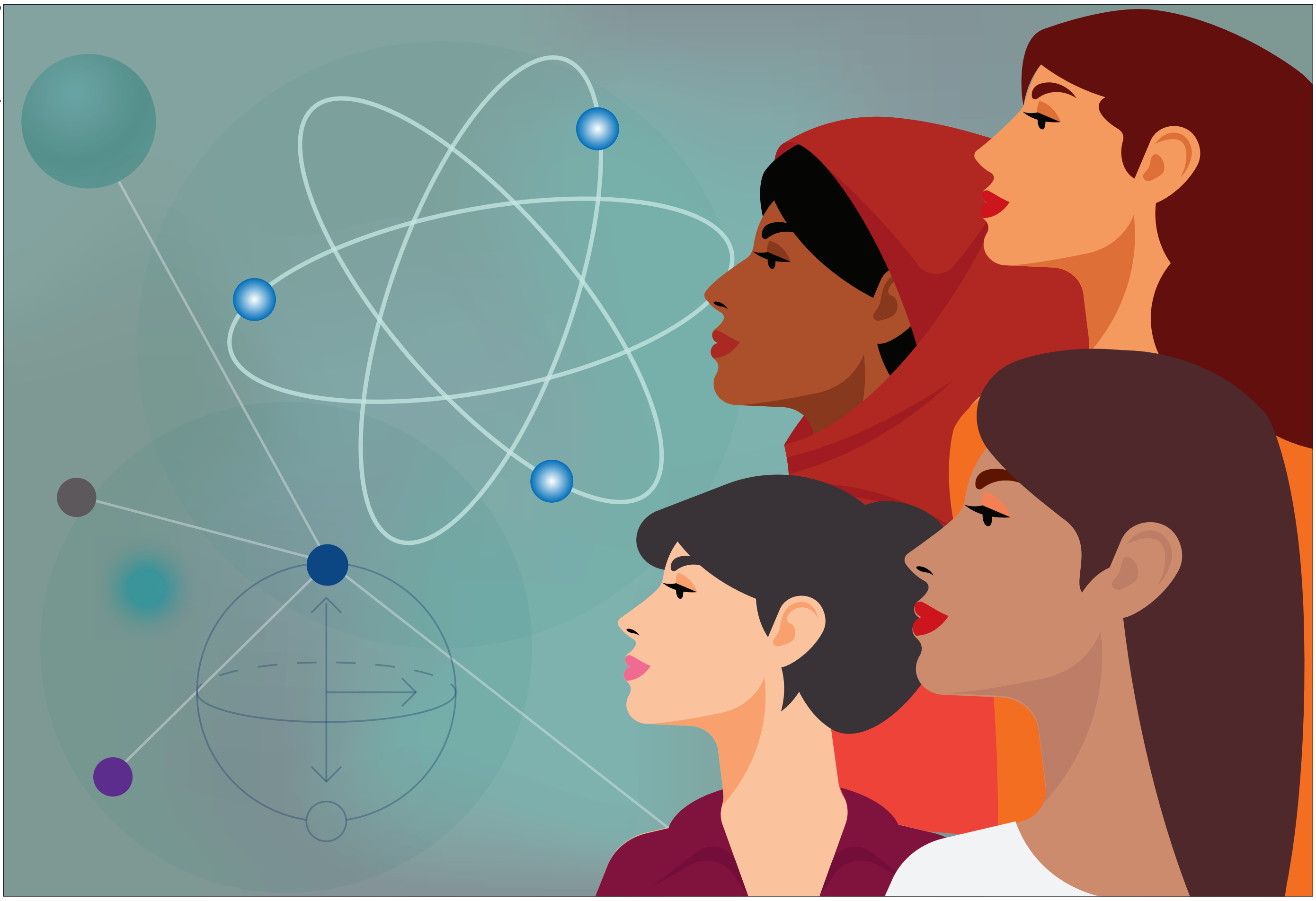
Corrections

The current defence-related budget for the US Department of Energy is $33bn, not $34bn, as stated last month (July p3).

The European Synchrotron Radiation Facility opened to users in 1994, not 1988 (May p27).

India’s women of quantum

INTERNATIONAL YEAR OF Quantum Science and Technology



Alison Tovey, IOP Publishing

Satyendra Nath Bose didn’t just make huge contributions to quantum science, he also welcomed women into what was at the time a male-dominated field. **Tanusri Saha-Dasgupta** and **Rupamanjari Ghosh** discuss Bose’s scientific and social legacy, and celebrate the women now at the forefront of quantum science in India

The 1920s was an era of transformation. In the US, the “Roaring Twenties” saw industrial growth, the rise of consumerism, and huge social change, marked by jazz music, prohibition and flapper fashion. Europe, meanwhile, was recovering from the devastating First World War, and experiencing political and economic instability alongside flourishing artistic and intellectual movements. And India – which was still under British rule at the time – was embracing Mahatma Gandhi’s policy of non-violence and civil disobedience, accelerating its nationalistic movement towards independence.

Amid worldwide cultural and sociopolitical change, another revolution was unfolding in science, particularly in our understanding of physical phenomena that cannot be explained by the classical laws of physics. Intense efforts were being made by European scientists to reconcile puzzling observations, and ground-breaking ideas were being introduced – such as Max Planck’s hypothesis of “quanta” and Albert Einstein’s quantization of electromagnetism. The first quantum revolution was flourishing.

In the midst of this excitement, a modest man from Bengal in undivided India, Satyendra Nath Bose, was teaching physics at Dacca (now Dhaka) University. He was greatly inspired by the new ideas in physics, and set about trying to solve the big inconsistency with the Plank distribution of black body radiation – the fact that it mixed classical and quantum concepts. Bose introduced the ground-breaking notion of indistinguishability of particles into the evolving quantum theory to rectify the problem, culminating in an equation describing the distribution of energy in the radiation from a black body purely based on quantum physics.

Bose’s derivation of Planck’s law impressed Einstein, who had also been trying to solve the problem. He translated the work and submitted it to *Zeitschrift für Physik* journal on Bose’s behalf. Bose’s novel quantum statistical approach later became known as Bose–Einstein statistics.

Tanusri Saha-Dasgupta is a senior professor and director at S N Bose National Centre for Basic Sciences. **Rupamanjari Ghosh** is the former vice-chancellor of Shiv Nadar University, Delhi NCR, and a former professor of physics and dean at the School of Physical Sciences, Jawaharlal Nehru University, New Delhi


Photographer unknown

Legacy lives on Satyendra Nath Bose in London, 1925.

Einstein followed up with its extension to atoms and the prediction of Bose–Einstein condensates. Bose's work was a breakthrough for quantum mechanics, and there have since been many discoveries and multiple Nobel prizes awarded for work related to his research. He also laid the foundation for novel technologies that are central to today's "second quantum revolution". This exciting era encompasses themes such as quantum computing, communications, sensing and metrology, and materials and devices. Bose's scientific breakthroughs were not his only contributions to physics at the time.

Competent and capable

Bose lived in an era when women were not welcome in the scientific community in India, as was the case in much of the rest of the world. Infamously, in 1933 biochemist Kamala Sohonie – who went on to be the first Indian woman to get a PhD in a scientific discipline – was denied admission to the Indian Institute of Science by the then-director Chandrasekhara Venkata Raman. Best known for his work on light scattering, Raman believed that women were not competent enough to do scientific research. While Sohonie eventually did get a place, she had to fight hard for it, and Raman enforced certain restrictions. For example, she was on probation for a year and Raman had to approve her work before it could be officially recognized.

Bose on the other hand, did not make any distinction between men and women as far as scientific ability was concerned. In 1951 he welcomed PhD student Purnima

Leading lights

Co-authors of this article, Tanusri Saha-Dasgupta and Rupamanjari Ghosh, are leading quantum scientists in India.

Tanusri Saha-Dasgupta

Director and senior professor at S N Bose National Centre for Basic Sciences in West Bengal, Tanusri Saha-Dasgupta uses computational tools to predict and understand novel quantum systems. A recent objective of her research has been to study extreme sensitivity and colossal response of strongly correlated quantum materials to external perturbations to develop them as quantum sensors. Her research aims to find new quantum information platforms – including detectors and qubits – based on correlated multipolar materials as well as developing novel quantum sensor platforms.

Saha-Dasgupta has been fascinated by scientific research since childhood. Her father was a doctoral researcher in physics when she started school, and she was determined to be a scientist too. She studied physics at Presidency College in Kolkata for her bachelor's degree. In a class of 22 students, there were only four women, and coming from an all-girls school, it was a challenge to cope in the male-dominated environment. However, her passion for science helped her succeed. Saha-Dasgupta ranked first in her master's at the University of Calcutta, and carried out her PhD work at the S N Bose Centre affiliated to University of Calcutta.

Following her studies, she did postdocs at the aerospace lab ONERA in Paris, France, and later at the Max Planck Institute in Stuttgart, Germany. Studying abroad was not easy for Saha-Dasgupta, as it was filled with hurdles, including serious illness and being separated from her husband. However, her persistence paid off.

Saha-Dasgupta became the first female director at the S N Bose National Centre for Basic Sciences in 2021. She is a fellow of the American Physical Society and the World Academy of Sciences, as well as all three science academies in India. As a senior professor, Saha-Dasgupta has played a pivotal role in mentoring many students, and has been in a leadership position for several national and international decision-making bodies.

Rupamanjari Ghosh

Rupamanjari Ghosh has held multiple prominent positions during her career. She was a professor of physics and dean of the School of Physical Sciences at Jawaharlal Nehru University (JNU) in New Delhi, before moving to Shiv Nadar University (SNU), a new, privately funded research university in the Delhi region. Here she was director of the School of Natural Sciences, and then vice-chancellor of the university. Under her leadership, SNU received the title of "Institution of Eminence" from the government of India within just a few years of its existence.

Born and raised in Kolkata, Ghosh did her undergraduate and master's degrees at the University of Calcutta. Chosen for "outstanding scholarly ability and the promise of exceptional contributions to scholarship and teaching" she was awarded a Rush Rhees fellowship for her PhD studies at the University of Rochester, New York, in the US, where she was the only female PhD student to graduate under Leonard Mandel.

Ghosh is credited with the discovery of a new source of entangled photons using spontaneous parametric down-conversion, and the first experimental demonstration of two-photon interference exhibiting nonlocality. Her group at JNU has worked extensively on the critical issue of decoherence from a quantum to a classical state in specific models. She also has an international collaboration that explores the process of electromagnetically induced transparency – which is a promising approach for implementing quantum memory.

While science and technology are deeply intertwined, Ghosh emphasizes the importance of inventions in science, often arising from singular, deep ideas, that define the "what" of a problem. She is also a big advocate for equality in physics.

Ghosh continues to mentor the next generation of researchers as a governing or advisory council member at several institutions in India. She has also been extensively involved as an expert with the National Quantum Mission (NQM) of the government of India. Furthermore, she is currently the first and only international member on the advisory board of the Executive Leadership Academy at the University of California, Berkeley, US.

The tradition continues

The tradition of succession from guru to disciple set up by Satyendra Nath Bose continues. The students of Tanusri Saha-Dasgupta and Rupamanjari Ghosh (see box on opposite page) inspired by their passion have now made their mark as established researchers.

Swastika Chatterjee
Swastika Chatterjee is an associate professor at the Indian Institute of Science Education and Research in Kolkata. Her research focuses on understanding quantum effects in Earth phenomena, such as the planet's magnetism and dynamo motion.

Chatterjee completed her undergraduate degree in physics with chemistry and maths at the University of Delhi, before specializing in condensed-matter physics for her master's. She went on to do her PhD under Tanusri Saha-Dasgupta at the S N Bose National Centre for Basic Science. Chatterjee got married during her studies, and she submitted her thesis while expecting her child. Her daughter was born just a few days later, and trying to balance motherhood and her career posed a significant challenge, but she succeeded through perseverance and determination. "The workplace environment has evolved significantly over the last decade, thanks to our academic predecessors who fought their way out," she says.

