PHYSICS TODAY

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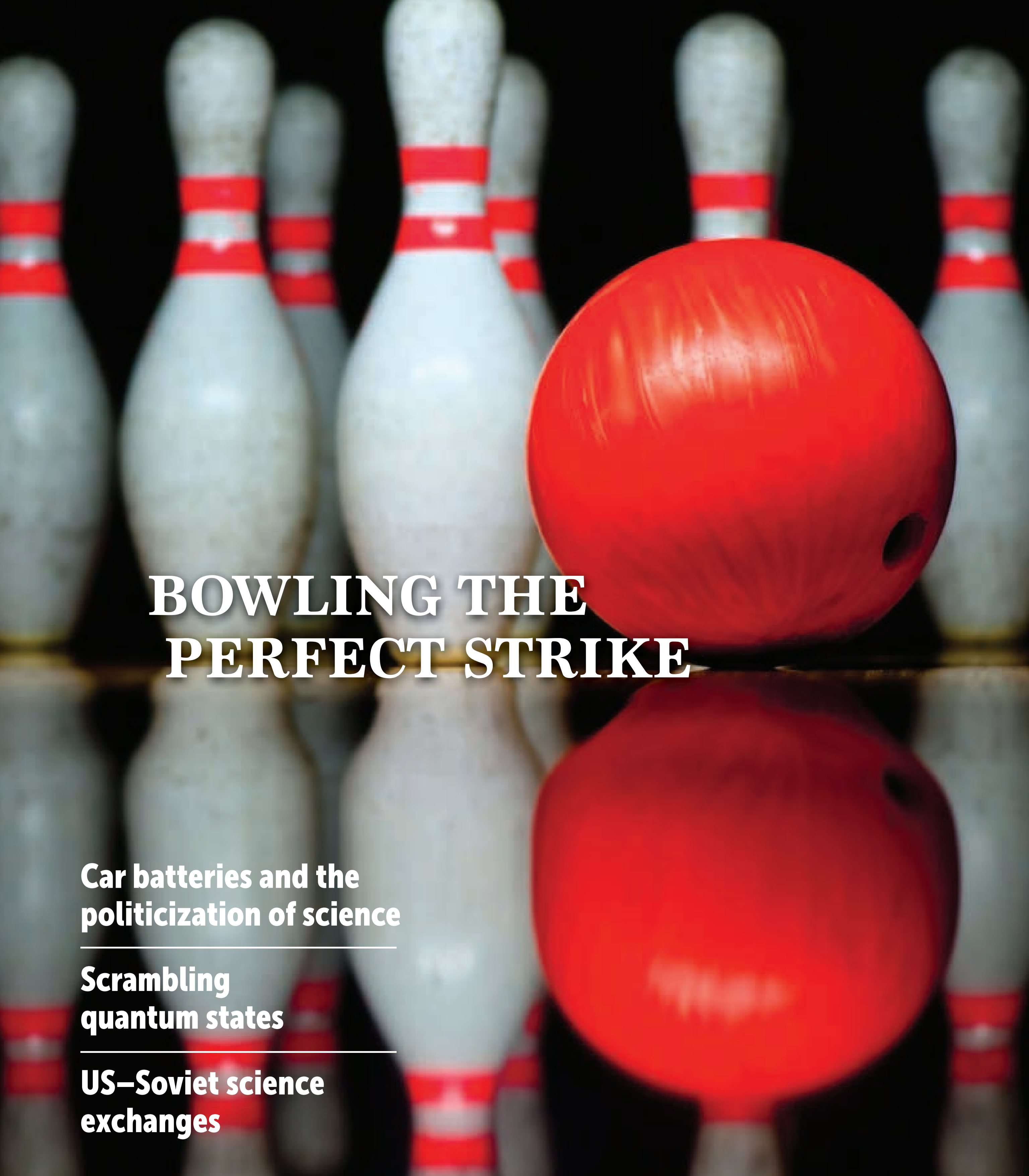

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FALL 2025

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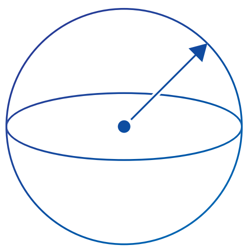

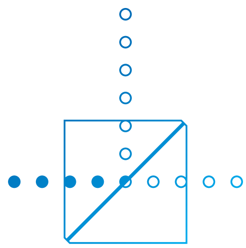

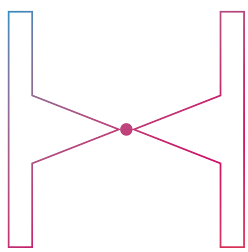

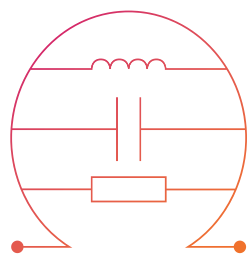

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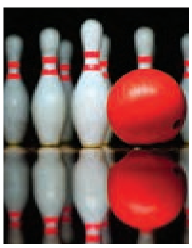
FEATURES



ON THE COVER: Tenpin bowlers aim to rack up points by rolling strikes, but the curvature of the pins and small variations in their starting positions can make their behavior difficult to predict and control. If a bowler can hit the headpin at a particular position and angle, though, there's a near guarantee that all ten pins will tumble. To learn how to reliably roll a perfect strike, turn to the Quick Study by Curtis Hooper on **page 54**. (Photo by Konstantin Labunskiy/Alamy.)

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Many physics students don't have a good understanding of their career options beyond academia. In a new interview series, Physics Today is profiling physicists who work in finance, science writing, law (including Louisa Eberle, pictured), and many other professions.
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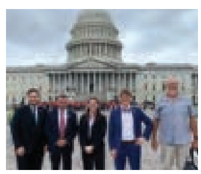

JASPER THOMSON

Science advocacy

Physics Today's Toni Feder details how an increasing number of US scientists are writing letters, making phone calls, publishing op-eds, and visiting and hosting lawmakers to advocate for science. Many of the efforts have been focused on lobbying Congress to pass a new budget that supports science.
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Quantum states can be scrambled extremely quickly

The surprising theoretical result holds both good news and bad news for the ease of making quantum measurements.

FIGURE 1. THE RIFFLE SHUFFLE is an effective way to quickly scramble the order of a deck of cards. The number of shuffles you need to perform depends on how thoroughly you want the cards to be randomized. (Image by Johnny Blood/Wikimedia Commons/CC BY-SA 2.0.)

Randomness takes time. If you're playing a card game with a standard 52-card deck, shuffling the cards just once or twice isn't enough to mix them up. A quick-thinking and attentive opponent could make meaningful guesses about the cards' post-shuffling order.

For most card games played by humans, seven riffle shuffles (the type shown in figure 1) suffice to mix a standard deck. But it doesn't completely randomize the cards: Some of the 52! (about 8×10^{67}) possible orders are still significantly more probable than others. If a uniform likelihood over all possible orders is your goal, you need to keep shuffling much longer.

New theoretical work by Thomas Schuster, Hsin-Yuan Huang (both at Caltech), and Jonas Haferkamp (of Saarland University in Germany) highlights the enormous gap between "truly random" and "random enough for practical purposes" in the quantum realm. It was already known that for a randomly chosen quantum circuit to truly scramble an n-qubit state, the complexity of the circuit needs to grow exponentially with n: If the number of qubits is doubled, the number of layers in the circuit is squared. Like any exponentially growing function, it quickly becomes unwieldy for large inputs.

Schuster, Huang, and Haferkamp proved that one can achieve a sufficiently scrambled state with a much, much smaller circuit.[1] A practically random circuit, indistinguishable from an exponentially sized one, can be built with a number of layers that scales just logarithmically with n: Squaring the number of qubits merely doubles the number of layers.

Uniquely quantum

It's a surprising result, to the point where the researchers themselves struggled to believe it at first. To see how strange the quantum situation is, it's helpful to consider the analogous classical system, illustrated in figure 2a. As the problem is typically posed, the input bits are arranged in a single-file line, and each layer of the scrambling circuit contains logic gates that operate on adjacent inputs.

Given that setup, a circuit needs to have at least $n - 1$ layers to fully scramble an n-bit state, because that's how long it takes for the influence of the first input bit to propagate to the last output bit. A circuit with fewer than $n - 1$ layers could never have the same effect as one with more, and it could always be easily exposed by testing it with two input states that differ only in the value of the first bit. Most of the bits in the output would necessarily be the same in each case.

So why is the quantum situation different, to the point where a logarithmically sized circuit can, for practical purposes, scramble a state just as well as an exponentially large one can? One part of the answer hinges on what's meant by "for practical purposes": It means that the circuit can be tested no more than some fixed number of times k. The other part hinges on the nature of quantum measurements: Measuring a quantum state doesn't reveal everything about it—and much of the time, it reveals nothing.

"Imagine that a particle is in a state of fixed position, and you try to measure its momentum," says Schuster. "You get a completely random measurement outcome, and the information about the position is lost. In many-body quantum systems, there are exponentially many possible observables, and most of them don't commute with one another, just like position doesn't commute with momentum."

In other words, if you tried to perform the quantum equivalent of the classical experiment that's sketched in figure 2a, most of the time you'd be stymied by the fact that the circuit output probably isn't an eigenstate of whatever observable you chose to measure. Two similar inputs could produce similar outputs, but

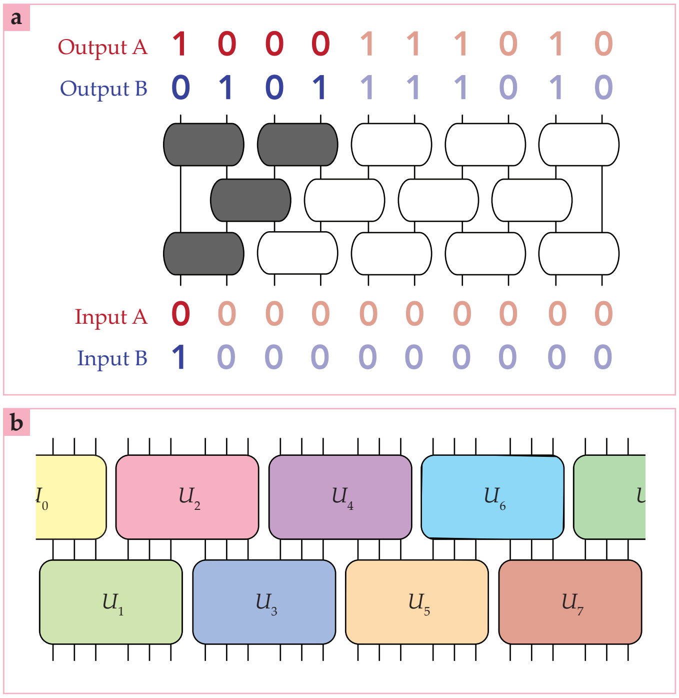

FIGURE 2. A CLASSICAL STATE (a) can't be thoroughly scrambled by a circuit with fewer layers than the number of input bits—at least not if the bits are arranged in 1D and the circuit gates operate on them locally—because, as the two test cases A and B illustrate, the influence of the first bit can't propagate all the way to the other end. But that argument doesn't apply to quantum states. An effectively random quantum circuit **(b)** can be built by grouping the qubits into small bunches and applying two layers of smaller scrambling circuits U_i, as shown. (Images adapted from ref. 1.)

you'd never know it unless you were lucky enough to guess the right way to probe the output states that wouldn't be affected by quantum measurement randomness. Most of your *k* chances to test the circuit are necessarily wasted, so even if *k* is large, it doesn't take a complicated circuit to make it look like the state is being completely scrambled.

But even with their expert intuition for quantum states and measurements, the researchers were surprised that so small a quantum circuit would be so effective. "Had you asked me two years ago whether this was possible, I would have emphatically said no," says Haferkamp. "Such a shallow circuit can't accumulate enough entanglement to approximate the near-maximal entanglement we thought we'd need. But that argument is flawed, because it turns out that near-maximal entanglement isn't something that can be detected in actual quantum experiments."

Not only did the researchers prove that a simple scrambling circuit is possible, but they also presented a formula for building it, as shown in figure 2b. Starting with *n* qubit inputs in a 1D line, they group the qubits into smaller bunches whose exact size depends logarithmically on *n* and *k*. They apply a randomly chosen scrambling circuit *U* to each bunch, then regroup the qubits and apply a second layer of scrambling circuits. Overall, the total number of layers in the circuit is logarithmic in *n* and *k*, and the researchers mathematically proved that, given the parameters of the test, the small circuit is indistinguishable from an exponentially large one.

Efficiency from randomness

"Our results contain both good and bad news," says Schuster. "We showed that quantum mechanics allows systems to hide information extremely rapidly. On the bad side, if a quantum state in nature or in the laboratory is hiding its properties from us, it becomes much harder for us to study. But if we ourselves are the ones hiding the information—and we know how it is hidden—it can be very useful."

Accordingly, the implications of the result include two broad classes of ideas: counterexamples and applications. The counterexamples can be used to prove that there can be no way to efficiently detect certain quantum properties, such as quantum topological order, in systems that have been scrambled for even a short time, because a little scrambling is indistinguishable from a lot of scrambling.

On the other hand, applications of the result include ways to perform other types of quantum measurements more easily than was previously thought possible. It might seem strange that performing uncontrolled scrambling operations on a quantum state would be the key to understanding it. But a similar idea underlies Monte Carlo simulations in the classical realm, in which randomness is used to quickly sample a space of possibilities that's too large to study systematically.

Along those lines, in 2020, Huang and two other colleagues, Richard Kueng and John Preskill, conceived of a technique called classical shadow tomography, in which an observer can efficiently extract information about a quantum state by repeatedly applying random operations to it.[2] "The role of the random operation is to effectively rotate the quantum object," explains Huang, "so the classical observer can look at it from different angles."

Although the number of required rotations is small—it scales logarithmically with the amount of information the observer wants to extract—researchers previously thought that each one would take impractically long to implement. With the new insight that effectively the same randomizing operations can be applied much more quickly, classical shadow tomography becomes a potentially more practical technique.

The new work is theoretical, but the researchers note that there's no barrier to experimentally building the circuits they describe, because all the component quantum gates are already being used in labs in even greater numbers. "Shallow circuits are strictly easier to build than deep circuits," says Schuster. "In fact, it's likely that they've already been built in quantum experiments before our work—it's just that their power was not recognized."

Johanna Miller

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2. H.-Y. Huang, R. Kueng, J. Preskill, *Nat. Phys*. **16**, 1050 (2020).

A machine that mechanically interlocks molecules

Researchers have shown how a molecular motor can be used to intertwine two molecules and form a linkage that couldn't be made with conventional synthesis.

It might be impossible to quantify the number of machines involved in daily life. We use machines to control the climate in our homes, move between places, and heat up water for our morning cup of coffee or tea, among other things. Somewhat less obvious, though, is the fact that our very ability to get up in the morning and make a caffeinated drink relies on a more hidden kind of machinery: molecular machines that convert the energy and carry the signals that power our bodies. Those tiny biological machines serve as inspiration for work that extends human engineering capacity down to the molecular level.

"The molecular scale, obviously, has very different rules than the macroscopic scale. Everything flies around in this Brownian hurricane all the time—everything moves and vibrates and

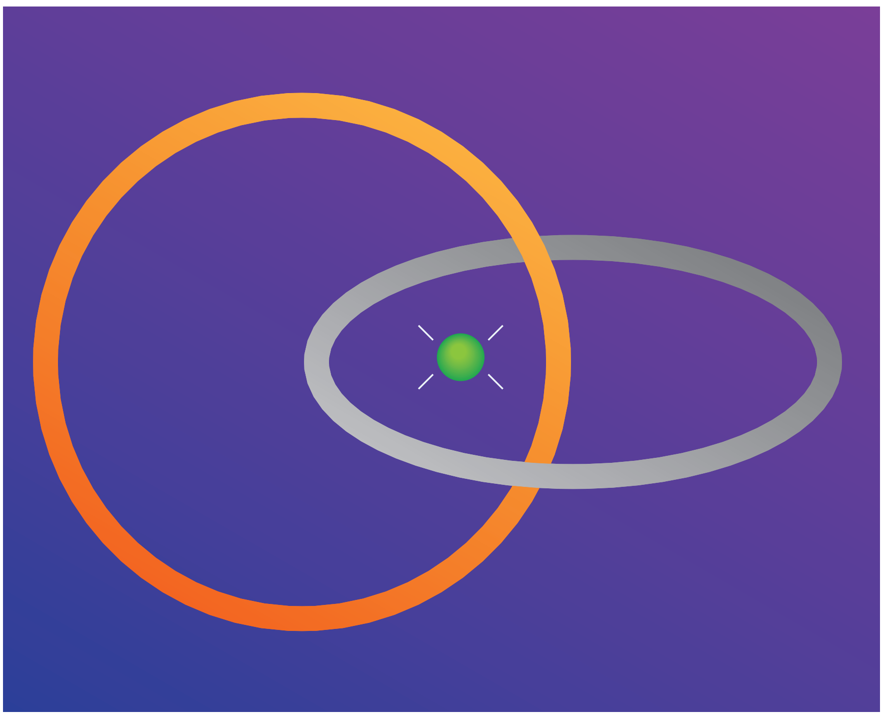


FIGURE 1. MECHANICALLY INTERLOCKED MOLECULES are connected not by chemical bonds but by their shapes, which makes them useful for engineering at the molecular scale. Ring-shaped molecules, represented here by orange and gray circles, can be connected like links in a chain to form what is known as a catenane. Catenanes have been effectively synthesized for decades by using ions, such as copper (green dot), that temporarily hold them in place—a process known as templated synthesis. (Illustration by Freddie Pagani.)

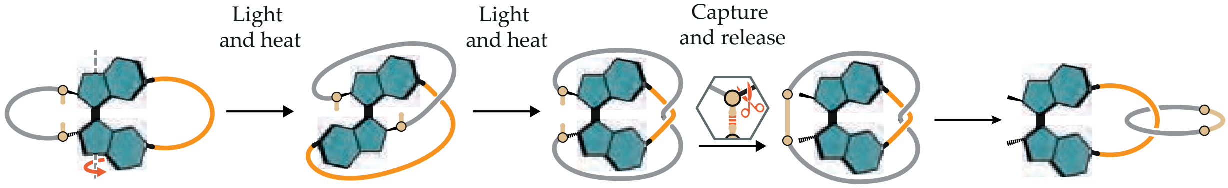


FIGURE 2. A MOLECULAR MOTOR (shown in blue) can be used to wind two hydrocarbon chains (shown in gray and orange) attached to its rotors. After a 360° turn, the chains cross twice. Chemical reactions can then be used to connect one of the chains to itself (tan line), which captures the interwound state, and then sever the chain's chemical bond to the motor to release it. The result is a mechanically interlocked molecule, a catenane, that could not have been made with conventional chemical reactions alone. (Figure adapted from ref. 1.)

wiggles," says Michael Kathan of Humboldt University of Berlin. In an environment awash with the noise of thermal motion, directing energy into specific tasks requires different strategies than the ones used in the macroscopic world (see the article by Dean Astumian and Peter Hänggi, Physics Today, November 2002, page 33). And just as the development of complex machinery began with simple tools like wheels and levers, making machines that work at the molecular scale required the establishment of basic components.

An early step was the synthesis of mechanically interlocked molecules. In contrast to covalently bonded atoms, which share valence electrons in a covalent bond, mechanically interlocked molecules are connected by their physical shapes, as shown in figure 1, in what's known as a mechanical bond. Mechanically interlocked molecules come in a few shapes, including knots, rings on an axle, and intertwined rings. Just like macroscopic metal chains, ring-shaped molecules linked together, known as catenanes, can combine the benefits of strength and flexibility and exhibit other emergent properties. Catenanes' shape flexibility, for example, could make them promising catalysts. Mechanically interlocked molecules' ability to move in relation to each other also makes them useful building blocks for nanoscale machines.

Another major advance in the engineering of molecular machines was the formulation of a molecular motor that can spin in one direction. The first molecular motors worked by exploiting shape interactions and energy-absorption differences to drive two sides of a molecule into relative circular motion about the axis of a carbon double bond. For creating the basic components of molecular machines—mechanically interlocked molecules and molecular motors—Jean-Pierre Sauvage, J. Fraser Stoddart, and Bernard Feringa were awarded the 2016 Nobel Prize in Chemistry (see Physics Today, December 2016, page 18).

The capabilities of synthetic molecular machines have been demonstrated in various applications: changing the shape of macroscopic materials they are embedded within, moving liquids up a ramp, replicating the movements of more-familiar machines like cranes and cars, and storing data, for example. Now Tommy Wachsmuth and a team of researchers in Kathan's lab at Humboldt University of Berlin have shown how a molecular motor can be used to build catenanes.[1] It's a molecular machine that builds the potential components of other molecular machines.

"It's the first real example of the motion of a molecular machine being connected to a specific bond-forming reaction. Each cycle of operation leads to a different product, not just switching between outcomes," says Jonathon Beves of the University of New South Wales in Sydney, Australia. The research provides a key demonstration that such machines can be used to do mechanical work at the molecular scale. Molecular motors can twist molecules into thermodynamically disfavored but kinetically stable shapes that could not be made with conventional chemical reactions. The use of molecular machines to create new molecules opens the door to a world of new possibilities in chemical synthesis.

Nanoscale rules

Chemists have been trying to make catenanes since the 1950s and 1960s. Those early efforts produced various aproaches that worked, but only with impractically small yields—a few percent at best. In the early 1980s, Sauvage devised a more effective way to build them. He used copper ions as a template to hold ring- and crescent-shaped molecules together. A subsequent chemical reaction would close each crescent to form interlocked loops, like those shown in figure 1, with a copper ion between them. The copper ion could then be removed. With the templated approach, yield increased to 42%. Since that breakthrough, researchers have found other templates that can be used to build catenanes and even more elaborate interlocked structures.

Using a motor to twist molecules into interlocked rings is a totally new approach. The molecular motor used by Kathan's team is essentially the same as the first ones built by Feringa in 1999. The motor is made of overcrowded alkenes—large molecules with a carbon double bond connecting two sets of branching lobes.

The lobes are large enough that they can't all sit in a single plane. Shining a specific wavelength of light on the molecule causes the double bond to flip, and the molecule takes on a higher-tension, metastable shape. The addition of heat then provides enough energy for what's known as thermal helix inversion—the molecule swivels to a stable shape. Those two steps produce a 180° turn, as shown in figure 2. Repeating them completes a full circular rotation back to the original shape.

