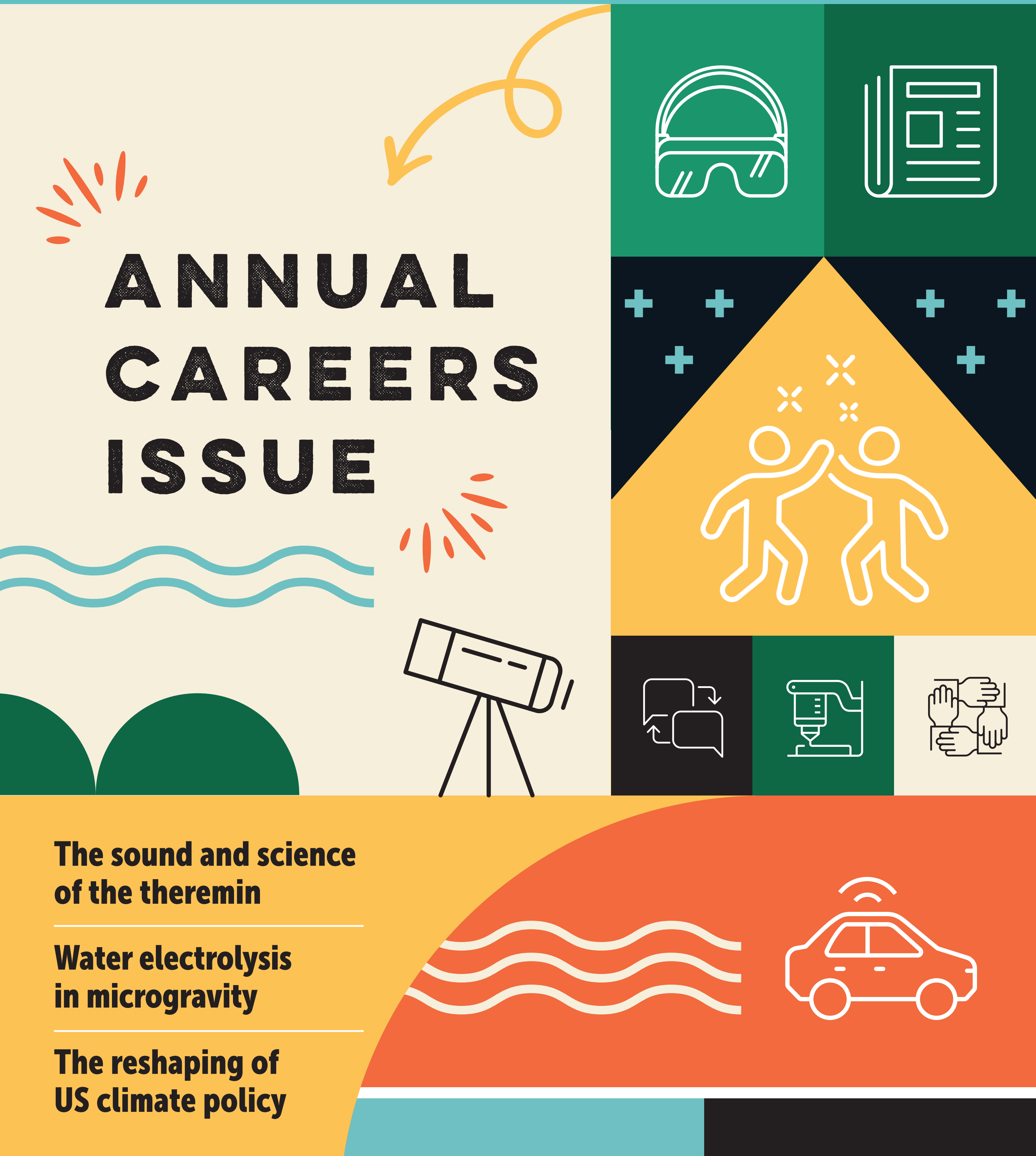
PHYSICS TODAY

November 2025 • volume 78, number 11

A publication of the American Institute of Physics

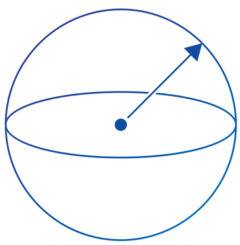


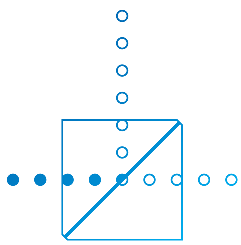
ANNUAL CAREERS ISSUE

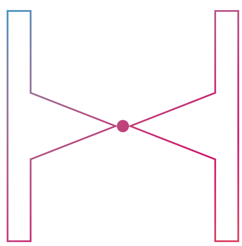
The sound and science of the theremin

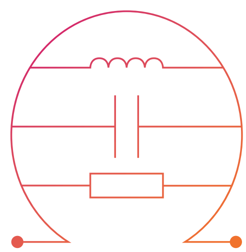
Water electrolysis in microgravity

The reshaping of US climate policy









Ultra-stable **DC Voltage Source**

DC205 ... $2995 (U.S. list)

- ±100 VDC range
- True 6-digit resolution
- 1 ppm/°C stability
- 0.0025 % accuracy (1 yr)
- Triggerable voltage scans
- Low-noise design
- Linear power supply

When you need a quiet, stable, high-resolution bias voltage, the DC205 is the right tool. Its bipolar, four-quadrant output delivers up to 100 volts with microvolt resolution and up to 50 mA of current. In 4-wire mode (remote sense), the instrument corrects for lead resistance delivering accurate potential to your load. The DC205's output stability is a remarkable ±1 ppm over 24 hours. With its linear power supply, there is no need to worry about high-frequency noise.

The DC205 can generate triggerable scans when voltage ramping is required. It is also fully programmable over RS-232 and USB, and there's a fiber optic interface for use with the SX199 Optical Interface Controller.

thinkSRS.com/DC205

Stanford Research Systems
Tel: (408)744-9040 • www.thinkSRS.com

RC2

PHYSICS TODAY

November 2025 | volume 78, number 11

CAREERS ISSUE

ON THE COVER: Many students in the physical sciences may perceive academia as the default career path. But a majority of people with degrees in physics (and related fields) go into the private, public, and nonprofit sectors. This year's careers issue explores eight diverse journeys into nonacademic jobs (**page 26**), skills in demand for private-sector positions (**page 38**), and ways that professional societies can help early-career scientists as they embark on their journeys in both nonacademic and academic settings (**page 46**). (Design by Masie Chong with artwork adapted from iStock.com artists ilyaliren, SpicyTruffel, VectorMine, appleuzr, spiralmedia, fleaz, Margi, and Giorgi Gogitidze.)

Physics Today (ISSN 0031-9228, coden PHTOAD) volume 78, number 11. Published monthly by the American Institute of Physics, 1305 Walt Whitman Rd, Suite 110, Melville, NY 11747-4300. Periodicals postage paid at Huntington Station, NY, and at additional mailing offices. POSTMASTER: Send address changes to Physics Today, American Institute of Physics, 1305 Walt Whitman Rd, Suite 110, Melville, NY 11747-4300.

PHYSICS TODAY

www.physicstoday.org

DEPARTMENTS

SUBSCRIPTION QUESTIONS? +1 800 344 6902 | +1 516 576 2270 | **ptsubs@aip.org**

Editor-in-chief
Richard J. Fitzgerald *rjf@aip.org*

Managing editors
Andrew Grant *agrant@aip.org*
Johanna L. Miller *jlm@aip.org*

Art and production
Freddie A. Pagani, art director
Masie Chong, senior graphic designer
Nathan Cromer
Abigail Malate

Editors
Ryan Dahn *rdahn@aip.org*
Jenessa Duncombe *jduncombe@aip.org*
Laura Fattaruso *lfattaruso@aip.org*
Toni Feder *tf@aip.org*
Abby Hunt *ahunt@aip.org*
Alex Lopatka *alopatka@aip.org*
Gayle G. Parraway *ggp@aip.org*

Assistant editor
Nashiah Ahmad *nahmad@aip.org*

Digital operations
Greg Stasiewicz *gls@aip.org*

Editorial assistant
Tonya Gary

Contributing editors
Mitch Ambrose
Andreas Mandelis
Lindsay McKenzie
Jacob Taylor
Clare Zhang

Sales and marketing
Christina Unger Ramos, director *cunger@aip.org*

Address
American Institute of Physics
1 Physics Ellipse
College Park, MD 20740-3842
+1 301 209 3100
pteditors@aip.org

Career choices in uncertain times

Richard J. Fitzgerald

Embarking on a new career has always been challenging, and not just in the physical sciences. Some people find it exhilarating; some are more apprehensive; almost all will seek advice—or give it—along the way. Providing useful information on the employment landscape, potential career journeys, and community resources was the motivation in 2019 for PHYSICS TODAY's first annual careers issue.

Today, six years later, the challenges facing those entering the workforce—and many seeking to remain in it—are unprecedented in recent memory. As the *PT* editors began planning this careers issue, we knew it shouldn't be a typical one. We wrestled with what we could present now, amid the turmoil roiling the scientific community, that would be helpful to those trying to navigate it.

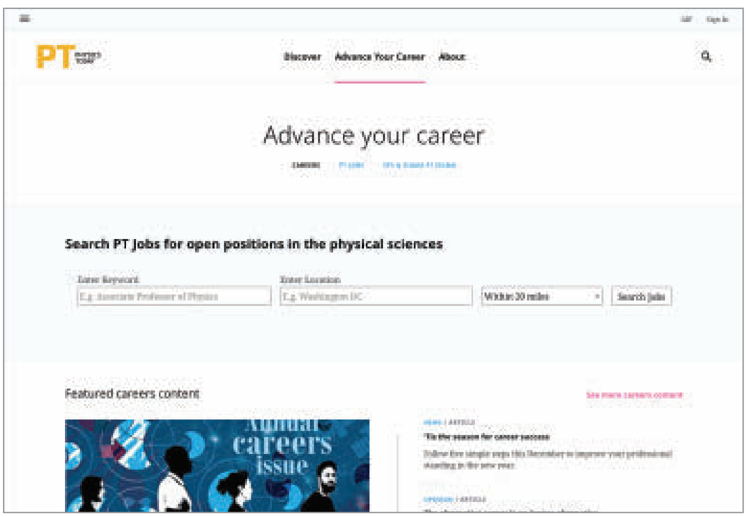
Our answer, ultimately, was a return to basics: the breadth of career options available and tools that can help along the way. Having a background in the physical sciences prepares you for much more than a career in academia. Starting on page 26, Toni Feder takes a "show, don't tell" approach: She has assembled a collection of short interviews, drawn from a new, recurring online series, featuring people whose jobs and career paths in nonacademic sectors illustrate how broad and varied the realm of possibilities is.

Survey data have shown that more than half the recipients of physics bachelor's degrees and a third of PhD earners find work in the private sector. To gain insights into that career step, Alex Lopatka talked with several people who work on the hiring side. As he reports starting on page 38, the technical skills you may have learned as an undergraduate, grad student, or postdoc get you only so far as you embark on a path in the private sector; companies are looking just as much for flexible problem-solving ability and strong collaboration and communication skills.

Networking remains key to landing a new job, especially when just starting out. The physical sciences community features a valuable set of resources: professional societies that can help provide networking opportunities, cultivate a sense of belonging, and nurture individuals at the start of their careers. In the article beginning on page 46, Trevor Owens and Anne Marie Porter explore how four such individuals have benefited from their society memberships. The authors share tips not only for early-career professionals but also for their mentors.

A new careers home

For those of you who are reading this on the *PT* website, you have already experienced our recently debuted, modernized experience. For those reading this in print, I encourage you to go check us out at https://physicstoday.org. *PT*'s refreshed and redesigned digital home makes it easy to stay abreast of the latest developments at the frontiers of science and at science's intersection with society, stay connected to the physical sciences community, follow topics of interest to you, and indulge your curiosity.



A dedicated section of *PT*'s new website gathers into a single place career resources from throughout *PT*'s extensive archives and from other parts of the American Institute of Physics (publisher of *PT*). The annual careers issues are just the start. In addition to seeing the latest in our interview series of what physicists can do, you can check out the latest employment trends, survey results, and interactive graphics from AIP's statistical research team. It's also an entry point into *PT*'s jobs board.

PT's collected careers-related content is but one segment of our new online experience. Let us know what you think at https://contact.physicstoday.org. PT

Magnetic fields facilitate water electrolysis in microgravity

The physics behind the levitating frog and a fictional submarine could help future astronauts to breathe easier.

Bremen, Germany, is not known for its skyscrapers. The tallest structure in the city is a 236 m telecommunications tower. The second tallest, the 146 m Bremen Drop Tower (shown in figure 1), is devoted to scientific research. It's the main facility of the Center of Applied Space Technology and Microgravity (ZARM) at the University of Bremen, and it houses an unobstructed vertical tube that allows researchers to see how experiments behave in free fall.

Diverse physical phenomena are studied at the Bremen Drop Tower, including turbulent flow and matter-wave interferometry. But the center's codirector Katharina Brinkert is an electrochemist with an interest in developing systems to produce oxygen and fuels, such as hydrogen, for space exploration missions.

On Earth, the electrochemical splitting of water into its component elements is a familiar and well-studied reaction. Hydrogen accumulates at the cathode, oxygen at the anode, and both gases bubble up through the liquid and can be collected at the surface. But without gravity, there is no "bubbling up." Some other forces are needed to pull the gas bubbles away from the electrodes.

Now Brinkert has teamed up with ZARM research associate Ömer Akay, Georgia Tech assistant professor in aerospace engineering Álvaro Romero-Calvo, and others to show that magnetic fields might do the job in not just one but two ways.[1] In their proof-of-principle experiments at the Bremen Drop Tower, the researchers demonstrated two fundamentally different uses of magnetic forces to facilitate water electrolysis in microgravity. In one, the forces act on the water molecules themselves; in the other, they act on ions in solution.

Lighter load

Magnetism isn't the only way to separate bubbles from water in microgravity, and it's not the first thing that's been tried. The life-support system on the International Space Station uses water electrolysis to produce oxygen for the astronauts to breathe—water is easier and safer than oxygen to carry in large amounts—and it uses a centrifuge to separate the reaction products. But the machinery uses a lot of energy, and its moving parts are prone to failure.

For a space mission, mechanical unreliability introduces a unique set of practical challenges, as Romero-Calvo explains. "Imagine you want to take a road trip across the desert," he says. "There are no service stations. What do you do if you get a flat tire? Well, you have to bring another tire with you—and not just one, but as many as you think you'll need for the whole trip."

There are no spacecraft repair shops in space. Astronauts need to bring with them all the spare parts they'll need for the whole mission, or at least until their next contact with Earth. For long missions, such as a future crewed trip to Mars, the mass of the payload adds up quickly, and so does the expense.

In that context, magnets have the considerable advantage that there's nothing to break. Neodymium permanent magnets produce extraordinarily strong magnetic fields, but with no moving parts and no power consumption.

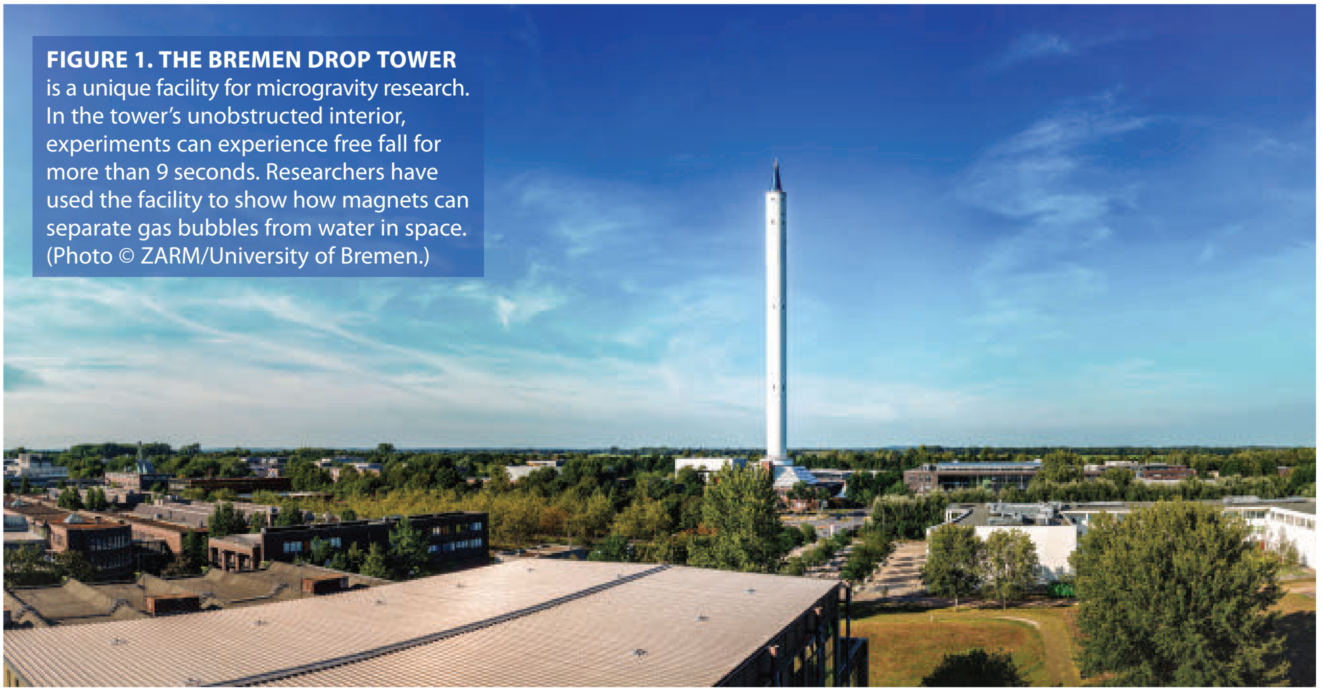


FIGURE 1. THE BREMEN DROP TOWER is a unique facility for microgravity research. In the tower's unobstructed interior, experiments can experience free fall for more than 9 seconds. Researchers have used the facility to show how magnets can separate gas bubbles from water in space. (Photo © ZARM/University of Bremen.)

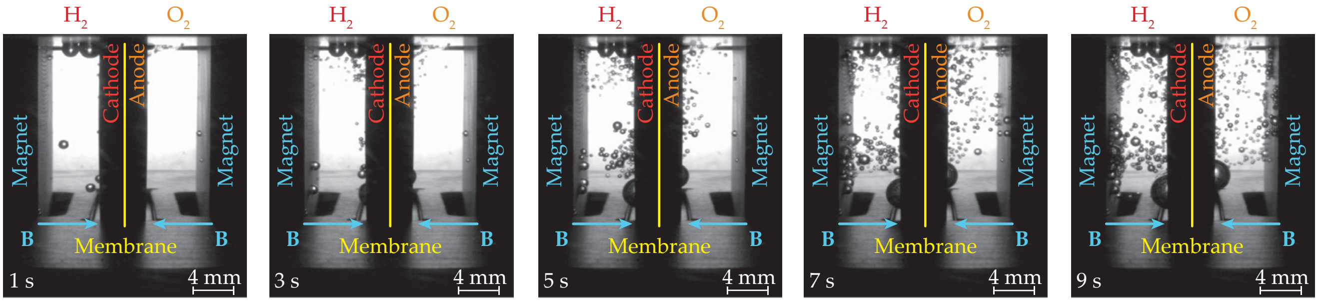


FIGURE 2. DIAMAGNETIC REPULSION pushes water away from magnets. So when a pair of magnets flank an electrochemical cell, the magnetic field **B** pushes the water toward the electrodes at the center. There, it displaces the hydrogen and oxygen gas bubbles, which flock toward the magnets. (Images adapted from Ö. Akay et al./CC BY 4.0.)

