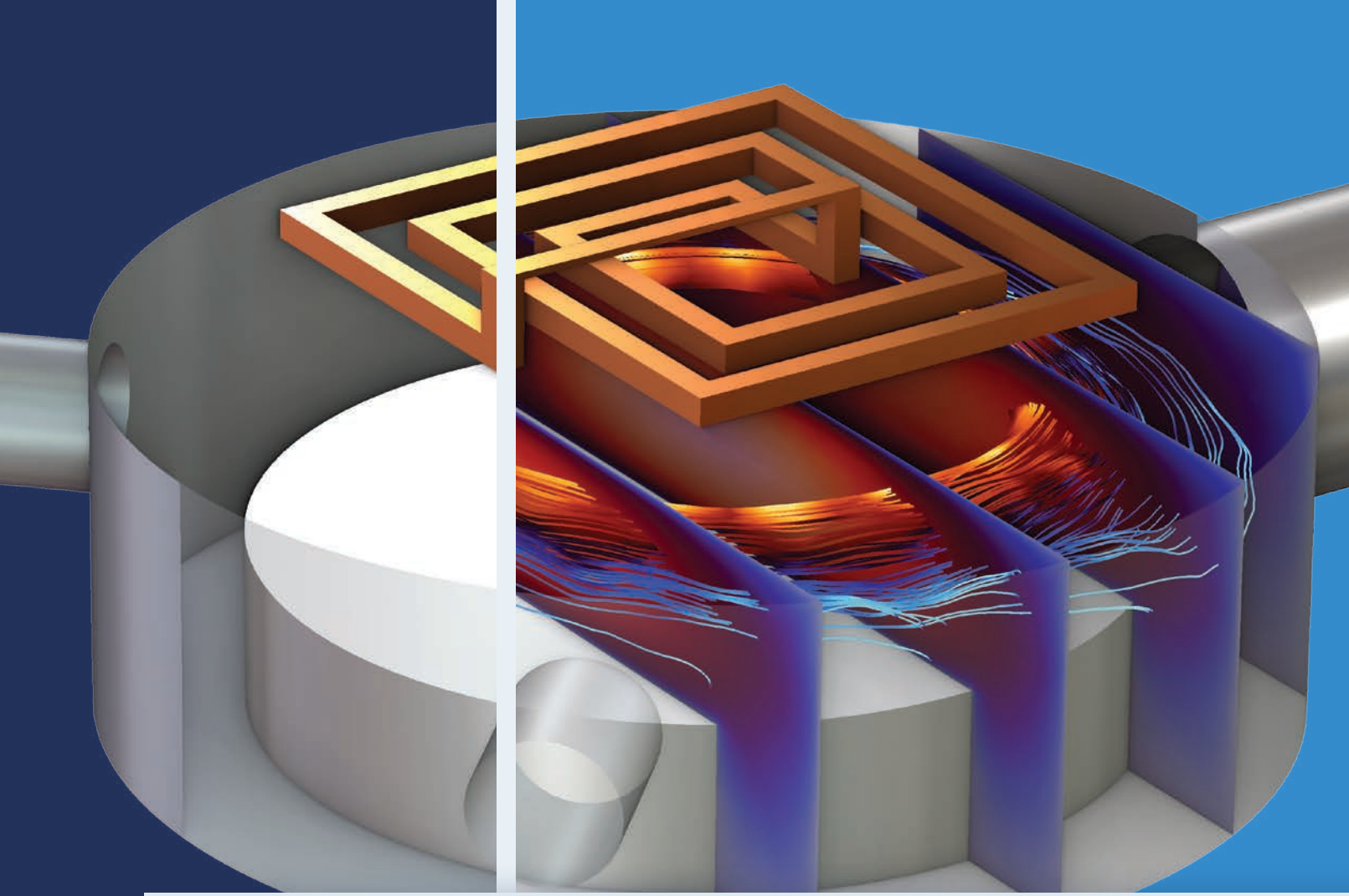
physicsworld
March 2026

Historic revelation How Chien-Shiung Wu missed out on the Nobel prize
Wonderful result Meet the physicist whose poster bagged a huge donation
Conflict resolution Can we quantify how war damages the environment?

Volcanic impact

The geophysical consequences of climate change



Take the Lead in Semiconductor Development

with COMSOL Multiphysics®

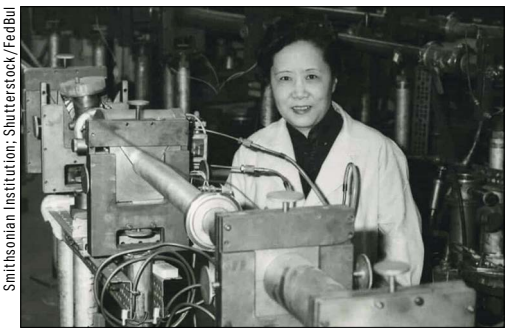
Designing system components, optimising manufacturing processes and developing next-generation semiconductor devices calls for precision and accuracy. This is why industry leaders are turning to multiphysics simulation to develop, test and verify their designs.

» *comsol.com/feature/semiconductor-innovation*

COMSOL

physicsworld

Volume 39 No 3



Smithsonian Institution; Shutterstock/FedBul

Historic revelation
How Chien-Shiung Wu missed out on the Nobel prize 41

Conflict resolution
Can we quantify how war damages the environment? 33

AUDIO

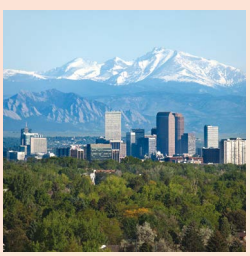
Physics World editors discuss their highlights of the March issue

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

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

EU RP (for authorities only)
eucomply OÜ
Pärnu mnt 139b-14, 11317 Tallinn, Estonia
hello@eucompliancepartner.com
+33757690241

Cover image
The geophysical consequences of climate change 46
(iStock/Panya_)

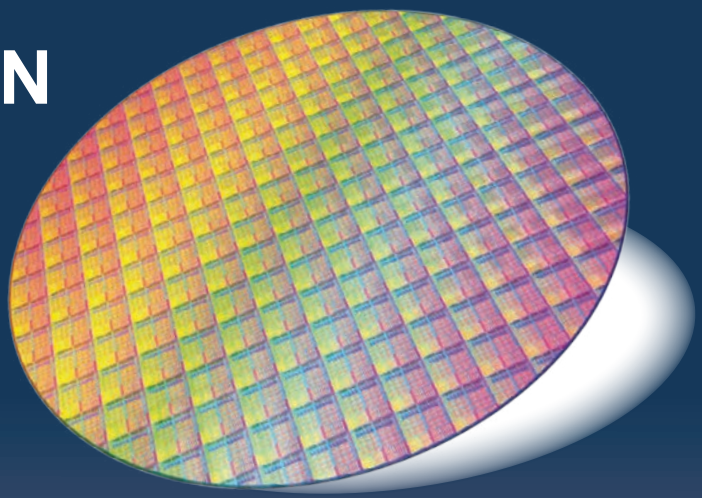


Physics World at GPS

Catch *Physics World* at the American Physical Society's Global Physics Summit in Denver, Colorado, this month.

Physics World sponsors the exhibitor lounge for 2026 and can be found at booth 500

UNLOCK PRECISION IN SEMICONDUCTOR SURFACE ANALYSIS



Ensure Performance. Guarantee Reliability. Maximize Yield.

The semiconductor industry demands **precise surface and interface characterizaton** to meet the challenges of advanced device manufacturing. **Physical Electronics (PHI)** delivers the most trusted analytical solutions:

X-ray Photoelectron Spectroscopy (XPS)

Quantitative elemental and chemical state analysis for ultra-thin films and surfaces.

Auger Electron Spectroscopy (AES)

High-resolution surface analysis for conductive materials and nano-scale features

Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS)

Ultra-sensitive detection of trace contaminants and organic species.

Applications include:

- Defect and particle analysis on wafers
- Depth profiling for thin films and interfaces
- 3D chemical imaging of complex structures
- Failure analysis and reliability studies

Discover how PHI's advanced tools can transform your semiconductor processes.
Visit www.phi.com | www.ulvac-phi.com

Physical Electronics, 18725 Lake Drive East, Chanhassen, MN 55317
ULVAC-PHI,2500 Hagisono, Chigasaki, Japan

PHYSICAL ELECTRONICS
A DIVISION OF ULVAC-PHI

News & Analysis

UK cuts put LHCb upgrade at risk

Funding changes within the UK's research councils could derail a major upgrade to the LHCb detector at CERN, as **Michael Banks** reports

Maximilien Brice/CERN

Troubling times
A major upgrade to the LHCb experiment at CERN is unlikely to go ahead if cuts are not reversed.

A major upgrade to the LHCb experiment at CERN is under threat after the UK did not commit any further contributions towards the project. The decision by UK Research and Innovation (UKRI) to defund the plan means that unless the decision is overturned, the experiment will now likely finish operations in 2033.

LHCb is one of the four large experiments based at the Large Hadron Collider (LHC) at CERN. It specializes in the measurements of the parameters of charge–parity (CP) violation in the interactions of b- and c-hadrons, studies of which help to explain the matter–antimatter asymmetry in the universe. LHCb began recording its first data in 2009 when the LHC began operations and started its main research programme in 2010. At the end of 2018 it was shut down for upgrades, which were completed in 2022. That led to a vast increase in the amount of data the experiment could collect, allowing significant improvements in precision for many measurements. The detector is expected to operate until 2033, by which time it would have reached the end of its lifetime after years of intense radiation damage.

LHCb is operated by the LHCb collaboration, which involves about 1700 scientists and technicians from over 100 institutions in 22 countries around the world, with work on the machine having already resulted in over 800 publications. The UK is one of the leading countries working on LHCb – four of the eight spokespeople for the experiment have come from the UK – and over the past decade physicists from the UK have been planning an upgrade to the experiment dubbed LHCb upgrade II. This would take advantage of the upgrade to the LHC – the High-Luminosity LHC (HL-LHC) – and offer an order-of-magnitude increase in luminosity over upgrade I.

AUDIO

Listen to Tim Gershon discuss the funding cuts with *Physics World*

The second upgrade would provide another boost in capability to answer questions such as whether all CP-violation phenomena are consistent with the Standard Model of particle physics or require an extended theory, as well as how the strong interaction binds together the exotic tetraquark and pentaquark states that have been discovered by LHCb. At a cost of about £150m, with the construction phase beginning in 2027, the upgrade components would be installed by 2035 before collecting data for five to six years until the HL-LHC is shut down in 2040.

UK researchers submitted a proposal to the UKRI infrastructure fund in 2021 to begin work on the upgrade and were awarded £49.4m in 2022. Some £5m has been spent on the pre-construction phase, in which agreements have been made with international partners on the scope and design of the improved detector. But on 19 December researchers working on the project were sent a letter telling them that the remaining funding has "not been prioritized" and will now be cancelled. "It was a complete shock," says Tim Gershon from the University of Warwick, who is principal investigator for the project in the UK and is set to become spokesperson for the international collaboration in July.

'Out in the cold'

The core budget of the Science and Technology Facilities Council (STFC) has been held relatively flat from £835m to £842m from 2026 to 2030. The council says that projects would need to be cut given inflation, rising energy costs and "unfavourable movements in foreign exchange rates", which have increased the STFC's annual costs by over £50m a year. The STFC has already said that it needs to reduce spending from the core budget by at least 30% over 2024/2025 levels. At the same time it also announced that it will need to

Michele Dougherty steps aside as president of the Institute of Physics

The space physicist Michele Dougherty has stepped aside as president of the Institute of Physics (IOP). The move was taken to avoid any conflicts of interest given her position as executive chair of the Science and Technology Facilities Council (STFC) – one of the main funders of physics research in the UK.

Dougherty, who is based at Imperial College London, spent two years as IOP president-elect from October 2023 before becoming president in October 2025. Dougherty was appointed executive chair of the STFC in January 2025 and in July that year was also announced as the next Astronomer Royal – the first woman to hold the position.

Moving on The space scientist Michele Dougherty from Imperial College London spent two years as IOP president-elect from October 2023 before becoming president in October 2025.

The changes at the IOP come in the wake of UK Research and Innovation (UKRI) stating in December that it will be adjusting how it allocates government funding for scientific research and infrastructure. Spending on curiosity-driven research will remain flat from 2026 to 2030, with UKRI prioritizing funding in three key areas or "buckets": curiosity-driven research, which will be the largest; strategic government and societal priorities; and supporting innovative companies. There will also be a fourth "cross-cutting" bucket with funding for infrastructure, facilities and talent. In the four years to 2030, UKRI's budget will be £38.6bn. With the STFC being one of nine research councils within UKRI, Dougherty is stepping aside as IOP president to ensure the IOP can play what it says is "a leadership role in advocating for physics without any conflict of interest".

In her role as STFC executive chair, Dougherty wrote to the UK's particle physics, astronomy and nuclear physics community, asking researchers to identify by March how their projects would respond to flat cash as well as reductions of 20%, 40% and 60% – and to "identify the funding point at which the project becomes non-viable". In the letter, Dougherty says that the UK's science minister Lord Vallance and UKRI chief executive Ian Chapman want to protect curiosity-driven research, which they say is vital, and grow it "as the economy allows". However, she adds, "the STFC will need to focus our efforts on a more concentrated set of priorities, funded at a level that can be maintained over time".

Tom Grinyer, chief executive officer of the IOP, says that the IOP is "gathering insight from across the physics community and engaging closely with government, UKRI and the research councils so that we can represent the sector with authority and evidence". Grinyer warns, however, that UKRI's shift in funding priorities and the subsequent STFC funding cuts will have "severe consequences" for physics. "The promised investment in quantum, AI, semiconductors and green technologies is welcome but these strengths depend on a stable research ecosystem," he says.

"I want to thank Michele for her leadership, and we look forward to working constructively with her in her capacity at STFC as this important period for physics unfolds," adds Grinyer. The nuclear physicist Paul Howarth, who has been IOP president-elect since September, will now take on Dougherty's responsibilities – as prescribed by the IOP's charter – with immediate effect, with the IOP Council due to have discussed its next steps at a meeting last month.

With a PhD in nuclear physics, Howarth has had a long career in the nuclear sector working on the European Fusion Programme and at British Nuclear Fuels, as well as co-founding the Dalton Nuclear Institute at the University of Manchester. He was a non-executive board director of the National Physical Laboratory and until his retirement earlier this year was chief executive officer of the National Nuclear Laboratory.

In response to the STFC letter, Howarth says that the projected cuts "are a devastating blow for the foundations of UK physics". "Physics isn't a luxury we can afford to throw away through confusion," says Howarth. "We urge the government to rethink these cuts, listen to the physics community, and deliver to a 10-year strategy to secure physics for the future."

reduce the number of projects that are funded by its infrastructure fund (see box above).

Four projects will now not be prioritized. They include two UK national facilities: the Relativistic Ultrafast Electron Diffraction and Imaging facility and a mass spectrometry centre dubbed CMASS. The other two are international particle-physics projects: the upgrade to LHCb as well as a contribution to the Electron-Ion Collider at the Brookhaven National Laboratory in the US, which is currently being built by a collaboration of 40 countries.

"This is more terrible news for physics, for the UK and for global scientific progress," says Paul Howarth, president elect of the Institute of Physics. "The withdrawal of funding in this abrupt way is incredibly damaging to our international reputation as a science superpower and could cause long-term damage to the UK economy. But even more important is the harm this cut will cause to human understanding of the universe and human progress."

Gershon adds that the LHCb collaboration was not asked for any input before the decision was made and since then has been trying to work out what it means. "The UK pays the CERN subscription, which pays for the accelerator, but needs to also invest in experiments to obtain scientific return from this," says Gershon. "It's like paying to heat your house but then sitting outside in the cold."

It might be possible for LHCb to get funding from elsewhere in the short term to cover the initial work on the upgrade, but Gershon says that without investment from UKRI/STFC, the project will be dead as it would not be possible for international partners to go ahead without UK involvement on the timescale dictated by the LHC schedule. That would mean that LHCb stops operating from 2033 and does not take advantage of the HL-LHC. "The move also goes against the European Strategy for Particle Physics roadmap, of which the top priority is fully exploiting the HL-LHC," says Gershon. "Without the LHCb upgrade, it won't be possible to do that."

Howarth adds there are "demonstrable impacts on UK growth and prosperity" for such research. "An earlier upgrade to the LHCb experiment generated about £15m in contracts for more than 80 UK companies," he adds. "This funding cut means the upgrade is unlikely to go ahead, so all this business for UK innovators is lost. We urge the government to step back and consider how its new funding strategy will impact UK science."

Michael Banks is news editor of *Physics World*

Duke of Edinburgh visits Institute of Physics

Prince Edward finds out about the work of physicists supporting the "green economy", as **Matin Durrani** reports

All photos: Carmen Valino

Royal approval (Clockwise from top left) The Duke of Edinburgh with IOP group chief executive Tom Grinyer; talking to Selina Ambrose from Promethean Particles; the exhibition he toured; and speaking after the panel debate.

The Duke of Edinburgh visited the headquarters of the Institute of Physics (IOP) in central London on 5 February to learn about the role that physics plays in supporting the green economy. The event was attended by about 100 business leaders, policy chiefs, senior physicists, and IOP and IOP Publishing staff. It highlighted how physics research is helping to deliver clean energy solutions and support economic growth.

A total of 12 companies took part in an exhibition that was visited by the duke. They included two carbon-capture firms – Nellie Technologies and Promethean Particles – as well as the fusion firm Tokamak Energy and Sunamp, which makes non-flammable "thermal batteries". The other firms were Inductive Power Protection, Intelligent Energy, Matoha Instrumentation, NESO, Oxford Instruments, QBA, Reclinker and Treeconomy.

The event included a panel debate chaired by Tara Shears, the IOP's vice-president for science and innovation. It featured ex-BP boss John Browne, who now works in green energy, along with Sizewell C energy-strategy director David Cole, Nellie Technologies founder Stephen Millburn, solar-cell physicist Jenny Nelson from Imperial College, and Emily Nurse from the UK's Climate Change Committee.

After the debate, the duke said the event had showcased "some of the brilliant ideas that are trying to solve some really challenging issues through creativity and imagination". He expressed particular delight that people are central to that mission. "Our ability to evolve the right skills for the future has been well demonstrated here," he said. "It comes down to creating the right climate to allow these ideas to flourish and come to market. We simply cannot drop this issue."

Tom Grinyer, group chief executive of the IOP, reminded delegates that physics is fundamental to the UK economy. "We're seeing how research is translating into real-world solutions that matter today, from clean power and climate intelligence, to advanced materials and future technologies," he said. But he warned that long-term investment in young people will be vital to create the physicists and business leaders who can tackle those challenges.

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

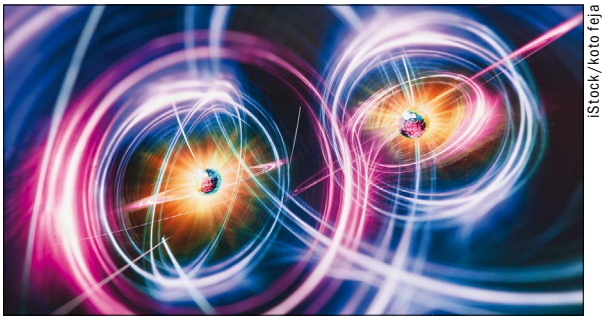
Quantum

Researchers oppose 'militarization' of quantum science

More than 250 quantum scientists have signed a "manifesto" opposing the use of quantum research for military purposes. The statement – "Quantum scientists for disarmament" – expresses a "deep concern" about the current geopolitical situation and "categorically rejects" the use of quantum research for military applications, population control or surveillance. The signatories now call for an open debate about the ethical implications of quantum research for military purposes (arXiv: 2601.14282).

While quantum science has the potential to improve or enable many different technologies – from sensors to computing – there are also concerns that it is being used for military purposes. This includes quantum key distribution and cryptographic networks for communication, as well as quantum clocks and sensing for military navigation and positioning.

Marco Cattaneo from the University of Helsinki in Finland, who co-authored the manifesto, says that even the potential application of quantum technologies in war scenarios can already be used to "militarize" universities and research agendas, which he says is already happening. Indeed, he notes is not unusual for scientists to openly discuss military applications at conferences or to include such details in scientific papers.



iStock/koto feja

Joining forces
Some 250 quantum scientists have signed a manifesto that "categorically rejects" the use of quantum research for military applications.

"We are already witnessing restrictions on research collaborations with fellow quantum scientists from countries that are geopolitically opposed or ambiguous with respect to the European Union, such as Russia or China," adds Cattaneo. "By talking with non-European colleagues, we also realized that these concerns are global and multifaceted."

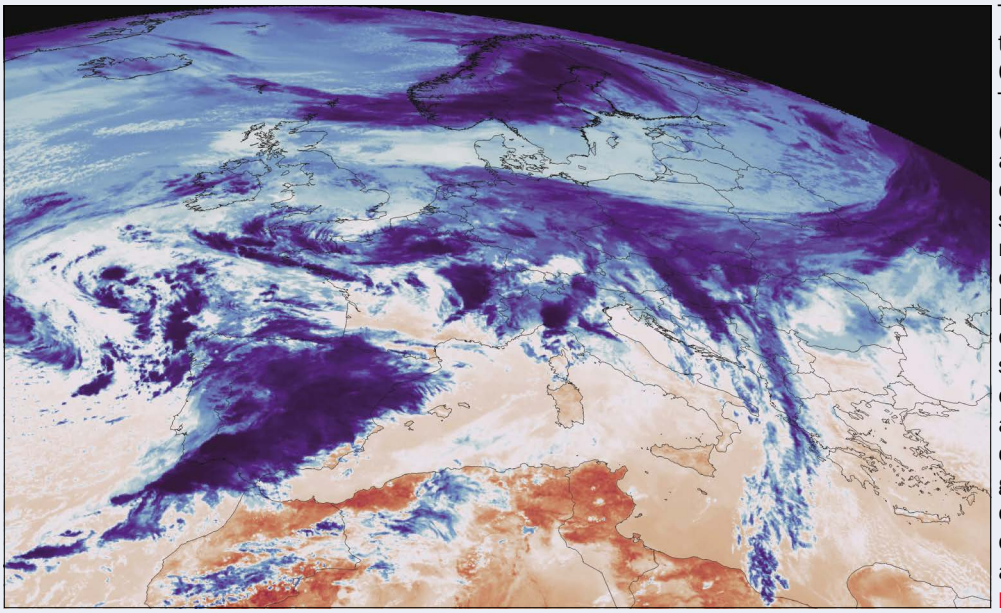
The idea for a manifesto came about during a quantum information workshop that was held in Benasque in Spain between June and July 2025. "As physicists," says Cattaneo, "we have a strong – and terrible – historical example that can guide our actions: the development of nuclear weapons, and the way the physics community organized to oppose them and to push for their control and abolition."

Cattaneo says that the manifesto aims to raise awareness and open a debate within the community and create a forum where concerns can be shared. "A longer-term goal is to prevent, or at least to limit and critically address, research on quantum technologies for military purposes," he adds. "One concrete proposal is to push public universities and research institutes to publish a database of all projects with military goals and/or military funding, which would be a major step forward."

Cattaneo claims that the group is "not naïve" and understands that stopping the technology's militarization will be difficult. "Even if military uses of some quantum technologies cannot be completely stopped, we can still advocate for excluding them from public universities, for abolishing classified quantum research in public research institutions, and for creating associations and committees that review and limit the militarization of quantum technologies," adds Cattaneo.

Michael Banks

European Space Agency unveils first images from Earth-observation 'sounder' satellite



EUMETSAT

The European Space Agency has released the first images from the Meteosat Third Generation-Sounder (MTG-S) satellite. They reveal variations in temperature (shown here) and humidity over Europe and northern Africa in unprecedented detail, with further data from the mission set to improve weather-forecasting models and measurements of air quality over Europe. Launched last year, MTG-S operates from a geostationary orbit about 36 000 km above Earth's surface and is able to provide coverage of Europe and part of northern Africa on a 15 minute repeat cycle. The satellite can also measure wind and trace gases in the atmosphere. The data will eventually be used to generate 3D maps of the atmosphere and help improve the accuracy of weather forecasts.

Michael Banks

Astronomy

India plans three new telescopes in the Himalayan desert

India intends to build two new optical-infrared telescopes and a dedicated solar telescope in the Himalayan desert region of Ladakh. The three new facilities, expected to cost INR 35bn (about £284m), were announced by the Indian finance minister Nirmala Sitharaman on 1 February.

First up is a 3.7 m optical-infrared telescope, which is expected to come online by 2030. It will be built near the existing 2 m Himalayan Chandra Telescope (HCT) at Hanle, about 4500 m above sea level.

"The arid and high-altitude Ladakh desert is firmly established as among the world's most attractive sites for multiwavelength astronomy," Annapurni Subramaniam, director of the Indian Institute of Astrophysics (IIA) in Bangalore, told *Physics World*. "HCT has demonstrated both site quality and opportunities for sustained and competitive science from this difficult location."

The 3.7 m telescope is a stepping stone towards the proposed 13.7 m National Large Optical-Infrared Telescope (NLOT), which is expected to open in 2038. "NLOT is intended to address contemporary astronomy goals, working in synergy with major domestic and international facilities," says Maheswar Gopinathan, a scientist at the IIA, which is leading all three projects. Gopinathan says NLOT's large collecting area will enable research on young stellar systems, brown dwarfs and exoplanets, while also allowing astronomers to detect faint sources and to rapidly follow up extreme cosmic events and gravitational-wave detections.

Indian Institute of Astrophysics

One for the future The proposed 2 m National Large Solar Telescope would be built in the Himalayan desert region of Ladakh and study coronal mass ejections.