That design paved the way for researchers to make motors with constant, speedy rotation by tweaking the alkene substituents and applying heat and light together. But for the task of winding molecules together into catenanes, the Kathan lab turned back to the first-generation design, in which high activation barriers provide exquisite control over every half turn of the motor.

The research team connected hydrocarbon chains as tethers to the motor's rotors, as shown in figure 2. With that configuration, the work of each rotation was put into the winding of those tethers. One chain was equipped with terminal alkene groups, shown in tan, that can be covalently bonded to each other through the addition of a catalyst. Finally, that tether's remaining connections to the motor were chemically cleaved. The product was two interlinked tethers, one of which was still attached to the motor.

Though a 360° turn was enough to build a catenane, the tethered motors could be turned as far as 720° to generate two crossings. Attempts to capture that doubly wound state were unsuccessful, though, because the molecule would spontaneously turn back 180°, presumably because of strain in the tethers. Unexpectedly, covalent capture of tethers that had been wound up by 540° produced a higher yield of catenanes than those that had only been turned one full circle: 90% compared with 82%. Both yields, though, were exceptional.

Winding forward

A template-based approach to catenane synthesis doesn't work for all molecules. One advantage of using a machine to interlock molecules is that it could be used on molecules that don't have the bonding sites necessary for templated synthesis. To demonstrate that distinct ability, the researchers used the motor to build catenanes out of hydrocarbon strands that, because of their limited number of functional groups, can't be readily manipulated with the templated method.

One drawback of the technique is that the motor is part of the final product. Unlike highly efficient biological machines, such as ribosomes, which can turn out thousands of proteins, one machine yields only one product, for now. Separating the motor from the second tether isn't as simple as reproducing the capture and release steps used to sever the first tether. If the researchers had used identical tethers, the symmetry of the molecules would have reduced the selectivity of the process—the asymmetry of the molecular system provides more control over the shape of the final product.

"Recycling is key because the motor is challenging to make," says Kathan. With the proof of concept in place, the Kathan lab is already looking for ways to separate and reuse the motor while retaining control over the final product.

The exact ways that such molecular motors and catenanes may be put to use, though, remain further off. "On the technological side, we are still far from real-world applications," says Emanuele Penocchio of Northwestern University in Evanston, Illinois, "but I think the results are promising."

Regarding the bigger picture of the design and use of new molecular machines, Penocchio says that unlike the development of macroscale technology in the industrial revolution, nanoscale engineering has the advantage of researchers knowing what is possible, because they "have biology that demonstrates it." (See, for example, the article by Mohammed Kaplan, Physics Today, March 2024, page 28.) Though not especially common, proteins can take on knotted or catenated structures that yield specific, unique properties. Knotted proteins, for example, often act as enzymes. Improved tools for understanding the complex world of proteins (see Physics Today, December 2024, page 17) offer hope for future discoveries about the function of natural molecular machinery, which may also serve as inspiration for engineered molecular machines.

"Since the synthesis of vitamin B_{12} by [Robert Burns] Woodward and [Albert] Eschenmoser in the 1970s, we basically know that you can make any organic molecule that you want. But this is by no means true for molecules that have a complex three-dimensional shape or topology," says Kathan. The high yields and chemical flexibility of the new method are both positive developments for the field. Thermodynamically unfavored molecules can also store energy. But perhaps most notable is the demonstration that molecular motors can be used to direct the synthesis of molecules that otherwise couldn't be made.

"Where this will lead us is difficult to say," says Kathan. "But I think biology and also macroscopic machines really set the stage for everything that's possible."

Laura Fattaruso

Reference

1. T. Wachsmuth et al., *Science* **389**, 526 (2025).

Matter–antimatter asymmetry is observed in baryon decay

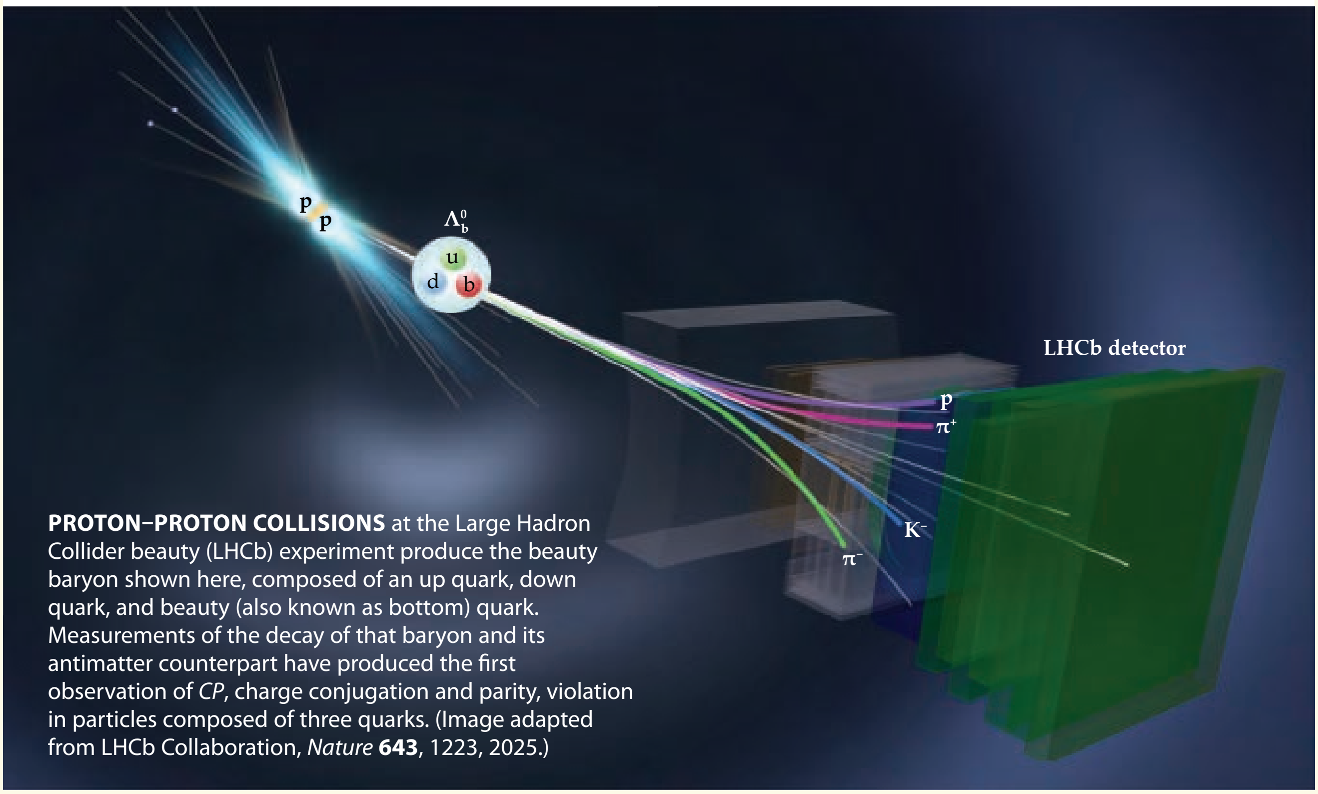
Previous detections of *CP* violation had been limited to the decay of quark–antiquark pairs. But it's baryons—particles composed of three quarks—that make up the observable universe.

Why is there matter in the universe? Matter and antimatter annihilate one another, and according to theory, equal amounts of each were produced in the Big Bang. If matter and antimatter exhibited perfectly symmetric and opposite behavior, everything would have been annihilated, and we wouldn't live in the matter-filled universe we see today. Somehow, for every billion matter–antimatter pairs that annihilated in the early universe, one particle of matter survived. The source of that asymmetry, though, is yet to be fully understood. Now, the Large Hadron Collider beauty (LHCb) collaboration at CERN has made the first observation of asymmetry in the decay rate of a baryon—a subatomic particle made of three quarks—and that of its antibaryon counterpart.

The first measurement of matter–antimatter asymmetry—specifically, the violation of *CP*, charge conjugation and parity, symmetry—in particle decays came in 1964 by James Cronin and Val Fitch. That detection and subsequent ones involved the decay of mesons, short-lived particles made up of a quark and an antiquark (see Physics Today, August 2019, page 14). Because they are generally lighter and less complex than baryons, mesons take less energy to make, and the theoretical calculations are easier to do. Extending *CP* violation searches to baryons is an important step because the observable universe is made of baryons: The protons and neutrons that make up atomic nuclei are baryons that are composed of up quarks and down quarks.

As its name suggests, the LHCb experiment was specifically designed to measure beauty (also known as bottom) quarks, which are known contributors to *CP* violation in meson decays (see Physics Today, September 2001, page 19). In the experiment, protons that are accelerated to relativistic speeds are smashed into each other about 40 million times per second. The collisions produce, among many things, beauty baryons—made of an up quark, a down quark, and a beauty quark—that quickly decay. Researchers focused on a beauty baryon decay channel that has four decay products: a proton, a kaon, and two pions, as shown in the figure.

It took tens of thousands of decay events, measured during two LHC runs



PROTON–PROTON COLLISIONS at the Large Hadron Collider beauty (LHCb) experiment produce the beauty baryon shown here, composed of an up quark, down quark, and beauty (also known as bottom) quark. Measurements of the decay of that baryon and its antimatter counterpart have produced the first observation of *CP*, charge conjugation and parity, violation in particles composed of three quarks. (Image adapted from LHCb Collaboration, *Nature* **643**, 1223, 2025.)

(at 7–8 TeV from 2011–12 and at 13 TeV from 2015–18), to home in on a reliable measure of *CP* violation in the baryons. Baryons and antibaryons are produced at slightly different rates, and the rate difference was corrected for in the analysis. Because the detector is made of matter, it also has a higher detection efficiency, which was accounted for as well, for matter than for antimatter. The researchers found that the beauty baryon decay rate was higher than that of its antibaryon counterpart: The relative difference of about 2.5% agrees with, and provides a more precise number than, existing theory.

Don Lincoln, a senior scientist at Fermilab and member of the Compact Muon Solenoid (CMS) collaboration, says he expects that researchers at other CERN experiments, such as CMS or ATLAS, will look to their own data to validate the result. Though the latest observation hasn't solved the mystery of matter–antimatter asymmetry, it does offer clues for where to look. Another next step will be to focus on intermediate processes in the baryon decay chain for which the observed *CP* violation is even greater, as high as 5.4%, than it is for the entire decay chain. (LHCb Collaboration, *Nature* **643**, 1223, 2025.)

Laura Fattaruso

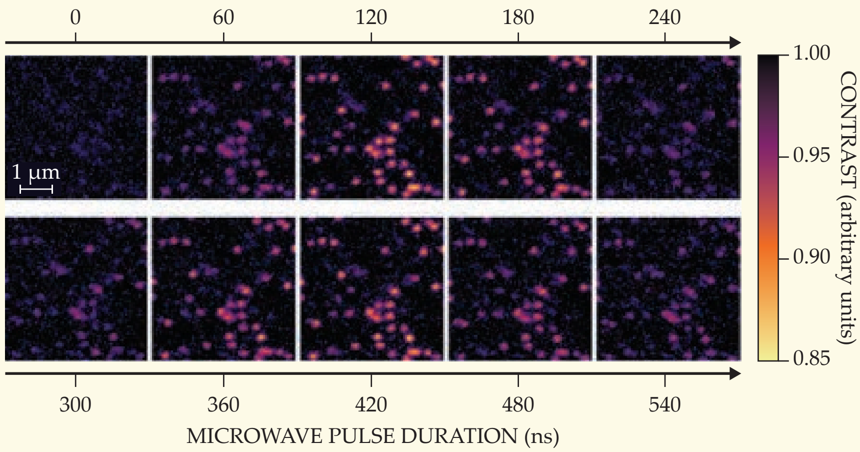
Diamond-defect clusters are measured with speed and precision

The improvement in measuring nitrogen–vacancy quantum sensors could make them more useful for observing correlated condensed matter, biological systems, and more.

In a crystal of diamond, the combination of a nitrogen atom and a nearby empty lattice site forms a nitrogen–vacancy (NV) center. NV centers are point defects that behave like tiny, atomic-scale magnetometers. Because of their sensitivity to magnetic fields, electric fields, temperature, and even strain, NV centers are useful quantum sensors for measuring surface chemistry, subcellular temperatures, and various other properties. (See the article by Lilian Childress, Ronald Walsworth, and Mikhail Lukin, Physics Today, October 2014, page 38.)

Optical measurements of an NV center's electronic and magnetic states offer nanoscale spatial resolution, but they show what's happening at only one location. Individual NV centers can be measured sequentially to cover a larger area, but that approach is slow and can't show what's happening in multiple locations at the same time. Alternatively, groups of many NV centers are measurable simultaneously, but signal averaging limits the spatial resolution.

Now researchers have combined the imaging benefits of single and multiple NV centers in one experimental platform, without each approach's limitations. Two independent groups—one led by Shimon Kolkowitz of the University of California, Berkeley, and the other by Nathalie de Leon of Princeton University—controlled and measured dozens of NV centers simultaneously. The parallel observations from multiple NV centers have the point-like precision of previous measurements of single NV centers.



THE BRIGHT SPOTS in each panel show fluorescing nitrogen–vacancy (NV) centers over time. Two research groups each controlled dozens of NV centers in parallel and obtained spatially and temporally precise images of them with high-sensitivity cameras. (Image adapted from K.-H. Cheng et al., *Phys. Rev. X* **15**, 031014, 2025.)

In neutral-atom quantum computing, dozens or hundreds of qubits are observed simultaneously. To make the observations, researchers have recently developed arrays of optical tweezers, in which each tweezer traps a single atom or molecule. Then a high-sensitivity camera can image the atoms or molecules in parallel by precisely counting the photons generated by the molecules' or atoms' fluorescence. Both Kolkowitz and de Leon, working with their collaborators, reasoned that a similar approach could work in diamond for NV centers. The two groups used the same high-sensitivity cameras for NV center readout and then added specialized optical instrumentation that controls the NV centers and manipulates their charge and spin states.

The speedy, simultaneous, and high-resolution measurements of dozens to hundreds of NV centers allow for the study of how one NV center's state may be correlated with another's. The investigation of temporally and spatially coherent fluctuations could be useful in studying noise or other stochastic properties in superconducting materials, for example. The new capability could also be useful for observing single biological molecules *in vivo* and measuring their chemical and dynamical interactions. (M. Cambria et al., *Phys. Rev. X* **15**, 031015, 2025; K.-H. Cheng et al., *Phys. Rev. X* **15**, 031014, 2025.)

Alex Lopatka PT

French space companies come to Texas for a startup accelerator program

Seeking to attract new ideas, the Rice University initiative introduces French space startups to the US commercial space market.

REPRESENTATIVES FROM FRENCH STARTUPS in the Texas–France space accelerator inaugural class visit NASA's Johnson Space Center in Houston, Texas, in April. (Photo by David Alexander.)

For many years, collaborating with other countries to bolster space technology was the job of governments. But today, space companies do most technology development. Forging international partnerships between businesses is tricky; for one, US trade laws closely control imports of space technology because of its potential link to military activities.

Rice University launched a new initiative this spring to address that key challenge. It paired up with Business France and CNES, France's national space agency, to create a six-month accelerator program that is familiarizing French space startups with the US market.

"There are really good ideas out there that may help the US space industry do things cheaper or better or more quickly," says David Alexander, the Rice Space Institute director and professor of physics and astronomy who coleads the accelerator program. He wants Rice to become a jumping-off point for international startups—not only from France but also from Germany, Mexico, Japan, and other countries—looking to enter the US commercial space ecosystem.

Gaining a foothold

The inaugural class of four French startup companies arrived in April. Each focuses on one of the following areas: satellite-based methane detection, software innovation, green propulsion, and power electronics. The four companies spent the first six weeks in Paris with Business France discussing US markets and business development. They then traveled to Houston to refine their sales pitch for a US audience and to network with Texas-based space companies over three months. During the final six weeks, they returned to France to consider the legal, customs, and human resources needs and intellectual property rights for their companies.

French participant Agena Space makes nontoxic liquid propellants for small commercial satellites. Alexander says that the company's technologies could one day help with in-space service assembly and manufacturing, one of the most challenging and important space technology areas for development. For instance, components of a space habitat could be launched separately and assembled in space. The program also aims to support R&D for lunar exploration and long-duration crewed missions.

Frédéric Rossi, Business France's regional director for North America, says the accelerator saves French startups time and money by introducing them to high-level industry contacts through the Rice Space Institute. Agena Space's chief commercial and business development officer, Jean-François Fenech, says it would have taken more time and been more difficult to make new connections with US companies without the accelerator, even though the US market size for small satellites is about twice as large as Europe's. Through the program, he found additional people interested in learning more about Agena's products.

A successful pitch meeting by a French startup could lead to holding follow-up meetings with an interested customer, signing a nondisclosure agreement, and beginning a collaboration, says Alexander. Foreign companies cannot compete for US government contracts, but their technology could be procured by a US-based company doing government work. Many US space companies have a presence in Texas, including well-established businesses like SpaceX, Boeing, and Lockheed Martin and high-market-value newcomers like Axiom Space and Firefly Aerospace.

The program has been relatively immune to recent US policy changes. The Texas–France space hub is fully funded by the French through a combination of private and government funds; no US government funding was used for the program. France is a member of the US visa waiver program, and there have been no disruptions to visa access this year, says Rossi.

International collaboration

This isn't the first accelerator held in Houston for international space companies. Six Italian startups visited the city for five weeks in 2023. The Space Foundation, a nonprofit advocacy organization for the space industry, partnered with the Italian Trade Agency and the Italian Space Agency to organize the program. One company that participated, Involve Space, has since expanded to the Houston area. It conducted its first stratospheric balloon launch in January.

Kelli Kedis Ogborn, the Space Foundation's vice president of space commerce and entrepreneurship, says the nonprofit organizations and universities that set up the programs are key players. The organizations have access to high-quality, credible information about technology and policy, and they can act as a neutral third party connecting commercial players.

Alexander doesn't see the program as a threat to US businesses. A US-based company offering better or cheaper technology will still outcompete a foreign competitor, he says. He hopes that the initiative will "bring in a different set of ideas." Rice's second accelerator class will arrive in the fall, with funding being renewed annually for the next three years.

US startups could one day travel to France through a reciprocal program to pitch European space industries, says Hugues Mbezal Bogam, the Rice Space Institute's space liaison with France. "We strongly see that having a more diverse and more dynamic industry will foster the development of the commercial space market," he says.

Jenessa Duncombe

A SMALL SATELLITE PROPULSION SYSTEM orbits above Earth in this illustration from Agena Space, a French company that is developing nontoxic liquid propellants. (Image from Agena Space.)

A crowdsourced database tracks US science grant cancellations

Increasing transparency and informing advocacy and litigation efforts are the main goals of the online resource, which monitors the status of funds awarded by NSF and NIH.

In the spring, NSF began canceling some previously awarded grants. The cuts targeted research in diversity, equity, and inclusion initiatives; environmental justice; and misinformation. Separately, the Trump administration froze federal funding at several large US research universities. Court challenges and settlements have since reinstated some grants, which has led to an evolving patchwork of federal science cuts. The cancellations and reinstatements can now be seen in one place with the online tracker Grant Witness.

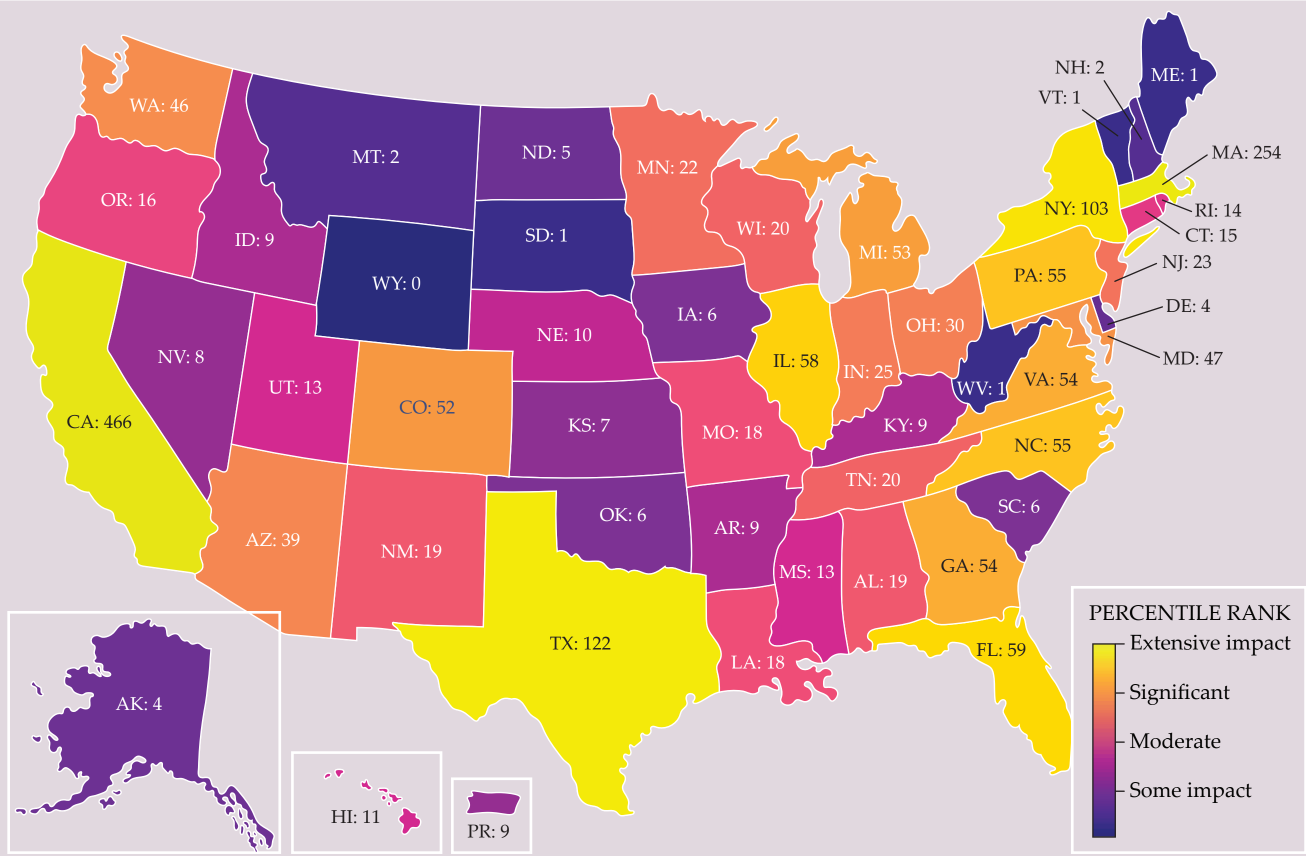
Noam Ross, a computational researcher and executive director at the nonprofit rOpenSci, and Scott Delaney, a Harvard University social and environmental epidemiologist, launched the tracker in March to track National Institutes of Health grant cancellations. NIH had posted conflicting information about the extent of the cuts, says Ross, so he and Delaney started collecting a list of grants through submissions from affected principal investigators, court filings, and official lists when available. The two researchers vetted submissions by comparing them with publicly available federal award identification numbers and the government's spending database tool, USAspending.gov. The tracker was originally called Grant Watch, but the pair renamed it Grant Witness in July for trademark reasons.