Joyee Ghosh
An associate professor of physics at the Indian Institute of Technology, Delhi, Joyee Ghosh is working to understand photon–atom interactions at the single-particle level, to be used in quantum networks. Her team's research involves "trusted-node-free" secure quantum communication, based on free-space and fibre-based entangled photon sources.

Ghosh grew up in Kolkata and then got her master's and PhD degrees from Jawaharlal Nehru University (JNU), under the supervision of Rupamanjari Ghosh. She went on to do postdoctoral research in Spain as a Marie Curie fellow, and in Germany as an Alexander von Humboldt fellow.

"My journey so far underscores the tenacity and positivity required by women physicists in India to navigate systemic challenges, secure funding and gain recognition in a complex and competitive scientific landscape," says Ghosh. "I have been fortunate to learn from great teachers and work in some of the best experimental research facilities."

Sinha to his group at the University of Calcutta. Despite being the only woman in the team, Sinha succeeded in leaving her indelible imprint on a male-dominated world, helped by the constant guidance and encouragement she received from Bose.

Sinha's research was on crystallographic and thermal analysis of clay samples taken from all over India. She built sophisticated X-ray instruments using military scrap equipment sold on the streets of Calcutta (now Kolkata) after the Second World War. In 1956 Sinha was awarded her doctorate, becoming the first woman to earn a PhD in physics from Calcutta University (and likely the first woman to get a PhD in physics from an institution in India).

She went on to conduct research in biophysics at Stanford University in the US, and found similarities between clay structure and DNA structure, providing pioneering thoughts on the origin of life. Sinha further broke gender stereotypes by doing masonry work, carpentry and even playing the tabla (a pair of hand drums). Bose was equally supportive of Asima Chatterjee, who started her research on medicinal plant extracts with Bose, and conducted the first small-molecule X-ray diffraction, which was ground-breaking work.

Breaking through

While times have changed and women today have more freedom to pursue science, technology, engineering and mathematics (STEM), these areas continue to be dominated by men. India produces the highest percentage of female STEM graduates in the world (43%), but women make up only 14% of the STEM workforce in the country and 18.6% of those directly involved in research and development activities.

The representation of women in the science and technology sector remains strikingly low, both in terms of job applicants and leadership roles. For example, a survey by the Council of Scientific Industrial Research (CSIR) in 2022 revealed that no woman had held the role of director general of CSIR until August of that year when chemical engineer Nallathamby Kalaiselvi became the first woman to lead the institute – a role that she still holds. Indeed, only five of the 35 CSIR labs were led by women at the time of the survey.

Gender bias and traditional role segregation are some of the key reasons why women remain under-represented in STEM careers in India. Several studies have found that women leave the workforce at key phases in their life – notably when they have children – and

Gender bias and traditional role segregation are some of the key reasons why women remain under-represented in STEM careers in India. However, the picture is changing rapidly

At the quantum frontier

Women at the forefront of quantum science in India today. This list is far from exhaustive, but it offers a glimpse of the broader picture.

Aditi Sen De

Aditi Sen De is a professor of physics at the Harish Chandra Research Institute in Allahabad. Her research exploits quantum mechanical principles to design quantum technologies, such as quantum communication networks, quantum thermal machines, and measurement-based quantum computers. She also characterizes resources responsible for achieving quantum technologies superior to their day-to-day versions.

Sen De was greatly inspired by her mother, a mathematics teacher, and developed a passion for teaching from an early age. "I used to teach using a small blackboard at home, imagining a classroom full of students," she explains. She completed her bachelor's degree at India's oldest women's college, Bethune College in Kolkata, before pursuing her interest in quantum and statistical physics at the University of Calcutta for her master's. Alongside her husband – they grew together both personally and professionally – she continued her scientific journey in Europe, completing her PhD at the University of Gdansk in Poland, and then doing postdoctoral research in Germany and Spain.

In 2018 Sen De was awarded the Shanti Swarup Bhatnagar Prize for Science and Technology (now the Vigyan Yuva – Shanti Swarup Bhatnagar Award). Given by the Indian government to recognize talented young scientists in all disciplines, the prize is one of the most prestigious scientific accolades in India. First awarded in 1958, only two women have ever received this honour in the physical sciences category (now physics), out of 103 recipients – a stark reflection of the gender imbalance.

Urbasi Sinha

The only other woman to receive the Bhatnagar award is Urbasi Sinha, a professor at the Raman Research Institute in Bangalore. Her research spans experimental studies on photonic quantum information processing, secure quantum communication, and precision tests of quantum mechanics.

Sinha's scientific journey was shaped by the constant support of her non-scientist parents, whose encouragement sparked her passion for discovery. After doing her undergraduate degree at Jadavpur University in Kolkata, Sinha went on to do a master's and PhD at the University of Cambridge, UK. She has gained significant international recognition for her work, with recent honours including the Canada Excellence Research Chair in Photonic Quantum Science and Technologies, the Gates Cambridge Impact Prize, and the Royal Academy of Engineering UK's Distinguished International Associateship. Sinha has also co-founded a quantum start-up, QuSyn Technologies, and leads a technical group under the NQM.

Meanwhile, as a mother raising a daughter, Sinha maintains a sense of work–life integration by being fully present – giving her complete attention to whatever requires it, whether personal or professional.

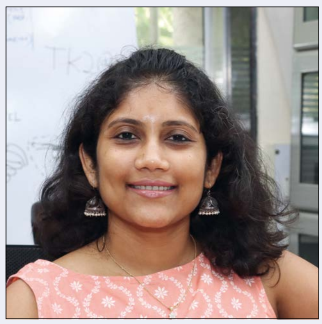
"Women in academia are breaking barriers as institutions embrace diversity," says Sinha. "While explicit obstacles fall through targeted initiatives, the academic community now faces the vital challenge of identifying subtle biases woven into institutional fabric. This evolving awareness promises a future where talent thrives regardless of gender, transforming scholarship through diverse perspectives."

Usha Devi A R

A professor at Bangalore University, Usha Devi A R is a theorist who has contributed to formulating figures of merit for non-classicality of photonic states – which are crucial for metrology, quantum target detection, quantum digital reading and more. Her team has put forth geometric visualization of spin states, which works like a fingerprint for entanglement and spin-squeezing, needed in metrology.

Devi was born in Thirthahalli town in Karnataka, where she completed her undergraduate degree in sciences. She was top of her class and received a gold medal for her master's in physics from Mysore University, where she also completed her PhD in 1998. She received the IPA young physicist award in 1997, and was a visiting scientist in Barry Sander's research group at Macquarie University in Sydney, Australia, in 2003. She also worked in Sandu Popescu's research group at the University of Bristol, UK, under a Commonwealth Academic Fellowship in 2008.

Working as a faculty member at a state-funded university comes with persistent challenges, such as limited resources for research and teaching, and sometimes outdated administrative priorities. "In quantum mechanics, we embrace uncertainty," Devi says. "In academia, we challenge it – especially as women physicists from state universities."



Kasturi Saha

Kasturi Saha is an associate professor at the Indian Institute of Technology (IIT) Bombay (Mumbai). She is the project director of Qmet Tech Foundation, the quantum sensing and metrology hub established by IIT Bombay under the National Quantum Mission (NQM) of the Government of India. She is the only female project director among the four NQM hubs established.

Saha was raised in the lively heart of Kolkata's Wellington Square, in a family filled with engineers and doctors. Drawn to the elegance of physics, she chose it as her major, inspired by the Nobel-winning work on Bose–Einstein condensates. Although she aspired to become a scientist, her decision was initially met with concern and scepticism from her family, who were worried about the challenges of pursuing a career in science – especially as female representation was (and still is) limited.

Despite their concerns, Saha's parents stood firmly by her side, supporting her throughout every step of her academic journey. After her undergraduate physics degree from St Stephen's College in Delhi, Saha moved to IIT Delhi for her master's, and then went to Cornell University in the US for her PhD. As she progressed through her degrees, the gender gap became increasingly apparent, with a sharp decline in the number of women.

Training to be an experimental physicist brought its own set of biases – people often assumed Saha couldn't handle technical tasks or heavy equipment. These subtle yet persistent doubts made her hyper-aware of her identity – she even stopped wearing pink T-shirts during her PhD. Yet, she persisted, bolstered by mentors including Michal Lipson and Paola Cappellaro.

are also often rejected when seeking jobs because of gender discrimination.

However, the picture is changing rapidly, aided by educational initiatives and grassroots movements advocating for gender equity. The quickly growing quantum sector is no different, and the need for quantum education is greater than ever, as a shortage of trained researchers is being felt globally.

One person hoping to inspire and educate women and girls about quantum computing is Singapore-based researcher Nithyasri Srivathsan, who founded SheQuantum in 2020. The initiative has built an e-learning platform offering lectures, quantum computing courses and other educational resources, as well as articles and interviews with experts. It was listed by *The Quantum Insider* as one of the "9 Educational Platforms to get the Quantum Workforce Up & Running", alongside IBM, Microsoft and MIT xPRO among others.

Another example is Women for Quantum (W4Q), which was set up by a group of female physics professors, mostly based in Europe and Japan, who work in the field of quantum optics, quantum many-body physics and quantum information. In its manifesto, the initiative highlights the "unsatisfactory current situation of women in quantum physics" and calls for a joint effort to make real change in the field.

Celebrating success

The good news is that such efforts seem to be paying off. According to the latest All India Survey on Higher Education (AISHE) (2020–2021) women make up 42.3% of undergraduate, postgraduate, MPhil, and PhD places in STEM education. There has also been a surge in women in all fields of STEM, including quantum science, where they are making significant contributions to the second quantum revolution.

To celebrate the growing presence of women at the forefront of quantum science in India, the S N Bose National Centre for Basic Sciences in Kolkata arranged an international conference in July 2024 on Women in Quantum Science and Technologies. The meeting was part of celebrations marking the 100th anniversary of Bose's seminal work, highlighting that his legacy encompasses both quantum science and gender equality in physics.

The three-day conference consisted of six talks from accomplished female scientists, two panel discussions, three special lectures, 10 invited talks from early-career women working across quantum science and technologies, and a poster session by PhD students. The panel discussions focused on the challenges faced by women in higher education and ways to overcome them, as well as opportunities for women in the quantum arena. Speakers included Rupamanjari Ghosh, Aditi Sen De, Indrani Bose, Anjana Devi, Shohini Ghose and Efrat Shimshoni.

Such events highlight the achievements of women in the field, providing a platform for sharing research and inspiring future generations. This visibility is crucial for normalizing women's participation in science and encouraging girls to pursue careers in physics and related disciplines.

With the second quantum revolution in progress, and the next likely to be driven by commercial innovations in areas such as cybersecurity, eco-materials and medical advancements, it is important to ensure that these breakthroughs do not reinforce societal inequalities. For that, we need women, and other under-represented groups in physics, to be encouraged into the field to ensure a diverse range of ideas.

S N Bose National Centre

Opportunity for change Women in Quantum Science and Technologies was a three-day conference held in Kolkata in July 2024.

To this end, in the box opposite we highlight some women at the forefront of quantum science in India.

Beyond academia

Impressive women in quantum science are not limited to academia. Government departments and industry in India can boast of some prominent female leaders. For example, Anindita Banerjee is a product manager for quantum technology projects at the Centre for Development of Advanced Computing (CDACINDIA), a premier research and development organization founded by the Ministry of Electronics and Information Technology. Anupama Ray is an award-winning senior research scientist at IBM Research in Bangalore, where she focuses on developing quantum machine learning algorithms. Meanwhile at Microsoft India and South Asia, Rohini Srivathsa is the chief technology officer, responsible for driving technology innovation and growth across industry and the government.

In addition to the accomplished Indian women working in quantum in their home country, there are several who have built successful careers abroad. Notable cases are Anjana Devi, director of the Institute for Materials Chemistry at the Leibniz Institute for Solid State and Materials Research, Dresden, Germany; Nandini Trivedi, professor of physics at Ohio State University, US; Nilanjana Datta, professor in quantum information theory at the University of Cambridge, UK; Vidya Madhavan, professor of physics at the University of Illinois Urbana-Champaign, US; Shohini Ghose, professor of physics and computer science, and director of research and programmes for the Centre for Women in Science at Wilfrid Laurier University in Waterloo, Canada, and chief technology officer at Quantum Algorithms Institute.