They should, in principle, reliably last for as long as they're needed.

What goes up

Water electrolysis under magnetic fields has been studied on Earth. "But the beauty of space research is that you can see lots of cool effects that are usually masked by gravity," says Romero-Calvo. The results aren't always what one expects, he explains, and there's no substitute for actually doing the experiments.

To bring microgravity to Earth, the Bremen Drop Tower exploits the well-known principle that when a whole system is in free fall, gravity acts on all parts of it equally, and it behaves as if there were no gravity. But the facility takes it a step further. Instead of carrying experimental devices to the top of the tower and dropping them, which would give a free-fall time of about 4.7 seconds, ZARM researchers launch their setups upward from ground level. The systems are subject to strong forces upon liftoff (and upon landing), but for the rest of their 9.3-second trajectory—on the way up and the way down—the devices experience weightlessness.

"There's nothing like it in the US," says Romero-Calvo. In comparison, NASA's Zero Gravity Research Facility in Cleveland, Ohio, has an underground drop shaft that's slightly taller than the Bremen Drop Tower, but it's equipped only for one-way trips of 5.2 seconds.

How do they work?

Water is diamagnetic, which means that its molecules are repelled by magnets. Normally, the force of repulsion is far too weak to have any practical effect unless the magnet is extremely strong. It was diamagnetism—mostly of water—that allowed Andre Geim and colleagues, in 1997, to famously levitate a frog. (See the article by Geim in Physics Today, September 1998, page 36.) The feat garnered Geim his Ig Nobel Prize in 2000, 10 years before he was awarded the real Nobel Prize for his work on graphene.

Levitating a frog in Earth's gravity required a 20 T electromagnet. The Nd permanent magnets used in the water-electrolysis experiments have just a few percent of that strength. But without the force of gravity to overcome, even a modest diamagnetic repulsion can be significant. The results of a 9-second ZARM test are shown in figure 2 and the video in the online version of this piece.

The electrochemical cell used in the first round of ZARM tests is about 1 cm in width. When an electric current is applied to a pair of mesh electrodes, bubbles of H_2 and O_2 quickly form on either side of a proton-exchange membrane. Without magnets, the gases would build up on the electrodes, and the reaction would grind to a halt. But magnets at the cell's outer edges push the water toward the cell's center. The bubbles, as a result, flow away from the electrodes and toward the magnets.

The team's second setup was cinematically inspired. In *The Hunt for Red October*, Sean Connery's character's submarine is powered by a magnetohydrodynamic drive: Seawater is subjected to both an electric current and a magnetic field, and the Lorentz force acting on the salt ions sends the water spiraling in a corkscrew trajectory that pushes the sub forward. Reality is not quite as elegant as fiction, but when the researchers designed a cell with ring-shaped electrodes and placed it in a magnetic field, the Lorentz forces did work to sweep the bubbles off the electrodes.

All coming together

"What we demonstrated is a TRL-3 technology," says Romero-Calvo, referring to NASA's scale of technology readiness levels: TRL 3 refers to the lab demonstration of a technology's critical function. "To get this to orbit," he says, "we'll need to reach TRL 8," with a full-scale electrolysis system built, tested, and ready to go.

In addition to constructing a larger electrolysis cell and testing it for more than 9 seconds, the researchers will need to grapple with several more practical considerations. For example, how will the product gases be collected from the cell, and how much humidity and other impurities will they contain? How much energy will the electrolysis consume, and will it be possible to integrate the cell directly with solar-powered photoelectrodes? With ongoing funding from NASA and the European Space Agency, the researchers are already working on those next steps.

The physics of magnetism at the heart of the technology is old news. If it's such an appealing way to separate liquids from gases in microgravity, why hasn't it been considered before now? "That's a good question," says Romero-Calvo. "I believe it's because we put together so many concepts from distant fields. Space electrochemistry is a very small field. Magnetic electrolysis is another very small field. Sustained access to microgravity is even more exceptional. The fundamental-science and applied-engineering perspectives are hard to mix. It's quite an exceptional combination of factors that really enabled our work."

Johanna Miller

Reference

1. Ö. Akay et al., *Nat. Chem.*, (2025), doi:10.1038/s41557-025-01890-0.

Radioactive ion beam enables monitoring of a cancer treatment as it's performed

Using radioactive ions for particle therapy could lead to real-time imaging of radiation doses to improve the precision of treatment.

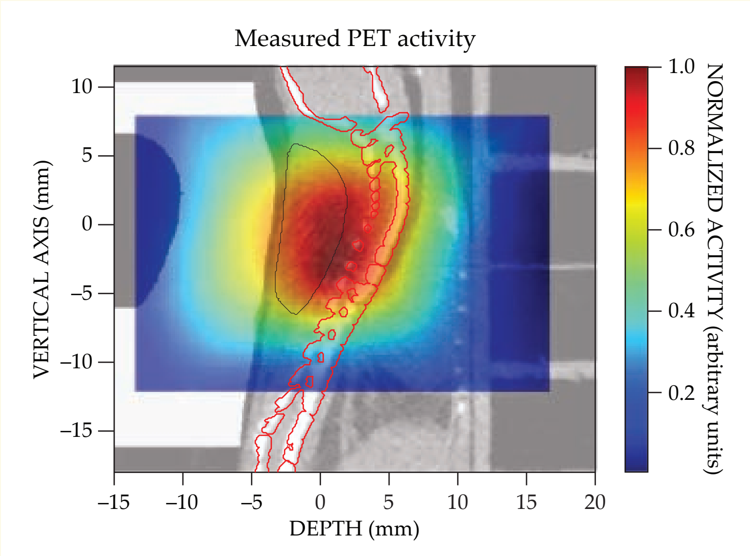
Among the radiation therapies used to treat cancer, particle therapy is notable for delivering radiation to a highly targeted location in the body while conveying limited radiation to surrounding tissue. That radiation is more targeted than photon radiation because, unlike gamma rays or x rays, accelerated particles release the most energy just before they come to a stop. Doctors use CT and MRI images, immobilization devices, dosage calculations, and robotic adjustments to target tumors with the greatest possible precision. But with no way for doctors to measure the location of the radiation peak as it's being applied, delivering it to the ideal place in the body poses a challenge.

Now researchers in the lab of Marco Durante at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, have shown, in living mice, how using a beam of radioactive ions enables measurement of the radiation peak during treatment. "If I can see where I'm shooting, I can correct," Durante says.

Particle therapy is typically administered using protons, neutrons, or carbon-12 ions. The researchers used carbon-11, a radioactive isotope that undergoes positron-emitting beta decay. Recent upgrades to the FAIR (Facility for Antiproton and Ion Research) particle accelerator at GSI enabled the generation of a ^{11}C beam with the necessary intensity to perform radiotherapy. The researchers used a positron emission tomography (PET) scanner to detect the dose of ions as they were delivered. PET is usually used for diagnostics to measure beta decay produced by small doses of radioactive drugs given to patients before a scan (see "Medical imaging with antimatter" by John Sunderland, Physics Today, September 2025, page 28).

The experiment was performed on osteosarcoma tumors, which are radioresistant and often treated with ^{12}C ions. Tumor cells were implanted in the mice's necks, next to the spinal cord, and allowed to grow for a few weeks. Damage to the spine from errant radiation could cause paralysis. The research team was able to precisely measure the delivered dose of radiation, as shown in the figure on the next page, and monitor as the ions decayed and got carried away by the blood. None of the mice exhibited paralysis. A single high-dose treatment was most effective in preventing tumor regrowth. The treatment had the same effi-

A HIGH-ENERGY BEAM OF CARBON-11 produced at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, was used to treat cancer in mice. Researchers Daria Boscolo (left) and Tamara Vitacchio (right) are shown arranging the components of the experimental beamline. (Photo © J. Hosan, GSI/FAIR.)



RADIOACTIVE ION BEAM THERAPY directed at a tumor (outlined in black) in a mouse delivered radiation that was measured in real time with a positron emission tomography (PET) scan. By measuring the radiation as it was delivered, the researchers were able to target a precise part of the body and minimize damage to the nearby spinal cord (outlined in red). (Figure adapted from D. Boscolo et al., *Nat. Phys.*, 2025, doi:10.1038/s41567-025-02993-8.)

cacy as traditional particle therapy but with higher precision. Clinical trials would be needed to test the technique on humans.

The researchers plan to investigate the use of other radioactive ions for cancer treatment, including carbon-10 and oxygen-15. Both have a shorter half-life (about 20 seconds and 2 minutes, respectively) than ^{11}C, which has a half-life of about 20 minutes. The shorter decay time would allow faster real-time tracking of the treatment. Plans are also in the works at CERN to create ^{11}C sources that could be used at existing ^{12}C-ion therapy synchrotrons. There are currently 17 carbon radiotherapy centers in the world—all in Asia and Europe. The first carbon radiotherapy facility in the US is under construction at the Mayo Clinic in Jacksonville, Florida, and slated to open in 2028. (D. Boscolo et al., *Nat. Phys.*, 2025, doi:10.1038/s41567-025-02993-8.)

Laura Fattaruso

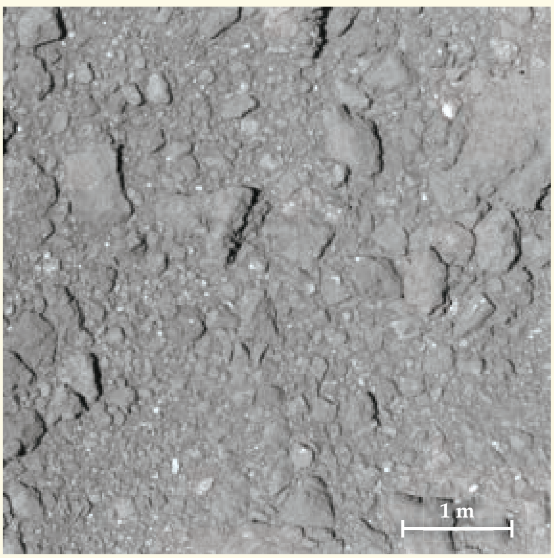
Lutetium and hafnium tell the story of liquid water on asteroid Ryugu

Despite the tumultuous history of the near-Earth object's parent body, water may have been preserved in the asteroid for about a billion years.

Shortly after the coalescence of the solar system 4.6 billion years ago, the parent body of the near-Earth asteroid 162173 Ryugu had liquid water. At that time, the parent body was in the solar system's outer region, where water is frozen. But for the first 7 million years of the parent body's existence, limited radioactive decay provided enough heat to melt the ice and make liquid water. Some time later, an asteroid smashed into the parent body, and Ryugu formed from the impact fragments. Today, Ryugu has almost no water—and how water left the asteroid and when is uncertain.

To study the long-term fate of water in Ryugu, the *Hayabusa2* mission, organized by the Japan Aerospace Exploration Agency, rendezvoused with the asteroid in June 2018. Then, automated instruments on the spacecraft scooped up samples from the asteroid, made various measurements, and arrived back to Earth in December 2020. Now the University of Tokyo's Tsuyoshi Iizuka and colleagues have presented isotope data from Ryugu samples that suggest water could have stuck around as ice for roughly a billion years before an impact fractured the asteroid and caused the ice to melt, mobilize, and escape to space.

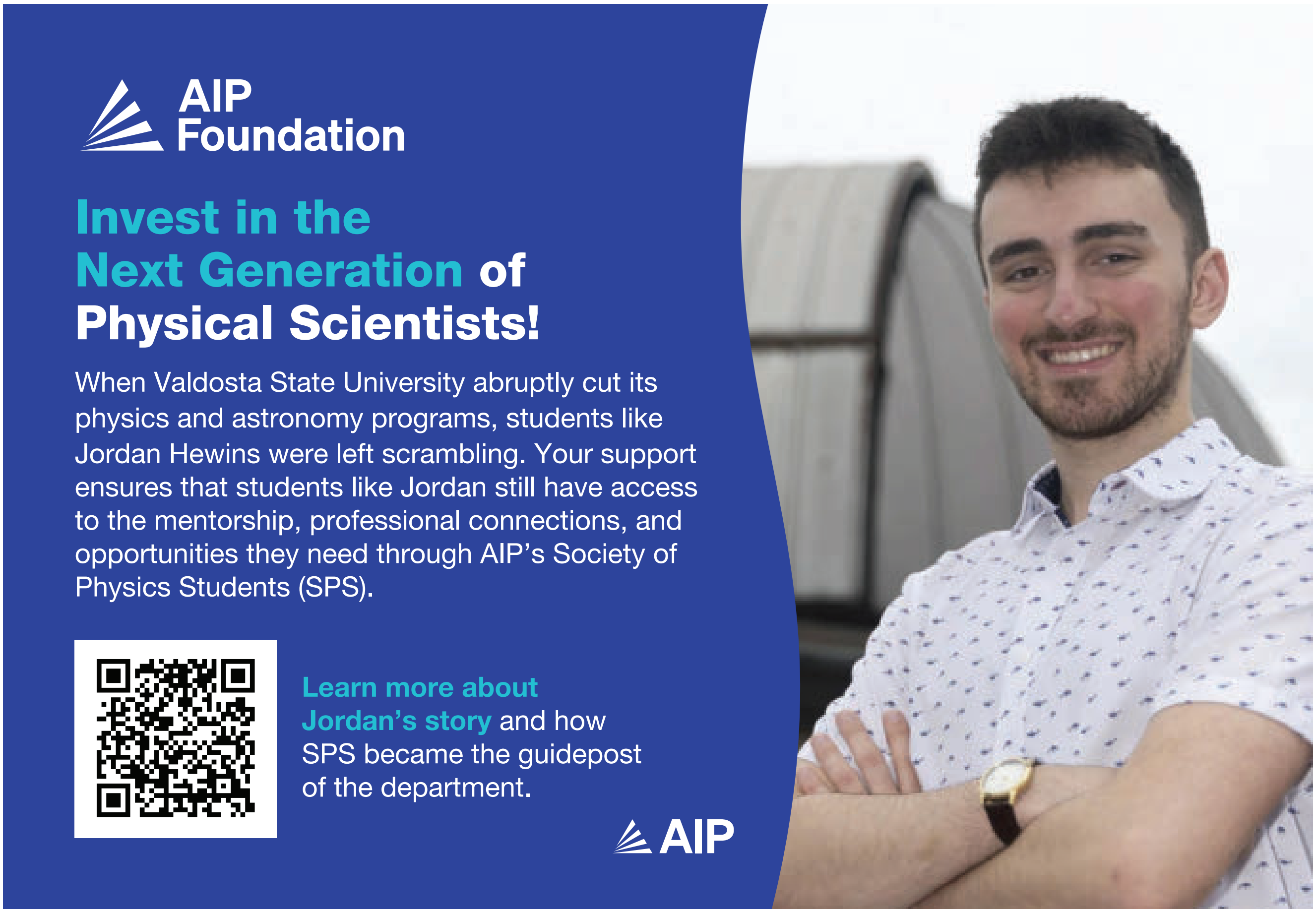
The researchers used mass spectrometry to measure the isotopic abundances of samples that contained the rare-earth element lutetium and the transition metal hafnium. The isotopes ^{176}Lu and ^{176}Hf can be used as a geological chronometer. In the asteroid, ^{176}Lu and some ^{176}Hf were found in apatite minerals, and the researchers saw that the minerals' grain boundaries were partially dissolved. Isotope results showed a ^{176}Lu deficit relative to ^{176}Hf, which is consistent with fluid reactions that would leave relatively insoluble ^{176}Hf behind. Together, those clues led the team to suspect that ice melted and water carried Lu to the parent body's surface after it was struck by the asteroid that likely formed Ryugu.



THE SURFACE OF THE RYUGU ASTEROID was photographed from an altitude of 42 m on 15 October 2018 by a camera on the *Hayabusa2* spacecraft. (Photo by JAXA, University of Aizu, and collaborators.)

According to the researchers' calculations of Lu's starting abundance and rate of loss, the water refroze after radioactive decay dissipated and remained as ice for the next billion years. Then, the asteroid impact could have generated enough heat to melt the ice, and the ensuing fractures would have allowed the fluid, with the dissolved Lu from apatite minerals, to flow predominantly from the inner region of the Ryugu parent body to its surface. As the asteroid's orbit drifted closer to the Sun, solar energy enhanced water degassing and ice sublimation, which would explain the lack of water in Ryugu that's observed today. (T. Iizuka et al., *Nature* **646**, 62, 2025.)

Alex Lopatka PT


AIP Foundation
Invest in the Next Generation of Physical Scientists!
When Valdosta State University abruptly cut its physics and astronomy programs, students like Jordan Hewins were left scrambling. Your support ensures that students like Jordan still have access to the mentorship, professional connections, and opportunities they need through AIP's Society of Physics Students (SPS).
Learn more about Jordan's story and how SPS became the guidepost of the department.
AIP


MAKE A DIFFERENCE IN SCIENCE AND SOCIETY
APS and AIP Congressional Science Fellowships
Help infuse science into the policy making process. The American Physical Society and the American Institute of Physics welcome applications for their 2026 Fellowship Programs. As a fellow, you will spend a year providing analytical expertise and scientific advice to Congress, informing important societal issues. Scientists of all career stages are welcome to apply.
Apply Now!
Congressional Fellowship Deadlines:
APS - November 4; AIP - December 1
bit.ly/CongressFellow
APS
AIP

Five ways the second Trump term is reshaping climate science and policy

A review of federal actions on science, data, and policy in the administration's first eight months shows far-reaching consequences.

PRESIDENT TRUMP SIGNS AN EXECUTIVE ORDER in the Oval Office during his second term. (Photo by the White House.)

The Environmental Protection Agency announced plans this summer to rescind its 16-year-old finding that carbon dioxide and other greenhouse gases harm public welfare. The potential revocation of the finding, which provides the legal basis for much of the agency's authority over climate pollution, is a prominent example of how the state of US climate science has not been business as usual since President Trump regained power in January. Administrative actions have broadly affected climate science in immediate, personal ways like layoffs and in wider-sweeping ways through policy.

It can be easy to lose sight of the big picture. What follows is a nonexhaustive list of the trends that are shaping climate science during the first eight months of Trump's second term. This list mostly excludes the budget fight going on in Congress, which could either cut or maintain science funding in the next fiscal year.

1. Tracking greenhouse gas emissions is becoming more difficult

The US has published a tally of its greenhouse gas emissions each year since 1997 as part of its responsibilities to the United Nations Framework Convention on Climate Change. The annual report is a highly used resource because it summarizes carbon sinks and emissions in economic sectors like agriculture and transportation. But this year, the EPA hasn't published the report, despite a draft of it being completed. The nonprofit advocacy group Environmental Defense Fund filed a Freedom of Information Act request for the report in April and published it online the following month. As of September, the final report is still not available on the EPA website.

The Trump administration also proposed in September to end the mandatory requirement, in place for at least 15 years, that polluters report greenhouse gas emissions to the EPA. Typically, around 8000 facilities submit emissions numbers each year, according to ProPublica. Those numbers are useful for tracking sectors' carbon footprints and efforts to curb emissions.

Separately, the *New York Times* reported in August that the EPA may stop updating a widely used database for calculating greenhouse gas emissions along supply chains. The Supply Chain Greenhouse Gas Emission Factors database is one of the top three resources used on Data.gov, the federal government's repository of hundreds of thousands of datasets.