Grant Witness began tracking NSF grants in April when the agency announced the first round of cuts. A small group of organizers helps Ross and Delaney regularly update the lists to reflect new cancellations or reinstatements. Ross has spent about $100 out of pocket to host the website, and the group received a small grant from the Alfred P. Sloan Foundation to fund one person for a few hours a week. All other organizers volunteer their time. Ross says the group is seeking more funding to support the work.

The cuts hit home for the Grant Witness team in May: Delaney's grants were terminated when the administration canceled all NIH funding to Harvard. Delaney says he expects to lose his job at Harvard as a result.

Grant cancellations by the numbers

As of 29 August, the database lists 1552 canceled NSF grants across all disciplines. In many cases, awardees have already received a portion of their funding. The cumulative remaining value of the canceled grants is about $860 million, according to Grant Witness.



A MAP OF NSF GRANT IMPACTS by state, created from Grant Witness data, reveals the hot spots nationwide as of 29 August. The numbers and colors indicate the total number of grants impacted, including canceled and possibly reinstated grants. (Image courtesy of Grant Witness.)

Another 417 NSF grants are labeled in the database as "possibly reinstated." Those funds have been restored by successful appeals, university settlements with the federal government, or court orders, such as the preliminary injunction in June that temporarily restored terminated grants for diversity, equity, and inclusion research across the University of California system. Grant Witness does not label a grant "fully reinstated" until organizers receive proof from principal investigators or through USAspending.gov of returned money flow, says Ross. "Frankly, we don't believe it until we see it," he says.

Physics and astronomy divisions in NSF's Directorate for Mathematical and Physical Sciences (MPS) have been affected by the cuts. Twenty-nine grants were canceled and 17 marked as "possibly reinstated" as of 29 August. Among those canceled are an astrophysics education program for American Indian and Alaska Native scientists at the University of Minnesota Twin Cities and an initiative to mentor and train new physical scientists across nine universities.

Twenty of the canceled grants supported physics and astronomy studies at Harvard, including research on supernovae, quantum nanophotonics systems, and miniaturized chemical computing devices. Sixteen physics and astronomy grants at the University of California, Los Angeles, were marked as "possibly reinstated" in August after a federal judge ordered the administration to unfreeze the school's nearly 800 affected science grants. (The Justice Department froze the grants in July after alleging that the university violated antidiscrimination statutes.)

Compared with other divisions in the MPS, the cuts to physics and astronomy are on par with those to chemistry, which has had 31 total grants affected, and materials research, at 26, but they are smaller than the cuts to mathematical sciences at 88. The MPS's total of 196 pales in comparison with the 805 grants affected in the Directorate for STEM Education.

Information as power

Other trackers have cropped up too. Users can browse federal layoffs, terminations to contracts and leases, hiring freezes, and other cuts on the Impact Map, an initiative by the private company Public Service Ventures. International student visa revocations were tracked in April by the publication *Inside Higher Ed*, and a list of federal actions to scale back climate regulations is updated regularly by Columbia Law School. Unbreaking, a volunteer-run project affiliated with the nonprofit Raft Foundation, hosts a tracker of trackers.

Providing accessible and transparent data for public advocacy and litigation is the main goal of Grant Witness, says Ross. The tracker has been used in evidence in five lawsuits and to prep speakers for congressional testimony. Ross says Grant Witness served as the inspiration for a campaign to publish op-eds in every state to highlight the impacts of cuts on local communities.

Jenessa Duncombe

Nobel laureates issue declaration for the prevention of nuclear war

They outline measures that world leaders, scientists, and the public can take to reduce the threat.

Nuclear weapons have been used in warfare twice: on 6 August and 9 August 1945, when the US dropped the Little Boy and Fat Man atomic bombs, respectively, on Hiroshima and Nagasaki in Japan. An estimated 110 000 to 210 000 people died from the explosions, and untold more were sickened. Since then, nuclear-armed states have threatened to use their bombs and justified maintaining or growing their arsenals as being necessary for deterring others from using nuclear weapons.

But 80 years later, security experts caution that the risk of nuclear weapons being used is as high as it's ever been. The US and Russia, which combined hold nearly 90% of the world's nuclear weapons, are building devices with new capabilities. No talks are in sight about a follow-on to the US–Russia New Strategic Arms Reduction Treaty (New START), the last remaining bilateral constraint on nuclear weapons, which is set to expire on 5 February 2026. China is expanding its nuclear arsenal. The six other nuclear-armed states—France, India, Israel, North Korea, Pakistan, and the UK—are updating and in some cases growing theirs.

To brainstorm what to do about the growing threat of nuclear weapons use, Nobelists, nuclear weapons experts, activists, and academics gathered for the Nobel Laureate Assembly for the Prevention of Nuclear War at the University of Chicago in July. They issued a declaration with more than a dozen recommendations to reduce the nuclear threat. As of press time, 129 Nobel Prize winners (including 39 in physics) and 44 nuclear experts had signed the declaration.

The recommendations include calls for

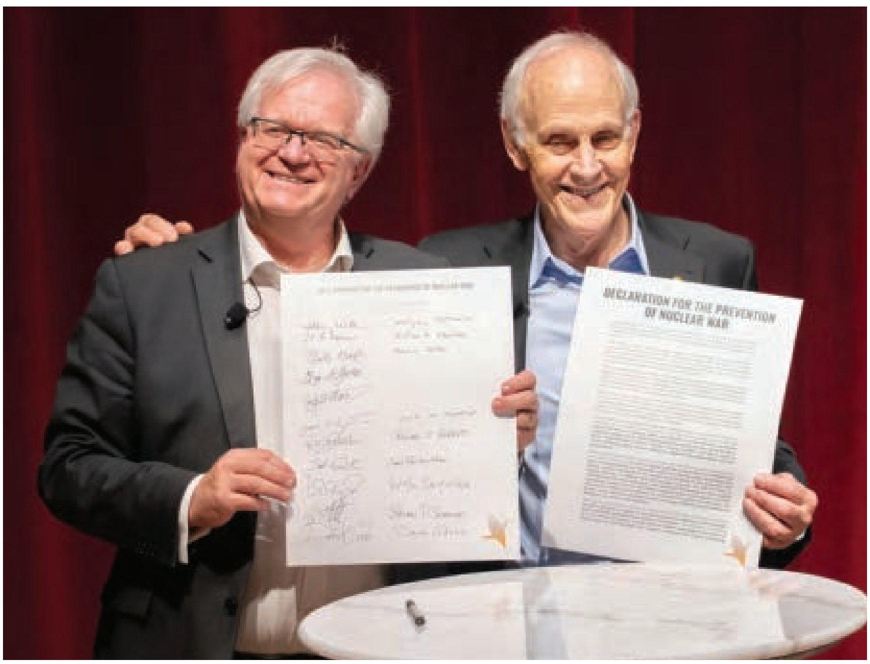
- All nations to publicly recommit to nonproliferation and disarmament objectives.
- Russia and the US to immediately enter into negotiations on a successor treaty to New START.
- China, Russia, and the US to forgo massive investments in strategic missile defense.
- All nations to reaffirm that no nuclear weapons will be stationed in outer space.
- Nuclear-armed states to ensure that at least two people are involved in decisions about the use of nuclear force.
- Scientists, academics, civil society, and communities of faith to pressure global leaders to implement nuclear risk-reduction measures.

Theoretical physicist Karen Hallberg, the secretary general of the Pugwash Conferences on Science and World Affairs and a member of the organizing committee for the July meeting, says the declaration lists "urgent and realistic actions" to reduce the increasing threat posed by weapons of mass destruction. Still, she says, "we must always remember that the only way to avoid a massive human and ecological tragedy is by the total elimination of nuclear weapons." (See also the interview with Hallberg in Physics Today, February 2025, page 26.)

The Nobel laureates are not the only group to speak out around the 80th anniversary of the start of the Atomic Age. The scientific advisory group for the United Nations Treaty on the Prohibition of Nuclear Weapons consists of 15 experts from around the world. In a 6 August statement, the group writes that "humanity today faces a renewed and growing danger from the nuclear arsenals and policies of the nine nuclear armed states and their allies. Nuclear weapons treaties have failed to enter into force, not been complied with, or been rejected altogether."

Zia Mian, co-chair of the advisory group and a nuclear disarmament scholar at Princeton University, says that there appears to be an "increasing willingness among nuclear weapons states to make threats, not for deterrence but as a tool of coercion."

Another concern, says Curtis Asplund, a San José State University theoretical physicist who studies the role of physicists in nuclear disarmament, is the possible integration of AI and other new technologies. "It's a short chain of steps from detection to nuclear catastrophe. Injecting new technologies into any step—targeting, detection, communication—



NOBEL PRIZE–WINNING PHYSICISTS Brian Schmidt (left) and David Gross (right), along with University of Chicago physicist Daniel Holz, first floated the idea for the recent gathering to address the increased risk of nuclear weapons use. Schmidt and Gross pose with the resulting declaration. (Photo by Jean Lachat.)

ATTENDEES AT THE NOBEL LAUREATE ASSEMBLY FOR THE PREVENTION OF NUCLEAR WAR gather by *Nuclear Energy*, Henry Moore's sculpture at the University of Chicago on the site of the world's first human-made self-sustaining nuclear reactor. (Photo by Jean Lachat.)

could dramatically increase the risk of nuclear use."

"Part of the scientific community's role," Asplund says, "is to maintain and strengthen connections with colleagues in other countries for our mutual benefit and survival." (See also "Science academies encourage G7 leaders to prioritize nuclear arms control," PHYSICS TODAY, 12 June 2024.)

Manpreet Sethi, a distinguished fellow at the Centre for Air Power Studies in New Delhi, India, writes in a 5 August column for the nonprofit think tank BASIC (British American Security Information Council) about the Nobel recommendations, "Even if one or two leaders of our times could heed the call of this declaration, it could turn the tide before we run out of time and luck."

Toni Feder

Q&A: Quantum computing researcher Matthias Troyer on his move from academia to industry

INTERNATIONAL YEAR OF
Quantum Science
and Technology

The main mindset change, he says, is the focus on making things work rather than on understanding why they don't.

"Combining chemistry and physics with computing is basically the story of my life," says Matthias Troyer, corporate vice president at Microsoft Quantum, where he leads the company's efforts in quantum system architecture, applications, and software.

Troyer earned his PhD at ETH Zürich in 1994 for work on computational approaches to high-temperature superconductors. After a stint as a postdoc in Japan, he joined the faculty at ETH as a professor of computational physics.

For years, Troyer resisted offers from industry. It was, he says, "always a question of, Should I go to a company that is doing computational science and engineering? Or should I stay in academia and continue teaching and writing papers?" Staying in academia was the familiar, easier path, he says. But eventually, in 2016, Microsoft convinced him to join its quantum computing team.

On top of his job at Microsoft, Troyer just completed a turn as president of the Aspen Center for Physics, which hosts physicists for conferences and workshops. He is also on the board of the Washington State Academy of Sciences. In that role, he says, he offers policymakers advice on a broad range of topics, including science policy, economic development, and ecological preservation.

Over the course of his career, says Troyer, his choices have often been met by colleagues with skepticism and warnings. When, in 2011, he started thinking about applications of quantum computers, one colleague scoffed, "You think quantum machines are real." When he left his tenured position at ETH to move to Microsoft, another warned, "You are a traitor. You won't be able to return to academia." But Troyer says he sees himself as a trailblazer who is willing to break from convention. "A leader doesn't just jump on the bandwagon," he says. "A leader dares to head out into the wilderness and do things that nobody else does."

MATTHIAS TROYER (Photo courtesy of Mark Villanueva Contratto/Filmateria.)

PT: How did you get into physics?

TROYER: In high school, I won a gold medal in the International Chemistry Olympiad. But when it came time to choose what I wanted to study, I didn't fully understand quantum mechanics, so I chose physics. When it came to selecting a topic for my master's thesis, there was one where I could use a Cray X-MP supercomputer. It was totally clear that I would go for that topic.

PT: What were your next steps?

TROYER: I started my university studies in Linz, Austria, where I am from, and then moved to ETH Zürich in Switzerland. I got my diploma and PhD there. After the PhD, there was the question, Should I go into banking or stay in physics? I had friends in Japan. Spending two or three years there sounded intriguing and fun. That, combined with Japan having at the time the world's fastest supercomputer, convinced me to go to Tokyo for a postdoc.

Writing codes and implementing new algorithms on the world's fastest machine let me work on interesting physics problems that nobody else could do at the time. The combination of new machines, new algorithms, good codes, and new physics problems led to a breakthrough: I simulated a model with 20 000 quantum spins. Being at that scale enabled me to study phase transitions in quantum systems.

PT: How did you end up back at ETH?

TROYER: I accepted an offer from ETH to build up a new curriculum for computational science. At the university, I could teach and work with industry. I started consulting on the side, about one day a week. I was helping banks and companies, teaching programming techniques to them, writing software for them. It was a nice balance.

PT: Why did you end up moving to Microsoft?

TROYER: In 2004, Microsoft asked me to join its new quantum computing program. They were starting it on the campus of the University of California, Santa Barbara. I decided not to go. I was working in computational quantum physics, developing new algorithms, using them on the latest supercomputers to solve interesting science problems. Why should I leave one of the best tenured positions in the world? Why would I trade an excellent academic team to work there?

But one of my postdocs joined the Microsoft program, and I consulted for it. At some point, I realized that my contact to the corporate setting was giving me interesting scientific questions: What could be the commercial value of a quantum computer? Which companies might be interested in investing in quantum computing? What are the applications? That was in 2011, a time when nobody really worked on those things.

In 2016, Microsoft made me an offer I couldn't refuse.

PT: How did your colleagues react?

TROYER: There were three interesting reactions. When *The New York Times* reported that I was moving, the European Commission complained about US companies poaching Europe's quantum talent. My response was that I was not being poached. Rather, I was taking opportunities that I didn't have in Europe. Academic colleagues told me to be very careful: Why would I give up tenure to go to a company, where you can be fired?

Financially, it was an easy calculation: If the company pays a multiple of the academic salary, and if I have the job for four or five years, I will break even, compared to my lifetime income in academia. The risk didn't seem too high.

The third response came from university presidents. Five of them, in the US and Europe, reached out to tell me that if in the future I wanted a job at a university, I should call them first. That means that while some faculty might consider me a traitor, the academic leadership understands that knowing both industry and academia adds value.

PT: What are the similarities and differences of working in academia and industry?

TROYER: At first, it was surprising that the differences were not that great. For me, the main difference was more one of big science versus small science than academia versus private sector. In big science—on experiments at CERN, for example, or in industry—one is part of a team and thus has less freedom to choose what one will do. At ETH, I had been working with smaller teams.

As we started building quantum computers and hardware, there was a shift from being a research team to being a product team. We still do research, because we are inventing things. But the focus has shifted to making things work. When things don't work, let's not get stuck finding out all the details. Let's jump to something that works. In industry, it's about building products. It's about making devices that work. That is the main mindset shift.

There is more structure in industry. But that helps you become more efficient. My family likes that since I moved to a company, I can take weekends off.

PT: How do you spend your time?

TROYER: As a professor, I was talking to people, helping them understand things, and charting a path forward. As corporate VP and a technical fellow at Microsoft, I am doing the same thing. I use my teaching skills when I talk to politicians, diplomats, business leaders, engineers on my team, graphic designers, and marketing people. The skills of a good professor come in handy.

PT: Can you elaborate on the interesting questions that you found in industry?

TROYER: Early on, there were basically three quantum computing communities: people doing quantum physics in the lab, building quantum devices; people working on the concepts and math behind quantum computers; and people at companies that were getting interested in quantum computing. But you needed someone who could look at applications and see how new hardware or new algorithms could lead to breakthroughs. I realized, "Hey, that's exactly what I've been doing for 20 years!" I have always used the fastest classical computers to look for new algorithms and run them to solve interesting science problems.

With quantum computers, it was the same approach but with theoretically new hardware. Microsoft is developing its own topological qubit and is also building a universal quantum computing platform in partnership with other hardware providers.

PT: Where do you expect quantum computing to have the greatest impact?

TROYER: One area is combining quantum computing with AI. We use AI now to predict the properties of materials and to design them. AI can screen a bigger chemical space and is much faster than the simulations we do. But AI models are never better than the data they train on. And classical simulations are approximate. By refining those models with better data from quantum computers, one can make the models faster and more accurate. Our goal is for generative AI to design materials. That requires quantum computers. The big impact is perhaps five years out. But it's coming.

Toni Feder

Major climate change indicators broke records in 2024

A report authored by hundreds of climate scientists worldwide documents surface temperatures, humidity, glacier mass, and more.

Last year saw the highest air and ocean temperatures on record globally, according to a peer-reviewed report published in August in the *Bulletin of the American Meteorological Society*. The annual *State of the Climate* report, now in its 35th year, pulls data from instruments and monitoring stations around the world on land, water, and ice and from space.

The report is an authoritative reference for scientists to follow the trajectory of the climate system on an annual basis, says former American Meteorological Society president Anjuli Bamzai. (The American Meteorological Society is a member society of the American Institute of Physics, the publisher of Physics Today.) The report does not include analyses of model simulations or address climate impacts or mitigation.

Annual surface air temperatures over the land and ocean in 2024 were 0.63–0.72 °C above the 1991–2020 average, according to the report, the highest since recordkeeping began in the mid 1800s. Although a strong El Niño at the beginning of 2024 helped enhance warming, the last 10 years have been the warmest 10 years on record. Sea surface temperatures were nearly half a degree Celsius higher in 2024 than the 1991–2020 average. The ocean has absorbed approximately 90% of Earth's excess heat from 1971 to 2020.

Last year featured record-breaking humidity as well. On average, a given location experienced about 36 more extremely humid days (days with wet-bulb temperatures 90% above the local normal) than it did annually from 1991–2020. The previous high was 26 days above average in 2023. The higher the wet-bulb temperature, the harder it is for sweat to cool the human body, which can lead to potentially life-threatening conditions.

Glaciers lost more mass than any year since recordkeeping began in 1970, the report says. It was the 37th consecutive year that global glaciers lost more mass than they gained. Venezuela registered the loss of all its glaciers, making it the first country in the Andes to do so.

DARK STORM CLOUDS gather over South Africa, which is among the regions where a new satellite monitoring program began tracking lightning in 2024. The most recent *State of the Climate* report, published in August, highlights last year's climate trends and scientific advancements in Earth monitoring. (Image by Ndumiso Mvelase/Pexels.)

Global averages for sea level height, annual maximum daily rainfall over land, and concentrations of atmospheric carbon dioxide, methane, and nitrous oxide also reached the highest levels ever recorded.

Other documented measures fell short of records in 2024. For example, the mass loss of the Greenland ice sheet was lower than the 2002–23 annual average. The report says that the region was influenced by the Arctic oscillation index's positive phase, which locks colder air over the Arctic and blocks warmer air coming from the south. The number of named global tropical cyclones last year, 82, was below the 1991–2020 annual average of 87.

The report also spotlights scientific advancements. The lightning imaging data from Europe's first Meteosat Third Generation imaging satellite over Europe, Africa, and South America went live last year; lightning strikes can serve as a proxy for tracking extreme weather. And the use of land surface measurements from Europe's Sentinel satellites shows promise for documenting temperature hot spots in areas with few weather stations.

Nearly 600 scientists from universities, forecast centers, and government labs across 58 countries contributed to the report. Several authors and editors who had participated in the report for decades had "retired prematurely and unexpectedly this year," according to the report's acknowledgments. Widespread layoffs have hit US science agencies throughout 2025.

Jenessa Duncombe

Percentage of physics bachelors who begin at two-year colleges remains steady

From 2014 to 2022, the proportion of physics bachelor's degree recipients who started their postsecondary education at two-year colleges remained stable between 13% and 15%, according to a recent report by the statistical research team at the American Institute of Physics (which publishes Physics Today.)

The report features survey responses from those who received their physics bachelor's degrees in the 2020–21 and 2021–22 academic years. The data show that in their initial post-degree outcomes, the students who started at two-year colleges became employed or attended graduate school for physics or astronomy at similar rates to those who did not start at two-year colleges. The former were also less likely to attend graduate school in other fields and more likely to report being unemployed.

The higher the level of physics a student took in high school, the less likely they were to have started at a two-year college, according to the data. Additionally, bachelor's recipients who started at two-year colleges were more likely to report science literature or a personal hobby as influences for choosing physics as a major, whereas those who did not start at two-year institutions were more likely to cite high school physics classes and participation in science fairs as influences.

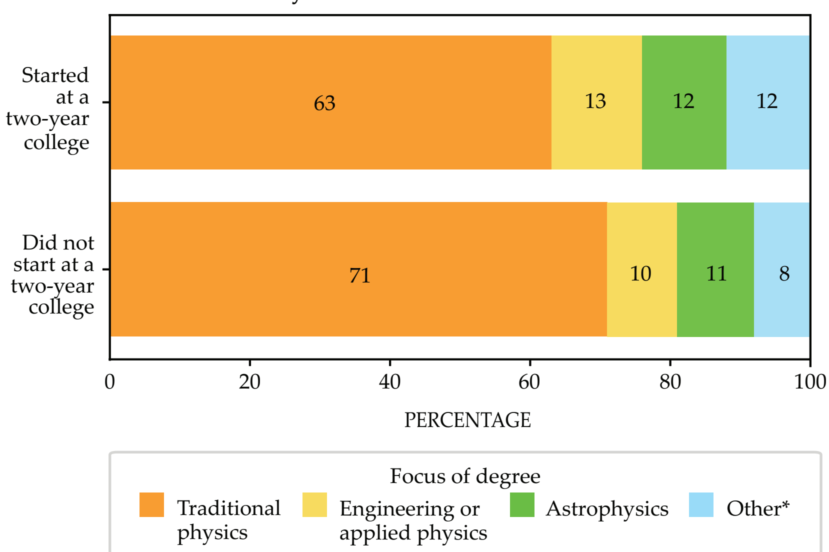
Physics bachelor's degree recipients who started at two-year colleges were more likely to choose a focus within the major, such as teaching, biophysics, or computational physics, than those who began their postsecondary education at four-year institutions. Even so, the majority in both groups earned a traditional physics degree (see graphs). Those who started at two-year colleges also tended to be older when they received their bachelor's degree: Their median age was 24, compared with 22 for those who started at four-year institutions.

