physicsworld
May 2025

Lighting the future
China gets set for new synchrotron source

Ticked off Jim Gates updates his theorist's bucket list

Weird stuff The quantum Zeno effect explained

Joyful work Lisa Manning on applying physics to biology

Contents: May 2025

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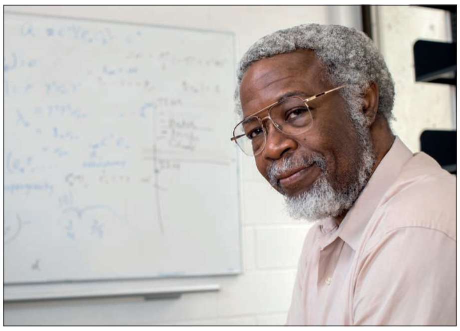
Physics World editors discuss their highlights of the May issue



Wish list redux
Jim Gates on the breakthroughs he wants to see 35

Mathematical models
Lisa Manning applies physics theory to biology 44

Spoiled genius
A new biography of Roger Penrose is revealing 40

On the cover
China gets set for new synchrotron source 26 (Shutterstock/NeoLeo)

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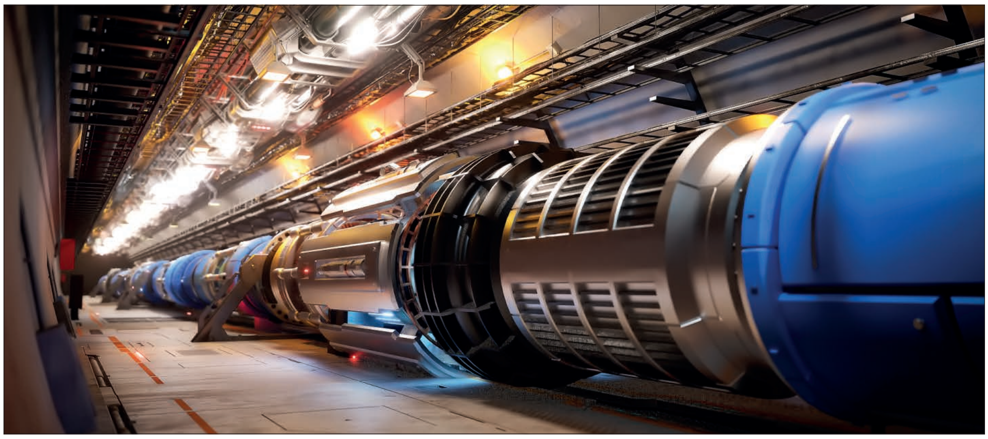
News & Analysis

CERN releases future collider plan

A three-volume feasibility study for the Future Circular Collider calls for a 90 km machine to look at the Higgs boson in unprecedented detail, as **Michael Banks** reports

The CERN particle-physics lab near Geneva has released plans for the 15bn SwFr (£13bn) Future Circular Collider (FCC) – a huge 91 km circumference machine. The three-volume feasibility study, released on 31 March, calls for the giant accelerator to collide electrons with positrons to study the Higgs boson in unprecedented detail. If built, the FCC would replace the 27 km Large Hadron Collider (LHC), which will come to an end in the early 2040s.

Work on the FCC feasibility study began in 2020 and the report examines the collider's physics objectives, geology, civil engineering, technical infrastructure and territorial and environmental impacts. It also looks at the R&D needed for the accelerators and detectors as well as the socioeconomic benefits and cost. The study, involving 150 institutes in over 30 countries, took into account some 100 different scenarios for the collider before focusing on a ring circumference of 90.7 km that would be built underground at a depth of about 200 m, on average.



PIXELRISE

To the energy frontier
If built, the FCC-hh would begin operation in 2073 and run to the end of the century.

The FCC would contain eight surface sites to access the tunnel– seven in France and one in Switzerland – along with four main detectors. "The design is such that there is minimal impact on the surface, but with the best possible physics output," says FCC study leader Michael Benedikt. The funding model for the FCC is still a work in progress, but it is estimated that at least two-thirds of the cost of building the FCC will come from CERN's 24 member states.

Four committees will now review the feasibility study, beginning with CERN's scientific committee in July. It will then go to a cost-review panel before being reviewed by the CERN council's scientific and finance committees. In November the CERN council will then examine the proposal with a decision to go ahead taken in 2028. If given the green light, construction on the FCC electron-positron machine, dubbed FCC-ee, would begin in 2030 and it would start operations in 2047, a few years after the High Luminosity LHC (HL-LHC) closes down, and run for about 15 years. Its main aim would be to study the Higgs boson with a much better precision that the LHC.

> The design is such that there is minimal impact on the surface, but with the best possible physics output

The FCC feasibility study then calls for a hadron machine, dubbed FCC-hh, to replace the FCC-ee in the same 91 km tunnel. It would be a "discovery machine", smashing together protons at high energy with the aim of creating new particles. If built, the FCC-hh would begin operation in 2073 and run to the end of the century. The original design energy for the FCC-hh was to reach 100 TeV but that has now been reduced to 85 TeV. That is mostly due to the uncertainty in magnet technology. The HL-LHC will use 12 T superconducting quadrupole magnets made from niobium-tin (Nb_3Sn) to squeeze the beams to boost the luminosity.

CERN engineers think it is possible to increase that to 14 T and – if implemented for the FCC – would result in a collision centre-of-mass energy of about 85 TeV. "It's a prudent approach at this stage," says Fabiola Gianotti, current CERN director-general, adding that the FCC would be "the most extraordinary instrument ever built". The original design called for high-temperature superconducting magnets, such as so-called ReBCO tapes, and CERN is looking into such technology. If it came to fruition in the necessary timescales and was implemented in the FCC-hh then it could push the energy to 120 TeV.

One potential spanner in the works is China's plan for a very similar machine called the Circular Election-Positron Collider (CEPC). A decision on the CEPC could come this year with construction beginning in 2027. Yet officials at CERN are not concerned. They point to the fact that many different colliders have been built by CERN, which has the expertise as well as infrastructure to build such a huge collider. "Even if China goes ahead, I hope the decision is to compete," says CERN council president Costas Fountas. "Just like Europe did with the LHC when the US started to build the [cancelled] Superconducting Super Collider."

If the CERN council decides, however, not to go ahead with the FCC, then Gianotti says that other designs to replace the LHC are still on the table such as a linear machine or a demonstrator muon collider.

Michael Banks is news editor of *Physics World*

US

Trump is making ‘wholesale assault’ on US science

The US administration is carrying out “a wholesale assault on US science” that could hold back research in the country for several decades. That is the warning from more than 1900 members of the US National Academies of Sciences, Engineering, and Medicine, who have signed an open letter condemning the policies introduced by Donald Trump since he took up office on 20 January.

US universities are in the firing line of the Trump administration, which is seeking to revoke the visas of foreign students, threatening to withdraw grants and demanding control over academic syllabuses. “The voice of science must not be silenced,” the letter writers say. “We all benefit from science, and we all stand to lose if the nation’s research enterprise is destroyed.” Particularly hard hit are the country’s eight Ivy League universities, which have been accused of downplaying antisemitism exhibited in campus demonstrations in support of Gaza. Columbia University in New York, for example, has been trying to regain $400m in federal funds that the Trump administration threatened to cancel.

Columbia initially reached an agreement with the government on issues such as banning facemasks on its campus and taking control of its department responsible for courses on the Middle East. But on 8 April, according to reports, the National Institutes of Health was ordered by the Department of Health and Human Services to block all of its grants to Columbia.

Shutterstock/meunierd

Clamp down US universities have been hit by the US administration revoking the visas of foreign students, threatening to withdraw grants and demanding control over academic syllabuses.

Harvard University, meanwhile, has announced plans to privately borrow $750m after the Trump administration announced that it would review $9bn in the university’s government funding. Brown University in Rhode Island faces a loss of $510m, while the government has suspended several dozen research grants for Princeton University. The administration also continues to oppose the use of diversity, equity and inclusion (DEI) programmes in universities. The University of Pennsylvania, from which Donald Trump graduated, faces the suspension of $175m in grants for offenses against the government’s DEI policy.

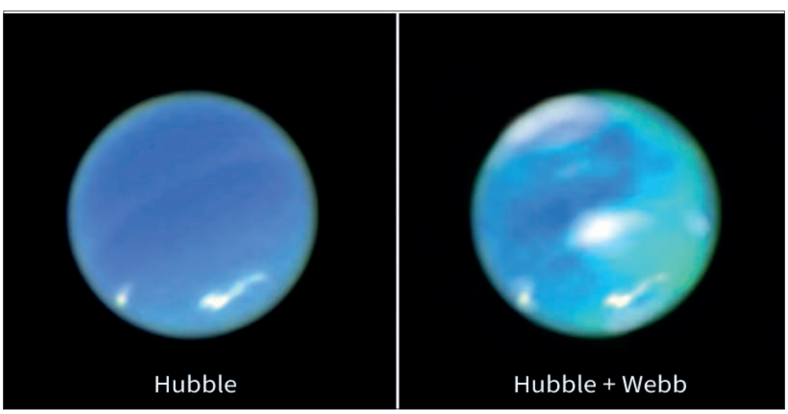
Researchers in medical and social sciences are bearing the brunt of government cuts, with physics departments seeing relatively little impact on staffing and recruitment so far. “Of course we are concerned,” says Peter Littlewood, chair of the University of Chicago’s physics department. “Nonetheless, we have made a deliberate decision not to halt faculty recruiting and stand by all our PhD offers.” David Hsieh, executive officer for physics at California Institute of Technology, told *Physics World* that his department has also not taken any action so far. “I am sure that each institution is preparing in ways that make the most sense for them,” he says. “But I am not aware of any collective response at the moment.”

Universities are already bracing themselves for a potential brain drain. “The faculty and postdoc market is international, and the current sentiment makes the US less attractive for reasons beyond just finance,” warns Littlewood.

Peter Gwynne
Boston, MA

Astronomy

JWST spots spectacular Neptune auroras



NASA, ESA, CSA, STScI, Heidi Hammel (AURA), Henrik Melin (Northumbria University), Leigh Fletcher (University of Leicester), Stefanie Milam (NASA-GSFC)

Auroral glow The cyan on the image represents auroral activity and is shown together with white clouds on a multi-hued blue orb that is Neptune.

The first direct evidence for auroras on Neptune has been spotted by the James Webb Space Telescope (JWST) and the Hubble Space Telescope. Auroral activity has previously been seen on Jupiter, Saturn and Uranus but not on Neptune despite hints in a flyby of the planet by NASA’s Voyager 2 in 1989.

Auroras occur when energetic particles from the Sun become trapped in a planet’s magnetic field and eventually strike the upper atmosphere with the energy released creating a signature glow. “Imaging the auroral activity on Neptune was only possible with [the JWST’s] near-infrared sensitivity,” notes Henrik Melin from Northumbria University. “It was so stunning to not just see the auroras, but the detail and clarity of the signature really shocked me.”

The data were taken by the JWST’s Near-Infrared Spectrograph as well as Hubble’s Wide Field Camera 3. While auroras on Earth occur at the poles, on Neptune they happen elsewhere. This is due to the nature of Neptune’s magnetic field, which is tilted by 47 degrees from the planet’s rotational axis. As well as the visible imagery, the JWST also detected an emission line from trihydrogen cation (H_3^+), which can be created in auroras.

Michael Banks

Astronomy

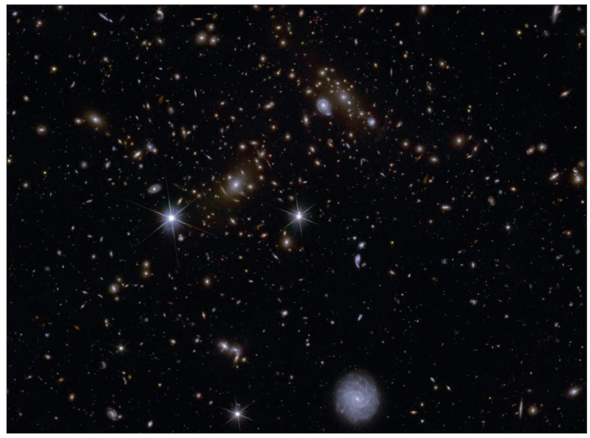
Euclid mission reveals galaxy treasure trove

The European Space Agency (ESA) has unveiled the first batch of survey data from its €1.4bn Euclid mission. The release includes a preview of its "deep field" where in just one week of observations, Euclid spotted 26 million galaxies as well as many transient phenomena such as supernovae and gamma-ray bursts. The dataset is published along with 27 scientific papers that will be submitted to the journal *Astronomy & Astrophysics*.

The dataset also features a catalogue of 380 000 galaxies that have been detected by artificial intelligence or "citizen-science" efforts. They include galaxies with spiral arms, central bars and "tidal tails", inferring merging galaxies. There has also been the discovery of 500 gravitational-lens candidates thanks to AI and citizen science. Gravitational lensing occurs when light from more distant galaxies is bent around closer galaxies due to gravity and it can help identify the location and properties of dark matter.

"For the past decade, my research has been defined by painstakingly analysing the same 50 strong gravitational lenses, but with the data release, I was handed 500 new strong lenses in under a week," says astronomer James Nightingale from Newcastle University. "It's a seismic shift – transforming how I do science practically overnight." The data release still represents only 0.4% of the total number of galaxies that Euclid is expected to image over its lifetime. Euclid will capture images of more than 1.5 billion galaxies over six years, sending back around 100 GB of data every day.

"Euclid shows itself once again to be the ultimate discovery machine. It is surveying galaxies on the grandest scale, enabling us to explore our cosmic history and the invisible forces shaping our universe," says ESA's science director, Carole Mundell. "With the release of the first data from Euclid's survey, we are unlocking a treasure trove of information for scientists to dive into and tackle some of the most intriguing questions in modern science".



ESA/Euclid/Euclid Consortium/NASA, image processing by J-C Cuillandre, E Bertin, G Anselmi

Deep field
An area of Euclid's Deep Field South features galaxies in a variety of shapes and colours.

Euclid was launched in July 2023 and is currently located in a spot in space called Lagrange Point 2 – a gravitational balance point that is 1.5 million kilometres beyond the Earth's orbit around the Sun. The Euclid Consortium comprises some 2600 members from more than 15 countries. Euclid has a 1.2 m-diameter telescope, a camera and a spectrometer that it uses to plot a 3D map of the distribution of galaxies. The images it takes are about four times as sharp as current ground-based telescopes. Euclid released its first images in November 2023 and began routine observations in February 2024, releasing a first data batch in May 2024. The mission's first "cosmology data" will be released in October 2026.

Michael Banks

Awards

CERN staff win 2025 Breakthrough Prize in Fundamental Physics

The 2025 Breakthrough Prize in Fundamental Physics has been given to 13 508 members of CERN's four main detector collaborations – ALICE, ATLAS, CMS and LHCb. The $3m prize was awarded "for detailed measurements of Higgs boson properties confirming the symmetry-breaking mechanism of mass generation, the discovery of new strongly interacting particles, the study of rare processes and matter–antimatter asymmetry, and the exploration of nature at the shortest distances and most extreme conditions at CERN's Large Hadron Collider".

The prize was awarded at a gala ceremony in Los Angeles in early April. ATLAS and CMS each received $1m, with LHCb and ALICE both getting $500 000. But following consultation with the leaders of the four experiments, the foundation will donate 100% of the prize to the CERN & Society Foundation. It will be used by the collaborations to offer grants for doctoral students from member institutes to spend research time at CERN.

Lester Cohen/Getty Images for Breakthrough Prize

Glitz and glamour
Andreas Hoecker, Patricia McBride, Marco van Leeuwen and Vincenzo Vagnoni from CERN at the Breakthrough award ceremony.

Meanwhile, the Nobel-prize-winning physicist Gerard 't Hooft has been awarded a $3m Special Breakthrough Prize in Fundamental Physics "for fundamental insights into gauge theory and the standard model". In the early 1970s 't Hooft made crucial contributions to the foundations of what would become the Standard Model of particle physics. He proved that Yang–Mills theories – the mathematical framework underlying theories of both the weak and strong nuclear forces – can give finite, calculable results rather than meaningless infinities.

The Breakthrough prizes were founded in 2012 by the billionaire physicist Yuri Milner and are awarded annually.

Michael Banks

Publishing

Allegations of sexual misconduct impact citations

Scientists who have been publicly accused of sexual misconduct see a significant and immediate decrease in the rate at which their work is cited, according to a study by behavioural scientists in the US. However, researchers who are publicly accused of scientific misconduct are found not to suffer the same drop in citations (*PLOS One* **20** e0317736).

The study was carried out by a team led by Giulia Maimone from the University of California, Los Angeles, who collected data from the Web of Science covering 31 941 scientific publications across 18 disciplines. They then analysed the citation rates for 5888 papers authored by 30 researchers accused of either sexual or scientific misconduct – the latter including data fabrication, falsification and plagiarism. Maimone told *Physics World* that the team used strict selection criteria to ensure that the two groups of academics were comparable and that the accusations against them were public. This meant they only used scholars whose misconduct allegations have been reported in the media and had "detailed accounts of the allegations online".

iStock/Kameleon007

Bad impact
Scientists who are accused of sexual misconduct experience a significant drop in citations in the three years after the allegations become public.

Maimone's team concluded that papers by scientists accused of sexual misconduct experienced a significant drop in citations in the three years after allegations become public compared with a "control" group of academics of a similar professional standing. Those accused of scientific fraud, meanwhile, saw no statistically significant change in the citation rates of their papers.

To further explore attitudes towards sexual and scientific misconduct, the researchers surveyed 231 non-academics and 240 academics. The non-academics considered sexual misconduct more reprehensible than scientific misconduct and more deserving of punishment, while academics said that they would be more likely to continue to cite researchers accused of sexual misconduct as compared to scientific misconduct. "Exactly the opposite of what we observe in the real data," adds Maimone.

According to the researchers, there are two possible explanations for this discrepancy. One is that academics, according to Maimone, "overestimate their ability to disentangle the scientists from the science". Another is that scientists are aware that they would not cite sexual harassers, but they are unwilling to admit it because they feel they should take a harsher professional approach towards scientific misconduct.

Maimone says they would now like to explore the longer-term consequences of misconduct as well as the psychological mechanisms behind the citation drop for those accused of sexual misconduct.

Michael Allen

Astronomy

Square Kilometre Array releases low-frequency image

The Square Kilometre Array (SKA) Observatory has released the first image from its partially built low-frequency telescope in Australia, known as SKA-Low. The new SKA-Low image was created using 1024 two-metre-high antennas. It shows an area of the sky that would be obscured by a person's clenched fist held at arm's length. Observed at 150 MHz to 175 MHz, the image contains 85 of the brightest known galaxies in that region, each with a black hole at their centre.