Along with India's upgraded Giant Metrewave Radio Telescope, a planned gravitational-wave observatory in the country and the Square Kilometre Array in Australasia and South Africa, Gopinathan says that NLOT "will usher in a new era of multimessenger and multiwavelength astronomy".

The third telescope to be supported is the 2 m National Large Solar Telescope (NLST), which will be built near Pangong Tso lake 4350 m above sea level. Also expected to come online by 2030, the NLST is an advance on India's existing 50 cm telescope at the Udaipur Solar Observatory, which provides a spatial resolution of about 100 km. Scientists plan to combine NLST observations with data from Aditya-L1, India's space-based solar observatory, which launched in 2023.

"We have two key goals [with NLST]," says Dibyendu Nandi, an astrophysicist at the Indian Institute of Science Education and Research in Kolkata. "We will probe small-scale perturbations that cascade into large flares or coronal mass ejections and improve our understanding of space weather drivers and how energy in localized plasma flows is channelled to sustain the ubiquitous magnetic fields."

Located between observatories in Europe, the Americas, East Asia and Australia, the Ladakh telescopes could improve global coverage of transient and variable phenomena.

Ganapati Mudur
New Delhi

Quantum

International Year of Quantum draws to a close

The International Year of Quantum Science and Technology (IYQ) has officially closed following a two-day event last month in Accra, Ghana. The year has seen hundreds of events worldwide celebrating the science and applications of quantum physics.

The closing event in Ghana, held on 10–11 February, was attended by government officials, UNESCO directors, physicists and representatives from international scientific societies, including the IOP. They discussed UNESCO's official 2025 IYQ report and heard a reading of the IYQ 2025 poetry contest's winning entry, as well as attending an exhibition with displays from IYQ sponsors.

Over the last year, IYQ has involved hundreds of organizations – including the Institute of Physics (IOP) – holding a wide range of international and national events touching on the use of quantum in everything from communications and computing to medicine and the arts.

Institute of Physics

Mark of success Tom Grinyer, chief executive of the Institute of Physics, speaking at the closing ceremony of the International Year of Quantum Science and Technology in Ghana last month.

One highlight was a workshop on 9–14 June 2025 in Helgoland – the island off the coast of Germany where Werner Heisenberg pioneered quantum mechanics exactly 100 years earlier. It was attended by more than 300 top quantum physicists, including four Nobel prize-winners. The IOP also organized a two-day conference on the past and future of quantum physics at the Royal Institution in London in November.

Organizers behind the IYQ hope its impact will be felt for many years to come. "The entire 2025 year was filled with impactful events happening all over the world. It has been a wonderful experience working alongside such dedicated and distinguished colleagues," notes Duke University physicist Emily Edwards, who is a member of the IYQ steering committee. "We are thrilled to see the enthusiasm continue through to 2026 with the closing ceremony and are proud that a strong foundation has been laid for the years ahead."

Michael Banks

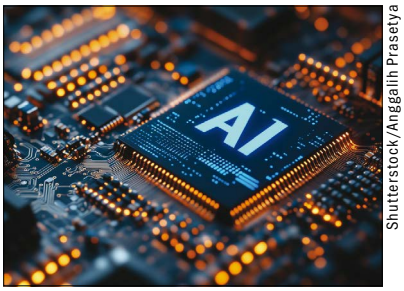
Research

AI boosts scientific productivity and career prospects

Using artificial intelligence (AI) increases scientists' productivity and impact but collectively leads to a shrinking of research focus. That is according to an analysis of more than 41 million research papers by scientists in China and the US, which finds that scientists who produce AI-augmented research also progress faster in their careers than their colleagues who do not (*Nature* 649 1237).

The study was carried out by James Evans, a sociologist at the University of Chicago, and his colleagues who analysed 41.3 million papers listed in the OpenAlex dataset published between 1980 and 2025. They looked at papers in physics and five other disciplines – biology, chemistry, geology, materials science and medicine.

Using an AI language model to identify AI-assisted work, the team picked out almost 310 000 AI-augmented papers from the dataset. They found that AI-supported publications receive more citations than non-AI-assisted papers, while also being more impactful across multiple indicators and having a higher prevalence in high-impact journals.



Shutterstock/Anggalih Prasetya

Help or hindrance? AI chatbots are increasingly being used as a collaborator in day-to-day research, from experiment planning and literature synthesis to mathematical reasoning and data analysis.

Individual researchers who adopt AI publish, on average, three times as many papers and get almost five times as many citations as those not using AI. In physics, researchers who use AI tools garner 183 citations every year, on average, while those who do not use AI get only 51 annually.

AI also boosts career trajectories. Based on an analysis of more than two million scientists in the dataset, the study finds that junior researchers who adopt AI are more likely to become established scientists. They also gain project leadership roles almost one-and-a-half years earlier, on average, than those who do not use AI.

But when the researchers examined the knowledge spread of a random sample of 10 000 papers, half of which used AI, they found that AI-produced work shrinks the range of topics covered by almost 5%. The finding is consistent across all six disciplines. Furthermore, AI papers are more clustered than non-AI papers, suggesting a tendency to concentrate on specific problems.

AI tools, in other words, appear to funnel research towards areas rich in data and help to automate established fields rather than exploring new topics. Evans and colleagues think this AI-induced convergence could drive science away from foundational questions and towards data-rich operational topics. AI could, however, help combat this trend. "We need to reimagine AI systems that expand not only cognitive capacity but also sensory and experimental capacity," they say. "[This could] enable and incentivize scientists to search, select and gather new types of data from previously inaccessible domains rather than merely optimizing analysis of standing data."

Michael Allen

Astronomy

Major threat to darkest skies is cancelled

A proposed industrial-scale green hydrogen and ammonia project in Chile, which astronomers warned could cause "irreparable damage" to the clearest skies in the world, has been cancelled. The decision by AES Andes, a subsidiary of the US power company AES Corporation, to shelve plans for the INNA complex has been welcomed by the European Southern Observatory (ESO).

AES Andes submitted an Environmental Impact Assessment for the green hydrogen project in December 2024. Expected to cover more than 3000 hectares, it would have been located just a few kilometres from ESO's Paranal Observatory in Chile's Atacama Desert, which is one of the world's most important astronomical research sites due to its stable atmosphere and lack of light pollution.

That same month, ESO conducted its own impact assessment, concluding that INNA would increase light pollution above Paranal's Very Large Telescope by at least 35% and by more than 50% above the southern site of the Cherenkov Telescope Array Observatory (CTAO). Once built, the CTAO will be the world's most powerful ground-based observatory for very-high-energy gamma-ray astronomy.

A Ghizzi Panizza/ESO

Danger averted A green hydrogen and ammonia project could have increased light pollution at ESO's Paranal Observatory in Chile's Atacama Desert.

ESO director general Xavier Barcons had warned that the hydrogen project would have posed a major threat to "the performance of the most advanced astronomical facilities anywhere in the world".

On 23 January, however, AES Andes announced that it will discontinue plans to develop the INNA complex. The firm stated that after a review of its project portfolio it had chosen to instead focus on renewable energy and energy storage. On 6 February AES Andes sent a letter to Chile's Environmental Assessment Service requesting that INNA is not evaluated, which formally confirmed the end of the project.

Barcons says that ESO is "relieved" about the decision, adding that the case highlights the urgent need to establish clear protection measures in the areas around astronomical observatories. Barcons notes that green-energy projects as well as other industrial projects can be "fully compatible" with astronomical observatories as long as the facilities are located sufficient distances away.

Michael Allen

Learn more at the APS Global Physics Summit!

APS OPEN SCIENCE

Where Every Research Step Builds Knowledge

Open Access. Experimental Innovation.

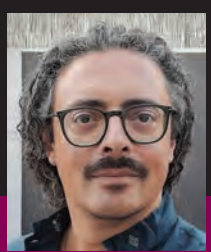
APS Open Science serves as an experimental sandbox for APS Publications, where new initiatives can be tested and refined to better serve the community. The journal will:

- Regularly incorporate feedback from researchers and stakeholders
- Test innovative features that may later be adopted across publications
- Stay at the leading edge of research communication innovation
- Explore potential evolution into broader open publishing platforms

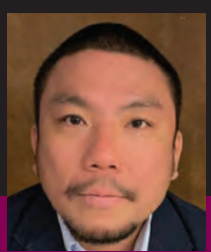
Badreddine Assouar
Chief Editor

Boyana Konforti
Managing Editor

Claudia Ratti
Associate Editor



Cosmo Lupo
Associate Editor



Kohei Nakajima
Associate Editor

Luiz F. Zagonel
Associate Editor

Now open for submissions!
go.aps.org/apsos

Research updates

Record ‘cat state’ achieved

Physicists say they have created clusters containing thousands of metal atoms that obey the laws of quantum mechanics, as **Isabelle Dumé** reports

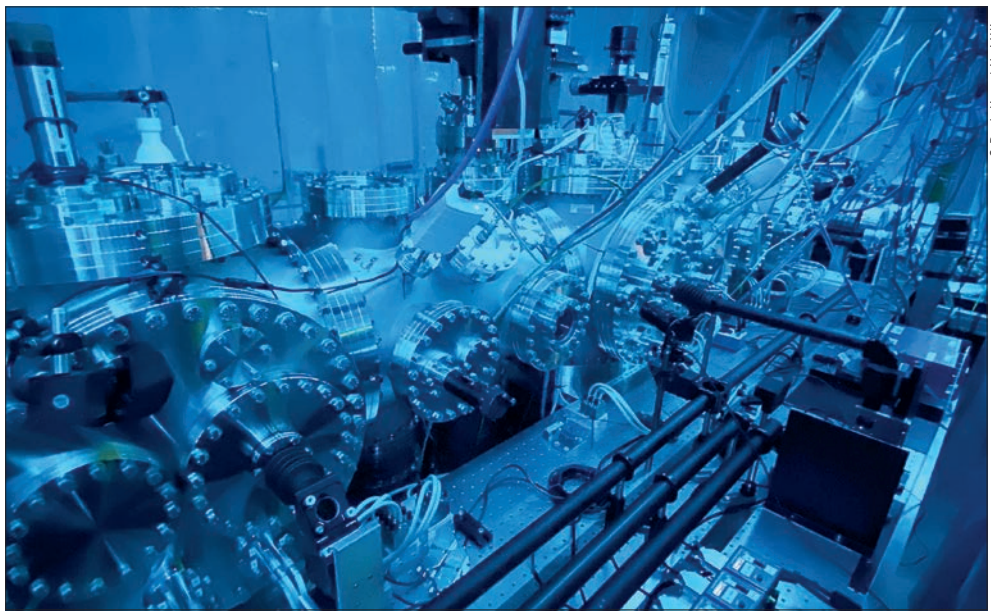
Researchers in Austria and Germany have pushed the boundary between the quantum and classical worlds by showing that metal nanoparticles made up of thousands of atoms clustered together obey the rules of quantum mechanics in a double-slit-type experiment. At over 170 000 atomic mass units, these nanoparticles are heavier than some viroids or proteins (*Nature* **649** 866).

According to the rules of quantum mechanics, even large objects behave as delocalized waves. However, we do not observe this behaviour in our daily lives because the characteristic length over which this behaviour extends – the de Broglie wavelength $\lambda_{dB} = h/mv$, where h is Planck’s constant, m is the object’s mass and v is its velocity – is generally much smaller than the object itself.

In the new work, a team led by Markus Arndt and Stefan Gerlich from the University of Vienna, in collaboration with Klaus Hornberger at the University of Duisburg-Essen, created clusters of sodium atoms in a helium–argon mixture at 77 K in an ultrahigh vacuum. The clusters each contained between 5000 and 1000 atoms and travelled at velocities of around 160 m s^{-1}, giving them de Broglie wavelengths between 10–22 femtometres (1 fm = 10^{-15} m).

To observe matter-wave interference in objects with such ultrashort de Broglie wavelengths, the team used an interferometer containing three diffraction gratings constructed with deep ultraviolet laser beams in a so-called Talbot–Lau configuration. The first grating channels the clusters through narrow gaps, from which their wave function expands. This wave is then modulated by the second grating, resulting in interference that produces a measurable striped pattern at the third grating.

This result implies that the cluster’s location is not fixed as it propagates through the apparatus. Instead, its wave function is spread over a span dozens of times larger than an individual cluster, meaning that it is in a superposition of locations rather than occupying a fixed position in space. This is known as a Schrödinger cat state, in reference to the famous thought experiment by physicist Erwin Schrödinger.



S Pedalino / Uni Wien

New bench mark
The team created clusters of sodium atoms in a helium–argon mixture at 77 K and used an interferometer to observe matter-wave interference in the objects.

The Vienna-Duisburg-Essen researchers characterized their experiment by calculating a quantity known as “macroscopicity”, which combines the duration of the quantum state (its coherence time), the mass of the object in that state, and the degree of separation between states. In this work, the macroscopicity reached a value of 15.5 – an order of magnitude higher than the best known previous reported measurement of this kind.

Arndt notes that the team’s set-up is very sensitive to small forces, which can generate notable deflections of the interference fringes. In future, he thinks this effect could be exploited to characterize the properties of materials. In the longer term, this force-sensing capability could even be used to search for new particles.

Arndt adds he is “impressed” that these mesoscopic objects are in principle easy to see and even to localize under a scattering microscope as they can be delocalized on a scale more than 10 times their size if they are isolated and non-interacting. Still, he is not entirely surprised. The challenge, he says, lies in understanding what it means. “The interpretation of this phenomenon, the duality between this delocalization and the apparently local nature in the act of measurement, is still an open conundrum,” he adds.

Looking ahead, the researchers say they would now like to extend their research to higher mass objects, longer coherence times, higher force sensitivity and different materials, including nanobiological materials as well as other metals and dielectrics. “We still have a lot of work to do on sources, beam splitters, detectors, vibration isolation and cooling,” says Arndt. “This is a big experimental adventure for us.”

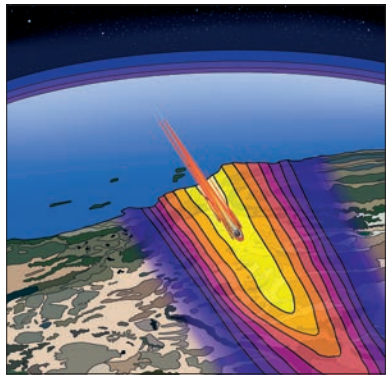
Space

Earthquake-sensing network detects space debris as it falls to Earth

Geophysicists have found a way to track space debris as it moves through the Earth's atmosphere via a network of earthquake sensors. They tested the system by monitoring the shock waves produced by China's Shenzhou-15 module as it fell to Earth. The method makes it possible to follow debris – which can be hazardous to humans and animals – in near-real time as it travels towards the surface (*Science* **391** 412).

As the Shenzhou-15 module re-entered the atmosphere in April 2024, it began to disintegrate, producing debris that travelled at supersonic speeds (between Mach 25–30) over the US cities of Santa Barbara, California and Las Vegas, Nevada. The resulting sonic booms produced vibrations strong enough to be picked up by a network of 125 seismic stations spread over Nevada and Southern California.

Benjamin Fernando from Johns Hopkins University in the US and his colleague Constantinos Charalambous at Imperial College London in the UK used freely available data from these stations to measure the arrival times of the largest sonic boom signals. Based on these data, they produced a contour map of the path the debris took and the direction in which it propagated. They also determined the altitude of the module as it travelled by using ratios of the speed of sound to the apparent speed of the incident wavefront its supersonic flight generated as it passed over the seismic stations. Finally, they used a best-fit seismic inversion model to estimate where remnants of the module may have landed and the speed at which they travelled over the ground.



S Economon and B Fernando

Boom and bust
The researchers used freely available data from seismic stations to measure the sonic boom signals from space debris travelling at supersonic speeds.

The analyses revealed that the module travelled roughly 20–30 km south of the trajectory that US Space Command had predicted based on measurements of the module's orbit alone. The seismic data also showed that the module gradually disintegrated into smaller pieces rather than undergoing a single explosive disassembly.

To estimate the object's trajectory within seconds or minutes, the researchers had to simplify their calculations by ignoring the effects of wind and temperature variations in the lower troposphere, the lowest layer of Earth's atmosphere. This simplification also did away with the need to simulate the path of wave signals through the atmosphere, which was essential for previous techniques that relied on radar data to follow objects decaying in low-Earth orbit. These older techniques, Fernando adds, produced predictions of the objects' landing sites that could, in the worst cases, be out by thousands of kilometres.

The availability of accurate, near-real-time debris tracking could help in cases where the debris is potentially harmful. In the longer term, the team hopes to develop an algorithm that automatically reconstructs the trajectory of an object.

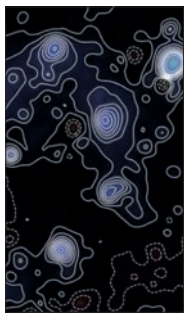
Isabelle Dumé

Astronomy

New cosmic map puts dark-matter theories to the test

Astronomers have created the most detailed map to date of the vast structures of dark matter that appear to permeate the universe. Using the James Webb Space Telescope (JWST), the team used gravitational lensing to plot the dark matter filaments and clusters with unprecedented resolution. As a result, physicists have new and robust data to test theories of dark matter (*Nat. Astron.* doi:10.1038/s41550-025-02763-9).

Dark matter is a hypothetical substance that appears to account for about 85% of the mass in the universe – yet it has never been observed directly. Dark matter is invoked by physicists to explain the dynamics and evolution of large-scale structures in the universe. This includes the gravitational formation of galaxy clusters and the cosmic filaments connecting them over 100-million-light–year distances.



Gavin Leroy/COSMOS-Webb collaboration

Cosmic web
The new map shows how dark matter acts as the hidden framework on which visible galaxies are built.

Light from very distant objects beyond these structures is deflected by the gravitational tug of dark matter within the clusters and filaments. This can be observed on Earth as the gravitational lensing of these distant objects. This distorts images of the distant objects and affects their observed brightness. These effects can be used to determine the dark-matter content of the clusters and filaments.

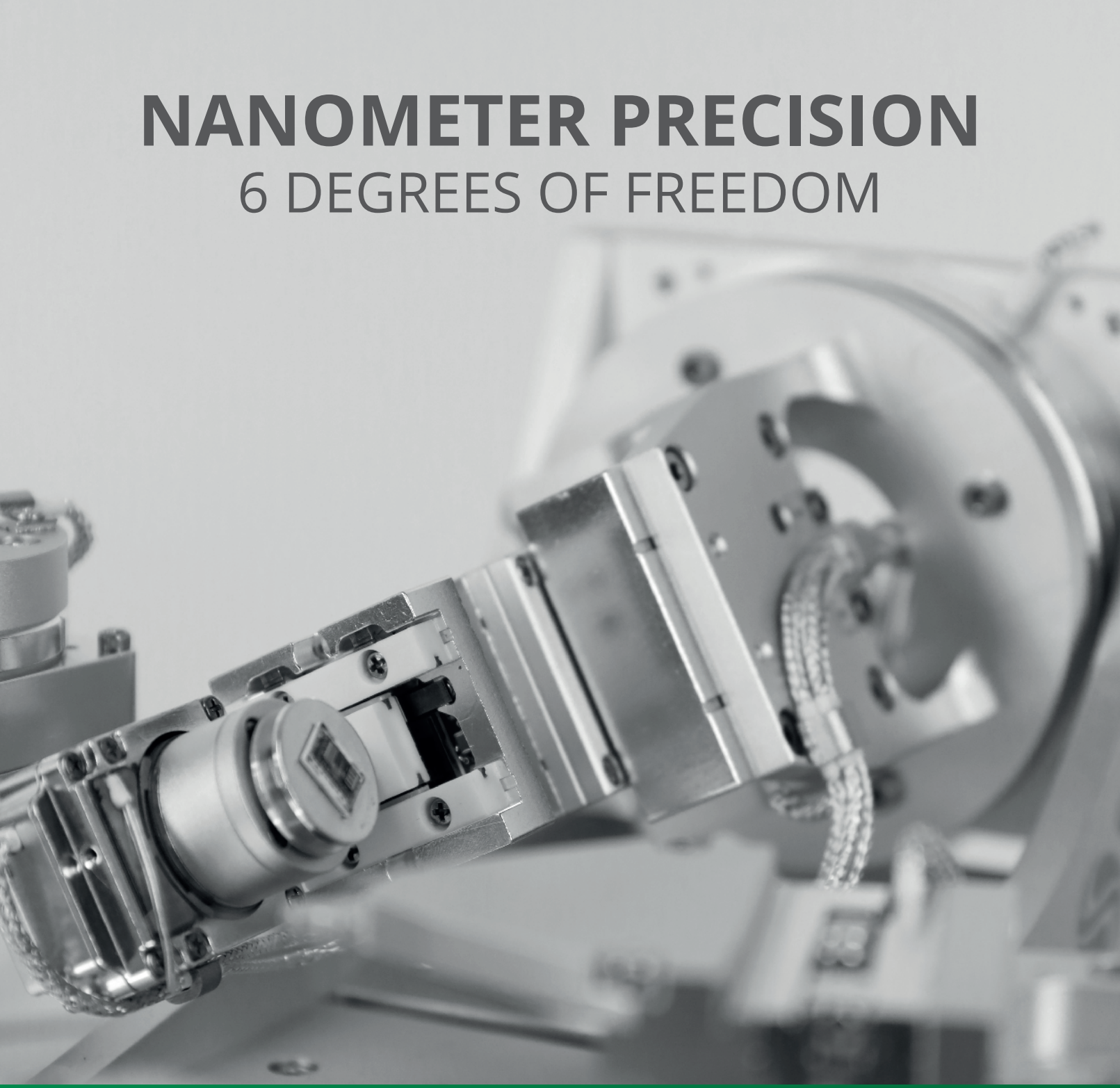
In 2007, the Cosmic Evolution Survey (COSMOS) used the Hubble Space Telescope to create a map of cosmic filaments in an area of the sky about nine times larger than that occupied by the Moon. However, Hubble's limited resolution meant that many smaller-scale features remained invisible in COSMOS. In a new survey called COSMOS-Web, Diana Scognamiglio at NASA's Jet Propulsion Laboratory and colleagues harnessed the vastly improved imaging capabilities of the JWST, which offers over twice the resolution of its predecessor.

With these improvements, the team could measure the shapes of 129 galaxies per square arcminute – an area of sky the size of 2.5 full moons. After a mathematical analysis, they could then identify which of these galaxies had been distorted by dark-matter lensing. The map allowed the team to identify lensing structures out to distances of roughly 5 billion light–years, corresponding to the universe's peak era of star formation. The team could also identify features as small as the dark matter halos encircling small clusters of galaxies, which were invisible in the original COSMOS survey.

Sam Jarman

NANOMETER PRECISION

6 DEGREES OF FREEDOM



Customized solutions with ultra-compact, configurable sample stages tailored to your materials science requirements

DPG Spring Meeting | Dresden | Booth A38

SmarAct | group

www.smaract.com

physicsworld

Want even more content?

Get more from *Physics World* without waiting for the next issue. The same great journalism you trust, but delivered to you daily.

Visit the homepage to see what's happening in physics right now

www.physicsworld.com

Opinion

physicsworld

Physics World
No.2 The Distillery, Glassfields, Avon Street, Bristol BS2 0GR, UK
Tel +44 (0)117 929 7481
E-mail pwld@ioppublishing.org
Web physicsworld.com
LinkedIn physics-world
Bluesky physicsworld

Head of media Jo Allen

Editorial
Editor-in-chief Matin Durrani
News editor Michael Banks
Features editors Tushna Commissariat, Sarah Tesh
Online editors Tami Freeman, Margaret Harris, Hamish Johnston

Product and content
Product and marketing Laura Gillham
Content and production Kate Gardner, Kyla Rushman
Technical illustrations Alison Tovey

Sales and distribution
Circulation Alison Gardiner
Advertisement sales Edward Jost
Advertisement production Katie Graham

The 2026 subscription rate for institutions is £1066 for the current year and electronic archive. Orders to: Subscriptions Dept, IOP Publishing, No.2 The Distillery, Glassfields, Avon Street, Bristol BS2 0GR, UK; tel +44 (0)117 929 7481; e-mail customerservices@ioppublishing.org. *Physics World* is available on an individual basis, worldwide, through membership of the Institute of Physics

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

Institute of Physics
37 Caledonian Road, London N1 9BU, UK
Tel +44 (0)20 7470 4800
E-mail membership@iop.org
Web www.iop.org

IOP Publishing

A shared future

The theme of the American Physical Society's main meeting this year is opportune

The Global Physics Summit (GPS) bills itself as "the world's largest physics research conference". Organized by the American Physical Society (APS), it combines the previously separate APS March and April meetings, with at least 14 000 people expected to attend this year's event in Denver, which has the theme "science for a shared future".

iStock/milehightraveler

The two APS meetings (especially APS March) have long been pilgrimages for physicists. They're a chance to meet people whose papers you've read, learn about new research or – with a bit of luck – land a dream job. They offer unparalleled opportunities for gossiping, networking and making your name. Sometimes they even host extraordinary announcements, such as in 2023 when one group claimed to have discovered room-temperature superconductors, or in 1987 when several groups really did present the first data on high-temperature ones.

Due to the current state of US politics, however, physicists from many countries may well have second thoughts about travelling to this and other scientific meetings in the US. Indeed, if you're from one of almost 40 nations to which the US government has partially or fully suspended issuing visas – supposedly "to protect the security of the United States" – you probably won't be able to get into the country at all.

One US physicist told me that outsiders should respond by boycotting the US entirely. To me, that's a step too far, not least because breaking contact would show a lack of solidarity with US-based scientists suffering from funding cuts or worse. After all, physics is a global enterprise, as two articles in this issue of *Physics World* make clear.