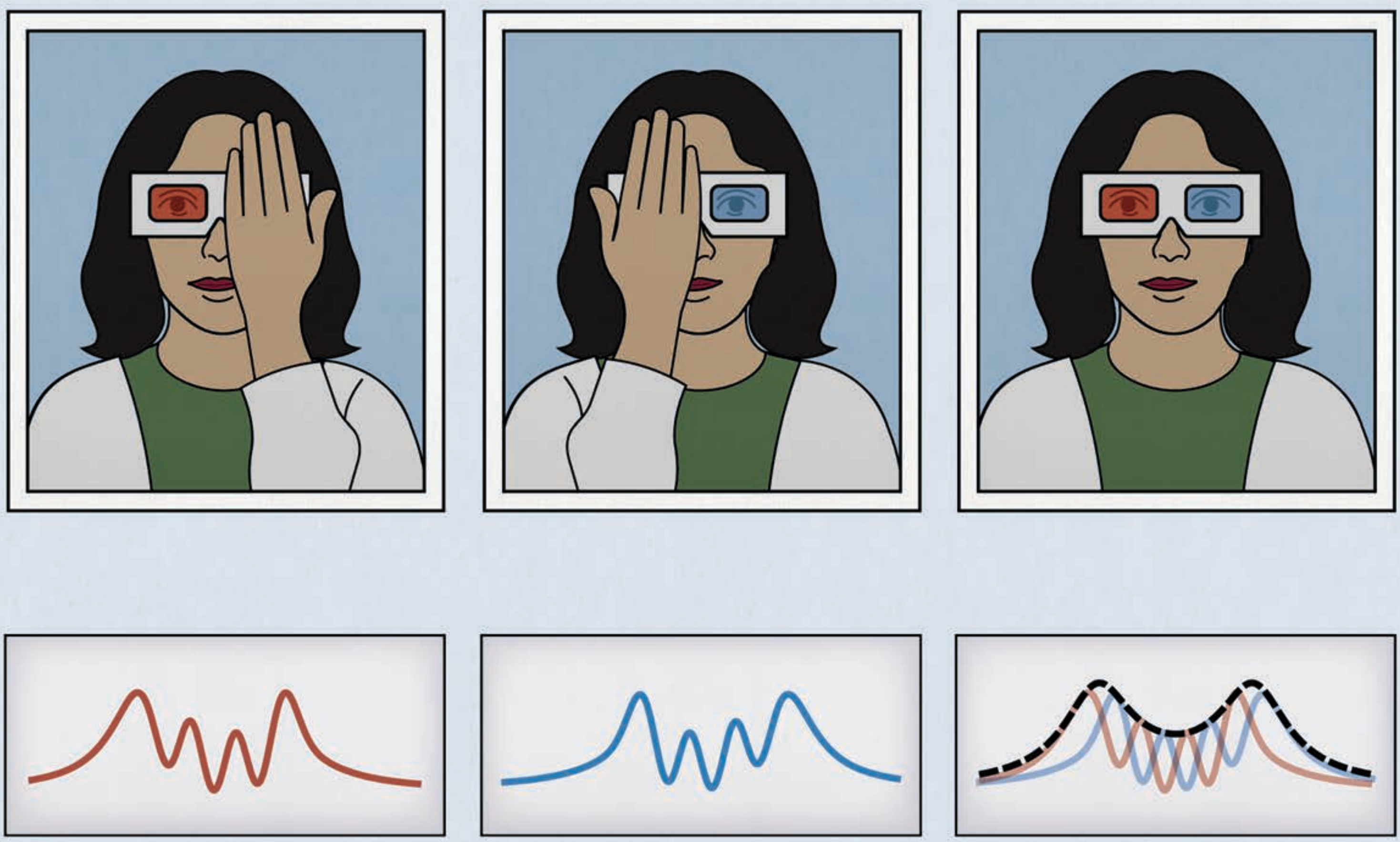
The rise of women in quantum science in India is a tribute to Bose's legacy, and a sign of a more inclusive and dynamic future. To sustain this momentum, we must create ecosystems that support curiosity, collaboration and equal opportunity – ensuring that every brilliant mind, regardless of gender, has the chance to transform the world.

● All portrait photos in this article were kindly supplied by their subjects ■

The quantum eraser doesn't rewrite the past – it rewrites observers

In the third of our series of truly weird quantum effects, **Maria Violaris** investigates the paradoxical delayed-choice quantum eraser

INTERNATIONAL YEAR OF
Quantum Science and Technology



Mayank Shreshtha

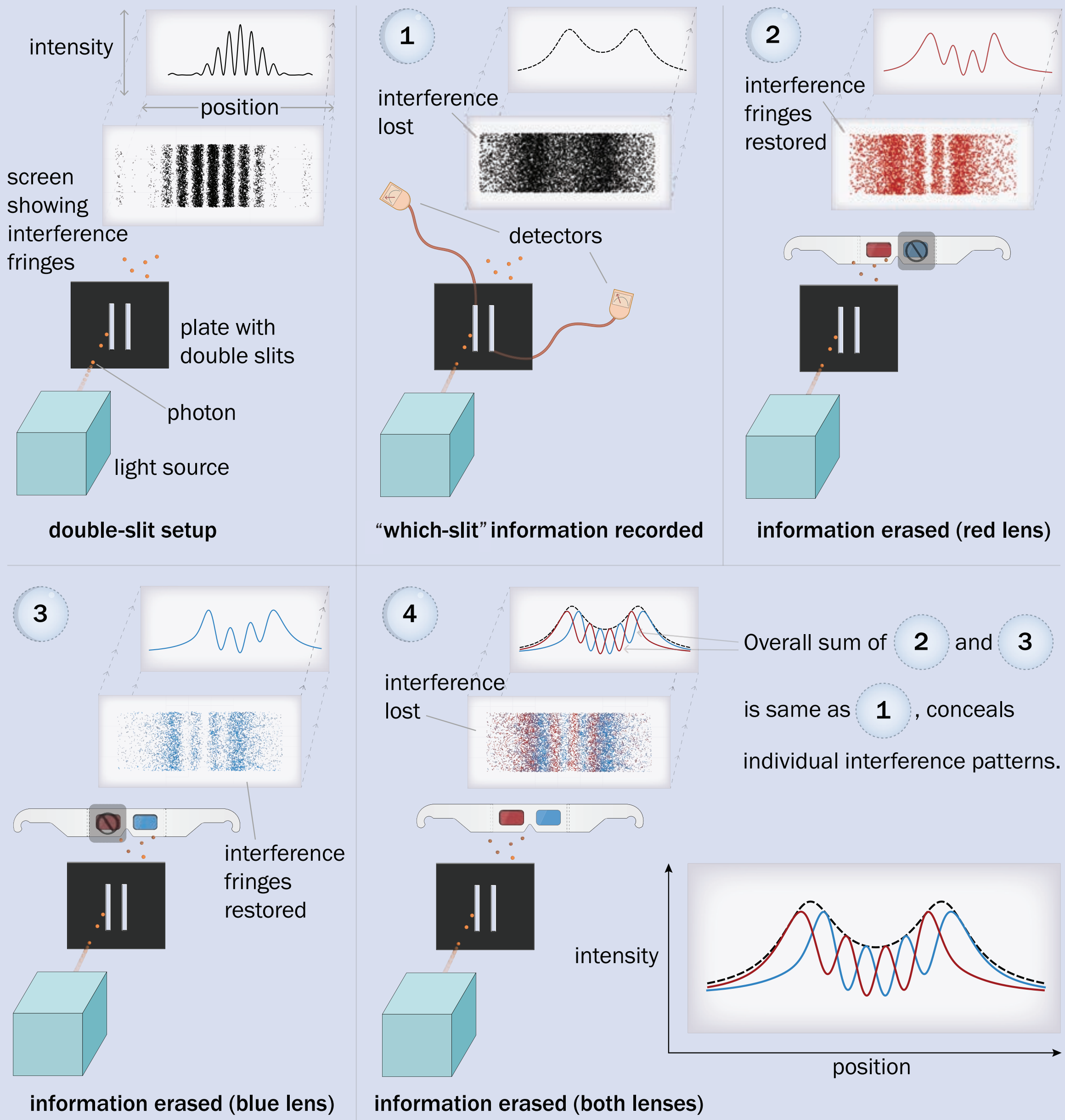
"Welcome to this special issue of *Physics World*, marking the 200th anniversary of quantum mechanics. In this double-quantum edition, the letters in this text are stored using qubits. As you read, you project the letters into a fixed state, and that information gets copied into your mind as the article that you are reading. This text is actually in a superposition of many different articles, but only one of them gets copied into your memory. We hope you enjoy the one that you are reading."

That's how I imagine the opening of the 2125 *Physics World* quantum special issue, when fully functional quantum computers are commonplace, and we have even figured out how to control individual qubits on display screens. If you are lucky enough to experience reading such a magazine, you might be disappointed as you can read only one of the articles the text gets projected into. The problem is that by reading the superposition of articles, you made them decohere, because you copied the information about each letter into your memory. Can you figure out a way to read the others too? After all, more *Physics World* articles is always better.

A possible solution may be if you could restore the coherence of the text just by erasing your memory of the particular article you read. Once you no longer have information identifying which article your magazine was projected into, there is then no fundamental reason for it

Maria Violaris is a quantum physicist, science communicator and content creator. She has a PhD from the University of Oxford in the foundations of quantum information science and was previously a PhD student contributor to *Physics World*

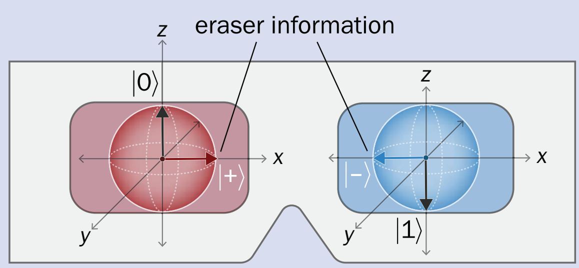
1 Delayed detections, path revelations and complementary measurements



How is path information erased?

A detector qubit measures |0⟩ for left slit and |1⟩ for right slit (0/1 basis).

The eraser measures the detector qubit in a complementary way (+/– basis).



Mayank Shreshtha

This illustration depicts how the quantum eraser restores the wave-like behaviour of photons in a double-slit experiment, using 3D-glasses as an analogy. The top left box shows the set-up for the standard double-slit experiment. As there are no detectors at the slits measuring which pathway a photon takes, an interference pattern emerges on the screen. In box 1, detectors are present at each slit, and measuring which slit the photon might have passed through, the interference patter is destroyed. Boxes 2 and 3 show that by erasing the "which-slit" information, the interference patterns are restored. This is done by separating out the photons using the eraser, represented here by a red filter and a blue filter of the 3D glasses. The final box 4 shows that the overall pattern with the eraser has no interference, identical to patten seen in box 1.
In boxes 2, 3 and 4, a detector qubit measures "which-slit" information, with states |0> for left and |1> for right. These are points on the z-axis of the "Bloch sphere", an abstract representation of the qubit. Then the eraser measures the detector qubit in a complementary way, along the x-axis of the Bloch sphere. This destroys the "which-slit information", but reveals the red and blue lens information used to filter the outcomes, as depicted in the image of the 3D glasses.

The results therefore reveal an intriguing aspect of quantum theory – the rich, counterintuitive structure of quantum correlations from entanglement – rather than past influences

to remain decohered into a single state. You could then reread it to enjoy a different article.

While this thought experiment may sound fantastical, the concept is closely connected to a mind-bending twist on the famous double-slit experiment, known as the delayed-choice quantum eraser. It is often claimed to exhibit a radical phenomenon: where measurements made in the present alter events that occurred in the past. But is such a paradoxical suggestion real, even in the notoriously strange quantum realm?