SKA-Low will ultimately have 131 072 two-metre-high antennas that will be clumped together in arrays to act as a single instrument. These arrays collect the relatively quiet signals from space and combine them to produce radio images of the sky with the aim of answering some of cosmology's most enigmatic questions, including what dark matter is, how galaxies form, and if there is other life in the universe.

SKA

Low impact
The new image was created using 1024 two-metre-high antennas belonging to SKA-Low, which is currently being built in Western Australia.

When the full SKA-Low gazes at the same portion of sky as captured in the newly released image, it will be able to observe more than 600 000 galaxies. "The bright galaxies we can see in this image are just the tip of the iceberg," says George Heald, lead commissioning scientist for SKA-Low. "With the full telescope we will have the sensitivity to reveal the faintest and most distant galaxies, back to the early universe when the first stars and galaxies started to form."

SKA-Low is one of two telescopes under construction by the observatory. The other, SKA-Mid, which observes mid-frequency range, will include 197 three-storey dishes and is being built in South Africa. The telescopes, costing £1bn, are projected to begin observations in 2028. They are being funded through a consortium of member states, including China, Germany and the UK.

Eloy de Lera Acedo, who is principal Investigator at the University of Cambridge for the observatory's science data processor, says the first image from SKA-Low is an "important milestone".

Sarah Wild

‘Paradigm shift’ needed to support disabled people

A new report by the UK National Association of Disabled Staff Networks calls for changing attitudes towards people with disabilities, as **Michael Banks** reports

Disabled people in science must be recognized and given better support to help reverse the numbers of such people dropping out of science. That is the conclusion of a new report released at the end of March by the National Association of Disabled Staff Networks (NADSN). It also calls for funders to stop supporting institutions that have toxic research cultures and calls for a change in equality law to recognize the impact of discrimination on disabled people including neurodivergent people.

About 22% of working-age adults in the UK are disabled. Yet it is estimated that only 6.4% of people in science have a disability, falling to just 4% for senior academic positions. In addition, barely 1% of research grant applications to UK Research and Innovation – the umbrella organization for the UK’s main funding councils – are from researchers who disclose being disabled. Disabled researchers who do win grants receive less than half the amount compared to non-disabled researchers.

NADSN is an umbrella organization for disabled staff networks, with a focus on higher education. It includes the STEMM Action Group, which was founded in 2020 and consists of nine people at universities across the UK who work in science and have experience of disability, chronic illness or neurodivergence. The group develops recommendations to funding bodies, learned societies and higher-education institutions to address barriers faced by those who are marginalized due to disability.

Issues to tackle

In 2021 the group published a “problem statement” that identified issues facing disabled people in science. They range from digital problems, such as the need for accessible fonts in reports and presentations, to physical concerns such as needing access ramps for people in wheelchairs or automatic doors to open heavy fire doors. Other issues include the need for adjustable desks in offices and wheelchair-accessible labs. “Many of these physical issues tend to be afterthoughts in the planning process,” says Francesca Doddato, a physicist from Lancaster University, who co-wrote the new report. “But at that point they are much harder, and more costly, to implement.”

iStock/Erdark

Support network A new report offers solutions to the many challenges faced by disabled people in science.

Workplace attitudes and cultures can also be a big problem for disabled people in science, some 62% of whom report having been bullied and harassed compared to 43% of all scientists. “Unfortunately, in research and academia there is generally a toxic culture in which you are expected to be hyper productive, move all over the world, and have a focus on quantity over quality in terms of research output,” says Doddato. “This, coupled with society-wide attitudes towards disabilities, means that many disabled people struggle to get promoted and drop out of science.”

The toxic culture in research and academia, coupled with society-wide attitudes towards disabilities, means that many disabled people struggle to get promoted and drop out of science

Small actions

The action group spent the past four years compiling their latest report – *Towards a Fully Inclusive Environment for Disabled People in STEMM* – to present solutions to these issues. The group hopes it will raise awareness of the inequity and discrimination experienced by disabled people in science and highlight the benefits of having an inclusive environment.

The report identifies three main areas that need reform to make science fully inclusive for disabled scientists: enabling inclusive cultures and practices; enhancing accessible physical and digital environments; and accessible and proactive funding.

In the short term, it calls on people to recognize the challenges and barriers facing disabled researchers and to improve work-based training for managers. “One of the best things is just being willing to listen and ask what can I do to help?” notes Doddato. “Being an ally is vitally important.” Doddato says that sharing meeting agendas and documents ahead of time, ensuring that documents are presented in accessible formats, or acknowledging that tasks such as getting around campus can take longer can all be useful. “All of these little things can really go a long way in shifting those attitudes and being an ally, and those things don’t need policies, but people need to be willing to listen and be willing to change.”

Medium- and long-term goals in the report involve holding organizations responsible for their working practice polices and to stop promoting and funding toxic research cultures. “We hope the report encourages funding bodies to put pressure on institutions if they are demonstrating toxicity and being discriminatory,” adds Doddato. The report also calls for a change to equality law to recognize the impact of intersectional discrimination, although it admits that this will be a “large undertaking” and will be the subject of a further NADSN report.

Doddato wants disabled people’s voices to be heard “loud and clear” as part of any changes. “What we are trying to address with the report is to push universities, research institutions and societies to stop only talking about doing something and actually implement change,” says Doddato. “We need to have a big paradigm shift in terms of how we see disability inclusion. It’s time for change.”

Michael Banks is news editor of *Physics World*

Research updates

CO_2 laser detects radioactive material

Remote detection of radioactive substances could play an important role in nuclear disaster response and nuclear security, as **Jacklin Kwan** reports

Researchers have demonstrated that they can remotely detect radioactive material from 10 m away using short-pulse carbon-dioxide (CO_2) lasers. This distance is more than 10 times farther than achieved via previous methods and the development could one day lead to remote sensing technologies in nuclear disaster response and nuclear security (*Phys. Rev. Applied* **23** 034004).

Radioactive materials emit particles – such as alpha, beta or gamma particles – that can ionize air molecules, creating free electrons and negative ions. Yet these charged particles are typically present at very low concentrations, making them difficult to detect. While conventional radiation detectors, such as Geiger counters, detect the particles that are emitted by radioactive material, their operational range is limited as the material has to be nearby.

The new method, developed by researchers at Brookhaven, Los Alamos and Lawrence Livermore national labs as well as the University of Maryland, instead uses the ionization in the surrounding air, enabling detection from much greater distances. They have demonstrated that CO_2 lasers could accelerate the charged particles, causing them to collide with neutral gas molecules, in turn creating further ionization. These additional free charges would then undergo the same laser-induced accelerations and collisions, leading to a cascade of charged particles. This effect, known as "electron avalanche breakdown", can create microplasmas that scatter laser light. By measuring the profile of the backscattered light, researchers can detect the presence of radioactive material.

The team tested their technique using a 3.6-mCi polonium-210 alpha particle source at a standoff distance of 10 m, significantly longer than previous experiments that used different types of lasers and electromagnetic radiation sources. Maryland's Howard Milchberg and collaborators had previously used a mid-infrared laser in a similar experiment in 2019. Changing to a long-wavelength (9.2 μm) CO_2 laser has significant advantages, he says. "You can't use any laser to do this cascading breakdown process," Milchberg adds. The CO_2 laser's wavelength was able to enhance the avalanche process, while being low energy enough to not create its own ionization sources. "CO_2 is sort of the limit for long wavelengths on powerful lasers and it turns out CO_2 lasers are very, very efficient as well," he says. "So this is like a sweet spot."

Shutterstock/fewerton

Distance control Carbon-dioxide lasers have been used to spot radioactive material using a new technique that was tested with a 3.6-mCi polonium-210 alpha particle source at a standoff distance of 10 m – much further than was possible before.

Imaging microplasmas

The team also used a CMOS camera to capture visible-light emissions from the microplasmas. Milchberg says that this fluorescence around radioactive sources resembled balls of plasma, indicating the localized regions where electron avalanche breakdowns had occurred. By counting these "plasma balls" and calibrating them against the backscattered laser signal, the researchers could link fluorescence intensity to the density of ionization in the air, and use that to determine the type of radiation source. The CMOS imagers, however, had to be placed close to the measured radiation source, reducing their applicability to remote sensing. "Although fluorescence imaging is not practical for field deployment due to the need for close-range cameras, it provides a valuable calibration tool," Milchberg says.

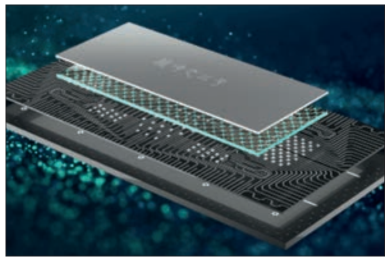
The researchers believe their method can be extended to standoff distances exceeding 100 m. The main limitation is the laser's focusing geometry, which would affect the regions in which it could trigger an avalanche breakdown. A longer focal length would require a larger laser aperture but could enable kilometre-scale detection. Milchberg says that the next steps will be to continue developing a technique that can differentiate between different types of radioactive sources completely remotely. "There's also the question of environmental conditions," says Milchberg, explaining that it is critical to ensure that detection techniques are robust against the noise introduced by aerosols or air turbulence.

Eun-Mi Choi from the Ulsan National Institute of Science and Technology in South Korea, whose team had used a gyrotron source to detect radioactive materials back in 2017, says the results are "highly impressive". "The researchers successfully demonstrated 10 m standoff detection of radioactive material, significantly surpassing the previous range of approximately 1 m," says Choi. She points out, however, that deploying a CO_2 laser may be difficult in real-world applications. "A CO_2 laser is a bulky system, making it challenging to deploy in a portable manner in the field," Choi says, adding that mounting the laser for long-range detection may be a solution.

Jacklin Kwan is a science writer based in the UK

Quantum computing

Chinese quantum computer extends lead over classical machines


USTC

Speed test The Zuchongzhi 3.0 processor, consisting of 105 qubits, has been shown to complete a random circuit sampling calculation in minutes.

Researchers in China have unveiled a 105-qubit quantum processor that can solve in minutes a quantum computation problem that would take billions of years using the world's most powerful classical supercomputer. The result sets a new benchmark for so-called "quantum advantage", though some previous claims have faded after classical algorithms improved (*Phys. Rev. Lett.* 134 090601).

The first claim that a quantum computer can solve a problem faster than a classical computer – quantum advantage – came in 2019 when researchers at Google reported that their 53-qubit Sycamore processor had solved a problem known as random circuit sampling (RCS) in just 200 seconds. In October 2024, Google researchers then announced that their 67-qubit Sycamore processor had solved an RCS problem that would take an estimated 3600 years for the Frontier supercomputer at the US's Oak Ridge National Laboratory to complete.

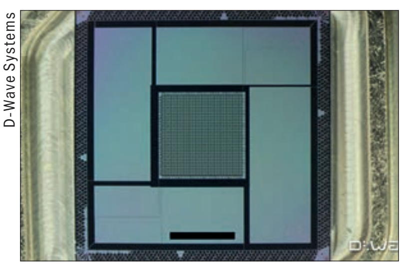
In the latest work, Jian-Wei Pan and Xiaobu Zhu at the University of Science and Technology of China in Hefei and colleagues have shown that their new Zuchongzhi 3.0 processor can complete in minutes an RCS calculation that they estimate would take Frontier billions of years using the best classical algorithms currently available. To achieve this, they redesigned the readout circuit of their earlier Zuchongzhi processor to improve its efficiency, modified the structures of the qubits to increase their coherence times and increased the total number of superconducting qubits to 105.

The USTC team now plans to demonstrate quantum-error correction on Zuchongzhi 3.0. This will involve using an error-correction code to combine multiple physical qubits into a single "logical qubit" that is robust to errors. "The requirements for error-correction readout are much more difficult than for RCS," says Zhu. "RCS only needs one readout, whereas error-correction needs readout many times with very short readout times. Nevertheless, RCS can be a benchmark to show we have the tools to run the surface code." Zhu adds that they hope to soon demonstrate "a good-quality" error-correction code.

Quantum information theorist Bill Fefferman of the University of Chicago in the US, who was not involved in the latest study, praises the work while offering two caveats. The first is that recent demonstrations of quantum advantage do not have efficient classical verification schemes – meaning, in effect, that classical computers cannot check the quantum computer's work. The second is that the rigorous hardness arguments proving that the classical computational power needed to solve an RCS problem grows exponentially with the problem's complexity apply only to situations with no noise. This is far from the case in today's quantum computers, and Fefferman says this loophole has been exploited in many past quantum advantage experiments.

Tim Wogan

D-Wave Systems claims quantum advantage in simulations


D-Wave Systems

Beyond classical D-Wave's Advantage2 processor has been used to simulate quantum magnetic phase transitions.

The US-based firm D-Wave Systems has used quantum annealing to do simulations of quantum magnetic phase transitions. It claims that some of its calculations would be beyond the capabilities of the most powerful conventional computers – known as quantum advantage. If confirmed, it would mark the first time quantum computers had achieved such a feat for a practical physics problem (*Science* 10.1126/science.ado6285).

While most companies trying to build practical quantum computers are developing "universal" or "gate model" quantum systems, US-based D-Wave has principally focused on quantum annealing devices. While such systems are less programmable than gate model systems, the approach has allowed D-Wave to build machines with thousands of quantum bits (qubits), many more than any of its competitors.

In the new work, researchers at D-Wave and elsewhere set out to show that their machines could use quantum annealing to solve practical physics problems beyond the reach of classical computers. The researchers used two different 1200-qubit processors to model magnetic quantum phase transitions. They studied multiple configurations, comprising ever-more spins arranged in increasingly complex lattice structures. The company says that its system performed the most complex simulation in minutes, compared to almost a million years on Frontier, which is one of the world's most powerful supercomputers.

However, the claim has been challenged by two independent groups of researchers – one at EPFL in Switzerland (arXiv: 2503.08247) and one at the Flatiron Institute in the US (arXiv: 2503.05693) – who report that similar calculations could be done using classical computers. They argue that their results should scale simply to larger sizes; the implication being that classical computers could solve the more complicated problems addressed by D-Wave.

Yet D-Wave says these classical results fall well short of the company's own accomplishments. "I see this as a healthy back and forth between quantum and classical methods," notes Trevor Lanting, chief development officer at D-Wave.

Tim Wogan

Astronomy

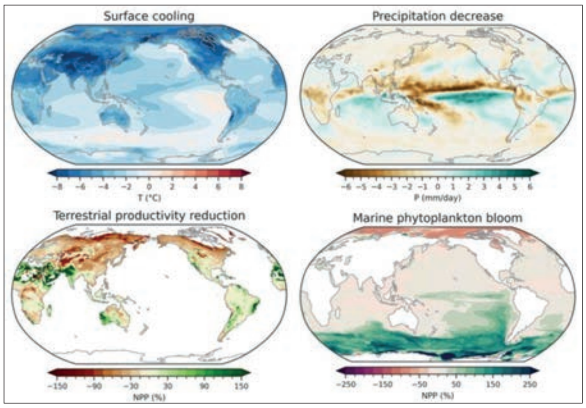
Medium-size-asteroid strike would make Earth cool by 4 °C

Researchers in South Korea have carried out supercomputer simulations to analyse how the Earth's climate and environment would change following an asteroid strike on land. The results show that the climate, atmospheric chemistry and even global photosynthesis would be dramatically disrupted in the three to four years following the event due to the huge amounts of dust produced by the impact (*Sci. Adv.* **11** eadq5399).

Beyond immediate effects such as scorching heat, earthquakes and tsunamis, an asteroid impact would have long-lasting effects on the climate due to the large quantities of aerosols and gases ejected into the atmosphere. These unfavourable climate conditions would inhibit plant growth via a decline in photosynthesis both on land and in the sea, which would affect food productivity.

In the latest study, the researchers simulated the effect of a medium-sized asteroid with a diameter of around 500 m impacting the Earth. This type of asteroid is more likely to impact Earth than the "planet killer" larger asteroids, but has been studied far less. The team ran the simulations on the supercomputer Aleph at the IBS Center for Climate Physics (ICCP) at Pusan National University. The simulations concluded that up to 400 million tonnes of dust would be injected into the stratosphere. The climate effects of impact-dust aerosols mainly depend on their abundance in the atmosphere and how they evolve there.

The simulations revealed that global mean temperatures would drop by 4 °C, a value that's comparable with the cooling estimated as a result of the Toba volcano erupting around 74 000 years ago (which emitted 2000 Tg (2×10^{15} g) of sulphur dioxide). Precipitation also decreased 15% worldwide and ozone dropped by a dramatic 32% in the first year following the asteroid impact.



Deep impact A 500 m diameter asteroid striking our planet would lead to climate conditions similar to those observed after some of the largest volcanic eruptions in the last 100 000 years.

Institute for Basic Science

The researchers admit that their model has some limitations. The climate model used is not designed and optimized to simulate the effects of massive amounts of aerosol injected into the atmosphere. Second, the researchers only focused on the asteroid colliding with the Earth's land surface, which is less likely given that roughly 70% of Earth's surface is covered by water. "An impact in the ocean would inject large amounts of water vapour rather than climate-active aerosols such as dust, soot and sulphur into the atmosphere and this vapour needs to be better modelled – for example, for the effect it has on ozone loss," says ICCP director Axel Timmermann. Yet he adds that results can serve as "useful benchmarks" to estimate the range of environmental effects from future medium-sized asteroid collisions."

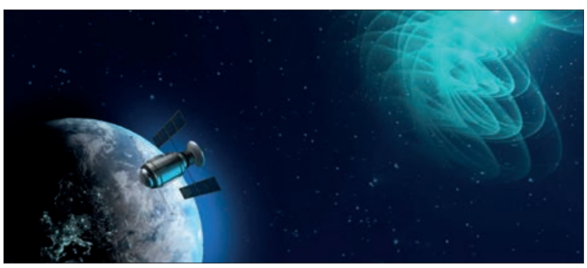
Isabelle Dumé

Machine learning boosts detection of neutron star mergers

A new artificial intelligence method rapidly and accurately characterizes binary neutron star mergers based on the gravitational-wave signature they produce. The method has not yet been tested on new mergers happening in real time, but it could enable astronomers to make quicker estimates of properties such as the location of mergers and the masses of the neutron stars (*Nature* 639 49).

When massive objects such as black holes and neutron stars collide and merge, they emit ripples in space–time known as gravitational waves (GWs) that have been detected by ground-based interferometers. When two neutron stars in a binary pair merge, they emit electromagnetic waves as well as GWs. While both types of wave travel at the speed of light, certain poorly understood processes that occur within and around the merging pair cause the electromagnetic signal to be slightly delayed. This means that the GW observatories can detect the signal coming from a binary neutron star merger seconds, or even minutes, before its electromagnetic counterpart arrives. Being able to identify GWs quickly and accurately therefore increases the chances of detecting other signals from the same event.