Proposed budget changes would affect the monitoring of greenhouse gases. NASA may terminate two greenhouse gas–tracking missions ahead of schedule, according to NPR in August. The Orbiting Carbon Observatories monitor carbon dioxide on Earth from instruments on a stand-alone satellite and on the International Space Station. The data are used by farmers, oil and gas companies, and scientists to monitor pollution and crop health. If decommissioned, the satellite would be purposely burned in the atmosphere, and the space station's device would no longer be supported. A 2023 NASA review had praised the satellite's "exceptionally high quality" data.

Budget cuts could also halt atmospheric measurements of greenhouse gases at the Mauna Loa Observatory in Hawaii (famous for the Keeling curve) and at dozens of other NOAA sites around the world.

2. The government is shrinking its climate workforce

The nonprofit Partnership for Public Service is tracking departures of federal employees; as of 23 September, the number is at more than 201 000. Scientists

AN ARTIST'S CONCEPTION of the *Orbiting Carbon Observatory-2* launched into space in 2014 to quantify, among other things, how forests and the ocean can offset carbon dioxide emissions. (Image by NASA/JPL-Caltech.)

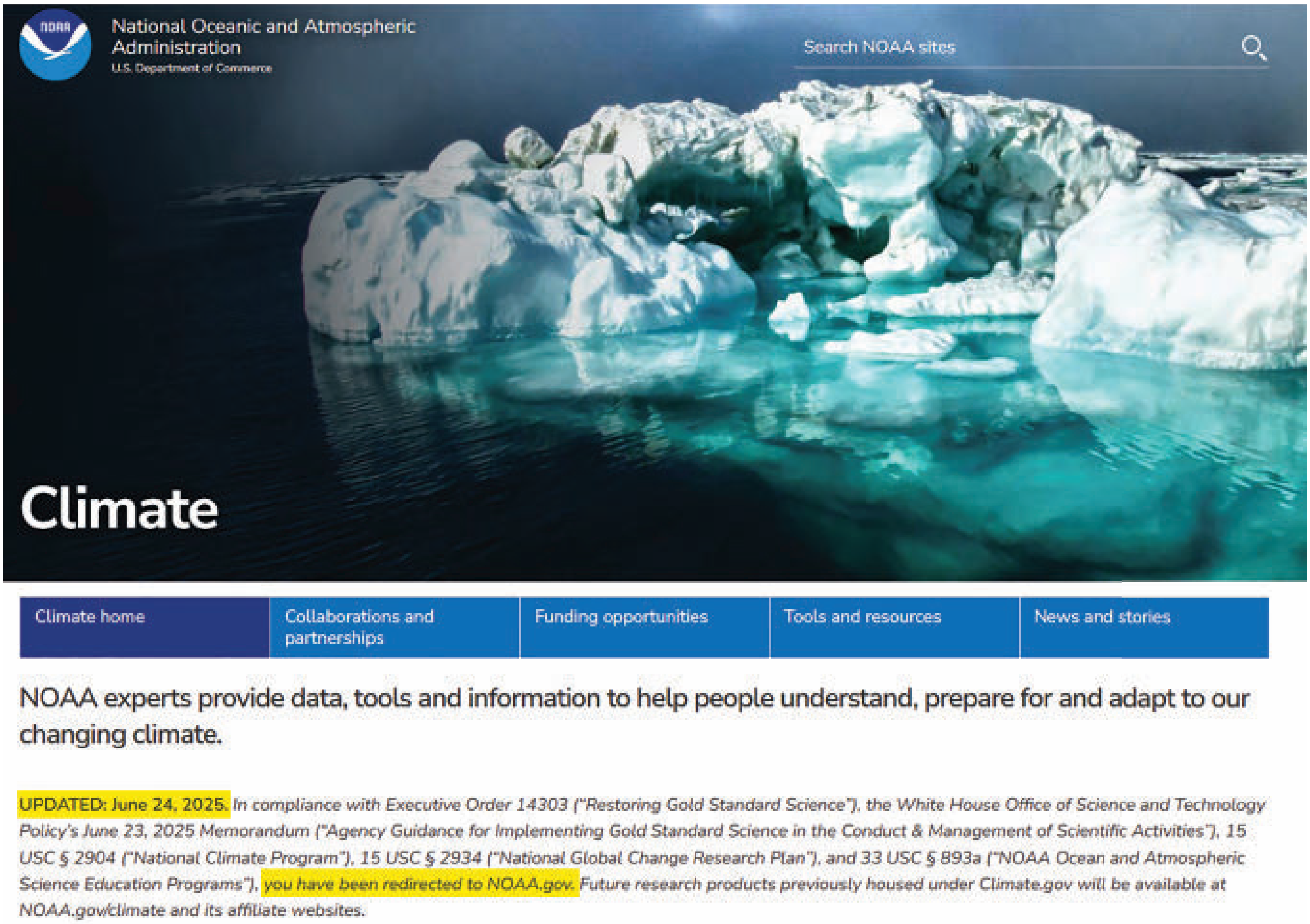
have left federal positions across diverse agencies, including the Department of Energy, the EPA, NASA, NSF, NOAA, and the Department of Agriculture. Some had been probationary employees, some took the deferred-resignation offers, and others were laid off as part of the administration's downsizing of the federal workforce. Others have been placed on administrative leave or fired after signing open letters to the EPA and the Federal Emergency Management Agency.

It's hard to know how many scientists have left the agencies—data reporting has been scattered and inconsistent. One data point is from NASA, whose work includes collaborating with NOAA and other federal agencies to study Earth's climate. According to documents obtained by *Politico* and reported on in July, of the 2694 employees who accepted NASA's offer to retire or resign, more than half held positions in mission areas in science or human spaceflight. In August, NASA acting administrator Sean Duffy said in a *Fox Business* interview that the agency will move away from climate and Earth science.

Some agencies are folding research offices and relocating research jobs. The EPA announced in July that it is dissolving its Office of Research and Development. The office conducts research on climate change's effects on air and water quality, among other topics. The agency said it will create a new research group in the policy-focused office of the administrator. *Politico* reported in September that Senate appropriators may require the EPA to keep the Office of Research and Development intact.

Although many jobs have been eliminated, some may come back: The National Weather Service wants to hire some 450 meteorologists, hydrologists,

FORMER NOAA DIRECTOR RICK SPINRAD (in blue hat and coat) addresses a crowd protesting NOAA layoffs outside the agency's headquarters in March. (Photo by Clare Zhang/AIP.)



CLIMATE.GOV NOW REDIRECTS to a NOAA.gov webpage, as seen in this screenshot. The US government climate change information website was shuttered in June. The highlights were added by PHYSICS TODAY for emphasis. (Image by PHYSICS TODAY.)

and radar technicians to partially replace the more than 500 employees lost to layoffs and retirements earlier this year, CNN reported in August. The service provides weather, water, and climate data for the public and runs the National Centers for Environmental Prediction.

3. Climate information and advisory panels are disappearing

In the first 100 days of Trump's second term, 310 changes were made to federal webpages about climate change, according to the Environmental Data and Governance Initiative. The changes totaled 847 by the end of June.

NOAA's premier climate change information website, Climate.gov, was shut down in June, weeks after the *Guardian* reported that NOAA had fired most of the site's staff. Nearly a million users had visited the site per month, according to NPR. The website now redirects to a different NOAA webpage. Most Climate.gov information is available at the new location, but navigation is more difficult and there are no staff to maintain the resources, says Izzy Pacenza, coauthor of the analysis published by the Environmental Data and Governance Initiative. Some members of the former Climate.gov team launched a public fundraiser in late August to start a nonprofit version of Climate.gov called Climate.us. The platform would provide resources for climate science, communication, and education, according to Climate.us.

Globalchange.gov, the website of the US Global Change Research Program that housed the country's five National Climate Assessments, was also deleted this summer. Despite initially saying that it would publish the assessments on NASA's website, the Trump administration said in a July email to the Associated Press that it has no obligation to post them. Some are still available as of September in NOAA's repository.

Nearly 400 scientists and other experts working on the sixth US National Climate Assessment, which is due by 2028, were dismissed by the administration in April. The congressionally mandated report is written by both federal and outside scientists, who were told that the process was being evaluated by the administration, according to Reuters. "What's at risk with this dismissal is not only the report itself, but its credibility if it moves forward without the experts that ensure its scientific integrity," climate scientist Meade Krosby at the University of Washington told CNN in April.

Through an executive order earlier this year, the administration disbanded dozens of federal advisory committees of scientists, including those advising on climate change for NOAA and the US Geological Survey, according to *FYI*. And databases geared toward scien-

EPA ADMINISTRATOR LEE ZELDIN at a truck dealership in Indiana on 29 July announces the proposed end of the 2009 endangerment finding that enables the agency to regulate carbon dioxide emissions. DOE Secretary Chris Wright stands at the far left. (Image from the EPA.)

tists, including many hosted by NOAA that Physics Today reported on in June, have been taken offline or ceased to be updated.

4. Climate-science doubters are placed in positions of power

DOE hired three scientists known as prominent climate-science doubters, reported the *New York Times* in July. The three—physicist Steven Koonin, atmospheric scientist John Christy, and meteorologist Roy Spencer—and two others formed the agency's new Climate Working Group. They authored a DOE report criticizing many established scientific findings in climate science. The group completed the 150-page report in about two months.

Energy Secretary Chris Wright writes in the foreword that the report's conclusions differ from the mainstream narrative and media coverage of climate change, which he claims distort science. For example, the authors write that the attribution of climate change to human carbon dioxide emissions "is challenged by natural climate variability, data limitations, and inherent model deficiencies."

The Intergovernmental Panel on Climate Change's sixth assessment report, released in parts between 2021 and 2023, involved hundreds of scientists from around the globe and took around six years to complete. Its conclusion: "Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming."

Several of the scientists whose work is cited in the DOE report told AFP (Agence France-Presse) for an August article that their research was misused or misrepresented. Retired atmospheric scientist Benjamin Santer, who worked at Lawrence Livermore National Laboratory for 29 years, said that the DOE report "completely misrepresents my work" on climate fingerprinting, a technique to separate human-caused climate change signals from naturally occurring signals.

Previously released National Climate Assessments may be updated by the administration as well, Wright said in an interview with CNN in August. He said that those reports were politically driven and are being reviewed. Each of the five assessments released since 2000 took years to complete and was reviewed by the 13 federal agencies responsible for climate research. The first Trump administration signed off on the fourth National Climate Assessment in 2018.

5. Policy shifts toward deregulation

There have been more than 250 steps taken by the administration to "scale back or wholly eliminate federal climate mitigation and adaptation measures," according to a tracker by Columbia University's Sabin Center for Climate Change Law.

A major such change came in late July when the EPA announced plans to rescind its previous finding that carbon dioxide and other greenhouse gases harm public welfare. The 2009 endangerment finding allows for widespread federal regulation of greenhouse gas emissions from cars, power plants, and other sources. The EPA cited the recent DOE Climate Working Group report as justification for a policy change.

In response, the National Academies of Sciences, Engineering, and Medicine launched a self-funded, fast-track study to summarize findings in climate science gathered since 2009. Although the National Academies carry out many activities requested by Congress and federal agencies, they are independent, nonprofit institutions that do not receive appropriations directly from the government. The report was published on 17 September, five days before the end of the EPA's public comment period on the rescindment proposal for the endangerment finding.

Separately, some 85 climate scientists coordinated by Andrew Dessler, director of Texas A&M University's Texas Center for Extreme Weather, penned a more than 400-page response to the DOE report. In announcing the review in September, they write that DOE's key assertions are "either misleading or fundamentally incorrect."

Environmental groups also filed a lawsuit in August against the administration for violating a law that governs advisory committees. The Environmental Defense Fund and the Union of Concerned Scientists allege that the administration secretly recruited climate-science doubters to write the DOE report and used it to pursue repealing the EPA's endangerment finding. Wright dissolved the Climate Working Group in September, according to CNN.

Jenessa Duncombe

Advocating for science gains urgency

In response to the US government's attacks on science, professional societies intensify efforts to prep scientists to lobby effectively.

Funding delays and grants not being renewed have forced Phillip Anderson to lay off several engineers this year from the W. B. Hanson Center for Space Sciences at the University of Texas at Dallas. If the budget isn't restored, he says, "it will be catastrophic."

So, when Representative Keith Self (R-TX) visited the university in August, Anderson jumped at the opportunity to show him around the space sciences center. In line with the representative's interests, one of the issues Anderson emphasized was the impact of space weather on national defense.

In advocating for science, says Abigail Vieregg, an astrophysicist at the University of Chicago, "you have to find the right angle and find staffers that care about science." In June, she contacted Representative Jake Ellzey's office to urge him to support NASA's Columbia Scientific Balloon Facility in Palestine, Texas, which is in the Republican's district—and which, per President Trump's proposed budget, would be shuttered. Vieregg, whose team was in Palestine for 10 weeks this spring and summer to prepare a balloon mission for launch from Antarctica in December, emphasized to Ellzey's staffers that the facility is NASA's main pathway to qualify technology for flying to space and to train people. She also noted its importance for the local economy.

Scientists and scientific societies are more engaged than ever in advocating for science, says Joel Parriott, the American Astronomical Society's director of public policy. "We've had around 3000 individuals contact congresspeople this year," he says. "It's not enough, but it's a dramatic increase."

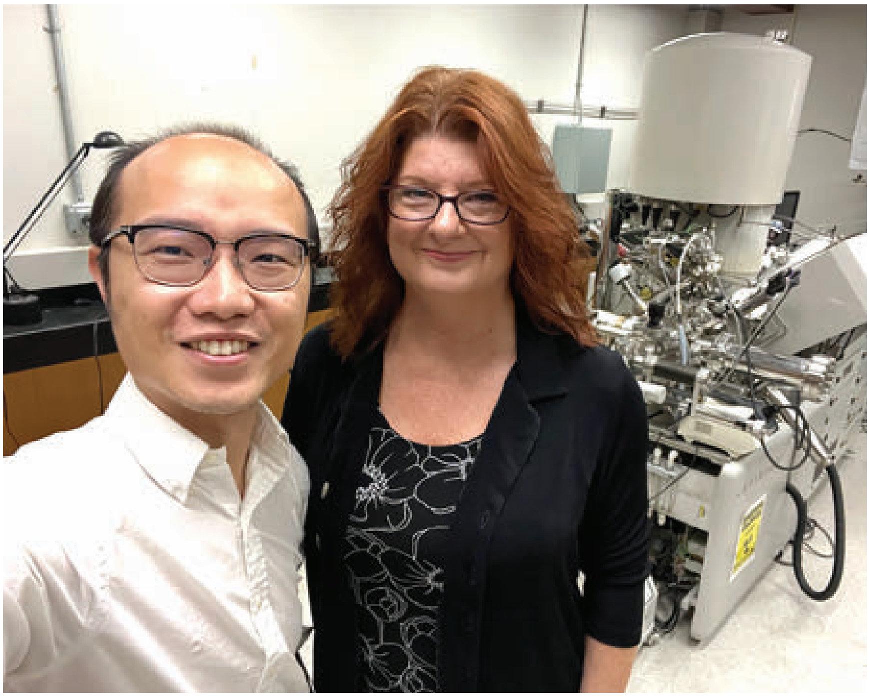
The scientists are writing letters, making phone calls, publishing op-eds, and visiting and hosting lawmakers. A main focus of their activities is convincing Congress to pass a budget for fiscal year 2026 that supports science. "If the cuts to the science budget are anywhere close to as deep as President Trump proposes," says Jonathan Bagger, CEO of the American Physical Society (APS), "there is not much reason to discuss other issues."

RESEARCHERS ARE KNOCKING ON LAWMAKERS' DOORS to make the case for funding science. These five scientists, part of a larger group organized by the grassroots Heliophysics Coalition, visited the offices of 12 congressional members from Arizona and Texas one day in June. From left are Gregory Szypko (PhD student, Rice University), Robert Ebert, Sophie Phillips (PhD student, Arizona State University), Kristopher Klein (professor, Lunar and Planetary Laboratory, University of Arizona), and Phillip Anderson (director, W. B. Hanson Center for Space Sciences, University of Texas at Dallas). (Photo by Jasper Thomson.)

APS created 50 customized letter templates to make it easy for members from every state to write their representatives and show what budget cuts would mean locally. So far, says Charlotte Selton, who manages the society's advocacy programs, members have sent more than 10 000 letters to Congress. APS also helps members craft op-eds; as of press time, members had published six.

Gay Stewart is a physicist and director of West Virginia University's Center for Excellence in STEM Education. In writing the op-ed "Gay Stewart: STEM funding crucial—and at risk," which appeared in the *Charleston Gazette-Mail* on 31 July, she followed APS's guidance to promote science generally and to give specific personal examples. "Investments in science have pushed the country forward. That includes welcoming scientists from around the world to be a part of our ecosystem," says Stewart. "My mind boggles that we have to do this advocacy."

APS is focusing on 11 Republican senators who are in 9 red or purple states



YI LIN (left), a tenure-track condensed-matter physicist at the University of Alabama, and Kelli Wolfe, a field officer for Alabama Senator Katie Britt, when she toured his lab in 2024. The two met again this summer as part of the American Physical Society's focus on senators from red and purple states. Lin is a leading volunteer in APS's advocacy activities. (Photo courtesy of Yi Lin.)

and have a strong interest in science, says Selton. Those states are Alabama, Alaska, Indiana, Kansas, Maine, Pennsylvania, South Dakota, Tennessee, and West Virginia. APS, sometimes jointly with other professional societies, has trained teams of scientists to meet in person with senators and their staffers. Strategically, she says, meetings are the most effective means of advocacy.

It's impossible to measure the success of the science community's advocacy efforts, Selton says. But Senate bill 2354—the Commerce, Justice, Science, and Related Agencies Appropriations Act, 2026—was marked up with better numbers than the president's budget, she says, and of the senators targeted by APS, "seven were on the committee and supported the bill. That's a positive sign."

Some scientists are making their voices heard independently. Stanford University physicist Giorgio Gratta says he has long been "obsessed" with conveying the importance of science to the public. "Ultimately, Congress reacts to the interests of their constituents," he says. To anyone who will look, he's showing slides he's made that pair images of applications with images related to the basic research those applications grew out of: Albert Einstein working on general relativity, juxtaposed with GPS; Isaac Newton bending light with glass, shown beside optical fibers; and the like. Gratta would like to see the images installed on highway billboards. The goal, he says, is to make "powerful connections that people remember." Increased public appreciation of science, he adds, "is required to maintain the robust government support that has served the US so well over the years."

In June, Anderson spent a packed day on Capitol Hill as part of a group of 55 space scientists from 30 institutions. The day was organized by the Heliophysics Coalition, a grassroots advocacy group in which the American Astronomical Society is involved. The scientists met with staffers from the offices of Republican Senators Ted Cruz and John Cornyn of Texas, among others. "Those that had familiarity were supportive. And those that didn't were surprised at just how bad the president's budget request was and how it would hurt science," says Anderson. "I came away from the meeting thinking, 'Our hope is the Senate.' "

Toni Feder

Q&A: Makarand Paranjape explores the microscale for medicine

Blending physics, materials science, chemistry, and biology, the researcher designs devices to improve human health.

"The simplicity of any kind of device—that's what makes it successful." Makarand Paranjape has studied the design and fabrication of microscale devices since his days as a doctoral student. Even before that, as a child, he relished taking apart broken radios, marveling at the "three-legged creatures" inside. He later learned they were transistors.