The first is a feature about quantifying the environmental impact of military conflicts (pp33–38). Numbers are hard to come by, but according to a 2022 estimate extrapolated from the small number of nations that do share their data, the total military carbon footprint is about 5.5% of global emissions. This would make the world's militaries the fourth biggest carbon emitter if they were a nation.

The other article examines how climate change could trigger extreme changes in the activity of earthquakes and volcanoes (pp46–52). Worryingly, increased volcanic eruptions not only contribute to the build-up of greenhouse gases but also create other problems too. In particular, a warming climate melts ice caps, lowering surface loads and potentially causing more earthquakes to occur.

Both issues will only be solved through global, interdisciplinary collaborations. As the theme of the GPS quite rightly puts it, we need science for a shared future.

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

Cryogen-Free Measurement Systems to 18 Tesla

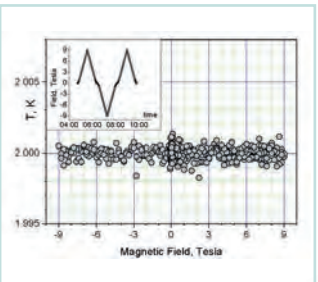
Specifications:

Temperature range from 1.5 K to 400 K
Sample in vacuum or exchange gas
Unique airlock and gate valve for rapid, cold sample change
mK stability across the full temperature range
20-bit power supply providing precise magnetic field control

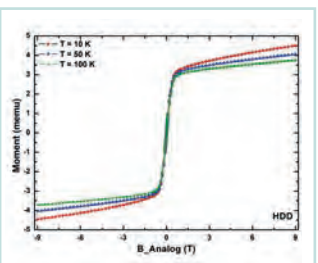
Compatible with:

VSM measurements up to 1000 K
Resistivity measurements up to 700 K
FMR spectroscopy
Single and two-axis rotator
Thermal transport measurements
^{3}He insert or ^{3}He rotator (285 mK)
Dilution Refrigerator (50 mK)

18 Tesla Cryogen-Free magnet with 50 mm VTI



1 mK temperature stability at 9 Tesla



Magnetization as a function of magnetic field for HDD at T = 10 K, 50 K and 100 K

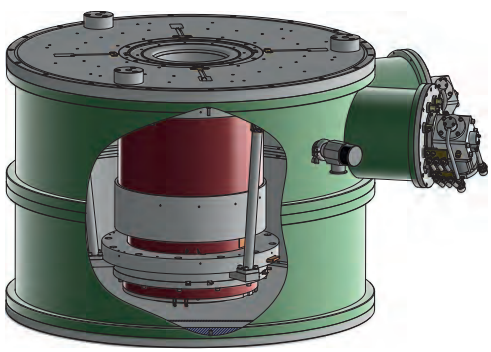
10.5 Tesla Cryogen-Free Gyrotron Magnet System
with Integrated X–Y Dipole Steering Coils

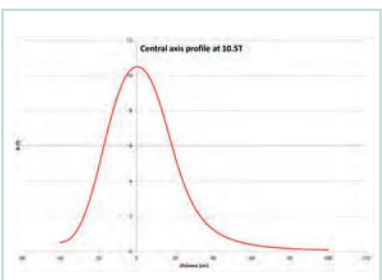
Specifications:

Maximum Field Strength: 10.5 T (with operational margin)
Large Room Temperature Bore: Ø 240 mm (Ø 290 mm at emitter)
Integrated X–Y Dipole Steering Coils: • ±0.5 mm electron beam shift • Independent control via dedicated power supplies
Four Individually Controlled Main Coil Circuits: • Primary (Nb_3Sn) • Compensation (NbTi) • Two Gun Coils (NbTi)
Field Homogeneity: ±0.1% in the cavity region
Gyrotron Mass: Supports up to 2,000 kg
Automation: Full PLC/LabVIEW Remote Control Interface

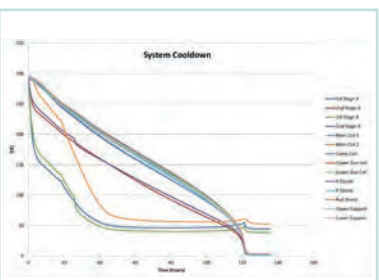
Parameter	Specification
Field Homogeneity (±5 mm at cavity)	±0.1%
Magnetic Axis Displacement	≤0.30 mm
Axis Drift (1 year)	≤0.1 mm
Emitter Field Range	$0.025B_C \leq B_E \leq 0.05B_C$
Field Vector Angle at Emitter	-5° to +2°
System cooldown	5 days

System installed on the KIT gyrotron test stand, pictured with the Karlsruhe Institute of Technology (KIT) team





Central axis profile at 10.5 Tesla



System Cooldown

Unit 6 Acton Park, The Vale,
London W3 7QE, United Kingdom

CRYOGENIC

Tel: +44 20 8743 6049
Email: sales@cryogenic.co.uk
www.cryogenic.co.uk

AI is like playing with fire

Johan Hansson says it is dangerous to treat artificial intelligence as a magic wand and thinks researchers should create their own AI tools that they can control better

According to today's leading experts in artificial intelligence (AI), this new technology is a danger to civilization. A statement on AI risk published in 2023 by the US non-profit Center for AI Safety warned that mitigating the risk of extinction from AI must now be "a global priority", comparing it to other societal-scale dangers such as pandemics and nuclear war. It was signed by more than 600 people, including the winner of the 2024 Nobel Prize for Physics and so-called "Godfather of AI" Geoffrey Hinton. In a speech at the Nobel banquet after being awarded the prize, Hinton noted that AI may be used "to create terrible new viruses and horrendous lethal weapons that decide by themselves who to kill or maim".

Despite signing the letter, Sam Altman of OpenAI, the firm behind ChatGPT, has stated that the company's explicit ambition is to create artificial general intelligence (AGI) within the next few years, to "win the AI-race". AGI is predicted to surpass human cognitive capabilities for almost all tasks, but the real danger is if or when AGI is used to generate more powerful versions of itself. Sometimes called "superintelligence", this would be impossible to control. Companies do not want any regulation of AI and their business model is for AGI to replace most employees at all levels. This is how firms are expected to benefit from AI, since wages are most companies' biggest expense.

AI, to me, is not about saving the world, but about a handful of people wanting to make enormous amounts of money from it. No-one knows what internal mechanism makes even today's AI work – just as one cannot find out what you think from how the neurons in your brain are firing. If we don't even understand today's AI models, how are we going to understand – and control – the more powerful models that already exist or are planned in the near future?

AI has some practical benefits but too often is put to mostly meaningless, sometimes downright harmful, uses such as cheating your way through school or creating disinformation and fake videos online. What's more, an online search with the help of AI requires at least 10 times as much energy as a search without AI. It already uses 5% of all electricity in the US and by 2028 this figure is expected to be 15%, which will be over a quarter of all US households' electricity consumption. AI data servers are more than 50% as carbon intensive as the rest of the US's electricity supply.

Shutterstock/khunkorn Studio

Jumping on the bandwagon Despite the potential benefits of artificial intelligence are we being too quick to embrace the technology?

AI has some practical benefits but too often is put to mostly meaningless, sometimes downright harmful, uses

Those energy needs are why some tech companies are building AI data centres – often under confidential, opaque agreements – very quickly for fear of losing market share. Indeed, the vast majority of those centres are powered by fossil-fuel energy sources – completely contrary to the Paris Agreement to limit global warming. We must wisely allocate Earth's strictly limited resources, with what is wasted on AI instead going towards vital things.

To solve the climate crisis, there is definitely no need for AI. All the solutions have already been known for decades: phasing out fossil fuels, reversing deforestation, reducing energy and resource consumption, regulating global trade, reforming the economic system away from its dependence on growth. The problem is that the solutions are not implemented because of short-term selfish profiteering, which AI only exacerbates.

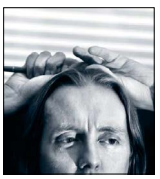
Playing with fire

AI, like all other technologies, is not a magic wand and, as Hinton says, potentially has many negative consequences. It is not, as the enthusiasts seem to think, a magical free resource that provides output without input (and waste). I believe we must rethink our naïve, uncritical, overly fast, total embrace of AI. Universities are known for wise reflection, but worryingly they seem to be hurrying to jump on the AI bandwagon. The problem is that the bandwagon may be going in the wrong direction or crash and burn entirely.

Why then should universities and organizations send their precious money to greedy, reckless and almost totalitarian tech billionaires? If we are going to use AI, shouldn't we create our own AI tools that we can hopefully control better? Today, more money and power is transferred to a few AI companies that transcend national borders, which is also a threat to democracy. Democracy only works if citizens are well educated, committed, knowledgeable and have influence.

AI is like using a hammer to crack a nut. Sometimes a hammer may be needed but most of the time it is not and is instead downright harmful. Happy-go-lucky people at universities, companies and throughout society are playing with fire without knowing about the true consequences now, let alone in 10 years' time. Our mapped-out path towards AGI is like a zebra on the savannah creating an artificial lion that begins to self-replicate, becoming bigger, stronger, more dangerous and more unpredictable with each generation.

Wise reflection today on our relationship with AI is more important than ever.



Johan Hansson is a theoretical physicist at Luleå University of Technology in Sweden

IPAC 2026

May 17 - 22

17th International Particle Accelerator Conference

Deauville | Normandy | France
International Convention Center

MAIN TOPICS

- Hadron accelerators
- Beam dynamics and EM fields
- Colliders and Related accelerators
- Accelerator technology and sustainability
- Photon sources and electron accelerators
- Advanced acceleration techniques and novel particle sources
- Beam instrumentations, operation Controls, Feedback and Operational Aspects
- Applications of Accelerators, Engagement with Industry, Technology Transfer and Outreach

Sponsorship and Booth reservations open

Early Bird registration closes on March 17th 2026

New deal for industrial start-ups at IPAC'26

More information on ipac26.org

Conception graphique : Atelier Chose & Co

IPAC26 GANIL cea cnrs EPS ACCELERATOR GROUP European Physical Society SOLEIL SYNCHROTRON ESRF The European Synchrotron

Transactions Pros & cons of patents

Shutterstock/kentoh

A right palaver Patents let you protect your hard-fought inventions, but applying for and maintaining them costs time, money and effort.

Honor Powrie reveals why she has a love–hate relationship with patents, which are often worthwhile but can be time-consuming and expensive to take out

For any company or business, it's important to recognize and protect intellectual property (IP). In the case of novel inventions, which can include machines, processes and even medicines, a patent offers IP protection and lets firms control how those inventions are used. Patents, which in most countries can be granted for up to 20 years, give the owner exclusive rights so that others can't directly copy the creation. A patent essentially prevents others from making, using or selling your invention.

But there are more reasons for holding a patent than IP protection alone. In particular, patents go some way to protecting the investment that may have been necessary to generate the IP in the first place, such as the cost of R&D facilities, materials, labour and expertise. Those factors need to be considered when you're deciding if patenting is the right approach or not.

Patents are in effect a form of currency. Counting as tangible assets that add to the overall value of a company, they can be sold to other businesses or licensed for royalties to provide regular income. Some companies, in fact, build up or acquire significant patent portfolios, which can be used for bargaining with competitors, potentially leading to cross-licensing agreements where both parties agree to use each other's technology.

Patents also say something about the competitive edge of a company, by demonstrating technical expertise and market position through the control of a specific technology. Essentially, patents give credibility to a company's claims of its technical know-how: a patent shows investors that a firm has a unique, protected asset, making the business more appealing and attractive to further investment.

However, it's not all one-way traffic and there are obligations on the part of the patentee. Firstly, a patent holder has to reveal to the world exactly how their invention works. Governments favour this kind of public disclosure as it encourages broader participation in innovation. The downside is that whilst your competitors cannot directly copy you, they can enhance and improve upon your invention, provided those changes aren't covered by the original patent.

It's also worth bearing in mind that a patent holder is responsible for patent enforcement and any ensuing litigation; a patent office will not do this for you. So you'll have to monitor what your competitors are up to and decide on what course of action to take if you suspect your patent's been infringed. Trouble is, it can sometimes be hard to prove or disprove an infringement – and getting the lawyers in can be expensive, even if you win.

Money talks

Probably the biggest consideration of all is the cost and time involved in making a patent application. Filing a patent requires a rigorous understanding of "prior art" – the existing body of relevant knowledge on which novelty is judged. You'll therefore need to do a lot of work finding out about relevant established patents, any published research and journal articles, along with products or processes publicly disclosed before the patent's filing date.

Before it can be filed with a patent office, a patent needs to be written as a legal description, which includes all the legwork like an abstract, background, detailed specifications, drawings and claims of the invention. Once filed, an expert in the relevant technical field will be assigned to assess the worth of the claim; this examiner must be satisfied that the application is both unique and "non-obvious" before it's granted.

Even when the invention is judged to be technically novel, in order to be non-obvious, it must also involve an "inventive step" that would not be obvious to a person with "ordinary skill" in that technical field at the time of filing. The assessment phase can result in significant to-ing and fro-ing between the examiner and the applicant to determine exactly what is patentable. If insufficient evidence is found, the patent application will be refused.

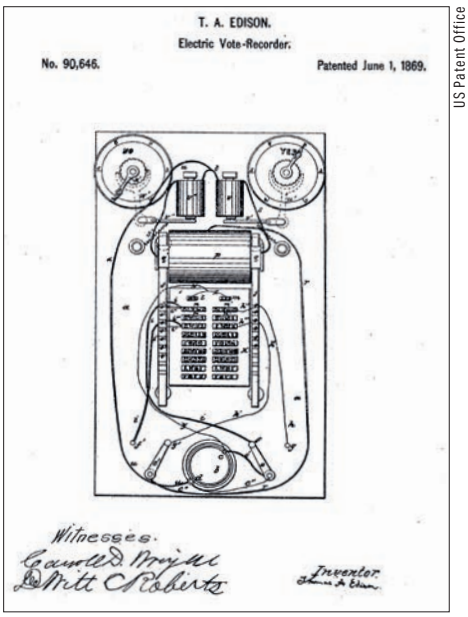
Patents are only ever granted in a particular country or region, such as Europe, and the application process has to be repeated for each new place (although the information required is usually pretty

similar). Translations may be required for some countries, there are fees for each application and, even if a patent is granted, you have to pay an additional annual bill to maintain the patent (which in the UK rises year on year).

Patent applications, in other words, can be expensive and can take years to process. That's why many companies pay specialized firms to support their patent applications. Those firms employ patent attorneys – legal experts with a technical background who help inventors and companies manage their IP rights by drafting patent applications, navigating patent office procedures and advising on IP strategy. Attorneys can also represent their clients in disputes or licensing deals, thereby acting as a crucial bridge between science/engineering and law.

Perspiration and aspiration

It's impossible to write about patents without mentioning the impact that Thomas Edison had as an inventor. During the 20th century, he became the world's most prolific inventor with a staggering 1093 US patents granted in his lifetime. This monumental achievement remained unsurpassed until 2003, when it was overtaken by the Japanese inventor Shunpei Yamazaki and, more recently, by the Australian "patent titan" Kia Silverbrook in 2008.



US Patent Office

Major inventor Thomas Edison took out more than 1000 US patents during his lifetime, including one for the electric lamp issued in 1880. This one here, dated 1 June 1869, shows a diagram for his electric vote recorder.

Edison clearly saw there was a lot of value in patents, but how did he achieve so much? His approach was grounded in systematic problem solving, which he accomplished through his Menlo Park lab in New Jersey. Dedicated to technological development and invention, it was effectively the world's first corporate R&D lab. And whilst Edison's name appeared on all the patents, they were often primarily the work of his staff; he was effectively being credited for inventions made by his employees.

I will be honest; I have a love–hate relationship with patents or at least the process of obtaining them. As a scientist or engineer, it's easy to think all the hard work is getting an invention over the line, slogging your guts out in the lab. But applying for a patent can be just as expensive and time-consuming, which is why you need to be clear on what and when to patent. Even Edison grew tired of being hailed a genius, stating that his success was "1% inspiration and 99% perspiration".

Still, without the sweat of patents, your success might be all but 99% aspiration.

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

Critical Point The Straton model

Sakata Memorial Archival Library

Meeting of minds Mao Zedong (left) at the 1964 Peking Symposium congratulating Japanese theorist Shoichi Sakata (right) on his achievements in particle physics, as distinguished Chinese physicist Peiyuan Zhou looks on.

An obscure theory of elementary particles proved to be key to China's re-emergence as a scientific nation after the Cultural Revolution had stalled its development. **Robert P Crease** finds out more from the Chinese historian of physics Jinyan Liu

"The Straton Model of elementary particles had very limited influence in the West," said Jinyan Liu as she sat with me in a quiet corner of the CERN cafeteria. Liu, who I caught up with during a break in a recent conference on the history of particle physics, was referring to a particular model of elementary particle physics first put together in China in the mid-1960s. The Straton Model was, and still largely is, unknown outside that country. "But it was an essential step forward," Liu added, "for Chinese physicists in joining the international community."

Liu was at CERN to give a talk on how Chinese theorists redirected their research efforts in the years after the Cultural Revolution, which ended in 1976. They switched from the Straton Model, which was a politically infused theory of matter favoured by Mao Zedong, the founder of the People's Republic of China, to mainstream particle physics as practised by the rest of the world. It's easy to portray the move as the long-overdue moment when Chinese scientists resumed their "real" physics research. But, Liu told me, "actually it was much more complicated".

A physicist by training, Liu received her PhD on contemporary theories of spontaneous charge-parity (CP) violation from the Institute of Theoretical Physics at the Chinese Academy of Sciences (CAS) in 2013. She then switched to the CAS Institute for the History of Natural Sciences, where she was its first member with a physics PhD. Her initial research topic was the history and development of the Straton Model.

The model is essentially a theory of the structure of hadrons – either baryons (such as protons and neutrons) or mesons (such as pions and kaons). But the model's origins are as improbable as they are labyrinthine. Mao, who had a keen interest in natural science, was convinced that matter was infinitely divisible, and in 1963 he came across an article by the Marxist-inspired Japanese physicist Shoichi Sakata (1911–1970).

First published in Japanese in 1961 and later translated into Russian, Sakata's paper was entitled "Dialogues concerning a new view of elementary particles". It restated Sakata's belief, which he had been working on since the 1950s, that hadrons are made of smaller constituents – "elementary particles are not the ultimate elements of matter" as he put it. With some Chinese scholars back then still paying close attention to publications from the Soviet Union, their former political and ideological ally, that paper was then translated into Chinese.

This version appeared in the *Bulletin of the Studies of Dialectics of Nature* in 1963. Mao, who received an issue of that bulletin from his son-in-law, was engrossed in Sakata's paper, for it seemed to offer scientific support for his own views. Sakata's article – both in the original Japanese and now in Chinese – cited Friedrich Engels' view that matter has numerous stages of discrete but qualitatively different parts. In addition, it quoted Lenin's remark that "even the electron is inexhaustible".

A wider dimension

"International politics now also entered," Liu told me, as we discussed the issue further at CERN. A split between China and the Soviet Union had begun to open up

Jinyan Liu

Major attraction The high-water mark for the Straton model occurred at a physics colloquium organized by the China Association for Science and Technology in Tiananmen Square, Beijing, in July 1966, the opening ceremony of which is shown here.

in the late 1950s, with Mao breaking off relations with the Soviet Union and starting to establish non-governmental science and technology exchanges between China and Japan. Indeed, when China hosted the Peking Symposium of foreign scientists in 1964, Japan brought the biggest delegation, with Sakata as its leader.

At the event, Mao personally congratulated Sakata on his theory. It was, Sakata later recalled, "the most unforgettable moment of my journey to China". In 1965, Sakata's paper was retranslated from the Japanese original, with an annotated version published in *Red Flag* and the newspaper *Renmin ribao*, or "People's Daily", both official organs of the Chinese Communist Party.

Chinese physicists, who had been assigned to work on the atomic bomb and other research deemed important by the Communist Party, now started to take note. Uninterested in philosophy, they realized that they could capitalize on Mao's enthusiasm to make elementary particle physics a legitimate research direction.

As a result, 39 members of CAS, Peking University and the University of Science and Technology of China formed the Beijing Elementary Particle Group. Between 1965 and 1966, they wrote dozens of papers on a model of hadrons inspired by both Sakata's work and quark theory based on the available experimental data. It was dubbed the Straton Model because it involved layers or "strata" of particles nested in each other.

Liu has interviewed most surviving members of the group and studied details of the model. It differed from the model being developed at the time by the US theorist Murray Gell-Mann, which saw quarks as not physical but mathematical elements. As Liu discovered, Chinese particle physicists were now given resources they'd never had before. In particular, they could use computers, which until then had been devoted to urgent national defence work. "To be honest," Liu chuckled, "the elementary particle physicists didn't use computers much, but at least they were made available."

The high-water mark for the Straton Model occurred in July 1966 when members of the Beijing Elementary Particle Group presented it at a summer physics colloquium organized by the China Association for Science and Technology. The opening ceremony was held in Tiananmen Square, in what was then China's biggest conference centre, with attendees including Abdus Salam from Imperial College London. The only high-profile figure to be invited from the West, Salam was deemed acceptable because he was science advisor to the president of Pakistan, a country considered outside the western orbit.

The proceedings of the colloquium were later published as "Research on the theory of elementary particles carried out under the brilliant illumination of Mao Tse-Tung's thought". Its introduction was what Liu calls a "militant document" – designed to reinforce the idea that the authors were carrying Mao's thought into scientific research to repudiate "decadent feudal, bourgeois and revisionist ideologies".

Participants in Beijing had expected to make their advances known internationally by publishing the proceedings in English. But the Cultural Revolution had just begun two months before, and publications in English were forbidden. "As a result," Liu told me, "the model had very limited influence outside China." Sakata, however, had an important influence on Japanese theorists having co-authored the key paper on neutrino flavour oscillation (*Prog. Theoretical. Physics* **28** 870).

A resurfaced effort

In recent years, Liu has shed new light on the Straton Model, writing a paper in the journal *Chinese Annals of History of Science and Technology* (**2** 85). In 2022, she also published a Chinese-language book entitled *Constructing a Theory of Hadron Structure: Chinese Physicists' Straton Model*, which describes the downfall of the model after 1966. None of its predicted material particles appeared, though a candidate event once occurred in a cosmic ray observatory in the south of China.

By 1976, quantum chromodynamics (QCD) had convincingly emerged as the established model of hadrons. The effective end of the Straton Model took place at a conference in January 1980 in Conghua, near Hong Kong. Hung-Yuan Tzu, one of the key leaders of the Beijing Group, gave a paper entitled "Reminiscences of the Straton Model", signalling that physics had moved on.

During our meeting at CERN, Liu showed me photos of the 1980 event. "It was a very important conference in the history of Chinese physics," she said, "the first opening to Chinese physicists in the West". Visits by Chinese expatriates were organized by Tsung-Dao Lee and Chen Ning Yang, who shared the 1957 Nobel Prize for Physics for their work on parity violation.

The critical point

It is easy for westerners to mock the Straton Model; Sheldon Glashow once referred to it as about "Maons". But Liu sees it as significant research that had many unexpected consequences, such as helping to advance physics research in China. "It gave physicists a way to pursue quantum field theory without having to do national defence work".

The model also trained young researchers in particle physics and honed their research competence. After the post-Cultural Revolution reform and its opening to the West, these physicists could then integrate into the international community. "The story," Liu said, "shows how ingeniously the Chinese physicists adapted to the political situation."

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

Agilent
Trusted Answers

The IDP Dry Scroll Pump Family Expands!

Clean, High Performance, Oil Free Vacuum Pumps

Coming Soon: The New Agilent IDP-4

- Compact footprint and lightweight
- Low power consumption
- Speed control with inverter technology
- Universal voltage
- Maintenance made simple
- Superior Helium management

www.agilent.com/en/product/vacuum-technologies

2G HTS IN YOUR LAB

Harnessing the inherent advantages of HTS materials, we engineer superior stability, cost-efficiency, and spatial flexibility into dependable magnets deployed across:

- manufacturing and materials processing
- neutron and X-ray beamline instruments
- NMRD and high-resolution spectroscopic systems
- superconductor research and characterisation
- fusion energy and plasma science

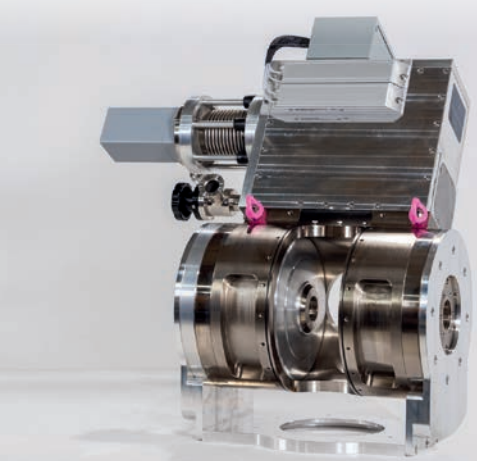
Modernise your Magnetic Environment: contact our engineering team to schedule a feasibility study or to discuss custom integration for your specific workflow.

hts-110.com

est. 2004

HTS-110

VISIT US AT APS
BOOTH 1929



Reviews

A life of twists and turns

Andrew Robinson reviews *Crick: a Mind in Motion – from DNA to the Brain* by Matthew Cobb

Extrovert and rebel Francis Crick at a dinner at the Nobel prize winners conference in Lindau, Germany, in 1981

Crick: a Mind in Motion – from DNA to the Brain
Matthew Cobb
2025 Profile Books
£30.00hb 595pp

Physicist, molecular biologist, neuroscientist: Francis Crick's scientific career took many turns. And now, he is the subject of zoologist Matthew Cobb's new book, *Crick: a Mind in Motion – from DNA to the Brain*.

