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October 2020 • volume 73, number 10

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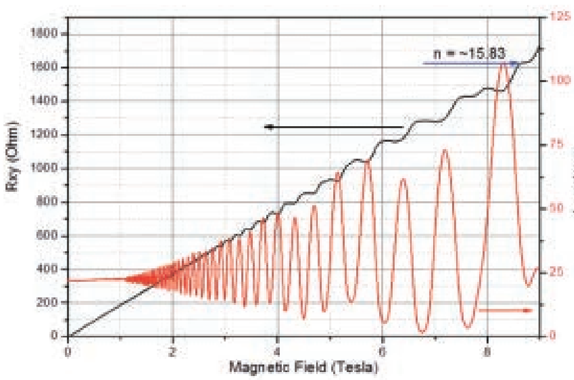

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CAREERS issue

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The road from reading a job posting to signing a contract is long and involved. Advice from a recently hired professor may smooth the path.

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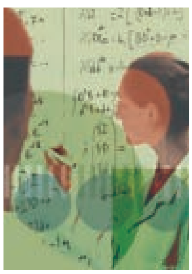

ON THE COVER: Our second annual careers issue focuses on early careers. On **page 40,** Patrick Mulvey of the American Institute of Physics surveys the initial employment of physicists who earned their PhD in 2017 and 2018. Two other features offer advice on how to land a type of job highly sought after by new PhDs: a tenure-track professorship. Matt Anderson of San Diego State University provides the perspective, on **page 52**, of a search committee member. Omar Magaña-Loaiza of Louisiana State University provides the perspective, on **page 30**, of a successful candidate. (Image by iStock.com/virtualphoto; adapted by Donna Padian.)

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▶ Satellite trails

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physicstoday.org/Oct2020a

BJOERN PENNING

▶ Switching jobs

The pandemic and the attending economic downturn have added stress and uncertainty for many academic job seekers. PHYSICS TODAY's Toni Feder talks with several physicists who navigated the challenging process, including one who has yet to set foot on the campus of her new employer.
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A Jupiter-sized exoplanet that orbits a considerably smaller white dwarf has been spotted by NASA's *Transiting Exoplanet Survey Satellite*. The discovery leads to questions about how the planet survived the turbulent past of its host star, particularly the red-giant phase.
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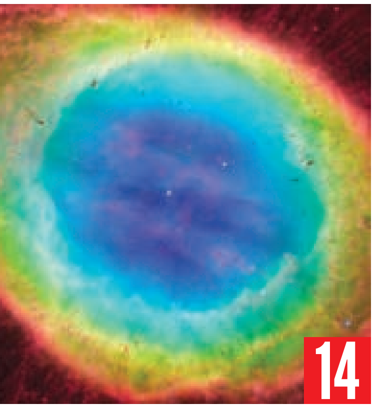

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FROM THE EDITOR

Career choices

Charles Day

Welcome to PHYSICS TODAY's second annual careers issue! The theme for this year is early careers.

On page 40, Patrick Mulvey of the American Institute of Physics's Statistical Research Center summarizes the results of a survey regarding the initial employment of physicists who earned their PhD in 2017 and 2018. (PHYSICS TODAY is published by AIP.) One recent trend that Mulvey and his collaborators discovered is a switch in the most common type of first position. It used to be a postdoc; now it's what he calls a potentially permanent position, most of which are in the private sector.

Few new PhDs land a potentially permanent position in academia, even after a postdoc or two. Still, a tenure-track position remains the most desired destination for 60% of the postdocs who responded to Mulvey's survey. The two other feature articles in this issue offer advice on how to obtain one of those coveted positions.

Matthew Anderson of San Diego State University provides the perspective, on page 52, of a professor whose task it is to help his or her department find the best candidate. Omar Magaña-Loaiza of Louisiana State University in Baton Rouge provides the perspective, on page 30, of a successful candidate.

Please don't take this year's focus as evidence that PHYSICS TODAY discounts the private sector or what physicists do in their middle and late careers. I intend to visit those and other topics in future careers issues. Still, I'd like to complement this year's articles with observations gleaned from my first job at this magazine: obituaries editor.

I joined PHYSICS TODAY in June 1997. Back then, magazines were replete with advertising. They could afford to print more pages than they can today. For obituaries, that meant running six—even eight—an issue. Most of the obituaries I solicited and edited recounted the sort of career that I hope Anderson and Magaña-Loaiza will continue to enjoy: that of a university researcher and teacher. But there were some less typical obituaries published in my first full year, 1998, that have stuck with me.