A double twist on the double slit

In a standard double-slit experiment, photons are sent one by one through two slits to create an interference pattern on a screen, illustrating the wave-like behaviour of light. But if we add a detector that can spot which of the two slits the photon goes through, the interference disappears and we see only two distinct clumps on the screen, signifying particle-like behaviour. Crucially, gaining information about which path the photon took changes the photon's quantum state, from the wave-like interference pattern to the particle-like clumps.

The first twist on this thought experiment is attributed to proposals from physicist John Wheeler in 1978, and a later collaboration with Wojciech Zurek in 1983. Wheeler's idea was to delay the measurement of which slit the photon goes through. Instead of measuring the photon as it passes through the double-slit, the measurement could be delayed until just before the photon hits the screen. Interestingly, the delayed detection of which slit the photon goes through still determines whether or not it displays the wave-like or particle-like behaviour. In other words, even a detection done long after the photon has gone through the slit determines whether or not that photon is measured to have interfered with itself.

If that's not strange enough, the delayed-choice quantum eraser is a further modification of this idea. First proposed by American physicists Marlan Scully and Kai Drühl in 1982 (*Phys. Rev. A* **25** 2208), it was later experimentally implemented by Yoon-Ho Kim and collaborators using photons in 2000 (*Phys. Rev. Lett.* **84** 1). This variation adds a second twist: if recording which slit the photon passes through causes it to decohere, then what happens if we were to erase that information? Imagine shrinking the detector to a single qubit that becomes entangled with the photon: "left" slit might correlate to the qubit being 0, "right" slit to 1. Instead of measuring whether the qubit is a 0 or 1 (revealing the path), we could measure it in a complementary way, randomising the 0s and 1s (erasing the path information).

Strikingly, while the screen still shows particle-like clumps overall, these complementary measurements of the single-qubit detector can actually be used to extract a wave-like interference pattern. This works through a sorting process: the two possible outcomes of the complementary measurements are used to separate out the photon detections on the screen. The separated patterns then each individually show bright and dark fringes.

I like to visualize this using a pair of 3D glasses, with one blue and one red lens. Each colour lens reveals a different individual image, like the two separate interference patterns. Without the 3D glasses, you see only the overall sum of the images. In the quantum eraser experiment, this sum of the images is a fully decohered pattern, with no trace of interference. Having access to the complementary measurements of the detector is like getting access to the 3D glasses: you now get an extra tool to filter out the two separate interference patterns (figure 1).

Rewriting the past – or not?

If erasing the information at the detector lets us extract wave-like patterns, it may seem like we've restored wave-like behaviour to an already particle-like photon. That seems truly head-scratching. However, Jonte Hance, a quantum physicist at Newcastle University in the UK, highlights a different conclusion, focused on how the individual interference patterns add up to show the usual decohered pattern. "They all feel like they shouldn't be able to fit together," Hance explains. "It's really showing that the correlations you get through entanglement have to be able to fit every possible way you could measure a system." The results therefore reveal an intriguing aspect of quantum theory – the rich, counterintuitive structure of quantum correlations from entanglement – rather than past influences.

Even Wheeler himself did not believe that his thought experiment actually allows for a backward-in-time influence, as explained by Lorenzo Catani, a researcher at the International Iberian Nanotechnology Laboratory (INL) in Portugal. Commenting on the history of the thought experiment, Catani notes that "Wheeler concluded that one must abandon a certain type of realism – namely, the idea that the past exists independently of its recording in the present. As far as I know, only a minority of researchers have interpreted the experiment as evidence for retrocausality."

Eraser vs Bell: a battle of the bizarre

One physicist who is attempting to unpack this problem is Johannes Fankhauser at the University of Innsbruck, Austria. "I'd heard about the quantum eraser, and it had puzzled me a lot because of all these bizarre claims of backwards-in-time influence", he explains. "I see something that sounds counterintuitive and puzzling and bizarre and then I want to understand it, and by understanding it, it gets a bit demystified."

Fankhauser realized that the quantum eraser set-up can be translated into a very standard Bell experiment.

View this e-magazine online to watch a video where Maria Violaris resolves the quantum eraser paradox – showing that we can fully understand the eraser without any backwards-in-time influence.

The quantum eraser emphasizes that even a single entanglement between qubits will cause decoherence, whether or not it is measured afterwards – meaning that no mysterious macroscopic observer is required

These experiments are based on entangling a pair of qubits, the idea being to rule out local "hidden-variable" models of quantum theory. This led him to see that there is no need to explain the eraser using backwards-in-time influence, since the related Bell experiments can be understood without it, as explained in his 2017 paper (*Quanta* **8** 44). Fankhauser then further analysed the thought experiment using the de Broglie–Bohm interpretation of quantum theory, which gives a physical model for the quantum wavefunction (as particles are guided by a "pilot" wave). Using this, he showed explicitly that the outcomes of the eraser experiment can be fully explained without requiring backwards-in-time influences.

So does that mean that the eraser doesn't tell us anything else beyond what Bell experiments already tell us? Not quite. "It turns different knobs than the Bell experiment," explains Fankhauser. "I would say it asks the question 'what do measurements signify?', and 'when can I talk about the system having a property?'. That's an interesting question and I would say we don't have a full answer to this."

In particular, the eraser demonstrates the importance that the very act of observation has on outcomes, with the detector playing the role of an observer. "You measure some of its properties, you change another property," says Fankhauser. "So the next time you measure it, the new property was created through the observation. And I'm trying to formalize this now more concretely. I'm trying to come up with a new approach and framework to study these questions."

Meanwhile, Catani found an intriguing contrast between Bell experiments and the eraser in his research. "The implications of Bell's theorem are far more profound," says Catani. In the 2023 paper (*Quantum* **7** 1119) he co-authored, Catani considers a model for classical physics, with an extra condition: there is a restriction on what you can know about the underlying physical states. Applying this model to the quantum eraser, he finds that its results can be reproduced by such a classical theory. By contrast, the classical model cannot reproduce the statistical violations of a Bell experiment. This shows that having incomplete knowledge of the physical state is not, by itself, enough to explain the strange results of the Bell experiment. It is therefore demonstrating a more powerful deviation from classical physics than the eraser. Catani also contrasts the mathematical rigour of the two cases. While Bell experiments are based on explicitly formulated assumptions, claims about backwards-in-time influence in the quantum eraser rely on a particular narrative – one that gives rise to the apparent paradox.

The eraser as a brainteaser

Physicists therefore broadly agree that the mathematics of the quantum eraser thought experiment fits well within standard quantum theory. Even so, Hance argues that formal results alone are not the entire story: "This is something we need to pick apart, not just in terms of mathematical assumptions, but also in terms of building intuitions for us to be able to actually play around with what quantumness is." Hance has been analysing the physical implications of different assumptions in the thought experiment, with some options discussed in his 2021 preprint (arXiv:2111.09347) with collaborators on the quantum eraser paradox.

It therefore provides a tool for understanding how quantum correlations match up in a way that is not described by classical physics. "It's a great thinking aid – partly brainteaser, partly demonstration of the nature of this weirdness."

Information, observers and quantum computers

Every quantum physicist takes something different from the quantum eraser, whether it is a spotlight on the open problems surrounding the properties of measured systems; a lesson from history in mathematical rigour; or a counterintuitive puzzle to make sense of. For a minority that deviate from standard approaches to quantum theory, it may even be some form of backwards-in-time influence.

For myself, as explained in my related video on the Qiskit YouTube channel, and my 2023 paper (*IEEE International Conference on Quantum Computing and Engineering* 10.1109/QCE57702.2023.20325) on quantum thought experiments, the most dramatic implication of the quantum eraser is explaining the role of observers in the double-slit experiment. The quantum eraser emphasizes that even a single entanglement between qubits will cause decoherence, whether or not it is measured afterwards – meaning that no mysterious macroscopic observer is required. This also explains why building a quantum computer is so challenging, as unwanted entanglement with even one particle can cause the whole computation to collapse into a random state.

Where does this leave the futuristic readers of our 200-year double-quantum special issue of *Physics World*? Simply erasing their memories is not enough to restore the quantum behaviour of the article. It is too late to change which article was selected. Though, following an eraser-type protocol, our futurists can do one better than those sneaky magazine writers: they can use the outcomes of complementary measurements on their memory, to sort the article into two individual smaller articles, each displaying their own quantum entanglement structure that was otherwise hidden. So even if you can't use the quantum eraser to rewrite the past, perhaps it can rewrite what you read in the future. ■

Helgoland 2025: the quantum island of adventure

More than 300 top quantum physicists gathered on Helgoland in June for a conference that was billed as a highlight of the International Year of Quantum Science and Technology. **Matin Durrani** reveals what the meeting achieved

Matin Durrani is editor-in-chief of *Physics World*

When Werner Heisenberg travelled to Helgoland in June 1925, he surely couldn't have imagined that more than 300 researchers would make the same journey exactly a century later. But his development of the principles of quantum mechanics on the tiny North Sea island proved so significant that the *crème de la crème* of quantum physics, including four Nobel laureates, attended a five-day conference on Helgoland in June to mark the centenary of his breakthrough.

Just as Heisenberg had done, delegates travelled to the German archipelago by boat, leading one person to joke that if the ferry from Hamburg were to sink, "that's basically quantum theory scuppered for a generation". Fortunately, the vessel survived the four-hour trip up the river Elbe and 50 km out to sea – despite strong winds almost leading to a last-minute cancellation. The physicists returned in one piece too, meaning the future of quantum physics is safe.

These days Helgoland is a thriving tourist destination, offering beaches, bird-watching and boating, along with cafes, restaurants and shops selling luxury goods (the island benefits from being duty-free). But even 100 years ago it was a popular resort, especially for hay-fever sufferers like Heisenberg, who took a leave of absence from his post-doc under Max Born in Göttingen to seek refuge from a particularly bad bout of the illness on the windy and largely pollen-free island.

More than five years in the making, Helgoland 2025 was organized by Florian Marquardt and colleagues at the Max Planck Institute for the Science of Light and Yale University quantum physicist Jack Harris, who said he was "very happy" with how the meeting turned out. As well as the quartet of Nobel laureates – Alain Aspect, Serge Haroche, David Wineland and Anton Zeilinger – there were many eager and enthusiastic early-career physicists who will be the future stars of quantum physics.

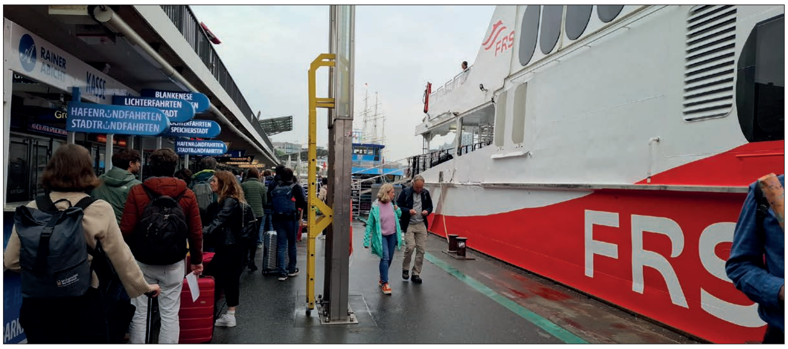
Questioning the foundations

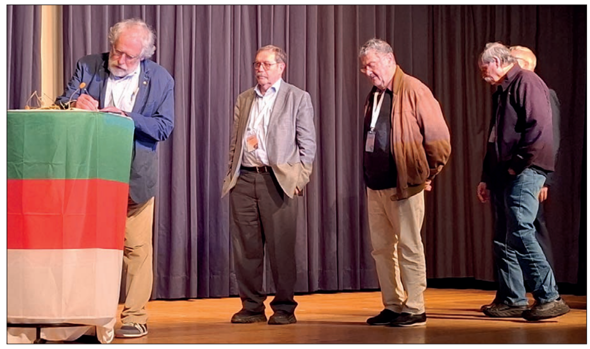
When quantum physics began 100 years ago, only a handful of people were involved in the field. As well as Heisenberg and Born, there were the likes of Erwin Schrödinger, Paul Dirac, Wolfgang Pauli, Niels Bohr and Pascual Jordan. If WhatsApp had existed back then, the protagonists would have fitted into their own small group chat (perhaps called "The Quantum Apprentices"). But these days quantum physics is a far bigger endeavour.