Born in 1916, Crick studied physics at University College London in the mid-1930s, before working for the Admiralty Research Laboratory during the Second World War. But after reading physicist Erwin Schrödinger's 1944 book *What Is Life? The Physical Aspect of the Living Cell,* and a 1946 article on the structure of biological molecules by chemist Linus Pauling, Crick left his career in physics and switched to molecular biology in 1947.

Six years later, while working at the University of Cambridge, he played a key role in decoding the double-helix structure of DNA, working in collaboration with biologist James Watson, biophysicist Maurice Wilkins and other researchers including chemist and X-ray crystallographer Rosalind Franklin. Crick, alongside Watson and Wilkins, went on to receive the 1962 Nobel Prize in Physiology and Medicine for the discovery.

Finally, Crick's career took one more turn in the mid-1970s. After experiencing a mental health crisis, Crick left Britain and moved to California. He took up neuroscience in an attempt to understand the roots of human consciousness, as discussed in his 1994 book, *The Astonishing Hypothesis: the Scientific Search for the Soul.*

Parallel lives

When he died in 2004, Crick's office wall at Salk Institute in La Jolla, US, carried portraits of Charles Darwin and Albert Einstein, as Cobb notes on the final page of his deeply researched and intellectually fascinating biography. But curiously, there is not a single other reference to Einstein in Cobb's massive book. Furthermore, there is no reference at all to Einstein in the equally large 2009 biography of Crick, *Francis Crick: Hunter of Life's Secrets*, by historian of science Robert Olby, who – unlike Cobb – knew Crick personally.

Nevertheless, a comparison of Crick and Einstein is illuminating. Crick's family background (in the shoe industry), and his childhood and youth are in some ways reminiscent of Einstein's. Both physicists came from provincial business families of limited financial success, with some interest in science yet little intellectual distinction. Both did moderately well at school and college, but were not academic stars. And both were exposed to established religion, but rejected it in their teens; they had little intrinsic respect for authority, without being open rebels until later in life.

The similarities continue into adulthood, with the two men following unconventional early scientific careers. Both of them were extroverts who loved to debate ideas with fellow scientists (at times devastatingly), although they were equally capable of long, solitary periods of concentration throughout their careers. In middle age, they migrated from their home countries – Germany (Einstein) and Britain (Crick) – to take up academic positions in the US, where they were much admired and inspiring to other scientists, but failed to match their earlier scientific achievements.

In their personal lives, both Crick and Einstein had a complicated history with women. Having divorced their first wives, they had a variety of extramarital affairs – as discussed by Cobb without revealing the names of these women – while remaining married to their second wives. Interestingly, Crick's second wife, Odile Crick (whom he was married to for 55 years) was an artist, and drew the famous schematic drawing of the double helix published in *Nature*

View this e-magazine online to watch a video about DNA's remarkable physical properties.

in 1953.

Although Cobb misses this fascinating comparison with Einstein, many other vivid stories light up his book. For example, he recounts Watson's claim that just after their success with DNA in 1953, "Francis winged into the Eagle [their local pub in Cambridge] to tell everyone within hearing distance that we had found the secret of life" – a story that later appeared on a plaque outside the pub.

"Francis always denied he said anything of the sort," notes Cobb, "and in 2016, at a celebration of the centenary of Crick's birth, Watson publicly admitted that he had made it up for dramatic effect (a few years earlier, he had confessed as much to Kindra Crick, Francis's granddaughter)." No wonder Watson's much-read 1968 book *The Double Helix* caused a furious reaction from Crick and a temporary breakdown in their friendship, as Cobb dissects in excoriating detail.

Watson's deprecatory comments on Franklin helped to provoke the current widespread belief that Crick and Watson succeeded by stealing Franklin's data. After an extensive analysis of the available evidence, however, Cobb argues that the data was willingly shared with them by Franklin, but that they should have formally asked her permission to use it in their published work – "Ambition, or thoughtlessness, stayed their hand."

In fact, it seems Crick and Franklin were friends in 1953, and remained so – with Franklin asking Crick for his advice on her draft scientific papers – until her premature death from ovarian cancer in 1958. Indeed, after her first surgery in 1956, Franklin went to stay with Crick and his wife at their house in Cambridge, and then returned to them after her second operation. There certainly appears to be no breakdown in trust between the two. When Crick was nominated for the Nobel prize in 1961, he openly stated, "The data which really helped us obtain the structure was mainly obtained by Rosalind Franklin."

As for Crick's later study of consciousness, Cobb comments, "It would be easy to dismiss Crick's switch to studying the brain as the quixotic project of an ageing scientist who did not know his limits. After all, he did not make any decisive breakthrough in understanding the brain – nothing like the double helix… But then again, nobody else did, in Crick's lifetime or since." One is perhaps reminded once again of Einstein, and his preoccupation during later life with his unified field theory, which remains an open line of research today.

Andrew Robinson is the author of *Genius: a Very Short Introduction*

Feedback

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

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

Targeting scientists

In response to the Forum article by Alireza Qaiumzadeh, which called for scientists to be "recognized and protected as civilians" under international humanitarian law (January p19).

I read Qaiumzadeh's article about the killing of Iranian scientists by the Israeli military with some concern. While I agree that scientists should not be targeted because of their expertise, I also hold that they should not be targeted because of their religious beliefs or nationality.

Iran has vowed to destroy Israel, and regrettably it has scientists working on critical offensive weapons such as nuclear explosives with this objective. In June last year Iranian missiles destroyed large parts of Israel's Weizmann Institute – a fact that Qaiumzadeh does not mention.

Calling for "global responsibility", as Qaiumzadeh does, is all very well. But any scientist who knowingly contributes to a war against civilians is a combatant. Personal responsibility is also vital if we are to uphold ethical standards in this area.

Gil Jones
Manchester, UK

Colourful impact

In response to the feature "The physics Nobel prizes you have never heard of" by Margaret Harris, which covered the 1908 award to Gabriel Lippmann, who invented an obscure version of colour photography (November 2025 pp28–32).

I very much enjoyed Harris's article, but I have an alternative perspective as someone who became a physicist after originally doing a PhD in chemistry and entering the photographic industry. Rather than considering Lippmann's version of photography as obsolete, we should label it as foundational.

Yes, the "autochrome" process is faster and proved to be commercially successful. But Lippmann's 20 years of work laid the foundations for the photographic recording of holograms, making it much more than just an elegant application of classical wave theory.

Photo public domain

Capturing colour A still life photograph taken by Gabriel Lippmann between 1890 and 1910, using the method he developed.

Alan Hodgson
Macclesfield, UK

Two's company

In response to Honor Powrie's Transactions article about whether entrepreneurship can be taught, or if it is something innate (February p15).

Powrie's article reminded me that Rolls-Royce was founded not by a single technical specialist with entrepreneurial skills but by a partnership of two people. Within science and engineering circles, Henry Royce is best remembered as a talented engineer, but the company's success also relied on the business executive Charles Rolls, famous for the motto "Whatever you make, I can sell".

Unfortunately, there is another reason why Rolls is the less well known of the pair, while Royce had a long and successful career. That's because Rolls has the dubious honour of being the first person to die – in an aviation accident only six years after the company was founded. His willingness to take risks may have enabled the enduring success of the company but it was also his downfall.

Penny Jackson
Derby, UK

Spirit of Chernobyl

As a physicist who has worked on the environmental consequences of the Chernobyl nuclear accident for most of my career, it's worth noting that next month marks the 40th anniversary of the event, which occurred on 26 April 1986. Together with our Ukrainian collaborators, my team and I have had lots of interesting experiences at Chernobyl, including studying how wildlife in the exclusion zone around the reactor has recovered over the last 40 years.

On a lighter note, we've also developed the ATOMIK Spirits project – a social enterprise producing safe, high-quality spirits from crops grown in the supposedly "contaminated" areas of Ukraine. So far we've sold 8000 bottles of both apple brandy and apple vodka, raising £45 000 to support affected communities. More information is available at www.atomikvodka.com and on the *Physics World Stories* podcast.

Jim Smith
School of the Environment and Life Sciences, University of Portsmouth, UK

Not remotely effective

In response to a news story about the benefits and pitfalls of remote working (January p5).

You wrote about a study into remote and hybrid working, which showed that it hampers research quality by reducing spontaneous, serendipitous in-person interactions – and leading to a decline in citation impact. Even though this kind of working expands collaboration networks and makes them more international, overall it seems to me to be a corollary of what I call Court's rule: "Online communication is more efficient than in-person, but less effective".

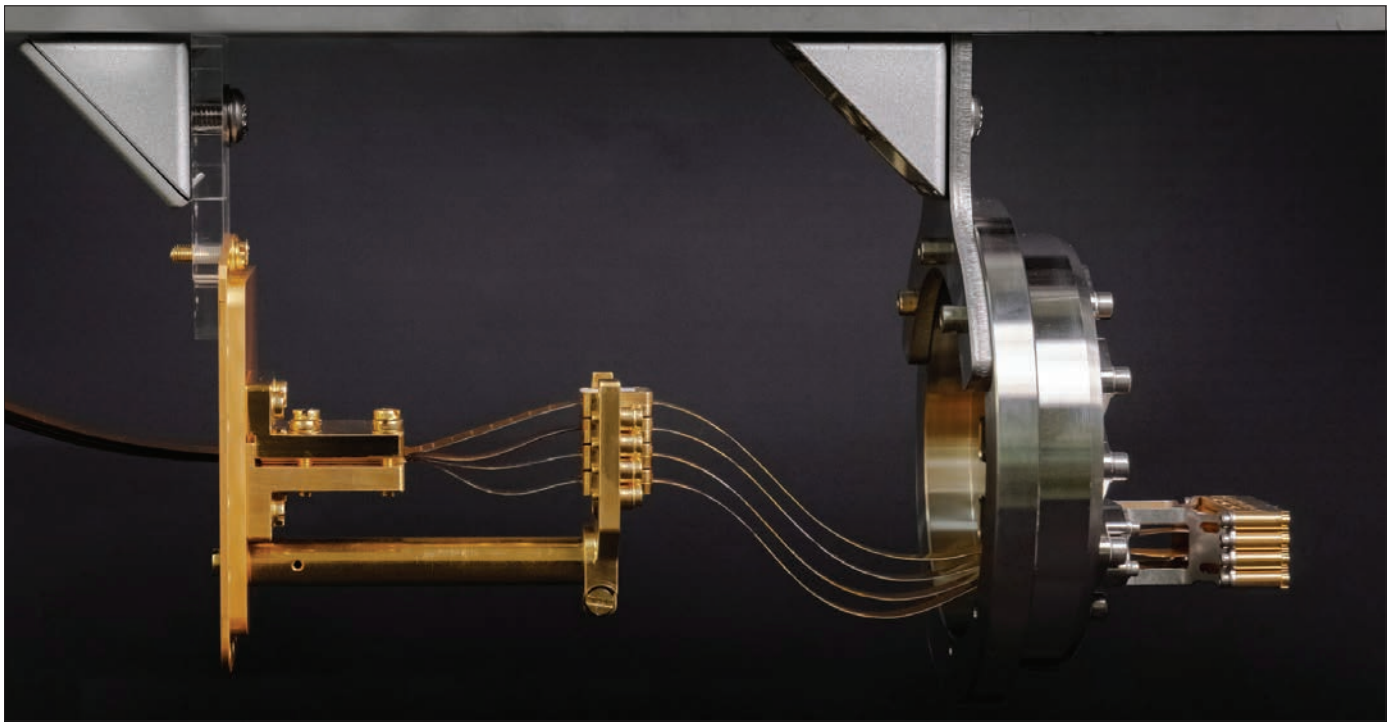
Robert Court
Hope Valley, Derbyshire, UK

Correction

Due to an editing error, Andrew Robinson's review of Frank Close's book *Destroyer of Worlds* (December pp38–39) said that Russia's "Tsar Bomba" was more powerful than the meteorite impact 65 million years ago that killed the dinosaurs; it was more powerful only than any recorded explosion since then.

Delft Circuits, Bluefors: the engine-room driving joined-up quantum innovation

Dutch-Finnish industry partnership establishes a 'one-stop shop' to deliver scalable cryogenic I/O cabling assemblies for applications in quantum science and technology



At-scale quantum By integrating Delft Circuits' Cri/oFlex® cabling technology (above) into Bluefors' dilution refrigerators, the vendors' combined customer base will benefit from an industrially proven and fully scalable I/O solution for their quantum systems. Cri/oFlex® cabling combines fully integrated filtering with a compact footprint and low heatload.

Better together. That's the headline take on a newly inked technology partnership between Bluefors, a heavyweight Finnish supplier of cryogenic measurement systems, and Delft Circuits, a Dutch manufacturer of specialist I/O cabling solutions designed for the scale-up and industrial deployment of next-generation quantum computers.

The drivers behind the tie-up are clear: as quantum systems evolve – think vastly increased qubit counts plus ever-more exacting requirements on gate fidelity – developers in research and industry will reach a point where current coax cabling technology doesn't cut it anymore. The answer? Collaboration, joined-up thinking and product innovation.

In short, by integrating Delft Circuits' Cri/oFlex® cabling technology into Bluefors' dilution refrigerators, the vendors' combined customer base will benefit from a complete, industrially proven and fully scalable I/O solution for their quantum systems. The end-game: to overcome the quantum tech industry's biggest bottleneck, forging a development pathway from quantum computing systems with hundreds of qubits today to tens of thousands of qubits by 2030.

Joined-up thinking

For context, Cri/oFlex® cryogenic RF cables comprise a stripline (a type of transmission line) based on planar microwave circuitry – essentially a conducting strip encapsulated in dielectric material and sandwiched between two conducting ground planes. The use of the polyimide Kapton® as the dielectric ensures Cri/oFlex® cables remain flexible in cryogenic environments (which are necessary to generate quantum states, manipulate them and read them out), with silver or superconducting NbTi providing the conductive strip and ground layer. The standard product comes as a multichannel flex (eight channels per flex) with a range of I/O channel configurations tailored to the customer's application needs, including flux bias lines, microwave drive lines, signal lines or read-out lines.

"Reliability is a given with Cri/oFlex®," says Robby Ferdinandus, global chief commercial officer for Delft Circuits and a driving force behind the partnership with Bluefors. "By integrating components such as attenuators and filters directly into the flex," he adds, "we eliminate extra parts and reduce points of failure. Combined with fast thermalization at every temperature stage, our technology ensures stable performance across thousands of channels, unmatched by any other I/O solution."

Technology aside, the new partnership is informed by a "one-stop shop" mind-

"Together with Bluefors, we will accelerate the journey to quantum advantage," says Robby Ferdinandus of Delft Circuits.

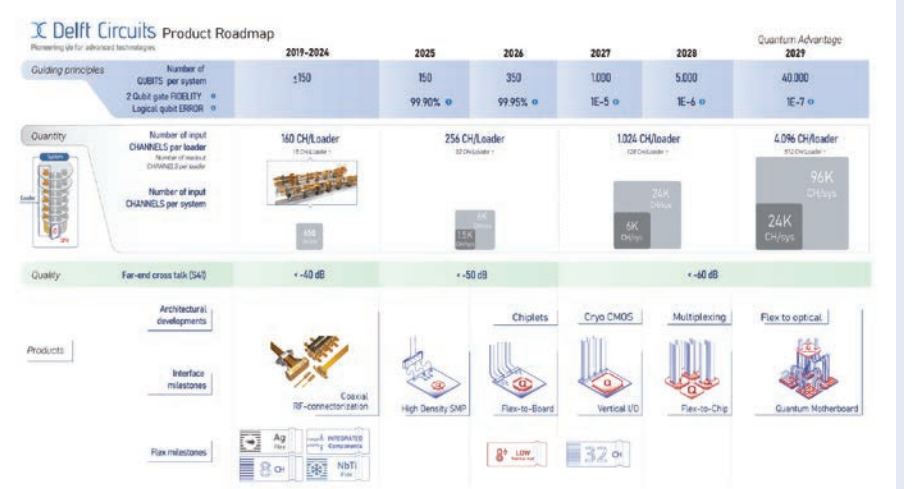
"Our market position in cryogenics is strong, so we have the 'muscle' and specialist know-how to integrate innovative technologies like Cri/oFlex®," says Reetta Kaila of Bluefors.

Scalable I/O will accelerate quantum innovation

Deconstructed, Delft Circuits' value proposition is all about enabling, from an I/O perspective, the transition of quantum technologies out of the R&D lab into at-scale practical applications. More specifically: Cri/oFlex® technology allows quantum scientists and engineers to increase the I/O cabling density of their systems easily – and by a lot – while guaranteeing high gate fidelities (minimizing noise and heating) as well as market-leading uptime and reliability.

To put some hard-and-fast performance milestones against that claim, the company has published a granular product development roadmap that aligns Cri/oFlex® cabling specifications against the anticipated evolution of quantum computing systems – from 150+ qubits today out to 40,000 qubits and beyond in 2029 (see figure below, "Quantum alignment").

The resulting milestones are based on a study of the development roadmaps of more than 10 full-stack quantum computing vendors – a consolidated view that will ensure the "guiding principles" of Delft Circuits' innovation roadmap align versus the aggregate quantity and quality of qubits targeted by the system developers over time.



Quantum alignment The new product development roadmap from Delft Circuits starts with the guiding principles, highlighting performance milestones to be achieved by the quantum computing industry over the next five years – specifically, the number of physical qubits per system and gate fidelities. By extension, cabling metrics in the Delft Circuits roadmap focus on "quantity": the number of I/O channels per loader (i.e. the wiring trees that insert into a cryostat, with typical cryostats having between 6–24 slots for loaders) and the number of channels per cryostat (summing across all loaders); also on "quality" (the crosstalk in the cabling flex). To complete the picture, the roadmap outlines product introductions at a conceptual level to enable both the quantity and quality timelines.

set, offering the high-density Cri/oFlex® solution pre-installed and fully tested in Bluefors cryogenic measurement systems. For the end-user, think turnkey efficiency: streamlined installation, commissioning, acceptance and, ultimately, enhanced system uptime.

Scalability is front-and-centre too, thanks to Delft Circuits' pre-assembled and tested side-loading systems. The high-density I/O cabling solution delivers up to 50% more channels per side-loading port to Bluefors' (current) High Density Wiring, providing a total of 1536 input or control lines to an XLDsl cryostat. In addition, more wiring lines can be added to multiple KF ports as a custom option.

Reciprocally, there's significant commercial upside to this partnership. Bluefors is the quantum industry's leading cryogenic systems OEM and, by extension, Delft Circuits now has access to the former's established global customer base, amplifying its channels to market by orders of magnitude. "We have stepped into the big league here and, working together, we will ensure that Cri/oFlex® becomes a core enabling technology on the journey to quantum advantage," notes Ferdinandus.

That view is amplified by Reetta Kaila, director for global technical sales and new products at Bluefors (and, alongside Ferdinandus, a main-mover behind the partnership). "Our market position in cryogenics is strong, so we have the 'muscle' and specialist know-how to integrate innovative technologies like Cri/oFlex® into our dilution refrigerators," she explains.

A win-win, it seems, along several coordinates. "The Bluefors sales teams are excited to add Cri/oFlex® into the product portfolio," Kaila adds. "It's worth noting, though, that the collaboration extends across multiple functions – technical and commercial – and will therefore ensure close alignment of our respective innovation roadmaps."

Delft Circuits
Pioneering i/o for advanced technologies

www.delft-circuits.com

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

The environmental and climate cost of war

Shutterstock/FedBul

The cost of war is most often framed in terms of the loss of human life and economic devastation. But, as **Benjamin Skuse** discovers, the world's militaries also account for over 5% of global greenhouse-gas emissions, with war causing untold and sometimes irreparable damage to the environment

Despite not being close to the frontline of Russia's military assault on Ukraine, life at the Ivano-Frankivsk National Technical University of Oil and Gas is far from peaceful. "While we continue teaching and research, we operate under constant uncertainty – air raid alerts, electricity outages – and the emotional toll on staff and students," says Lidiia Davybida, an associate professor of geodesy and land management.

Last year, the university became a target of a Russian missile strike, causing extensive damage to buildings that still has not been fully repaired – although, fortunately, no casualties were reported. The university also continues to leak staff and students to the war effort – some of whom will tragically never return – while new student numbers dwindle as many school graduates leave Ukraine to study abroad.

Despite these major challenges, Davybida and her colleagues remain resolute. "We adapt – moving lectures online when needed, adjusting schedules, and finding ways to keep research going despite limited opportunities and reduced funding," she says.

Resolute research

Davybida's research focuses on environmental monitoring using geographic information systems (GIS), geospatial analysis and remote sensing. She has been using

Benjamin Skuse is a freelance science journalist based in the UK

Sergei Chuzavkov/SOPPA Images/Shutterstock

Wider consequences Ukrainian military, emergency services and volunteers work together to rescue people from a large flooded area in Kherson on 8 June 2023. Two days earlier, the Russian army blew up the dam of the Kakhovka hydroelectric power station, meaning about 80 settlements in the flood zone had to be evacuated.

these techniques to monitor the devastating impact that the war is having on the environment and its significant contribution to climate change.

In 2023 she published results from using Sentinel-5P satellite data and Google Earth Engine to monitor the air quality impacts of war on Ukraine (*IOP Conf. Ser.: Earth Environ. Sci.* **1254** 012112). As with the COVID-19 lockdowns worldwide, her results reveal that levels of common pollutants such as carbon monoxide, nitrogen dioxide and sulphur dioxide were, on average, down from pre-invasion levels. This reflects the temporary disruption to economic activity that war has brought on the country.

More worrying, from an environment and climate perspective, were the huge concentrations of aerosols, smoke and dust in the atmosphere. "High ozone concentrations damage sensitive vegetation and crops," Davybida explains. "Aerosols generated by explosions and fires may carry harmful substances such as heavy metals and toxic chemicals, further increasing environmental contamination." She adds that these pollutants can alter sunlight absorption and scattering, potentially disrupting local climate and weather patterns, and contributing to long-term ecological imbalances.

A significant toll has been wrought by individual military events too. A prime example is Russia's destruction of the Kakhovka Dam in southern Ukraine in June 2023. An international team – including Ukrainian researchers – recently attempted to quantify this damage by combining on-the-ground field surveys, remote-sensing data and hydrodynamic modelling; a tool they used for predicting water flow and pollutant dispersion.

The results of this work are sobering (*Science* **387** 1181). Though 80% of the ecosystem is expected to re-establish itself within five years, the dam's destruction released as much as 1.7 cubic kilometres of sediment contaminated by a host of persistent pollutants, including nitrogen, phosphorous and 83 000 tonnes of heavy metals. Discharging this toxic sludge across the land and waterways will have unknown long-term environmental consequences for the region, as the contaminants could be spread by future floods, the researchers concluded (figure 1).

Previous page: **Counting costs** Borodyanka, in the Kyiv region of Ukraine, on 5 April 2022, after Russian bombing. Wars do not only cause death and economic destruction but also have many climate and environmental costs.

Dangerous data

A large part of the reason for the researchers' uncertainty, and indeed more general uncertainty in environmental and climate impacts of war, stems from data scarcity. It is near-impossible for scientists to enter an active warzone to collect samples and conduct surveys and experiments. Environmental monitoring stations also get damaged and destroyed during conflict, explains Davybida – a wrong she is attempting to right in her current work. Many efforts to monitor, measure and hopefully mitigate the environmental and climate impact of the war in Ukraine are therefore less direct.

In 2022, for example, climate-policy researcher Mathijs Harmsen from the PBL Netherlands Environmental Assessment Agency and international collaborators decided to study the global energy crisis (which was sparked by Russia's invasion of Ukraine) to look at how the war will alter climate policy (*Environ. Res. Lett.* **19** 124088).

They did this by plugging in the most recent energy price, trade and policy data (up to May 2023) into an integrated assessment model that simulates the environmental consequences of human activities worldwide. They then imposed different potential scenarios and outcomes and let it run to 2030 and 2050. Surprisingly, all scenarios led to a global reduction of 1–5% of carbon dioxide emissions by 2030, largely due to trade barriers increasing fossil fuel prices, which in turn would lead to increased uptake of renewables.

But even though the sophisticated model represents the global energy system in detail, some factors are hard to incorporate and some actions can transform the picture completely, argues Harmsen. "Despite our results, I think the net effect of this whole war is a negative one, because it doesn't really build trust or add to any global collaboration, which is what we need to move to a more renewable world," he says. "Also, the recent intensification of Ukraine's 'kinetic sanctions' [attacks on refineries and other fossil fuel infrastructure] will likely have a larger effect than anything we explored in our paper."

Elsewhere, Toru Kobayakawa was, until recently, working for the Japan International Cooperation Agency (JICA), leading the Ukraine support team. Kobayakawa used a non-standard method to more realistically estimate the carbon footprint of reconstructing Ukraine when the war ends (*Environ. Res.: Infrastruct. Sustain.* **5** 015015). The Intergovernmental Panel on Climate Change (IPCC) and other international bodies only account for carbon emissions within the territorial country. "The consumption-based model I use accounts for the concealed carbon dioxide from the production of construction materials like concrete and steel imported from outside of the country," he says.

Using an open-source database Eora26 that tracks financial flows between countries' major economic sectors in simple input–output tables, Kobayakawa calculated that Ukraine's post-war reconstruction will

1 Dam destruction

This map shows areas of Ukraine affected or threatened by dam destruction in military operations. Arabic numbers 1 to 6 indicate rivers: Irpen, Oskil, Inhulets, Dnipro, Dnipro-Bug Estuary and Dniester, respectively. Roman numbers I to VII indicate large reservoir facilities: Kyiv, Kaniv, Kremenchuk, Kaminske, Dnipro, Kakhovka and Dniester, respectively. Letters A to C indicate nuclear power plants: Chornobyl, Zaporizhzhia and South Ukraine, respectively.

amount to 741 million tonnes carbon dioxide equivalent over 10 years. This is 4.1 times Ukraine's pre-war annual carbon-dioxide emissions, or the combined annual emissions of Germany and Austria.