More than half the degree recipients reported entering the workforce after graduation.

Those and other data are available at https://www.aip.org/statistics/physics-bachelors-two-year-colleges-as-a-starting-point.

Tonya Gary

Focus of physics bachelor's recipients for academic years 2020–21 and 2021–22 combined



(*High school physics teaching, biophysics, computational physics, and other fields.)

(Figure adapted from J. Pold, P. Mulvey, *Physics Bachelors: Two-Year Colleges as a Starting Point*, American Institute of Physics, 2025.)

FYI SCIENCE POLICY BRIEFS

Trump gives political appointees final say on grants

President Trump signed an executive order in August that will give political appointees ultimate decision-making power over grants and will require them to align all awards with presidential priorities, including policies on race and gender, indirect cost rates, and compliance with "gold standard science." The order also blocks agencies from issuing new funding opportunities until they implement grant-review processes that meet the requirements.

Critics of the order, including Zoe Lofgren (D-CA), the ranking member on the House Committee on Science, Space, and Technology, argue that it opens the door to bias in the grant-review process and will lead to projects being selected or rejected based on appointees' personal interests rather than on merit. A White House spokesperson said that the order "restores merit-based grantmaking" and that the administration "is committed to ending wasteful grants."

The Trump administration's goal for the order is to root out funding for "anti-American ideologies," which alludes to a report from Ted Cruz (R-TX), chair of the Senate Committee on Commerce, Science, and Transportation. The October 2024 report used keyword searches of NSF grants to determine that more than a quarter of new grants went to projects that "pushed far-left perspectives" on status, social justice, gender, race, and environmental justice. Minority staff on the House Science Committee issued a rebuttal report in April that criticized Cruz's methodology.

The order also requires agency heads and the White House Office of Management and Budget to ensure that all new grants—and existing ones whenever possible—can be terminated for convenience, with a few exceptions. —CZ

NSF and Nvidia to partner on scientific AI models

NSF announced a partnership in August with technology company Nvidia to develop open-source AI models that are trained on scientific data and literature. The project, called the Open Multimodal AI Infrastructure to Accelerate Science, is led by the nonprofit Allen Institute for Artificial Intelligence. NSF will contribute $75 million to the project through its midscale research infrastructure program, and Nvidia will contribute $77 million.

The program aims to increase researcher access to AI, according to a press release, given that "the cost of creating and researching powerful AI models has grown beyond the budgets of university labs and federally funded researchers." The project will also include a development program to build an AI-ready workforce and to "expand participation and expertise beyond traditional tech hubs." —CZ

NSF board elects new leaders

The National Science Board elected chemist Victor McCrary as its official chair and particle physicist Aaron Dominguez as its vice chair in July. McCrary, vice president for research at the University of the District of Columbia, had served as vice chair of the board since 2020, and he became acting chair earlier this year when Darío Gil stepped down after being nominated to the top science job in the Department of Energy. Dominguez joined the board in 2020 and is executive vice president and provost at the Catholic University of America.

The board's main functions are to oversee NSF and to provide advice to the president and Congress on science and technology policy. Among the board's current priorities that McCrary and Dominguez will continue is developing domestic STEM talent, according to the press release announcing the election results. Other priorities are "winning the technology race with China," fostering public–private partnerships, and "championing a reimagined NSF." —HD PT

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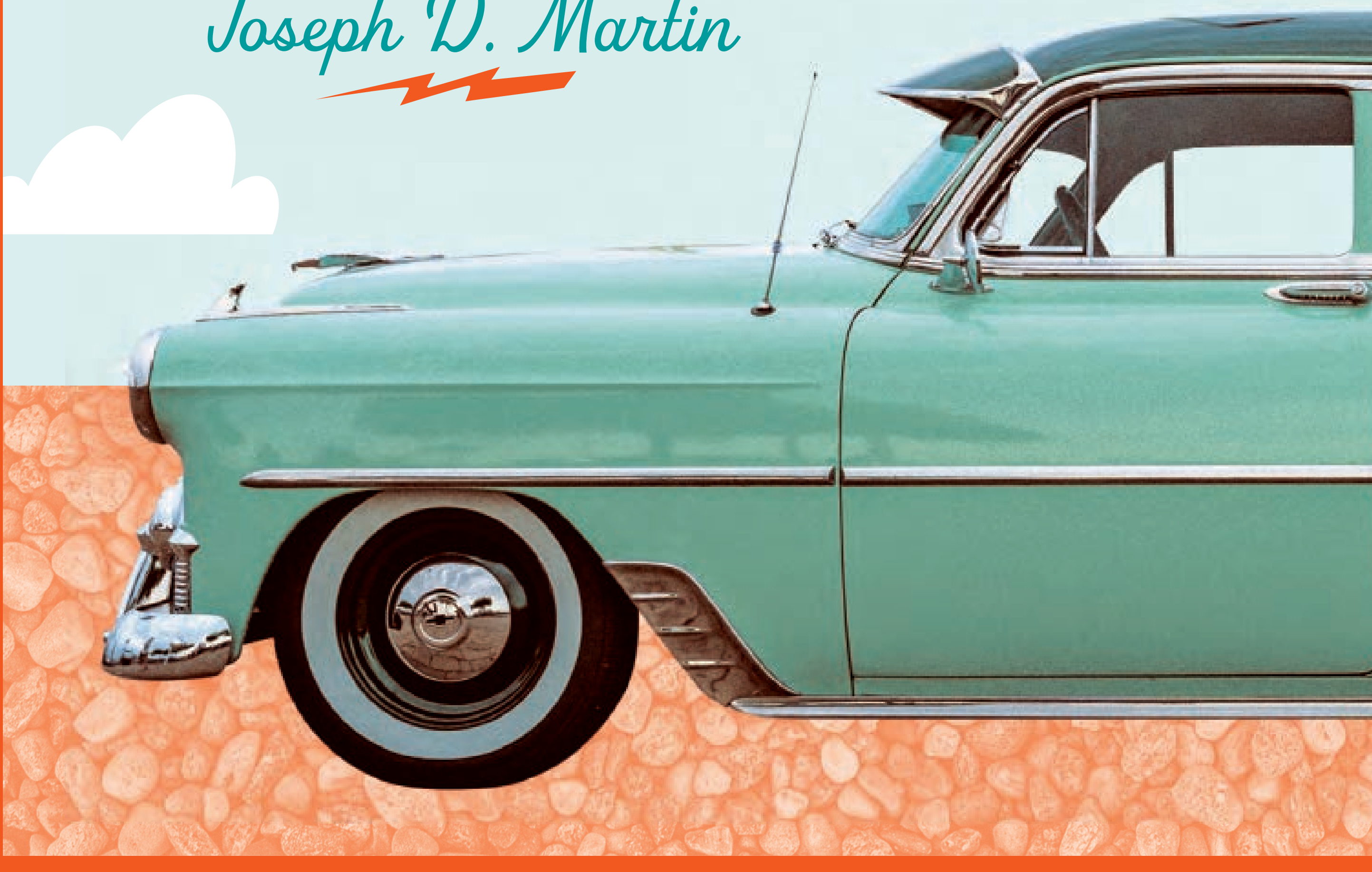
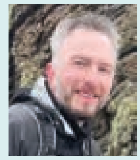
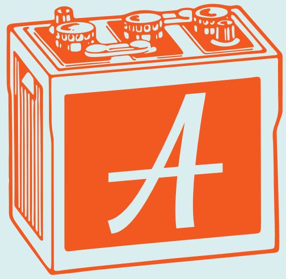
POLITICAL CURRENTS

Joseph D. Martin

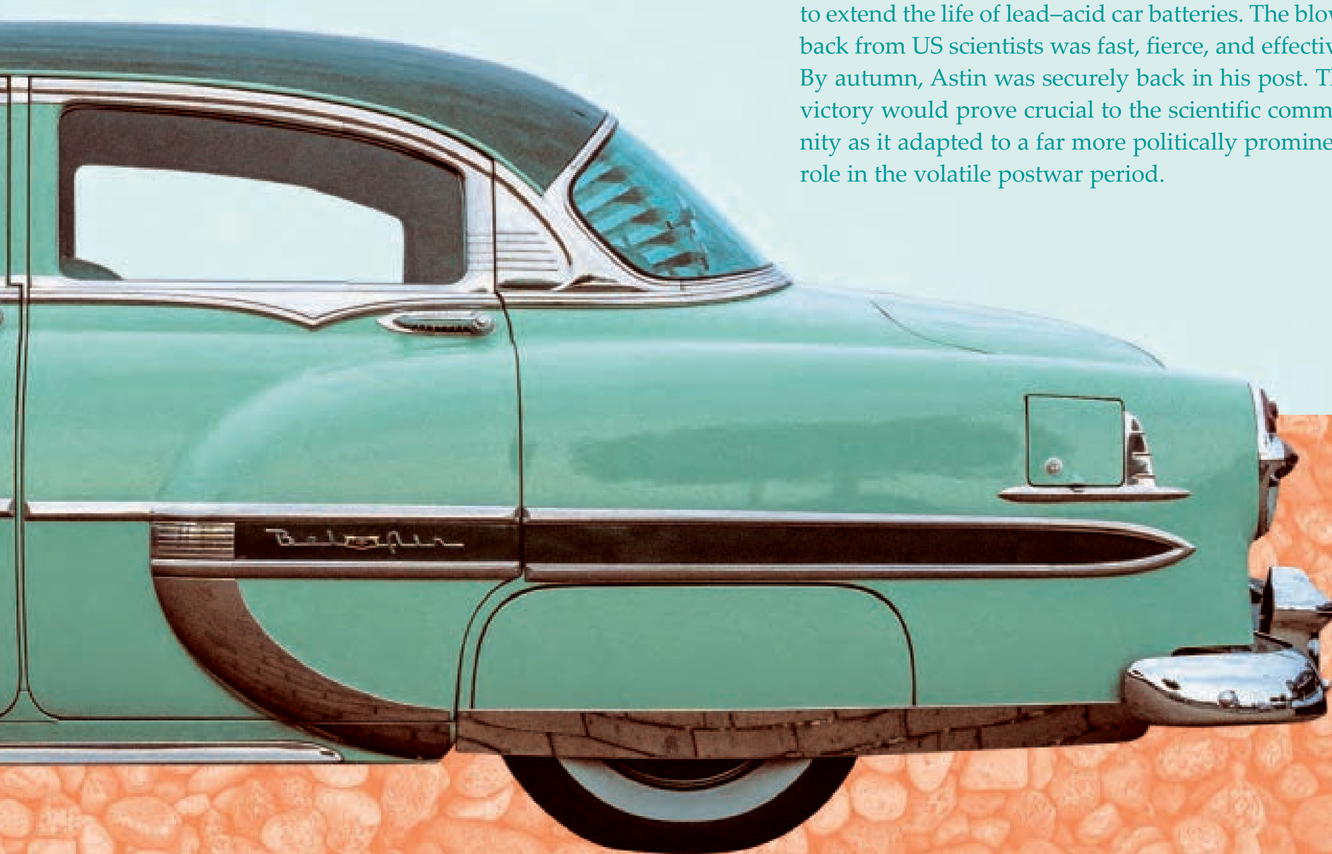



Joseph D. Martin is an associate professor of history of science and technology at Durham University in the UK.

The Eisenhower administration dismissed the director of the National Bureau of Standards in 1953. Suspecting political interference with the agency's research, scientists fought back—and won.



A brash California automobile entrepreneur works the levers of a new presidential administration to advance his interests. Political meddling in research institutions scandalizes US scientists. The intersection of science and politics becomes a cultural battleground. That scene unfolded in spring 1953, when Sinclair Weeks, President Dwight Eisenhower's secretary of commerce, ousted Allen Astin as director of the National Bureau of Standards (NBS), NIST's predecessor. The bureau, Weeks claimed, had acted prejudicially when it tested and condemned AD-X2, an additive intended to extend the life of lead–acid car batteries. The blowback from US scientists was fast, fierce, and effective: By autumn, Astin was securely back in his post. The victory would prove crucial to the scientific community as it adapted to a far more politically prominent role in the volatile postwar period.



(Image adapted from Milos Ruzicka/Shutterstock.com.)

THE COVER OF THE SECOND ISSUE of *The Battery Man* magazine, from October 1921, features a humorous poem that emphasizes the mystery surrounding battery function. (Image courtesy of HathiTrust.)

A 1931 ADVERTISEMENT for the Nu-Life battery additive made extravagant claims about the product's magical effects. (Image from *The Pathfinder: Digest of World Affairs*, 28 February 1931, p. 27.)

That story has gained alarming new relevance in recent months. The current US administration has taken aim at many federal institutions, with scientific research institutions singled out for vicious cuts. One goal appears to be to dismantle the long-standing relationship between science and the US government. The parameters of that relationship were negotiated in the years immediately following World War II, and—perhaps improbably—one of the keys to those negotiations was a controversy over a small packet of salts that blossomed into outsized proportions.

What was AD-X2?

Starting around 1920, battery-powered electrical systems began replacing hand-crank starters in new cars. US motorists soon became well acquainted with battery trouble. In the days before alternators, when DC generators created uneven charging conditions, battery performance was much spottier than it is today. And although early motorists were often keen amateur mechanics, car batteries were widely regarded as mysterious pieces of equipment.

The most prevalent problem was sulfation. The discharge reaction in lead–acid batteries converts active material at both plates into lead sulfate crystals, which form a fine film over the surface of each plate. During charging, those films are converted back into active material: lead at the anode and lead dioxide at the cathode. But poor charging and storage practices can encourage larger, more stubborn crystals to form. Over time, the accumulation of hard lead sulfate crystals increases the internal resistance of a battery and can inhibit it from accepting a charge. Sulfation can gradually degrade a battery until it struggles to deliver sufficient current to start an engine.

Battery dopes, as electrolyte additives were called, were often sold as salves for sulfation. The prevalence of battery trouble, combined with the general mystery surrounding batteries, created a healthy market for those nostrums, which promised magical results. All manner of substances were advertised as being effective sulfation treatments, but the most common involved some mixture of sulfur salts: usually Epsom salt (magnesium sulfate), Glauber's salt (sodium sulfate), or alum (aluminum sulfate).

By 1953, battery dopes were old news. The NBS began testing them in the early 1920s. It issued its first condemnation of them in 1925, a judgment it expanded six years later into a four-page document that it would send to anyone inquiring about battery additives. The bureau's battery experts regarded dopes as the stuff of small-time fraud. When entrepreneur Jess Ritchie began selling Battery AD-X2 in the late 1940s and assays showed it to be a familiar mix of magnesium sulfate and sodium sulfate, they had little reason to regard it any differently.

But compared with the fly-by-night mountebanks who peddled battery dopes through leaflets in the 1920s and 1930s, Ritchie was persistent, well connected, and dedicated to establishing legitimacy for his product. The name AD-X2 evoked high-tech postwar feats like Chuck Yeager's October 1947 supersonic flight in a Bell X-1 experimental plane. Ads for the additive appeared in respected trade publications, and it enjoyed endorsements from established scientists, most notably Merle Randall, whom Ritchie retained as a consultant. Randall was an emeritus chemistry professor from the University of California, Berkeley, and coauthor of a standard textbook on chemical thermodynamics.

When Ritchie became aware of the NBS's blanket condemnation of battery additives, he rose to the fight. AD-X2, he argued, was different. Armed with Randall's endorsement and a thick stack of customer testimonials, he took the fight to Washington, DC, where he pressed his case that his product should be exempted from the bureau's judgment against battery additives. In an attempt to convince them of AD-X2's merit, Ritchie and Randall corresponded with NBS scientists from 1948 to 1952. The bureau tested the product repeatedly, one time in collaboration with Ritchie, but found no effect. Ritchie's happy customers, the NBS team reasoned, were taken in by the fact that the procedures for administering the product—cleaning the posts, topping up and stirring the electrolyte, and charging the battery slowly, among others—were themselves likely to perk up an unresponsive battery. Based on the bureau's tests, the US Post Office Department issued a fraud order in February 1953 that prevented Ritchie's company from conducting business through the mail.

Undeterred, Ritchie pressed his case with renewed energy. He found a sympathetic ear in Weeks, whom Eisenhower had tapped for secretary of commerce shortly after winning the 1952 election. Weeks had been chairman of the board of a company that used, and liked, Ritchie's product. In AD-X2, Weeks saw an opportunity to signal his support for small business. He successfully pressured the postmaster general into suspending the fraud order. But the controversy was far from over.

Firing and mobilization

In late March 1953, two months into the new administration, Astin was called to a meeting with one of Weeks's assistant secretaries and asked to resign. He had yet to meet Weeks in person. Weeks justified Astin's removal on the grounds that the bureau had "not been sufficiently objective" in handling the AD-X2 affair because it ignored "the play of the market place."[1] More broadly, he considered it his prerogative to appoint new leaders at Department of Commerce agencies. "The Bureau of Standards is, I think, my responsibility as long as I hold the office I have," he explained.[2]

US scientists were scandalized. On 31 March 1953—the day that news of Astin's firing broke—the president of the American Physical Society (APS), Enrico Fermi, took a phone call from F. Wheeler Loomis, one of his predecessors. Loomis had learned from the morning papers of Astin's removal and smelled political interference. He asked Fermi to explore the possibility of an APS response, and Fermi agreed.[3]

Loomis's overture to Fermi was part of a large, spontaneous, and rapidly organized pressure campaign that sought to force Weeks to back down. Throughout April and May 1953, members of APS, the American Institute of Physics, the Federation of American Scientists, and many other scientific organizations worked zealously to coordinate a clear and forceful response with the goal of getting Astin reinstated and sending a message to Eisenhower that the independence of scientific institutions needed to be sacrosanct. Doing so required overcoming the reticence of many segments of the scientific

A PORTRAIT OF ALLEN ASTIN on display in NIST's hall of directors.

world—particularly in the physics community—to get deeply involved in politics. As Robert Bacher, one of the members of APS's governing committee, put the problem to Fermi, the physics community's delicate task was to "stay out of politics but protest against injecting political or business considerations in judging scientific merits of a situation."[4]

While the controversy raged, Astin spoke at an APS meeting in Washington, DC, on 1 May 1953. Referring to the controversy only obliquely, he delivered a defense of the role of impartial science in government. (The text of the talk is in the June 1953 issue of Physics Today.) He enumerated standard scientific virtues, such as reliability, objectivity, open communication, and the importance of fundamental research. He emphasized the attributes he considered to be instrumental to the NBS mission, including the maintenance of standards, "romance in precision measurement," and the importance of communicating accessible scientific knowledge to the public.

Astin argued that those virtues were essential for effective public service: "We believe that in order for the National Bureau of Standards to carry out its various functions and activities we must have an alert and competent staff, suitable equipment and facilities, and an environment favorable to scientific investigation and methodology. This environment or climate essentially means the provision of the opportunity to practice the beliefs I have been stating." He needed no reference to the AD-X2 controversy for his subtext to be coruscatingly clear to an APS audience: To maintain the luxury of self-governance, US scientists would have to fight for it.

In an editorial in the June 1953 issue of Physics Today, Gaylord Harnwell, a University of Pennsylvania physicist, was far less circumspect. "The Secretary of Commerce appears to believe that science and politics are miscible in the cauldron of the marketplace," he admonished. The NBS's ability to provide disinterested scientific information relevant to the administration of government affairs, Harnwell said, was threatened by the specter of political interference: "If the administrative location of the Bureau in the Department of Commerce subjects it to commercial pressures inimical to the disinterested rendering of those scientific services which it is uniquely qualified to perform, it should be established as an independent agency."

Pressure built from multiple angles. In addition to pressure from scientific organizations, countless individuals peppered Weeks and Eisenhower with letters and telegrams. Behind the scenes, well-placed scientists implored Weeks to reconsider. Among them were members of the NBS visiting committee, the body established by Congress to oversee the bureau and report directly to the secretary of commerce. At the bureau, morale plummeted. Scores of technical staff threatened to resign on the grounds that Astin's dismissal was an insult to their work. On 17 April, Weeks announced that he would allow Astin to remain in the post while the National Academy of Sciences surveyed the bureau's functions and its conduct while testing AD-X2. Shortly thereafter, the Senate Select Committee on Small Business scheduled hearings on the matter. While the academy's committees deliberated in private, the Senate hearings challenged Astin and the bureau to make their case in public.

THE FRONT AND BACK of a box of Battery AD-X2, which includes directions for properly using the product. (Image from the National Institute of Standards and Technology Digital Collections.)

Lab and field

Testifying before the Senate in June 1953, Astin had difficulty convincing the committee to accept the reasoning that led to his conclusions about AD-X2. The hearings aimed to determine "whether or not agencies of the Government have been fair and just in the treatment of Mr. Ritchie and his product."[5] But government officials' approach to scientific knowledge in the hearings favored AD-X2's supporters. That aided Ritchie's campaign in the political arena and made the NBS's position more challenging.