This is no easy task, however. GW signals are long and complex, and the main technique currently used to interpret them, Bayesian inference, is slow. While quicker alternatives exist, they often make algorithmic approximations that negatively affect their accuracy. Physicists led by Maximilian Dax of the Max Planck Institute for Intelligent Systems in Tübingen, Germany, have now developed a machine learning framework that accurately characterizes and localizes binary neutron star mergers within a second of a GW being detected, without resorting to such approximations.



Speeding up science
AI could aid "multimessenger" astronomy by quickly locating sources of gravitational waves during neutron star mergers.

MPI-IS/A Posada

To do this, they trained a deep neural network model with millions of GW simulations. Once trained, the neural network can take fresh GW data as input and predict corresponding properties of the merging neutron stars – for example, their masses, locations and spins – based on its training dataset. Crucially, this neural network output includes a sky map, which provides a fast and accurate estimate for where the neutron star is located.

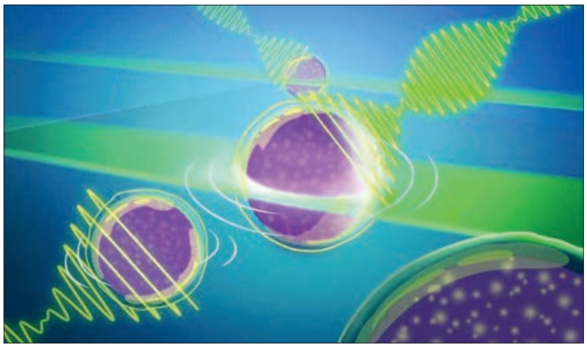
Isabelle Dumé

Optics

Brillouin microscopy speeds up by a factor of 1000

Researchers at the European Molecular Biology Laboratory (EMBL) in Germany have dramatically reduced the time required to create images using Brillouin microscopy, making it possible to study the viscoelastic properties of biological samples far more quickly and with less damage than before. Their new technique can image samples with a field of view of roughly 10 000 pixels at a speed of 0.1 Hz – a thousand times faster than standard confocal techniques (*Nature Photonics* 10.1038/s41566-025-01619-y).

Measuring mechanical properties such as the elasticity and viscosity of biological cells is not easy since most existing techniques are invasive and disrupt the systems being imaged. In recent years, Brillouin microscopy has emerged as a non-destructive, label- and contact-free optical spectroscopy method for probing the viscoelastic properties of biological samples with high resolution in three dimensions. The technique relies on Brillouin scattering, which occurs when light interacts with the phonons (or collective vibrational modes) that are present in all matter.



Daniela Velasco/EMBL

Shining light The new Brillouin microscopy approach allows entire "light-sheets" to interact with 3D biological samples, speeding up image acquisition.

This interaction produces two additional peaks, known as Stokes and anti-Stokes Brillouin peaks, in the spectrum of the scattered light. The position of these peaks (the Brillouin shift) and their linewidth (the Brillouin width) are related to the elastic and viscous properties, respectively, of the sample.

The downside is that standard Brillouin microscopy approaches analyse just one point in a sample at a time. Given the scattering signal from a single point is weak, imaging speeds are slow, yielding long light exposure times that can damage photosensitive components within biological cells.

To overcome this problem, EMBL researchers led by Robert Prevedel began exploring ways to speed up the rate at which Brillouin microscopy can acquire 2D and 3D images.

Initially, they were only able to visualize one pixel at a time but in 2022 they expanded the field of view to include an entire spatial line – that is, acquiring image data from more than 100 points in parallel. In their latest work, they have now been able to view roughly 10 000 pixels in parallel over the full plane of a sample. "This advance enables much faster Brillouin imaging, and in terms of microscopy, allows us to perform 'light sheet' Brillouin imaging," says Prevedel. "In short, we are able to 'under-sample' the spectral output, which leads to around 1000 fewer individual measurements than normally needed."

Prevedel and colleagues have already used the new approach to study mechanical changes in live zebrafish larvae and they hope their results will lead to more widespread use of Brillouin microscopy, particularly for photosensitive biological samples.

Isabelle Dumé

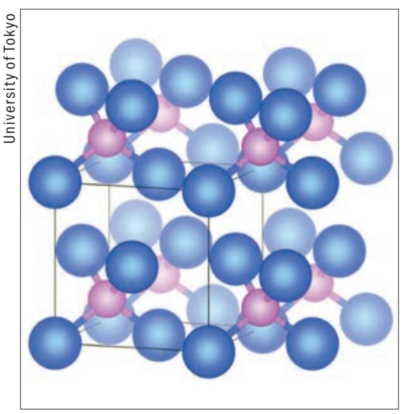
Geophysics

Earth's core could contain significant amounts of primordial helium

Experiments by scientists in Japan and Taiwan have shown that helium deep with the Earth could bond with iron to form stable compounds. The work suggest that Earth's core could host a vast reservoir of primordial helium-3 – reshaping our understanding of the planet's interior (*Phys. Rev. Lett.* **134** 084101).

Noble gases are normally chemically inert but under extreme pressures heavier members of the group can form a variety of compounds with other elements. To date, however, less is known about compounds containing helium, the lightest noble gas. As a result, the conventional view is that any primordial helium-3 present when our planet first formed would have quickly diffused through Earth's interior, before escaping into the atmosphere and then into space.

Yet there are tantalizing clues that helium compounds could exist in some volcanic rocks on Earth's surface. These rocks contain unusually high isotopic ratios of helium-3 to helium-4 and it hints that helium-3 must have somehow become trapped in the Earth.



University of Tokyo

Hidden mystery Reactions between helium and iron in the Earth's core could have led to a vast reservoir of helium that is making its way to the surface.

One explanation is that the extreme pressures present in Earth's iron-rich core enabled primordial helium-3 to bond with iron to form stable molecular lattices. To explore this experimentally, the researchers triggered reactions between iron and helium within a laser-heated diamond-anvil cell at pressures as high as 54 GPa. While this is less than the 350 GPa pressure in the core, the reactions created molecular lattices of iron and helium. These structures remained stable even when the diamond-anvil's extreme pressure was released. The team also performed first-principles calculations, which revealed a dynamically stable crystal structure that supported the experimental findings.

The results suggest that similar reactions between helium and iron may have occurred within Earth's core shortly after its formation to create a vast reservoir of helium in the core, which is gradually making its way to the surface.

Sam Jarman

Opinion

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Physics World
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BS2 0GR, UK
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Institute of Physics
37 Caledonian Road, London N1 9BU, UK
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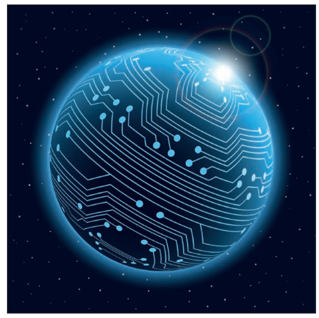
Quantum advantage

The quantum-technology sector is looking for more than just PhD physicists

Andrew Martin, skills policy lead at the UK's Department for Science, Innovation and Technology (DSIT), flashed up a slide. Speaking at the ninth Careers in Quantum event in Bristol last month, he listed the eight skills that the burgeoning quantum-technology sector wants. Five are various branches of engineering, including electrical and electronics, mechanical, software and systems. A sixth is materials science and chemistry, with a seventh being quality control.



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Quantum companies, of course, do also want "quantum specialists", which was the eighth skill identified by Martin. But it's a sign of how mature the sector has become that being a hotshot quantum physicist is no longer the only route in. That point was underlined by Carlos Faurby, a hardware integration engineer at Sparrow Quantum in Denmark, which makes single-photon sources for quantum computers. "You don't need a PhD in physics to work at Sparrow," he told attendees.

Quantum tech certainly has a plethora of career options, with the Bristol event featuring a selection of firms from across the quantum ecosystem. Some are making prototype quantum computers (Quantum Motion, Quantinuum, Oxford Ionics) or writing the algorithms to run on quantum computers (Phasecraft). Others are building quantum networks (BT, Toshiba), working on quantum error correction (Riverlane) or developing quantum cryptography (KETS Quantum). Businesses building hardware such as controllers and modems were present too.

With the 2025 International Year of Quantum Science and Technology (IYQ) now in full swing, the event underlined just how thriving the sector is, with lots of career choices for physicists – whether you have a PhD or not. But competition to break in is intense. Phasecraft says it gets 50–100 applicants for each student internship it offers, with Riverlane receiving almost 200 applications for two summer placements.

That's why it's vital for physics students to develop their "soft skills" – or "professional skills" as several speakers preferred to call them. Team working, project management, collaboration and communication are all essential for jobs in the quantum industry, as indeed they are for all careers. Sadly, many physicists don't realize soon enough just how crucial soft skills are.

Reflecting on his time at Light Trace Photonics, which he co-founded in 2021, Dominic Sulway joked that he'd "enjoyed developing all the skills people told me I'd need for my PhD". So why not just start a business yourself? It's a rewarding experience, I was told, and there doesn't seem to be any slow-down in quantum firms starting up.

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


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Three rules for teaching

Decades of university teaching has made **Mike Edmunds** and **Zbig Sobiesierski** realize that student learning can be boosted by enthusiasm, engagement and enablement

Last year the UK government placed a new cap of £9535 on annual tuition fees, a figure that will likely rise in the coming years as universities tackle a funding crisis. Indeed, shortfalls are already affecting institutions, with some saying they will run out of money in the next few years. The past couple of months alone have seen several universities announce plans to shed academic staff and even shut departments.

Whether you agree with tuition fees or not, the fact is that students will continue to pay a significant sum for a university education. Value for money is part of the university proposition and lecturers can play a role by conveying the excitement of their chosen field. But what are the key requirements to help do so? In the late 1990s we carried out a study aimed at improving the long-term performance of students who initially struggled with university-level physics.

With funding from the Higher Education Funding Council for Wales, the study involved structured interviews with 28 students and 17 staff. An internal report – *The Rough Guide to Lecturing* – was written which, while not published, informed the teaching strategy of Cardiff University's physics department for the next quarter of a century.

From the findings we concluded that lecture courses can be significantly enhanced by simply focusing on three principles, which we dub the three "E"s. The first "E" is enthusiasm. If a lecturer appears bored with the subject – perhaps they have given the same course for many years – why should their students be interested? This might sound obvious, but a bit of reading, or examining the latest research, can do wonders to freshen up a lecture that has been given many times before.

For both old and new courses it is usually possible to highlight at least one research current paper in a semester's lectures. Students are not going to understand all of the paper, but that is not the point – it is the sharing in contemporary progress that will elicit excitement. Commenting on a nifty experiment in the work, or the elegance of the theory, can help to inspire both teacher and student.

As well as freshening up the lecture course's content, another tip is to mention the wider context of the subject being taught, perhaps by mentioning its history or possible exciting applications. Be inventive –we have evidence of a lecturer "live" translating parts of Louis de Broglie's classic 1925 paper "La relation du quantum et la relativité" during a lecture. It may seem unlikely, but the students responded rather well to that.

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Knowledge transfer Lecturers shouldn't succumb to the apocryphal definition of a lecture as a means to transfer the notes of the lecturer to the pad of the student without going through the mind of either.

> If a student asks a question, never insult them – there is no such thing as a "stupid" question

Supporting students

The second "E" is engagement. The role of the lecturer as a guide is obvious, but it should also be emphasized that the learner's desire is to share the lecturer's passion for, and mastery of, a subject. Styles of lecturing and visual aids can vary greatly between people, but the important thing is to keep students thinking.

Don't succumb to the apocryphal definition of a lecture as only a means of transferring the lecturer's notes to the student's pad without first passing through the minds of either person. In our study, when the students were asked "What do you expect from a lecture?", they responded simply to learn something new, but we might extend this to a desire to learn how to do something new.

Simple demonstrations can be effective for engagement. Large foam dice, for example, can illustrate the non-commutation of 3D rotations. Fidget-spinners in the hands of students can help explain the vector nature of angular momentum. Lecturers should also ask rhetorical questions that make students think, but do not expect or demand answers, particularly in large classes.

More importantly, if a student asks a question, never insult them – there is no such thing as a "stupid" question. After all, what may seem a trivial point could eliminate a major conceptual block for them. If you cannot answer a technical query, admit it and say you will find out for next time – but make sure you do. Indeed, seeing that the lecturer has to work at the subject too can be very encouraging for students.

The final "E" is enablement. Make sure that students have access to supporting material. This could be additional notes; a carefully curated reading list of papers and books; or sets of suitable interesting problems with hints for solutions, worked examples they can follow, and previous exam papers. Explain what amount of self-study will be needed if they are going to benefit from the course.

Have clear and accessible statements concerning the course content and learning outcomes – in particular, what students will be expected to be able to do as a result of their learning. In our study, the general feeling was that a limited amount of continuous assessment (10–20% of the total lecture course mark) encourages both participation and overall achievement, provided students are given good feedback to help them improve.

Next time you are planning to teach a new course, or looking through those decades-old notes, remember enthusiasm, engagement and enablement. It's not rocket science, but it will certainly help the students learn it.

Mike Edmunds is an emeritus professor of astrophysics at Cardiff University, UK, and former president of the Royal Astronomical Society. **Zbig Sobiesierski** recently retired as director of continuing and professional education at Cardiff University. E-mail m.g.edmunds@gmail.com

Transactions Writing on the wall

James McKenzie recalls working for a company making LED-based lighting when it dawned on him that a rival business was doomed because it refused to confront the problems with its products

iStock/DKsamco

Light-bulb moment It was while attending a trade show that James McKenzie realized that a competitor's product was flawed, even though the rival firm could not see what was wrong.

I recently met an old friend from the time when we both worked in the light-emitting diode (LED) industry. We started discussing how every technology has its day – a window of opportunity – but also how hard it is to know which companies will succeed long-term. As we got talking, I was reminded of a very painful product launch by an LED lighting firm that I was running at the time.

The incident occurred in 2014 when my company had a technology division that was developing wirelessly connected lighting. Our plan was to unveil our new Bluetooth control system at a trade show, but everything that could go wrong for us on the day pretty much did. However, the problems with our product weren't down to any particular flaws in our technology.

Instead, they were triggered by issues with a technology from a rival lighting firm that was also exhibiting at the event. We ended up in a rather ugly confrontation with our competitors, who seemed in denial about their difficulties. I realized there was a fundamental problem with their technology – even if they couldn't see it – and predicted that, for them, the writing was on the wall.

Bother at the booth

Our plan was to put microprocessors and radios into lighting to make it smart, more energy efficient and with integrated sensors and Bluetooth controls. There were no fundamental physics barriers – it just needed some simple thermal management (the LEDs and particularly the radios had to be kept below 70 °C), some electronics and lots of software.

Back then, the LED lighting industry was following a technology roadmap that envisaged these solid-state devices eventually generating 320 lumens per watt, compared to about 10 lumens per watt from conventional incandescent lamps. As the road map progressed, there'd be ever fewer thermal challenges.

With more and more countries phasing out conventional bulbs, LEDs are continuing their march along the roadmap. Almost every bulb sold these days is an LED and the overall global lighting market was worth $140bn in 2023, according to Fortune Business Insights. Lighting accounts for 15–18% of all electricity consumption in the European Union alone.

Back at that 2014 trade show, called LuxLive, all initially seemed to be going well as we set up our display. There was the odd software bug, but were able to work around that and happily control our LED lights with a smart phone connected via WiFi to a low-cost lighting server (a bit like a Raspberry Pi), with the smart LED fixtures and sensors connected via Bluetooth.

With final preparations over, the trade show opened and our first customer came up to the stand. We started giving them a demo but nothing seemed to be working – to our surprise, we simply could not get our lights to respond. A flurry of behind-the-scenes activity ensured (mostly us switching everything off and on again) but nothing made a difference.

To try to get to the bottom of things, I stepped a decent distance away from our booth and rang one of our technical team up in London for support. I explained our problem but, strangely, as I walked back towards the booth, I got cut off. My call appeared to have gone dead just as I passed another booth from a rival firm called Ceravision.

It was developing high-efficiency plasma (HEP) lamps that could generate up to 100 lumens per watt – roughly where LEDs were at the time. Its lamps used radio-frequency waves to heat a plasma without needing any electrodes. Designed for sports stadia and warehouses, Ceravision's bulbs were super bright. In fact, I was almost blinded by its products, which were pointing into the aisle, presumably to attract attention.

Back at base, our technical team frantically tried to figure out why our products weren't working. But they were stuck and I spent the rest of the day unable to demonstrate our products to potential customers. Then, as if by magic, our system started working again – just as someone noticed we weren't being blinded by Ceravision's light any more.

I walked over to Ceravision's booth as its team was packing up and had a chat with a sales guy, who I asked how the system worked. He told me it was a microwave waveguide light source but didn't appear to know much more. So I asked him if he wouldn't mind turning on the light again to demonstrate its output, which he did.

I glanced back at my team, who a few moments earlier had been all smiles that our system was now working, even if they were confused as to why. Suddenly, as the Ceravision light was turned on, our system broke down again. I requested to speak to one of Ceravision's technical team but was told they wouldn't be back until the following day.

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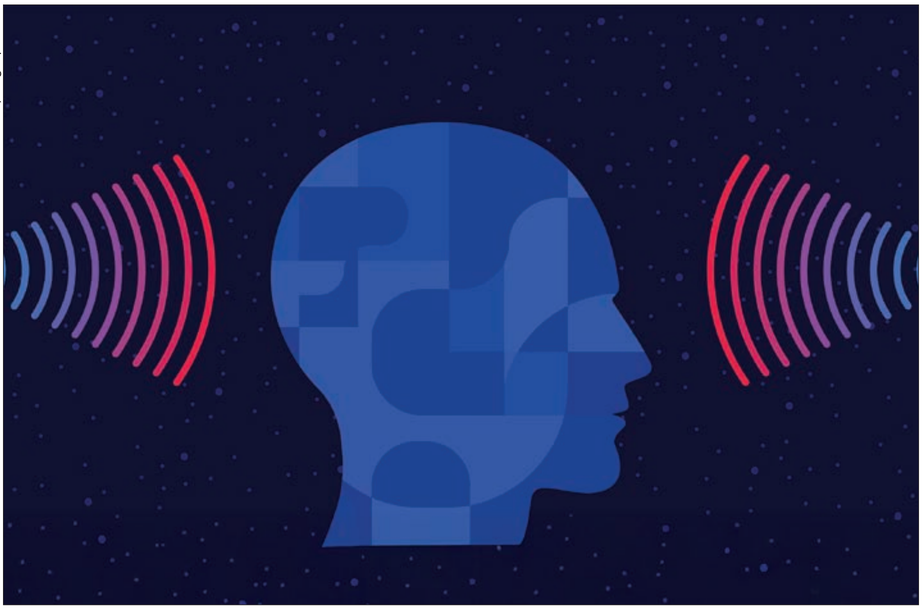

Messaging matters For companies developing new products, it's vital to listen and act on customer feedback as the market develops.