Paranjape is now an associate professor of physics at Georgetown University and the director of the Georgetown Nanoscience and Microtechnology Laboratory. Elected as a fellow of the National Academy of Inventors in 2024, he holds 21 issued and pending patents. He is also considering launching a startup company. Focusing on commercialization is unusual in most physics departments, he says, noting that they often prioritize journal publications over patents.

MAKARAND PARANJAPE (Image from Georgetown University.)

One of Paranjape's microscale devices is a Band-Aid-like transdermal patch that measures molecules like glucose without using needles. The lessons learned while experiencing the twists and turns of trying to commercialize the technology have led him to explore new applications for the patch that expand its reach to drug delivery and diagnostic testing. Paranjape says his favorite parts of research are applying his designs toward making health management more efficient and patient friendly.

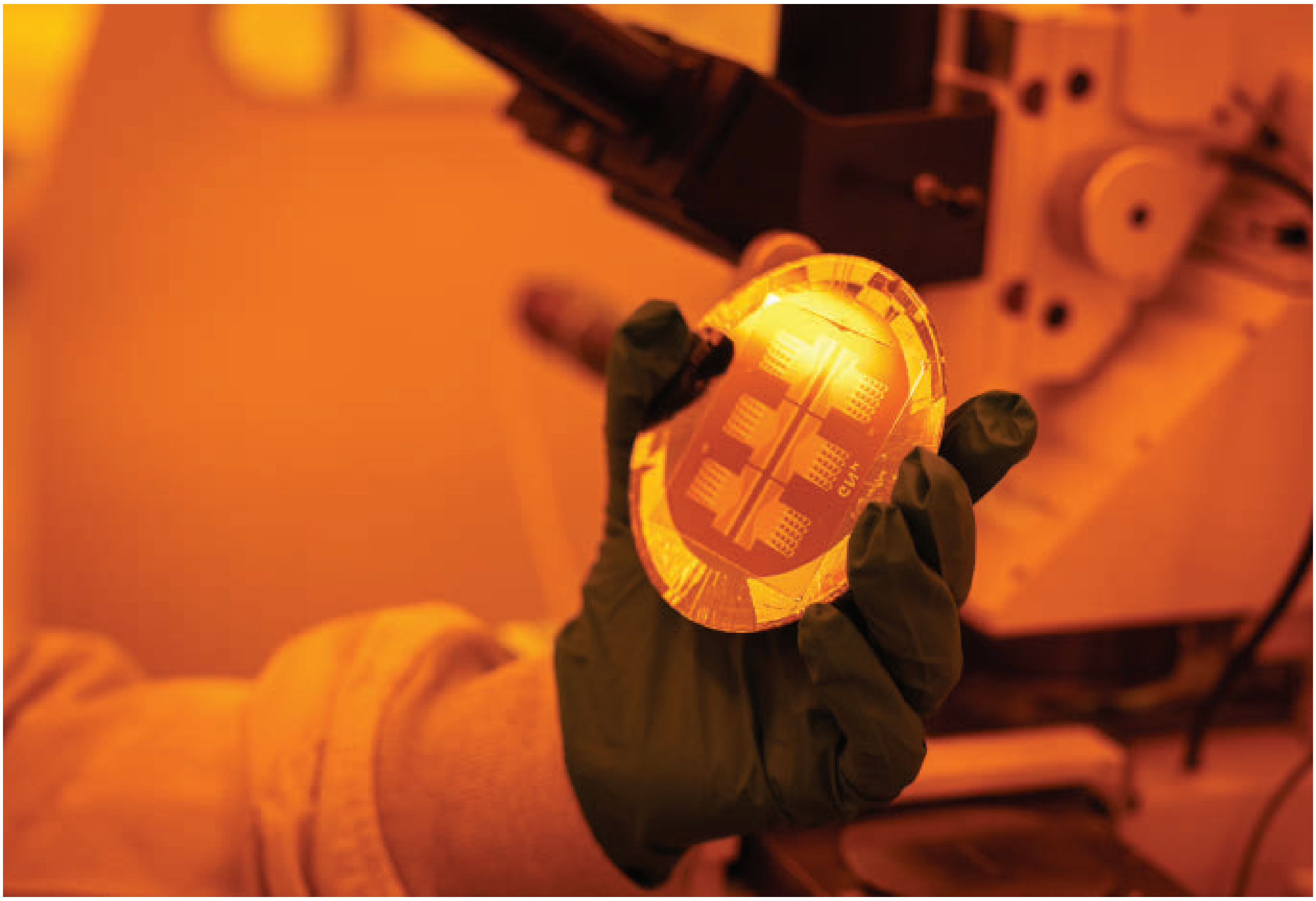
PT: Tell me about your path into research.

PARANJAPE: My father was a theoretical physicist at Lakehead University in Ontario, Canada. My uncle and cousin are also theoretical physicists. When I was growing up, I liked the lifestyle that my dad had. He could do the research of his choosing. I wanted to follow in my dad's footsteps, to which most dads would say, "Yeah, absolutely." But my dad knew that I had more of a hands-on experimental side to me, so he suggested that engineering might be better for me.

I went into electrical engineering, and I obtained my bachelor's, master's, and PhD at the University of Alberta in Edmonton, Canada. Even though my dad had told me there are more jobs for engineering than for physics, ironically, where do I end up? In a physics department.

PT: What inspired you to focus on biomedical research?

PARANJAPE: I got into biomedical technologies when I went to Vancouver for my second postdoc. One of our projects was with a biology professor who wanted to see how cells grow when they are fed. Typically, biologists monitor the growth of hundreds of thousands of cells, weigh them, feed them, and then weigh them afterward. The biologists would then divide the total weight by the number of cells to figure



A TRANSDERMAL PATCH, here on a silicon handle wafer, has been a major focus of Makarand Paranjape's research at Georgetown since the early 2000s. (Image from Georgetown University.)

out the weight per cell. Everything was based on averages, but we wanted to try to see if we could do a weight measurement on just one cell.

So, we created a MEMS [microelectromechanical systems] device. It's like a simple cantilever beam, which is like a diving board over a swimming pool. And this diving board has a natural resonant frequency at which it oscillates. If you put a mass like a cell on the MEMS cantilever, it oscillates at a slightly different frequency. And as you feed the cell, its mass increases, and the resonant frequency changes.

This was 1994, so it was pretty exciting. It made me think, Why aren't there other MEMS devices interacting with more biological entities, or even with human physiology? Antibodies, white and red blood cells, viruses—their length scales are similar to what micro- and nanodevices use. Putting MEMS devices and biology together was what really excited me about going into this biomedical area.

PT: What inspired the transdermal patch?

PARANJAPE: We started on the project fairly soon after I arrived at Georgetown as an assistant professor in 1998. It was funded through DARPA [Defense Advanced Research Projects Agency]. They wanted to evaluate a war fighter's severity of injury. The severity of injury can be determined by monitoring two biomolecules in the blood: glucose and lactate. These two biomolecules start to spike and do weird things as your blood volume decreases, so DARPA wanted a completely nonintrusive, noninvasive device that's always monitoring the soldier's glucose and lactate. Our patch technology was born from that idea.

PT: How did you go about it?

PARANJAPE: Our idea was to go after the interstitial fluid. The interstitial fluid bathes every living cell in your body. Small biomolecules like glucose leave the blood through tiny pores in our capillaries and travel into the interstitial fluid to feed cells. If you can sample interstitial fluid rather than blood, you're going to get most of the markers of interest, including glucose and lactate.

The interstitial fluid is just under the topmost layer of your skin, called the stratum corneum. People often refer to it as a dead skin layer. If you can get past the stratum corneum, then you've got a whole pool of interstitial fluid underneath. Blood vessels and nerve endings are far below this layer.

The patch uses a miniaturized stovetop coil that turns on and off on the millisecond scale. The thermal pulse that's generated by this little coil vaporizes—or ablates—only the topmost layer of skin locally. The interstitial fluid comes out through the resulting micropore because the heart is providing hydrostatic pressure to push out the fluid. We sample that fluid and look for biomolecules using standard electrochemical or mass spectroscopy processes.

PT: Did DARPA choose your technology?

PARANJAPE: After three years, they said they weren't going to implement it for their soldiers. The patch technology was ours to run with however we wanted. So, we thought, why don't we go after the diabetes market?

In 2013, we did a clinical trial. Our trial comprised 10 people with type 1 diabetes, and we applied the patch to their arms or forearms and did the test. Out of the 10, not one felt anything. It turned out that the detections of glucose by the patch tracked nicely with actual blood draws. The company sponsoring the clinical trial immediately licensed the technology.

The clinical trial was one of the most rewarding things I've ever done. I never thought in my wildest dreams I'd be involved in a clinical trial of my own device.

PT: What happened when you tried to bring the technology to market?

PARANJAPE: The company found that cracking the glucose market is very difficult. I'd be lying if I didn't say I wasn't disappointed. But I think the more disappointing part was that the major pharmaceutical players that we talked with bristled at the fact that the patch technology measures glucose in interstitial fluid and not blood. They contended that physicians only think about blood-glucose concentrations. Now almost every major continuous glucose monitor on the market takes measurements of glucose in interstitial fluid.

PT: What did you do next?

PARANJAPE: The company that licensed the technology is looking at other molecules to detect using the patch, like alcohol. And I am starting a project right now looking at biomarkers for traumatic brain injury.

We're also looking at using the patch as a drug-delivery technology platform for treating diseases like Parkinson's. The patches that exist right now on the market, like the nicotine patch, must chemically modify a drug to be delivered through the topmost intact layer of skin. The drug must go through FDA [Food and Drug Administration] approval again. With our process, we're taking FDA-approved drugs and not modifying them.

I've also applied for a patent that uses my patch technology to simplify the diagnosis of cystic fibrosis. Collaborating with my wife, a cystic fibrosis physician at Johns Hopkins University, we are targeting the patch for use in countries like India and China and regions in Africa where cystic fibrosis is often misdiagnosed.

PT: What would you say to others considering commercializing their research?

Quantum sector jobs span specialties, degree requirements

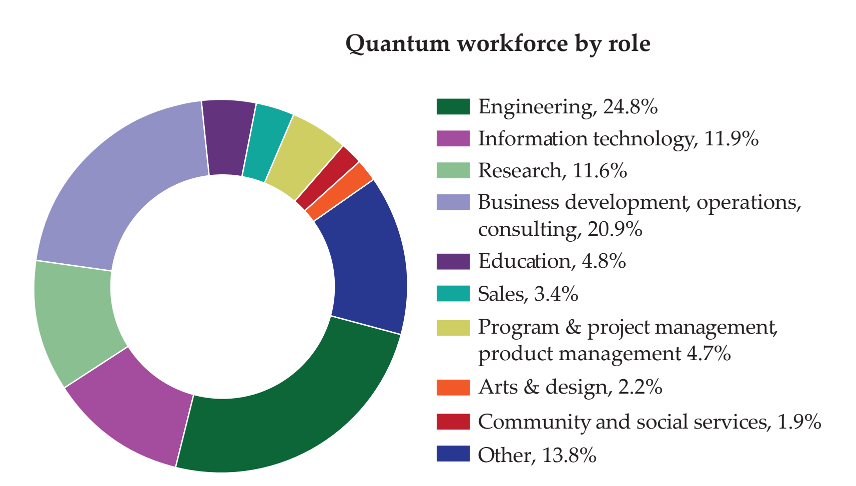
Jobs in engineering, information technology, and research together make up nearly half of the roles in the global quantum workforce. Yet many quantum-related jobs in business development, arts and design, sales, community services, and other fields listed in the figure do not rely on STEM skills. (See also Physics Today, April 2025, page 17.) The chart is adapted from one in a 2025 report by the Quantum Economic Development Consortium (QED-C), which provides research and market forecasts on the quantum economy.

Data reveal other qualities that employers in the quantum space are looking for in candidates. Last year, using QED-C and Quantum Computing Report job postings from 2021 to 2023, the Chicago Quantum Exchange (CQE)—whose members include five universities and two national labs—did an analysis of more than 5000 roles in the quantum technology workforce. Among the ads posted in 2022 and 2023, about 31% requested that candidates have a PhD, and some 14% specified a master's degree. The remainder of the positions required a degree no more advanced than a bachelor's or no degree.

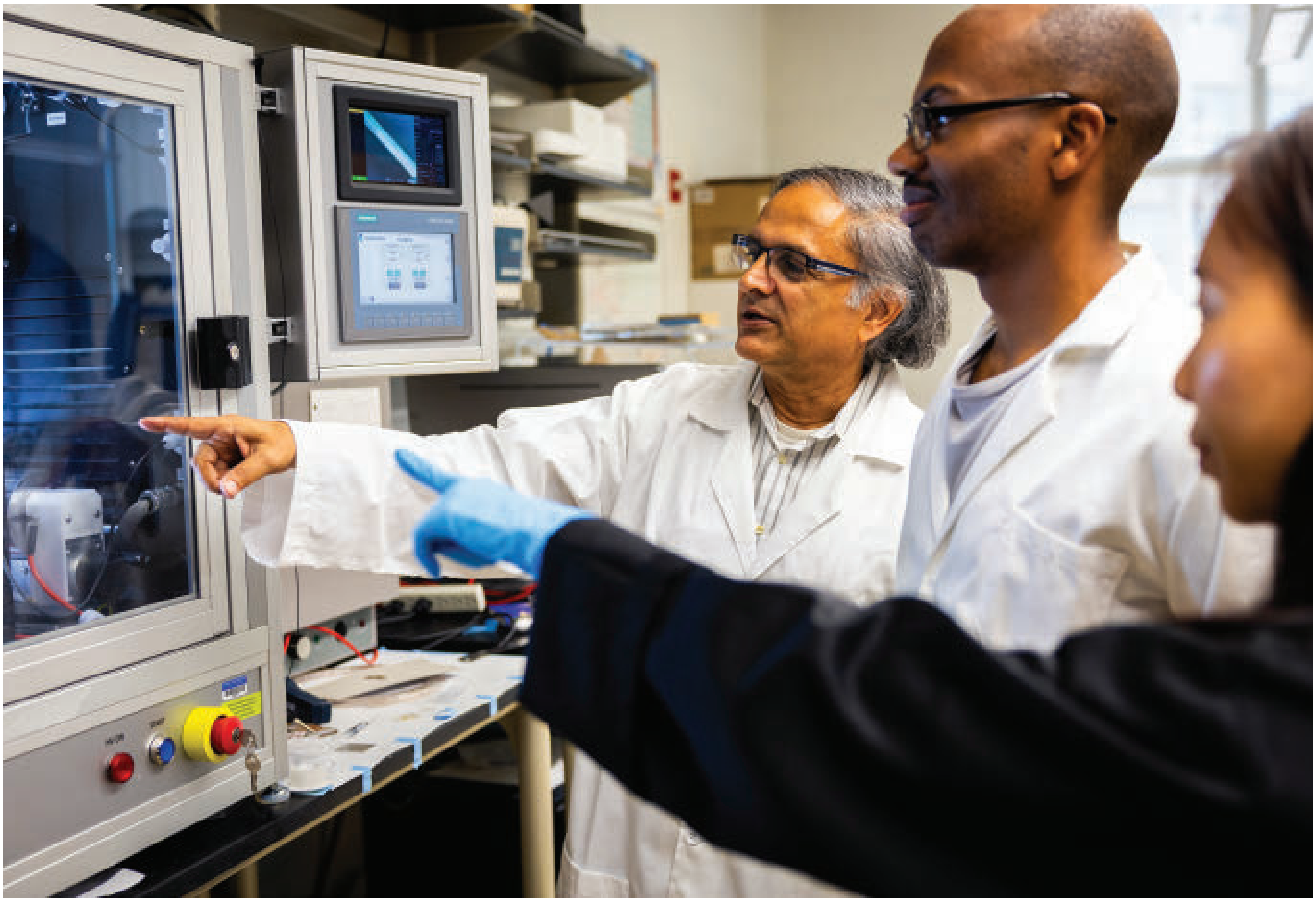
The authors of the CQE report found that the percentage of jobs requiring PhDs slipped from about 35% for 2021 to 29% for 2023, whereas the percentage asking for a bachelor's degree rose from about 35% to 38%. Ads for positions in the industry sector were less likely to require a PhD than were ads for roles in academia or government.

For more information on the quantum workforce, see the reports at https://quantumconsortium.org/publications/stateofthequantumindustry2025/#2025report and https://chicagoquantum.org/degreereports.

Tonya Gary



(Figure adapted from Quantum Economic Development Consortium (QED-C), *State of the Global Quantum Industry*, 2025.)



THE CLEAN ROOM at the Georgetown Nanoscience and Microtechnology Laboratory is the workspace for Makarand Paranjape (left) and graduate students Darrian Mills (center) and Karma Dema (right). (Image from Georgetown University.)

PARANJAPE: People wrongly think that once you patent a technology, you can't publish about it. No. You can publish, but make sure you have the patent application submitted before you publish. If you do it the other way around, you cannot get a patent because you've made a public disclosure.

If you're ever wondering whether to get a patent, get it. You just submit an application to your university's technology office. They will assess whether it's a patentable idea, and if it is, then they'll pay for it. In the end, the university owns that patent.

PT: Where do you see the influence of physics in biomedical fields?

PARANJAPE: A lot of biomedical advancements are a result of physics. You look at imaging technologies that are widespread, like MRI and CT and PET scans. The invention of MRI contrast agents allowed for new ways to brighten what you're looking at. Now physics in the nanorealm is starting to look at quantum effects and the use of nanoparticles for delivery of drugs. There's always going to be some overlap.

PT: What advice would you give people interested in interdisciplinary research?

PARANJAPE: I do all this work in physiology and biomedicine, but the last time I took a biology course was in grade 12. You pick up everything that you need to know along the way. A person should not feel restricted or anxious about not having the appropriate background.

Try to get into a research environment early—you learn so much from that. I've got a tremendous group of grad students past and present, but I also have a huge number of undergrads who work in my lab. I also had six high school students this summer.

PT: Has your work been affected by recent US funding cuts?

PARANJAPE: At the moment, I'm not funded by NSF or the National Institutes of Health, so the US federal grants situation is a little less problematic for me. It has affected our enrollment, in the number of grad students we could take. If there are no students doing such cutting-edge research, the whole innovation process may grind to a halt.

PT: What's next?

PARANJAPE: We're looking at initiating a startup company for the drug-delivery technology. Being an electrical engineer in the physics department who is working on devices that have potential applications for health care and who is starting a business—it's a little daunting, but I think it's also exciting. I have business advisers already in place, and I'm taking some business courses and getting my feet wet in that area.

Jenessa Duncombe

FYI SCIENCE POLICY BRIEFS

White House details R&D priorities

In September, the Trump administration released a memo that lays out its federal R&D priorities for fiscal year 2027. Although it will not directly influence federal spending, it outlines the administration's science goals, which include boosting economic growth, strengthening national security, and promoting US leadership in key technology areas.

The memo is authored by Russell Vought, director of the Office of Management and Budget, and Michael Kratsios, director of the Office of Science and Technology Policy. They criticize years of "unfocused Federal investments weighed down by woke ideology and diversity, equity, and inclusion initiatives"—a stark contrast to a memo, also with Vought as coauthor and published during the first Trump administration, that called for federal agencies to prioritize "activities that advance innovation in STEM education and increase diversity, equity, and inclusion in STEM."