The lab–field distinction became the biggest sticking point between Astin and the committee. Astin consistently

THE CELEBRATED CARTOONIST HERB BLOCK, in response to the AD-X2 affair, lampooned political reception of scientific tests in the 16 April 1953 issue of *The Washington Post*. (Cartoon © the Herb Block Foundation.)

maintained that a field test would be costly, introduce greater error, and add nothing to the bureau's understanding of AD-X2's effects. But the Republican members of the committee remained convinced that effects invisible in the laboratory might plausibly manifest in the field. They were inclined to trust the know-how of technicians and the wisdom of the market to establish a product's usefulness. That dynamic emerged during an early exchange between Astin and Edward Thye, the Minnesota Republican who chaired the committee:

> Dr. Astin. As nearly as I can determine, the laboratory people, that is, the engineers in the military, wherever they have made evaluations of this, have rejected it. There are some instances of shop technicians who have used the material and liked it.
> The Chairman. They liked it?
> Dr. Astin. And they liked it.
> The Chairman. And they were shop-experienced men.
> Dr. Astin. I can say that they were experienced probably in handling batteries, but I would be skeptical whether they were experienced in evaluating and interpreting data. In other words, I think that the conclusion that they drew that the material was useful might be questioned.
> The Chairman. There you have again, the Bureau of Standards' capacity for evaluating these things against the practical experience of those using the product in actual operation.[6]

Astin struggled to respond to that critique in a way that satisfied skeptical lawmakers. From their commonsense perspective, a definitive test could be conducted only under operating conditions—and something like that sort of test was being conducted in real time by Ritchie's customers, especially those who managed large fleets. Astin, conscious that discerning real effects in the field was no mean feat, struggled to say so without insulting the competence of a whole class of technical workers.

Astin slept on the exchange and tried again to explain his rationale on day two of his testimony:

> Many people think that the laboratory test is a sort of theoretical test and that the field test is a practical test. Now, I believe that the reverse is actually true, because in the laboratory test it is possible to make with much greater accuracy and control the measurements by which the comparisons between the two groups of samples can be compared. In the field test, additional variables are introduced; it is more difficult to make the measurements by which one will evaluate the performance of the two samples, so that from a strictly practical point of view, you can learn more about the effect of an additive in a laboratory test than you can in a field test.[7]

But his reassurances appealed to public trust in the laboratory process—the very thing at issue for some committee members. Astin's testimony illustrates that the NBS's judgment about battery additives in general, and AD-X2 in particular, rested on laboratory tests that were followed by sophisticated statistical analysis of the type only recently adopted for interpreting laboratory work. The results were then placed into context with the long-standing battery-related expertise the bureau had been amassing almost since its inception. In Astin's judgment, those steps collectively sanctioned the conclusion

ALLEN ASTIN (left) and Jess Ritchie shake hands after the former completed two grueling days of Senate testimony in June 1953. (Image from the Associated Press.)

that field tests were superfluous because laboratory tests detected no statistically significant effects that a field test could be designed to look for. It also led to the uncomfortable conclusion that many presumably competent technicians had been duped.

To some senators, that reasoning and its key implication were unsatisfactory. For scientific observers, each layer of argument added additional credibility to the tests, but for skeptical laypeople, each layer offered another opportunity to quibble. Laboratory tests could be faulted for not replicating field conditions and for being conducted on a time scale well short of a battery's lifespan. Statistical analysis methods were new, obscure, and difficult to communicate, which made them rhetorically weak. The bureau's historical expertise could be faulted because it was based on additives other than the one in question. And hard-won practical experience could command credence at least equal to that granted to arcane laboratory procedures.

Furthermore, Thye and his fellow Republicans could not fathom that so many hardheaded businesspeople could have been hoodwinked. "The American businessman is not fooled very often—you can fool him for a little while, but you do not fool him for very long," Thye declared.[8] The idea that thousands of US businessmen were suckers for remaining loyal to an ineffective product was perceived as an insult. "Those who have spent this money buying and rebuying can't be all fools, Doctor," was Thye's refrain during Astin's two days of testimony. Astin repeatedly declined to take the bait.[9] In fact, NBS scientists had postulated many reasons why even experienced users could be seduced into believing the product worked, but Astin would only speak to what he knew for certain.

The senators arguing that Ritchie had been wronged indulged themselves in a certain amount of performative zeal for the wisdom of US businessmen, but the fundamental question of why, if the product did not work, none of its many users had seemed to notice was not itself absurd. Nor was Astin well positioned to respond. He could say only that the answer would require market research, which lay outside the bureau's ambit. The select committee's final report insisted that the question of AD-X2's effectiveness remained unresolved.

For all its material and intellectual resources, the NBS could not provide a knockdown demonstration that AD-X2 was ineffective. Nor could it condemn the additive from first principles because battery science remained a largely empirical discipline.[10] Fundamental electrochemistry was a lively area of research, but by the 1950s, it had largely decoupled from the development, use, and assessment of battery technology. The bureau convinced the scientific community of its conclusions by using statistical reasoning that extrapolated from short-term laboratory tests to infer long-term behavior in the field. But that chain of reasoning was too opaque to gain traction among policymakers.

Political success

"Astin is now a symbol rather than anything else."[11] That was how metallurgist Robert Mehl described the situation to astrophysicist Donald Menzel, his fellow NBS visiting committee member, following a trip to Washington, DC, in May 1953. At the start of the controversy, the visiting committee was not yet convinced that Astin was a good fit as NBS director and contemplated using the brouhaha to install someone the members liked better. But as the political stakes of the controversy became apparent, they, too, lined up in his defense.

Astin's performance in the Senate hearings cemented his symbolic status, which continues today at NIST. Even though he failed to sway skeptical committee members, he projected a consistent image of a dutiful, upright civil servant who was committed to the technical work of his organization and staunchly agnostic about matters outside his expertise. In a context in which the objectivity and integrity of the bureau were called into question, the manifest personal integrity that Astin so successfully projected made him an ideal champion for the independence of scientific institutions.

Although Thye remained skeptical of the NBS's conclusions, he was won over by Astin's apparent decency. As he told Astin at the close of his testimony, "I could accept you as one whom I would like to have as a friend, and that is my sincere inner feeling at this time."[12] Remarkably, even Ritchie met Astin for a warm handshake when the latter concluded his testimony. Things might well have played out differently with a different director. Edward Condon's outspoken liberalism had seen him hounded from the NBS directorship in 1951 amid the Red Scare.[13] But Astin's dispassionate demeanor and subdued personal politics rendered him unthreatening to lawmakers who were otherwise wary of physicists with grand political visions.

Astin's persona was even more crucial for resolving the affair because a political victory would not be won by convincing the government of the bureau's scientific conclusions. In October, the National Academy of Sciences released its reports, which vindicated both the bureau's testing of AD-X2 and its conduct as a government laboratory. Weeks agreed that Astin should stay on; he would serve as NBS director until his retirement in 1969. But at about the same time, the post office announced that it could not prove that Ritchie intended to deceive customers. Citing the select committee's view that the question of AD-X2's efficacy remained open, it vacated the fraud order against his company. Ritchie declared that he would "pour this material in every battery in the United States."[14]

The ultimate success of Astin and the scientific community was not based on the strength of their factual claims. Theirs was a political and institutional victory. It was a consequence of their focused, coordinated, and untiring efforts to mobilize and defend scientists' authority over scientific institutions. Scientists' efforts to shape the politics of nuclear weapons, such as calls for international control from the likes of J. Robert Oppenheimer and Leo Szilard, had been largely rebuffed. The first Republican administration in two decades left the federal commitment to science uncertain. In that context, the fight over the NBS was a negotiation of the terms on which government science would be conducted.

As a result of that negotiation, federal scientific institutions in the US have, for the past seven decades, enjoyed a great degree of autonomy. The AD-X2 controversy did show the scientific community its limits, as well as its power, as a political bloc, and in subsequent years, the bureau and other government agencies would face further pressure to bend with the political winds.[15] But at the same time, government science remained independent enough to become an increasingly attractive career path. And federally supported research positioned itself as a powerful engine of basic research, technological development, medical advances, and economic growth.

The attack that the federal scientific system now faces is far fiercer than the one mounted by the Eisenhower administration. But the lesson to be drawn from the slant rhyme of history is that the facts alone are insufficient defense against political assault. Astin and his colleagues recognized that governments rely on scientific advice, whether or not they accept scientists' judgment on specific issues. The work of the NBS, and NIST today, was and remains essential to the smooth functioning of the economy. Other government institutions perform similarly vital functions. That is both a reason to value their independence and a basis for mobilizing to defend it. But successfully defending institutions requires the will among scientists—who often seek to stay aloof from politics—to get political.

Many thanks to the referees for attention and insight that improved this piece, which is adapted in part from the article "Acid test: The AD-X2 affair and the political awakening of American science," American Quarterly **77**, *481 (2025).*

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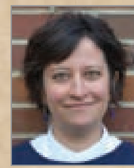
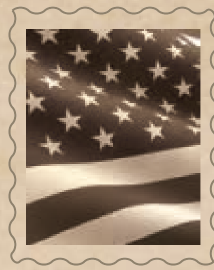
US and Soviet seismologists informally gather in Moscow in 1982 during a project facilitated by the US–Soviet environmental agreement. (Photo courtesy of Alexander Ponomarev and David Simpson.)

Anna Doel is a historian of science at the American Institute of Physics in College Park, Maryland. She studies intellectual communication during the Cold War through oral histories and other historical materials.





The successes and challenges of US–Soviet scientific communication

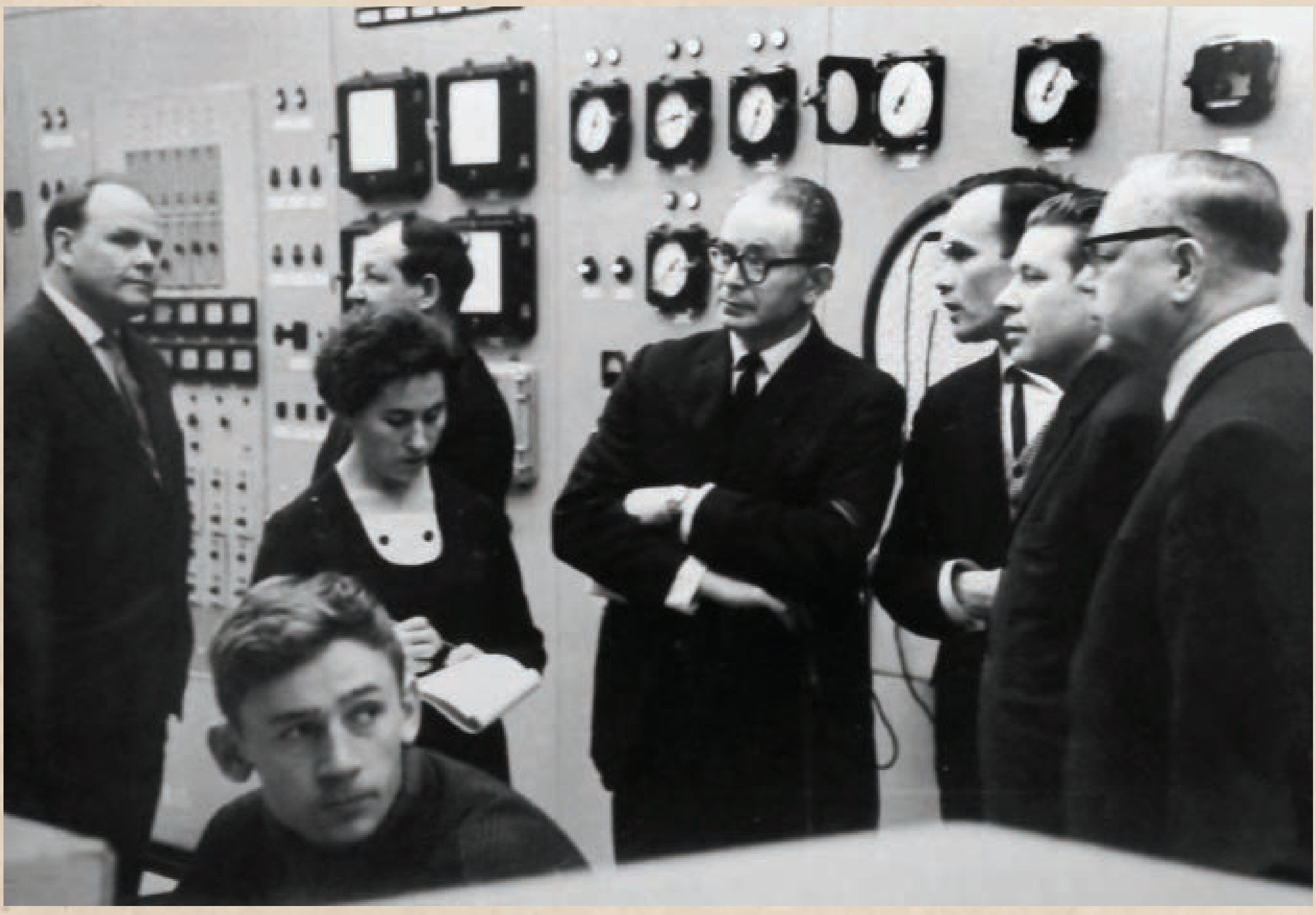
Anna Doel

Research exchanges between US and Soviet scientists during the second half of the 20th century may be instructive for navigating today's debates on scientific collaboration.

I've given many talks in the past 10 years about the history of academic exchanges and collaborative research between the US and the USSR. Often, at least one audience member, usually a scientist, shares personal recollections with me. When I mentioned my research to a young postdoc, she said that her father, a plasma physicist, had participated in the exchanges and that stories about his trips to the USSR had become family lore. Hundreds of researchers from various disciplines—including high-energy physics, mathematics, Earth sciences, and astronomy—have shared memories of exchanges in conversations, oral histories, memoirs, photographs, and archival records. (To learn about one US–Soviet radio astronomy collaboration, see the recent PHYSICS TODAY article "From radio with love: A Cold War astronomical collaboration" by Rebecca Charbonneau.)

Launched in the late 1950s, a state-approved, academy-administered exchange program brought US and Soviet scientists face-to-face. It continued to evolve with the times and survived several crises in bilateral diplomatic relations, proxy wars, scattered budget cuts, the collapse of the Soviet government, and the sociopolitical upheaval of the Russian "wild nineties."

Despite the longevity of the exchange program, many factors stood in the way of collaboration: ideological differences, mistrust, profound disagreements, and prejudices, among others. Polarization of opinions and calls for a reduction or cessation of exchanges emerged more than once in the scientific communities of both countries. The most productive decades of the US–USSR scientific exchanges and collaborations, the 1970s and 1980s, also



HERBERT ISBIN (center), a nuclear scientist who worked primarily at the University of Minnesota, visits a Soviet atomic power station in the city of Voronezh in 1966 with academician Victor Spitsyn (far left). (Photo courtesy of the University of Minnesota Archives, University of Minnesota Twin Cities.)

Frank Press, a geophysicist and an adviser to four US presidents, helped lead the development of science exchange programs between the US and USSR. As he recalled in an interview,

> I had a Russian friend, Professor V. I. Keilis-Borok—Volodya we called him—who I wrote several papers with. And he introduced me to one of the world's great mathematicians, a man named [Izrail Moiseevich] Gelfand. They introduced me to a lot of techniques in computer learning and prediction that I used subsequently in my other work. I learned that technique from them. That was a very valuable contribution.[17]

(Photograph by T. Polumbaum, courtesy of the AIP Emilio Segrè Visual Archives.)

included heated discussions in the US scientific community over the USSR's invasion of Afghanistan in 1979. Those debates resemble, in some ways, the current ones of whether to expel Russian scientists from the global professional community because of Russia's aggression in the mid 2010s toward Ukraine and the more recent 2022 invasion.

Beginning of an era

At the onset of the Cold War, scientific dialogue between US and Soviet academic communities was scarce. To arrange a consultation with a Soviet colleague on the other side of the Iron Curtain, a US scientist first had to identify a potential match. One of the few means of doing so was to study Soviet scientific publications in the library. A book and journal circulation program between university and research libraries began in the mid 1950s.[1]

Once a collaborator was found, the university, the State Department, the colleague's respective employer, and the Soviet state authority all had to approve of the rendezvous. Correspondence by intercontinental mail could take months, and the response did not necessarily come back positive. At any stage, the process could be stonewalled because of suspicions of intellectual espionage or fear of fraternization with the enemy and defection. Furthermore, national airlines didn't always fly to the cities where professional meetings were held, and entry visas were not necessarily issued for visits by nondiplomatic personnel.

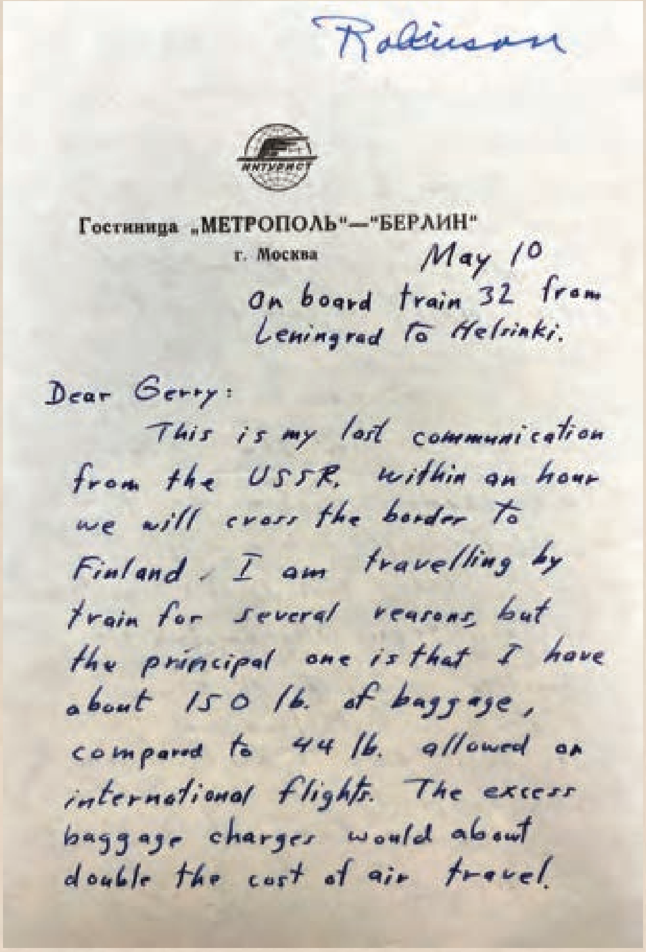
After Joseph Stalin's death in 1953 and Nikita Khrushchev's rise to power, political repression and censorship in the USSR were reduced. In scientific fields, Soviet experts joined international unions, and the USSR participated in the International Geophysical Year, which took place from July 1957 to December 1958.[2] (See the article by Fae Korsmo, Physics Today, July 2007, page 38.) New opportunities for US and Soviet researchers to communicate unfolded with the 1958 Lacy–Zarubin agreement. It opened the two countries to various cultural exchanges, and one clause in the agreement allowed for science-related activities. The agreement created a state-supported diplomatic foundation for the US–USSR interacademy program.[3]

The first, largest, and longest-running academic exchange between a Western and an Eastern country began in 1959. The exchange between the US National Academy of Sciences and the Academy of Sciences of the USSR was launched after their respective presidents, Detlev Bronk and Alexander Nesmeyanov, signed the first of many memoranda of cooperation.[4] The interacademy program became a communication channel through which most scientific contact was managed. The program was a new, unprecedented financial and bureaucratic concept of science cooperation.[5,6]

Nuts and bolts of communication

The interacademy program's first decade, from 1959 to 1970, was a bumpy ride. Ideological differences, blocked visas, diplomatic rifts, and bureaucratic hindrances instigated by the State Department and Soviet authorities repeatedly threatened to limit the program or inhibit the productivity of research collaborations.

In the US, Congress and the news media routinely questioned the validity of the exchanges and whether government



Robinson

Гостиница „МЕТРОПОЛЬ"—"БЕРЛИН"
г. Москва

May 10
On board train 32 from Leningrad to Helsinki.

Dear Gerry:
This is my last communication from the USSR, within an hour we will cross the border to Finland. I am travelling by train for several reasons, but the principal one is that I have about 150 lb. of baggage, compared to 44 lb. allowed on international flights. The excess baggage charges would about double the cost of air travel.

THE FIRST PAGE of a handwritten letter sent in 1968 by Clark Robinson, who was on his way back to the US from the USSR, to Gerald M. Almy, the head of the physics department at the University of Illinois Urbana-Champaign. A nuclear physicist at the university, Robinson spent seven months in Novosibirsk working on R&D for electron accelerators. (Photo courtesy of the University of Illinois Urbana-Champaign department of physics.)

should fund the programs. A major concern was that any exchange would be a one-way street of the US science community continuously supplying knowledge and know-how to the science community in the USSR but getting nothing in return. Officials of the National Academy of Sciences and interacademy program participants routinely made public statements and gave testimonies at congressional hearings to defend the program and provide evidence of the mutual benefits of exchange.

A recurring sticking point in an exchange was for everyone involved to approve candidates for visits and agree on acceptable research topics. Cold-climate research, for example, would have given US scientists access to data and locations in the polar regions bordering Soviet military facilities, including missile launch sites and radar-monitoring installations. When the US Public Health Service put cold-climate research on its approved list in 1959, a participating US geologist, Wallace Atwood, wrote to Bronk that "the Soviets froze up like permafrost." Ultimately, cold-climate research was not approved for joint exploration.[7]

Gradually, the program expanded from 20 visits per year by a small group of participants to hundreds of visits per year by a vast multidisciplinary network of contacts. In 1966, for example, about 200 US scientists attended the second International Oceanographic Congress, which was held in Moscow.

Amid the 1970s détente in US–Soviet diplomatic relations, the interacademy program provided a model for joint research. With gentle diplomacy from influential scientists—for example, Frank Press, who later served as President Jimmy Carter's science adviser—an agreement was added to the 1972 Moscow Summit suite of accords for developing "cooperation in the field of environmental protection on the basis of equality, reciprocity, and mutual benefit."[8] The objective of the environmental agreement was to create a collaborative forum for US and Soviet scientists to share data and findings and conduct joint research in geographic and epistemological areas that were previously off limits in the exchanges.

By the late 1970s, the environmental agreement spurred progress in at least four large-scale joint research initiatives: atmospheric physics and climate studies, ecosystems and pollution, geophysics and seismology, and wildlife and plant conservation. New programs, including geological field studies in Central Asia, research cruises in the Pacific Ocean, a comparative study of Lake Erie and Lake Baikal, and the tracking of marine-life migration across the Arctic, were running by 1980.

The interacademy exchanges were well populated with participants who found the experience professionally meaningful and culturally rewarding. The scientists were exposed to unfamiliar research methods, data-processing techniques, and ways of thinking. Sometimes, intellectual partnerships between US and Soviet experts yielded new research fields, such as space plasma physics.[9] In other cases, they brought clarity to debated research issues, such as earthquake prediction; gave global access to scientific technologies, like tokamaks for nuclear fusion; and resolved a concern that stood in the way of banning nuclear tests (see the article by Frank von Hippel, Physics Today, September 2013, page 41).

Controversy: To hold or to halt?