Lighting the way

I left for the show's awards dinner, where my firm won an innovation award for the wireless lighting system we'd been trying – unsuccessfully – to demonstrate all day. Later that night, I started looking into Ceravision in more detail. Based in Milton Keynes, UK, its idea of an electrodeless lamp wasn't new – Nikola Tesla had filed a patent for such a device back in 1894.

Tesla realized that this type of lamp would benefit from a long life and little discolouration as there are no electrodes to degrade or break. In fact, Tesla knew how to get around the bulbs' technical drawbacks, which involved constraining the radio waves and minimizing their power. Eventually, in the late 1990s, as radio-frequency sources became available, a US company called Fusion Lighting got this technology to market.

Its lamps consisted of a golf ball-sized fused-quartz bulb containing several milligrams of sulphur powder and argon gas at the end of a thin glass spindle. Enclosed in a microwave-resonant wire-mesh cage, the bulb was bombarded by 2.45 GHz microwaves from a magnetron of the kind you get in a microwave oven. The bulb had a design lifetime of about 60 000 hours and emitted 100 lumens per watt.

Unfortunately, its efficiency was poor as 80–85% of the light generated was trapped inside the opaque ceramic waveguide. Worse still, various satellite companies petitioned the US authorities to force Fusion Lighting to cut its electromagnetic emissions by 99.9%. They feared that otherwise its bulbs would interfere with WiFi, cordless phones and satellite radio services in North America, which also operate at 2.4 GHz.

In 2001 Fusion Lighting agreed to install a perforated metal shield around its lamps to reduce electromagnetic emissions by 95%. However, this decision only reduced the light output, making the bulbs even more inefficient. Ceravision's solution was an optically clear quartz waveguide and integrated lamp that yielded 100–5000 watts of power without any damage to the lamps.

The company claimed its technology was ideal for growing plants – delivering blue and ultraviolet light missing from other sources – along with everything from sterilizing water to illuminating TV studios. And whereas most magnetrons break down after about 2000 hours, Ceravision's magnetrons lasted for more than 40 000 hours. It had even signed an agreement with Toshiba to build high-efficient magnetrons.

What could possibly go wrong?

The truth hurts

Back at the trade show, I arrived the following morning determined to get a resolution with the Ceravision technical team. Casually, I asked one of them, who had turned up early, to come over to our booth to see our system. It was working – until the rest of Ceravision arrived and switched their lights on. Once again, our award-winning system gave up the ghost.

Things then got a little ugly. Ceravision staff refused to accept there was a correlation between their lights going on and our system breaking down. Our product must be rubbish, they said. If so, I asked, how come my mobile phone had stopped working too? Silence. I went to talk to the show organizers – all they could do was tell Ceravision to point its lights down, rather than into the aisle.

This actually worked for us as it seemed the "blocking signal" was reasonably directional. It became obvious from Ceravision's defensive response that this WiFi blocking problem must have come up before – its staff had some over-elaborate and clearly rehearsed responses. As for us, we simply couldn't show our product in its best light to customers, who just felt it wasn't ready for market.

In the intervening years, I've talked to several ex-employees of Ceravision, who've all told me it trialled lots of different systems for different markets. But its products always proved to be too expensive and too complex – and eventually LEDs caught up with them. When I asked them about lights disrupting WiFi, most either didn't seem aware of the issue or, if they did, knew it couldn't be fixed without slashing the light output and efficiency of the bulbs.

That in turn forced Ceravision to look for ever more niche applications with ever-tinier markets. Many staff left, realizing the emperor had no clothes. Eventually, market forces took their toll on the company, which put its lighting business into receivership in 2020. Its parent company with all the patents and intellectual property suffered a similar fate in 2023.

I suspect (but don't know for sure) that the window of opportunity closed due to high system costs, overly complex manufacturing and low volumes, coupled with LEDs becoming cheaper and more efficient. Looking back on 2014, the writing was really on the wall for the technology, even if no-one wanted to read the warning signs. A product that disrupts your mobile or WiFi signal was simply never going to succeed.

It was a classic case of a company having a small window of opportunity before better solutions came along and it missed the proverbial boat. Of course, hindsight is a wonderful thing. Clearly the staff could see what was wrong, but it took a long time for managers and investors to see or tackle the issues too. Perhaps when you are trying to deliver on promises you end up focusing on the wrong things.

The moral of the story is straightforward: constantly review your customers' feedback and re-evaluate your products as the market develops. In business, it really is that simple if you want to succeed.

James McKenzie is a physicist who helps bring new technology and products to market. He is writing here in a personal capacity

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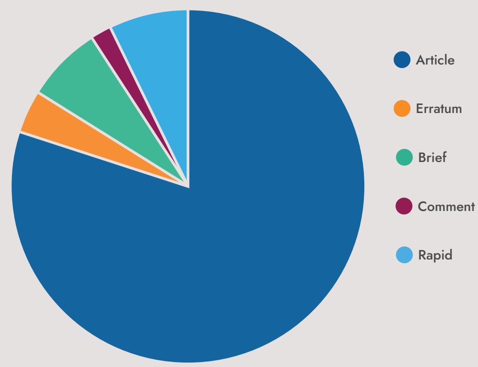

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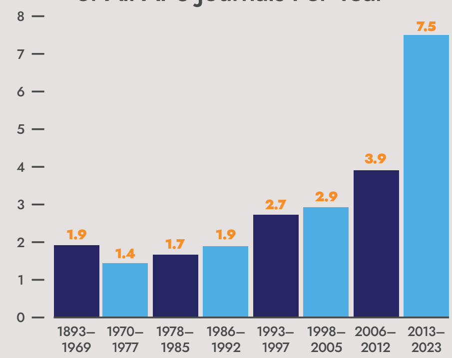

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Feedback

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Learning to think

In response to the article by former school teacher Mark Whalley (February p40) about how he used to respond to pupils who questioned why they had to learn physics.

Whalley makes important points about the value and purposes of a good education in physics and the role that school-level physics has in developing tools and capabilities that will be of enduring value to all young people – not just those who go on to study physics or engineering. We at the Institute of Physics (IOP) have also been thinking about these issues since the previous rounds of curriculum reform and have come to a similar conclusion.

Learning physics can be of enormous benefit to young people (whatever path they take) especially if it explicitly develops their capability in the practices and ways of thinking of the discipline – and gives them a deep understanding of a few of the big ideas in physics. The outcome of the IOP's work can be found in a new report entitled *The Fundamentals of 11-19 Physics*. It aims to support the development of future-focused physics curricula, outlines what we mean by "thinking like a physicist", and identifies the "thinking skills" that physics engenders.

Charles Tracy
Senior adviser, learning and skills, Institute of Physics

Diversity at CERN

In response to the interview with Mark Thomson, who takes over from Fabiola Gianotti next year as director-general of the CERN particle-physics lab (April pp7–8).

It's nice to hear that Thomson has some interest in diversity and inclusion, but I have several concerns from the interview and from CERN's history as lagging – not leading – on inclusion. Until 2017 CERN had a "women's club", which – contrary to all the excellent women in STEM initiatives – meant wives of men who work at CERN.

It has fortunately changed its scope since then to support partners of any gender who come with someone to the area. But why did it take the lab until so recently to consider that "CERN woman" might better describe a woman who actually works there – and that partners of employees and users may not be their wives?

In the early 2010s there was also resistance to CERN setting up an LGBT staff network because it would be exclusionary towards straight people. When something finally got off the ground, posters were frequently torn down or defaced, which are also big red flags for a poor organizational culture and an atmosphere of not expecting consequences for homophobia.

Thomson, meanwhile, says nationality is not one of the "normal protected characteristics". Whether that is true varies by country, but nationality certainly has that status in the UK, thanks to the 2010 Equality Act. Thomson's comments don't fill me with confidence of his knowledge of the topic. If he is serious about diversity and inclusion, he needs to acknowledge the lab's previous failings.

Penny Jackson
Barrow-in-Furness, UK

Nobel dreams

In response to the article by Kate Shaw about why Nobel prizes are dominated by people who are mostly white men from western nations (February p17).

I fully support Shaw's call for a shift in the demographics of Nobel prize winners to ensure more equitable representation. But why stop there? Why not abolish prizes altogether? After all, very few major advances in physics are made single-handedly today, if indeed they ever were. Awarding prizes to individuals seems outdated.

Having worked both inside and outside academia, the former is far more pleasant, which makes it hard for me to understand why further inducements are needed at all. While I accept that pay and tenure do need improving, prizes don't address either issue. Wouldn't it be better if prize money were allocated to a programme to attract would-be physicists from under-represented groups, in a slightly less all-or-nothing way?

Jim Grozier
Brighton, UK

I have concerns about CERN lagging – not leading – on inclusion

Fusion realism

Following my article about the extreme extrapolations and optimism underpinning the UK's current fusion strategy (November 2024 pp17–18), I received a message alerting me to an English-language summary of a report from the technology-assessment office of the German parliament (Bundestag). Entitled *Towards a Possible Fusion Power Plant*, it provides a comprehensive and realistic assessment of fusion as an energy source by an independent body that gives impartial advice to the Bundestag and the German public.

The report's conclusions, which are consistent with my own, are in stark contrast to the rose-tinted view presented by the UK Atomic Energy Authority (UKAEA) under the leadership of chief executive Ian Chapman. The UKAEA's successes at attracting funding into fusion are impressive and, for some, this is all that matters. But I believe this has been achieved by setting PR above realistic narratives about fusion.

In January UK energy secretary Ed Miliband announced £410m of government investment in nuclear fusion, saying it meant that Britain was "now within grasping distance of unlocking the power of the sun and providing families with secure, clean, unlimited energy". But as Luca Garzotti, a senior UKAEA physicist and former colleague, subsequently pointed out in the *Guardian*, many severe difficulties still need to be overcome, making fusion the domain of long-term R&D.

Such opinions, although widely held, are rarely expressed publicly and are not encouraged. In my experience, most physicists in this area just roll their eyes in response to misleading PR about fusion and try to focus on their own bubble of expertise where politics doesn't feature. The government and public, however, appear to receive their information on fusion from public labs, private businesses and experts, which all have vested interests.

In my opinion, the UK should set up its own technology-assessment office – a sort of scientific equivalent to the Office for Budgetary Responsibility. Only then can UK research be held to account by an impartial assessment of the facts.

Guy Matthews
Oxfordshire, UK

Architectural flaws

In response to the Transactions article by Honor Powrie, who concluded that people at work fall into one of three categories: artist, artisan or architect (March p23).

As someone who worked for many years in the telecoms sector, I have seen too many good and technically gifted engineers, who one could classify as "artisans", move into project management. There they would now be expected to play the role of "architects", but they were simply unused to managing people and/or were too focused on details.

As such, they found it hard to prioritize work streams and, even worse, would always say "yes" to senior managers, who played the role of "artists". They didn't push back on unrealistic targets and ended up getting stressed and burnt out, with the team below them suffering in turn. One person in the wrong role can have a big impact on the wider organization.

Rhys Thomas
Denbigh, Wales

Rebellious thoughts

In response to Robert P Crease's article (March p21), describing how the physicist Freeman Dyson saw scientists as rebels, fighting other academics who don't respect them.

Crease writes about the need for scientists to discuss their differences and let dissenters have a voice. He then considers the politicization of science, and the way in which some powerful political figures are now opponents of science. Crease uses climate science as his major example, but fails to say that Dyson himself was a "heretic" on this issue.

In a 2009 interview with *Yale Environment 360*, he was described as "the poster child for global warming scepticism". Dyson was encouraging a debate among scientists, but this did not happen, with those scientists who thought like Dyson finding themselves marginalized. Today, the climate-science consensus fails to acknowledge that there are scientists who see problems with the messages being given to politicians and the public. Some of these are distinguished physicists, including members of the advisory council of the Global Warming Policy Foundation. We need to know what "rebellious thoughts" they have.

David Tyler
Manchester Metropolitan University, UK

Standing joke

In response to Matin Durrani's editorial (April p15), which suggested that an International Year of Classical Physics – this year's *Physics World* April Fool's joke – might actually make sense.

Durrani wonders if a celebration of classical physics might not be such a daft idea. "After all," he concludes, "with Newton's laws you know exactly where you stand." Surely, the answer, according to classical physics, is "on the shoulders of giants". But who, I'm intrigued to know, are the "giants" that we're standing on today?

Philip Bradfield
Edinburgh, UK

Fourth and finest

Robert P Crease visits the High Energy Photon Source near Beijing, which will be – when it opens later this year – the most advanced fourth-generation synchrotron-light source

Robert P Crease is a professor in the Department of Philosophy, Stony Brook University, US and writes the monthly Critical Point column for *Physics World*, robertpcrease.com, e-mail robert.crease@stonybrook.edu. His latest book is *The Leak: Politics, Activists, and Loss of Trust at Brookhaven National Laboratory*

I'm standing next to Yang Fugui in front of the High Energy Photon Source (HEPS) in Beijing's Huairou District about 50 km north of the centre of the Chinese capital. The HEPS isn't just another synchrotron light source. It will, when it opens later this year, be the world's most advanced facility of its type. Construction of this giant device started in 2019 and for Yang – a physicist who is in charge of designing the machine's beamlines – we're at a critical point.

"This machine has many applications, but now is the time to make sure it does new science," says Yang, who is a research fellow at the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences (CAS), which is building the new machine. With the ring completed, optimizing the beamlines will be vital if the facility is to open up new research areas.

From the air – Google will show you photos – the HEPS looks like a giant magnifying glass lying in a grassy field. But I've come by land, and from my perspective it resembles a large and gleaming low-walled silver sports stadium, surrounded by well-kept bushes, flowers and fountains.

I was previously in Beijing in 2019 at the time ground for the HEPS was broken when the site was literally a green field. Back then, I was told, the HEPS would take six-and-a-half years to build. We're still on schedule and, if all continues to run as planned, the facility will come online in December 2025.

Lighting up the world

There are more than 50 synchrotron radiation sources around the world, producing intense, coherent beams of electromagnetic radiation used for experiments in everything from condensed-matter physics to biology. Three significant hardware breakthroughs, one after the other, have created natural divisions among synchrotron sources, leading them to be classed by their generation.

Along with Max IV in Sweden, SIRIUS in Brazil and the Extremely Brilliant Source at the European Synchrotron Radiation Facility (ESRF) in France, the HEPS is a fourth-generation source. These days such devices are vital and prestigious pieces of scientific infrastructure, but synchrotron radiation began life as an unexpected nuisance (*Phys. Perspect.* **10** 438).

Classical electrodynamics says that charged particles undergoing acceleration – changing their momentum or velocity – radiate energy tangentially to their trajectories. Early accelerator builders assumed they could ignore

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the resulting energy losses. But in 1947, scientists building electron synchrotrons at the General Electric (GE) Research Laboratory in Schenectady, New York, were dismayed to find the phenomenon was real, sapping the energies of their devices.

Nuisances of physics, however, have a way of turning into treasured tools. By the early 1950s, scientists were using synchrotron light to study absorption spectra and other phenomena. By the mid-1960s, they were using it to examine the surface structures of materials. But a lot of this work was eclipsed by seemingly much sexier physics.

High-energy particle accelerators, such as CERN's Proton Synchrotron and Brookhaven's Alternating Gradient Synchrotron, were regarded as the most exciting, well-funded and biggest instruments in physics. They were the symbols of physics for politicians, press and the public – the machines that studied the fundamental structure of the world.

Researchers who had just discovered the uses of synchrotron light were forced to scrape parts for their instruments. These "first-generation" synchrotrons, such as "Tantalus" in Wisconsin, the Stanford Synchrotron Radiation Project in California, and the Cambridge Electron Accelerator in Massachusetts, were cobbled together from discarded pieces of high energy accelerators or grafted onto them. They were known as "parasites".

In the 1970s, accelerator physicists realized that synchrotron sources could become more useful by shrinking the angular divergence of the electron beam, thereby improving the "brightness". Renate Chasman and Kenneth Green devised a magnet array to maximize this property. Dubbed the "Chasman–Green lattice", it begat a second-generation of dedicated light sources, built not borrowed.

Hard on the heels of Synchrotron Radiation Light Source, which opened in the UK in 1981, the National Synchrotron Light Source (NSLS I) at Brookhaven was the first second-generation source to use such a lattice. China's oldest light source, the Beijing Synchrotron Radiation Facility, which opened to users in Beijing early in 1991, had a Chasman–Green lattice but also had to skim photons off an accelerator; it was a first-generation machine with a second-generation lattice. China's first fully second-generation machine was the Hefei Light Source, which opened later that year.

By then instruments called "undulators" were already starting to be incorporated into light sources. They increased brightness hundreds-fold, doing so by wiggling the electron beam up and down, causing a coherent addition of electron field through each wiggle. While undulators had been inserted into second-generation sources, the third generation built them in from the start.

The first of these light sources was the ESRF, which opened to users in 1994. It was followed by the Advanced Photon Source (APS) at Argonne National Laboratory in 1995 and SPring-8 in Japan in 1999. The first third-generation source on the Chinese mainland was the Shanghai Synchrotron Radiation Facility, which opened in 2009.

In the 2010s, "multi-bend achromat" magnets drastically shrank the size of beam elements, further increasing brilliance. Several third generation machines, including the APS, have been upgraded with achromats, turning third-generation machines into fourth. SIRIUS, which has an energy of 3 GeV, was the first fourth-generation machine to be built from scratch.

Set to operate at 6 GeV, the HEPS will be the first high-energy fourth-generation machine built from scratch. It is a step nearer to the "diffraction limit" that's ultimately imposed by the way the uncertainty principle limits the simultaneous specification of certain properties. It makes further shrinking of the beam possible – but only at the expense of lost brilliance. That limit is

Leading light The High Energy Photon Source (HEPS), due to start operating in December 2025, will be the world's most advanced synchrotron light source of its type.