With 31 lectures, five panel debates and more than 100 posters, Helgoland 2025 had sessions covering everything from the fundamentals of quantum mechanics and quantum information to applied topics such as sensors and quantum computing. In fact, Harris said in an after-dinner speech on the conference's opening night in Hamburg that he and the organizing team could easily have "filled two or three solid programmes with people from whom we would have loved to hear".

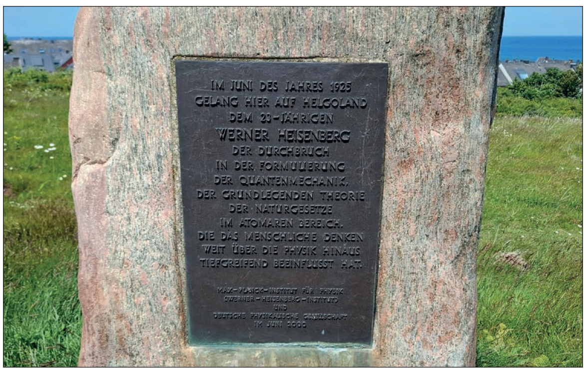
Harris's big idea was to bring together theorists working on the foundational aspects of quantum mechanics with researchers applying those principles to quantum computing, sensing and communications. "[I hoped they] would enjoy talking to each other on an equal footing," he told me after the meeting. "These topics have a lot of overlap, but that overlap isn't always well-represented at conferences devoted to one or the other."

In terms of foundational questions, speakers covered issues such as entanglement, superposition, nonlocality, the meaning of measurement and the nature





All images: Matin Durrani



Quantum centenary After taking a ferry from Hamburg (top left), physicists at the Helgoland 2025 conference took part in talks, poster sessions and discussions in the island's Nordseehalle, where the four Nobel laureates in attendance (top right) signed a book marking the occasion (from left to right – Anton Zeilinger, Alain Aspect, Serge Haroche and David Wineland). While on the island, there was a visit to the plaque (centre left) that had been installed in 2000 by the Max Planck Society near the spot where Werner Heisenberg said he formulated the principles of quantum mechanics in June 1925.

Bahar Gholipour

Where it all began
More than 300 quantum physicists attended the Helgoland 2025 conference on 9–14 June celebrating the centenary of quantum mechanics.

of information, particles, quantum states and randomness. Nicholas Gisin from the University of Geneva said physics is, at heart, all about extracting information from nature. Renato Renner from ETH Zurich discussed how to treat observers in quantum physics. Zeilinger argued that quantum states are states of knowledge – but, if so, do they exist only when measured?

Italian theorist and author Carlo Rovelli, who was constantly surrounded in the coffee breaks, gave a lecture on loop quantum gravity as a solution to marrying quantum physics with general relativity. In a talk on quantizing space–time, Juan Maldacena from the Institute for Advanced Study in Princeton discussed information loss and black holes, saying that a "white" black hole the size of a bacterium would be as hot as the Sun and emit so much light we could see it with the naked eye.

Markus Aspelmeyer from the University of Vienna spoke about creating non-classical (i.e. quantum) sources of gravity in table-top experiments and tackled the prospect of gravitationally induced entanglement. Jun Ye from the University of Colorado, Boulder, talked about improving atomic clocks for fundamental physics. Bill Unruh from the University of British Columbia discussed the nature of particles, concluding that: "A particle is what a particle detector detects".

It almost came as a relief when Gemma de les Coves from the Universitat Pompeu Fabra in Barcelona flashed up a slide joking: "I do not understand quantum mechanics."

Applying quantum ideas

Discussing foundational topics might seem self-indulgent given the burgeoning (and financially lucrative) applications of quantum physics. But those basic questions are not only intriguing in their own right – they also help to attract newcomers into quantum physics. What's more, practical matters like quantum computing, code breaking and signal detection are not just technical and engineering endeavours. "They hinge on our ability to understand those foundational questions," says Harris.

In fact, plenty of practical applications were discussed at Helgoland. As Michelle Simmons from the University of New South Wales pointed out, the last 25 years have been a "golden age" for experimental quantum physics. "We now have the tools that allow us to manipulate the world at the very smallest length scales," she said in an interview for the *Physics World Weekly* podcast. "We're able for the first time to try and control quantum states and see if we can use them for different types of information encoding or for sensing."

One presenter discussing applications was Jian-Wei Pan from the University of Science and Technology of China, who spoke about quantum computing and quantum communication across space, which relies on sustaining quantum entanglement over long distances and times. David Moore from Yale discussed some amazing practical experiments his group is doing using levitated, trapped silica microspheres as quantum sensors to detect what he called the "invisible" universe – neutrinos and perhaps even dark matter.

Nergis Mavalvala from the Massachusetts Institute of Technology, meanwhile, reminded us that gravitational-wave detectors, such as LIGO, rely on quantum physics to tackle the problem of "shot noise", which otherwise limits their performance. Nathalie de Leon from Princeton University, who admitted on the final day she was going a bit "stir crazy" on the island, discussed quantum sensing with diamond.

Outside influences

Helgoland 2025 proved that quantum physicists have much to shout about, but also highlighted the many challenges still lying in store. How can we move from systems with just a few quantum bits to hundreds or thousands? How can quantum error correction help make noisy quantum systems reliable? What will we do with an exponential speed-up in computing? Is there a clear border between quantum and classical physics – and, if so, where is it?

By cooping participants together on an island with such strong historical associations, Harris hopes that Helgoland 2025 will have catalysed new thinking. "I got to meet a lot of people I had always wanted to meet and re-connect with folks I'd been out of touch with for a long time," he said. "I had wonderful conversations that I don't think would have happened anywhere else. It is these kinds of person-to-person connections that often make the biggest impact."

> It is these kinds of person-to-person connections that often make the biggest impact
>
> Jack Harris, quantum physicist at Yale University

Occasionally, though, the outside world did encroach on the meeting. To a round of applause, Rovelli said that physicists must keep working with Russian scientists, and warned of the dangers of demonizing others. Pan, who had to give his talk on a pre-recorded video, said it was “with much regret” that he was prevented from travelling to Helgoland from China. There were a few rumbles about the conference being sponsored in part by the US Air Force Office of Scientific Research and the Army Research Office.

Quantum physicists would also do well to find out more about the philosophy of science. Questions like the role of the observer, the nature of measurement, and the meaning of non-locality are central to quantum physics but are philosophical as much as scientific. Even knowing the philosophy relevant to the early years of quantum physics is important. As Elise Crull from the City University of New York said: “Physicists ignore this early philosophy at their peril.”

Towards the next century

The conference ended with a debate, chaired by Tracy Northup from the University of Innsbruck, on the next 100 years of quantum physics, where panellists agreed that the field’s ongoing mysteries are what will sustain it. “When we teach quantum mechanics, we should not be hiding the open problems, which are what interest students,” said Lorenzo Maccone from the University of Pavia in Italy. “They enjoy hearing there’s no consensus on, say the Wigner’s friend paradox. They seem engaged [and it shows] physics is not something dead.”

The importance of global links in science was underlined too. “Big advances usually come from international collaboration or friendly competition,” said panellist Gerd Leuchs from the Max Planck Institute for the Science of Light. “We should do everything we can to keep up collaboration. Scientists aren’t better people but they share a common language. Maintaining links across borders dampens violence.”

Leuchs also reminded the audience of the importance of scientists admitting they aren’t always right. “Scientists are often viewed as being arrogant, but we love to be proved wrong and we should teach people to enjoy being wrong,” he said. “If you want to be successful as a scientist, you have to be willing to change your mind. This is something that can be useful in the rest of society.”

I’ll leave the final word to Max Lock – a postdoc from the Technical University of Vienna – who is part of a new generation of quantum physicists who have grown up with the weird but entirely self-consistent world of quantum physics. Reflecting on what happened at Helgoland, Lock said he was struck most by the contrast between what was being celebrated and the celebration itself.

“Heisenberg was an audacious 23-year-old whose insight spurred on a community of young and revolutionary thinkers,” he remarked. “With the utmost respect for the many years of experience and achievements that we saw on the stage, I’m quite sure that if there’s another revolution around the corner, it’ll come from the young members of the audience who are ready to turn the world upside down again.” ■

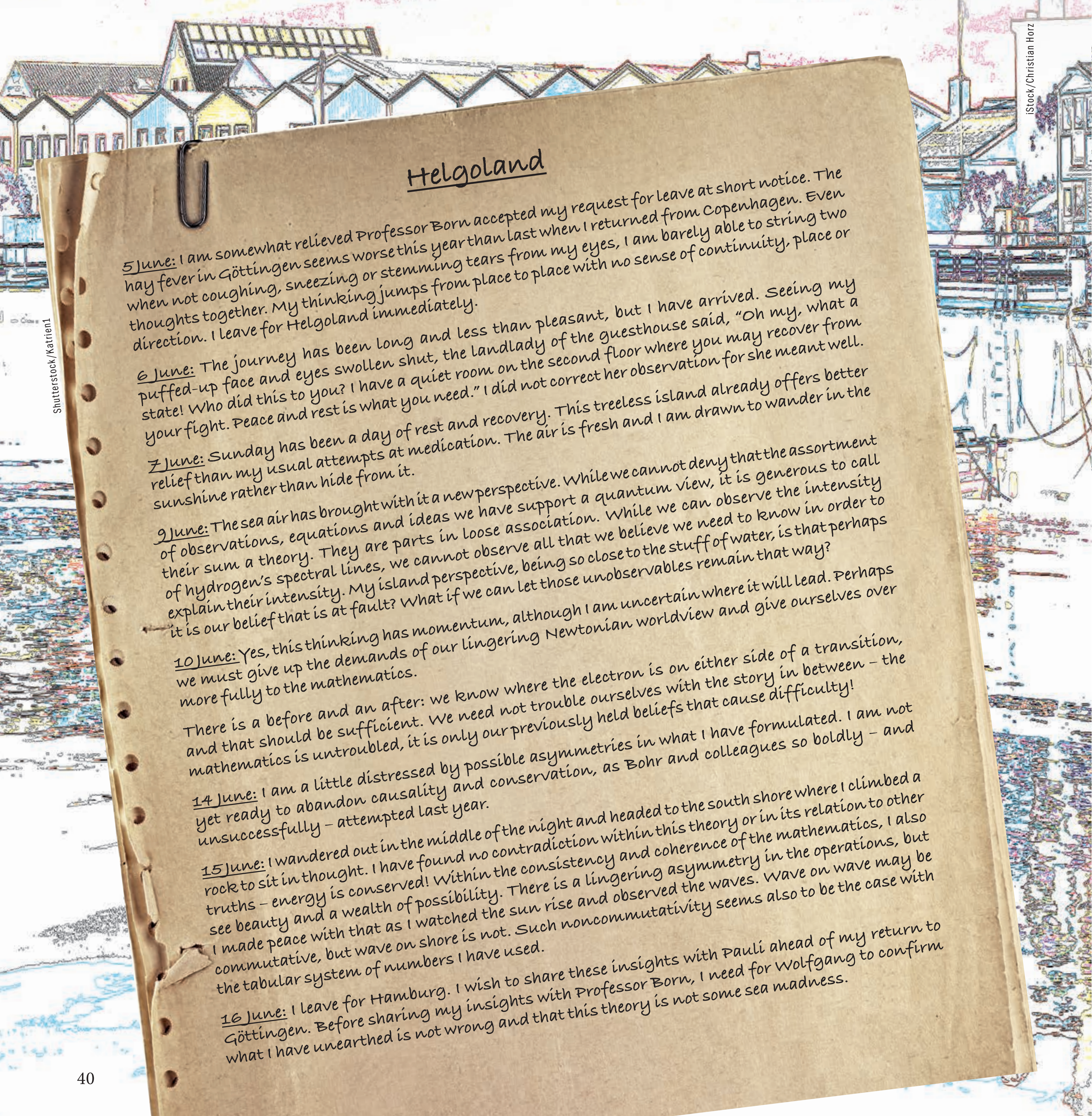
● Tracy Northup and Michelle Simmons appear with fellow quantum physicist Peter Zoller on the 19 June 2025 episode of the *Physics World Weekly* podcast

Big advances usually come from international collaboration or friendly competition

Gerd Leuchs from the Max Planck Institute for the Science of Light

Heisenberg |not⟩ in Helgoland

In a dark corner of a guest house in Helgoland, a diary by Werner Heisenberg has been discovered, describing how he developed quantum mechanics on the island 100 years ago. But in an even stranger twist of events, a second diary – perhaps from an alternate reality where he never made it to the island – has seemingly been unearthed in his lab at the University of Göttingen. **Kevlin Henney** presents edited extracts from the imagined notebooks.