Gaspar Valenzuela was born in Coelemu, Chile, in 1933. He moved to the US to study electrical engineering. His first job was in the radio division of Westinghouse Electric in Baltimore. He remained in Maryland to work at the Applied Physics Laboratory (APL) and then get his PhD at the Johns Hopkins University. After returning to APL, he switched the focus of his research from developing millimeter-wave systems to developing an application of them: measuring from space what sailors and oceanographers call the sea state or how rough the sea's surface is. His obituary on page 94 of the February 1998 issue describes how fruitful that line of research became after he moved to his final professional home, the US Naval Research Laboratory in Washington, DC.

Glenn Dyer was born in 1939 in rural New Brunswick, where he attended a one-room schoolhouse. A scholarship funded by media magnate Lord Beaverbrook enabled him to attend university, where he studied physics. Like Valenzuela, he opted first for a career in industry—in his case, at Technical Operations, which made measurement instruments in Burlington, Massachusetts. There, he acquired the skills and confidence to start his own company, Dyer Energy Systems, in 1974. From his obituary on page 104 of the October 1998 issue, we learn of the new heat engine he designed and his abiding interest in farm tractors.

Dyer and Valenzuela were too young to serve in World War II, but many of the physicists whose obituaries appeared in 1998 had fought or done war-related R&D. Among them was Rutherford Adkins, who was born in Alexandria, Virginia, in 1924. He was an undergraduate at Temple University in Philadelphia when, in 1941, he was drafted. Trained as a pilot at Tuskegee Army Air Field in Alabama, he flew 14 combat missions in Western Europe. A photograph from his Wikipedia entry shows him standing next to a P-51D Mustang, presumably the one he piloted. After his discharge, he resumed his education and chose physics. He went on to become a nuclear physicist and university administrator. At the time of his death, he was president of Fisk University in Nashville, Tennessee. His obituary appeared on page 90 of the September 1998 issue.

I don't know why Adkins became a physicist after fighting the Luftwaffe, why Dyer started his own company, or why Valenzuela changed his line of research. But their lives remind us of the choices we have, even in difficult times. PT

Science's endangered reputation

THE VIDEO "What Makes Science True?" from Nova PBS explores how the scientific process is self-correcting and the frontier always uncertain.

For many people, science is no longer an indisputable enterprise that builds knowledge and defines the progress of our society. Highly publicized cases of scientific misconduct, misrepresentation or oversimplification by the media, and the low reproducibility of research results have created an impression that science in general cannot be trusted. A YouTube video with the title "Is There a Reproducibility Crisis in Science?" has more than 300 000 views, "Is Science Reliable?" has more than 400 000, and "Is Most Published Research Wrong?" has more than 2.4 million; other online publications and videos with similar titles abound. For comparison, the NOVA PBS video "What Makes Science True?," which explains the ability of science to eventually correct misleading results, has only 39 000 views on YouTube.

Scientific research does not take place in a vacuum; it is directly connected to the politics of society because most research is funded with taxpayers' dollars. The general public and members of the US Congress are increasingly asking, Why should money be wasted on unreliable and, consequently, useless research?

Scientific misconduct has been discussed extensively by federal funding agencies, and in 2000 the White House Office of Science and Technology Policy adopted a specific definition for research misconduct to be applied across all government agencies. According to that definition, research misconduct means "fabrication, falsification, or plagiarism (FFP) in proposing, performing, or reviewing research, or in reporting research results." A published analysis of data on FFP and the reproducibility of research results shows that although physics and related sciences are definitely not immune, they fare better than biology, medicine, psychology, and other branches of science.[1–5]

The most likely reasons for that difference are that physics is a quantitative science and is governed by a set of major laws. So, it is especially sad to see some research papers include statements and conclusions that directly violate those laws and misuse scientific terminology. For example, I know of papers reporting solar cells, LEDs, photodetectors, and other devices with efficiency over 100%. Interestingly, soon after those results were published came new reports that claimed 250%, 60 000%, and even higher efficiency.

An important question is, What separates good science from bad—is it a narrow line or a gray area? These days, one can find physics and engineering papers stating that a presented result, approach, or method "has opened the door for a revolutionary device design," or "offers an unmatched portfolio of properties," or "leads to fabrication strategies not possible with traditional technology," or "will find use in widespread technological applications," and so forth. Definitely, such statements cannot be considered FFP. At the same time, they cannot be proven. Many of my colleagues consider exaggerations and overstatements to be a first step into the gray area that separates honest science from everything else.