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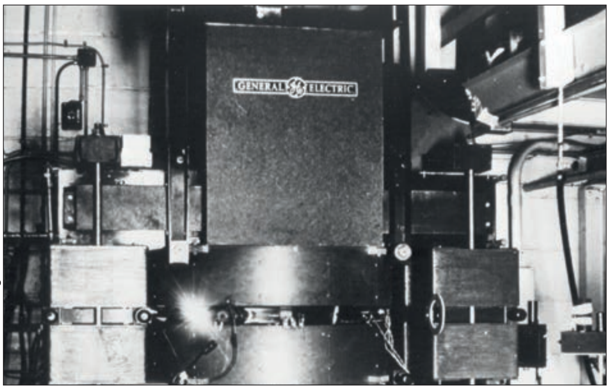
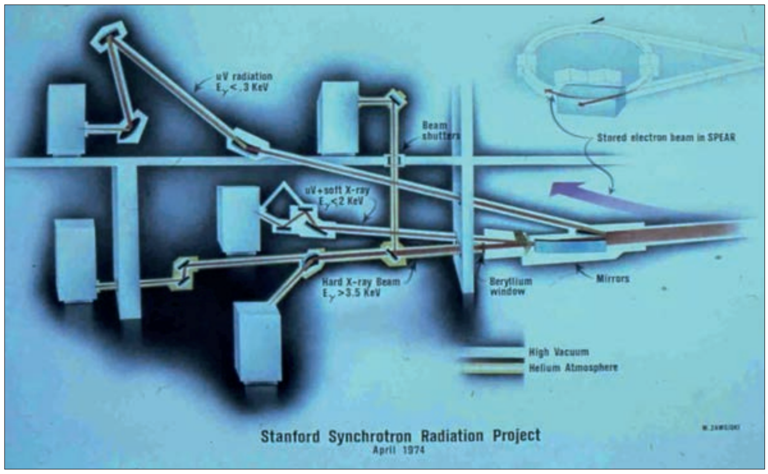


▲ **Where it all began** Synchrotron light is created whenever charged particles are accelerated. It gets its name because it was first observed in 1947 by scientists at the General Electric Research Laboratory in New York, who saw a bright speck of light through their synchrotron accelerator's glass vacuum chamber – the visible portion of that energy.

SLAC – Zawojski



▲ **First up** A drawing of plans for the Stanford Synchrotron Radiation Project in the US, which became one of the "first generation" of dedicated synchrotron-light sources when it opened in 1974.

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▲ **Next up** Fourth-generation sources, such as the High Energy Photon Source (HEPS), need to attract academic and business users from home and abroad. But only time will tell what kind of new science might be made possible.

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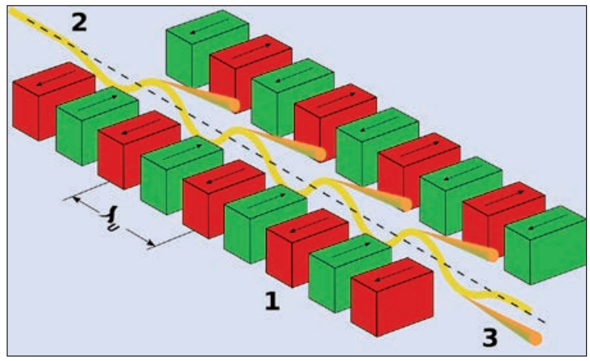
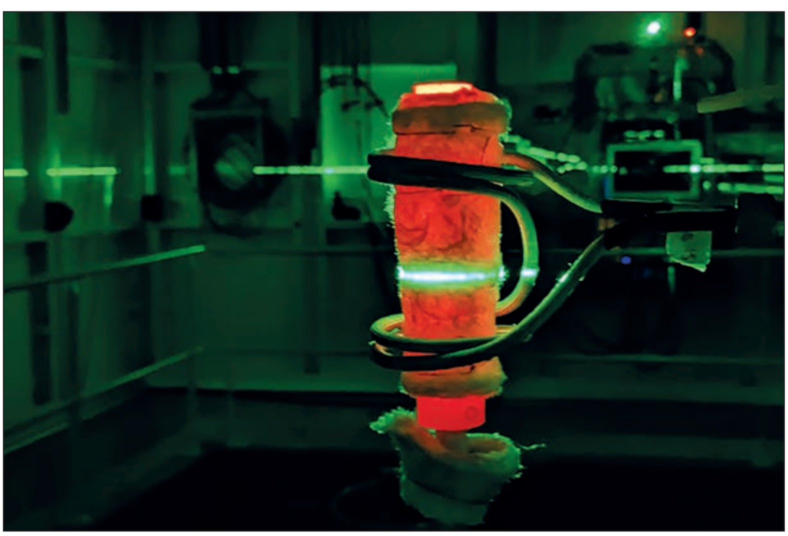


▲ **Second thoughts** Consisting of a periodic array of dipole magnets (red and green blocks), undulators have a static magnetic field that alternates with a wavelength λu. An electron beam passing through the magnets is forced to oscillate, emitting light hundreds of times brighter than would otherwise be possible (orange). Such undulators were added to second-generation synchrotron sources – but third-generation facilities had them built in from the start.

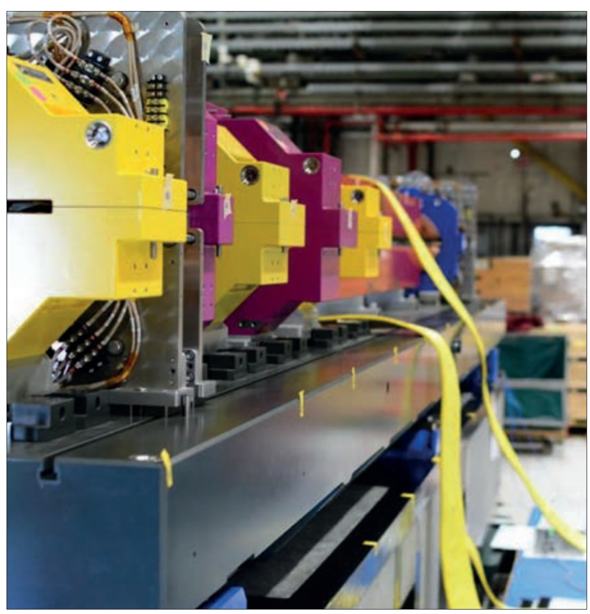
▼ **Fourth up** The BM18 beamline on the Extremely Brilliant Source (EBS) at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. The EBS is a dedicated fourth-generation light source, with the BM18 beamline being ideal for monitoring very slowly changing systems.

ESRF



▼ **Third in sequence** The Advanced Photon Source at the Argonne National Laboratory in the US, which is a third-generation synchrotron-light source.

Argonne National Laboratory



still on the horizon, but the HEPS draws it closer.

The HEPS is being built next to a mountain range north of Beijing, where the bedrock provides a stable platform for the extraordinarily sensitive beams. Next door to the HEPS is a smaller stadium-like building for experimental labs and offices, and a yet smaller building for housing behind that.

Staff at the HEPS successfully stored the machine's first electron beam in August 2024 and are now enhancing and optimizing parameters such as electron beam current strength and lifetime. When it opens at the end of the year, the HEPS will have 14 beamlines but is designed eventually to have around 90 experimental stations. "Our task right now is to build more beamlines" Yang told me.

Looking around

After studying physics at the University of Science and Technology in Hefei, Yang's first job was as a beamline designer at the HEPS. On my visit, the machine was still more than a year from being operational and the experimental hall surrounding the ring was open. It is spacious unlike of many US light sources I've been to, which tend to be crammed due to numerous upgrades of the machine and beamlines.

As with any light source, the main feature of the HEP is its storage ring, which consists of alternating straight sections and bends. At the bends, the electrons shed X-rays like rain off a spinning umbrella. Intense, energetic and finely tunable, the X-rays are carried off down beamlines, where are they made useful for almost everything from materials science to biomedicine.

We pass other stations optimized for 2D, 3D and nanoscale structures. Occasionally, a motorized vehicle loaded with equipment whizzes by, or workers pass us on bicycles. Every so often, I see an overhead red banner in Chinese with white lettering. Translating, Yang says the banners promote safety, care and the need for precision in doing high-quality work, signs of the renowned Chinese work ethic.

We then come to what is labelled a "pink" beam. Unlike a "white" beam, which has a broad spread of wavelengths, or a monochromatic beam of a very specific colour such as red, a pink beam has a spread of wavelengths that are neither broad nor narrow. This allows a much broader flux – typically two orders of magnitude more than a monochromatic beam – allowing a researcher fast diffraction patterns.

Another beamline, meanwhile, is labelled "tender" because its energy falls between 2 keV ("soft" X-rays) and 10 keV ("hard" X-rays). It's for materials "somewhere between grilled steak and Jell-O" one HEPS researcher quips to me, referring to the wobbly American desert. A tender beam is for purposes that don't require atomic-scale resolution, such as the magnetic behaviour of atoms.

Three beam pipes pass over the experimental hall to end stations that lie outside the building. They will be used, among other things, for applications in nanoscience, with a monochromator throwing out much of the X-ray beam to make it extremely coherent. We also pass a boxy, glass structure that is a clean room for making parts, as well as a straight pipe about 100 m long that will be used to test tiny vibrations in the Earth that might affect the precision of the beam.

The HEPS will need to get in users from business, convincing companies of the value of their machine

Challenging times

I once spoke to one director of the NSLS, who would begin each day by walking around that facility, seeing what the experimentalists were up to and asking if they needed help. His trip usually took about 5–10 minutes; my tour with Yang took an hour.

But fourth-generation sources, such as the HEPS, face two daunting challenges. One is to cultivate a community of global users. Nearby the HEPS is CAS's new Yanqi Lake campus, which lies on the other side of the mountains from Beijing, from where I can see the Great Wall meandering through the nearby hills. Faculty and students at CAS will form part of academic users of the HEPS, but how will the lab bring in researchers from abroad?

The HEPS will also need to get in users from business, convincing companies of the value of their machine. SPring-8 in Japan has industrial beamlines, including one sponsored by car giant Toyota, while China's Shanghai machine has beamlines built by the China Petroleum and Chemical Corporation (Sinopec).

Yang is certainly open to collaboration with business partners. "We welcome industries, and can make full use of the machine, that would be enough," he says. "If they contribute to building the beamlines, even better."

The other big challenge for fourth-generation sources is to discover what new things are made possible by the vastly increased flux and brightness. A new generation of improved machines doesn't necessarily produce breakthrough science; it's not like one can turn on a machine with greater brightness and a field of new capabilities unfolds before you.

Instead, what can happen is that techniques that are demonstrations or proof-of-concept research in one generation of synchrotron become applied in niche areas in the next, but become routine in the generation after that. A good example is speckle spectrometry – an interference-based technique that needs a sufficiently coherent light source – that should become widely used at fourth-generation sources like HEPS.

For the HEPS, the challenge will be to discover what new research in materials, chemistry, engineering and biomedicine these techniques will make possible. Whenever I ask experimentalists at light sources what kinds of new science the fourth-generation machines will allow, the inevitable answer is something like, "Ask me in 10 years!"

Yang can't wait that long. "I started my career here," he says, gesturing excitedly to the machine. "Now is the time – at the beginning – to try to make this machine do new science. If it can, I'll end my career here!" ■

A frozen quantum arrow: the quantum Zeno effect

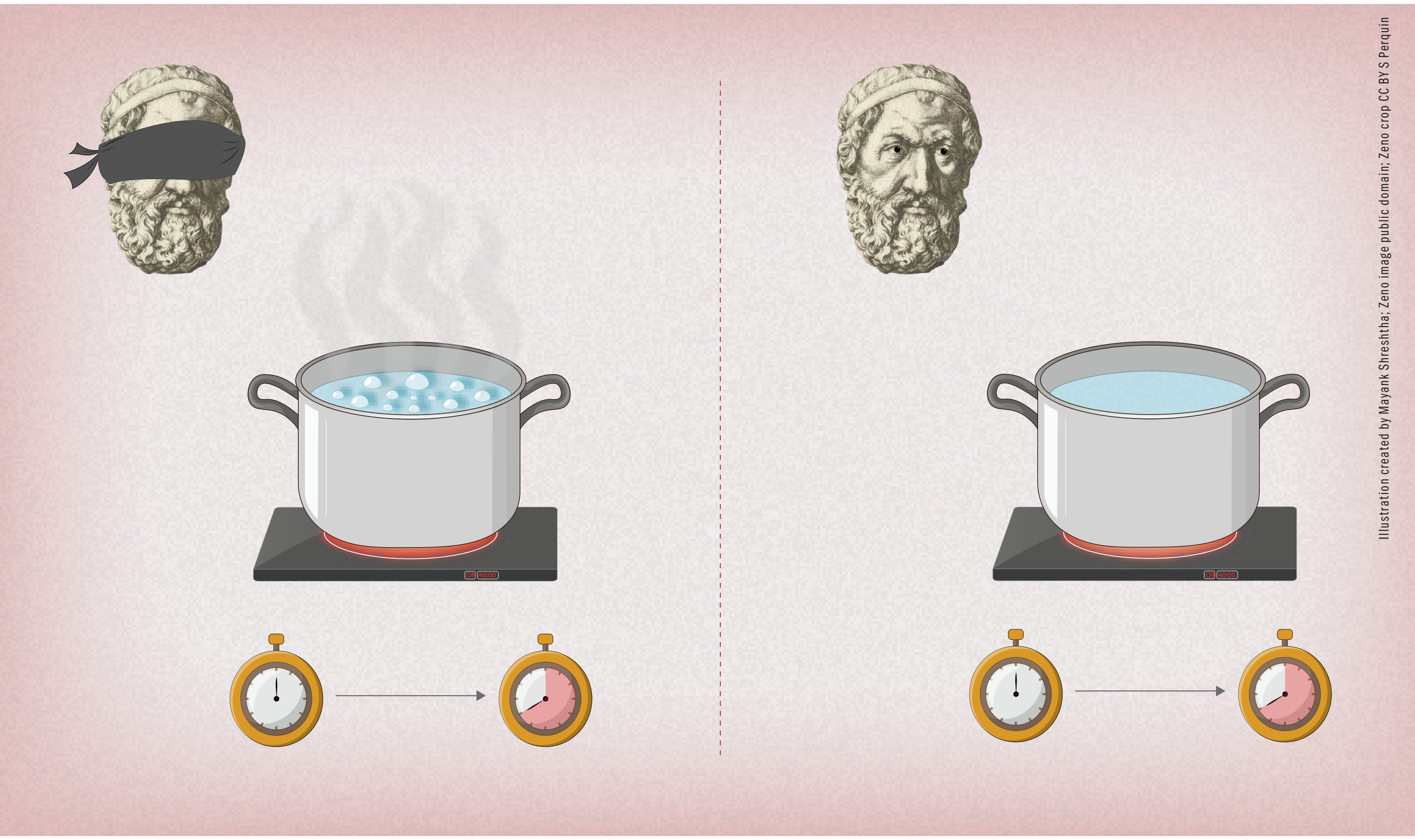


Illustration created by Mayank Shreshtha; Zeno image public domain; Zeno crop CC BY S Perquin

For the International Year of Quantum Science and Technology, *Physics World* is shining a spotlight on quantum effects so "weird" they make superposition and entanglement seem almost ordinary. In the first of this series, Margaret Harris sets her sights on the quantum Zeno effect

Imagine, if you will, that you are a quantum system. Specifically, you are an unstable quantum system – one that would, if left to its own devices, rapidly decay from one state (let's call it "awake") into another ("asleep"). But whenever you start to drift into the "asleep" state, something gets in the way. Maybe it's a message pinging on your phone. Maybe it's a curious child peppering you with questions. Whatever it is, it jolts you out of your awake–asleep superposition and projects you back into wakefulness. And because it keeps happening faster than you can fall asleep, you remain awake, diverted from slumber by a stream of interruptions – or, in quantum terms, measurements.

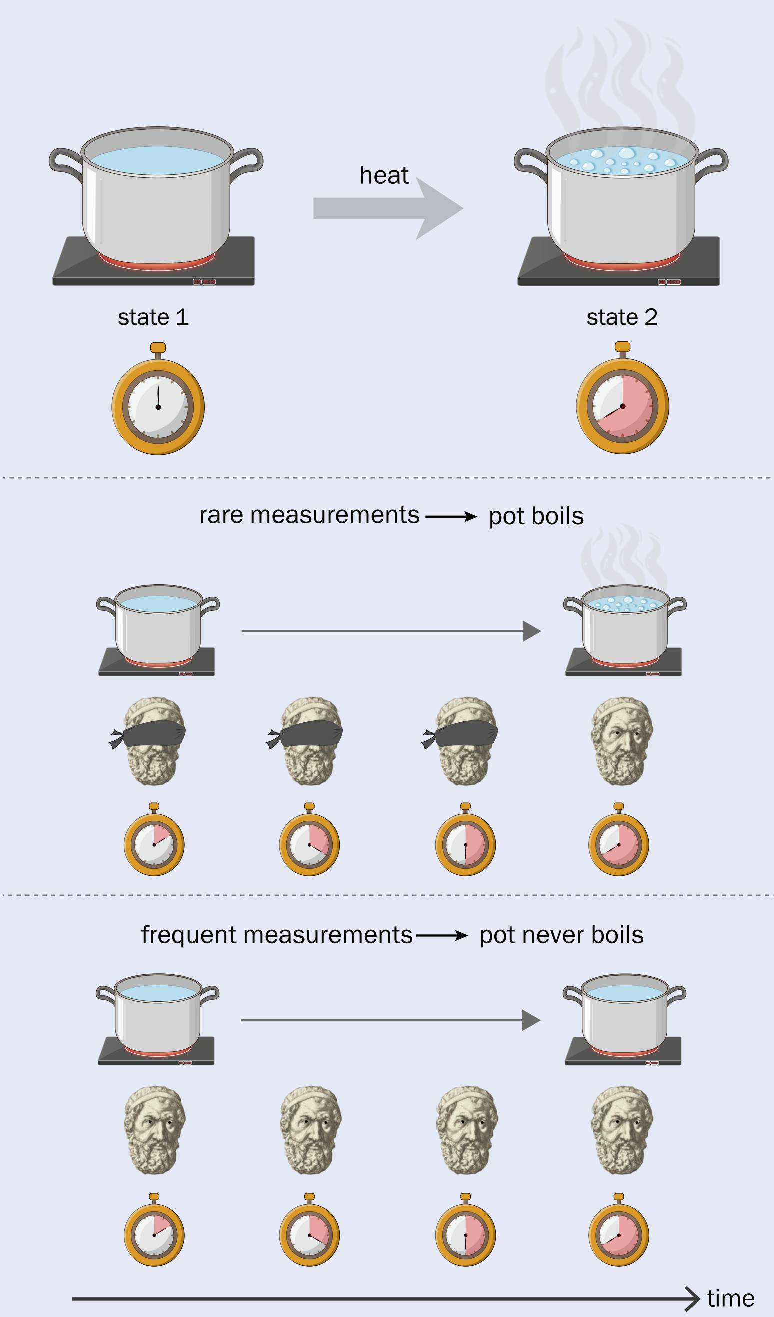
This phenomenon of repeated measurements "freezing" an unstable quantum system into a particular state is known as the quantum Zeno effect (figure 1). Named after a paradox from ancient Greek philosophy, it was hinted at in the 1950s by the scientific polymaths Alan Turing and John von Neumann but only fully articulated in 1977 by the physicists Baidyanath Misra and George Sudarshan (*J. Math. Phys.* **18** 756).