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Helgoland

5 June: I am somewhat relieved Professor Born accepted my request for leave at short notice. The hay fever in Göttingen seems worse this year than last when I returned from Copenhagen. Even when not coughing, sneezing or stemming tears from my eyes, I am barely able to string two thoughts together. My thinking jumps from place to place with no sense of continuity, place or direction. I leave for Helgoland immediately.

6 June: The journey has been long and less than pleasant, but I have arrived. Seeing my puffed-up face and eyes swollen shut, the landlady of the guesthouse said, "Oh my, what a state! Who did this to you? I have a quiet room on the second floor where you may recover from your fight. Peace and rest is what you need." I did not correct her observation for she meant well.

7 June: Sunday has been a day of rest and recovery. This treeless island already offers better relief than my usual attempts at medication. The air is fresh and I am drawn to wander in the sunshine rather than hide from it.

9 June: The sea air has brought with it a new perspective. While we cannot deny that the assortment of observations, equations and ideas we have support a quantum view, it is generous to call their sum a theory. They are parts in loose association. While we can observe the intensity of hydrogen's spectral lines, we cannot observe all that we believe we need to know in order to explain their intensity. My island perspective, being so close to the stuff of water, is that perhaps it is our belief that is at fault? What if we can let those unobservables remain that way?

10 June: Yes, this thinking has momentum, although I am uncertain where it will lead. Perhaps we must give up the demands of our lingering Newtonian worldview and give ourselves over more fully to the mathematics.

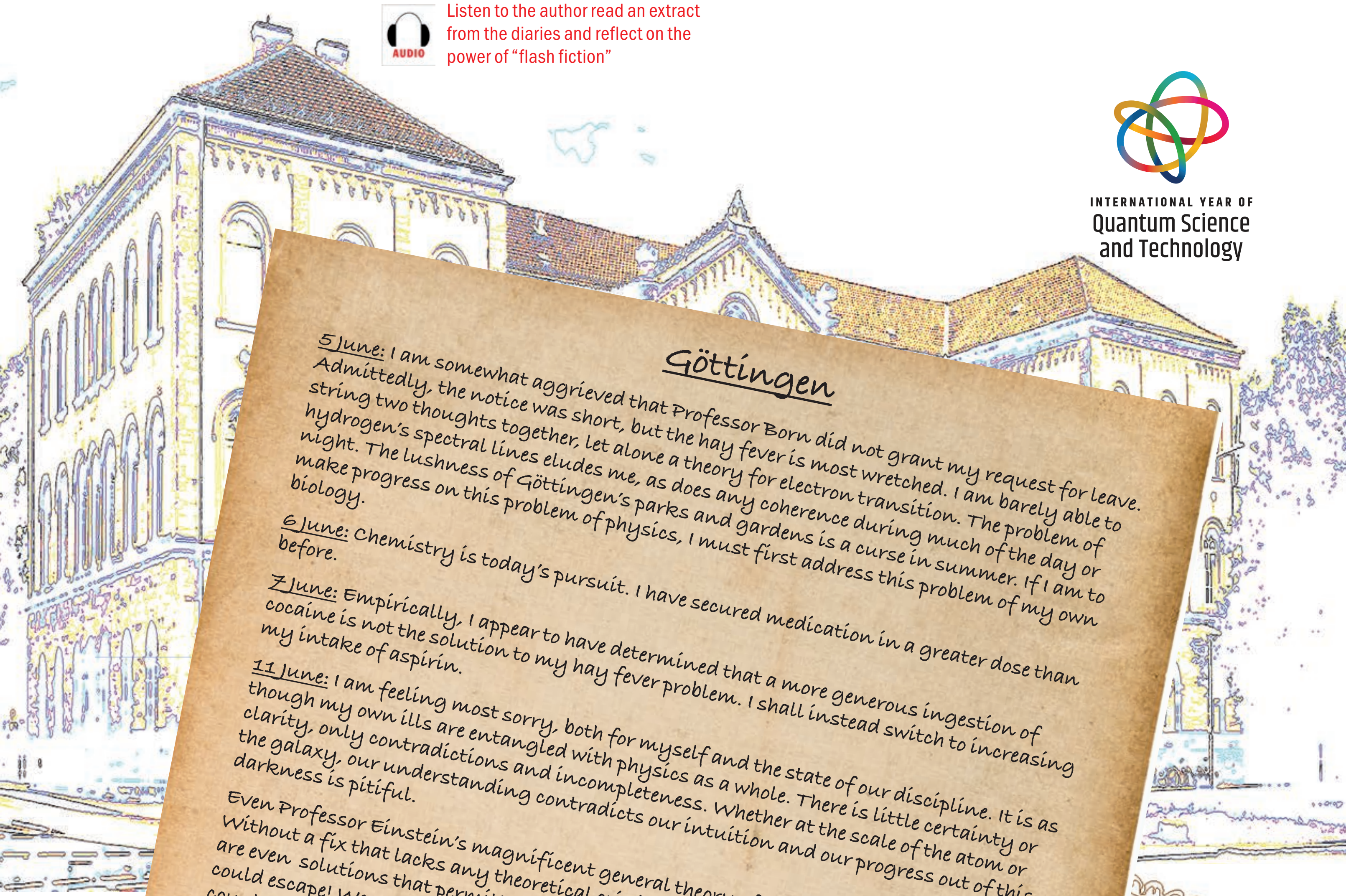
There is a before and an after: we know where the electron is on either side of a transition, and that should be sufficient. We need not trouble ourselves with the story in between – the mathematics is untroubled, it is only our previously held beliefs that cause difficulty!

14 June: I am a little distressed by possible asymmetries in what I have formulated. I am not yet ready to abandon causality and conservation, as Bohr and colleagues so boldly – and unsuccessfully – attempted last year.

15 June: I wandered out in the middle of the night and headed to the south shore where I climbed a rock to sit in thought. I have found no contradiction within this theory or in its relation to other truths – energy is conserved! Within the consistency and coherence of the mathematics, I also see beauty and a wealth of possibility. There is a lingering asymmetry in the operations, but I made peace with that as I watched the sun rise and observed the waves. Wave on wave may be commutative, but wave on shore is not. Such noncommutativity seems also to be the case with the tabular system of numbers I have used.

16 June: I leave for Hamburg. I wish to share these insights with Pauli ahead of my return to Göttingen. Before sharing my insights with Professor Born, I need for Wolfgang to confirm what I have unearthed is not wrong and that this theory is not some sea madness.

AUDIO Listen to the author read an extract from the diaries and reflect on the power of "flash fiction"



Göttingen

5 June: I am somewhat aggrieved that Professor Born did not grant my request for leave. Admittedly, the notice was short, but the hay fever is most wretched. I am barely able to string two thoughts together, let alone a theory for electron transition. The problem of hydrogen's spectral lines eludes me, as does any coherence during much of the day or night. The lushness of Göttingen's parks and gardens is a curse in summer. If I am to make progress on this problem of physics, I must first address this problem of my own biology.

6 June: Chemistry is today's pursuit. I have secured medication in a greater dose than before.

7 June: Empirically, I appear to have determined that a more generous ingestion of cocaine is not the solution to my hay fever problem. I shall instead switch to increasing my intake of aspirin.

11 June: I am feeling most sorry, both for myself and the state of our discipline. It is as though my own ills are entangled with physics as a whole. There is little certainty or clarity, only contradictions and incompleteness. Whether at the scale of the atom or the galaxy, our understanding contradicts our intuition and our progress out of this darkness is pitiful.

Even Professor Einstein's magnificent general theory of relativity has its difficulties. Without a fix that lacks any theoretical origin, it predicts an expanding universe! There are even solutions that permitted dark stars whose gravity would be so large that nothing could escape! We are mired in questions and nonsense, all the while I am little more than coughs, sneezes and reddened eyes. What I might generously call my mind is barely deserving of the name.

I am consoled, at least, that in mathematics the story is not the same. Russell and Whitehead have shown that mathematics is complete and consistent – although I know of no one who has managed to read the whole proof. This result offers a firm bedrock I am sure mathematicians will continue to celebrate a hundred years from now.

15 June: I was en route to the department this morning when I entirely lost my bearings after taking a wrong turn from my usual route. Imagine knowing where I was going but not knowing where I was!

Just last week I had the opposite experience. My landlady accosted me just in front of the Friedhofskapelle Stadtfriedhof. I was as surprised to see her as we was to see me. "Good day, Professor Heisenberg." I long ago stopped reminding her that I was no professor, merely a Privatdozent. She means well. "Where are you heading?" And do you know, I had no idea! How I wish, though, that Born had let me travel to Helgoland.

16 June: As I walk – and sneeze – into the university this morning, I am caused to wonder from where answers to our quantum troubles might emerge. Bohr has great insight, so will it be from Copenhagen that an interpretation will appear? Or perhaps it will from Cambridge — Paul Dirac's thinking is particularly fresh.

For now, I wish an end to summer and the fog it has brought to my thinking, yet I also wonder whether we are asking more of nature than she is prepared to share with us. Perhaps it is our dearly held beliefs that hold us back. Perhaps nature and mathematics do not share those beliefs. Perhaps. There is an uncertainty within me that I find hard to articulate.

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Kevlin Henney is a software development consultant and writer based in Bristol, UK. Somewhere in his past is a degree in physics.

Reviews

A quest for space rocks

Iain Dale-Trotter reviews *The Meteorite Hunters: On the Trail of Extraterrestrial Treasures and the Secrets Inside Them* by Joshua Howgego

The Meteorite Hunters
Joshua Howgego
2025 Oneworld Publications 272pp
£18.99 hb /
£9.99 ebook

Shutterstock/Eshma

Rock of ages *Meteorite Hunters* by Joshua Howgego tries to answer two questions: "how do you find them, and what do they tell us?".

Every mystical quest features a journey riddled with challenges, a cast of colourful characters, and a treasure trove that unlocks more intrigue. *The Meteorite Hunters: On the Trail of Extraterrestrial Treasures and the Secrets Inside Them* is no exception to this canon.

Written by science journalist Joshua Howgego, the book takes the reader on the pursuit of space rocks and how they have unravelled our understanding of the solar system. And, as is so often the way in science as it is with quests, the search and the people you meet along the way are just as interesting as the discoveries themselves.

Towards the end of *Meteorite Hunters*, Howgego confides that his aim for the book distils down to two questions: "how do you find them, and what do they tell us?". Indeed, the tale follows this two-act structure pretty neatly. The first half sees the eponymous hunters and their adventures take centre stage, with enough science dotted throughout to set the scene for the second half, which takes us right up to date with the very latest missions to asteroids Itokawa and Ryugu, and the return of the Bennu sample from the OSIRIS-Rex mission. It is a tactic that is kind to the general reader, and there are plenty of interesting anecdotes and characters to keep things from getting too dry, along with some truly astonishing astrophysics.

The journey begins with a look at how people came to understand that rocks can fall from the sky. The truth of course is that civilizations throughout human history have (separately but repeatedly) come to this realization. Howgego highlights how existing knowledge and compelling physical evidence of meteorites from central South American cultures was dismissed as primitive superstitious nonsense by European invaders in the 16th century. It is the perennial story of knowledge being lost during the waves of European colonialism.