Key R&D priorities outlined by Vought and Kratsios include advancing critical and emerging technologies, such as AI, quantum science, semiconductors, and advanced manufacturing. They emphasize achieving "American energy dominance" through support for fossil fuels, nuclear technologies, geothermal energy, and hydropower. They also call for increased private-sector involvement in later-stage energy R&D while maintaining federal support for foundational research infrastructure.

National and economic security are also central themes, for which Vought and Kratsios urge support for increased military capabilities, strengthened cybersecurity capabilities, and President Trump's Golden Dome missile defense system. They also prioritize safeguarding US health and biotechnology by focusing on the most urgent health challenges, boosting biosafety, and building domestic biomanufacturing capabilities.

Maintaining global space leadership is another priority. The authors express support for crewed missions to the Moon and Mars and for basic and applied research into such areas as novel sensing modalities and radiation-belt remediation.

Vought and Kratsios urge agencies to "prioritize research and associated research infrastructure investments that enhance America's ability to observe, understand, and predict the physical, biological, geologic, and socioeconomic processes and interacting systems of the Arctic to protect and advance American interests and ensure prosperity of America's Arctic residents." —LM

Scientific societies protest grant-making executive order

More than 50 scientific and medical organizations are urging Congress to block key elements of the grant-making executive order (EO) that President Trump issued in August (see the October 2025 *FYI* science policy brief "Trump gives political appointees final say on grants"). The groups argue that the order will increase politicization of federally funded research and add inefficiencies to the grant-making process. "The EO does not advance the Administration's goal of implementing Gold Standard Science," reads their 24 September letter. (Several member societies of the American Institute of Physics, which publishes Physics Today, signed the letter.)

> **"It is critical that we safeguard the integrity of the merit-based peer review process."**
>
> —From the September letter to Congress by more than 50 scientific societies

The EO requires agencies to launch new grant-review processes that are overseen by political appointees. In their letter, the groups say that such processes will slow down the awarding of grants and increase the administrative burden on researchers.

The signatories "urge Congress to ensure that independent peer review remains the cornerstone of the scientific grantmaking process, such that the most meritorious proposals are funded in this and all future administrations." Trump's order states that agencies may use peer-review methods for grant making on an advisory basis but places ultimate decision authority in the hands of political appointees. But, the organizations write, "shifting final authority to political appointees will significantly undermine the grant review and award system and could distort federal research priorities based on ideological or partisan agendas, stifle innovation, and erode public confidence in research."

The organizations also ask Congress to reject the EO's requirement that science agencies permit "termination for convenience" for all grants. The groups warn of a "chilling effect" on any research that could be perceived as controversial. In its efforts to reduce federal research spending, the Trump administration appears to have found it easier to void grants and contracts with termination-for-convenience clauses than those without them. The administration has cited misalignment with agency priorities as the reason for terminating thousands of grants without those clauses.

Additionally, the signatories call on Congress to block the order's directive for agencies to prioritize research proposals from academic institutions with the lowest rates of indirect costs, which cover research-related facilities and administrative expenses. The Trump administration has sought to cap indirect cost rates at 15% (see the August 2025 *FYI* brief "Higher-ed groups propose new indirect-cost models") but has been blocked repeatedly in court. —CZ PT

FYI (https://aip.org/fyi), the science policy news service of the American Institute of Physics, focuses on the intersection of policy and the physical sciences.

AIP | FYI

FELLOWSHIP OPPORTUNITIES FOR

Ph.D. STUDENTS IN STEM

DOE CSGF

Department of Energy Computational Science Graduate Fellowship

DEADLINE: 1/15/2026

www.krellinst.org/csgf

SSGF

Department of Energy National Nuclear Security Administration Stewardship Science Graduate Fellowship

DEADLINE: 1/13/2026

www.krellinst.org/ssgf

LRGF

Department of Energy National Nuclear Security Administration Laboratory Residency Graduate Fellowship

DEADLINE: 3/4/2026

www.krellinst.org/lrgf

BENEFITS

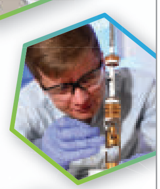
- $45,000 yearly stipend
- Payment of full tuition and required fees
- Annual professional development allowance
- Yearly program review participation
- 12-week DOE laboratory experience(s)
- Renewable up to four years

SCAN HERE TO EXPLORE ELIGIBILITY, SUPPORTED FIELDS OF STUDY AND OTHER PROGRAM DETAILS

U.S. DEPARTMENT of ENERGY

KRELL institute

Named Distinguished Postdoc Programs at Idaho National Laboratory



The **INL Named Distinguished Postdoctoral Associate Program** is designed to attract, recruit, develop and inspire early-career Ph.D researchers who have the potential to develop into INL's future scientific and technical leaders. These appointments are highly competitive and intended to recognize and provide Named Distinguished Postdoc Associates with a competitive award, research experience, mentorship, and training to develop their capabilities. All the appointments are in-person at our Idaho Falls complex and site facilities and provide up to two years of research support with a possible one-year extension.

INL's Named Distinguished Postdoctoral Program Opportunity:

- Develop and build independent research projects while helping advance INL, Department of Energy and national agendas for energy and security
- Access to cutting-edge instrumentation and facilities
- Mentors include top INL researchers and leaders
- A prestigious and competitively compensated position

Apply Today!

Scan for more information or to apply online.

Applications are open through Nov.12, 2025.

Positions are starting in 2026.

https://inl.gov/postdoc-program/

INL Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy

WHAT CAN PHYSICISTS DO?

Toni Feder

Interviews offer a glimpse of how physicists get into—and thrive in—myriad nonacademic careers.

Toni Feder is a senior editor at Physics Today.

Physics students are told their degree is a ticket to, well, anything. But elaboration is rarely forthcoming. Part of the problem is that physics professors are often ill-prepared to help: They simply don't know—and don't have time to find out—about options for their students. Despite departmental efforts such as hosting alumni to give talks about their work, the message to US physics graduate students tends to be that anything other than following in the footsteps of one's adviser would be a failure.

Even if everyone who earned a PhD in physics wanted to be a professor, job seekers vastly outnumber tenure-track job openings. Of an estimated 43 050 working-age, US-trained physics PhD recipients across the nation in 2023, about one-third (14 500) worked in educational institutions, according to the National Center for Science and Engineering Statistics; the rest were in business or industry (24 450) and the government (4100). Typically, about half of bachelor's recipients pursue graduate studies in physics or other fields; many of the others enter the private sector, according to the American Institute of Physics' (publisher of Physics Today) statistical research team.

So where do physicists end up? Surprise: Physicists can do—and actually do—(almost) anything. They join startup companies, do research in the private sector and at national labs, and work in finance, data science, policy, museums, and the film industry. They are teachers, lawyers, science writers, and much more.

In a new interview series, Physics Today is profiling physicists who opted for careers outside of academia. They discuss what motivated their decisions, how they got into their fields, how their physics backgrounds come into play, what skills they need, and how they like their jobs. What follows are eight interviews selected from this series. Going forward, look for more profiles to be published online and in these pages.

To suggest a physicist (bachelor's degree or higher) for Physics Today to highlight in this series, please email pteditors@aip.org.

(Design by Masie Chong with artwork adapted from iStock.com artists ilyaliren, enjoynz, SpicyTruffel, invincible_bulldog, VectorMine, Illustrator de la Monde, Moto-rama, appleuzr, m.malinika, spiralmedia, Giorgi Gogitidze, fleaz, cnythzl, and Abbasy Kautsar.)

Jovana Andrejević Kim minimizes fabric waste

Research scientist, CLO Virtual Fashion

BS, engineering physics, Cornell University, 2016
PhD, applied physics, Harvard University, 2022

(Photo courtesy of Jovana Andrejević Kim.) | (Image courtesy of CLO Virtual Fashion.)

What was your research focus?

Modeling how paper crumples. It was a fun mathematical problem, and our explanation tied into other fragmentation-inspired models, such as how rocks fragment and how glass shatters.

What were you looking for in a job?

One thing that was lacking in academia was being able to see an immediate impact of my work. During my postdoc, I decided it might be good to give industry a try. I did not know what was out there for physicists.

I was open-minded, but I had always loved the intersection of art and science. It turned out that the computer graphics industry has what I was looking for.

How did you get your job?

My husband had seen a video about CLO Virtual Fashion on YouTube. Later, when I was looking for a job, I saw on LinkedIn that CLO was hiring. I applied. I started in 2023.

How do you spend your time?

My day-to-day looks like academic research: reading papers and programming—developing and improving software. But the projects are driven by user needs.

One project involved figuring out how to cut pattern pieces with a goal of minimizing fabric waste. You have to contain the pieces within boundaries, allow for seams, and account for the grain line of the fabric. Recently, the project extended to include respecting print placement.

How does your work transfer to actual fashion?

Brands, fashion houses, and vendors use the software CLO creates to help design garments. They can visualize in 3D how a garment will fit and how it will look as the wearer moves—all before moving into production

What do you like about your job?

The same things I loved about research: the creative aspects and trying to solve challenging problems.

How do you use your physics in your job?

My physics background was a way in. And there are similarities between how paper and fabric sheets behave. My background influences my approach to problem-solving, even if the problem is not inherently a physics one.

What new skills have you learned?

I've learned about the fashion design and production process and how to discuss my technical research in that context. I've also gained skills in collaborative software development.

Josiah Schwab
evaluates self-driving cars

(Photo by Annelise Beck.)

Software engineer, Waymo

BS, physics, MIT, 2009
PhD, physics, University of California, Berkeley, 2016

What was your research focus?

Astrophysics. I did computational work on stellar evolution and the mergers of white dwarf stars.

How did you make the switch into the private sector?

I had thought I would go into academia. But during my postdoc, my intent changed as I realized the constraints, such as not having much choice about where I'd live. My first step was talking to other people who had left academia. It was helpful hearing what people did and didn't like about their jobs. Some of the conversations crystallized for me that I wanted to try software engineering.

It can be tricky as a physicist with no job experience to put together a résumé that makes clear what your transferable skills are. I got much higher uptake when someone referred me for a position. I joined Waymo in 2021.

How do you spend your time?

I'm on a team that evaluates the performance of new software releases for Waymo's self-driving cars. We figure out how to process both real and simulated driving data to measure the rate of safety-relevant events like collisions.

What do you like about your job?

I get to scratch my problem-solving itch every day. I work 40 to 45 hours a week, less than when I was in academia. I also get paid more. And I have more mobility—there are lots of companies I could work at.

How does your physics background come into your work?

The quantitative and analytical aspects of working with data and reasoning about complex systems feel familiar from physics. In modeling collisions, I've used kinematics and rigid-body dynamics.

What new skills did you need?

A lot of the growth for me was working in a different-paced environment. Projects are faster moving and smaller scope. And writing software with 1000 engineers requires different kinds of coordination than in the small collaborations I had experienced in academia.

Is there anything you'd like to add?

The transition is not easy. If I were doing it again, I would look outside academia earlier in my career. It's good to have awareness of options and what is required to pursue them. I'm happy I made the career change.

Katrina Miller
explores and explains science news

Science writer, *New York Times*
BS, physics, Duke University, 2016
PhD, physics, University of Chicago, 2023

(Photo by David Dowd.)

What was your PhD research focus?
I worked on the MicroBooNE experiment at Fermilab, measuring neutrino cross sections in liquid argon.

What were you looking for in a job?
In the day-to-day work of my PhD, I felt like a software developer. And I didn't like the structure of particle-physics research, which, because of the nature of the experiments, has huge collaborations. I realized I liked learning about science more than I liked doing it. I was looking for something more connected to society, something where I could use my expertise for the good of people.

How did you get into science writing?
As a graduate student, I did an internship with the University of Chicago's news office. I have always liked writing, but that's where I started learning the tricks of the trade of journalism—how to write a lede, how to conduct interviews. Then I got an AAAS [American Association for the Advancement of Science] mass media fellowship, and I worked for a summer at *Wired* magazine. I wrote freelance up until I finished my PhD. I applied for a *New York Times* fellowship and got it. That was for a year, and then they hired me.

What do you like about science writing?
I love that I am immersed in science, and I get to talk to scientists about the cool work they do. And I get to bridge the gap between scientists and the public.

How do you use your physics in your job?
My technical expertise comes into play with translating for the public what scientists say. It guides my choices of articles to pitch to my editor and the angle I approach a story from. And it comes in handy in building trust, in both directions: with scientists and with readers.

Is there anything you'd like to add?
Recently, I served on a career panel and was asked whether I have any regrets about leaving academia. So far, no.

Phil Broughton
keeps laboratories safe

Laser safety officer, University of California, Berkeley

BS, physics, University of California, Santa Cruz, 1998
MS, health physics, Oregon State University, 2008

What was your research focus for your master's degree?

Radioecology: how radioactive materials propagate through the environment via food chains, groundwater, and soil.

What were you looking for in a job?

I got into lab safety because I was terrible at programming. I originally fell into it as an undergraduate working in an isotope geochemistry lab. After graduation, I was hired as a laser tech and then service engineer. I picked up safety roles until they became my entire job. But I wanted to learn at the ground level. I wanted to learn history and industrial knowledge, not just the ropes of how to do things.

Then, as a health and safety technician at Lawrence Livermore National Laboratory, I saw that to advance, I needed to get a higher degree. I wanted to work with ionizing radiation. I got my master's in health physics very intentionally, while working full time. After four years at Livermore, and after I finished my degree, I moved to UC Berkeley in 2008.

What does your job involve?

I inspect labs. I look for radioactive contamination and make sure shielding is appropriate and that people have not altered setups. I check laser safety. I calibrate instruments. I spend a lot of time reviewing proposals and procedures for experimental design. I document problems and make sure researchers know where things go wrong—so it won't happen again.

What do you like about your job?

It's fun working with students. And I never know what I will do on any day. I love that.

(Photo by Gabriel Mosher.)

How do you use your physics in your job?

In radiation safety and control, we have a good understanding of how ionizing radiation interacts with materials, biology, and the environment. That takes advantage of the breadth and flexibility that a physics degree fosters. And I use physical intuition for how things work and for doing the math and then checking if the answer makes sense.

Is there anything you'd like to add?

Among research physicists, there is some prejudice against safety roles: It's not seen as real physics. But I like that as a physicist in a safety role, I am helping people make sure that their research succeeds and can continue.

Liting Xiao
searches for patterns in financial markets

Quant researcher, Graham Capital Management

BA, astronomy–physics; BA, math;
University of Virginia, 2015

PhD, physics, California Institute of Technology, 2022

What was your PhD research focus?

Designing and improving statistical and computational methods for detecting and characterizing gravitational-wave signals from the LIGO–Virgo network. [LIGO is the US-based Laser Interferometer Gravitational-Wave Observatory; Virgo, its counterpart in Italy.]

What were you looking for in a job?

I was looking for a transition out of academia, something that would allow me to stay close to rigorous analytical work but with more tangible, real-world impact.

How did you make the switch?

I branded myself with a personal website and built out my LinkedIn profile. Recruiters reached out, and I applied to both big tech and financial firms. Within a month of intense interviewing, I landed a job. I chose GCM because I connected with my interviewers and with the company's data-driven research culture.

What do you like about your job?

What I enjoy most is the continuous learning: It keeps me intellectually engaged and connected to real-world events. I train myself to think critically about how global developments, like tariffs or geopolitical tensions, might ripple through inflation, commodity prices, and broader markets. I also really value the collaborative, intellectually curious culture.

(Photo by Xinghui Yan.)

How do you use your physics in your job?

It was not a huge leap. Instead of searching noisy data for black holes, I'm searching for patterns in markets to help decide when to buy or sell assets. The work is fast paced. We formulate ideas, validate them empirically, and subject them to internal peer review before iterating or discarding.

My PhD training gave me the mindset of an independent researcher and the tenacity to push through ambiguity. Both are essential for quant research. I had done a lot of signal processing, which translates well.

Have you needed new skills?

I've picked up, almost from zero, mathematical optimization skills. I also needed to build a foundation in finance, which I mostly taught myself. It took a few months to get fluent in the language of markets, and there's an expectation to ramp up quickly.

One major shift was the importance of networking. In industry, relationships and communication matter a lot. You need to put yourself out there and be visible. It's about building a network, exchanging ideas, and staying connected to the broader research community.

Roohi Dalal
advocates on Capitol Hill for the astronomy community

Deputy director of public policy, American Astronomical Society (AAS)

BS, astrophysics and history, California Institute of Technology, 2018
PhD, astrophysics, Princeton University, 2024

What was your research focus?

To understand the distribution of dark matter in the universe, I looked at how gravitational lensing distorts the shapes of galaxies. I also earned a certificate in science, technology, and environmental policy.

What were you looking for in a job?

I knew that I wanted to do policy, but I didn't know if I wanted to be in an academic setting or in something where I would interact directly with policymakers.

How did you make the transition to policy?

As a postdoc, I realized I wanted to do something that was government facing. When this opportunity at the American Astronomical Society came up, I thought I was not qualified because the job ad asked for five years of experience. I applied anyway. I left my postdoc early to start here in October 2024.

How do you spend your time?

I work on legislative and regulatory aspects in three areas related to astronomy: funding, workforce, and access to the night sky.

I am on the Hill every week or two talking to committee staff and congressional members about our priorities and how we can help. On the regulatory side, I submit comments—to the FCC [Federal Communications Commission] on satellite regulations, for example, or to the Department of Homeland Security to oppose a proposal to limit the duration of student visas to four years.

I go to receptions and happy hours. Networking is important.

What do you like about your job?

I feel that I have agency—that there is something I can do about the times we are in.

How do you use physics in your job?

I work with volunteer committees made up of professional astronomers. A lot of it is talking and distilling what they say so that it's understandable to people in the government.

What new skills did you need to learn?

I'm still developing my communication skills. In legislative offices, the staffers have 100 things going on; how do you grab their attention? I am also learning to multitask, prioritize, and triage.

Anything else?

When I was hired, the salary range was posted as $118 000–$130 000. Also, all PhDs at the AAS can choose to do research 20% of the time.

(Photo by Tori Repp/Fotobuddy Photography.)

Jack Lambert
teaches high school physics

High school physics teacher, Utah

BS, physics, Washington State University, 2019
MA, teaching, Westminster University, 2021

(Photo courtesy of Jack Lambert.)

Why did you go into teaching?

I intended to get a PhD and stay in research. But while I was getting my bachelor's degree, I got involved in outreach through the physics and astronomy club. I found value in thinking of ways to share the physics I love. By the end of college, I realized that I could continue to do that if I went into education. And I realized I was good at it.

How did you move into teaching?

I found an accelerated master's program in education, three semesters long.

I was lucky: One of the places I did observations and student teaching was at Utah's top public high school. The school's initial response to the program's inquiry about taking on a student teacher in physics was, "No, but can we hire him?" I did end up student teaching there and then got hired.

What do you like about teaching?

I teach AP physics. I also teach IB [International Baccalaureate] physics, where I cover things in a different way. I love that.

It's rewarding to see it click with people that math can be used to explore the universe, and how beautiful and incredible that is.

The less fun parts are the grading, parents, emails, and students' stress about exam scores.

How do you use physics in your job?

Most high school physics teachers have backgrounds in math, chemistry, or geology, not physics. I'm not sure I would have the same enthusiasm if I hadn't studied physics. And I think that helps kids, who often have the perception that physics is difficult and scary.

What new skills did you need?

I had to learn classroom management and how to have the right presence. I also had to rethink how to present material. My master's helped with that. So did conversations with the high school's instructional coach.

Do you earn a living wage?

It's been pretty good for me. I make about \$70 000 a year, plus \$5000 from Utah's Teacher Salary Supplement Program. And there are opportunities through the school to earn more. Last year, I swapped a prep period to take on an extra class. That gave me a 12% bump.