Despite the successes, the exchanges had some challenges. David Apirion, a microbiologist at the Washington University School of Medicine in Saint Louis, Missouri, had a monthlong interacademy visit to the USSR in 1980. During his trip, he was jailed for one night for openly visiting individuals who were denied permission to emigrate and for raising the issue at the beginning of his lecture in Kyiv.

Apirion concluded from his trip that full members of the Academy of Sciences of the USSR were "extremely privileged

Laura Greene, a physicist and past president of the American Physical Society, shared in an oral history interview:

> Two of my mentors, David Pines and Charlie Slichter, in the '50s, the height of the Cold War between the US and the USSR, with huge stockpiles of nuclear weapons, they broke the rules set by the governments and started working with the Soviet physicists. That diversity beautifully changed the face of theoretical physics.
>
> There are many unsolved problems in correlated electron physics, and only a few are solved. They solved one of them by working together. They were in competition, of course. But these two groups of white men, one raised Soviet and one raised American, provided enough diversity to solve the fundamental mechanism of conventional superconductivity.[18]

(Photo courtesy of the AIP Emilio Segrè Visual Archives, gift of Laura H. Greene.)

people (very high salaries, a special car provided with two chauffeurs and many other perks)" and that Soviet science was "highly politicized, and the 'Commissar' or his equivalent, not the Scientist, is supreme." He argued that the Soviet scientific enterprise functioned to maintain secrecy and control. Little valuable information, therefore, could be extracted from it for the advancement of research. In view of that, Apirion asked, "Should we sacrifice our principles and dignity to the Moloch of scientific progress?"[10] Apirion never participated in the exchanges again and condemned them as malign and unethical.

Also in 1980, the US boycotted the Summer Olympics in Moscow because of the Soviet invasion of Afghanistan the year before, and communication with the USSR was discouraged. That put some US scientists, including a group of paleoclimatologists who had already accepted an invitation to attend a bilateral symposium in Siberia, in a tough spot.

The scientific leader of the paleoclimatology group, John Imbrie of Brown University, polled colleagues on whether to join the Siberia trip. Some came down against it. "My decision is basically a matter of principles, but I see a finite physical risk involved," one said. "I had already decided that the time has come to make a small personal protest to Soviet action," responded another. Others had more positive opinions: "I am more scared by the recent war propaganda and anti-Soviet propaganda in this country." "We should keep the personal contacts alive and avoid sinking into a cold war situation again." Although the State Department unofficially offered the paleoclimatologists the option to bail out, four of them attended the symposium.[11]

Despite the political tension, the interacademy program and the environmental agreement continued. In fact, many US participants refer to the 1980s as the golden age of joint scientific work with the Soviets. Toward the end of the Cold War, for example, US and Soviet scientists jointly studied the recently discovered ozone hole in Earth's atmosphere. In August 1991, a Soviet Meteor-3 weather satellite equipped with a NASA ozone-mapping spectrometer launched from the previously secret military-operated Plesetsk Cosmodrome. The launch came just four days before an attempted coup in the Russian government.

Investments in collaboration

In a recent email, Michael MacCracken, a climate scientist and past president of the International Association of Meteorology and Atmospheric Sciences, shared that "the 1980s were the good old days of communication with Russian (Soviet) scientists." What made that sentiment possible? Someone who knows Soviet Cold War history would be tempted to say that the country's opening to the West, the weakening of its ideology, and the lifting of many travel restrictions must have done the trick. That thinking is reasonable, but the situation is more complex.

US–Soviet scientific exchanges and collaborations were particularly fruitful in the final Soviet decade not only because of sociopolitical reasons but also because organizers and participants had made critical investments. For the two decades before 1980, they established the mechanisms of exchange, created a culture of bilateral scientific work, fostered

EARTH SCIENTISTS from the US and the USSR convene in 1978 at Columbia University's Lamont–Doherty Earth Observatory to participate in a science exchange program. (Photo courtesy of the University of Minnesota Archives, University of Minnesota Twin Cities.)

a safe environment of mutual understanding and trust, and found informal ways to work around restrictive official systems.

The collapse of the USSR brought about new challenges, new rules, and a makeover to scientific collaborations. In the 1990s, Russian academic institutions went into survival mode because of a lack of government funding and the emigration of many scientists. The US scientific enterprise benefited from the brain drain—the talent that was gained created a more competitive academic labor market.

Despite the changes in Russia, many previous ties endured. US collaborators organized informal relief operations for Russian colleagues in need, sometimes in unexpected ways. In 1992, for example, astronomer Stanford Woosley spoke to Irving Lerch, director of international scientific affairs at the American Physical Society, about the American Astronomical Society's plan to send funds, disbursed as small grants, to Russian astronomers. Several representatives of the Russian Academy of Sciences each offered to carry $10 000 in cash to Moscow after a meeting of the World Space Congress in Washington, DC.[12]

Communication breakdown

Collaboration between US and Russian scientists persisted until Russia annexed Crimea in 2014, and it deteriorated quickly after Russia's invasion of Ukraine in February 2022. In the US, some have advocated for isolating Russian scientists from Western professional communities—part of a larger diplomatic effort to urge citizens of a militant nation to provoke governmental reform—and for directing resources to Ukraine.[13] Others have argued for the internationality of science and have urged their communities not to penalize Russian scientists for their government's actions.[14,15]

Unlike in the 1970s and 1980s, those advocating for cutting off collaborations with Russian scientists have carried the debate this time around. Three years into the Russia–Ukraine war, Russian scientists have been excluded from international forums, and their names have been expunged from coauthored articles. Even as global research teams are ubiquitous, US scientists who have ongoing collaborations with Russian counterparts or who are willing to initiate them are hard to find (see Physics Today, December 2024, page 20).

Perhaps the lack of support is partially because US and Russian scientists have different motivations to collaborate today than they did in the past. The exchanges during the Cold War gave researchers access to new, previously unavailable global and local data; today, robust global networks have reduced the need for local assistance with data extraction. The urge to join forces and fight against a common enemy—the Cold War's threat to academic freedom and independence—has dissipated.

In the 1990s, a team of US and Russian nuclear physicists and engineers worked together to prevent disastrous accidents by developing and implementing innovative security mechanisms for the Russian nuclear arsenal. Siegfried Hecker, one of the team's leaders and former head of Los Alamos National Laboratory, later was the editor of a collection of essays about the significance and urgency of that unlikely venture. He called the book *Doomed to Cooperate*, a phrase provided by one of the Russians he interviewed. (For more about the venture, see Matthew Bunn's review of the book in Physics Today, November 2016, page 56.)

Despite evidence of the success and mutual benefit of US–Soviet programs, the productivity of US–Russian collaborations that were adapted from Cold War bilateral models, and the understanding that diverse teams make for stronger science,[16] exchanges with Russian scientists have diminished. In the present moment, when the prevailing opinions seem to disfavor rekindling scientific collaboration, the historic exchanges may offer some guidance for how to move forward.

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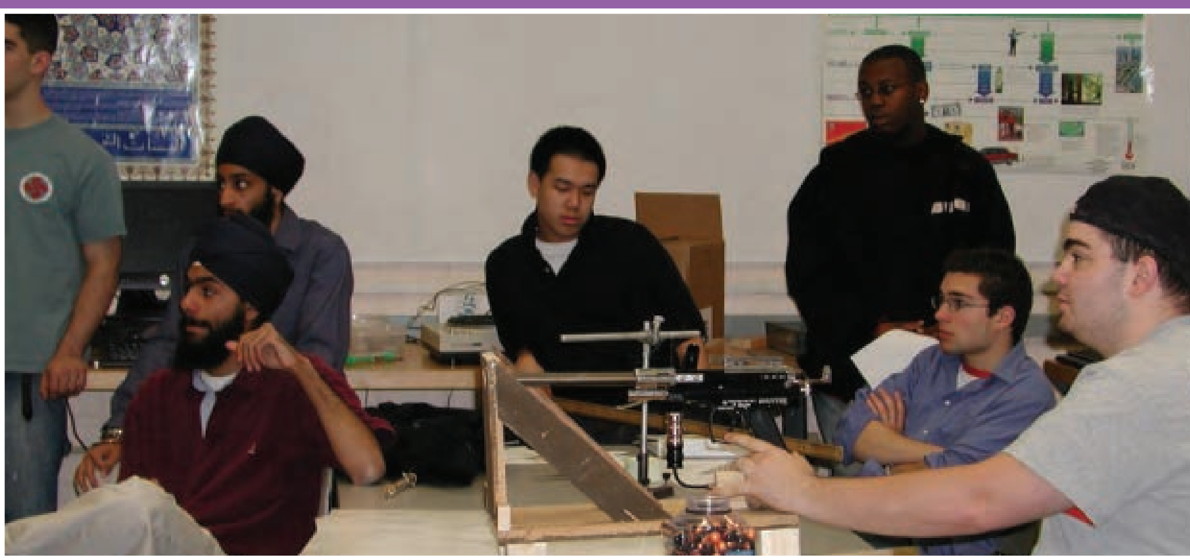
REFRAMING THE NARRATIVE ON PHYSICS READINESS

Suzanne White Brahmia and **Geraldine L. Cochran**

Alternative undergraduate physics courses expand access to students and address socioeconomic barriers that prevent many of them from entering physics and engineering fields. The courses also help all students develop quantitative skills.



Isaac aspired to be an engineer. He excelled in every available math and science class, but his school didn't offer calculus. After graduating from high school as the class valedictorian, he enrolled in his state university. There, a math placement exam put him into precalculus, which made him ineligible for the calculus-based physics and chemistry courses required for an engineering degree. The academic placement would delay Isaac's graduation by at least a year.

Initially, Isaac pushed forward, even as he felt increasingly disconnected from the engineering track. The added financial cost of a fifth year to his family, however, ultimately led him to switch majors so that he could graduate in four years.

Although Isaac's case is a hypothetical example, many students we have advised and worked with have had similar experiences. To start taking physics courses—a common entry point for a math-based career path not only in physics but also in computer science, engineering, and the like—US students typically must enroll in or have completed calculus. The rigid requirement disproportionately affects students from socioeconomically disadvantaged districts, where access to advanced math is limited. In addition, the pandemic's disruption to education has had a similar disproportionate effect on them. The exclusion from physics is especially troubling given how little calculus is actually used in most introductory physics instruction.

Discussions around success in calculus-based physics often focus on student readiness—defined solely by the students' prior experience with calculus techniques as measured by placement tests—and are less focused on how well departments support the students admitted to their institution. Students labeled as underprepared are typically required to complete remedial math, which both extends the time it takes them to complete a degree and increases their costs. Some students persist; others are advised to change majors. Advisers usually place students in a physics class based solely on their university math-placement score. That thinking pushes away capable students for reasons unrelated to their potential.

This article examines evidence of unequal access to advanced math before college, explores the unintended gatekeeping function of placement tests, and reflects on the skills that are actually necessary for success in introductory physics. A compelling alternative to the current practice is the long-running, successful program at Rutgers University that expands access into physics while strengthening the integration of calculus concepts into physics. More broadly, a national consortium is beginning to coordinate resources and support physics departments so that outcomes for all students in introductory physics sequences can be improved.

Barriers to calculus-based physics

Who gets to take physics in college often depends less on students' ability to succeed and more on their access to math opportunities long before college begins.[1] Precollege education in the US is marked by unequal access to advanced coursework, particularly in math and physics. The gaps are shaped by broad structural inequities across school districts and are often tied to wealth inequality.

Some 21% of US public high school students in fall 2021 attended high-poverty schools, where at least three-quarters of students qualify for free or reduced-price lunch.[2] As shown in figure 1, students attending high-poverty schools are significantly less likely to have an option to take calculus in high school.

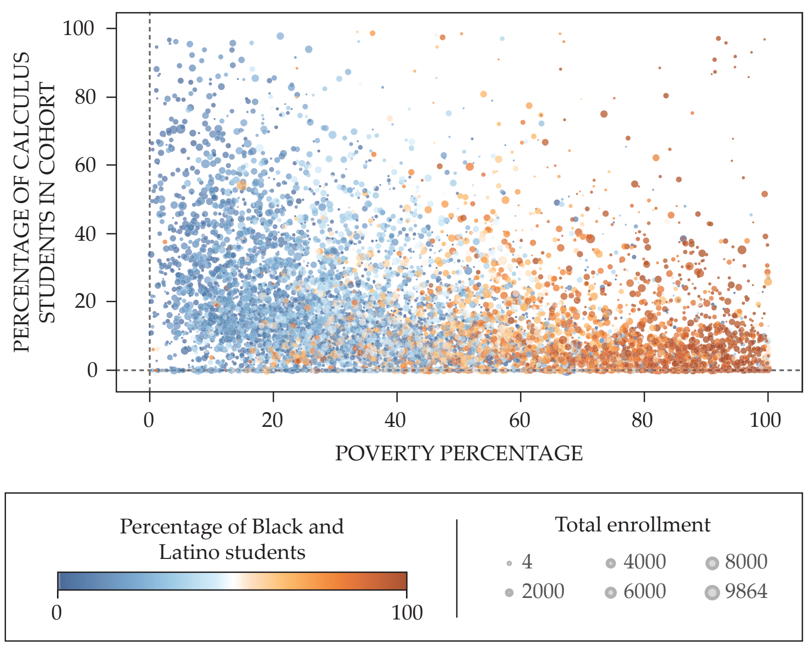


FIGURE 1. THE PERCENTAGES OF HIGH SCHOOL STUDENTS who enroll in calculus classes in US school districts depend in part on the poverty percentage in those districts. The size of the dots reflects the number of students enrolled in a school district, and colors represent the percentage of Black and Latino students. (Figure courtesy of Michael Marder, data from ref. 3.)

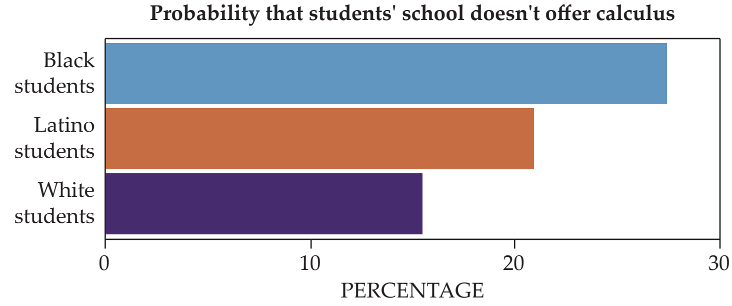


FIGURE 2. THE OPPORTUNITY TO TAKE CALCULUS in US public high schools is substantially different among students that identify primarily as Black, Latino, or white. (Data from Civil Rights Data Collection files for the years 2020–21 and 2021–22; available at https://civilrightsdata.ed.gov/data.)

The disparities are even more pronounced for Black and Latino students. In 2021, only 35% of US public high schools with predominantly Black and Latino students offered calculus compared with 54% of schools with lower enrollment of the two groups. That same year, the only mathematics courses available in some US public schools were at a level below Algebra 1.[3] As shown in figure 2, Black students were nearly twice as likely as white students to attend a high school where calculus wasn't offered.

The differences in course availability are not merely academic; they shape college trajectories and limit access to STEM majors, which often require calculus as a prerequisite. Recognition of that context is essential to designing physics instruction and placement practices that do not penalize students for unequal access to opportunity.

The use of math placement tests to determine readiness for physics courses mirrors and reinforces inequities in educational opportunity. The tests tend to promote the fundamental attribution error made by instructors: that they interpret a student's lack of calculus preparation as a personal shortcoming rather than as a result of systemic barriers, such as unequal access to advanced math in high school.

Additionally, most placement tests emphasize procedural skills in algebra and trigonometry. Typical math problems test a student's ability to rearrange equations without real-world context.

That kind of procedural competence is important, but excellence in math procedures shouldn't form the basis for inclusion in a physics course. Students' success in physics relies predominantly on their physics quantitative literacy (PQL): the ability to interpret equations, apply math in context, and connect math to physical meaning, all of which are best learned in a physics course.[4,5] Such flexible, context-based reasoning is rarely taught in standard prerequisite math courses, yet it benefits all students regardless of prior preparation.[6]

Students who struggle with foundational algebra will need added support that is beyond the scope of a physics course. But for schools to rely on placement-test scores to determine readiness for physics is deeply flawed. Test scores often serve as rigid gates that filter out capable students and reinforce opportunity gaps. That sort of gatekeeping reflects a broken-student narrative—students must fix themselves to belong—when, in fact, many were never given a fair opportunity to begin with.

Even among students who do enroll in calculus-based physics courses, disparities in preparation shape outcomes. About 75% of students who place into college calculus took it

Physics quantitative literacy

The following example, about the first law of thermodynamics, aims to assess an aspect of quantitative reasoning that is ubiquitous in physics.

> The internal energy of a system can be increased by doing work on the system or by heating it, and it can be decreased by cooling the system or if the system does positive work on the environment. Which of the following equations represent(s) this relationship (U is the internal energy of the system, Q is positive when energy flows into the system, and W is positive when work is done on the system)? ***Choose all that apply.***
>
> a. $\Delta U = Q - W$
> b. $\Delta U = -Q + W$
> c. $\Delta U = Q + W$
> d. $-\Delta U = Q + W$
> e. $-\Delta U = Q - W$
> f. $-\Delta U = -Q + W$

Students are often challenged when asked to symbolize scalar quantities that take both positive and negative values and to interpret a change in a signed scalar quantity. Only about one-third of students at the end of their calculus-based physics sequence and only about two-thirds of physics majors by the end of their junior year answer this question correctly. The correct answer is C. (Example from S. White Brahmia et al., Physics Inventory of Quantitative Literacy, 2021.)

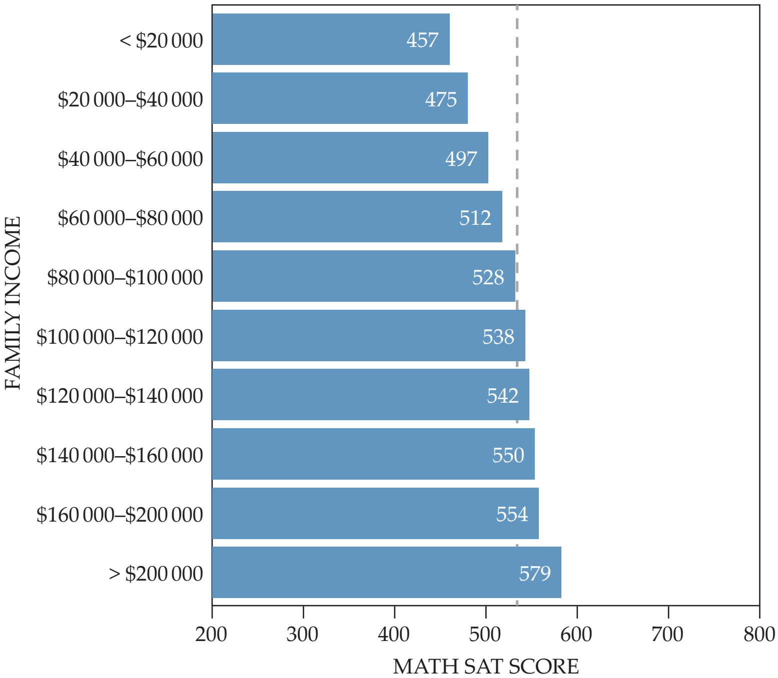


FIGURE 3. AVERAGE MATH SAT SCORES of student test takers in 2009 are correlated with family income. The College Board suggests that a score of 530 indicates college readiness, but students from households with an income under $100 000 often score below that benchmark on average and require remedial coursework. (Chart adapted from ref. 8.)

in high school, which puts students without that opportunity at a disadvantage.[6] One study across three selective institutions found that Analytical Physics exam scores are correlated with math SAT scores and prior physics experience[7]—both of which are tied to family income[8] (see figure 3).

When course design aligns with student preparation, however, performance gaps shrink. After controlling for a student's socioeconomic status and SAT scores, researchers found that ethnic disparities in learning gains—the actual learning that was done during a course—were largely eliminated.[9] Rather than asking who is prepared for physics, instructors should ask whether their courses are prepared for the students that their institutions enroll.

Preparing to teach all students

When instructors focus only on student readiness—rather than on how they can effectively support diverse learners—it can have unintended consequences. They often rely on metrics of mathematical readiness that are misaligned with the goals of physics courses, that reflect disparities in students' access to relevant high school courses rather than students' abilities, and that disproportionately affect Black and Latino students. The narrow focus on procedural mathematical preparation can also lead students to question whether they belong in physics at all.

Remediation-focused approaches, which address disparities in student access to precollege mathematics, often place the burden on students and leave the structural issues in physics courses unexamined. Even valuable, well-intentioned supports, such as tutoring or bridge programs, require extra effort and time from students and leave the physics courses themselves unchanged. A more effective approach focuses on redesigning instruction to support a broad, diverse group of learners.

Instead of requiring students to complete remedial math before enrolling in physics, departments can embed their course sequences with PQL. That integration helps students develop the ability to interpret equations, explain physical quantities, and connect math relationships to real-world phenomena. Optional instructor-led support courses or extended, credit-bearing pathways that integrate PQL into instruction offer a more inclusive and effective alternative. They are beneficial to students with various levels of preparation.

A sensible starting point for integrating PQL support is to examine how instructors use math in introductory physics. Most problem-solving exercises in introductory physics courses in the US don't require calculus, even in courses that are designated as calculus based.[10] Yet reasoning about core calculus ideas—for example, variation, rate of change, and accumulation—is essential for students who are learning for the first time about dozens of physics quantities, including force, momentum, and energy.

Compared with a traditional, familiar math course that provides context-free practice, a course with contextual physics quantities requires a different approach from students and instructors.[4,11] Conceptual quantitative skills are rarely outcomes of traditional calculus instruction, which tends to focus on symbolic manipulation for solving math problems,[11] most of which are irrelevant in physics. Moreover, the math structures that physicists depend on—basic operations with simple function types like linear and inverse proportionalities and quadratic polynomials—are more widely accessible to students than are advanced techniques such as integration by partial fractions. By emphasizing how physical quantities and their relationships to each other can be constructed and symbolized, instructors can better support all students in developing meaningful mathematical reasoning in physics. (See the box for an example that tests PQL.)