Since then, researchers have observed it in dozens of quantum systems, including trapped ions, superconducting flux qubits and atoms in optical cavities. But the apparent ubiquitousness of the quantum Zeno effect cannot hide the strangeness at its heart. How does the simple act of measuring a quantum system have such a profound effect on its behaviour?

INTERNATIONAL YEAR OF Quantum Science and Technology

Margaret Harris is an online editor at *Physics World*

1 A watched quantum pot



Applying heat to a normal, classical pot of water will cause it to evolve from state 1 (not boiling) to state 2 (boiling) at the same rate regardless of whether anyone is watching it (even if it doesn't seem like it). In the quantum world, however, a system that would normally evolve from one state to the other if left unobserved (blindfolded Zeno) can be "frozen" in place by repeated frequent measurements (eyes-open Zeno).

A watched quantum pot

"When you come across it for the first time, you think it's actually quite amazing because it really shows that the measurement in quantum mechanics influences the system," says Daniel Burgarth, a physicist at the Friedrich-Alexander-Universität in Erlangen-Nürnberg, Germany, who has done theoretical work on the quantum Zeno effect.

Giovanni Barontini, an experimentalist at the University of Birmingham, UK, who has studied the quantum Zeno effect in cold atoms, agrees. "It doesn't have a classical analogue," he says. "I can watch a classical system doing something forever and it will continue doing it. But a quantum system really cares if it's watched."

For the physicists who laid the foundations of quantum mechanics a century ago, any connection between measurement and outcome was a stumbling block. Several tried to find ways around it, for example by formalizing a role for observers in quantum wavefunction collapse (Niels Bohr and Werner Heisenberg); introducing new "hidden" variables (Louis de Broglie and David Bohm); and even hypothesizing the creation of new universes with each measurement (the "many worlds" theory of Hugh Everett).

But none of these solutions proved fully satisfactory. Indeed, the measurement problem seemed so intractable that most physicists in the next generation avoided it, preferring the approach sometimes described – not always pejoratively – as "shut up and calculate".

Today's quantum physicists are different. Rather than treating what Barontini calls "the apotheosis of the measurement effect" as a barrier to overcome or a triviality to ignore, they are doing something few of their forebears could have imagined. They are turning the quantum Zeno effect into something useful.

Noise management

To understand how freezing a quantum system by measuring it could be useful, consider a qubit in a quantum computer. Many quantum algorithms begin by initializing qubits into a desired state and keeping them there until they're required to perform computations. The problem is that quantum systems seldom stay where they're put. In fact, they're famously prone to losing their quantum nature (decohering) at the slightest disturbance (noise) from their environment. "Whenever we build quantum computers, we have to embed them in the real world, unfortunately, and that real world causes nothing but trouble," Burgarth says.

Quantum scientists have many strategies for dealing with environmental noise. Some of these strategies are passive, such as cooling superconducting qubits with dilution refrigerators and using electric and magnetic fields to suspend ionic and atomic qubits in a vacuum. Others, though, are active. They involve, in effect, tricking qubits into staying in the states they're meant to be in, and out of the states they're not.

The quantum Zeno effect is one such trick. "The way it works is that we apply a sequence of kicks to the system, and we are actually rotating the qubit with each kick," Burgarth explains. "You're rotating the system, and then effectively the environment wants to rotate it in the other direction." Over time, he adds, these opposing rotations average out, protecting the system from noise by freezing it in place.

Quantum state engineering

While noise mitigation is useful, it's not the quantum Zeno application that interests Burgarth and Barontini the most. The real prize, they agree, is something called quantum state engineering, which is much more complex than simply preventing a quantum system from decaying or rotating.

The source of this added complexity is that real quantum systems – much like real people – usually have more than two states available to them. For example, the set of permissible "awake" states for a person – the Hilbert space of wakefulness, let's call it – might include states such as cooking dinner, washing dishes and cleaning the bathroom. The goal of quantum state engineering is to restrict this state-space so the system can only occupy the state(s) required for a particular application.

As for how the quantum Zeno effect does this, Barontini explains it by referring to Zeno's original, classical paradox. In the fifth century BCE, the philosopher Zeno of Elea posed a conundrum based on an arrow flying through the air. If you look at this arrow at any possible moment during its flight, you will find that in that instant, it is motionless. Yet somehow, the arrow still moves. How?

In the quantum version, Barontini explains, looking at the arrow freezes it in place. But that isn't the only thing that happens. "The funniest thing is that if I look somewhere, then the arrow cannot go where I'm looking," he says. "It will have to go around it. It will have to modify its trajectory to go outside my field of view."

By shaping this field of view, Barontini continues, physicists can shape the system's behaviour. As an example, he cites work by Serge Haroche, who shared the 2012 Nobel Prize for Physics with another notable quantum Zeno experimentalist, David Wineland.

In 2014 Haroche and colleagues at the École Normale Supérieure (ENS) in Paris, France, sought to control the dynamics of an electron within a so-called Rydberg atom. In this type of atom, the outermost electron is very weakly bound to the nucleus and can occupy any of several highly excited states.

The researchers used a microwave field to divide 51 of these highly excited Rydberg states into two groups, before applying radio-frequency pulses to the system. Normally, these pulses would cause the electron to hop between states. However, the continual "measurement" supplied by the microwave field meant that although the electron could move within either group of states, it could not jump from one group to the other. It was stuck – or, more precisely, it was in a special type of quantum superposition known as a Schrödinger cat state.

Restricting the behaviour of an electron might not sound very exciting in itself. But in this and other experiments, Haroche and colleagues showed that imposing such restrictions brings forth a slew of unusual quantum states. It's as if telling the system what it can't do forces it to do a bunch of other things instead, like a procrastinator who cooks dinner and washes dishes to avoid cleaning the bathroom. "It really enriches your quantum toolbox," explains Barontini. "You can generate an entangled state that is more entangled or methodologically more useful than other states you could generate with traditional means."

Just what is a measurement, anyway?

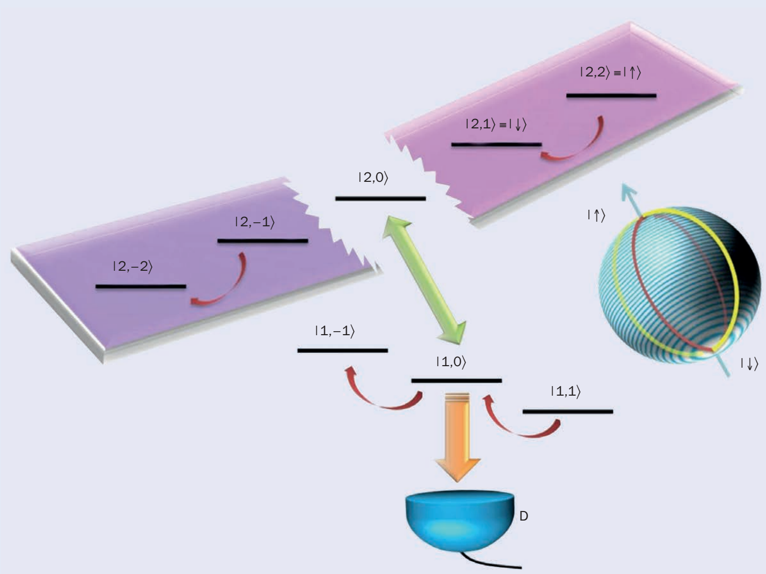
As well as generating interesting quantum states, the quantum Zeno effect is also shedding new light on the nature of quantum measurements. The question of what constitutes a "measurement" for quantum Zeno purposes turns out to be surprisingly broad. This was elegantly demonstrated in 2014, when physicists led by Augusto Smerzi at the Università di Firenze, Italy, showed that simply shining a resonant laser at their quantum system (figure 2) produced the same quantum Zeno dynamics as more elaborate "projective" measurements – which in this case involved applying pairs of laser pulses to the system at frequencies tailored to specific atomic transitions. "It's fair to say that almost anything causes a Zeno effect," says Burgarth. "It's a very universal and easy-to-trigger phenomenon."

Other research has broadened our understanding of what measurement can do. While the quantum Zeno effect uses repeated measurements to freeze a quantum system in place (or at least slow its evolution from one state to another), it is also possible to do the opposite and use measurements to accelerate quantum transitions. This phenomenon is known as the quantum anti-Zeno effect, and it has applications of its own. It could, for example, speed up reactions in quantum chemistry.

Over the past 25 years or so, much work has gone into understanding where the ordinary quantum Zeno effect leaves off and the quantum anti-Zeno effect begins. Some systems can display both Zeno and anti-Zeno dynamics, depending on the frequency of the measurements and various environmental conditions. Others seem to favour one over the other.

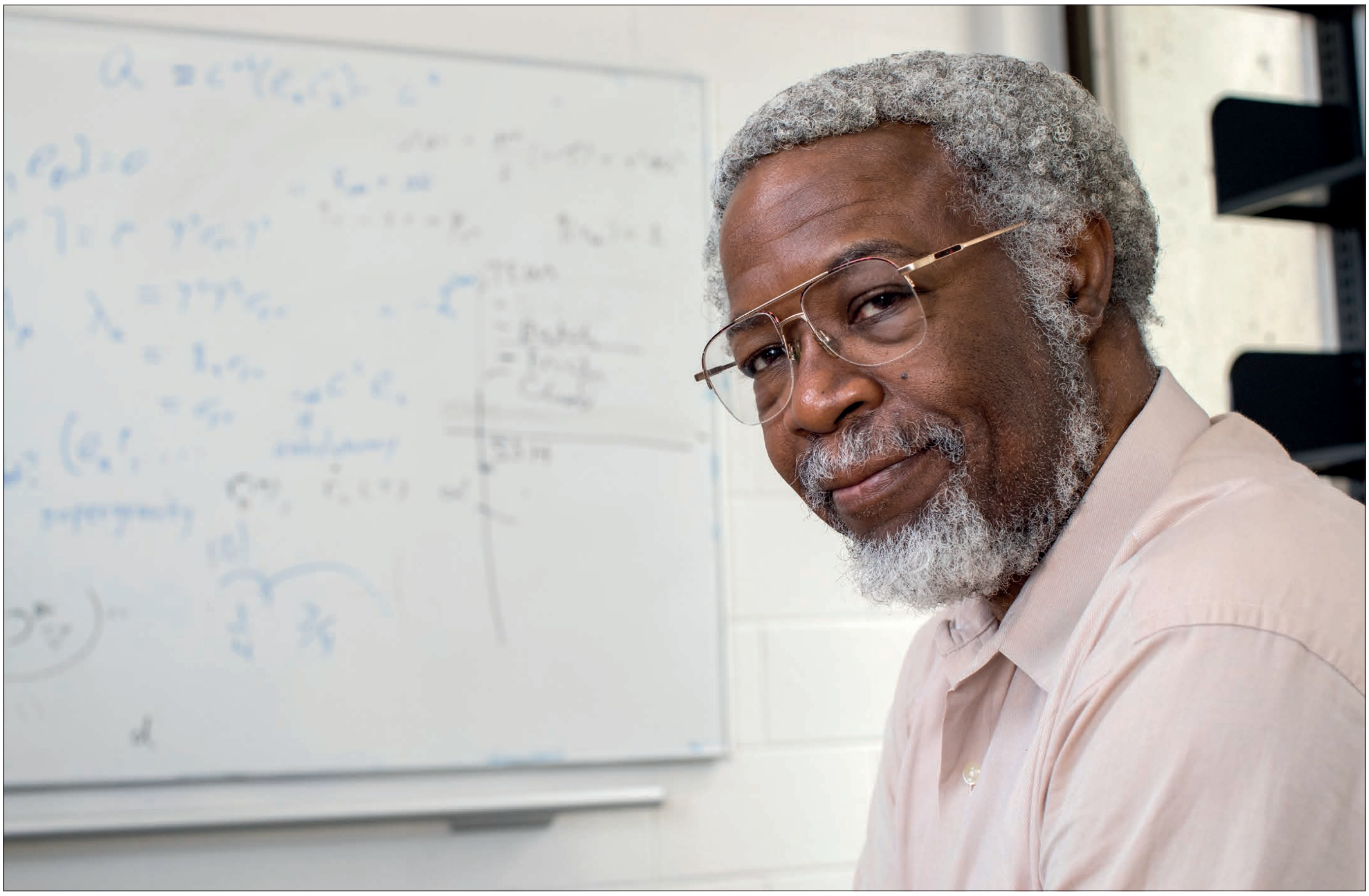
But regardless of which version turns out to be the most important, quantum Zeno research is anything but frozen in place. Some 2500 years after Zeno posed his paradox, his intellectual descendants are still puzzling over it. ■

2 Experimental realization of quantum Zeno dynamics



The energy level structure of a population of ultracold ^{87}Rb atoms , evolving in a five-level Hilbert space given by the five spin orientations of the *F*=2 hyperfine ground state. An applied RF field (red arrows) couples neighbouring quantum states together and allows atoms to "hop" between states. Normally, atoms initially placed in the $|F, m_F> = |2,2>$ state would cycle between this state and the other four *F*=2 states in a process known as Rabi oscillation. However, by introducing a "measurement" – shown here as a laser beam (green arrow) resonant with the transition between the |1,0> state and the |2,0> state – Smerzi and colleagues drastically changed the system's dynamics, forcing the atoms to oscillate between just the |2,2> and |2,1> states (represented by up and down arrows on the so-called Bloch sphere at right). An additional laser beam (orange arrow) and the detector D were used to monitor the system's evolution over time. (First published in *Nature Commun.* **5** 3194. Reproduced with permission from Springer Nature)

Nature Commun. **5** 3194



Brown University

A theoretical physicist's bucket list, 10 years later

Jim Gates talks to Margaret Harris about the discoveries he can tick off his "theorist's bucket list", adds some new ones, and delves into the state of science and society in the US today

In 2014 the American mathematical physicist S James Gates Jr shared his "theorist's bucket list" of physics discoveries he would like to see happen before, as he puts it, he "shuffles off this mortal coil". A decade later, *Physics World*'s Margaret Harris caught up once more with Gates, who is now at the University of Maryland, US, to see what discoveries he can check off his list; what he would still like to see discovered, proven or explored; and what more he might add to the list, as of 2025.

The first thing on your list 10 years ago was the discovery of the Higgs boson, which had happened. The next thing on your list was gravitational waves.

The initial successful detection of gravity waves [in 2015] was a spectacular day for a lot of us. I had been following the development of that detector [the Laser Interferometer Gravitational-wave Observatory, or LIGO] almost from its birth. The first time I heard about detecting gravity waves was around 1985. I was a new associate professor at Maryland, and a gentleman by the name of [Richard] Rick Isaacson, who was a programme officer at the National Science Foundation (NSF), called me one day into his office to show me a proposal from a Caltech-MIT collaboration to fund a detector. I read it and I said this will never work. Fortunately, Isaacson is a superhero and made this happen because for decades he was the person in the NSF with the faith that this could happen; so when it did, it was just an amazing day.

Why is the discovery of these gravitational waves so exciting for physicists?

Albert Einstein's final big prediction was that there would be observable gravitational waves in the universe. It's very funny – if you go back into the literature, he first says yes this is possible, but at some point he changes his mind again. It's very interesting to think about how human it is to bounce back and forth, and then to have Mother Nature say look, you got it right the first time. So such a sharp confirmation of the theory of general relativity was unlike anything I could imagine happening in my lifetime, quite frankly,

CC0 1.0 The Virgo collaboration

Wish fulfilled Aerial view of the Virgo detector in Italy. This facility became the third to detect gravitational waves, in 2017, after the two LIGO detectors in the US. As more gravitational-wave facilities come online around the world, we increase our chance of detecting gravitons.

even though it was on my bucket list.

The other thing is that our species knows about the heavens mostly because there have been "entities" that are similar to Mercury, the Greek god who carried messages from Mount Olympus. In our version of the story, Mercury is replaced by photons. It's light that has been telling us for hundreds of thousands of years, maybe a million years, that there's something out there and this drove the development of science for several hundred years. With the detection of gravitational waves, there's a new kid on the block to deliver the message, and that's the graviton. Just like light, it has both particle and wave aspects, so now we have detected gravitational waves, the next big thing is to be able to detect gravitons.

We are not completely clear on exactly how to see gravitons, but once we have that knowledge, we will be able to do something that we've never been able to do as a species in this universe. After the initial moments of the Big Bang, there was a period of darkness, when matter was far too hot to form neutral atoms, and light could not travel through the dense plasma. It took 380 000 years for electrons to be trapped in orbits around nuclei, forming the first atoms.

Eventually, the universe had expanded so much that the average temperature and density of particles had dropped enough for light to travel. Now what's really interesting is if you look at the universe via photons, you can only look so far back up to that point when light was first able to travel through the universe, often referred to as the "first dawn". We detected this light in the 1960s, and it's called the cosmic microwave background. If you want to peer further back in time beyond this period, you can't use light but you can use gravitational waves. We will be able as a species eventually to look maybe all the way back to the Big Bang, and that's remarkable.

What's the path to seeing gravitons experimentally?

At the time that gravitational waves were detected by LIGO there were three different detectors, two in the US and one on the border of France and Italy called Virgo. There is a new LIGO site coming online in India now, and so what's going to happen, provided there continues to be a global consensus on continuing to do this science, is that more sites like this are going to come online, which will give us higher-fidelity pictures. It's going to be a difference akin to going from black and white TV to colour.

AUDIO Listen to an extended version of this interview

> Observations of particle physics are not the only way to think about finding supersymmetry. Within string theory, there might be cosmological implications

In the universe now, the pathway to detecting gravitons involves two steps. First, you probably want to measure the polarization of gravitons, and Fabry–Pérot interferometers, such as LIGO, have that capacity. If it's a polarized graviton wave, the bending of space-time has a certain signature, whether it's left or right-handed. If we are lucky enough we will actually see that polarization, I would guess within the next 10 years.