Western understanding of meteorites only really gets going in the very late 18th century, and Howgego introduces two key characters who helped cement the topic as a legitimate line of enquiry. Ernst Chladni was a German polymath who wrote the first book on meteorites in 1794 but whose ideas were initially ridiculed. Meanwhile, playwright and journalist Edward Topham had a large meteorite fall on his land in 1795 (witnessed by labourer John Shipley) and went on to the champion the idea of rocks falling from the sky. However, it would take until the mid-1960s, and the anticipation of lunar samples being returned by the Apollo missions, for this area of study to crystallize into the modern field of meteoritics.

Drama and dust

The origin story of many modern meteorite hunters – those who go out searching for these space rocks – often begin in a similar vein to that of Topham, with an inspiring find close to home leading to elaborate expeditions to track down historic falls. The meteorite scientists Howgego interviews are diplomatic when asked about the hunters – after all, they have the resources to investigate reports of fresh falls much more quickly than the hunters can decipher historical reports and local legends. But there is also a real tension between the two camps – there are serious issues with permanent loss of data from the scientific record through mishandling or denial of access to specimens in private collections.

Howgego goes on to discuss efforts to track meteorite falls in real-time, which may be more scientific and systematic but are no less dramatic. Modern programmes involving networks of automated digital cameras can trace their origins back to a resourceful young scientist, Zdeněk Ceplecha, who narrowly escaped the worst of the Stalinist purges in soviet Czechoslovakia. In 1959 he managed to reconstruct the trajectory of an incoming meteorite to within a very respectable margin of modern computations by using long-exposure photographic plates. In a beautiful full-circle moment, the tracking network initiated by Ceplecha followed a 2002 meteorite fall that turned out to have the exact same trajectory as that 1959 space rock – confirming that the two came from the same parent body.

One of the book's more modern – and most interesting – characters is Swedish jazz guitarist Jon Larsen. His obsession of sifting through tonnes of urban dust for elusive micrometeorites has yielded invaluable (and beautifully photographed) specimens – something dismissed as an urban myth before someone with his patience and ingenuity came along. These pristine remnants of the protoplanetary disc, literal "star dust", offer unique insights into the earliest days of our solar system.

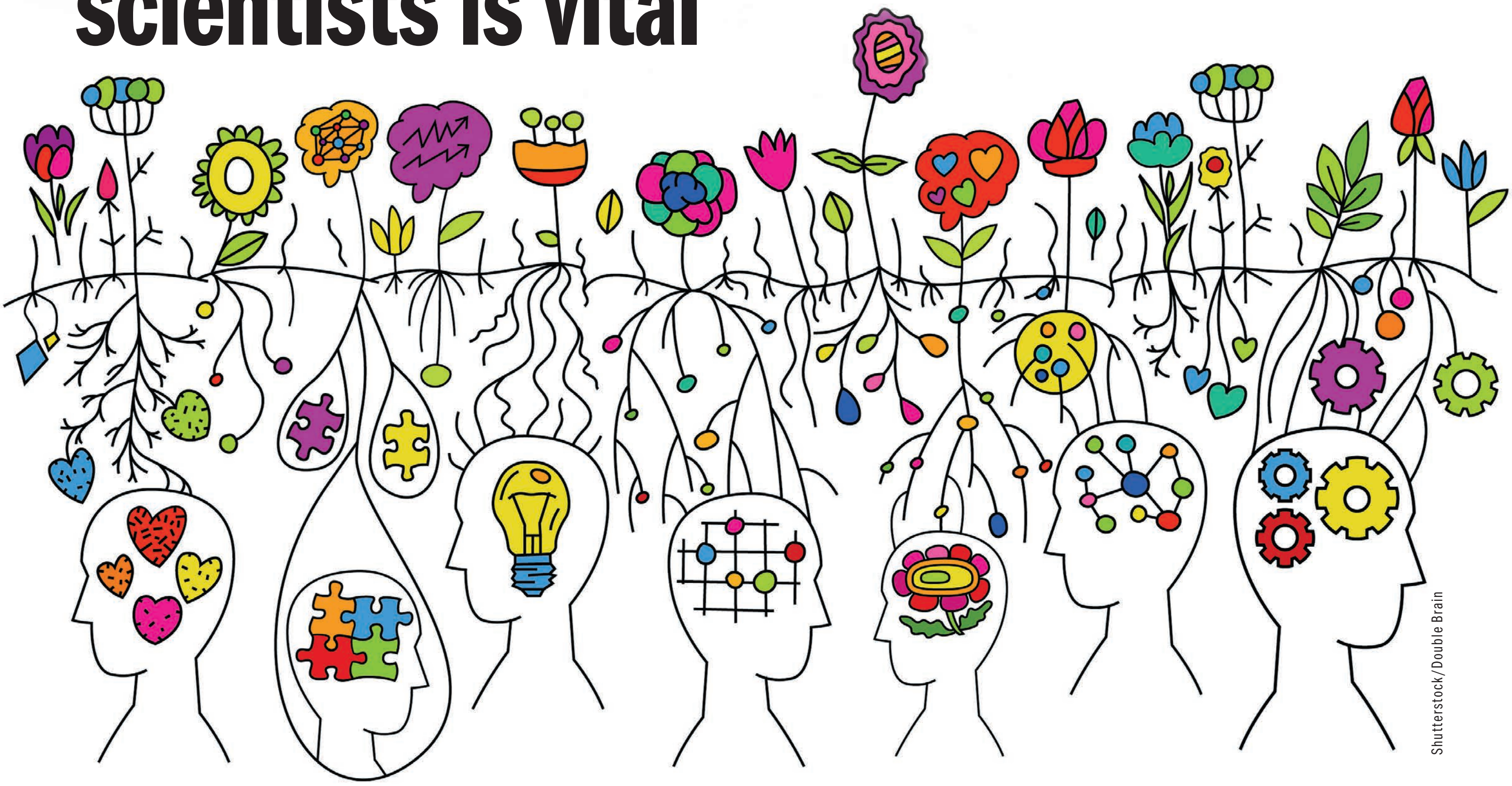
Alongside his array of characters, Howgego creates a beautiful and accessible rendering of the complex astrophysics underlying the evolution and structure of our solar system as revealed from the study of meteorites. The descriptions of how competing theories have developed and merged also gives a realistic insight into the scientific method in action; consensus building, refinement through accretion of evidence, and an admission that the picture is not yet settled.

The hunt for, and study of, meteorites touches upon an unexpected variety of topics in modern science. But Howgego manages to weave them seamlessly together into a rich fabric, allowing his colourful cast of characters to tell their fascinating stories.

Iain Dale-Trotter is a publisher at IOP Publishing

Careers

Why accommodating neurodivergent scientists is vital


Shutterstock/Double Brain

Vive la difference Neurodivergent people remain over-represented in the sciences, so we need to ensure that the needs of these individuals are recognized.

With more neurodivergent people in science than in the general population, it is important to make accommodations in the workplace to help them – and science – thrive. **Meagan Hough** explains

It wasn't until the second year of my undergraduate degree that someone finally put a name to why I'd been struggling with day-to-day things throughout my life – it was Attention Deficit Hyperactivity Disorder (ADHD). It explained so much; my extreme anxiety around work and general life, my poor time management, the problems I had regulating my emotions, and my inability to manage everyday tasks. Being able to put a label on it, and therefore start taking steps to mitigate the worst of its symptoms, was a real turning point in my life.

As such, when I started my PhD at the Quantum Engineering Centre for Doctoral Training at the University of Bristol, I got on the (notoriously long) waiting list for an assessment and formal diagnosis. I knew that because of my ADHD, my PhD journey would look a little different compared to the average student, and that I'd have to work harder in some aspects to mitigate the consequences of my symptoms.

People with ADHD exhibit a persistent pattern of inattention, hyperactivity and/or impulsivity that interferes with day-to-day life. It is a type of neurodivergence – when someone's brain functions in a different way to what is considered "typical". Other neurodivergent conditions include autism, dyslexia and dyspraxia, but the term also encompasses mental-health issues, learning difficulties and acquired neurodivergence (for example, after a brain injury).

According to Genius Within, at least 5% of the population have ADHD, 1–2% are autistic, 14% have mental health needs, and many more have other neurodevelopmental conditions. It is also common for those with one neurodivergence to have one or more other co-occurring neurodivergent conditions.

However, if you look specifically at the scientific community, these percentages are much higher. For example, in a 2024 survey "Designing Neuroinclusive Laboratory Environments" run by HOK, it was found that out of 241 individuals, 18.6% had ADHD and 25.5% were autistic. If neurodivergent people remain highly over-represented in the sciences, then it is imperative that we understand and accommodate for the needs of these individuals in work and research environments.

Spiky skills

One common trait among neurodivergent people is that they have greater strengths and bigger weaknesses across skillsets when compared to neurotypical people. This is known as having a "spiky profile" – it appears as peaks and troughs above and below a "normal" baseline (figure 1). The skillsets commonly included in a profile are analytical, mathematical, motor, situational and organizational skills; relationship management; sensory sensitivities; processing speed; verbal and visual comprehension; and working memory. So while neurodivergent people may be extremely capable at certain skills, they may really struggle with others.

Personally, I have problems with working memory, organization and processing speed, but each of these issues present differently in certain situations. For example, it's not uncommon for me to reach the end of a meeting with my supervisor and feel that I understand all that was discussed and have no questions – but then I may come up with some important queries sometime later that didn't occur to me at the time. This demonstrates a difference in processing speed, which thankfully can be accommodated for by maintaining an open line of communication between myself and my supervisors.

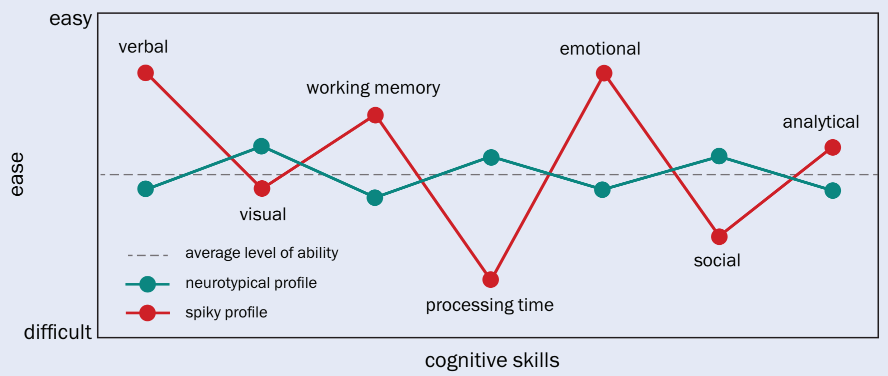
Meanwhile, for Daisy Shearer – who leads the outreach and education programme at the National Quantum Computing Centre (NQCC) in the UK – their autism affects their day-to-day life in other ways. "I experience sensory inputs and emotion regulation differently to neurotypical people, which uses a lot of energy to manage," Shearer explains. "My executive functioning skills [those that help you manage everyday tasks] tend to be poor, as well as my social skills, which I work hard to overcome."

Despite our different neurotypes, Shearer and I also have some symptoms in common. For example, we both struggle with switching between tasks, and time blindness, which means we have difficulty in perceiving and managing time. But while many traits can overlap between neurotypes in this way, even two individuals with the same diagnosis won't have the exact same symptoms or profile.

Furthermore, neurodivergent people can be "dynamically disabled", meaning that our abilities and sensitivities fluctuate day-to-day or even hour-to-hour, regardless of the accommodations and strategies in place. Shearer, for instance, used to be primarily lab-based and would find that environment soothing, but occasionally the lab would become overwhelming when their sensory profile shifted.

Meanwhile for me, one day I may be able to focus and complete multiple large tasks in a day, attend various meetings and answer e-mails in a timely fashion. But on another day – sometimes even the next day – I may only be able to answer half of my e-mails and will flit between tasks, unable to focus deeply on any one thing. This can make monitoring progress and completing milestones difficult, and requires a high degree of flexibility and understanding from those around me.

1 Peaks and troughs



IOP Publishing adapted from WikiCommons

A neurodivergent person will have what is known as a "spiky profile" because they can find some cognitive skills easy (peaks) but struggle with others (troughs). Every person has an individual profile – even if two people have the same neurodivergent condition, they will have different strengths and weaknesses.