Eric Frederick
programs motion-tracking software

Director of technology, Xcitex

BA, physics and mathematics, Clark University, 2003
PhD, physics, University of Massachusetts Lowell, 2011

(Photo courtesy of Eric Frederick.)

What was your research focus?

Hyperpolarized gases for MRI. I used hyperpolarized xenon to get a ventilation map of the lungs. And from the fraction that enters the bloodstream, you can estimate the surface-to-volume ratio of the lungs.

What were you looking for in a job?

Physicists know that we can do a lot, but we don't know how to market ourselves. Originally, I hoped to get a job in medical physics. But my program didn't have the necessary accreditation or residency program. In 2012, I went to Bruker to remain in research and provide support to the research community. The company specializes in test equipment for materials advancement and drug discovery. I worked mostly with preclinical animal MRI, CT, x-ray scanners, and optical methods and later worked with the sales team.

How did you find your job at Bruker and then at Xcitex?

Someone I knew at Bruker told me about the opening. I was there from 2012 to 2017. For my job at Xcitex, I was poached.

Describe your work.

At Xcitex, we have a software suite that can track motion and synchronize data from accelerometers and other sensors with videos. There's a lot of ballistics tracking and testing of showerheads and of how paint gets sprayed out of cans to get a better coating. The software can track points, edges, and contours and perform more complex tasks like particle tracking and particle-image velocimetry.

I mostly update legacy code. I also do training and interact with customers.

What do you like about your work?

I work with computers and get a broad exposure—we work with biomedical companies, defense companies, and more. What I like most is consulting with customers.

How do you use your physics?

We take real-world observables—speed, position, et cetera—and give them to clients so they can create models. We need to be aware of optics to advise customers on proper lighting—a good-looking video is not always the same as one that will work well for tracking.

What new skills did you need to pick up?

Physics and other skills I picked up along the way prepared me for industry jobs. For me, it's more about trying to be a good person in industry. People want to take shortcuts and do quick fixes. Having a backbone and doing what is right—and not what's easy—is important and sometimes challenging. PT

RICE

ASSISTANT PROFESSOR
IN EXPERIMENTAL AMO PHYSICS

The Department of Physics and Astronomy at Rice University in Houston, Texas invites applications for a **tenure-track faculty position in the area of experimental atomic, molecular, or optical physics**, focusing on quantum science which encompasses quantum information processing, quantum sensing, quantum networks, quantum transduction, quantum many-body physics, and quantum simulation. The ideal candidates will intellectually connect AMO physics to topics in condensed matter and quantum information theory. We seek outstanding scientists whose research will complement and extend existing quantum activities within the Department and across the University. In addition to developing an independent and vigorous research program, the successful applicants will be expected to teach, on average, one undergraduate or graduate course each semester, and contribute to the service missions of the Department and University. The Department anticipates making an appointment at the assistant professor level. A Ph.D. in physics or related field is required.

Applications for this position must be submitted electronically at **https://apply.interfolio.com/174345**. Applicants will be required to submit the following: (1) cover letter; (2) curriculum vitae; (3) statement of research; (4) statement on teaching; (5) PDF copies of up to three publications; and (6) the names, affiliations, and email addresses of three professional references. Rice University, and the Department of Physics and Astronomy, actively promotes a dynamic and inclusive environment. In this spirit, we welcome applications from all backgrounds and members of historically underrepresented groups. We will begin reviewing applications by November 15, 2025. To receive full consideration, **all application materials must be received by December 15**, 2025. The expected appointment date is July, 2026.

浙江大學 物理学院

SCHOOL OF PHYSICS
ZHEJIANG UNIVERSITY

Professors/Associate Professors at School of Physics, Zhejiang University, is actively recruiting up to 60 faculty members of different grade in all subfields of experimental and theoretical physics, for group leader, tenured position and tenure-track position. We offer start up resources and competitive benefits including housing. The positions are open till filled.

Qualified applicants please submit their applications in PDF format to Ms. Youxiu Zheng, at phyac@zju.edu.cn, with the following materials:

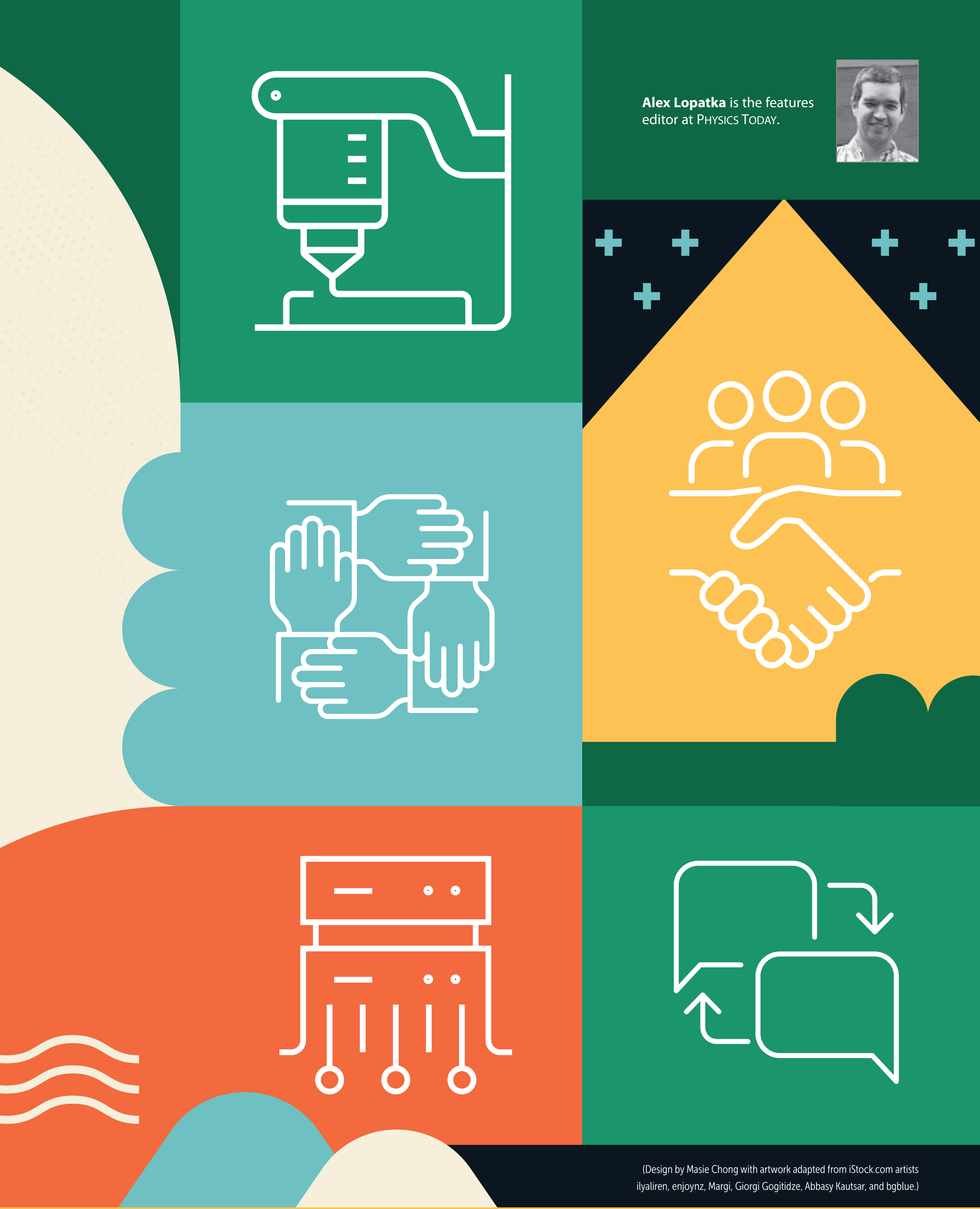
- Curriculum Vitae including publications list plus 3-5 representative publications
- Summary of research accomplishment, and a research plan with start-up budget
- Statement of teaching experience and capabilities
- Contact information of at least three referees

Further information can be found at:
https://physics.zju.edu.cn/2024zp/list.htm

LANDING A JOB IN THE PRIVATE SECTOR

Alex Lopatka

Technical knowledge and skills are only some of the considerations that managers have when hiring physical scientists. Soft skills, in particular communication, are also high on the list.



Alex Lopatka is the features editor at Physics Today.

(Design by Masie Chong with artwork adapted from iStock.com artists ilyaliren, enjoynz, Margi, Giorgi Gogitidze, Abbasy Kautsar, and bgblue.)

For many students in the physical sciences, a career in academia may seem like the default path. But for most, that's not the path taken. After obtaining a PhD in solid-state physics and working as a postdoc, Evgeni Gousev left the academic track and went to work for IBM and then the telecommunications company Qualcomm Technologies, where now he's a senior director. "Physicists have really good background and training," he says. "They know how to solve problems, how to tackle complex and challenging tasks, and how to research and learn."

An advanced degree isn't necessarily a prerequisite for technical jobs at many companies. Ryan Caverly, a senior technical recruiter at HRL Laboratories, a company headquartered in Malibu, California, that conducts applied R&D for automotive, aerospace, and defense applications, says, "The last few people we've hired for our quantum testing team have had bachelor's degrees or master's degrees with a couple years of experience." (For more on what education and skills are needed for jobs in the quantum workforce, see "Quantum sector jobs span specialties, degree requirements" on page 22.)

In fact, according to a report published by the American Institute of Physics (publisher of Physics Today), more than 55% of students who graduated with a physics bachelor's degree in 2021–22 found employment in the private sector.[1] That's also where about one-third of recent physics PhD graduates work, and PhD-level industry positions are nearly five times as likely as academic posts to be potentially permanent.[2]

Physics Today interviewed scientists and engineers from private companies to better understand what attributes and skills companies look for when hiring for technical jobs. The 12 interviewees have a range of jobs, including conducting applied R&D in the physical sciences, manufacturing specialized equipment and instruments, exploring and extracting oil and gas resources, and developing software products. A few themes were persistent across all the conversations. Physical scientists have the training required to succeed in various types of jobs, but technical adeptness will get you only so far. Communication, teamwork, and flexible problem-solving are also important skills.

Transferring technical skills

Many companies look for candidates who have hands-on experience with installing, tuning, or repairing specialized equipment. A hiring manager isn't necessarily looking for someone who is familiar with instruments or products particular to their company but rather someone who is comfortable reading schematics, following established procedures, and learning the specifics on the job.

A test of those sorts of skills is conducted for some job seekers at TOPTICA Photonics, for example, which manufactures lasers and other optical equipment. "The level of education is not the only factor TOPTICA is considering during the hiring process," says human resources manager Michelle Prohov. Optical-assembly technicians, for example, are evaluated for their hands-on experience, and they may need to think creatively to solve problems with various instruments.

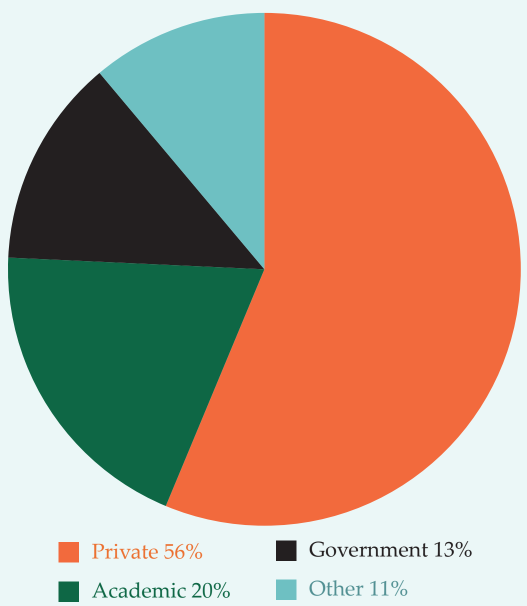
For other types of jobs—such as data scientists or machine-learning engineers—no hands-on experience is required, but some familiarity with programming is usually necessary to land an interview. Openings for machine-learning specialists required more-specific technical skills than postings for data analysts in 2017, when Jacob Lynn of the travel company Booking.com starting hiring for positions there. He has a PhD in physics and over the past eight years has hired around 200 people for the company. "About 25% of the interview is really specific technical knowledge that you have to know," he says, "and the other 75% is, Can you think through the problem?"

The vast majority of the time, he and others at Booking.com are seeking people who have a certain set of baseline skills. He looks for people "who can quickly wrap their head around a business problem," he says, "and then propose a technical or semitechnical approach to learn something from the data."

David Nelson, the president of Massachusetts-based Aerodyne Research, which offers R&D services, chemical sensors, and software products for global environmental research, says that "people who can write code are really helpful. Some projects slow down because nobody is facile at writing software to automate or facilitate or analyze data."

Technical competence can sometimes make a candidate more competitive, but managers typically expect the specifics to be learned on the job. "Learning is really important to TOPTICA," says Prohov. "We put aside money in our budget so that our staff can continue to take classes and learn."

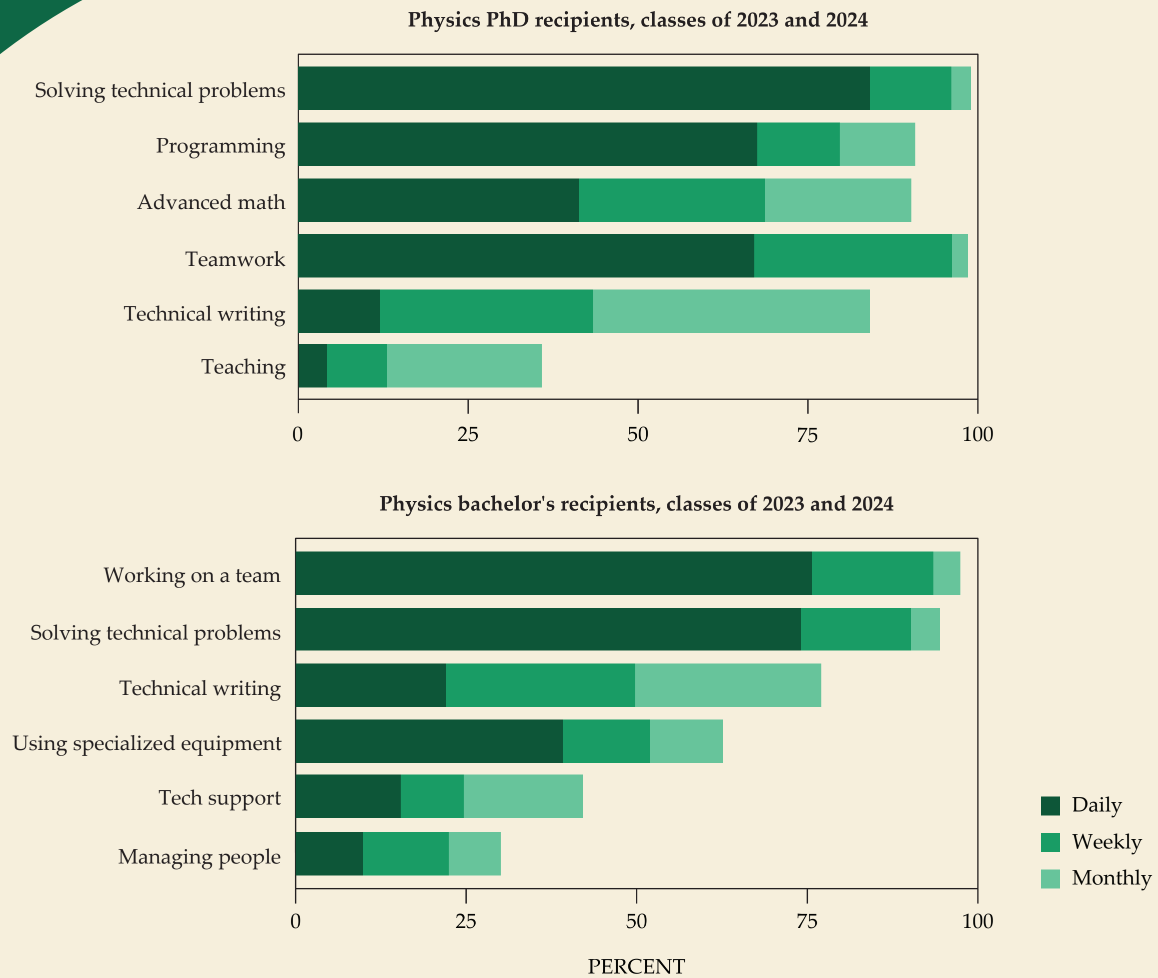
At Intel headquarters in Santa Clara, California, engineering manager Annelise Beck says, "There's a long training process. There are specific tools used in the industry which you're going to find in just three or four companies in the world. There's no chance you're going to ever have experience with them."



THE FIRST JOBS of the majority of US students who obtained physics bachelor's degrees in 2023 and 2024 were in the private sector. (Data courtesy of the American Institute of Physics.)

Communicating to colleagues and clients

To be competitive for just about any job, employees need strong communication skills.[3] For physical science jobs, that may mean explaining details to technical and nontechnical coworkers and writing research proposals. "At every single company meeting, we have a tech talk where one of the scientists or engineers talks about their work," says Nelson, whose background is in chemical physics. "They are charged with using as little jargon as possible to make sure that everybody in the company understands what they're working for, what they're supporting, and how cool it is."



SOME OF THE SKILLS used by employees in the private sector with a physics bachelor's degree or a PhD are specialized, such as solving technical problems, and others are nontechnical, including working on a team. Most PhD-level employees routinely use programming and advanced math skills; most bachelor's-level employees regularly use specialized equipment. (Data courtesy of the American Institute of Physics.)

Princeton Scientific Corporation, a supplier of materials science and engineering products that's based in Bethlehem, Pennsylvania, has similar needs. General manager Ashley Pascoe says, "Maybe the client needs to improve adhesion for one of their products, but they don't know why a plasma cleaner would do that. Our scientists need to communicate those technical concepts to our clients to help them understand."

Physicist Howard Winston spent years at the oil and gas exploration company Schlumberger and the aerospace company United Technologies Corporation (now owned by RTX). He's now a physics professor at the University of Connecticut Waterbury. "You have to communicate clearly with people in positions of power who control lots of money in a business unit," he says. "How are you going to get their business right?" Winston recalls that his communication skills got him and his team new business from a high-level executive. "He was very impressed," says Winston. "And in the end, he said, 'Wow, I want you guys in my marketing group. Take my wallet.'"

For six years, Satish Rao worked at Newlab, which seeks to commercialize and scale technology startup companies. After obtaining his PhD in physics and working at Columbia University's tech-transfer office, Rao moved to Newlab and built its consulting practice, which provides business strategy and advice to industries and the government on how to transfer specific physical science technologies to their markets and organizations. To succeed, Rao says, "you

> **You have to be willing to drop everything and quickly do something else. For some people, their work style is suitable for that. And for other people, it's not.**
>
> **—Annelise Beck, engineering manager, Intel**

have to be able to explain the impact of the problem you're solving. We have to inspire minds that this type of science is worth pursuing and investing in."

Solving problems and working in teams

Nearly every interviewee mentioned that the pace of industry is faster than that of academia. In such a dynamic environment, where priorities or projects shift according to business needs, candidates need to be flexible. "If you always strive for perfection, it will negatively impact your ability to deliver impactful results in a lot of industry roles," says James McBride, the vice president of R&D at CeresAI, an Oakland, California, company that provides predictions of agricultural crop health using remote sensing and data analysis.