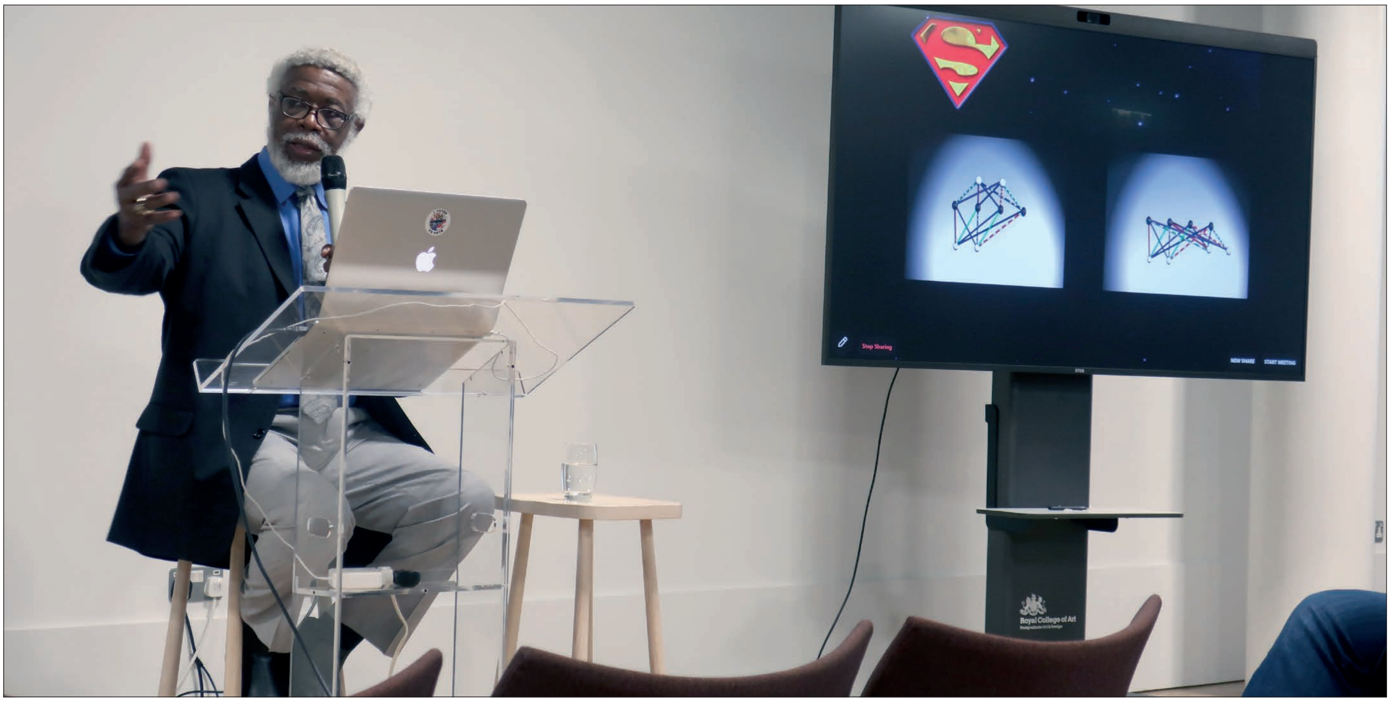
The second step is quantization, which is going to be a challenge. Back in the 1960s a physicist at the University of Maryland named Joseph Weber developed what are now called Weber bars. They're big metal bars and the idea was you cool them down and then if a graviton impinges on these bars, it would induce lattice vibrations in the metal, and you would detect those. I suspect there's going to be a big push in going back and upgrading that technology. One of the most exciting things about that is they might be quantum Weber bars. That's the road that I could see to actually nailing down the existence of the graviton.

Number three on your bucket list from a decade ago was supersymmetry. How have its prospects developed in the past 10 years?

At the end of the Second World War, in an address to the Japanese people after the atomic bombing of Hiroshima and Nagasaki, the Japanese emperor [known as Showa in Japan, Hirohito in the West] used the phrase "The situation has developed not necessarily to our advantage", and I believe we can apply that to supersymmetry. In 2006 I published a paper where I said explicitly I did not expect the Large Hadron Collider (LHC) to detect supersymmetry. It was a back-of-the-envelope calculation, where I was looking at the issue of anomalous magnetic moments. Because the magnetic moments can be sensitive to particles you can't actually detect, by looking at the anomalous magnetic moment and then comparing the measured value to what is predicted by all the particles that you know, you can put lower bounds on the particles that you don't know, and that's what I did to come up with this number.

It looked to me like the lightest "superpartner" was probably going to be in the range of 30 Tev. The LHC's initial operations were at 7 TeV and it's currently at 14 TeV, so I'm feeling comfortable about this issue. If it's not found by the time we reach 100 Tev, well, I'm likely going to kick the bucket by the time we get that technology. But I am confident that SUSY is out there in nature for reasons of quantum stability.

Also, observations of particle physics – particularly high-precision observations, magnetic moments, branching ratios, decay



Margaret Harris

Still hopeful Jim Gates discusses his career and his lifelong interest in supersymmetry with an audience at the Royal College of Art in London earlier this year.

rates – are not the only way to think about finding supersymmetry. In particular, one could imagine that within string theory, there might be cosmological implications (arXiv:1907.05829), which are mostly limited to the question of dark matter and dark energy. When it comes to the dark-matter contribution in the universe, if you look at the mathematics of supersymmetry, you can easily find that there are particles that we haven't observed yet and these might be the lightest supersymmetric particle.

The final thing in your bucket list, which you've touched on, was superstring theory. When we last spoke, you said that you did not expect to see it. How has that changed, if at all?

Unless I'm blessed with a life as long as Methuselah, I don't expect to see that. I think that for superstring theory to win observational acceptance, it will likely come about not from a single experiment, but from a confluence of observations of the cosmology and astrophysics type, and maybe then the lightest super symmetric particle will be found. By the way, I don't expect extra dimensions ever to be found. But if I did have several hundred years to live, those are the kinds of likely expectations I would have.

And have you added anything new to your bucket list over the past 10 years?

Yes, but I don't quite know how to verbalize it. It has to do with a confluence of things around quantum mechanics and information. In my own research, one of the striking things about the graphs that we developed to understand the representation theory of supersymmetry –we call them "adinkras" – is that error-correcting codes are part of these constructs. In fact, for me this is the proudest piece of research I've ever enabled – to discover a kind of physics law, or at least the possibility of a physics law, that includes error-correcting codes. I know of no previous example in history where a law of physics includes error-correcting codes, but we can clearly see it in the mathematics around these graphs (arXiv:1108.4124).

That had a profound impact on the way I think about information theory. In the 1980s, John Wheeler came up with this very interesting way to think about quantum mechanics ("Information, physics, quantum: the search for links" *Proc. 3rd Int. Symp. Foundations of Quantum Mechanics*, Tokyo, 1989, pp354–368). A shorthand phrase to describe it is "it from bit" – meaning that the information that we see in the universe is somehow connected to bits. As a young person, I thought that was the craziest thing I had ever heard. But in my own research I saw that it's possible for the laws of physics to contain bits in the form of error-correcting codes, so I had to then rethink my rejection of what I thought was a wild idea.

In fact, now that I'm old, I've concluded that if you do theoretical physics long enough, you too can become crazy – because that's what sort of happened to me! In the mathematics of supersymmetry, there is no way to avoid the presence of error-correcting codes and therefore bits. And because of that my new item for the bucket list is an actual observational demonstration that the laws of quantum mechanics entail the use of information in bits.

In terms of when we might see that, it will be long after I've gone. Unless I somehow get another 150 years of life. Intellectually, that's how long I would estimate it will take as of now, because the hints are so stark, they suggest something is definitely going on.

We've talked a little bit about how science has changed in the past 10 years. Of course, science is not unconnected with the rest of the world. There have been some changes in other things that impinge on science, particularly those recently developing in the US. What's your take on that?

Unfortunately, it's been very predictable. Two years ago I wrote an essay called "Expelled from the mountain top?" (*Science* **380** 993). I took that title from a statement by Martin Luther King Jr where he says "I've been to the mountaintop", and the part about being "expelled" refers to closing down opportunities for people of colour. In my essay I talked about the fact that it looked to me like the US was moving in a direction where it would be less likely that people like me – a man of colour, an African American, a scientist – would continue to have access to the kind of educational training that it takes to do this [science].

I'm still of the opinion that the 2023 decision the Supreme Court made [about affirmative action] doesn't make sense. What it is saying is that diversity has no role in driving innovation. But there's lots of evidence that that's not right. How do you think cities came into existence? They are places where innovation occurs because you have diverse people coming to cities.

You add to that the presence of a new medium – the Internet – and the fact that with this new medium, anyone can reach millions of people. Why is this a little bit frightening? Well, fake news. Misinformation.

I ran into a philosopher about a year ago, and he made a statement that I found very profound. He said think of the printing press. It allowed books to disseminate through Western European society in a way that had never happened before, and therefore it drove literacy. How long did it take for literacy levels to increase? 50 to 100 years. Then he said, now let's think about the Internet. What's different about it? The difference is that anyone can say anything and reach millions of people. And so the challenge is how long it will take for our species to learn to write the Internet without misinformation or fake news. And if he's right, that's 100, 150 years. That's part of the challenge that the US is facing. It's not just a challenge for my country, but somehow it seems to be particularly critical in my country.

So what does this have to do with science? In 2005 I was invited to deliver a plenary address to the American Association for the Advancement of Science annual meeting. In that address, I made statements about science being turned off because it was clear to me, even back then in my country, that there were elements in our society that would be perfectly happy to deny evidence brought forth by scientists, and that these elements were becoming stronger.

You put this all together and it's going to be an extraordinarily important, challenging time for the continuation of science because, certainly at the level of fundamental science, this is something that the public generally has to say "Yes, we want to invest in this". If you have agencies and agents in society denying vaccines, for example, or denying the scientific evidence around evolution or climate change, if this is going to be something that the public buys into, then science itself potentially can be turned off, and that's the thing I was warning about in 2005.

What are some practical things that members of the scientific community can do to help prevent that from happening?

First of all, come down from the ivory tower. I've been a part of some activities, and they normally are under the rubric of restoring the public's trust in science, and I think that's the wrong framing. It's the public faith in science that's under attack. So from my perspective, that's what I'd much rather have people really thinking about.

What would you say the difference is between having trust in science and having faith in science?

In my mind, if I trust something, I will listen. If I have faith in something, I will listen and I will act. To me, this is a sharp distinction.

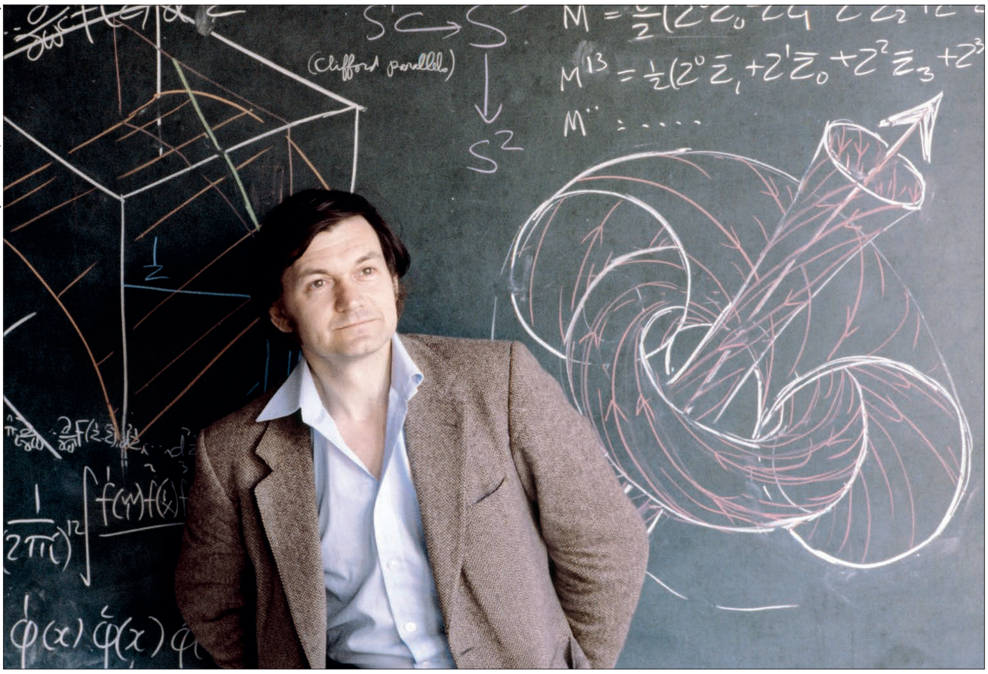
Personally, even though I expect that it's going to be really hard going forward, I am hopeful. And I would urge young people never to lose that hope. If you lose hope, there is no hope. It's just that simple. And so I am hopeful. Even though people may take my comments as "oh, he's just depressed" – no, I'm not. Because I'm a scientist, I believe that one must, in a clear-eyed, hard-headed manner, look at the evidence that's in front of us and not sentimentally try to dodge what you see, and that's who I am. So I am hopeful in spite of all the things that I've just said to you. ■

Margaret Harris is an online editor of *Physics World*

Reviews

Roger Penrose: spoiled genius

Chanda Prescod-Weinstein reviews *The Impossible Man: Roger Penrose and the Cost of Genius* by Patchen Barss



Anthony Howarth/Science Photo Library

Impossible man Roger Penrose at the University of Oxford with his diagram of a twistor in 1980.

The Impossible Man: Roger Penrose and the Cost of Genius
Patchen Barss
2024 Basic Books (US)/Atlantic Books (UK) 352pp $32/£25hb

I was unprepared for the Roger Penrose that I met in *The Impossible Man*. As a PhD student training in relativity and quantum gravity at the Perimeter Institute for Theoretical Physics in Waterloo, Canada, I once got to sit next to Penrose. Unsure of what to say to the man whose ideas about black-hole singularities are arguably why I took an interest in becoming a physicist, I asked him how he had come up with the idea for the space-time diagrams now known as "Penrose diagrams".

Penrose explained to me that he simply couldn't make sense of space-time without them, that was all. He spoke in kind terms, something I wasn't quite used to. I was more familiar with people reacting as if my questions were stupid or impertinent. What I felt from Penrose – who eventually shared the 2020 Nobel Prize for Physics with Reinhard Genzel and Andrea Ghez for his work on singularities – was humility and generosity.

In hindsight, I wonder if I overread him, or if, having been around too many brusque theoretical physicists, my bar as a PhD student was simply too low. The Penrose of *The Impossible Man* isn't so much humble as oblivious and, in my reading, quite spoiled. As a teenager he was especially good at taking care of his sister and her friends, generous with his time and thoughtfulness. But it ends there.

As we learn in this biography – written by the Canadian journalist Patchen Barss – one of those young friends, Judith Daniels, later became the object of Penrose's affection when he was a distinguished faculty member at the University of Oxford in his 40s. A significant fraction of the book is centred on Penrose's relationship with Daniels, whom he became reacquainted with in the early 1970s when she was an undergraduate studying mathematics at John Cass College in London.

At the time Penrose was unhappily married to Joan, an American he'd met in 1958 when he was a postdoc at the University of Cambridge. In Barss's telling, Penrose essentially forces Daniels into the position of muse. He writes her copious letters explaining his intellectual ideas and communicating his inability to get his work done without replies from her, which he expects to contain critical analyses of his scientific proposals.

The letters are numerous and obsessive, even when her replies are thin and distant. Eventually, Penrose also begins to request something more – affection and even love. He wants a relationship with her. Barss never exactly states that this was against Daniels's will, but he offers readers sufficient details of her letters to Penrose that it's hard to draw another conclusion.

Unanswered questions

Barss was able to read her letters because they had been returned to Penrose after Daniels's death in 2005. Penrose, however, never re-examined any of them until Barss interviewed him for this biography. This raises a lot of questions that remain unanswered by the end of the book. In particular, why did Daniels continue to participate in a correspondence that was eventually thousands of pages long on Penrose's side?

My theory is that Daniels felt she owed it to this great man of science. She also confesses at one point that she had a childhood crush on him. Her affection was real, even if not romantic; it is as if she was trapped in the dynamic. Penrose's lack of curiosity about the letters after her death is also strange to me. Daniels was a significant figure in his life, yet her death and memory seem to have been unremarkable to him for much of his later life.

By the mid-1970s, when Daniels was finally able to separate herself from what was – on Penrose's side – an extramarital emotional affair,

> Judith Daniels was a significant figure in Penrose's life, yet her death and memory seem to have been unremarkable to him for much of his later life

Penrose went seeking new muses. They were always female students of mathematics and physics.

Just when it seems like we've met the worst of Penrose's treatment of women, we're told about his "physical aggression" toward his eventual ex-wife Joan and his partial abandonment of the three sons they had together. This is glossed over very quickly. And it turns out there is even more.

Penrose, like many of his contemporaries, primarily trained male students. Eventually he did take on one woman, Vanessa Thomas, who was a PhD student in his group at Oxford's Mathematical Institute, where he'd moved in 1972.

Thomas never finished her PhD; Penrose pursued her romantically and that was the end of her doctorate. As scandalous as this is, I didn't find the fact of the romance especially shocking because it is common enough in physics, even if it is increasingly frowned upon and, in my opinion, generally inappropriate. For better or worse, I can think of other examples of men in physics who fell in love with women advisees.

But in all the cases I know of, the woman has gone on to complete her degree either under his or someone else's supervision. In these same cases, the age difference was usually about a decade. What happened with Thomas – who married Penrose in 1988 – seems like the worst-case scenario: a 40-year age difference and a budding star of mathematics, reduced to serving her husband's career. Professional boundaries were not just transgressed, but obliterated.

Barss chooses not to offer much in the way of judgement about the impact that Penrose had on the women in science whom he made into muses and objects of romantic affection. The only exception is Ivette Fuentes, who was already a star theoretical physicist in her own right when Penrose first met her in 2012. Interview snippets with Fuentes reveal that the one time Penrose spoke of her as a muse, she rejected him and their friendship until he apologized.

No woman, it seems, had ever been able to hold him to the fire before. Fuentes does, however, describe how Penrose gave her an intellectual companion, something she'd previously been denied by the way the physics community is structured around insider "families" and pedigrees. It is interesting to read this in the context of Penrose's own upbringing as landed gentry.

Gilded childhood

An intellectually precocious child growing up in 1930s England, Penrose is handed every resource for his intellectual potential to blossom. When he notices a specific pattern linking addition and multiplication, an older sibling is on hand to show him there's a general rule from number theory that explains the pattern. The family at this point, we're told, has a cook and a maid who doubles as a nanny. Even in a community of people from well-resourced backgrounds, Penrose stands out as an especially privileged example.

When the Second World War starts, his family readily secures safe passage to a comfortable home in Canada – a privilege related to their status as welcomed members of Britain's upper class and one that was not afforded to many continental European Jewish families at the time (Penrose's mother and therefore Penrose was Jewish by descent). Indeed, Canada admitted the fewest Jewish refugees of any Allied nation and famously denied entry to the St Louis, which was sent back to Europe, where a third of its 937 Jewish passengers were murdered in the Holocaust.