Physical constants are universal; it does not matter when, how, or by whom measurements and calculations were performed, as long as they were performed and reported correctly. Similarly, scientific definitions are useful only if they have been applied properly, and any deviation from the established norm should at least be explained. Overstatements, misuses of scientific definitions, and exaggerations of research results, often due to the pressure to publish and the competition for funding, do not fall under the umbrella of FFP. Nevertheless, they do harm the reputation of science (as well as the reputation of the authors) and should not be tolerated by the reviewers and editors of research journals.

It is well known that reputation is hard to build and easy to lose; however, it is even harder to rebuild. We still have a chance to rebuild the reputation of science, but we have to start as soon as possible.

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More thoughts on physics pedagogy

John Winfrey's thought-provoking letter in PHYSICS TODAY's April 2020 Readers' Forum (page 10) makes two points regarding the physics curriculum and teaching materials. First, he notes that gaps in understanding originate in the undergraduate curriculum and persist into faculty teaching; second, he suggests that they are part of a problem with physics textbooks and pedagogy not adhering to well-known discoveries in cognitive science.

Gaps are not a problem in just the physics curriculum; they are pervasive throughout undergraduate education. One of us (Kevin) has taught the mathematics sequence from college algebra through differential equations and has seen the problem most clearly exhibited in trigonometry courses. Despite its elementary nature, trigonometry is an important recruiting ground for physical-sciences and engineering students: Class rosters are filled with students who show mathematical and scientific talents but have had poor guidance about how to apply them.

A typical trigonometry course is divided into three parts: trigonometric ratios and functions; analytic trigonometry, with its identities and equations; and applications and advanced topics. The courses tend to overemphasize part two, with classes wallowing for week after week in identities. As a result, advanced topics such as complex numbers, polar coordinates, and vectors aren't covered at all, and an opportunity to introduce concepts that physical scientists and engineers use extensively is squandered. Similarly, algebra courses will skip important material later in the textbook, such as an introduction to exponential and logarithm functions, because of lack of time. In a differential equations course, operational mathematics might be skipped.

In physics classes, instructors may eliminate topics such as hydrostatics or some of the introduction to fields—especially quantities related to the magnetic field—to make room for advanced topics that may be of more interest to faculty and students but actually do most students little good. Moreover, introductory courses in physics and in engineering will present vectors in somewhat different ways. Mechanical engineering students may not even take Physics I because the material is ostensibly covered in their statics and dynamics courses. So various cohorts of students entering Physics II possess different ideas and tools.

Winfrey posits that gaps in understanding result from instructors' attempts to build from specific to general ideas, and because of time constraints in most courses, the students never reach the general material. That approach, he writes, ignores the primacy effect: Material presented earlier is mastered better than material presented later. Textbook authors should therefore take the primacy effect into account and go from broad, general concepts to specifics.

Winfrey's suggestion runs into the somewhat unsettled realm of educational theory. Every teacher recognizes that students learn early course material best, but it isn't clear why. Many theories, all with some supporting evidence, attempt to explain the effect. For example, some researchers propose that information is easier to retrieve when it is subjected to occasional tests of recall, and early course content is tested more often.[1,2] Another theory holds that later course content exceeds the cognitive load that students are able to successfully process and store in their long-term memory.[3]

An introductory physics course will seek to teach students the foundations of electrostatics, in which time derivatives are zero. Winfrey's more general formulation of Coulomb's law brings in dynamical quantities. Although that formulation is in keeping with his general-to-specific paradigm, it runs counter to the idea of reducing unnecessary complexity in order to avoid cognitive overload.

Whatever the true sources of cognitive barriers in instruction turn out to be, all of us who teach mathematics, physics, and engineering can do better by learning what our customers—the students—need most and reordering or reemphasizing instruction to meet those needs. Possibly we can add big-picture generalizations, as Winfrey suggests, while also removing redundant material to avoid adding to the cognitive load. It is our responsibility as instructors to determine, in coordination with other departments, what is germane for each course we teach and to design our instruction accordingly.

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A footnote on the founding of NSF

Emily Gibson's article "NSF and postwar US science" (PHYSICS TODAY, May 2020, page 40) was an enjoyable read. I have a personal footnote to add.

In 1954, as a graduating senior at the University of Wisconsin–Madison, I had been interested in solar astronomy even though I was majoring in physics. Joseph Hirschberg, Newell Mack, and I took a laboratory slate tabletop and other equipment to Mellen, Wisconsin, to observe an eclipse.

Although we did not get the information we wanted during that eclipse, another one was going to occur in the South Pacific in 1958. Groups from the High Altitude Observatory, the Sacramento Peak Observatory, and other facilities were planning to go there with support from the US Navy.