For physics instructors, the lesson is clear: By identifying when students need PQL-specific skills and weaving those skills into courses, they can boost learning without lowering expectations.[5] Instructors who use that approach report im-

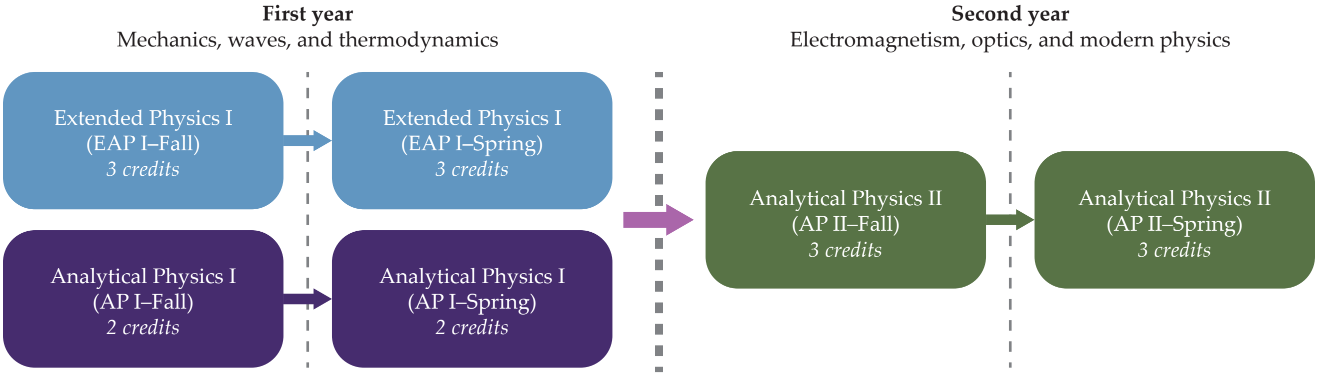


FIGURE 4. TWO PHYSICS SEQUENCES are available to undergraduate students at Rutgers University. The standard Analytical Physics (AP) pathway requires a calculus placement test. For students who lack the opportunity to take calculus in high school, the Extended Analytical Physics (EAP) sequence incorporates calculus-based reasoning and includes additional time for them to develop skills in physical quantitative literacy. By the end of the first year, all students are prepared for the second-year physics courses. A separate honors track is not shown. (Figure adapted from ref. 13.)

proved outcomes for all students.[12] Many physics departments already offer honors programs for students that are well prepared by their precollege physics and calculus courses. Why not invest in students who lack access to those courses? The challenge isn't fixing students—it's designing courses that help all of them thrive.

One extended course model removes the calculus prerequisite and adds credit hours for students to develop PQL at the same time that they are learning the course's core physics content. The Extended Analytical Physics (EAP) program at Rutgers demonstrates how that model works in practice.

A case study in New Jersey

Since 1986, Rutgers' department of physics and astronomy has supported mathematically underprepared engineering students through the EAP program.[13–15] Launched with state and federal funding, the program aims to address the mismatch between New Jersey's diverse population and the STEM-graduate population at its flagship university. The students who enroll in precollege calculus in New Jersey public schools mirror the national trend shown in figure 1, and those students are primarily from affluent districts with few Black and Latino students. To address the disparity, Rutgers created a parallel physics pathway that allows students who are not placed into calculus to stay on track for engineering degrees. The Rutgers program was already unusual in 1986: It split the mechanics sequence across two semesters to make room for the increasing demand for first-year programming courses.

The EAP pathway, shown in figure 4, is an introductory physics sequence for engineering majors who place in a math course below calculus.[13] It spans three or four semesters and totals 9 or 12 credit hours, depending on the major. Typically, students take EAP I in fall and spring, which prepares them for the standard Analytical Physics (AP) II course in the following fall—for some majors, a second AP II course may be taken in the spring. The alternative EAP pathway complements the standard AP sequence, which also runs three or four semesters with 7 or 10 credits. Since its launch, EAP enrollment has grown from 90 students annually to approximately 300, compared with the 900 students who are in the AP sequence each year. Most students remain in either the EAP or AP sequence, although some switch pathways.

Students in the EAP pathway take an additional credit hour each semester of the first year for deeper engagement with physics concepts and PQL. Importantly, the course does not teach remedial math; instead, it helps students understand how algebra, precalculus, and introductory calculus concepts apply in physics contexts and introduces PQL topics as needed.

The program has broadened access to STEM degrees for students from diverse educational backgrounds. Figure 5 illustrates how the EAP is meeting its objectives. Degree completion for all students is boosted by the gains among women and those from historically underrepresented groups in STEM. Compared with the two years before the EAP's implementation, the number of underrepresented minority students who complete STEM degrees in six years has increased by about 50%.[13] A 10-year follow-up study of Rutgers first-year students that pass the introductory physics sequence yielded similar results.

The strength and longevity of the EAP model lies in implicit structures that build student agency in a rigorous scientific community:

- **Flexible entry.** Placement scores help inform what courses students take, but they can choose or switch pathways through the start of the spring semester of the first year to maintain control over their courses.
- **Representative instructors.** The faculty instructors and leaders of the EAP program include members from underrepresented groups in physics who serve as role models for students.

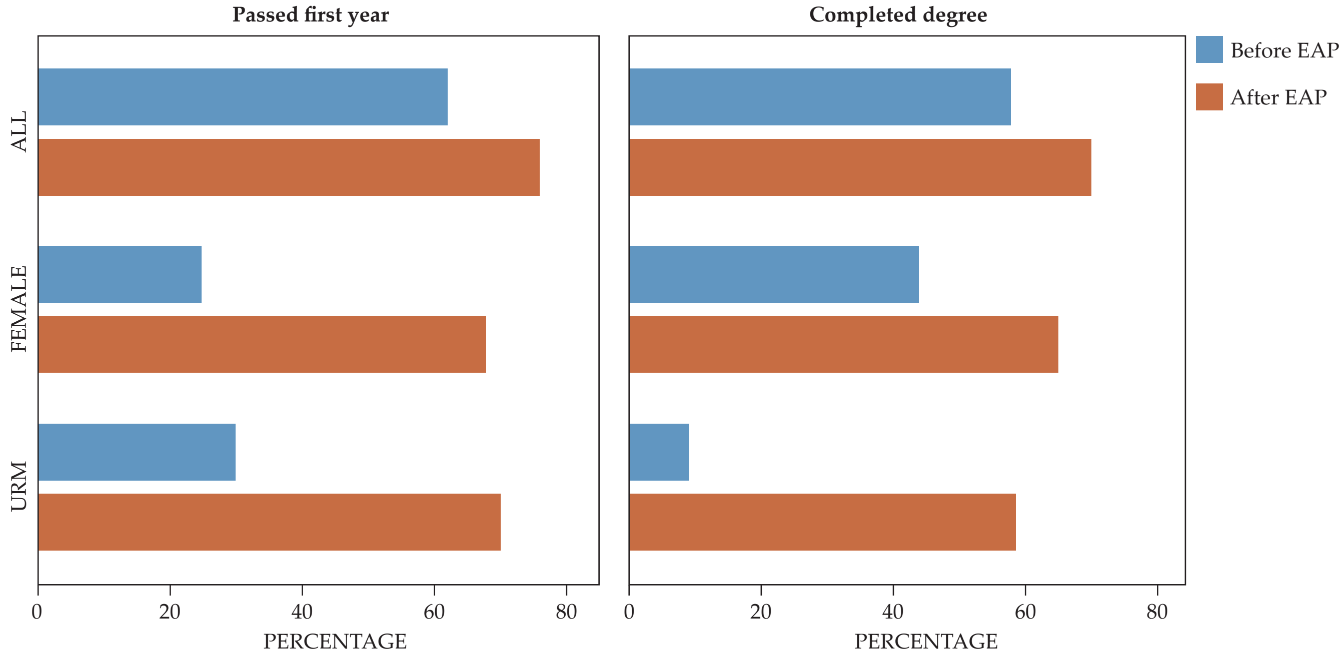


FIGURE 5. THE PERCENTAGES OF STUDENTS who passed first-year physics courses and who completed a STEM degree increased after the introduction of the Extended Analytical Physics (EAP) program at Rutgers University. Results are averaged over the two years before and over seven years after the program's introduction. The left group of bar graphs shows percentages of all students, female-identifying students, and students from underrepresented minority (URM) groups who passed first-year physics, regardless of the physics pathway they took. The right group of bar graphs shows similar results for students who earned STEM degrees within six years. A conservative estimate of uncertainty is about 4%. (Figure adapted from ref. 13.)

► **Supportive environment.** The program fosters a safe pedagogical space where students can take risks and learn from mistakes.

► **Deep learning focus.** Activities emphasize conceptual and procedural understanding of linear and inverse proportional relationships and extend that reasoning to other critical functions commonly found in physics models.

► **Calculus foundations without calculus.** Students explore core calculus ideas, such as quantities, rates of change, and accumulation, through accessible precalculus reasoning.[11]

The Rutgers EAP model integrates PQL development into standard introductory physics by emphasizing quantitative reasoning that's rarely addressed in math courses but is essential for physics. Physical quantities, which are central to every physics model, are related through a few core equation types that occur across various contexts. Helping students identify the mathematical role of each quantity deepens their understanding of precalculus concepts and prepares them to engage with the scientific ideas that the quantities represent. Crucially, the reasoning is accessible to precalculus students and focuses on conceptual skills rather than on procedural calculus skills.

Developing PQL also means that students will be able to interpret symbols and letters as representations of measurable, variable quantities with units and often with direction and sign. Vector quantities add representational complexity that requires students to be fluent with notation such as unit vectors, subscripts, and signed scalars. Those conventions convey essential information about orientation and reference frames, which are vital for students to accurately model physical systems and are suitable to introduce to students before they take calculus.

The Rutgers EAP program serves as a model for effective expanded access and sustained success. Some institutions of higher education are beginning to rethink introductory physics through an access lens. The Ohio State University now offers an extended course structure based on the Rutgers model. The structures at other schools tend to result in students taking an extra year. Given the financial strain of an additional year in college, it is critical to reevaluate access criteria for calculus-based physics and expand programs that effectively support those students.

Supporting all capable students

Efforts are underway to expand the Rutgers model to other US schools. The nascent NSF-funded network known as TIPSSS, or Transforming Introductory Physics Sequences to Support all Students (https://u.osu.edu/tipsss), aims to help connect departments and educators who are committed to rethinking introductory physics instruction for all driven, capable students, regardless of what math courses they were able to take in high school.

Through its members, TIPSSS supports departmental transformation by adapting curricula and conducting studies on student learning and identity.[16] TIPSSS resources promote PQL and help college-level instructors customize materials. It also offers a rare professional community for instructors who are driving change. TIPSSS is a step toward collective action—it connects departments that are committed to rethinking instruction and broadening access so physics becomes a path, not a barrier, to students' futures.

Meeting students where they are academically requires instructors to rethink long-standing course designs with sustained effort and institutional support. Research on PQL and programs like Rutgers' EAP show that improvement is possible. Physicists are natural problem solvers, but physics instructors cannot single-handedly fix the deep disparities in US precollege math education. That essential work is underway elsewhere and will take time. Meanwhile, we have agency. As university faculty, we can rethink the signals we send through course design and placement policies. Physics instructors share a commitment to unlocking student potential. Now we must ensure that our instruction supports all students—not just those fortunate enough to take physics and calculus in high school.

Isaac's story may be common, but it doesn't have to be the norm. What are we doing to make sure students like Isaac aren't turned away before they've had a chance to pursue the futures they envision?

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What does it mean to be a physicist right now?

The scientific enterprise is under attack. Being a physicist means speaking out for it.

Editor's note: This essay was adapted from a town hall speech given by John Doyle, president of the American Physical Society, at the June 2025 conference of APS's Division of Atomic, Molecular, and Optical Physics. It has been lightly edited for length and clarity.

JOHN DOYLE at the American Physical Society's Global Physics Summit in March 2025. (Photo courtesy of the American Physical Society.)

What does it mean to be a physicist right now? It's a question that has hovered in my mind from time to time. But today, it is sharply in focus as I see our members face not just rapidly growing challenges to their professional future but also attacks on the core values that have defined America. America is a place, but it is also a set of ideas, including a devotion to discovery and a deep commitment to truth. These ideals led to America becoming a global hub for study and research. They were a guide star for many and represented a higher aspiration for what the world could be.

So, right now, what does it mean to be a physicist? As president of the APS [American Physical Society], and as someone who has spent a career collaborating across continents and disciplines, I must constantly ask, What should we be doing right now? For some of us, physics is rooted here in the United States; for others, it's a journey that began halfway around the world and continues across borders. Wherever we call home, we're all part of a community whose choices matter—now more than ever.

As I stand before you today, I feel a deep sense of responsibility and grave concern not only for the scientific enterprise but also for the scientists—all of you—who drive it forward. Yet I also feel genuine enthusiasm for the exciting science that is represented here at DAMOP [the Division of Atomic, Molecular, and Optical Physics]. I have optimism because I believe in the strength of this society, in our worldwide community, and in the power of science to illuminate the path forward, even, or maybe especially, in turbulent times. To be a physicist right now means balancing our emotions and prioritizing what can make the greatest impact for our scientific community. It means facing uncertainty with integrity, speaking up for our values, and drawing strength from our colleagues, collaborators, and friends.

It is bitterly ironic that this year, the International Year of Quantum Science and Technology, which celebrates an area I have devoted much of my professional life to, coincides with the recent challenges we face. Quantum science and technology has undoubtedly made major contributions to national security and the economic wealth of the global community. Yet it, too, is under threat and, with it, the broad scientific umbrella that DAMOP is a part of. To be a physicist right now means to plot a future for our shared scientific enterprise in which we've invested our time and passion, because—make no mistake—its future is at serious risk.

Many of these pressures are not unique to one nation. Actions by the US executive branch have put strains on our scientific enterprise, and we know that physicists around the world contend with their own headwinds. Funding threats, mobility barriers, and skepticism of expertise are all global challenges. At APS, these challenges only reinforce the importance of focusing on key priorities and actions that will make a substantive difference, including supporting our members and working to strengthen the international foundation of science.

Physicists must be not only scientists but also advocates, educators, and champions. Our ongoing goal, at APS and as physicists more broadly, must be to share our knowledge, to communicate, and to connect—not only to inform the public and policymakers about the wonder of discovery but also to make clear the practical value and social impact of our work.

One of the highest priorities has got to be explaining the best we can to elected officials and the public at large not only the enriching wonder of science and discovery but also the economic power the scientific enterprise brings and how it actually functions. I have learned that many physics students don't know how this all works. We should have been better at explaining this. Now, as we face new challenges, advocacy must become a part of what we all do. This includes understanding how science is funded and how public understanding drives the decisions of our elected officials, which in turn influences how the government supports our work. Why would a senator prioritize scientific funding over many of the other pressing issues the country faces? Good question.

An important part of the functionality of our scientific enterprise is two forces working together. The first is raw curiosity of how the physical world works. Many of us are driven by fascination with a mathematical understanding of the world and the need to comprehend in detail a certain pet piece of physics; some, by building and running experiments to get at that one mystery or make a new physical system. The second is the application of that knowledge to create tangible benefits for society, including transformative technologies and systems with commercial value.

These two forces—discovery and application—reinforce each other. This dynamic is what fuels progress. By supporting both pure curiosity-driven research and basic physics research with an eye toward future applications (either scientific or commercial), we ensure that science continues to advance knowledge and drive the innovation needed to build a better, healthier, more sustainable future for our global society. We need Congress to hear this. We need the executive branch and its advisers to hear this. We need the public to hear this. We have a responsibility to our fellow citizens to share our knowledge and also to be visibly responsible gatekeepers of what projects are funded with our citizens' money.

APS champions both curiosity-driven and application-minded research, recognizing that this dynamic is what keeps science innovative, relevant, and progressive. Those two research paradigms are part of the triad of the technology-innovation engine. The third part is the combination of venture capital, startups, and, yes, large corporate partners. Our advocacy efforts—whether through broad public engagement or direct, ongoing dialogue with Congress, university leaders, and industry partners—reflect our strategy that was set in motion before these latest challenges coalesced.

In all these arenas, we are deliberately working to remind our audiences that fundamental discovery and application go hand in hand and that continued support for both is vital to the future of not only our field but also the daily lives of all citizens. Successfully meeting the challenges of this century requires both political will and cutting-edge science. Economic prosperity will depend on maintaining the special triad that creates the innovation engine.

Recent government actions and funding threats in the US have only reaffirmed the relevance of our long-term work in science. Our work is about more than money and policy—it's about people. But make no mistake: Every cut in federal research funding is a cut in the number of trained students. It is the elimination of future industrial leaders, teachers, and problem solvers for our society. It is the ending of careers. It is scientists who will not develop the medical technologies of the future, never have the opportunity to develop new fundamental theories of nature, and not build the commercial products that put people and sensors into space. This is one reason APS is placing so much weight on the 2026 budget. Because society needs that investment in people who create new knowledge, produce new products, and discover the wonders of the world that enrich our lives.

In light of that, it's important to remember that to be a physicist right now means to be a person too. It's about the scientists, from every corner of the globe, who enrich our labs, our classrooms, and our country. Today, too many face visa delays, travel barriers, financial hardship, or even personal attacks, purely because of who they are or where they were born.

This is why APS is granting free membership to anyone in need. This is why APS is continuing to fund programs like Bridge, which encourages graduate school for students underrepresented in physics, and like IDEA, which influences physics departments to be more accessible, more welcoming. APS programs are about creating opportunities and meeting people where they are. Our programs have always been open to everyone. APS values didn't change with previous changes of government, and they did not change with this last one either. We will continue to give travel grants, to fund innovative projects, and to equip K–12 teachers to spark interest in physics. Because it matters.

We owe it to this next generation of scientists to build a community that is truly open, supportive, and welcoming. We must foster a culture that upholds the well-being and dignity of all scientists and works to remove social or political barriers. And if America is to remain a global pillar of science, we must keep our doors open to talented scientists, ensuring that opportunity and respect are real for the next generation. Science cannot flourish in an atmosphere of fear or exclusion.

Thus, an issue of parallel importance with the federal science-funding level is immigration—in particular, keeping the doors open for international scholars, an extreme challenge lately. Our physics community has a large fraction of scientists who were born and raised in other countries; many are non-US citizens. The US scientific enterprise gets much of its vibrancy from these scholars. I was reminded of this in March while handing out prize after prize to international colleagues during the Global Physics Summit meeting. As public debate grows ever more polarizing, we must keep immigration and its overwhelming benefits clearly in focus.

As we move forward, clarity and unity are essential. We cannot fight every battle at once, but we can and must focus our energy where it matters most: supporting federal science funding, defending the ability of scientists to pursue essential research, keeping our doors open, helping policymakers and the public understand how science really works, and reminding everyone that investment in science is an investment in our shared future. The path is not perfectly laid out for us. We will wrestle with really big questions: What does it mean to stand at the intersection of scientific truth and societal change? Where can we go that preserves our scientific and APS values while surviving in a changing world? We are not the first group of scientists to face these questions, and we will not be the last.

My own international experience has shaped my perspective on the challenges we now face. For example, having observed Russia, now for decades, some of the recent actions I see lately here in the US are familiar to me. And sometimes I put down my APS journals—*PRX* [*Physical Review X*], *PRL* [*Physical Review Letters*], et cetera—and read a book.

Books like *The Spanish Civil War* and *Moscow, 1937* are tomes that have some relevance. How was it that in the middle of the last century, with modernism moving quickly across Europe, many subgroups in Spain were to aggregate and decide it was better to go to war than to compromise? None were willing to change their stance on some pet issue, none were willing to find a middle ground, regardless of the grave practical consequences. How is it that in 1937, the technological and scientific leaders that brought Russia so far so quickly over the previous decade—including those whose scientific and technological efforts showed a direct benefit to the people—were then summarily executed? It is bewildering to comprehend. All of this was done within an allegedly "stable" political system.

The landscape we work in today is not what we envisioned for the US 20 years ago. The myths that we carry with us day to day—as any people in a society do—these myths that ground us and make us happy should be looked at with a cold eye. It is a changed landscape, socially and politically, and we must remain focused on our APS mission to preserve—and maybe even enhance—the scientific enterprise while promoting our shared values. Thankfully, there is actually great consensus about what those values are.

Progress is never inevitable. Societies can lose their way. It is up to each of us to make the case, in language that resonates beyond academia, that science is not a luxury but a necessity. A necessity that is a key pillar of a civil society, one that flourishes by solving the real problems of our time.

The truth is under attack, and physicists, perhaps more than any group, must continue to tell the truth, even when it is uncomfortable. Truth is our major currency among the public. It is our superpower. Never give in on this. Never hold back.

The actions you have taken these past months—your letters, your advocacy, your engagement—are building the foundation for what comes next. The plan we've been enacting over the past six months reaches across partisan lines because it is grounded in facts, values, and a vision of shared prosperity.

We are not simply reacting to threats: We are organizing for the long-term health of science and of our society. In this work, every voice matters.

So I come back to where I started: What does it mean to be a physicist right now? For me, it's about standing up for truth, for openness, for each other, and for the future of science, wherever it's practiced.

We are facing real challenges, and we have a responsibility to shape what comes next. Every time we support one another, speak out for our values, or push back against obstacles to discovery, we help protect and advance the scientific enterprise—not just for ourselves but for generations to come.

Let's keep moving forward, together. Let's keep raising our voices for science, defending our community, and making sure that physics remains a force for progress and hope. I know that, together, we can meet this moment and help science thrive, in America and around the world.

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Focus on test, measurement, quantum metrology, spectroscopy, and spectrometry

The descriptions of the new products listed in this section are based on information supplied to us by the manufacturers. Physics Today can assume no responsibility for their accuracy. For more information about a particular product, visit the website at the end of its description. Please send all new product submissions to ptpub@aip.org.