However, as with most war-related findings, these figures come with a caveat. "Our input–output model doesn't take into account the current situation," notes Kobayakawa "It is the worst-case scenario." Nevertheless, the research has provided useful insights, such as that the Ukrainian construction industry will account for 77% of total emissions.

"Their construction industry is notorious for inefficiency, needing frequent rework, which incurs additional costs, as well as additional carbon-dioxide emissions," he says. "So, if they can improve efficiency by modernizing construction processes and implementing large-scale recycling of construction materials, that will contribute to reducing emissions during the reconstruction phase and ensure that they build back better."

Military emissions gap

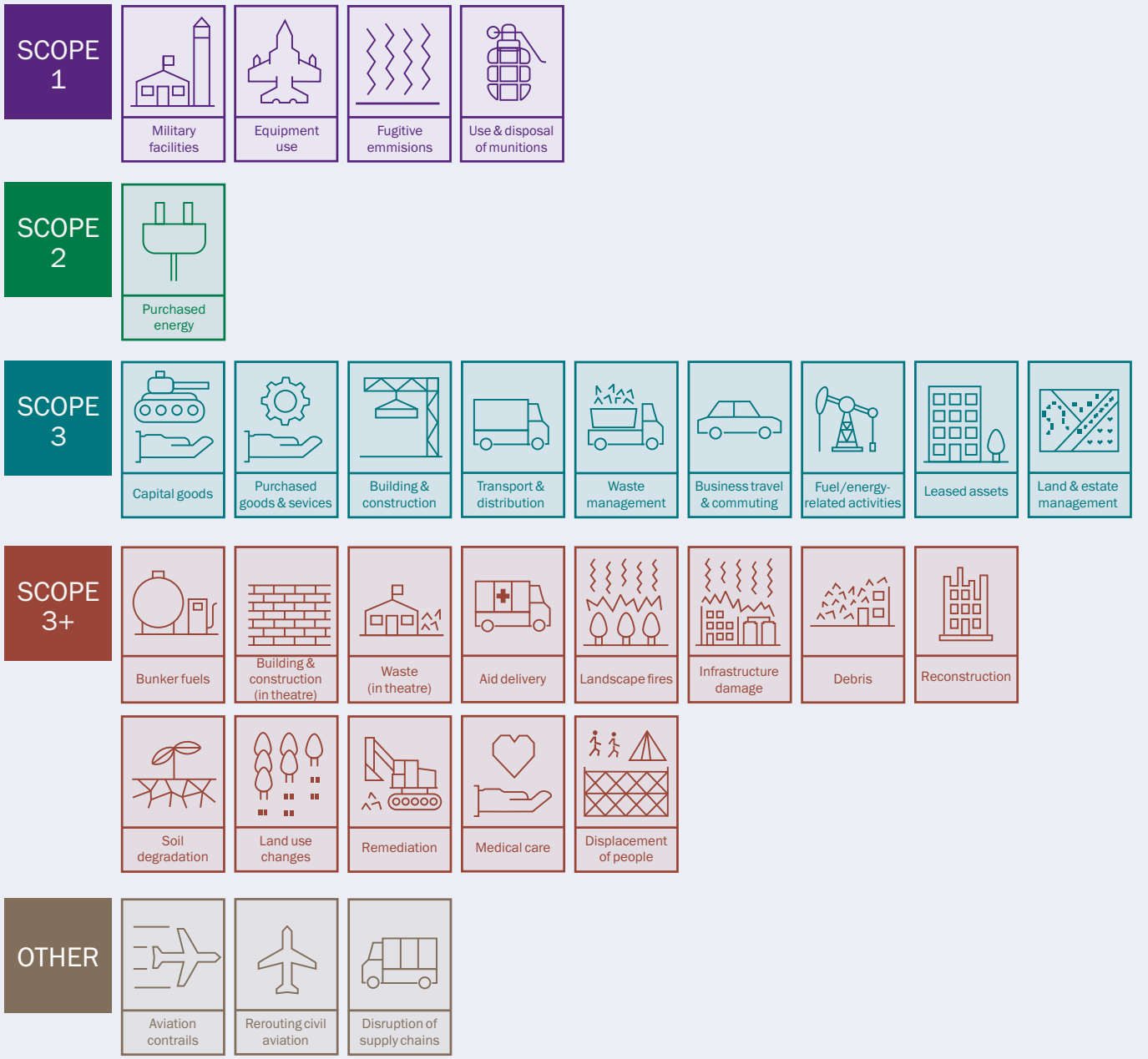
As the experiences of Davybida, Harmsen and Kobayakawa show, cobbling together relevant and reliable data in the midst of war is a significant challenge, from which only limited conclusions can be drawn. Researchers and policymakers need a fuller view of the environmental and climate cost of war if they are to improve matters once a conflict ends.

That's certainly the view of Benjamin Neimark, who studies geopolitical ecology at Queen Mary University of London. He has been trying for some time to tackle the fact that the biggest data gap preventing accurate estimates of the climate and environmental cost of war is military emissions. During the 2021 United Nations Climate Change Conference (COP26), for example, he and colleagues partnered with the Conflict and Environment Observatory (CEOBS) to launch The Military Emissions Gap, a website to track and trace what a country accounts for as its military emissions to the United Nations Framework Convention on Climate Change (UNFCCC).

At present, reporting military emissions is voluntary, so data are often absent or incomplete – but gathering such data is vital. According to a 2022 estimate extrapolated from the small number of nations that do share their data, the total military carbon footprint is approximately 5.5% of global emissions. This would make the world's militaries the fourth biggest carbon emitter if they were a nation.

The website is an attempt to fill this gap. "We hope that the UNFCCC picks up on this and mandates transpar-

2 Closing the data gap



Current United Nations Framework Convention on Climate Change (UNFCCC) greenhouse-gas emissions reporting obligations do not include all the possible types of conflict emissions, and there is no commonly agreed methodology or scope on how different countries collect emissions data. In a recent publication *War on the Climate: a Multitemporal Study of Greenhouse Gas Emissions of the Israel-Gaza Conflict*, Benjamin Neimark *et al.* came up with this framework, using the UNFCCC's existing protocols. These reporting categories cover militaries and armed conflicts, and hope to highlight previously "hidden" emissions.

ent and visible reporting of military emissions," Neimark says (figure 2).

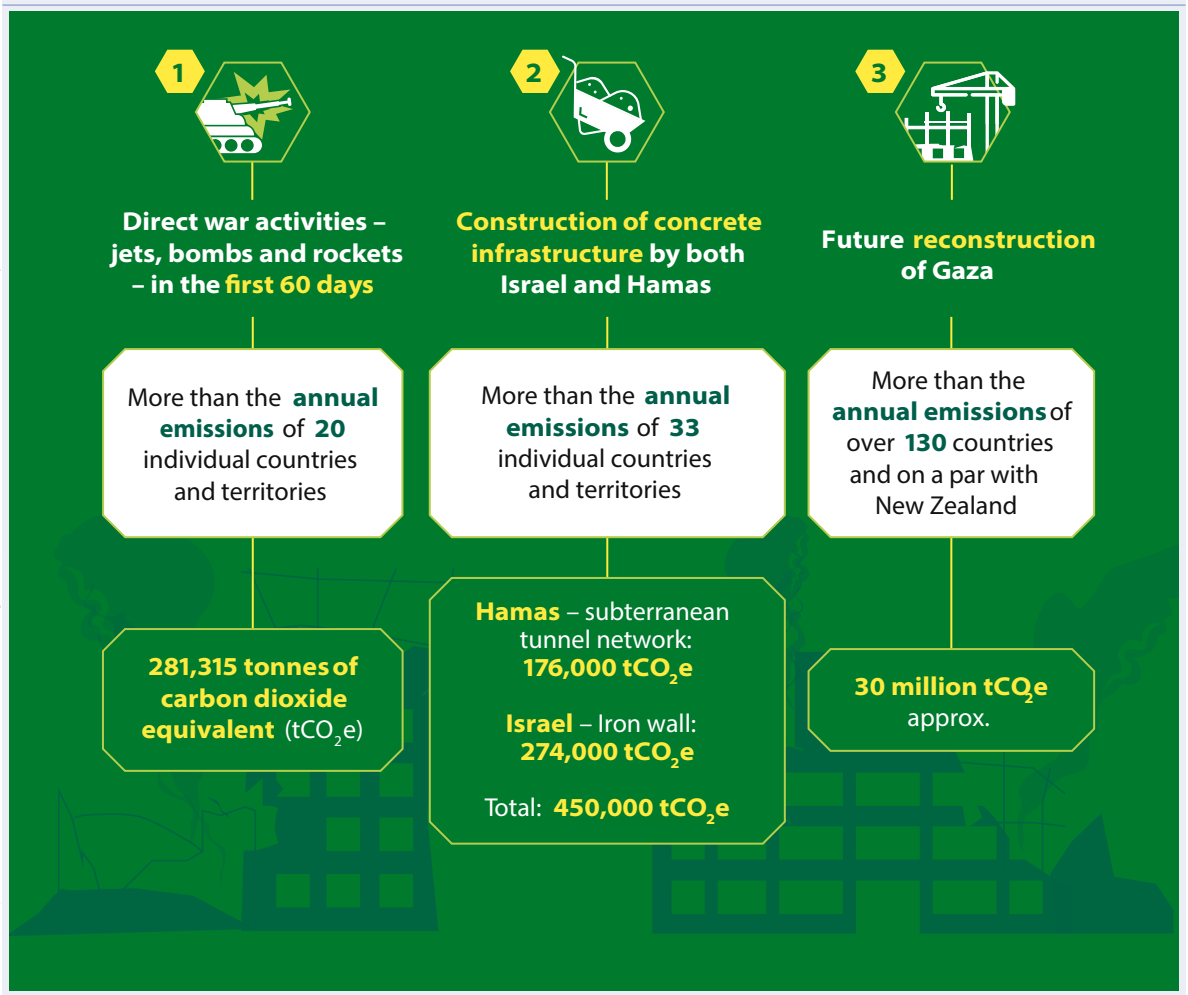
Measuring the destruction

Beyond plugging the military emissions gap, Neimark is also involved in developing and testing methods that he and other researchers can use to estimate the overall climate impact of war. Building on foundational work from his collaborator, Dutch climate specialist Lennard de Klerk – who developed a methodology for identifying, classifying and providing ways of estimating the various sources of emissions associated with the Russia–Ukraine war – Neimark and colleagues are trying to estimate the greenhouse-gas emissions from the Israel–Gaza conflict.

Their studies encompass pre-conflict preparation, the conflict itself and post-conflict reconstruction. "We were working with colleagues who were doing similar work in Ukraine, but every war is different," says Neimark. "In Ukraine, they don't have large tunnel networks, or they didn't, and they don't have this intensive, incessant onslaught of air strikes from carbon-intensive F16 fighter aircraft." Some of these factors, like the carbon impact of Hamas' underground maze of tunnels under Gaza, seem unquantifiable, but Neimark has found a way.

"There's some pretty good data for how big these are in terms of height, the amount of concrete, how far down

3 Climate change and the Gaza war



Data from Benjamin Neimark, Patrick Bigger, Frederick Otu-Larbi and Reuben Larbi's *Confronting Military Greenhouse Gas Emissions* report estimates the carbon emissions of the war in Gaza for three distinct periods: direct war activities; large-scale war infrastructure; and future reconstruction.

they're dug and how thick they are," says Neimark. "It's just the length we had to work out based on reported documentation." Finding the total amount of concrete and steel used in these tunnels involved triangulating open-source information with media reports to finalize an estimate of the dimensions of these structures. Standard emission factors could then be applied to obtain the total carbon emissions. According to data from Neimark's *Confronting Military Greenhouse Gas Emissions* report, the carbon emissions from construction of concrete infrastructure by both Israel and Hamas were more than the annual emissions of 33 individual countries and territories (figure 3).

The impact of Hamas' tunnels and Israel's "iron wall" border fence are just two of many pre-war activities that must be factored in to estimate the Israel–Gaza conflict's climate impact. Then, the huge carbon cost of the conflict itself must be calculated, including, for example, bombing raids, reconnaissance flights, tanks and other vehicles, cargo flights and munitions production.

Gaza's eventual reconstruction must also be included, which makes up a big proportion of the total impact of the war, as Kobayakawa's Ukraine reconstruction calculations showed. The United Nations Environment Programme (UNEP) has been systematically studying and reporting on "Sustainable debris management in Gaza" as it tracks debris from damaged buildings and infrastructure in Gaza since the outbreak of the conflict in October 2023. Alongside estimating the amounts of debris, UNEP also models different management scenarios – ranging from disposal to recycling – to evaluate the time, resource needs and environmental impacts of each option.

Visa restrictions and the security situation have prevented UNEP staff from entering the Gaza strip to undertake environmental field assessments to date. "While remote sensing can provide a valuable overview of the situation … findings should be verified on the ground for greater accuracy, particularly for designing and implementing remedial interventions," says a UNEP spokesperson. They add that when it comes to the issue of contamination, UNEP needs "confirmation through field sampling and laboratory analysis" and that UNEP "intends to undertake such field assessments once conditions allow".

The main risk from hazardous debris – which is likely to make up about 10–20% of the total debris – arises when it is mixed with and contaminates the rest of the debris stock. "This underlines the importance of preventing

The United Nations Environment Programme models debris-management scenarios – ranging from disposal to recycling – to evaluate the time, resource needs and environmental impacts

Shutterstock/Anas Mohammed

Rubble and ruins Khan Younis in the Gaza Strip on 11 February 2025, showing the widespread damage to buildings and infrastructure.

such mixing and ensuring debris is systematically sorted at source," adds the UNEP spokesperson.

The ultimate cost

With all these estimates, and adopting a Monte Carlo analysis to account for uncertainties, Neimark and colleagues concluded that, from the first 15 months of the Israel–Gaza conflict, total carbon emissions were 32 million tonnes, which is huge given that the territory has a total area of just 365 km^2. The number also continues to rise.

Why does this number matter? When lives are being lost in Gaza, Ukraine, and across Sudan, Myanmar and other regions of the world, calculating the environmental and climate cost of war might seem like something only worth bothering about when the fighting stops.

But doing so even while conflicts are taking place can help protect important infrastructure and land, avoid environmentally disastrous events, and to ensure the long rebuild, wherever the conflict may be happening, is informed by science. The UNEP spokesperson says that it is important to "systematically integrate environmental considerations into humanitarian and early recovery planning from the outset" rather than treating the environment as an afterthought. They highlight that governments should "embed it within response plans – particularly in areas where it can directly impact life-saving activities, such as debris clearance and management".

With Ukraine still in the midst of war, it seems right to leave the final word to Davybida. "Armed conflicts cause profound and often overlooked environmental damage that persists long after the fighting stops," she says. "Recognizing and monitoring these impacts is vital to guide practical recovery efforts, protect public health, prevent irreversible harm to ecosystems and ensure a sustainable future."

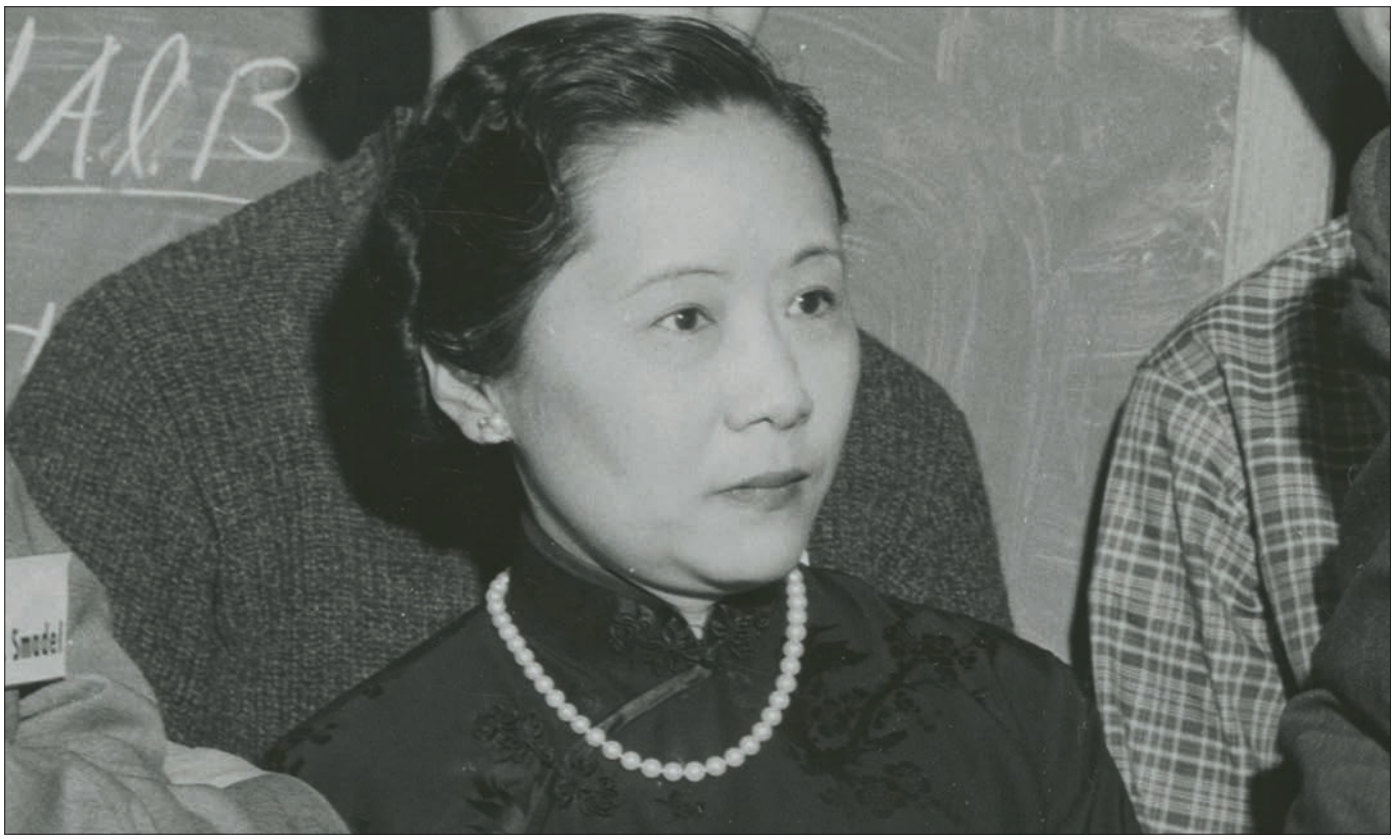
- The journal *Environmental Research Letters* has launched a Focus on Initial and Enduring Environmental Consequences of Armed Conflict (iopscience.iop.org/collections/erl-251125-1010)

PRX **Intelligence**

PRX Intelligence is a new open-access journal from APS for high-impact research at the intersection of physics and machine intelligence. It publishes rigorous, innovative work where AI, machine learning, and data science deepen our understanding of physical systems and scientific discovery.

Now open for submissions
go.aps.org/prxi

PUBLISHED BY
APS



Smithsonian Institution Archives

Chien-Shiung Wu: how she missed the 1957 Nobel prize

Many have wondered why the Chinese-American physicist Chien-Shiung Wu never won a share of the 1957 Nobel Prize for Physics for her experimental verification of parity violation. **Mats Larsson** and **Ramon Wyss** reveal the true story after becoming the first people to open that year's Nobel archives

The facts seem simple enough. In 1957 Chen Ning Yang and Tsung-Dao Lee won the Nobel Prize for Physics "for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles". The idea that parity is violated shocked physicists, who had previously assumed that every process in nature remains the same if you reverse all three spatial co-ordinates.

Thanks to the work of Lee and Yang, who were Chinese-American theoretical physicists, it now appeared that this fundamental physics concept wasn't true (see box "The Wu experiment"). As Yang once told *Physics World* columnist and historian of science Robert Crease, the discovery of parity violation was like having the lights switched off and being so confused that you weren't sure you'd be in the same room when they came back on.

But one controversy has always surrounded the prize.

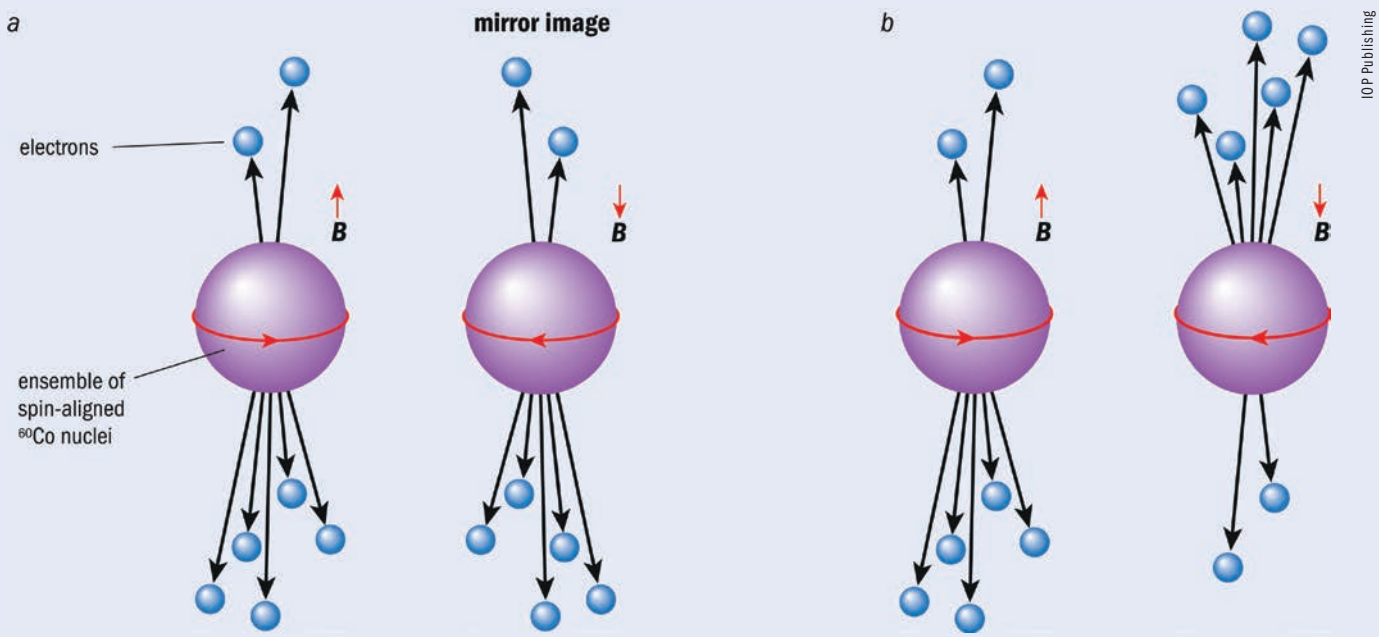
Lee and Yang published their findings in a paper in October 1956 (*Phys. Rev.* **1** 254), meaning that their Nobel prize was one of the rare occasions that satisfied Alfred Nobel's will, which says the award should go to work done "during the preceding year". However, the first verification of parity violation was published in February 1957 (*Phys. Rev.* **105** 1413) by a team of experimental physicists led by Chien-Shiung Wu at Columbia University, where Lee was also based. (Yang was at the Institute for Advanced Study in Princeton at the time.)

Surely Wu, an eminent experimentalist (see the box "Chien-Shiung Wu: a brief history"), deserved a share of the prize for contributing to such a fundamental discovery? In her paper, entitled "Experimental Test of Parity Conservation in Beta Decay", Wu says she had "inspiring discussions" with Lee and Yang. Was gender bias at play, did her paper miss the deadline, or was she simply never nominated?

Back then, the Nobel statutes stipulated that all details about who had been nominated for a Nobel prize – and why the winners were chosen by the Nobel committee – were to be kept secret forever. Later, in 1974, the rules were changed, allowing the archives to be opened

Mats Larsson is in the Department of Physics at Stockholm University and **Ramon Wyss** is at KTH Royal Institute of Technology in Stockholm, Sweden

The Wu experiment



Parity is a property of elementary particles that says how they behave when reflected in a mirror. If the parity of a particle does not change during reflection, parity is said to be conserved. In 1956 Tsung-Dao Lee and Chen Ning Yang realized that while parity conservation had been confirmed in electromagnetic and strong interactions, there was no compelling evidence that it should also hold in weak interactions, such as radioactive decay. In fact, Lee and Yang thought parity violation could explain the peculiar decay patterns of K mesons, which are governed by the weak interaction.

In 1957 Chien-Shiung Wu suggested an experiment to check this based on unstable cobalt-60 nuclei radioactively decaying into nickel-60 while emitting beta rays (electrons). Working at very low temperatures to ensure almost no random thermal motion – and thereby enabling a strong magnetic field to align the cobalt nuclei with their spins parallel – Wu found that far more electrons were emitted in a downward direction than upward.

In the figure, (*a*) shows how a mirror image of this experiment should also produce more electrons going down than up. But when the experiment was repeated, with the direction of the magnetic field reversed to change the direction of the spin as it would be in the mirror image, Wu and colleagues found that more electrons were produced going upwards (*b*). The fact that the real-life experiment with reversed spin direction behaved differently from the mirror image proved that parity is violated in the weak interaction of beta decay.

50 years after an award had been made. So why did the mystery not become clear in 2007, half a century after the 1957 prize?