This example compares a neurodivergent profile (red) with a neurotypical one (green) and an average (dashed), for a small set of cognitive skills;

- Verbal comprehension – how we communicate and understand speech and its meaning
- Visual perception – how we interpret our visual environment and surroundings
- Working memory – our short-term memory that assists us with decision making and problem solving
- Processing speed – how quickly we take in information, interpret it and respond
- Emotional intelligence – how we perceive, use, understand and regulate emotions
- Social – how we develop and maintain social relationships
- Analytical skills – how we solve problems by analysing information

Accommodating the troughs

So what can the physics community do to help people who are neurodivergent like myself? While we absolutely don't want to be treated leniently – we want our work as physicists to be as high a standard as anyone else's – working with individuals to accommodate them correctly is key to helping them succeed.

That's why in 2019 Shearer founded Neuroinclusion in STEM, after having no openly autistic role models in their physics career to date. The project, which is community-driven, aims to increase the visibility of neurodivergent people in science, technology, engineering and mathematics (STEM), and provide information on best practices to make the fields more inclusive.

Shearer also takes part in many equality, diversity and inclusion (EDI) committees, and gives talks at conferences to highlight how the STEM community can improve the working environment for its neurodivergent members.

Indeed, Shearer's own set up at the NQCC is a great example of workplace accommodations helping an employee thrive. Firstly, Shearer had a high level of autonomy in defining their role when they joined the NQCC. "It was incredibly helpful when it comes to managing how my brain works," they explain. Shearer also has the flexibility to work from home if they're feeling particularly sensory sensitive, and were consulted in the design of the NQCC's "wellbeing room" – a fully sensorily controllable space that they can use during their work day when feeling overwhelmed by sensory stimuli. Other, small adjustments that have helped include having an allocated desk away from general people-traffic, and colleagues being educated to ensure a more inclusive environment.

For physicists working in a lab – dependent on health and safety measures – it can help to wear headphones or earplugs and have dimmable lights to minimize sensory inputs. Some neurodivergent people also benefit from visual aids and written instructions for experiments and equipment. Personally, as a theorist in an office, I find noise cancelling headphones, and asking colleagues to consider e-mailing rather than interrupting me at my desk, can help reduce distractions.

Reaching the peak

While education and accommodations are key, it's also important to remember the strengths that come with having a neurodivergent spiky profile – the peaks, so to speak. "I have strong analytical, communication and creative skills," explains Shearer, "which make me very good at what I do professionally."

For me, I excel in visual, written and communication skills, and try to use these to my advantage. I'm good at spotting errors in mine and others' work, I'm a concise but detailed writer, and when not working on my PhD, I'm trying to communicate complex ideas in quantum physics to different audiences with varying degrees of understanding of physics and science.

Reminding myself of these strengths is key, as it can be too easy to focus on the negatives that come with being neurodivergent. By recognizing all of our unique capabilities and adequately accommodating those additional neurodivergent struggles, we can build systems that empower instead of limit us.

I believe Shearer put this best: "By embracing our individual strengths, we can enable everyone to thrive in their professional and personal lives, but that can only come with understanding how to accommodate each other."

Meagan Hough is a PhD student at the University of Bristol, UK

Ask me anything: Giulia Rubino

Giulia Rubino is a lecturer and research fellow at the University of Bristol, UK, who explores the interface between quantum foundations and quantum technologies. As a member of the Quantum Engineering and Technology Lab and team leader of the Quantum Technologies ⇆ Foundations group, she uses integrated photonics to explore new architectures for quantum information processing and studies quantum information theory and quantum thermodynamics.

Wavelength Studio/Christy Nunns

What skills do you use every day in your job?

Beyond the technical skills tied to specific aspects of my research, my work involves continuously engaging a balance of creativity, critical thinking and curiosity. Creativity alone isn't enough – in physics, ideas must ultimately stand up to scrutiny. Something is either right or it isn't, so the goal is to let your imagination run free, while keeping it anchored to scientific rigour.

This balance becomes especially important when it comes to defining your own research direction. Early in your career, you're usually handed a problem to work on. But, over time, you have to learn to ask your own questions, and formulating good ones is much harder than it sounds.

In the beginning, most of the ideas you come up with turn out either to be flawed or have already been explored. The alternative is to stay in safe territory and do incremental work, which certainly has its place, but it's difficult to build a research career on that alone.

What helps is staying curious. Finding a meaningful research question often means diving into unfamiliar literature, following sparks of interest, and carving out time to read and think critically. It also means being open to inspiration from other people's work, not just from research that overlaps with your own, but potentially from entirely different areas.

I've seen how easy it can be to fall into the trap of only valuing ideas that align with your own. To me, one of the most precious traits in research is the ability to keep your curiosity alive: to remain open to surprise, ready to recognize when you're wrong, be willing to learn, and to be excited by someone else's discovery, even when it has nothing to do with your own work.

What do you like best and least about your job?

What I like best is the freedom. I get to choose what my next research project will be about, and sometimes that process starts in the simplest of ways. I see an exciting talk at a conference, become fascinated by a new idea, and find myself reading everything I can about it. I'll come back, pitch it to a student, and if they're excited too, we explore it together.

When I start something new, I often feel like an imposter, venturing into foreign territory and trying to operate as if I know my way around, but as time goes on, things start to fall into place. Eventually, you reach the point where you create something new that others in the field may find interesting or inspiring in turn. That moment – when a once-distant topic becomes something you have actually contributed to – is deeply rewarding.

What I like least is answering e-mails. As a student, I couldn't understand why some professors took ages to reply. Now I do. Some days, my inbox just fills up endlessly, and responding thoughtfully to every message would take the whole day. It's a balancing act, deciding when to say yes and when to say no, and learning to say no in a considerate and fair way takes time and emotional energy. You want to be generous with your time, especially when someone genuinely needs help, but finding this balance can be exhausting. It's an important part of the job, but I wish it took up a bit less space.

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

That everyone feels like an imposter sometimes. When I started out as a student, I looked around and assumed everyone else was an expert, while I was just trying to find my way, painfully aware of how much I didn't know. Over time, you do gain confidence in certain areas, but research constantly pushes you in new directions. That means learning new things, starting from scratch, and feeling like an imposter all over again.

The first time I heard the term "imposter syndrome", it felt like a revelation. Just knowing that this feeling had a name, and that others experienced it too, was validating. Does this mean I feel less like an imposter now? Not really. But I've come to understand that it's part of the process. It means I'm still learning, still being challenged, still exploring new directions. And if that feeling never goes away entirely, maybe that's a good sign.

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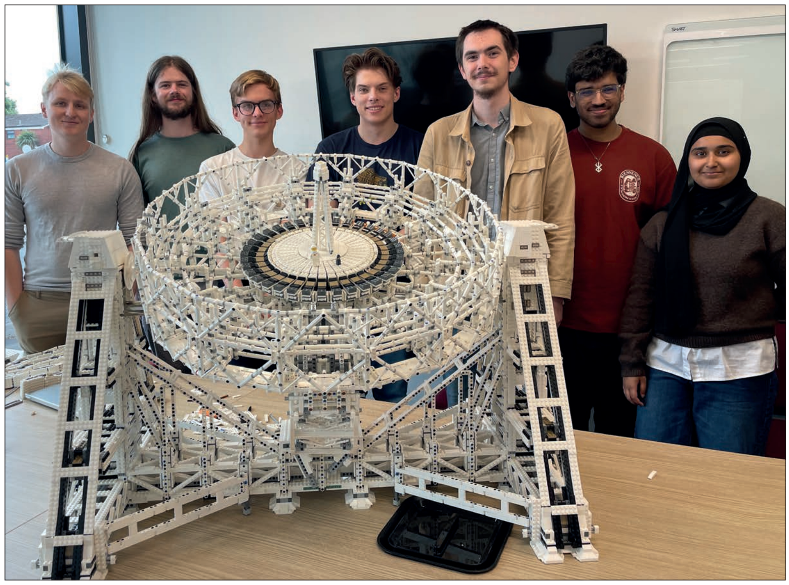
LEGO telescope, tiny Sorbonne, biodress

Michael Banks picks his favourite stories and quotes from the weird and wonderful world of physics

Students at the University of Manchester in the UK have created a 30 500-piece LEGO model of the iconic Lovell Telescope to mark the 80th anniversary of the Jodrell Bank Observatory. Built in 1957, the 76.2 m diameter telescope was the largest steerable dish radio telescope in the world at the time. The LEGO model has been designed by Manchester's undergraduate physics society and is based on the telescope's original engineering blueprints. Student James Ruxton spent six months perfecting the design, which even involved producing custom-designed LEGO bricks with a 3D printer. Ruxton and fellow students began construction in April and the end result is a model weighing 30 kg with 30 500 pieces and a whopping 4000-page instruction manual. "It's definitely the biggest and most challenging build I've ever done, but also the most fun," says Ruxton. "I've been a big fan of LEGO since I was younger, and I've always loved creating my own models, so recreating something as iconic as the Lovell is like taking that to the next level!" The model will now go on display in a "specially modified cabinet" at the university's Schuster building, taking pride of place alongside a decade-old LEGO model of CERN's ATLAS detector.



The University of Manchester

Model build The LEGO Lovell Telescope features 30 500 pieces and took two months to build.

[It] is just so sad and odd

In 2012 Nobel prize-winning physicist **Andre Geim** took British citizenship to accept a knighthood for his services to science, but as a result can no longer be a citizen of the Netherlands, adding he has now been "kicked out of the country as a useless thing". (Source: *New York Times*)

The idea was to bring historical inspiration and modern computation together

A study by engineer **Rajat Mittal** from Johns Hopkins University and colleagues suggests that a helicopter design created by Leonardo da Vinci more than 500 years ago could hold the key to quieter and stealthier flight. (Source: *Independent*)

Micro Sorbonne Chapel

A physicist from Vilnius University in Lithuania has created a 3D-printed replica of the Sorbonne Chapel so small it fits on a human hair. Located in Paris's Latin Quarter, the Chapel of Sainte-Ursule de la Sorbonne is a Roman Catholic chapel and was constructed in the 17th century. To create the structure, Gordon Zyla, who carries out research in light technologies at Vilnius's Laser Research Centre, used a laser nanofabrication technique known as multiphoton 3D lithography. "Unlike conventional 3D printing, this approach can solidify a light-sensitive material at virtually any point in space, enabling the fabrication of truly three-dimensional structures," notes Zyla. Roughly 120 μm long, the finished product is 275 000 times smaller than the original yet still preserves its architectural details. In late June, the model was presented as a symbolic gift to Sorbonne University president Nathalie Drach-Temam during a visit to Vilnius.

Physics meets fashion

Fashion designer Iris van Herpen has unveiled a bioluminescent dress that features 125 million living algae. The garment involved Herpen collaborating with designer Chris Bellamy as well as biophysicists Nico Schramma and Mazi Jalaal from the University of Amsterdam. Bioluminescence is the production of light by a living organism, caused by a chemical reaction such as the molecule luciferin reacting with oxygen to release light. The bioluminescent dress is composed of a gel material that incorporates millions of single celled bioluminescent algae of the species *Pyrocystis lunula*, named after their Moon-like shape. In the wild, the bioluminescent algae emit light as a defence mechanism. The flash serves as a warning signal that attracts secondary predators, which hunt the main predator of the cells. In 2019 Jalaal, Schramma and colleagues began to study how the cells respond to mechanical stresses. By combining microscopy and mechanical tests, they were able to measure the light-emission of the cells and how it depended on deformation, which led to a mathematical model that described the light-production mechanism (*Phys. Rev. Lett.* **125** 028102). The researchers then worked with Chenghai Li and Shengqiang Cai at the University of California San Diego and bioluminescence researcher Michael Latz from the Scripps Institution of Oceanography in San Diego. They incorporated the cells in a gel matrix to create a flexible yet resistant substance that emits light upon deformation and movement while at the same time keeping the cells alive. Bellamy and van Herpen developed and refined the bioluminescent material and incorporated it into a spectacular "living" garment, which was part of van Herpen's new fashion collection – *Sympoiesis* – that was unveiled at Paris Haute Couture Week in July.

Michael Banks is news editor of *Physics World*

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