Andreas Mandelis

Quantum computer calibration framework

According to Quantum Machines, its QUAlibrate framework can shorten quantum computer calibration time from hours to minutes. By transforming the process from a collection of isolated scripts into a modular, collaborative system, QUAlibrate enables researchers and quantum engineers to create reusable calibration components, combine them into complex workflows, and execute calibrations through an intuitive interface. It abstracts away hardware complexities and lets teams focus on quantum system logic rather than low-level details. QUAlibrate's open-source access and modular architecture allow newly developed calibration protocols to be immediately shared, validated, and built upon by the broader quantum computing community. On top of QUAlibrate, companies can also develop proprietary solutions that leverage advanced approaches such as quantum system simulation and deep-learning algorithms. Along with the framework, Quantum Machines is releasing its first calibration graph for superconducting quantum computers. ***Quantum Machines***, *HaMasger St 35, Tel Aviv-Yafo, 6721407, Israel, www.quantum-machines.co*

Sampling oscilloscopes

Keysight Technologies has developed the single optical channel DCA-M and dual optical channel DCA-M sampling oscilloscopes. The digital communication analyzers (DCAs) are designed to optimize measurement sensitivity and test efficiency in 1.6-terabit transceiver optical testing for R&D and manufacturing of next-generation optical interconnects in data centers and AI clusters. The oscilloscopes provide high-speed optical signal analysis at up to 240 gigabits/second per lane. Wide precise bandwidth, less than 15 μW optical channel noise, and less than 90 fs of intrinsic time-based jitter preserve the critical measurement margin at the very high data rates and challenging signal conditions of 1.6-terabit transceivers. To minimize test-system complexity and ensure standards compliance, integrated clock recovery supports baud rates of up to 120 gigabauds and therefore enables the DCA-M to recover the clock at the full data rate, as prescribed by the standards. ***Keysight Technologies Inc***, *1400 Fountaingrove Pkwy, Santa Rosa, CA 95403-1738, www.keysight.com*

Magneto-optical cryostat

Quantum Design has unveiled the OptiCool Vector, a 4-1-1 vector magnet version of its OptiCool magneto-optical cryostat. The OptiCool platform is designed for investigating materials and various technologies at very low temperatures and high magnetic fields, in applications including quantum optics, spintronics, and magnetic thin films. While the standard OptiCool features a 7 T split-conical magnet with the field perpendicular to the table, the OptiCool Vector provides a magnetic field of up to ±4 T in the plane perpendicular to and ±1 T in the plane parallel to the optical table. The four side windows in the x- and y-axes of the magnet allow for transmission and reflection experiments in the plane parallel to the table. The top and optional bottom windows in the z-direction allow for reflection or transmission experiments perpendicular to the optical table. The magnet power supplies in the OptiCool Vector let users precisely set the magnetic field direction relative to their sample and optical systems. ***Quantum Design***, *10307 Pacific Center Ct, San Diego, CA 92121, www.qdusa.com*

Single-shot autocorrelator

APE's portfolio of autocorrelators now includes the pulseCheck Single model, which delivers single-shot measurements of ultrashort, low-repetition-rate laser amplifiers. It can also measure high-repetition-rate lasers. According to the company, the single-shot operation and fast refresh rate let users record pulse-duration changes as fast as possible, generating real-time feedback for laser optimization. The pulseCheck Single is suitable for fine-tuning ultrafast lasers, particularly during the making of adjustments such as grating alignments or compressor tweaks. The built-in camera system can simultaneously capture the pulse duration and spatial properties of the laser beam in one direction. The software provides a wide range of parameters and statistics. In one glance, users can track the autocorrelation trace, beam properties, pulse duration along the beam profile, beam pointing, energy stability, and more. Alignment is simple, and the compact size and minimal hardware requirements make the pulseCheck Single easy to integrate. Laser polarization can be adjusted easily by flipping the device. ***APE GmbH***, *Plauener Strasse 163–165, Haus N, 13053 Berlin, Germany, www.ape-berlin.de*

WDXRF spectrometer

Bruker has launched its S8 Tiger Series 3 high-power WDXRF (wavelength dispersive x-ray fluorescence) spectrometer for elemental analysis in research and industry. The spectrometer supports materials research applications with detection limits below 1 ppm and industrial-process and quality-control applications with high uptime requirements. Various detector options optimize the spectrometer's performance in analysis speed and data quality. For example, SensorBoost technology increases the signal-processing speed by a factor of two for light elements and enhances sample throughput for cement, industrial minerals, and ceramics applications. Bruker's proprietary solid-state detector, HighSense XE, improves process control in metals, geology, and mining, for order-of-magnitude higher count rates than conventional detectors, the company says. The single-element channels for specific elements, such as boron in glass, and the HighSense XP multi-element channel for groups of elements have a sample throughput more than 30% higher than purely sequential spectrometers'. The new EasyLoad sample magazine with its integrated camera AI autonomously handles different kinds of liquid and solid samples. ***Bruker AXS***, *Östliche Rheinbrückenstr 49, 76187 Karlsruhe, Germany, www.bruker.com*

New literature: Ebook on low-level measurement techniques

Lake Shore Cryotronics has published an ebook titled *New Low-Level Measurement Techniques for Device Characterization*. The ebook examines an approach to instruments for low-level measurement setups that use the company's MeasureReady M81-SSM synchronous source measure system. It describes how the modular multichannel system simplifies measurements by requiring fewer instruments: It combines the capabilities of DC picoammeters, DC voltmeters, and AC lock-in amplifiers in an all-in-one configuration. The ebook explains how fewer cables and faster setup between sources, measures, and sample connections minimize leakage, injected noise, wiring resistance, and other undesirable effects and optimize signal sensitivity and precision. The number of source and measure channels can be increased to allow for synchronized or parallel sample and device testing. They ensure tight sampling and channel synchronization. The ebook explores how the system's lock-in and differential (balanced) source and measure technologies remove noise from measurements, particularly in low-temperature applications. It also describes how finite impulse-response filtering can speed up lock-in measurements. ***Lake Shore Cryotronics Inc***, *575 McCorkle Blvd, Westerville, OH 43082, www.lakeshore.com*

Signal and spectrum analyzer

Designed to facilitate new measurement scenarios in RF system testing, the FSWX signal and spectrum analyzer from Rohde & Schwarz addresses the growing demand for higher data rates, wider modulation bandwidths, and increased modulation orders in wireless, satellite, and mobile communications applications. The multichannel signal and spectrum analyzer integrates multiple input ports with an internal multipath architecture that enables a novel cross-correlation feature and advanced triggering options. With its low phase noise for high signal purity, spurious-free dynamic range, and precise error-vector-magnitude analysis capability, the FSWX delivers a better RF performance than other available signal and spectrum analyzers, according to the company. The instrument features high measurement speed, advanced filter banks, broadband A/D converters, and analysis tools tailored to users' needs. An 8 GHz wide internal bandwidth allows for comprehensive analysis of complex waveforms and modulation schemes. ***Rohde & Schwarz GmbH & Co KG***, *Mühldorfstr 15, 81671 Munich, Germany, www.rohde-schwarz.com*

High-bandwidth sampling oscilloscopes

Pico Technology has extended its PicoScope 9400A series of high-bandwidth sampling oscilloscopes. Built on Pico's SXRTO (sampler-extended real-time oscilloscope) technology, the series now includes three new models: 6-, 16-, and 33-GHz-bandwidth versions are now available in addition to the previously announced 25 GHz one. Designed for accuracy and performance, the 33 GHz model achieves rise and fall times of under 12 ps, enabling precise analysis of ultrafast signals. All the oscilloscopes feature four channels with 12-bit voltage resolution and jitter specification of less than 1.5 ps rms, a feature that is critical for time-domain precision in advanced research environments. An optional clock-recovery function can generate a trigger from a received data signal where a separate trigger signal is not readily available. The oscilloscopes are suitable for use in semiconductor and materials research, high-speed electronics and communications, and high-energy physics, in all of which accurate waveform capture and signal integrity analysis are critical. The compact, PC-connected design facilitates easy integration into automated test setups or shared laboratory environments. ***Pico Technology***, *320 N Glenwood Blvd, Tyler, TX 75702, www.picotech.com* PT

Curtis Hooper is a doctoral fellow at the Sports Technology Institute in the Wolfson School of Mechanical, Electrical and Manufacturing Engineering at Loughborough University in the UK. An avid bowler since he was seven years old, Hooper has represented England in bowling competitions around the world, and he is a current Team England coach.

The perfect strike in tenpin bowling

How hitting just 4 pins can result in knocking down all 10, over and over.

Curtis Hooper

The main objective of tenpin bowling is to roll a ball down a long, narrow lane in such a way that all 10 pins at the end of the lane are knocked down. If that is achieved in one shot, it's called a strike. Rolling strikes is the best way to accumulate big scores and win. The combination of the curved shape of the pins and potential small changes in their initial positions because of variance in the pinsetter machines means that the exact direction they travel after a collision is difficult to predict and control.

There are many ways that the pins can interact to produce a strike. In some cases, pins momentarily leave the deck where they are initially positioned, bounce off the side walls, and return to knock down pins that were briefly left standing. Though those lucky strikes might elicit a wild reaction from the crowd, they rely on a fair amount of good fortune. But amid the chaos and variety of pin action, there is a particular sequence that consistently results in a strike and relies on very little luck: what's known as the perfect strike.

If you've seen videos of professionals bowling strikes, you may have noticed that the bowlers' strategy is not to throw the ball as fast as possible. Instead, they apply rotation to the ball. By taking advantage of rotation and an oil pattern applied to the lane, experienced bowlers can unlock the ideal sequence of collisions. Here's how it works.

Chain reaction

To achieve the perfect strike, the bowler must hit the front pin, commonly called the headpin, about 6.5 cm away from its center at a 4–6° angle. In the first part of the sequence, the headpin hits pin 2 in such a way that pin 2 hits pin 4, and then pin 4 hits pin 7. Those four pins, shown in green in figure 1, topple.

Next comes a crucial part of the sequence: the deflection of the ball from the headpin to pin 3. That must happen at a specific angle (more on that later) for pin 3 to hit pin 6 in the correct position and, in turn, for pin 6 to hit pin 10. After hitting pin 3, the ball carries on and hits pin 5, which sends pin 5 into pin 8, as shown by the arrow through the blue pins in the left panel of figure 1. Finally, the ball hits pin 9 (yellow), the last to fall. Though the ball directly strikes only four pins, all of them topple.

The sequence for a hit on the right side (from the bowler's perspective) of the headpin, as shown in figure 1, is simply mir-

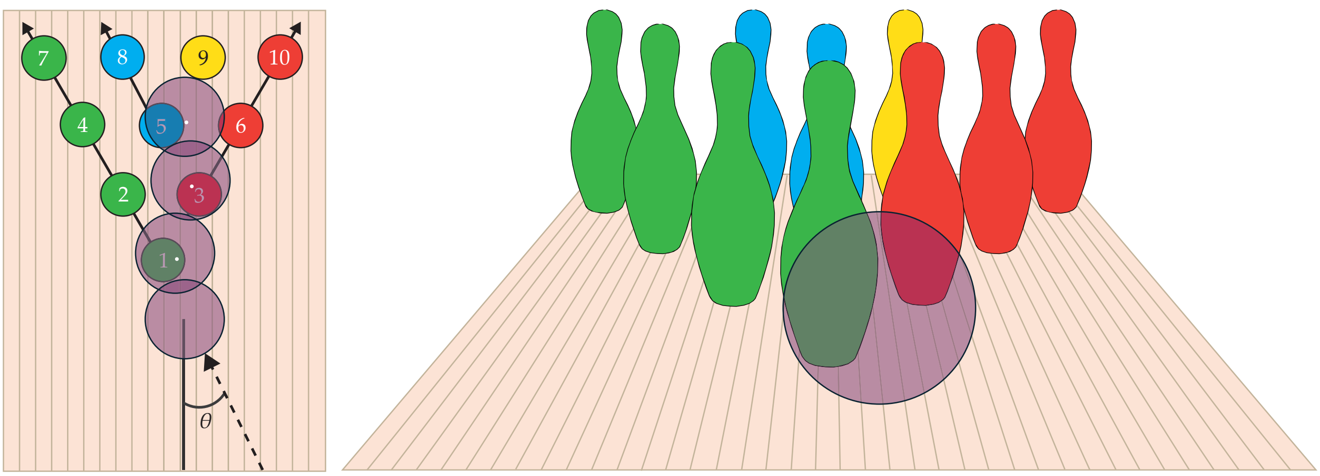

FIGURE 1. A PERFECT STRIKE. Hitting the headpin at a specific position and angle produces a predictable sequence of collisions in which the ball hits four pins that knock down the other six. The ball first hits pin 1, which in turn hits pin 2 into pin 4, which then hits pin 7 (green). The ball then hits pin 3, which sends pin 6 into pin 10 (red). Next, the ball hits pin 5 into pin 8 (blue), before the ball finally hits pin 9 (yellow).

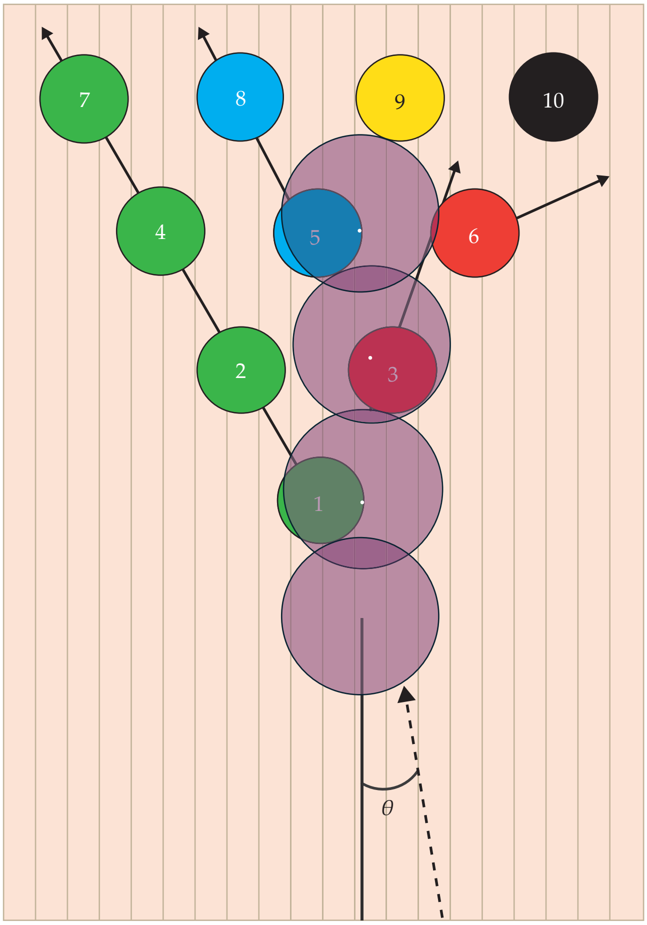

FIGURE 2. ONE PIN LEFT STANDING. When a ball hits the headpin in the correct position but with too shallow an entry angle, pin 3 hits pin 6 out to the side instead of toward pin 10. As a result, one pin is left standing in the back corner.

rored when the ball hits the left side. The former is applicable mostly to right-handed bowlers and the latter to left-handed bowlers. Elite bowlers can aim for either side of the headpin and spin the ball both ways, depending on their strategy.

Spin it

Hitting the headpin around 6.5 cm away from its center requires a great deal of accuracy. The headpin is more than 18 m from the foul line, the boundary that the players' feet must stay behind when they release the ball. It is in a bowler's best interest to increase the area of the headpin that can be hit such that the perfect strike results. That can be achieved through a strategy that involves imparting spin to the ball and uses the oil pattern applied to the lane to one's advantage.

Oil is typically applied to the two-thirds of the lane closest to the bowler. There are a variety of oil patterns, but often, more oil is applied to the center of the lane than to the edges, near the gutters. The low-friction center of the lane promotes skidding, and the edges of the lane provide more traction so that the ball's spin will start to alter its trajectory.

If a bowler can get a ball with rotation close enough to an ideal path, the oil pattern helps funnel it to the desired position on the headpin. A spin-imparted ball that is aimed slightly too close to the gutter curves toward the center of the lane, back toward the ideal position. A ball sent slightly too close to the middle of the lane skids for longer, which lands it closer to the ideal position than it would have been if it had curved earlier in the roll. A graphical explanation can be found in my 2023 article listed in the additional resources.

Hitting the right position on the headpin will not necessarily guarantee a strike. Again, the rotation applied to the bowling ball comes into play. The entry angle θ is that between the line parallel to the edges of the lane and the path that the ball is traveling along as it hits the headpin. If the angle is too shallow, around 2–3°, as shown in figure 2, the chances of incorrect deflection are higher: The headpin must be hit in a very small area to achieve the perfect strike. If the ball strikes the headpin too far from its center, the ball then hits pin 3 too far to the right. Pin 6 is then hit too far to the left and flies in front of pin 10, which is left standing.

As the entry angle is increased up to 6°, the area of the headpin that can be hit to produce the correct deflection increases. As discussed in a 2018 technology study by the US Bowling Congress, a 6° entry angle yields a greater than 95% chance of a strike if the headpin is hit between roughly 5.0 and 7.6 cm from its center. For a 2° entry angle, however, the size of the zone that yields a strike is cut in half—there's a 95% chance of a strike only when the headpin is hit roughly 5.7–7.0 cm from its center.

Though 6° may not seem large, angles greater than 2° can be achieved only by spinning the ball. When the ball is imparted with rotation, it skids along the oil and then gains traction at the unoiled end of the lane. There, it transitions from a skid into a pure roll, in which its translational velocity is equal to the radius of the ball multiplied by its angular velocity. During that transition, the rotation causes the ball to change direction and creates the desired entry angle into the headpin. If bowlers can hit the right speed, rotation, and area of the lane, they can bowl perfect strikes time and time again.

Additional resources

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PT

BACK SCATTER

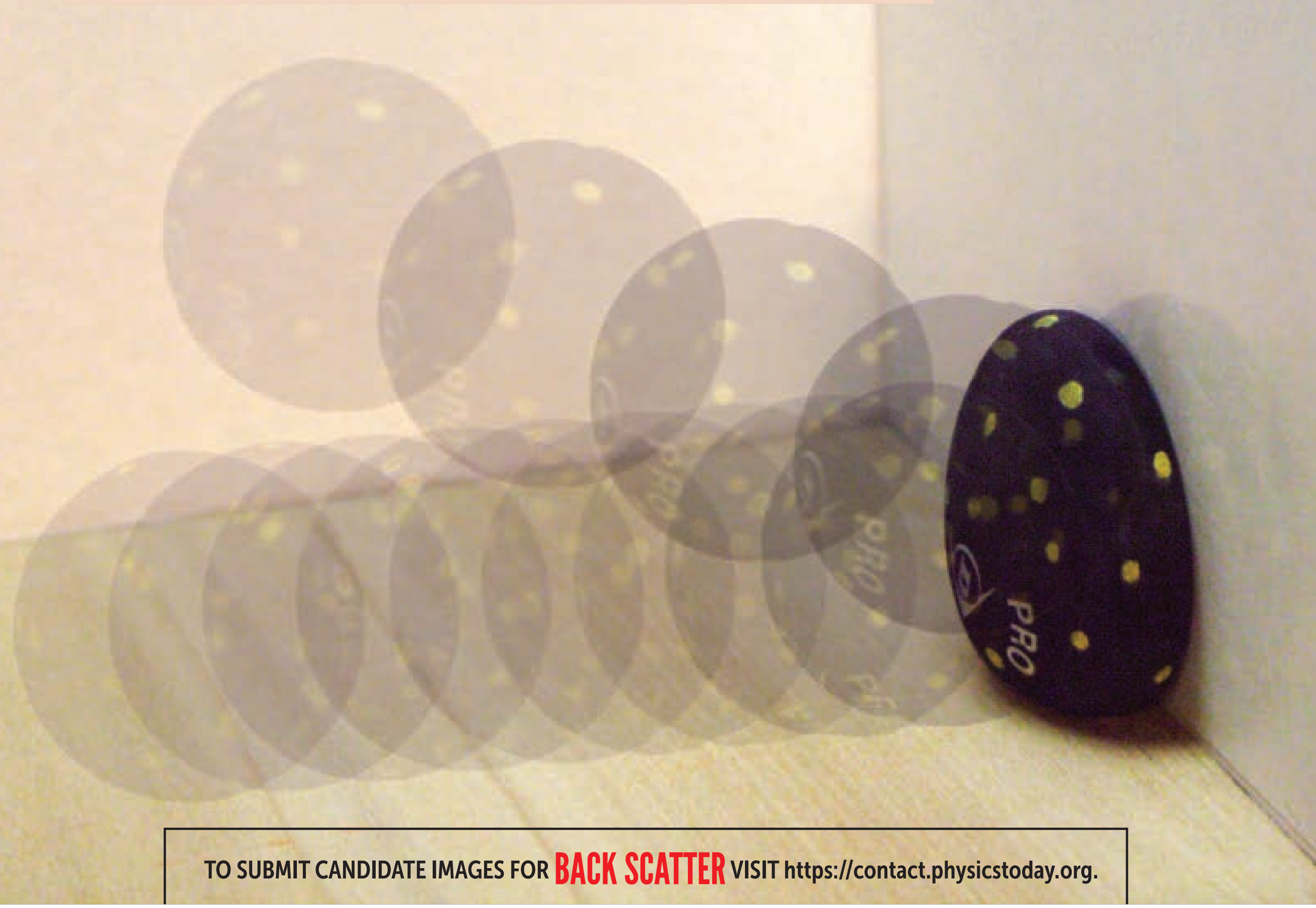
The ingredients for an unbeatable squash shot

In four-walled racket sports such as squash, one type of shot reigns supreme: the nick. It occurs when a player hits the 4-centimeter ball to the right-angled spot where the wall of the court meets the floor. Instead of ricocheting off the surfaces in a way that allows the opposing player to potentially return it, the ball hits the wall and the floor nearly simultaneously and then simply rolls along the floor. The player who pulls off the nick shot is guaranteed to win the point.

A group led by Roberto Zenit at Brown University in Providence, Rhode Island, used a pressurized-air cannon and a high-speed camera to investigate the mechanics of the nick shot. The researchers captured footage of the shot under varying conditions, including different ball types, speeds, and temperatures. As the image illustrates, the unique shot occurs when the ball hits the wall ever so slightly above where it meets the floor. (Successive frames in the image were captured 1 millisecond apart.)

With those observational data, Zenit and his team constructed a mathematical model of the nick shot. They determined that the key to the shot is the slight downward roll of the ball that occurs after it hits the wall and deforms. If the ball is still rolling along the wall when it collides with the floor, that new contact point induces a torque that cancels out the roll and brings the ball's vertical velocity to zero. But because the ball still has energy stored from its deformation, it decompresses and rebounds from the wall solely in the horizontal direction.

Zenit and his team say that along with helping squash players achieve the nick shot more easily—a warm ball is best, and players should fully extend their arm when swinging—their modeling of the shot could lead to better designs for shock-absorbing dampers. (M. Ravisankar et al., *Proc. Natl. Acad. Sci. USA* **122**, e2505715122, 2025; image courtesy of the Zenit Research Lab/Brown University.) —RD



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