The reason is that there is a secondary criterion for prizes awarded by the Royal Swedish Academy of Sciences – in physics and chemistry – which is that the archive must stay shut for as long as a laureate is still alive. Lee and Yang were in their early 30s when they were awarded the prize and both went on to live very long lives. Lee died on 24 August 2024 aged 97 and it was not until the death of Yang on 18 October 2025 at 103 that the chance to solve the mystery finally arose.

Entering the archives

As two physicists based in Stockholm with a keen interest in the history of science, we had already examined the case of Lise Meitner, another female physicist who never won a Nobel prize – in her case for fission. We'd published our findings about Meitner in the December 2023 issue of *Fysikaktuellt* – the journal of the Swedish Physical Society. So after Yang died, we asked the Center for History of Science at the Royal Swedish Academy of Sciences if we could look at the 1957 archives.

A previous article in *Physics World* from 2012 by Magdolna Hargittai, who had spoken to Anders Bárány, former secretary of the Nobel Committee for Physics, seemed to suggest that Wu wasn't awarded the 1957 prize because her *Physical Review* paper had been published in February of that year. This was after the January cut-off and therefore too late to be considered on that occasion (although the trio could have been awarded a joint prize in a subsequent year).

After receiving permission to access the archives, we went to the centre on Thursday 13 November 2025, where – with great excitement – we finally got our hands on the thick, black, hard-bound book containing information about the 1957 Nobel prizes in physics and chemistry. About 500 pages long, the book revealed that there were a total of 58 nominations for the 1957 Nobel Prize for Physics – but none at all for Wu that year. As we shall go on to explain, she did, however, receive a total of 23 nominations over the next 16 years.

Lee and Yang, we discovered, received just a single nomination for the 1957 prize, submitted by John Simpson, an experimental physicist at the University of Chicago in the US. His nomination reached the Nobel Committee on 29 January 1957, just before the deadline of 31 January. Simpson clearly had a lot of clout with the committee, which commissioned two reports from its members – both Swedish physicists – based on his

recommendation. One was by Oskar Klein on the theoretical aspects of the prize and the other by Erik Hulthén on the experimental side of things.

Report revelations

Klein devotes about half of his four-page report to the Hungarian-born theorist Eugene Wigner, who – we discovered – received seven separate nominations for the 1957 prize. In his opening remarks, Klein notes that Wigner's work on symmetry principles in physics, first published in 1927, had gained renewed relevance in light of recent experiments by Wu, Leon Lederman and others. According to Klein, these experiments cast a new light on the fundamental symmetry principles of physics.

Klein then discusses three important papers by Wigner and concludes that he, more than any other physicist, established the conceptual background on symmetry principles that enabled Lee and Yang to clarify the possibilities of experimentally testing parity non-conservation. Klein also analyses Lee and Yang's award-winning *Physical Review* paper in some detail and briefly mentions subsequent articles of theirs as well as papers by two future Nobel laureates – Lev Landau and Abdus Salam.

Klein does not end his report with an explicit recommendation, but identifies Lee, Yang and Wigner as having made the most important contributions. It is noteworthy that every physicist mentioned in Klein's report – apart from Wu – eventually went on to receive a Nobel Prize for Physics. Wigner did not have to wait long, winning the 1963 prize together with Maria Goeppert Mayer and Hans Jensen, who had also been nominated in 1957.

As for Hulthén's experimental report, it acknowledges that Wu's experiment started after early discussions with Lee and Yang. In fact, Lee had consulted Wu at Columbia on the subject of parity conservation in beta-decay before Lee and Yang's famous paper was published. According to Wu, she mentioned to Lee that the best way would be to use a polarized cobalt-60 source for testing the assumption of parity violation in beta-decay.

Many physicists were aware of Lee and Yang's paper, which was certainly seen as highly speculative, whereas Wu realized the opportunity to test the far-reaching consequences of parity violation. Since she was not a specialist of low-temperature nuclear alignment, she contacted Ernest Ambler at the National Bureau of Standards in Washington DC, who was a co-author on her *Physics Review* paper of 15 February 1957.

Hulthén describes in detail the severe technical challenges that Wu's team had to overcome to carry out the experiment. These included achieving an exceptionally low temperature of 0.001 K, placing the detector inside the cryostat, and mitigating perturbations from the crystalline field that weakened the magnetic field's effectiveness.

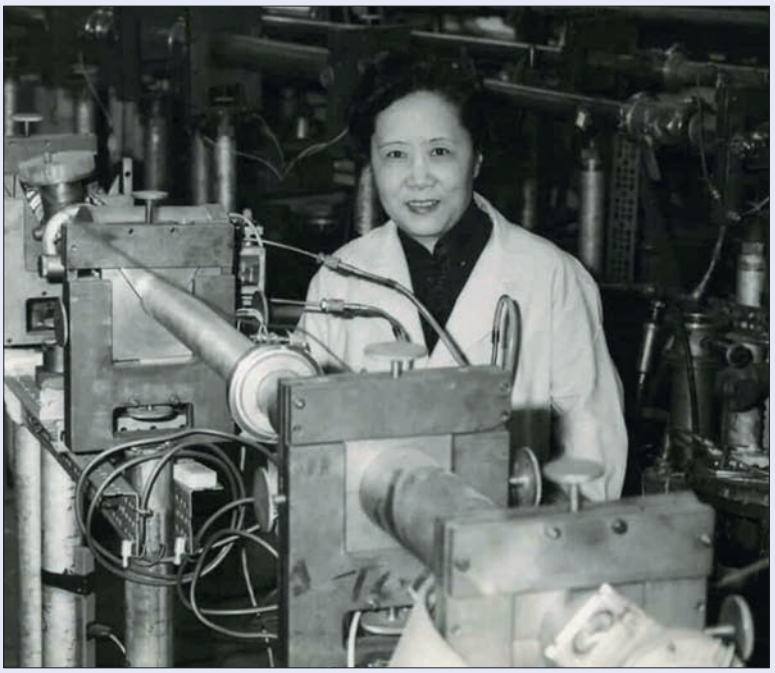
Despite these difficulties, the experimentalists managed to obtain a first indication of parity violations, which they presented on 4 January 1957 at a regular lunch that took place at Columbia every Friday. The news of these preliminary results spread like wildfire throughout the physics community, prompting other groups to immediately follow suit.

Hulthén mentions, for example, a measurement of the magnetic moment of the mu (μ) meson (now known as the muon) that Richard Garvin, Leon Lederman and Marcel Weinrich performed at Columbia's cyclotron almost as soon as Lederman had obtained information of Wu's work. He also cites work at the University of Leiden in the Netherlands led by C J Gorter that apparently had started to look into parity violation independently of Wu's experiment (*Physica* **23** 259).

Wu's nominations

It is clear from Hulthén's report that the Nobel Physics Committee was well informed about the experimental work carried out in the wake of Lee and Yang's paper of October 1956, in particular the groundbreaking results of Wu. However, it is not clear from a subsequent report

Chien-Shiung Wu: a brief history



Smithsonian Institution Archives

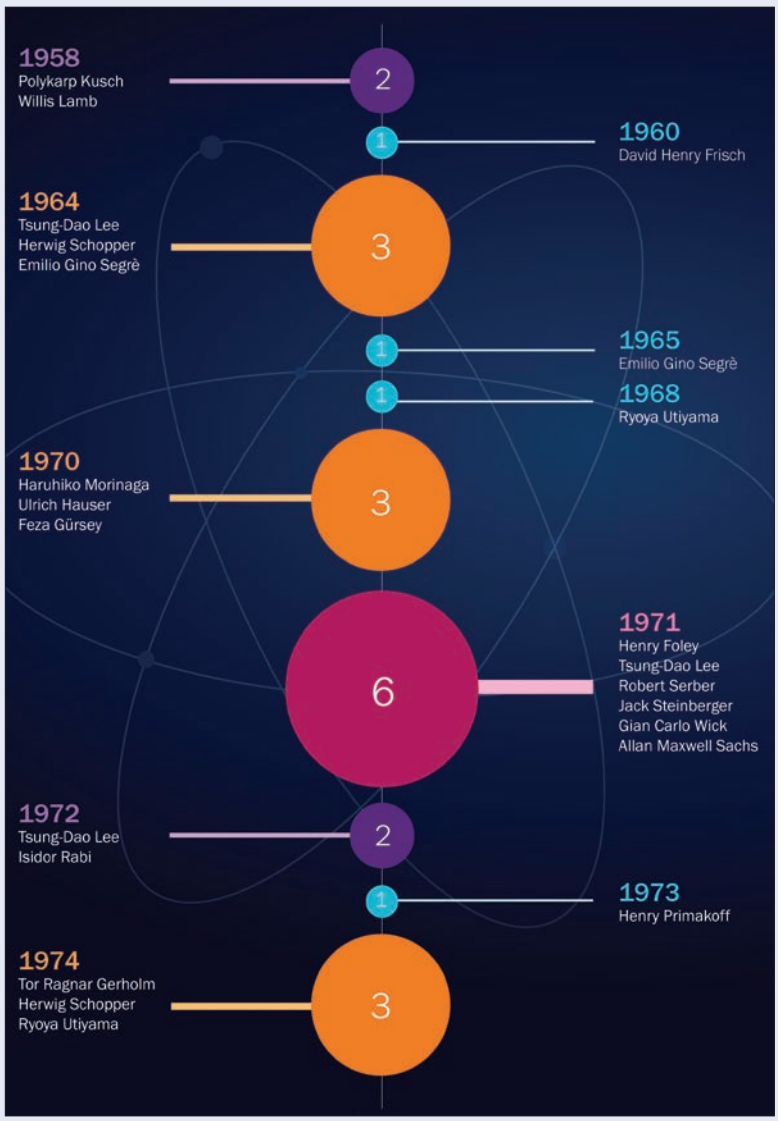
Born on 31 May 1912 in Jiangsu province in eastern China, Chien-Shiung Wu graduated with a degree in physics from National Central University in Nanjing. After a few years of research in China, she moved to the US, gaining a PhD at the University of California at Berkeley in 1940. Three years later Wu took up a teaching job at Princeton University in New Jersey – a remarkable feat given that women were not then even allowed to study at Princeton.

During the Second World War, Wu joined the Manhattan atomic-bomb project, working on radiation detectors at Columbia University in New York. After the conflict was over, she started studying beta decay – one of the weak interactions associated with radioactive decay. Wu famously led a crucial experiment studying the beta decay of cobalt-60 nuclei, which confirmed a prediction made in October 1956 by her Columbia colleague Tsung-Dao Lee and Chen Ning Yang in Princeton that parity can be violated in the weak interaction.

Lee and Yang went on to win the 1957 Nobel Prize for Physics but the Nobel Committee was not aware that Lee had in fact consulted Wu in spring 1956 – several months before their paper came out – about potential experiments to prove their prediction. As she was to recall in 1973, studying the decay of cobalt-60 was "a golden opportunity" to test their ideas that she "could not let pass".

The first woman in the Columbia physics department to get a tenured position and a professorship, Wu remained at Columbia for the rest of her career. Taking an active interest in physics well into retirement, she died on 16 February 1997 at the age of 84. Only now, with the publication of this *Physics World* article, has it become clear that despite receiving 23 nominations from 18 different physicists in 16 years between 1958 and 1974, she never won a Nobel prize.

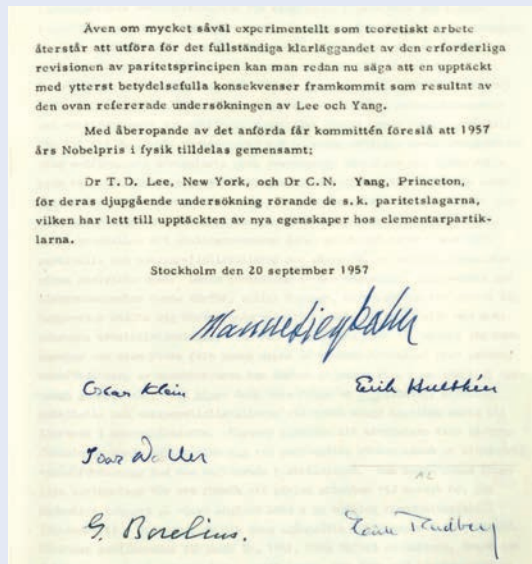
Nominations for Wu from 1958 to 1974



IOP Publishing

Our examination of the newly released Nobel archive from 1957 indicates that although Chien-Shiung Wu was not nominated for that year's prize, which was won by Chen Ning Yang and Tsung-Dao Lee, she did receive a total of 23 nominations over the next 16 years (1974 being the last open archive at the time of writing). Those 23 nominations were made by 18 different physicists, with Lee nominating Wu three times and Herwig Schopper, Emilio Segrè and Ryoya Utiyama each doing so twice. The peak year for nominations for her was 1971 when she received six nominations. The archives also show that in October 1957 Werner Heisenberg submitted a nomination for Lee (but not Yang); it was registered as a nomination for 1958. The nomination is very short and it is not clear why Heisenberg did not nominate Yang.

The Nobel Committee report of 1957



Även om mycket såväl experimentellt som teoretiskt arbete återstår att utföra för det fullständiga klarläggandet av den erforderliga revisionen av paritetsprincipen kan man redan nu säga att en upptäckt med ytterst betydelsefulla konsekvenser framkommit som resultat av den ovan refererade undersökningen av Lee och Yang.

Med åberopande av det anförda får kommittén föreslå att 1957 års Nobelpris i fysik tilldelas gemensamt:

Dr T. D. Lee, New York, och Dr C. N. Yang, Princeton, för deras djupgående undersökning rörande de s.k. paritetslagarna, vilken har lett till upptäckten av nya egenskaper hos elementarpartiklarna.

Stockholm den 20 september 1957

Manne Siegbahn
Oskar Klein
Erik Hulthén
Ivar Waller
G. Borelius.
Erik Rudberg

The Nobel Archive, The Royal Swedish Academy of Sciences, Stockholm

This image is the final page of a report written on 20 September 1957 by the Nobel Committee for Physics about who should win the 1957 Nobel Prize for Physics. Dated 20 September 1957 and published here for the first time since it was written, the English translation is as follows. "Although much experimental and theoretical work remains to be done to fully clarify the necessary revision of the parity principle, it can already be said that a discovery with extremely significant consequences has emerged as a result of the above-mentioned study by Lee and Yang. In light of the above, the committee proposes that the 1957 Nobel Prize in Physics be awarded jointly to: Dr T D Lee, New York, and Dr C N Yang, Princeton, for their profound investigation of the so-called parity laws, which has led to the discovery of new properties of elementary particles." The report was signed by Manne Siegbahn (chair), Gudmund Borelius, Erik Hulthén, Oskar Klein, Erik Rudberg and Ivar Waller.

dated 20 September 1957 (see box above right: "The Novel Committee report of 1957) from the Nobel Committee why Wigner was not awarded a share of the 1957 prize, despite his seven nominations. Nor is there any suggestion of postponing the prize a year in order to include Wu. The report was discussed on 23 October 1957 by members of the "Physics Class" – a group of physicists in the academy who always consider the committee's recommendations – who unanimously endorsed it.

Most noteworthy with regard to this meeting of the Physics Class was that Meitner – who had also been overlooked for the Nobel prize – took part in the discussions. Meitner, who was Austrian by birth, had been elected a foreign member of the Royal Swedish Academy of Sciences in 1945, becoming a "Swedish member" after taking Swedish citizenship in 1951. In the wake of these discussions, the academy decided on 31 October 1957 to award the 1957 Nobel Prize for Physics to Lee and Yang. We do not know, though, if Meitner argued for Wu to be awarded a share of that year's prize.

Although Wu did not receive any nominations in 1957, she was nominated the following year by the 1955 Nobel laureates in physics, Willis Lamb and Polykarp Kusch. In fact, after Lee and Yang won the prize, nominations to give a Nobel prize to Wu reached the committee on 10 separate years out of the next 16 (see box "Nominations for Wu from 1958 to 1974"). She was nominated by a total of 18 leading physicists, including various Nobel-prize winners and Lee himself. In fact, Lee nominated Wu for a Nobel prize on three separate occasions – in 1964, 1971 and 1972.

However, it appears she was never nominated by Yang (at the time of writing, we only have archive information up to 1974). One reason for Lee's support and Yang's silence could be attributed to the early discussions that

Anne Miche de Malleray

Anne Miche de Malleray

History in the making Above: Mats Larsson (centre) and Ramon Wyss (left) at the Center for History of Science at the Royal Swedish Academy of Sciences in Stockholm, Sweden, on 13 November 2025, where they become the first people to view the archive containing information about the nominations for the 1957 Nobel Prize for Physics. They are shown here in the company of centre director Karl Grandin (right). Right image: Larsson and Wyss with their hands on the archives, on which this *Physics World* article is based.

Lee had with Wu, influencing the famous Lee and Yang paper, which Yang may not have been aware of. It is also not clear why Lee and Yang never acknowledged their discussion with Wu about the cobalt-60 experiment that was proposed in their paper; further research may shed more light on this topic.

Following Wu's nomination in 1958, the Nobel Committee simply re-examined the investigations already carried out by Klein and Hulthén. The same procedure was repeated in subsequent years, but no new investigations into Wu's work were carried out until 1971 when she received six nominations – the highest number she got in any one year.

That year the committee decided to ask Bengt Nagel, a theorist at KTH Royal Institute of Technology, to investigate the theoretical importance of Wu's experiments. The nominations she received for the Nobel prize concerned three experiments. In addition to her 1957 paper on parity violation there was a 1949 article she'd written with her Columbia colleague R D Albert verifying Enrico Fermi's theory of beta decay (*Phys. Rev.* **75** 315) and another she wrote in 1963 with Y K Lee and L W Mo on the conserved vector current, which is a fundamental hypothesis of the Standard Model of particle physics (*Phys. Rev. Lett.* **10** 253).

After pointing out that four of the 1971 nominations came from Wu's colleagues at Columbia, which to us may have hinted at a kind of lobbying campaign for her, Nagel stated that the three experiments had "without doubt been of great importance for our understanding of the weak interaction". However, he added, "the experiments, at least the last two, have been conducted to certain aspects as commissioned or direct suggestions of theoreticians".

In Nagel's view, Wu's work therefore differed significantly from, for example, James Cronin and Val Fritsch's famous discovery in 1964 of charge-parity (CP) violation in the decay of K^0 mesons. They had made their discovery under their own steam, whereas (Nagel suggested) Wu's work had been carried out only after being suggested by theorists. "I feel somewhat hesitant whether their theoretical importance is a sufficient motivation to render Wu the Nobel prize," Nagel concluded.

Missed opportunity

The Nobel archives are currently not open beyond 1974 so we don't know if Wu received any further nominations over the next 23 years until her death in 1997. Of course, had Wu not carried out her experimental test of parity violation, it is perfectly possible that another physicist or group of physicists would have something similar in due course.

Nevertheless, to us it was a missed opportunity not to include Wu as the third prize winner alongside Lee and Yang. Sure, she could not have won the prize in 1957 as she was not nominated for it and her key publication did not appear before the January deadline. But it would simply have been a case of waiting a year and giving Wu and her theoretical colleagues the prize jointly in 1958.

Another possible course of action would have been to single out the theoretical aspects of symmetry violation and award the prize to Lee, Wigner and Yang, as Klein had suggested in his report. Unfortunately, full details of the physics committee's discussions are not contained in the archives, which means we don't know if this was a genuine possibility being considered at the time.

But what is clear is that the Nobel committee knew full well the huge importance of Wu's experimental confirmation of parity violation following the bold theoretical insights of Lee and Yang. Together, their work opened a new chapter in the world of physics. Without Wu's interest in parity violation and her ingenious experimental knowledge, Lee and Yang would never have won the Nobel prize. ■

Earth, air, fire, water: climate change and geophysical hazards

Scientists across the world are finding that global warming could cause extreme changes in earthquakes and volcanic activity. **Michael Allen** speaks to the researchers connecting climate physics with Earth's geophysical processes

Michael Allen is a science writer based in the UK

A few years ago, Swiss seismologist Verena Simon noticed a striking shift in the pattern of seismic activity and micro earthquakes in the Mont Blanc region. She found that microquakes in the area, which straddles Switzerland, France and Italy, have fallen into an annual pattern since 2015.

Simon and colleagues at the Swiss Seismological Service in fact found that this annual pattern is linked to heat waves driven by climate change. But they are not the only researchers finding such geophysical links to climate change. There is growing evidence that global warming could cause changes in seismicity, volcanic activity and other such hazards.

In the first eight years from 2006, Simon's team saw no clear pattern. But then from 2015 they found that seismicity always increases in autumn and stays at a higher level until winter. The researchers wondered if the seasonal pattern was linked to a known increase in meltwater infiltration into the Mont Blanc massif in late summer and autumn every year.

Seasonal seismic trends

Scientists have long known that when water percolates underground it increases the pressure in gaps, or pores, in rocks, which alters the balance of forces on faults, leading to slips – and triggering seismic activity.

In the late 1990s researchers analysed water flow into the 12 km long Mont Blanc tunnel, which links France and Italy (*La Houille Blanche* **86** 78). They also found a yearly pattern, with a rapid increase in water entering the tunnel between August and October. The low mineral content of the water and results from tracer tests, using fluorescent dyes injected into a glacier crevasse on the massif, confirmed that this increased flow was fresh water from snow and glacier melt.

To explore the seasonal trend in the water table, Simon and colleagues created a hydrological model (a simplified mathematical model of a real-world water flow system) using the tunnel inflow data; plus metrological, hydrological and snow-pack data from elsewhere in the Alps. They also included information on how water diffuses into rocks, alters pore pressure and increases seismic activity (*Earth and Planetary Sci. Lett.* **666** 119372).

When combined with their seismicity data, autumn seismic activity appeared to be triggered by spring surface runoff, which arises from melting glacial ice and snow. The exact timing depends on the depth of the microquakes, with shallow quakes being linked to surface runoff from the previous year, while there is a two-year delay between runoff and deeper quakes. Essentially, their work found a link between meltwater and seismic activity in the Mont Blanc massif; but it could not explain why


Shutterstock/Rasto SK

Underground menace
The Mont Blanc Massif, with Lac Blanc in the foreground. The timing of heatwaves in this region seemingly correlates with increased microquakes.

the autumn increase in microquakes only started in 2015.

Perhaps the answer lies in historic meteorological data of the area. In 2015 the Alps experienced a prolonged, record-breaking heatwave, which led to very many high-altitude rockfalls in a number of areas, including in the Mont Blanc massif, as rock-wall permafrost warmed. Data also show that since then there has been a big increase in days when the average temperatures in the Swiss Alps is above 0 °C. These so-called "positive degree days" are known to lead to increased glacial melt.

All of these findings support the idea that the onset of seasonal seismic activity is linked to climate change-induced increases in meltwater and alterations in flow paths. Simon explains that rock collapses can alter the pathways that water follows as it infiltrates into the ground. Combined with increases in meltwater, this can lead to pore-pressure changes that increase seismicity and trigger it in new places.

These small earthquakes in the Mont Blanc massif are unlikely to trouble local communities. But the researchers did find that at times the seismic hazard – an indicator of how often and intensely the earth could shake in a specific area – rose by nearly four orders of magnitude, compared with pre-2015 level. They warn that similar processes in glaciated areas that experience larger earthquakes than the Alps, such as the Himalayas, might be less gentle.

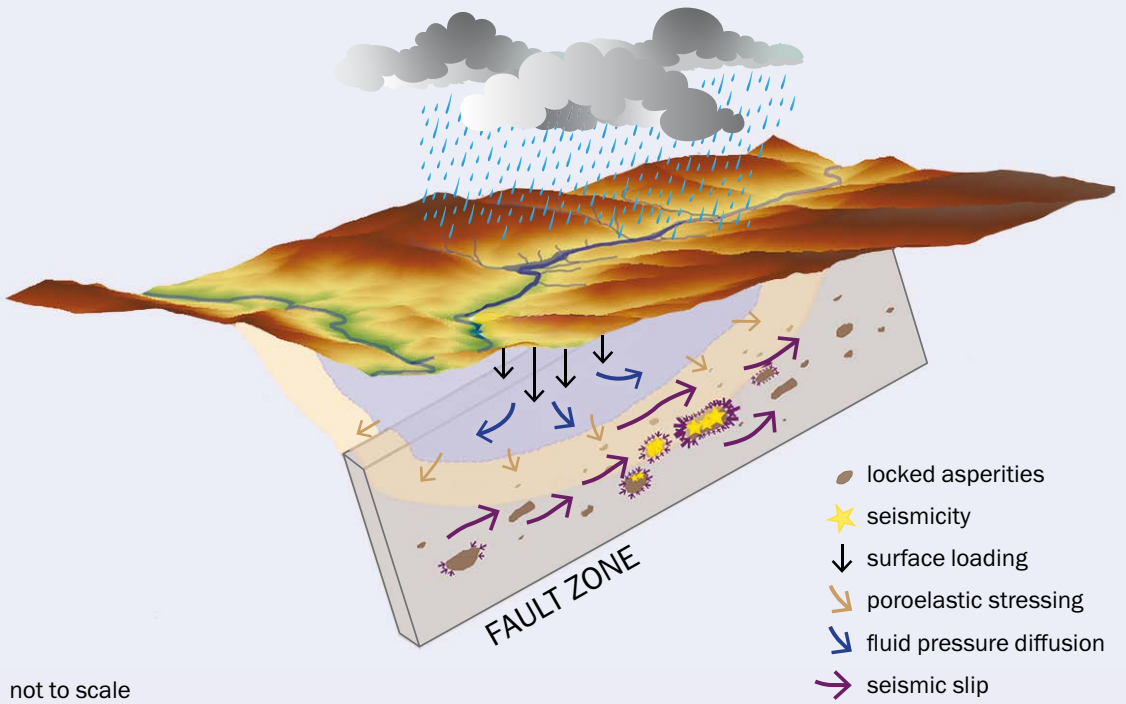
Extreme rainfall

Climate change is also altering water-flow patterns by increasing the intensity of extreme weather events and heavy rainfall. And there is already evidence that such extreme precipitation can influence seismic activity.