In Ontario, the Penrose children have a relatively idyllic experience. Throughout the rest of his childhood and his adult life, the path has been continuously smoothed for Penrose, either by his parents (who bought him multiple homes) or mentors and colleagues who believed in his genius. One is left wondering how many other people might have such a distinguished career if, from birth, they are handed everything on a silver platter and never required to take responsibility for anything.

To tell these and later stories, Barss relies heavily on interviews with Penrose. Access to their subject for any biographer is tricky. While it creates a real opportunity for the author, there is also the challenge of having a relationship with someone whose memories you need to question. Barss doesn't really interrogate Penrose's memory but seems to take them as gospel.

During the first half of the book, I wondered repeatedly if *The Impossible Man* is effectively a memoir told in the third person. Eventually, Barss does allow other voices to tell the story. Ultimately, though, this is firmly a book told from Penrose's point of view. Even the inclusion of Daniels's story was at least in part at Penrose's behest.

I found myself wanting to hear more from the women in Penrose's life. Penrose often saw himself following a current determined by these women. He came, for example, to believe his first wife had essentially trapped him in their relationship by falling for him.

Penrose never takes responsibility for any of his own actions towards the women in his life. So I wondered: how did they see it? What were their lives like? His ex-wife Joan (who died in 2019) and estranged wife Vanessa, who later became a mathematics teacher, both gave interviews for the book. But we learn little about their perspective on the man whose proclivities and career dominated their own lives.

View this e-magazine online to watch a video of *Physics World*'s Tushna Commissariat interviewing Roger Penrose in 2015.

One day there will be another biography of Penrose that will necessarily have distance from its subject because he will no longer be with us. *The Impossible Man* will be an important document for any future biographer, containing as it does such a close rendering of Penrose's perspective on his own life.

The cost of genius

When it comes to describing Penrose's contributions to mathematics and physics, the science writing, especially in the early pages, sings. Barss has a knack for writing up difficult ideas – whether it's Penrose's Nobel-prize-winning work on singularities or his attempt at quantum gravity, twistor theory. Overall, the luxurious prose makes the book highly readable.

Sometimes Barss indulges cosmic flourishes in a way that appears to reinforce Penrose's perspective that the universe is happening to him rather than one over which he has any influence. In the end, I don't know if we learn the cost of genius, but we certainly learn the cost of not recognizing that we are a part of the universe that has agency.

The final chapter is really Barss writing about himself and Penrose, and the conversations they have together. Penrose has macular degeneration now, so while both are on a visit to Perimeter in 2019, Barss reads some of his letters to Judith back to Penrose. Apparently, Penrose becomes quite emotional in a way that it seems no-one had ever seen – he weeps.

After that, he asks Barss to include the story about Judith. So, on some level, he knows he has erred.

The end of *The Impossible Man* is devastating. Barss describes how he eventually gains access to two of Penrose's sons (three with Joan and one with Vanessa). In those interviews, he hears from children who have been traumatized by witnessing what they call "physical aggression" toward their mother. Even so, they both say they'd like to improve their relationship with their father.

Barss then asks a 92-year-old Penrose if he wants to patch things up with his family. His reply: "I feel my life is busy enough and if I get involved with them, it just distracts from other things." As Barss concludes, Penrose is persistently unwilling to accept that in his life, he has been in the driver's seat. He has had choices and doesn't want to take responsibility for that. This, as much as Penrose's intellectual interests and achievements, is the throughline of the text.

The Penrose we meet at the end of *The Impossible Man* has shown that he doesn't really care what others think, as long as he gets what he wants scientifically. It's clear that Barss has a real affection for him, which makes his honesty about the Penrose he finds in the archives all the more remarkable. Perhaps motivated by generosity toward Penrose, Barss also lets the reader do a lot of the analysis.

I wonder, though, how many physicists who are steeped in this culture, and don't concern themselves with gender equity issues, will miss how bad some of Penrose's behaviour has been, as his colleagues at the time clearly did. The only documented objections to his behaviour seem more about him going off the deep end with his research into consciousness, cyclic theory and attacks on cosmic inflation.

As I worked on this review, I considered whether a different reviewer would have simply complained that the book has lots of stuff about Penrose's personal messes that we don't need to know. Maybe, to other readers, Penrose doesn't come off quite as badly. For me, I prefer the hero I met in person rather than in the pages of this book. *The Impossible Man* is an important text, but it's heartbreaking in the end.

Penrose has shown that he doesn't really care what others think, as long as he gets what he wants scientifically

Chanda Prescod-Weinstein is an associate professor of physics and core faculty in women's and gender studies at the University of New Hampshire, US. She is the author of *The Disordered Cosmos: a Journey into Dark Matter, Spacetime, and Dreams Deferred*

Careers

The physics of biology

After doing a PhD in theoretical condensed-matter physics, **Lisa Manning** has built a career applying the principles of maths and physics to biological phenomena from cancer to embryogenesis. She talks to Katherine Skipper about her wide-ranging work and how she encourages early-career researchers to broaden their horizons

Syracuse University

Physics on the move Lisa Manning applies her background in theoretical physics to a wide range of problems in biology, from cancer to embryogenesis.

At a conference in 2014, bioengineer Jeffrey Fredberg of Harvard University presented pictures of asthma cells. To most people, the images would have been indistinguishable – they all showed tightly packed layers of cells from the airways of people with asthma. But as a physicist, Lisa Manning saw something no one else had spotted; she could tell, just by looking, that some of the model tissues were solid and some were fluid.

Animal tissues must be able to rearrange and flow but also switch to a state where they can withstand mechanical stress. However, whereas solid-liquid transitions are generally associated with a density change, many cellular systems, including asthma cells, can change from rigid to fluid-like at a constant packing density.

Many of a tissue's properties depend on biochemical processes in its constituent cells, but some collective behaviours can be captured by mathematical models, which is the focus of Manning's research. At the time, she was working with postdoctoral associate Dapeng Bi on a theory that a tissue's rigidity depends on the shape of the cells, with cells in a rigid state touching more neighbouring cells than those in a fluid-like one. When she saw the pictures of the asthma cells she knew she was right. "That was a very cool moment," she says.

Manning – now the William R Kenan, Jr Professor of Physics at Syracuse University in the US – began her research career in theoretical condensed-matter physics, completing a PhD at the University of California, Santa Barbara, in 2008. The thesis was on the mechanical properties of amorphous solids – materials that don't have long-ranged order like a crystal but are nevertheless rigid. Amorphous solids include many plastics, soils and foods, but towards the end of her graduate studies, Manning started thinking about where else she could apply her work.

> I had implicit expectations that were based on my culture and background, and they were distinct from those of some of my students

"I was looking for a project where I could use some of the skills that I had been developing as a graduate student in an orthogonal way," Manning recalls. Inspiration came from of a series of talks on tissue dynamics at the Kavli Institute for Theoretical Physics, where she recognized that the theories she had worked on could also apply to biological systems. "I thought it was amazing that you could apply physical principles to those systems," she says.

Manning has been at Syracuse since completing a postdoc at Princeton University, and although she has many experimental collaborators, she is happy to still be a theorist. Whereas experimentalists in the biological sciences generally specialize in just one or two experimental models, she looks for "commonalities across a wide range of developmental systems". That principle has led Manning to study everything from cancer to congenital disease and the development of embryos.

"In animal development, pretty universally one of the things that you must do is change from something that's the shape of a ball of cells into something that is elongated," says Manning, who working to understand how this happens. With collaborator Karen Kasza at Columbia University, she has demonstrated that rather than stretching as a solid, it's energy efficient for embryos to change shape by undergoing a phase transition to a fluid, and many of their predictions have been confirmed in fruit fly embryo models.

More recently, Manning has been looking at how ideas from AI and machine learning can be applied to embryogenesis. Unlike most condensed-matter systems, tissues continuously tune individual interactions between cells, and it's these localized forces that drive complex shape changes during embryonic development. Together with Andrea Liu of the University of Pennsylvania, Manning is now developing a framework that treats cell–cell interactions like weights in a neural network that can be adjusted to produce a desired outcome.

"I think you really need almost a new type of statistical physics that we don't have yet to describe systems where you have these individually tunable degrees of freedom," she says, "as opposed to systems where you have maybe one control parameter, like a temperature or a pressure."

Developing the next generation

Manning's transition to biophysics was spurred by an unexpected encounter with scientists outside her field. Between 2019 and 2023, she was director of the Bioinspired Institute at Syracuse University, which supported similar opportunities for other researchers, including PhD students and postdocs. "As a graduate student, it's a little easy to get focused on the one project that you know about, in the corner of the universe that your PhD is in," she says.

As well as supporting science, one of the first things Manning spearheaded at the institute was a professional development programme for early-career researchers. "During our graduate schools, we're typically mostly trained on how to do the academic stuff," she says, "and then later in our careers, we're expected to do a lot of other types of things like manage groups and manage funding." To support their wider careers, participants in the programme build non-technical skills in areas such as project management, intellectual property and graphic design.

Manning's senior role has also brought opportunities to build her own skills, with the COVID-19 pandemic in particular making her reflect and reevaluate how she approached mentorship. One of the appeals of academia is the freedom to explore independent research, but Manning began to see that her fear of micromanaging her students was sometimes creating confusion.

"What I realized is that I did have implicit expectations that were based on my culture and background, and that they were distinct from those of some of my students," she says. "Because I didn't name them, I was actually doing my students a disservice." If she could give advice to her younger self, it would be that the best way to support early-career researchers as equals is to set clear expectations as soon as possible.

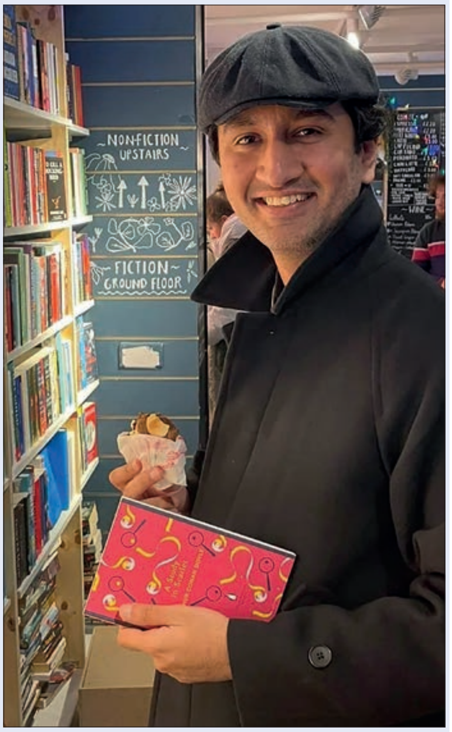
When Manning started at Syracuse, most of her students wanted to pursue research in academia, and she would often encourage them to think about other career options, such as working in industry. However, now she thinks academia is perceived as the poorer choice. "Some students have really started to get this idea that academia is too challenging and it's really hard and not at all great and not rewarding."

Manning doesn't want anyone to be put off pursuing their interests, and she feels a responsibility to be outspoken about why she loves her job. For her, the best thing about being a scientist is encapsulated by the moment with the asthma cells: "The thrill of discovering something is a joy," she says, "being for just a moment, the only person in the world that understands something new."

Katherine Skipper is a science journalist

Ask me anything: Muhammad Hamza Waseem

Muhammad Hamza Waseem is a research scientist at Quantinuum, where he works on quantum natural language processing as well as quantum physics education and outreach. His other research interests include quantum foundations, applied category theory and mathematical linguistics.



Muhammad Hamza Waseem

Waseem completed his DPhil in physics at the University of Oxford in the UK, where he worked on applied process-relational philosophy and employed string diagrams to study interpretations of quantum theory, constructor theory, wave-based logic, quantum computing and natural language processing. At Oxford, Waseem continues to teach mathematics and physics at Magdalen College, the Mathematical Institute, and the Department of Computer Science.

Waseem has played a key role in organizing the Lahore Science Mela, the largest annual science festival in Pakistan. He also co-founded *Spectra*, an online magazine dedicated to training popular-science writers in Pakistan. For his work popularizing science he received the 2021 Diana Award, was highly commended at the 2021 SEPnet Public Engagement Awards, and won an impact award in 2024 from Oxford's Mathematical, Physical and Life Sciences (MPLS) division.

> I believe the most important skill is creativity, and the ability to dream and imagine

What skills do you use every day in your job?

I'm a theoretical physicist, so if you're thinking about what I do every day, I use chalk and a blackboard, and maybe a pen and paper. However, for theoretical physics, I believe the most important skill is creativity, and the ability to dream and imagine.

What do you like best and least about your job?

That's a difficult one because I've only been in this job for a few weeks. What I like about my job is the academic freedom and the opportunity to work on both education and research. My role is divided 50/50, so 50% of the time I'm thinking about the structure of natural languages like English and Urdu, and how to use quantum computers for natural language processing. The other half is spent using our diagrammatic formalism called "quantum picturalism" to make quantum physics accessible to everyone in the world. So, I think that's the best part. On the other hand, when you have a lot of smart people together in the same room or building, there can be interpersonal issues. So, the worst part of my job is dealing with those conflicts.

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

It's a cynical view, but I think scientists are not always very rational or fair in their dealings with other people and their work. If I could go back and give myself one piece of advice, it would be that sometimes even rational and smart people make naive mistakes. It's good to recognize that, at the end of the day, we are all human.

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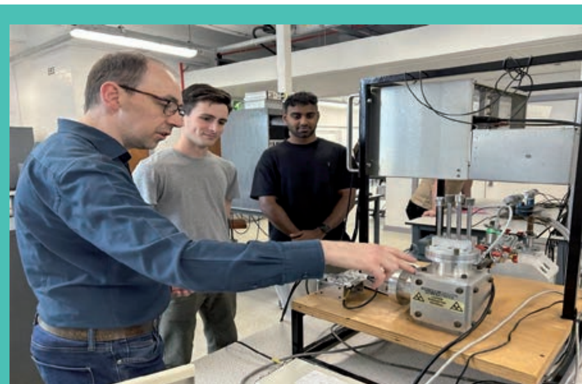

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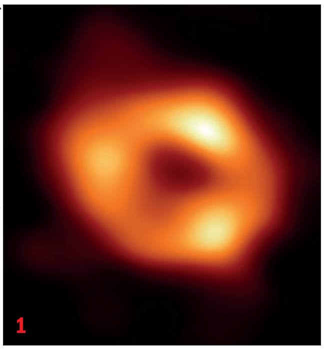
Do you know your AI?

Iulia Georgescu and **Matin Durrani** invite you to test your knowledge of the deep connections between physics, big data and AI

EHT Collaboration; Los Alamos National Laboratory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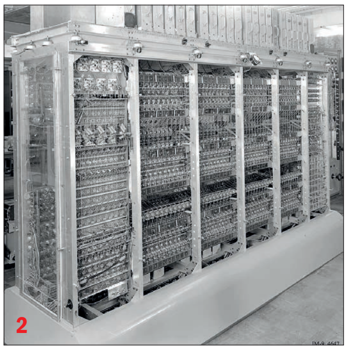
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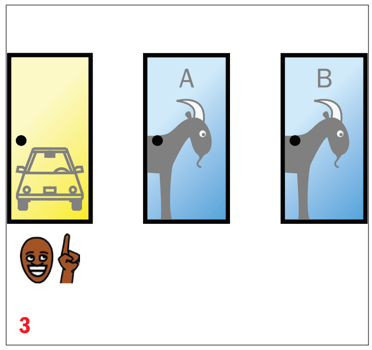

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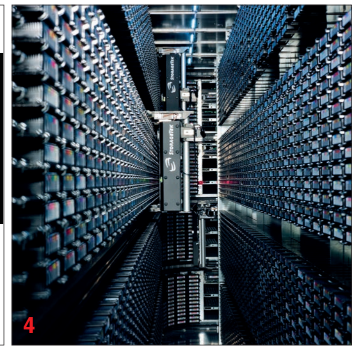
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IOP Publishing; CERN

1 When the Event Horizon Telescope imaged a black hole in 2019, what was the total mass of all the hard drives needed to store the data?
A 1 kg
B 50 kg
C 500 kg
D 2000 kg

2 In 1956 MANIAC I became the first computer to defeat a human being in chess, but because of its limited memory and power, the pawns and which other pieces had to be removed from the game?
A Bishops
B Knights
C Queens
D Rooks

3 The logic behind the Monty Hall problem, which involves a car and two goats behind different doors, is one of the cornerstones of machine learning. On which TV game show is it based?
A *Deal or No Deal*
B *Family Fortunes*
C *Let's Make a Deal*
D *Wheel of Fortune*

4 In 2023 CERN broke which barrier for the amount of data stored on devices at the lab?
A 10 petabytes (10^{16} bytes)
B 100 petabytes (10^{17} bytes)
C 1 exabyte (10^{18} bytes)
D 10 exabytes (10^{19} bytes)

5 What was the world's first electronic computer?
A Atanasoff–Berry Computer (ABC)
B Electronic Discrete Variable Automatic Computer (EDVAC)
C Electronic Numerical Integrator and Computer (ENIAC)
D Small-Scale Experimental Machine (SSEM)

6 What was the outcome of the chess match between astronaut Frank Poole and the HAL 9000 computer in the movie *2001: A Space Odyssey*?
A Draw
B HAL wins
C Poole wins
D Match abandoned

7 Which of the following physics breakthroughs used traditional machine learning methods?
A Discovery of the Higgs boson (2012)
B Discovery of gravitational waves (2016)
C Multimessenger observation of a neutron-star collision (2017)
D Imaging of a black hole (2019)

8 The physicist John Hopfield shared the 2024 Nobel Prize for Physics with Geoffrey Hinton for their work underpinning machine learning and artificial neural networks – but what did Hinton originally study?
A Biology
B Chemistry
C Mathematics
D Psychology

9 Put the following data-driven discoveries in chronological order.
A Johann Balmer's discovery of a formula computing wavelength from Anders Ångström's measurements of the hydrogen lines
B Johannes Kepler's laws of planetary motion based on Tycho Brahe's astronomical observations
C Henrietta Swan Leavitt's discovery of the period-luminosity relationship for Cepheid variables
D Ole Rømer's estimation of the speed of light from observations of the eclipses of Jupiter's moon Io

10 Inspired by Alan Turing's "Imitation Game" – in which an interrogator tries to distinguish between a human and machine – when did Joseph Weizenbaum develop ELIZA, the world's first "chatbot"?
A 1964
B 1984
C 2004
D 2024

● This quiz is for fun and there are no prizes. Answers – and three bonus questions – can be found on the *Physics World* blog.

Iulia Georgescu is a physicist interested in the history of computing and big science. **Matin Durrani** is editor-in-chief of *Physics World*