McBride says that because of money and time constraints, industry employees need to "have the willingness to get a problem 80–90% of the way done." Then, refinements to a product can be made after it's launched. In a survey of employees who recently obtained physics bachelor's degrees, those in the private sector reported that the second most-used skill in their jobs was solving technical problems.[4]

In that survey, the skill that private-sector employees most commonly reported using was working on a team. Likewise, in a similar survey of people who recently obtained their physics PhDs, respondents working in potentially permanent private-sector positions were most likely to list teamwork and solving technical problems as skills they use.[2]

After earning a masters in physics, Carlos Guzman worked as a geoscientist at Shell for 30 years and for the past 18 years has been a consultant in oil and gas exploration. He says that companies are looking for multidisciplinary teams to solve complicated problems. "You're going to work with more than just physicists," says Guzman. "There will be geologists on your team. There will be physicists. There will probably be artificial intelligence and neural network researchers, and there will be business people."

Networking for jobs

People seeking career advice often hear about the importance of networking, and job seekers in the physical sciences are not exempt. Intel's Beck says to "talk to people that you know, use whatever connections you have to get your foot in the door, get the interview, but also just to understand what the jobs are like."

If you're still in school, Beck advises that any list of professionals that you build should include nonacademic contacts. "Many professors are thinking about academia as being the path that you should follow," says Beck. "Not all of them are going out of their way to put other contacts in your path." She encourages job seekers to call or email people whose jobs they find interesting. "I get those kinds of messages, and I'm very willing to talk to people for 30 minutes. It's not a big deal," says Beck.

Job hunting is challenging in the current employment environment. Many private companies are supported, at least in part, by the US government, whose funding for science has been drastically cut by the Trump administration. Even some companies that don't directly rely on federal funding have been affected, and unpredictable tariffs are contributing to business uncertainty (see "Fluctuating tariffs exacerbate US science funding woes," Physics Today, September 2025, page 18).

Despite the threats to science jobs, companies are still hiring for technical roles. "One of the latest hires on my team I met at a conference," says Qualcomm's Gousev. In-person conversations can help build a connection with a potential hiring manager. "You talk to a person and think they're smart. I want to keep an eye on them," says Gousev. "If I have any position, maybe I can hire them."

To get a sense of the gamut of jobs and career paths open to someone with a background in physics or the physical sciences, see the collection of short interviews in "What can physicists do?," which starts on page 26 of this issue.

REFERENCES

1. P. Mulvey, J. Pold, *Physics Bachelors Initial Employment Booklet—Academic Years 2020–21 and 2021–22*, American Institute of Physics (2025).
2. P. Mulvey, J. Pold, *Physics PhDs Initial Employment Booklet—Academic Years 2020–21 and 2021–22*, American Institute of Physics (2024).
3. J. A. Rios et al., *Educ. Res.* **49**, 80 (2020).
4. P. Mulvey, J. Pold, *Physics Trends: Knowledge and Skills Used—New Physics Bachelors Employed in STEM Fields*, American Institute of Physics (2025).

the SPS Observer
Volume LIX, Issue 2
FALL 2025
Presented by GradSchoolShopper, the Society of Physics Students, and the American Institute of Physics
THE GRAD SCHOOL ISSUE
READ NOW!
gradschoolshopper.com/magazine
Particle Accelerators to Cirrus Clouds
+ Slowing Atoms and Finding Momentum as a Researcher
+ Put Your Creativity on Display at the 2025 Congress
+ Navigating Job Interviews
SPS
AIP

SPECIAL OFFER

Post your REU at Physics Today Jobs Career Network for *FREE*

Physics Today Jobs Career Network offers FREE postings to employers recruiting seasonal REUs and interns.

Your positions are redistributed across all relevant job boards in the Physics Today Jobs Career Network:

- Physics Today Jobs
- SPS Jobs
- AAPT Career Center
- AVS Career Center

Don't Miss Out! Students are on the hunt for summer opportunities now.

GET STARTED NOW!

1. Visit employers.physicstodayjobsnetwork.org and select the 60- or 90-day free REU option at the bottom of the posting chart.
2. Create or login to your Physics Today Jobs Career Network account
3. Post Your REU

PLEASE NOTE: Valid intern-level opportunities are defined as limited-term (up to 12 weeks) employment for current undergraduates or recent Bachelor-degree recipients (within one year), with compensation in the form of a modest salary/stipend or academic credits.

PHYSICS TODAY | JOBS
Career Network

AIP

A HOME BASE FOR YOUR CAREER

Trevor Owens and Anne Marie Porter

Professional societies can foster a sense of belonging and offer early-career scientists opportunities to give back to their community.

TREVOR OWENS is the chief research officer and **ANNE MARIE PORTER** is the assistant director for social science research at the American Institute of Physics.

(Design by Masie Chong with artwork adapted from iStock.com artists ilyaliren, enjoynz, cnythzl, Giorgi Gogitidze, and Fourleaflover.)

Katie Burzynski was anxious. It was October 2018, and she was at her first AVS International Symposium and Exhibition, held every fall. (AVS is a professional society focused on the science and technology of materials, interfaces, and processing.) A graduate student at the time, she "was really nervous on how to present" her science. To her surprise, the symposium ended up being a great experience, and she recalls that "the AVS community was just so welcoming and inviting and really nurturing." Burzynski left the event thinking, "This is really fun, and I can see myself needing to have a larger community outside of my school." Burzynski, now a materials engineer at the Air Force Research Laboratory, attributes much of her career success to her ongoing engagement with AVS.

Tips for students and early-career professionals

- **Join societies and engage.** Most societies have discounted rates for students. Undergraduate students who join the Society of Physics Students get to join two of the societies in the American Institute of Physics federation for free.
- **Get to the conferences.** Throughout our interviews, we heard how important in-person interaction with colleagues has been for developing connections and careers.
- **Volunteer for leadership roles.** As a starting place, look for student or local chapters. Most societies also have open committee sessions that students can attend at conferences to learn how to get involved. Ask if a committee allows guests to experience what a committee meeting is like before joining it.

KATIE BURZYNSKI gives a student an award while serving as the 2023 AVS Ohio chapter chair. (Photo courtesy of Katie Burzynski.)

Science careers are often winding and weaving pathways across different jobs, fields, and institutions. As careers shift and evolve over time, people need a home base where they can reliably find support from their peers and friends.

As it's uncommon for someone to spend their whole career with a single institution, Burzynski says, "it's really important to have that network outside of your home organization, to help understand the different pathways that are open to you . . . other perspectives, other industries, other jobs." A society can be "your home base, no matter who's signing that paycheck."

Burzynski's society experience illustrates many of the themes that our research team at the American Institute of Physics (AIP, publisher of Physics Today) found in conversations with 22 early-career scientists and engineers. Given the critical role that professional societies play in career development, we interviewed society members to better understand why early-career scientists join societies and how their society connections advance their careers. AIP will release a full report on the results of this research in fall 2025. We highlight here some of the personal journeys of those early-career members: how they found a sense of belonging in societies and how societies gave them opportunities to give back to the scientific community.

A growing home for industry professionals

Benjamin Cromey is a member of Optica and a principal optical engineer at BAE Systems' Space and Mission Systems in Boulder, Colorado. There, Cromey has worked on the civil space business team, where he has been instrumental in leading optical design and analysis for the wide-field instrument on NASA's *Nancy Grace Roman Space Telescope*.

Cromey's connection to Optica started during a summer NSF Research Experiences for Undergraduates program after his freshman year at the University of Arizona in Tucson. His mentor for that summer was part of the Optica student chapter and encouraged him to get involved. He recalls, "I became a student member in the fall of 2012, and I'm now a life member of Optica. I'm sticking with it." He shares a number of fond memories about his undergraduate experience. He helped plan and run outreach programs, like Laser Fun Day: "We turn the optics building into a museum for the day, and we'll get anywhere from 600 to 1400 people showing up from the community." He later served as president of the Optica student chapter at the university as he was working on his PhD.

Now working in industry, Cromey sees a lot of value in continuing to engage with the community in Optica. That's in part, he says, because a lot of his company's customers are scientists, "so it is helpful to go to these conferences and give presentations that they're going to see." But unless there is a clear benefit for the business, companies may not fund conference attendance or provide employees with the time off to travel.

"The way that I've been able to stay involved is always having a business-related angle for going to the conference," Cromey says. "I resolved the first time I went to a conference to be the world's greatest notetaker. That way, if I went to a whole bunch of presentations, then other people could benefit from my going." He has informed his coworkers about new technological developments, for example, and identified new specialists to invite for potential company presentations.

In industry, Cromey has had fewer opportunities to mentor and teach students, which were two of his passions. Being an Optica member gave him the chance to teach. With encouragement from his supervisor at Ball Aerospace (which became the Space and Mission Systems sector at BAE), Cromey applied to and was admitted into Optica's ambassador program. He did not get into that competitive program the first time, but he was persistent and made it in the second time he applied.

BENJAMIN CROMEY (center) at a speed mentoring event in 2025. (Photo courtesy of Benjamin Cromey.)

As an ambassador, he gave back to future industry professionals by giving "talks about how to transition well into industry out of a PhD program, how to write a good résumé, how to give good presentations." It's rewarding to help students have great careers, Cromey says, and "getting students to think about their careers years before they might graduate is super satisfying."

Cromey's journey in Optica demonstrates how a society's student chapters can initiate a long-term relationship between their members and the society and how industry professionals can stay connected and mentor others in the community built by the society.

"Maybe there's one kid in that class who sees your presentation and it blows her mind, and she wants to go into physics," says Cromey. "She might not have thought about it before, and that's why you do it."

A community for international students

Chuqiao "Elise" Chen was born and raised in Beijing. She attended Waseda University in Tokyo and graduated with a BS degree in chemistry in 2018. She completed a PhD in molecular engineering at the University of Chicago and is

Tips for mentors

- **Show students and early-career professionals the value of societies.** Nearly all of the early-career volunteers in scientific societies attributed their success to a specific mentor who encouraged them to get involved.
- **Help find financial support for conferences.** Early-career members often need financial assistance for conference travel, lodging, and registration. That could come from research funding or from travel grants that societies offer.
- **Support and engage with local student chapters.** Many of our participants got their start with volunteering through society student chapters or the Society of Physics Students. These are great places for students to start building their career skills and confidence.

now working as a postdoctoral researcher at the University of California, Santa Barbara. She recalls that her graduate adviser sent her to a Society of Rheology (SoR) meeting in her third year, which was one of her first times presenting research at a conference. She vividly remembers the excitement of attending: “I was very nervous, but I saw that people are very kind and patient, and I also had really good conversations with people in the community.”

The SoR conference exposed her to the broader field of rheology—the study of the flow and deformation of matter—beyond her own project and provided her with a way to “get to know the people who are behind these research works.” Outside of the conference, the society has been a valuable resource for career advice and connections with others in her field. She says the sense of community has made her feel more motivated in her research work. “When I got to know these societies, it helped me pursue my own graduate research and feel I’m not alone. I’m not just one person isolated in my own research.”

Chen wanted to contribute to maintaining that community with others, especially to help students stay connected and pursue their career goals. At the conferences, she became curious about how they and other activities at SoR are organized. “It’s really nice to learn the machinery that is behind all these activities we engage in. I get to know the people who are running these activities, and one thing I learned is that none of us is paid to do this,” she says. “People do it totally out of their love for the community.”

Science careers are often winding and weaving pathways across different jobs, fields, and institutions. As careers shift and evolve over time, people need a home base where they can reliably find support from their peers and friends.

Chen has been giving back by serving as the student representative to the SoR executive committee in 2024 and 2025 and helping organize the Future of Rheology seminar series. Webinars in the series showcase the “very wide variety of research that is being carried out by the student members, postdoctoral researchers, and early-career industrial researchers,” she says. Supporting that work is something that she has found to be “a very inspiring thing.” Scientists like Chen show how international students find homes in their fields and create community for others.

“It’s not just a higher authority,” Chen says. “I hope that they recognize that it consists of people who are actively there and who are their peers, their friends.”

CHUQIAO “ELISE” CHEN (center) at an activity she organized—a student trivia night at the 2024 Society of Rheology annual meeting, held in Austin, Texas. Also pictured are Arshiya Bhadu (left) and Aldaly Pineda Hernandez (right). (Photo courtesy of Elise Chen.)

A place for mentorship and professional development

Martin Lawless earned his PhD in acoustics at the Pennsylvania State University and works as an assistant professor at the Cooper Union in New York City. He joined the Acoustical Society of America (ASA) as an undergraduate student and became more involved with the society in graduate school. His graduate program had an active ASA student chapter, and his adviser, Michelle Vigeant-Haas, encouraged all her students to publish research, join her at conferences, and participate in society activities.

When Lawless talks about his first ASA conference, he says that “it did feel like home right away.” The experience made him “feel included in this community," he says, and the feeling of being welcomed inspired him to get involved in the society. Being an ASA member has connected him with “a huge social network” that helps him with his professional development and provides a place where he can talk with others “doing similar work and compare notes.”

As a student, Lawless volunteered on the ASA student council. The council is responsible for organizing student orientations at conferences, planning social events, providing travel awards, and getting “students involved and feel-

Opportunities in professional societies

The 10 professional societies that are part of the AIP federation offer a wide range of programs, councils, conferences, workshops, and fellowships that provide avenues to get involved and form connections in the research community. Here are just a few examples:

- **Ambassador programs.** Many societies offer ambassador programs in which members act as representatives of the society to amplify resources and research. Some programs offer special trainings and focus on outreach by individuals to their home institutions, while others provide funding for ambassador-led outreach efforts, such as giving talks and writing articles that offer perspective and advice to students.
- **Committees and councils.** Serving as a council or committee member is a great way to learn about the inner workings of a society and gain experience in leadership and governance. Such groups often administer existing programs, fellowships, and awards and make decisions about what new programs should be developed. They offer a way for members to make their voices heard and shape the future of their research community.
- **Workshops and retreats.** Though conferences are a great way to connect across a discipline, workshops and retreats can provide tailored experiences that focus on specific research areas or career stages. They may be offered in connection with conferences or as stand-alone programs. Meeting in smaller, focused groups provides an ideal setting for building connections with new peers and mentors.
- **Conference sessions and abstract reviews.** Society meetings and conferences offer plenty of volunteer opportunities. Early-career members can serve as session chairs or co-chairs, roles in which they introduce speakers and provide technical support during presentations. Conferences also need volunteers to review abstract submissions for poster sessions, travel grants, and research awards.

ing comfortable in the society," he says. In 2016, he was one of the founders of the Early-Career Acousticians Retreat, which was held again in May 2025. Lawless says the retreat provides "professional development and workshops for those in industry, government, and academia" and encourages forming "collaborations between them."

Now Lawless serves on several committees. He also chairs the member engagement committee, which develops programming to attract new members and retain current members, with a particular focus on maintaining the diversity of ASA in all its aspects. Lawless continues to build communities and networks in ASA, including assisting the society in the launch of a new formal mentoring program in 2025.

Lawless says the goal of ASA's programming is not only getting members and students to engage with conference presentations but also having them "see ASA as their research or technical home."

MARTIN LAWLESS, an assistant professor at the Cooper Union in New York City and chair of the Acoustical Society of America's member engagement committee. (Photo courtesy of Martin Lawless.)

Building careers and communities

Throughout our interviews, we heard time and again that early-career leaders in scientific societies are simultaneously building their careers and their scientific communities. As Burzynski explains, when early-career scientists and engineers get involved in volunteer leadership roles, it also helps their own careers by demonstrating their capabilities as leaders and expanding their professional networks. Burzynski has worked hard to grow the AVS community by organizing regional chapter events in Ohio, and she now oversees the activities of all the society's chapters at the national level.

What does it mean for a society to be a home base for a career? Home is ultimately about belonging. It is about feeling welcome and being a part of something bigger than yourself, with people who care about your science and your community. Across the board, when our interview participants talked about what they were most proud of, it was the ways that they were able to build a sense of connection and help others advance their research and careers.

We hope this article and the upcoming full report inspire more students and early-career scientists and engineers to join a scientific society to experience the connection and sense of belonging that the participants describe.

Statement of Ownership, Management, and Circulation

(Act of 12 August 1970; Section 3685, Title 39, USC)

1. *Title of publication:* PHYSICS TODAY
2. *Publication no.:* 0031-9228
3. *Date of Filing:* 19 September 2025
4. *Frequency of issue:* Monthly
5. *No. of issues published annually:* 12
6. *Annual subscription price:* $25.00
7. *Complete mailing address of known office of publication:* 1305 Walt Whitman Road, Suite 110, Melville, NY 11747-4300
8. *Complete mailing address of the headquarters or general business offices of the publisher:* American Institute of Physics, 1 Physics Ellipse, College Park, MD 20740-3842
9. *Full names and complete mailing addresses of publisher, editor, and managing editor:*
   Publisher: Richard Fitzgerald, American Institute of Physics, 1 Physics Ellipse, College Park, MD 20740-3842
   Editor: Richard Fitzgerald, American Institute of Physics, 1 Physics Ellipse, College Park, MD 20740-3842
   Managing Editors: Andrew Grant and Johanna Miller, American Institute of Physics, 1 Physics Ellipse, College Park, MD 20740-3842
10. *Owner (if owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as that of each individual owner. If the publication is published by a nonprofit organization, give its name and address.):* American Institute of Physics, 1 Physics Ellipse, College Park, MD 20740-3842
11. *Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages, or other securities:* None
12. *The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes:* Has not changed during the preceding 12 months
13. *Publication title:* PHYSICS TODAY
14. *Issue date for circulation data below:* August 2025
15. *Extent and nature of circulation:*
   A. *Total number of copies (net press run)*
      Average* 68 965 August** 69 711
   B. *Paid subscriptions*
      1,2. *Mailed subscriptions*
      Average* 46 579 August** 46 309
      3,4. *Sales through dealers and carriers, street vendors, counter sales outside USPS; other classes mailed*
      Average* 8 667 August** 8 710
   C. *Total paid distribution (sum of B1–B4)*
      Average* 55 246 August** 55 019
   D. *Free or nominal rate distribution*
      1,2. *Free or nominal rate mail copies*
      Average* 10 271 August** 10 860
      3,4. *Free or nominal rate copies mailed at other classes or other distribution*
      Average* 2 873 August** 3 252
   E. *Total free or nominal rate distribution (sum of D1–D4)*
      Average* 13 144 August** 14 112
   F. *Total distribution (sum of C and E)*
      Average* 68 390 August** 69 131
   G. *Copies not distributed (office use, leftovers and spoiled)*
      Average* 575 August** 580
   H. *Total (sum of F and G—should equal net press run shown in A)*
      Average* 68 965 August** 69 711
   I. *Percent paid (C/F × 100)*
      Average* 80.78% August** 75.59%
16. *Electronic copy circulation:* PHYSICS TODAY
   A. *Paid electronic copies*
      Average* 41 631 August** 43 744
   B. *Total paid print copies (line 15C) plus electronic copies (line 16A)*
      Average* 96 877 August** 98 763
   C. *Total print distribution (line 15F) plus electronic copies (line 16A)*
      Average* 110 021 August** 112 875
   D. *Percent paid (both print and electronic copies) (B/C × 100)*
      Average* 88.05% August** 87.50%

* *Average number of copies of each issue during preceding 12 months.*

** *Actual number of copies of single issue published nearest to filing date.*

I certify that the statements made by me above are correct and complete.