In 2020 Storm Alex brought record-breaking rainfall to the south-east of France, with some areas seeing more than 600 mm in 24 hours. In the following 100 days 188 earthquakes were recorded in the Tinée valley, in south-eastern France. Although all were below two in magnitude, that volume of microquakes would usually be spread over a five-year period in the region. A 2024 analysis carried out by seismologists in France concluded that increased fluid pressure from the extreme rainfall caused a stressed fault system to slip, initiating a seismic swarm – a localized cluster of earthquakes, without a single "mainshock", that take place over a relatively short period of days, months or years (see figure 1).

There have been other examples in Europe of seismic activity linked to extreme rainfall. For instance, in September 2002 a catastrophic storm in western Provence

1 How extreme rainfall triggers seismic swarms



French seismologist Laeticia Jacquemond and colleagues have developed a model showing the sequence of mechanisms that likely trigger a seismic swarm, which is a localized cluster of earthquakes. The sequence starts with abrupt and extreme rainfall, like 2020's Storm Alex. Thanks to open fault zones, a lot of rainfall is transmitted deep within a critically stressed crust. The fluid invasion through the fractured medium then induces a poroelastic response of the crust at shallow depths, triggering or accelerating a seismic slip on fault planes. As this slip propagates through the fault network, it pressurizes and stresses locked asperities (areas on an active fault where there is increased friction), predisposed to rupture, and initiates a seismic swarm.

in southern France, with similar rainfall levels as Storm Alex, triggered a clear and sudden increase in seismic activity, a study concluded. While another analysis found that an unusual series of 47 earthquakes over 12 hours in central Switzerland in August 2005 was likely caused by three days of intense rainfall.

According to Marco Bohnhoff from the GFZ Helmholtz Centre for Geosciences in Potsdam, Germany, the link between fluid infiltration into the ground and seismicity is well understood – from fluid injection for oil and gas production, to geothermal development and heavy rainfall. "The pore pressure is increased if there is a small load on top, enforced by water, and that changes the pressure conditions in the underground, which can release energy that is already stored there," Bohnhoff explains.

A good example of this is the Koyna Dam, one of India's largest hydroelectric projects, which consists of four dams. Every year during the monsoon season the water level in the reservoir behind the dams increases by about 20–25 m, and with this comes an increase in seismic activity. "After the rain stops and the water level decreases, the earthquake activity stops," says Bohnhoff. "So, the earthquake activity distribution nicely follows the water level."

Anything that increases the pressure underground could trigger earthquakes

Rising seas and seismic activity

According to Bohnhoff, anything that increases the pressure underground could trigger earthquakes. But he has also been studying the effect of another consequence of climate change: sea-level rise.

Undisputed and accelerating, sea-level rise is driven by two main effects linked to climate change: the expansion of ocean waters as they warm, and the melting of land ice, mainly the Antarctic and Greenland ice sheets. According to the World Meteorological Organization, sea levels will rise by half a metre by 2100 if emissions follow the Paris Agreement, but increases of up to two metres cannot be ruled out if emissions are even higher.

As ocean waters increase, so does the load on the underground. "This will change the global earthquake activity rate," says Bohnhoff. In a study published in 2024, Bohnhoff and colleagues found that sea-level rise will advance the seismic clock, leading to more and in some cases stronger earthquakes (*Seismological Research Letters* **95** 2571).

"It doesn't mean that all of a sudden there will be earthquakes everywhere, but earthquakes that would have occurred sometime in the future will occur sooner," he says. "We're changing the regularity of earthquakes." The risk created by this is greatest in coastal mega-cities, located near critical fault zones, such as San Francisco and Los Angeles in the US; Istanbul in Turkey; and Tokyo and Yokohama in Japan.

The findings cannot be used to predict individual earthquakes – in fact, it is very difficult to predict how much the seismic clock will advance, as it depends on the amount of sea-level rise. But there are faults around the world that are critically stressed and close to the end of their seismic cycle.

"Faults that are very, very close to failure, where basi-

cally there would be an earthquake, say in 100 years or 50 years, they might be advanced and that might occur very soon," he explains.

Between a rock and a hard place

Another significant geological hazard linked to climate change and heavy rainfall is volcanic activity. In December 2021 there was devastating eruption of Mount Semeru, on the Indonesian island of Java. "There was a really heavy rainfall event and that caused the collapse of the lava dome at the summit," says Jamie Farquharson, a volcanologist at Niigata University in Japan.

This led to a series of eruptions, pyroclastic flows and "lahars" – devastating flows of mud and volcanic debris – that killed at least 69 people and damaged more than 5000 homes. Although it is challenging to attribute this specific event to climate change, Farquharson says that it is a good example of how global warming-induced heavy rainfall could exacerbate volcanic hazards.

Farquharson and colleagues noticed links between ground deformations and rainfall at several volcanoes. "We started seeing some correlations and thought why shouldn't we? Because from a rock mechanics point of view, these volcanoes would be more prone to fracturing and other kinds of failure when the pore pressure is high," says Farquharson. "And one of the easiest ways of increasing pore pressure is by dumping a load of rain onto the volcano."

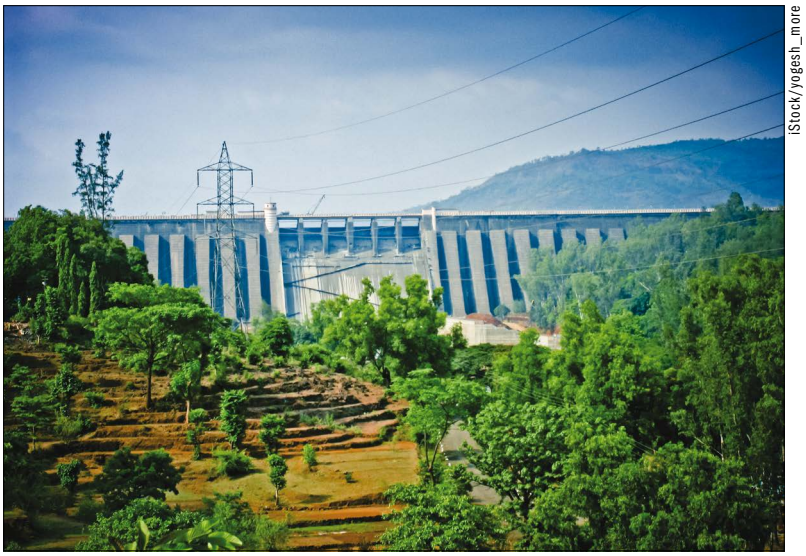
Such rock fracturing can open new pathways for magma to propagate towards the surface. This can happen deep underground, but also near the surface, for instance by causing a chunk of the flank to slide off a volcano. As with earthquakes, these changes could alter the timing of eruptions. For volcanoes that might be primed for an eruption, where the magma chamber is inflating, extreme rainfall events might hasten an eruption. But as Farquharson explains, such rainfall events "could bring something that was going to happen at an unspecified point in the future across a tipping point".

A few years ago Farquharson, together with atmospheric scientist Falk Amelung of the University of Miami in the US, published a study showing that if global warming continues at current rates, rainfall-linked volcanic activity – such as dome explosions and flank collapses – will increase at more than 700 volcanoes around the globe (*R. Soc. Open Sci.* **9** 220275).

To explore the impact of rainfall, Farquharson and Amelung analysed decades of reports on volcanic activity from the Smithsonian's Global Volcanism Program. This showed that heavy or extreme rainfall has been linked to eruptions and other hazards, such as lahars at at least 174 volcanoes (see figure 2).

There are 1234 volcanoes on land that have been active in the Holocene, the current geological epoch, which began around 12 000 years ago. The geologists used nine different models to explore how climate change might alter rainfall at these volcanos. They found that 716 of these volcanoes will experience more extreme rainfall as global temperatures continue to rise. The models did not agree on whether rainfall will become more or less extreme at 407 of the volcanoes, and the remaining 111 are in regions expected to see a drop in heavy rain.

Volcanic regions where heavy rainfall is expected to increase include the Caribbean islands, parts of the Mediterranean, the East African Rift system, and most of the Pacific Ring of Fire.



iStock/yogesh_more

Pressure conditions Scientists have tracked the change in water level in the reservoir behind the four dams that make up the Koyna hydroelectric project in Maharashtra, India, finding that the rise during monsoon season is accompanied by an increase in seismic activity over the same period.

iStock/Panya_

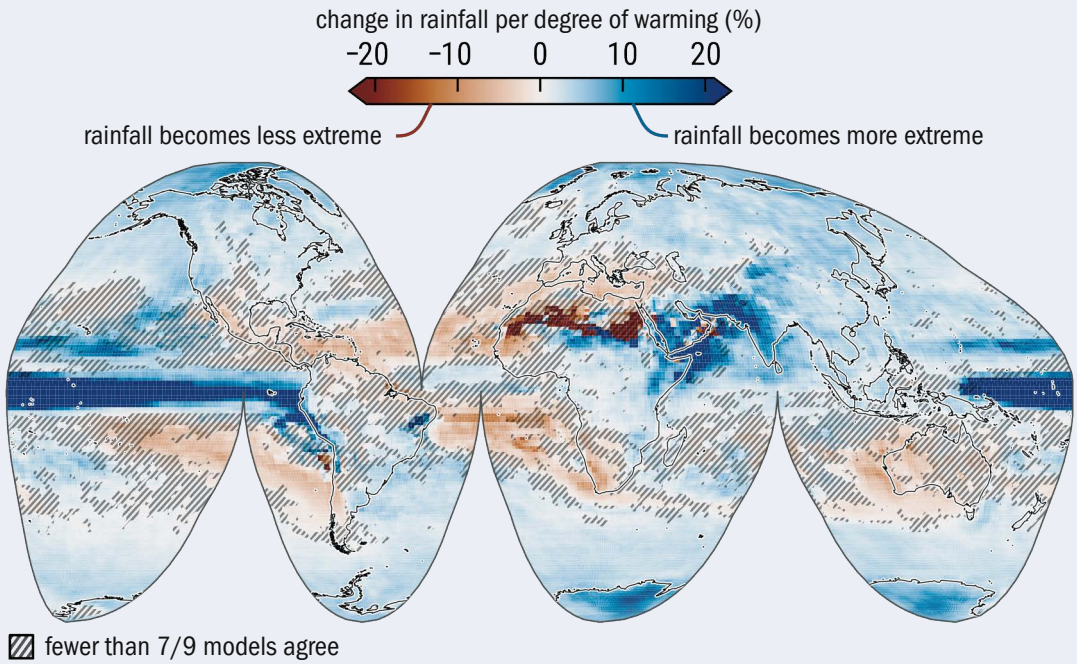
Active link Bromo volcano in East Java, Indonesia, which is the most volcanically active country in the world, where heavy rainfall has triggered explosive activity and eruptions at active volcanoes.

In fact, volcanic hazards in many of these regions have already been linked to heavy rainfall. For instance, in 1998 extreme rainfall in Italy led to devastating debris flows on Mount Vesuvius and Campi Flegrei, near Naples, killing 160 people.

Elsewhere, rainfall has sparked explosive activity at Mount St Helens, in the Cascade Mountains of Canada and the western US. Other volcanoes in this range, which is part of the Ring of Fire, put major population centres at significant lahar risk, due to their steep slopes. In both the Caribbean and Indonesia – the world's most volcanically active country, heavy rainfall has triggered explosive activity and eruptions at active volcanoes.

Farquharson and Amelung warn that if heavy rainfall increases in these regions as predicted, it will heighten

2 Modelling magma



Jamie Farquharson and colleagues are studying how heavy rainfall drives a range of volcanic hazards. The colours on the map reflect the "forced model response" (FMR) – the percentage change of heavy precipitation for a given unit of global warming. Serving as a proxy for the likelihood of extreme rainfall events, the value of FMR was averaged from nine different "general circulation models" (i.e. global climate models). FMR is shown here as the percentage rise or fall in extreme rainfall projected by the models for every degree of global warming between 2005 and 2100 CE. The darkest reds show areas that will experience a 20% or more decrease in extreme rainfall for each degree of warming, while the darkest blues highlight areas which will experience a 20% or more increase in extreme rainfall per degree of warming. The figures were made with CMIP5 model data, which assumes a "high emissions" scenario. Their results suggest that if global warming continues unchecked, the incidence of primary and secondary rainfall-related volcanic activity – such as dome explosions or flank collapse – will increase at more than 700 volcanoes around the globe.

an already considerable threat to life, property and infrastructure. As we enter a new era of much higher resolution climate modelling, Farquharson hopes that we will "be able to get a much better handle on exactly which [volcanic] systems could be affected the most". This may enable scientists to better estimate how hazards will change at specific geographical locations.

Fire and ice

Scientists are also concerned about what will happen to volcanoes currently buried under ice as the climate warms. Through modelling work and studying volcanoes that sat below the Patagonian Ice Sheet during and at the end of the last ice age, Brad Singer, a geoscientist at the University of Wisconsin-Madison in the US, and colleagues have been exploring the impact of deglaciation on volcanic processes.

They found that ice loss can lead to an increase in large explosive eruptions. This occurs because as the ice melts, the weight on the volcano drops, which allows magma to expand and put pressure on the rock within the volcano. Also, as pressure from the ice reduces, dissolved volatile gases like water and carbon dioxide separate from the magma to form gas bubbles. This further increases the pressure in the magma chamber, which can promote an eruption.

But each volcano responds differently to ice. Singer's team has been dating and studying the chemical composition of lava flow samples from South America, to track the behaviour of volcanoes over tens of thousands of years, through the build-up of the ice and after deglaciation.

The Patagonian Ice Sheet began to melt very rapidly about 18 000 years ago and by about 16 000 years ago it was gone. "We develop a timeline and put compositions on that timeline and look to see if there were any changes in the composition of the magmas that were erupting as a function of the thickness of the ice sheet," explains Singer. "We are finding some really interesting things."

The Puyehue-Cordón Caulle and Mocho-Choshuenco volcanic complexes in southern Chile both erupt rhyolitic magmas. But they were not producing this type of magma before the ice retreated, as Singer and colleagues found (*GSA Bulletin* **136** 5262) (see figure 3).

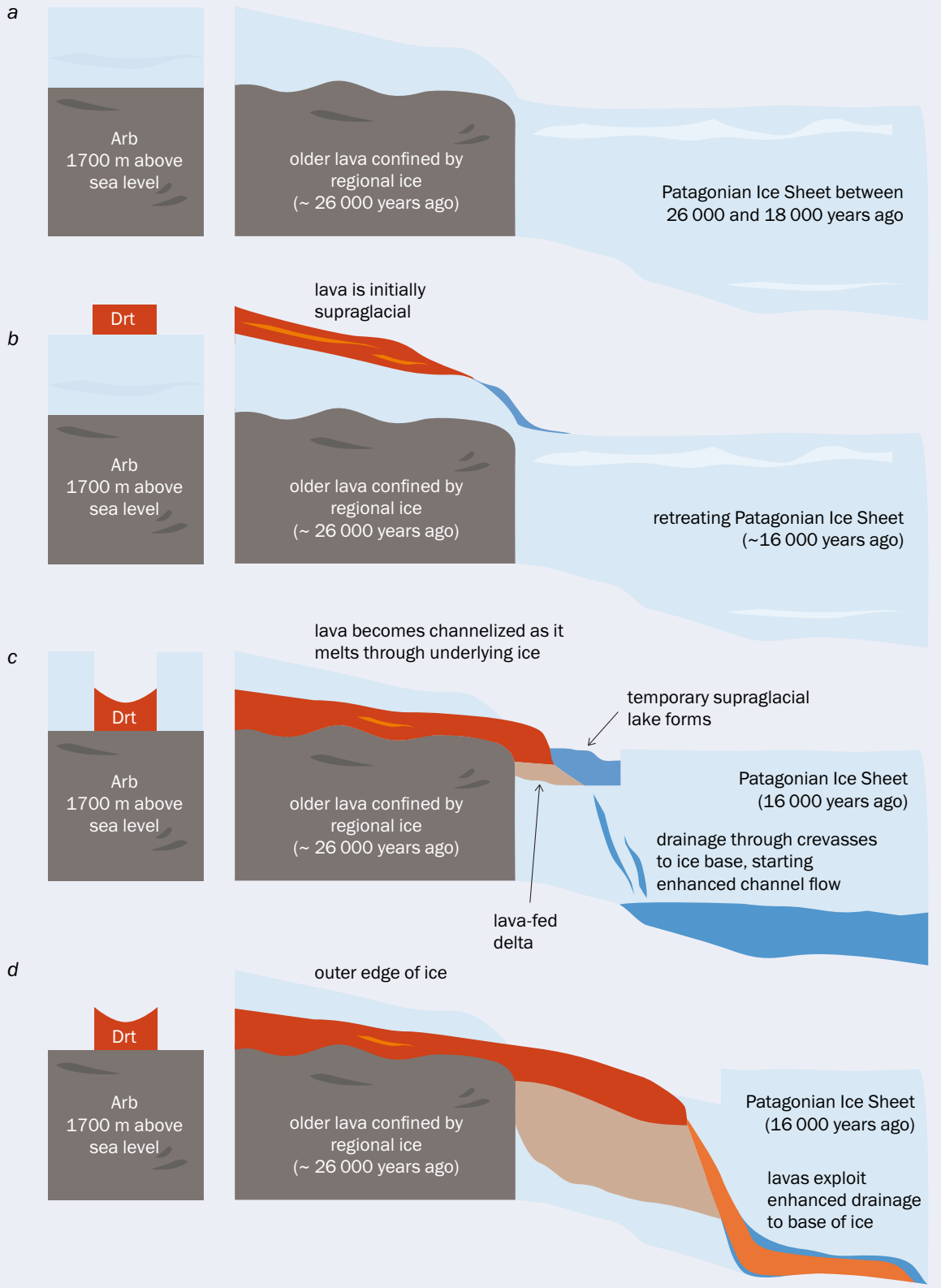
"We don't know for sure that [magma change] is attributable to the glaciation, but it is curious that immediately following the deglaciation we start to see the first appearance of these highly explosive rhyolitic magmas," says Singer. The volcanologists suspect that the ice sheet reduced eruptions at these volcanos, leading magma to accumulate over thousands of years. "That accumulated reservoir can evolve into this explosive dangerous magma type called rhyolite," Singer adds.

But that didn't always happen. The Calbuco volcano, in southern Chile, has always erupted andesite, an intermediate-composition magma. "It's never erupted basalt, it's never erupted rhyolite, it's erupting andesite, regardless of whether the ice is there or not," explains Singer.

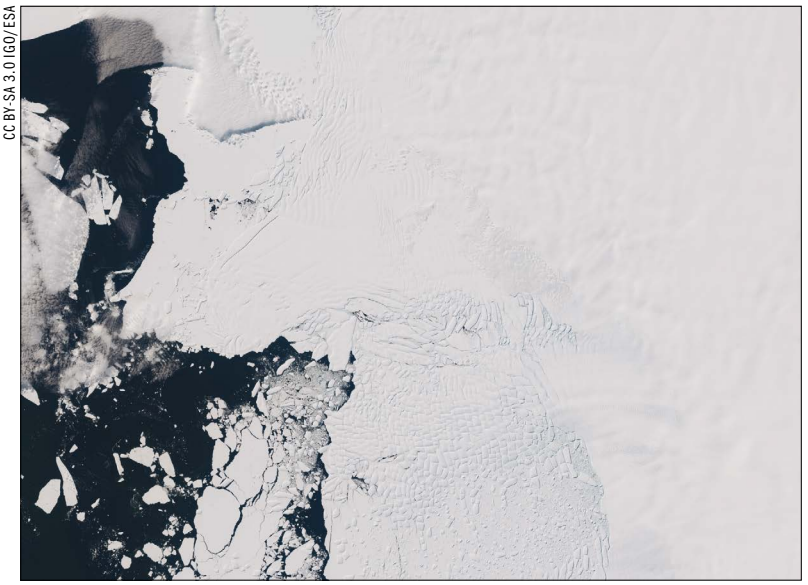
There are also differences in how quickly volcanoes

Higher resolution climate modelling may enable scientists to better estimate how hazards will change at specific geographical locations

3 When volcanic lava and ice interact



Geologist Brad Singer and colleagues are studying how glaciers and ice sheets impact the evolution of volcanoes, to develop a "lava-fed delta" model. (*a*) The researchers studied basaltic andesites in the Río Blanco river in Argentina (Arb). A fine-grained extrusive igneous rock that forms when volcanic magma erupts and crystallizes outside of the volcano, basaltic andesites were impounded by the Patagonian Ice Sheet roughly 26 000 years ago. Here they formed cliffs that were then occupied by the Patagonian Ice Sheet at 1500–1700 m above sea level between 26 000 and 20 000 years ago. Ice on top of the edifice should have been comparatively thinner than in the surrounding valleys. (*b*) As the ice sheet retreated between 18 000 and 16 000 years ago, dacite – a fine-grained volcanic rock formed by rapid solidification of lava that is high in silica and low in alkali metal oxides – from the Río Truful river in Chile (Drt) flowed onto it. (*c*) Lava is channelized as it melts the ice to form a lava-fed delta. (*d*) Dacite flows through the ice and to its base.



Icy danger Thwaites Glacier (photographed by the Copernicus Sentinel-2 satellite in 2019) is a tongue of the West Antarctic Ice Sheet and has so much ice that it alone could raise global sea levels by around 60 cm. The ice sheet sits on top of a rift system thought to contain 100 active volcanoes. Reduced ice load as the sheet melts could trigger these volcanoes, which would in turn accelerate melting.

reacted to the deglaciation. At Mocho-Choshuenco, for example, there was a large rhyolite eruption about 3000 years after the loss of ice. Singer suspects that the delay "reflects the time that it took to exsolve the volatiles from the rhyolite". But at the nearby, very active Villarrica volcano, there was no such delay. It experienced a huge eruption 16 800 years ago, almost immediately after the ice disappeared.

Melting ice sheets

Volcanic activity from melting ice sheets, due to current climate change, is probably not a direct hazard to people. But below the West Antarctic Ice Sheet sits the West Antarctic Rift – a system that is thought to contain at least 100 active volcanoes.

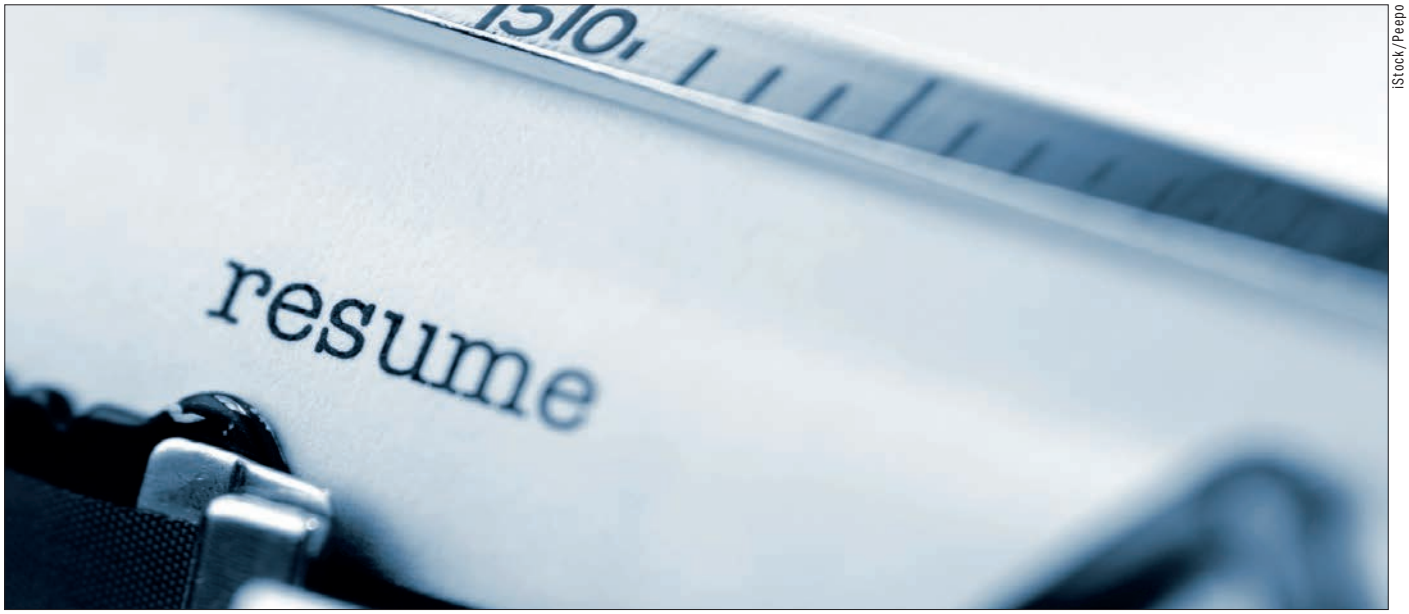
A major contributor to global sea-level rise, the West Antarctic Ice Sheet is particularly vulnerable to collapse as temperatures rise. If they become more active and explosive, the volcanoes of the West Antarctic Rift System could accelerate ice melting and sea-level rise.

"The melting of the West Antarctic Ice Sheet could remove the surface load that's preventing eruptions from occurring," says Singer. Such eruptions could bring lava and heat to the base of the ice sheet, which is dangerous because melting at the base can cause the ice to move faster into the ocean. The resulting rising sea levels could go on to advance the seismic clock and trigger earthquakes.

In the long run, increased volcanic activity will impact global climate, with the cumulative effect of multiple eruptions contributing to global warming thanks to a build-up of greenhouse gases. Essentially, a positive feedback loop is created, as melting ice caps, helped by volcanoes, could lead to more earthquakes. Managing the Earth's warming and protecting the world's remaining glaciers and ice sheets is therefore more crucial than ever.

Careers

Why a physics degree is so valuable



iStock/Peepo

Storyteller Tailor your résumé for each specific role. You can also use generative AI to help you pull together a concise CV.

Today's graduates face a shifting job-market influenced by AI, funding cuts and evolving industry demands – but their skills remain valuable across various numerous roles, as **Sophia Chen** discovers

Nothing stays static in today's job market. Physicist Gabi Steinbach recalls that about five years ago, fresh physics PhDs could snag lucrative data-scientist positions in companies without job experience. "It was a really big boom," says Steinbach, at the University of Maryland, US. Then, schools started formal data-science programmes that churned out job-ready candidates to compete with physicists. Now, the demand for physicists as data scientists "has already subsided," she says.

Today, new graduates face an uncertain job market, as companies wrestle with the role of artificial intelligence (AI), and due to the funding cuts of science research agencies in the US. But those with physics degrees should stay optimistic, according to Matt Thompson, a physicist at Zap Energy, a fusion company based in Seattle, Washington.

"I don't think the value of a physics education ever changes," says Thompson, who has mentored many young physicists. "It is not a flash-in-the-pan major where the funding and jobs come from changes. The value of the discipline truly is evergreen."

Evergreen discipline

In particular, a physics degree prepares you for numerous technical roles in emerging industrial markets. Thompson's company, for example, offers a number of technical roles that could fit physicists with a bachelor's, master's or PhD.

A good way to set yourself up for success is to begin your job hunt two years before you expect to graduate, says Steinbach, who guides young researchers in career development. "Many students underestimate the time it takes," she says.

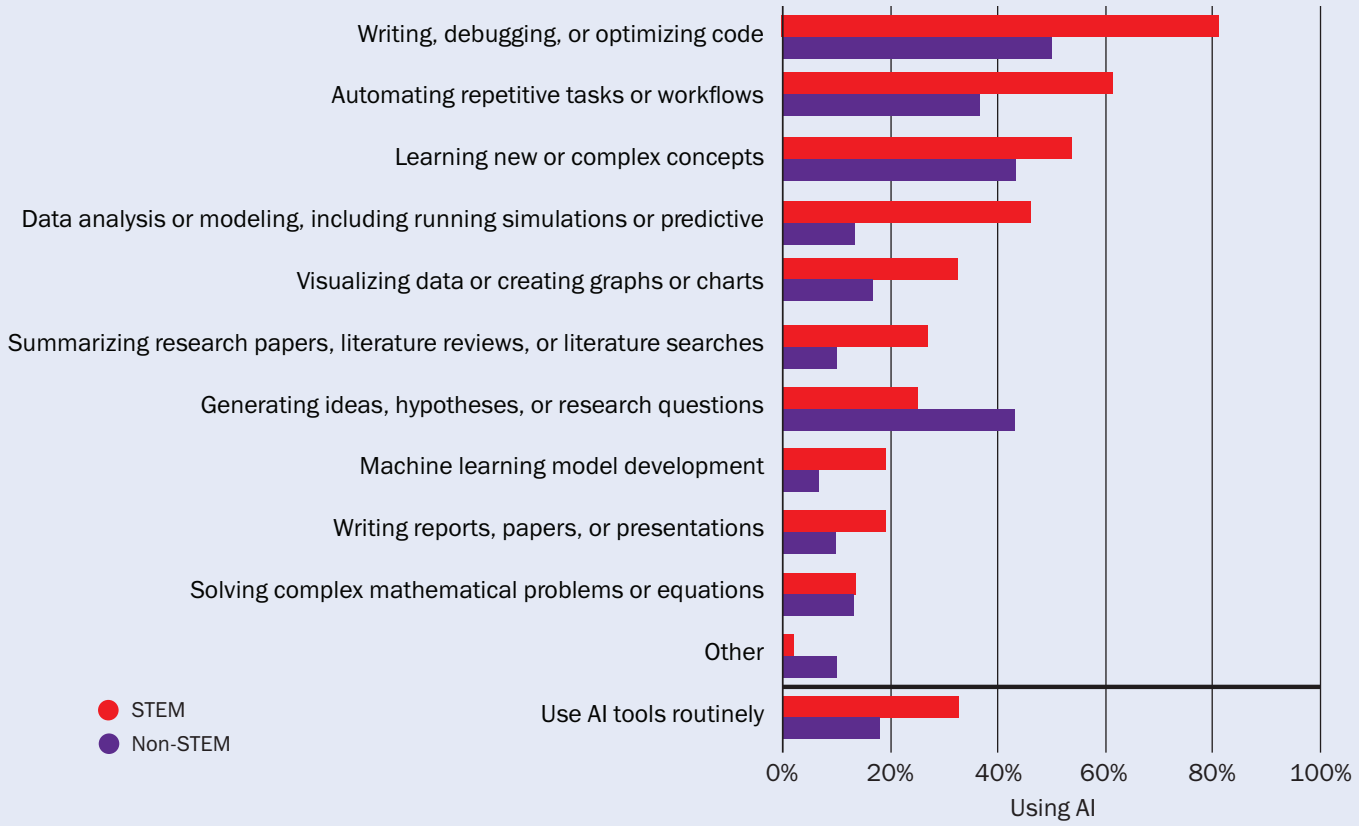
The early start should help with the "internal" work of job hunting, as Steinbach calls it, where students figure out their personal ambitions. "I always ask students or postdocs, what's your ultimate goal?" she says. "What industry do you want to work in? Do you like teamwork? Do you want a highly technical job?"

Then, the external job hunt begins. Students can find formal job listings on Physics World Jobs, APS Physics Jobs and in the *Physics World Careers* and *APS Careers* guides, as well as companies' websites or on LinkedIn. Another way to track opportunities is to read investment news, says Monica Volk, who has spent the last decade hiring for companies, including Silicon Valley start-ups. She follows *Term Sheet*, a Fortune newsletter, to see which companies have raised money. "If they just raised $20 million, they're going to spend that money on hiring people," she says.

Volk encourages applicants to tailor their résumé for each specific job. "Your résumé should tell a story, where the next chapter in the story is the job that you're applying for," she says.

Hiring managers want a CV to show that a candidate from academia can "hit deadlines, communicate clearly, collaborate and give feedback." Applicants can show this capability by describing their work specifically. "Talk about different equipment you've used, or the applications your research has gone into," says Carly Saxton, the vice-president of HR at Quantum Computing, Inc. (QCI), based in New Jersey, in the US. Thompson adds that describing your academic research with an emphasis on results – reports written, projects completed and the importance of a particular numerical finding – will give those in industry the confidence that you can get something done.

What physics graduates use AI tools for in their jobs



American Institute of Physics / IOP Publishing

The *AI Use Among Physics Degree Recipients* report by the American Institute of Physics, published in August 2025, shows how recent physics degree recipients are engaging with AI, encompassing both its development and its application in daily professional activities. New bachelor's graduates working in both STEM and non-STEM roles who received their degrees between 2023 and 2024 answered whether they routinely used AI tools in their day-to-day work in February 2025.

It's also important to research the company you're applying for. Generative AI can help with this, says Valentine Zatti, the HR director for Alice & Bob, a quantum computing start-up in France. For example, she has given ChatGPT a LinkedIn page and asked it to summarize the recent news about a company and list its main competitors. She is careful to verify the veracity of the summaries.

When writing a CV, it's important to use the keywords from the job description. Many companies use applicant-tracking systems, which automatically filter out CV without those keywords. This may involve learning the jargon of the industry. For example, when Thompson looked for jobs in the defence sector, he found out they called cameras "EO/IR," short for electro-optic infrared instruments. Once he started referring to his expertise using those words, "I got a lot better response," he says.

Generative AI can also assist you in putting together a résumé. For example, it can make résumés, which should be one page long, more concise, or help you better match your language to the job description. But Steinbach cautions that you must stay vigilant. "If it's writing things that don't sound like you, or if you can't remember what's written on it, you will fail at your interview," says Steinbach.

Companies fill job openings quickly, especially right now, so Thompson also recommends focusing on networking. "It's fine to apply for jobs you see online, but that should be maybe 20 percent of your effort," he says. "Eighty percent should be talking to people." One effective approach is through company internships before graduation. "We jump at the opportunity to hire former interns," says Saxton.

Thompson suggests arranging a half-hour call with someone whose job looks interesting to you. You can find people through your alumni networks, LinkedIn or APS's Industry Mentoring for Physicists (IMPact) programme, which connects students and early-career physicists from any country with industrial physicists worldwide for career guidance. You can also attend career fairs at your university and those organized by the APS.

Skills showcase

Once a company is interested in you, you can expect several rounds of interviews. The first will be about the logistics of the job – whether you'd need to relocate, for example. After that, for technical roles you can expect technical interviews. Recently, companies have encountered candidates secretively using AI to cheat during these interviews. They may eliminate the candidate for cheating. "If you don't know how to do something, it's better to be honest about it than to use AI to get through a test," says Saxton. "Companies are willing to teach and develop core skills."

From left to right: Gabi Steinbach; Zap Energy; Mike Craig; Crouse Powell Photography; Alice & Bob

Expert advice From left to right: Gabi Steinbach, Matt Thompson, Monica Volk, Carly Saxton and Valentine Zatti.

However, with transparency, showcasing AI skills could be a boon during job interviews. A 2025 survey from the American Institute of Physics found that around one in four students with a physics bachelor's degree (see graph on p55) and two in five with physics PhDs routinely use AI for work. The report also found that one in 12 physics bachelor's degree-earners and nearly one in five physics doctorate-earners who entered the workforce in 2024 have jobs in AI development.

The emerging quantum industry is also a promising job market for physicists. Globally, investors put nearly $2 billion in quantum technology in 2024, while public investments in quantum in early 2025 reached $10 billion. "You'll have an opportunity to work for companies in their building stage, and you're able to earn equity as part of that company," says Saxton.

Alice & Bob is in the midst of hiring 100 new staff, 25 of whom are quantum physicists, including experimentalists and theorists, based in Paris. Zatti, in particular, wants to boost the number of women working in the field.

Currently, the pool of qualified candidates in quantum is small. Consequently, Alice & Bob can screen CVs manually, says Zatti. Both Alice & Bob and US-based QCI say they are willing to hire internationally. QCI is willing to pay legal fees for candidates to help them continue working in the US, says Saxton.

It's important to stay flexible in today's job market. "Don't ignore current trends, but don't get married to them either," suggests Steinbach. Thompson agrees, adding that curiosity is key. "You just have to be creative. If you can open your aperture to all of private industry, there's a lot of opportunity out there."

● This article was first published in *APS Careers 2026*.

Sophia Chen is a freelance science writer based in Columbus, Ohio, who covers physics, engineering and computing @sophurky.bsky.social

Ask me anything: Mažena Mackoit-Sinkevičienė

Mažena Mackoit-Sinkevičienė is a researcher at the Institute of Theoretical Physics and Astronomy, Vilnius University, Lithuania. Working in quantum optics and technology, with a focus on quantum emission from point defects in solid-state platforms, and non-classical spin states in ultracold atomic gases, she is a co-author of Lithuania's National Quantum Guidelines and vice-president of the Lithuanian Physical Society. Mackoit-Sinkevičienė has received several awards, including the Lindau Nobel Laureate Meeting Alumnus distinction and the Lithuanian Government Award. Most recently, she won the 2025 Baltic Women in Science Fellowship awarded by the Baltic National Academies of Sciences and UNESCO National Commissions.

Photo by Justinas Auškelis. Courtesy: Vilnius University

Joy in understanding Quantum optics researcher Mažena Mackoit-Sinkevičienė, who won the 2025 Baltic Women in Science Fellowship, likes to sit with hard problems until a discovery reveals itself.

What skills do you use every day in your job?

Much of my time is spent trying to build and refine models in quantum optics, usually with just a pencil, paper and a computer. This requires an ability to sit with difficult concepts for a long time, sometimes far longer than is comfortable, until they finally reveal their structure.

Good communication is equally essential – I teach students; collaborate with colleagues from different subfields; and translate complex ideas into accessible language for the broader public. Modern physics connects with many different fields, so being flexible and open-minded matters as much as knowing the technical details. Above all, curiosity drives everything. When I don't understand something, that uncertainty becomes my strongest motivation to keep going.

What do you like best and least about your job?

What I like the best is the sense of discovery – the moment when a problem that has evaded understanding for weeks suddenly becomes clear. Those flashes of insight feel like hearing the quiet whisper of nature itself. They are rare, but they bring along a joy that is hard to find elsewhere.

I also value the opportunity to guide the next generation of physicists, whether in the university classroom or through public science communication. Teaching brings a different kind of fulfilment: witnessing students develop confidence, curiosity and a genuine love for physics.

What I like the least is the inherent uncertainty of research. Questions do not promise favourable answers, and progress is rarely linear. Fortunately, I have come to see this lack of balance not as a weakness but as a source of power that forces growth, new perspectives, and ultimately deeper understanding.

Above all, curiosity drives everything. When I don't understand something, that uncertainty becomes my strongest motivation to keep going

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

I wish I had known that feeling lost is not a sign of inadequacy but a natural part of doing physics at a high level. Not understanding something can be the greatest motivator, provided one is willing to invest time and effort. Passion and curiosity matter far more than innate brilliance. If I had realized earlier that steady dedication can carry you farther than talent alone, I would have embraced uncertainty with much more confidence.

Recruitment

Recruitment Advertising
Physics World
IOP Publishing
No.2 The Distillery,
Glassfields,
Avon Street, Bristol BS2 0GR

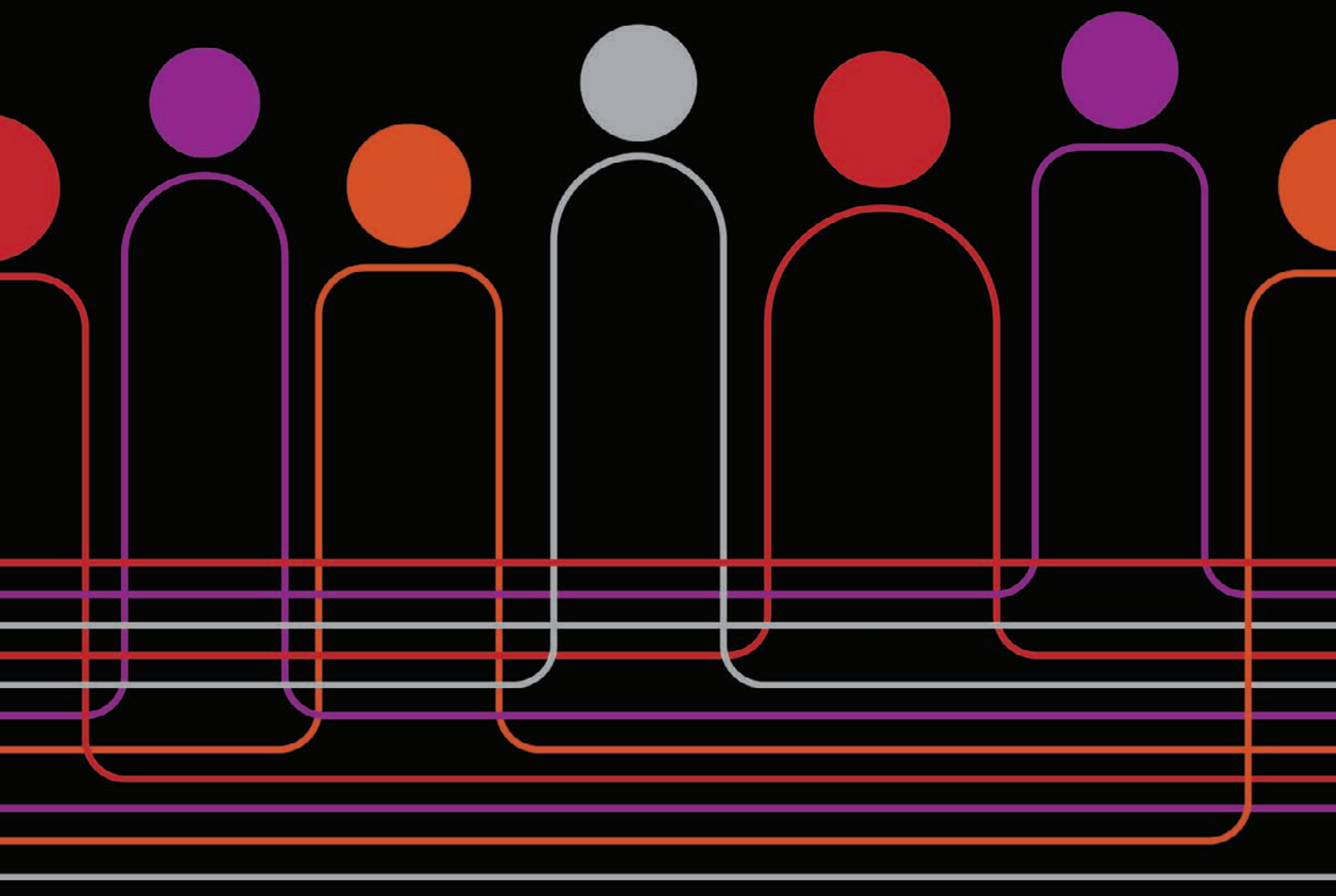
Tel +44 (0)117 930 1264
E-mail sales.physicsworld@ioppublishing.org

The place for physicists and engineers to find jobs, studentships, courses, calls for proposals and announcements

physicsworld

careers

Explore the 2026 Physics World Careers Guide today



The power of a poster

While some researchers might find making academic posters a thankless task, **Kevin McGuigan** proves that they can reap great rewards

Most researchers know the disappointment of submitting an abstract to give a conference lecture, only to find that it has been accepted as a poster presentation instead. If this has been your experience, I'm here to tell you that you need to rethink the value of a good poster.

For years, I pestered my university to erect a notice board outside my office so that I could showcase my group's recent research posters. Each time, for reasons of cost, my request was unsuccessful. At the same time, I would see similar boards placed outside the offices of more senior and better-funded researchers in my university. I voiced my frustrations to a mentor whose advice was, "It's better to seek forgiveness than permission." So, since I couldn't afford to buy a notice board, I simply used drawing pins to mount some unauthorized posters on the wall beside my office door.

Some weeks later, I rounded the corner to my office corridor to find the head porter standing with a group of visitors gathered around my posters. He was telling them all about my research using solar energy to disinfect contaminated drinking water in disadvantaged communities in Sub-Saharan Africa. Unintentionally, my illegal posters had been subsumed into the head porter's official tour that he frequently gave to visitors.

The group moved on but one man stayed behind, examining the poster very closely. I asked him if he had any questions. "No, thanks," he said, "I'm not actually with the tour, I'm just waiting to visit someone further up the corridor and they're not ready for me yet. Your research in Africa is very interesting." We chatted for a while about the challenges of working in resource-poor environments. He seemed quite knowledgeable on the topic but soon left for his meeting.

A few days later while clearing my e-mail junk folder I spotted an e-mail from an Asian "philanthropist" offering me €20 000 towards my research. To collect the money, all I had to do was send him my bank account details. I paused for a moment to admire the novelty and elegance of this new e-mail scam before deleting it. Two days later I received a second e-mail from the same source asking why I hadn't responded to their first generous offer. While admiring their persistence, I resisted the urge to respond by asking them to stop wasting their time and mine, and instead just deleted it.

Imagine my surprise when the following Monday morning I received a phone call from the university deputy vice-chancellor inviting me to pop up for a quick chat. On arrival, he wasted no time before asking why I had been so foolish as to ignore repeated offers of research funding from one of the college's most generous benefactors.

The gentleman that I'd chatted with outside my office was indeed a wealthy philanthropic funder who had been visiting our university. Having retrieved the e-mails from my deleted items folder, I re-engaged with him and subsequently received €20 000 to install 10 000-litre harvested-rainwater tanks in as many primary schools in rural Uganda as the money would stretch to.

Kevin McGuigan

Pay-back time
For Kevin McGuigan, some well-placed posters outside his office proved to be very beneficial.

About six months later, I presented the benefactor with a full report accounting for the funding expenditure, replete with photos of harvested-rainwater tanks installed in 10 primary schools, with their very happy new owners standing in the foreground. Since you miss 100% of the chances you don't take, I decided I should push my luck and added a "wish list" of other research items that the philanthropist might consider funding.

The list started small and grew steadily ambitious. I asked for funds for more tanks in other schools, a travel bursary, PhD registration fees, student stipends and so on. All told, the list came to a total of several hundred thousand euros, but I emphasized that they had been very generous so I would be delighted to receive funding for any one of the listed items and, even if nothing was funded, I was still very grateful for everything he had already done. The following week my generous patron deposited a six-figure-euro sum into my university research account with instructions that it be used as I saw fit for my research purposes, "under the supervision of your university finance office".

In my career I have co-ordinated several large-budget, multi-partner, interdisciplinary, international research projects. In each case, that money was hard-earned, needing at least six months and many sleepless nights to prepare the grant submission. It still amuses me that I garnered such a large sum on the back of one research poster, one 10-minute chat and fewer than six e-mails.

So please don't underestimate the power of a strategically placed and impactful poster describing your research. You never know down which road it might lead.

I paused for a moment to admire the novelty and elegance of this new e-mail scam before deleting it

Kevin McGuigan is a professor of medical physics and academic director of engagement at the Royal College of Surgeons, University of Medicine and Health Sciences in Dublin, Ireland

IOP Publishing

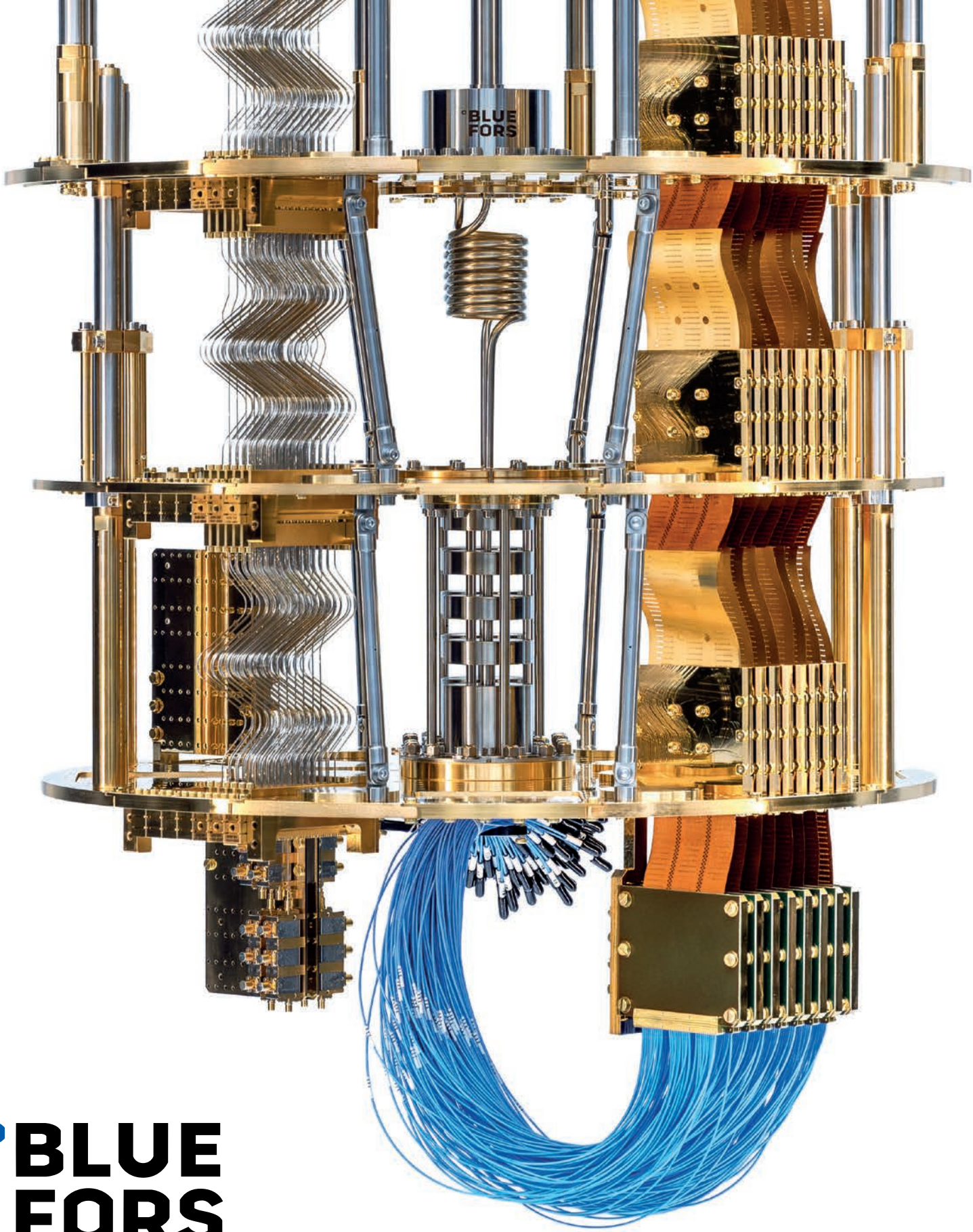
Discover *Chinese Physics B* and *Chinese Physics Letters*

Published by IOP Publishing on behalf of the Chinese Physical Society

Chinese Physics B is an international journal covering the latest developments and achievements in all branches of physics.

Chinese Physics Letters provides rapid publication of short reports and important research in all fields of physics.

Start exploring these journals today →



BLUE FORS

The Complete Measurement Infrastructure Solution

Cool for Progress.