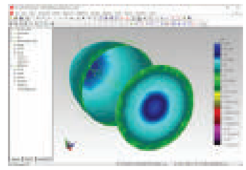
Richard Fitzgerald, Publisher

NEW PRODUCTS

Focus on software, data acquisition, and instrumentation

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

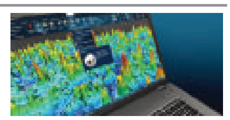


Optical and illumination design software

Lambda Research has released TracePro 2025.3, the latest version of its TracePro software that provides a versatile design, analysis, and simulation environment for illumination systems and nonimaging aspects of optical systems. In addition to updates and fixes that improve stability, accuracy, and workflow efficiency, the 2025.3 version introduces a powerful new capability: support for simulating metasurfaces using PlanOpSim ray-tracing files. Those files, generated by PlanOpSim's meta-component software, enable designers to model the behavior of surfaces with nanostructured patterns that can bend, focus, or manipulate light in ways that traditional optics cannot. In addition, the sequence editor has been enhanced with expanded functionality, including the ability to open a wider range of existing lens-design files. The improvements make it easier to bring optical designs into TracePro for sequential analysis and offer more flexibility for users working across different design platforms. ***Lambda Research Corporation***, *515 Groton Rd, Westford, MA 01886, https://lambdares.com*

Linear stages for precise and stable positioning

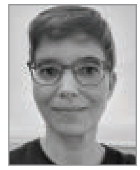
Physik Instrumente (PI) designed its L-511 high-precision linear stage series for demanding positioning tasks, such as optical alignment, laser cutting, and automated manufacturing processes. Suitable for scientific and industrial applications that require maximum motion precision, the L-511 series features repeatability down to 0.15 µm, travel ranges from 52 to 155 mm, a choice of motors that includes DC, gear, and stepper, and a wide range of configuration options. The stress-relieved aluminum base ensures high stability and prevents drift caused by mechanical loads. The backlash-free, recirculating ball-bearing guide with a 2 mm pitch provides for a high level of load capacity and run-out accuracy; the vertical and lateral run-out of up to ±1.5 µm across the entire travel range satisfies the requirements of applications requiring a high level of run-out accuracy. Noncontact optical linear encoders provide direct position measurement with high resolution in the range of a few nanometers. ***Physik Instrumente (PI) SE & Co KG***, *Auf der Römerstr 1, 76228 Karlsruhe, Germany, www.physikinstrumente.com*



Software for image and surface analysis

Digital Surf's Mountains 11 software expands on the previous version's capabilities for image and surface analysis in microscopy and metrology. MountainsSEM for 2D image analysis of scanning electron microscope images offers correction and enhancement features, particle analysis, semiautomatic multiple-object colorization, and correlative analysis—for example, with energy dispersive spectroscopy maps. MountainsSPIP Nanospectral Starter and Expert for the analysis of data at the nanoscale have been added to the software's existing scanning probe image processor (SPIP) tools. Those new products are dedicated to scanning probe microscopy instruments equipped for spectral analysis, such as nano-IR, tip-enhanced Raman spectroscopy, and scanning near-field optical microscopy. The software includes advanced tools for image processing, topography, correlative analysis, multichannel-image analysis, and full spectral and hyperspectral analysis. ***Digital Surf***, *16 rue Lavoisier, 25000 Besançon, France, www.digitalsurf.com* PT

Silvia Alonso-Pérez (salonsop@ull.edu.es) is a professor in the department of industrial engineering at the University of La Laguna in the Canary Islands, Spain. Her research combines engineering with her passion for electronic music.



Playing with electromagnetic waves: The science of the theremin

The physics behind the unique instrument lets players turn hand gestures into music.

Silvia Alonso-Pérez

Roughly four decades before Stevie Wonder and the Doors began incorporating electronic synthesizers into their music, another electronic instrument took the world by storm. Demonstrated by the Russian physicist, inventor, and musician Leon Theremin in 1920, the unique device came to carry its creator's name. It was brought to market by RCA in 1929 and was the first commercially available electronic instrument.

Unlike earlier electromechanical musical instruments, the theremin was conceived from the beginning as an apparatus whose sound would be generated entirely electronically. Working in the laboratory of famed theoretical physicist Abram Ioffe, Theremin had developed an early wireless motion-detection alarm system and a device to measure the density and dielectric constant of gases. Both projects explored capacitance changes in circuits, which led Theremin to notice that the position of his hand in an electromagnetic field affected the pitch of the sound emitted by an electric oscillator. That observation inspired him to create a musical instrument, originally marketed as the etherophone and the thereminvox, that could play melodies based on the performer's hand position relative to an antenna.

Theremin probably never imagined that his fascinating creation would have such a significant influence on popular culture and art music. It is indelibly linked to science-fiction film soundtracks—notable examples include the classic 1951 film *The Day the Earth Stood Still* and 2018's *First Man*. Arguably the only instrument that is played without being touched, the theremin has acquired an unmistakable aura of mystery because of its eerie sound. This Quick Study provides an overview of the physics behind this unusual instrument.

The most mysterious instrument

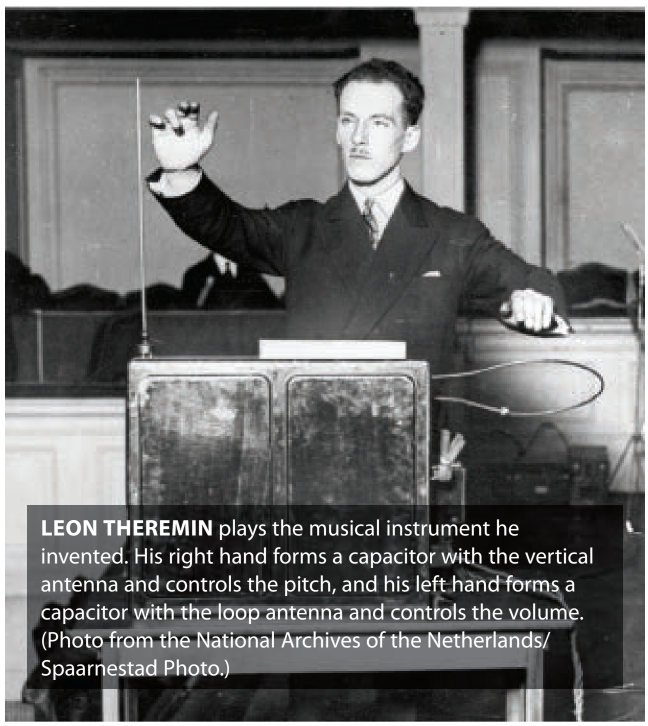
Theremin's first prototype for his device consisted of a wooden box that housed electronic circuits, a vertical antenna for pitch control, and a pedal for volume control. He soon replaced the pedal with a horizontal loop antenna, which resulted in the design that is commonly used today. Both antennas produce an electromagnetic field.

Together, the vertical antenna and the player's hand make up the two conductive plates of a capacitor whose dielectric is the air between them. As the hand approaches the antenna, the capacitance increases, which changes the frequency of the alternating current in a circuit and results in a higher pitch. Specifically, the change in capacitance—typically only a few picofarads—changes the frequency of a variable oscillator. That oscillator and one of fixed frequency form the pitch-control circuit. Both oscillators typically consist of a capacitor and an inductor connected in parallel.

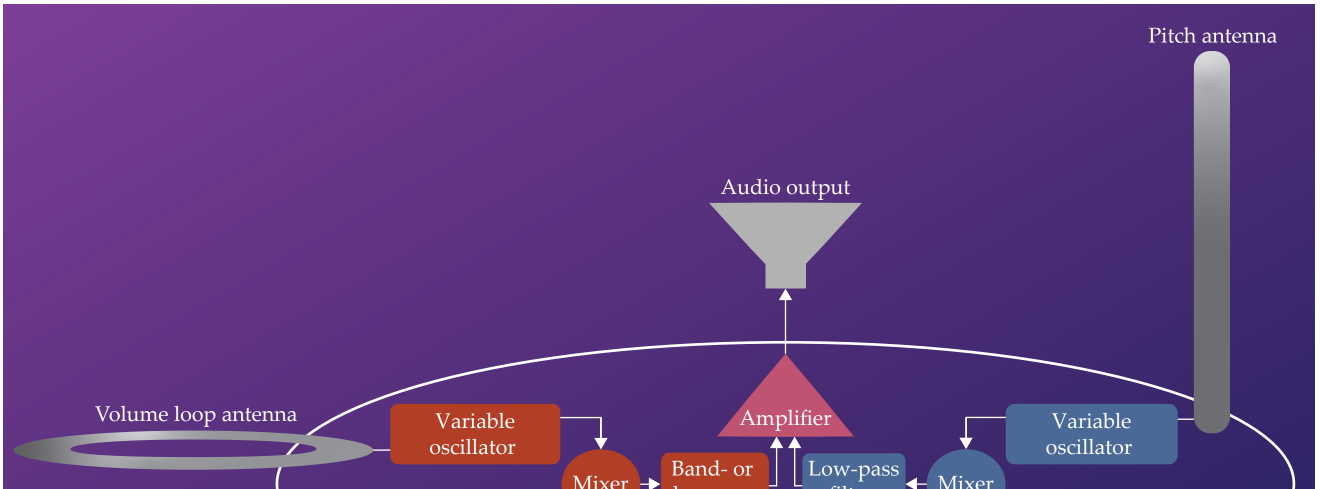
The player's other hand forms a capacitor with the horizontal loop antenna, which is used for volume control. Attached to it is a second circuit that is also made of a fixed-frequency oscillator and a variable oscillator. In the volume-control circuit, changes in capacitance result in changes in the volume of the produced sound: The closer the hand is to the horizontal antenna, the lower the volume. The shape of the loop antenna makes the instrument particularly sensitive to vertical motion just above and inside the loop. That sensitivity allows players to easily create nuanced dynamic changes—and even instantaneous silences—with intuitive hand motions.

How the magic happens

Both circuits operate on the heterodyne principle. Developed in the early 20th century for radio communications, the technique involves multiplying two electromagnetic oscillating signals of different frequencies to produce new signals at the sum and



LEON THEREMIN plays the musical instrument he invented. His right hand forms a capacitor with the vertical antenna and controls the pitch, and his left hand forms a capacitor with the loop antenna and controls the volume. (Photo from the National Archives of the Netherlands/Spaarnestad Photo.)



A DIAGRAM of the electronic circuits that make up an analog theremin.

the difference of the original frequencies. In the pitch-control circuit, the variable and fixed-frequency oscillators each produce a high-frequency AC signal: between 170 kHz and 1 MHz, depending on the design. The two oscillator signals are then multiplied by a nonlinear mixer (see the circuit diagram) to create a signal with two frequency components. The lower-frequency component of the new signal, which ranges from about 65 Hz to 3 kHz, is termed the beat frequency.

To obtain an audible tone that can be sent to an output, the mixed signal is sent through a low-pass filter, which isolates the audible components by attenuating higher frequencies that are still contained in the signal as harmonics and intermodulation products. The signal is subsequently routed through a voltage-controlled amplifier before being sent to the audio output, which is typically an external speaker.

In the volume-control circuit, one or two high-frequency oscillators are used, whose combined signal is routed first through another nonlinear mixer before being sent to a filter. A band-pass filter is sometimes used instead of a low-pass filter because the former gives the instrument a greater dynamic range and makes the volume response more sensitive to smaller hand motions. The signal from the filter is then routed through the amplifier.

Classic analog theremins do not produce sounds precisely tuned to traditional musical notes; instead, they generate a continuous set of tones depending on the player's ability to stabilize the position of their hands within the electromagnetic field. Some digital or hybrid theremins—those that combine analog sensor circuits with digital sound engines and processing—incorporate pitch quantization, which adjusts the sound to the nearest note in a chosen musical scale. That feature comes at the cost of the expressiveness that is possible on analog theremins.

Both classic and digital theremins have a chromatic range of up to six octaves. But players rarely use more than five octaves because the extreme high register is difficult to control with precision: Notes get closer together in the higher octaves as the hand approaches the antenna.

From circuits to sound

Analog and digital theremins differ significantly in their tonal character. The classic analog theremin design incorporates vacuum tubes or discrete transistors in the oscillators, mixers, and amplifiers. Those components shape the harmonic coloration and the overall timbre of the tone produced. The instrument's tone, linearity, and sensitivity are influenced by the types of capacitors and inductors used, differences in the physical layout of the circuit components, and even the ambient environmental temperature. In fact, the natural nonlinearity and slight instabilities inherent in analog electronic instruments—including early synthesizers—contribute to the characteristic warm sound of classic theremins, with their lively, expressive, stringlike, and sometimes unpredictable tone.

Digital, also known as hybrid, theremins use microprocessors or digital signal processors not only to interpret the position of the player's hands relative to the antennas but also to generate sound. Those theremins often come with built-in effects, pitch quantization, and banks of preset sounds, some of which attempt to emulate the classic theremin. But digital circuitry makes the sound of those theremins more stable and less harmonically complex. Their timbre is cleaner or cooler than that of analog theremins.

The reference standard used by both builders and performers to evaluate the tone quality of a theremin is the sound emitted by the first model manufactured by RCA. Known for producing what is sometimes called the holy grail of theremin tones, it has a resonant, woody low end; a sweet high register; and the distinctive warm harmonic coloration that is characteristic of vacuum-tube circuitry. Although current technology can approximate that ideal sound, the dexterous hands of skilled performers like Theremin himself are still required to achieve sonic excellence.

Additional resources

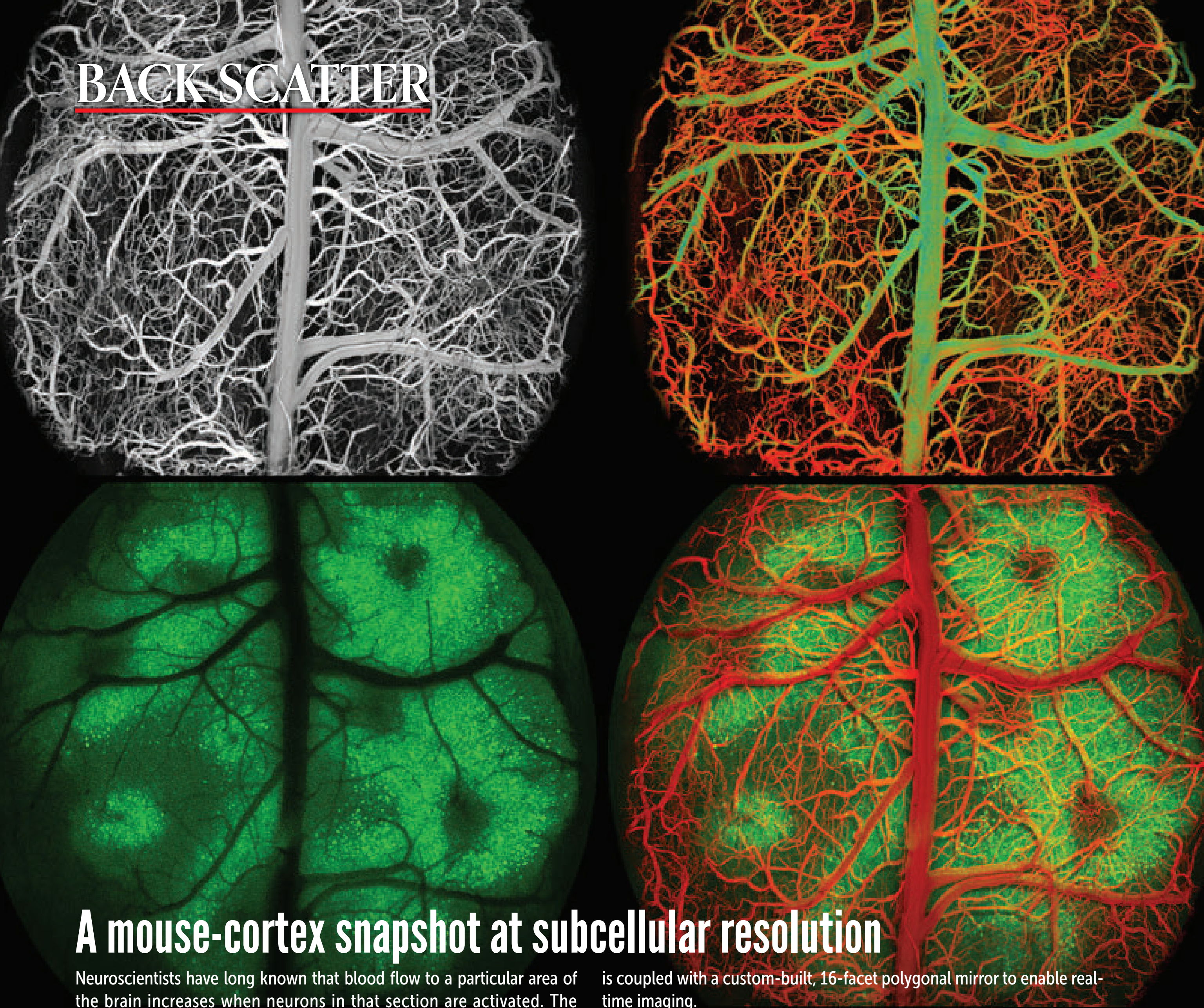
▶ K. D. Skeldon et al., "Physics of the theremin," *Am. J. Phys.* **66**, 945 (1998).

▶ F. K. Prieberg, *Musica ex machina: Über das Verhältnis von Musik und Technik* (Musica ex machina: On the relationship between music and technology), Ullstein (1960).

▶ A. Glinsky, *Theremin: Ether Music and Espionage*, U. Illinois Press (2000).

PT

BACK SCATTER



A mouse-cortex snapshot at subcellular resolution

Neuroscientists have long known that blood flow to a particular area of the brain increases when neurons in that section are activated. The phenomenon, termed neurovascular coupling, enables the imaging of brain function on a local level through use of techniques such as functional MRI. But a broader understanding of the spatial and temporal features of neurovascular coupling at the cellular level has eluded researchers: It has proven difficult to develop an imaging technique with both the necessary field of view and resolution to capture brain activity on a cortex-wide level.

To solve that problem, a team led by Chengbo Liu at the Shenzhen Institutes of Advanced Technology in China has constructed a new type of hybrid microscope that integrates two imaging techniques: confocal fluorescence microscopy and photoacoustic microscopy. The first captures fluorescent calcium signals that are emitted during neuronal activity; the second, based on the photoacoustic effect—when sound waves form in a material after it has absorbed light—exploits the optical absorption of hemoglobin.

The microscope consists of an array of eight miniature high-frequency transducers, which extend the field of view for both microscopies without any loss of sensitivity in photoacoustic microscopy. The transducer array is coupled with a custom-built, 16-facet polygonal mirror to enable real-time imaging.

The team demonstrated the combined technique's high resolution and field of view by imaging the neurons and blood flow in the dorsal cortices of mice that were in the resting state, under anesthesia, or in an induced epileptic seizure. These images from a resting mouse's brain show a map of blood-vessel intensity (top left); a map of blood-oxygen saturation, in which red shading indicates higher oxygen levels (top right); a fluorescence-intensity map (bottom left); and the merged final image output, in which the blood vessels have been colorized in red for clarity (bottom right).

Liu and his team see the technique helping researchers study neurological disorders associated with aberrant neurovascular coupling, such as seizure disorders, strokes, and Alzheimer's disease. They also envision miniaturized versions of the hybrid microscope allowing neurosurgeons to see brain oxygenation and activity in real time. (L. Liu et al., *Sci. Adv.* **11**, eadw5275, 2025; images courtesy of Chengbo Liu laser-induced ultrasound lab, Shenzhen Institutes of Advanced Technology.) —RD