Julian Mack, who had been my senior thesis adviser, suggested that I write a proposal. He signed it, sent it to the Office of Naval Research (ONR), and then went off for an appointment as a scientific attaché in Sweden.

I received a letter from the ONR that they no longer provided general scientific support for the study of solar eclipses. But a new federal agency, the National Science Foundation, now handled such proposals, and the ONR forwarded my request. A while later I received a letter from NSF that included a check to fund the trip.

I took the check to the department chair, Ragnar Rollefson, who said he would have an account opened so that I could spend funds for equipment and travel. Time was short to have equipment dockside at Naval Base San Diego for the navy to take it to Pukapuka, New Zealand, via Honolulu. So I asked George Streander, Mack's instrument maker, if he would sign on and help make the equipment to study the eclipse. I designed an observation hut and gave lumber estimates to the navy, which would get the wood in Hawaii. I also designed the optics and heliostat; George made castings and all the fine parts, and he suggested bearings and a drive system for the heliostat. Narrow band-pass filters, lenses, photographic plate holders, tools, and other items were ordered and purchased. The university carpentry shop made the boxes for the equipment, and we took them to the train station in Madison for shipment.

We were ready at Pukapuka, but the weather wasn't. Clouds prevented most of the observers from getting data, although the rocket launches from the ship deck were successful.

Later on, in the 1960s, I served as the program director for Solar Terrestrial Research at NSF while on leave from Los Alamos National Laboratory. And in 1973 NSF approved a grant for my study of the total solar eclipse over Africa aboard a prototype Concorde, whose supersonic speed allowed 74 minutes of observing the Sun's corona.

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Milutin Milanković's time in Serbia

In their article "Physics in the former Yugoslavia: From socialist dreams to capitalist realities" (PHYSICS TODAY, August 2019, page 30), authors Mićo Tatalović and Nenad Jarić Dauenhauer wrote that "Although the region gave the world these eminent physicists"—referring to Jožef Stefan, Andrija Mohorovičić, Milutin Milanković, Nikola Tesla, and others—"all of them worked abroad." For Milanković, at least, that statement may mislead readers: Although he did work abroad, he spent most of his scientific career in Serbia.

Milanković (1879–1958) is best known for discovering the Milankovitch cycles, changes in climate driven by variations in insolation at midlatitudes caused by changes in Earth's orbit over tens of thousands of years. He studied engineering at the Technical University of Vienna and earned his doctorate there in 1904 with a thesis on reinforced concrete, a new material at the time. He worked in Vienna until 1909, when he accepted the chair in applied mathematics at the University of Belgrade. There he taught mechanics, celestial mechanics, and theoretical physics and developed his astronomical theory of climate.

Milanković was on his honeymoon in 1914 in his hometown of Dalj, in Croatia, part of the Austro-Hungarian Empire, when the empire declared war on Serbia in July. A Serbian citizen, Milanković became a prisoner of war. Due to pressure from Austrian scientists, he was released on Christmas Eve 1914, and he was offered two choices, to live in Vienna or in Budapest. He chose Budapest because, as he noted, "in Vienna everybody was starving." He returned to Belgrade in March 1919 and remained there until his death in 1958.

Milanković vividly recorded the above details in his extensive diaries, which the Serbian Academy of Sciences published in the 1950s. A small part was translated from Serbian into English by his son, Vasko, in *Milutin Milanković 1879–1958*, published in 1995 by the European Geophysical Society.

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Cold War particle-physics collaborations

Gerson Sher's book *From Pugwash to Putin*, reviewed by Rebecca Charbonneau in PHYSICS TODAY's May 2020 issue (page 56), captures his experience as an NSF coordinator and sometime participant in US–Soviet scientific collaborations. But his telling omits significant other Cold War–era US–Soviet collaborations and participants—in particular, the entire area of particle physics.

One major participant was Wolfgang Panofsky, the force behind the creation of SLAC and its first director, an internationally known leader in particle physics, and a highly regarded adviser to policymakers in Washington, DC. Panofsky wrote of his role in international collaborations in his memoir, *Panofsky on Physics, Politics and Peace: Pief Remembers*, published in 2007, the year in which he passed away. In his book, Panofsky describes a trip to the Soviet Union in 1956—a year before the first Pugwash conference—when he and 14 other scientists were invited to tour a number of high-energy-physics laboratories. He writes that the visit initiated "a new era of communications in high-energy physics." It was during that trip that he met Gersh Budker, which initiated years of scientific collaboration between the two.

The next major step in particle-physics collaboration came in 1970: a joint high-energy-physics experiment at the Institute for High Energy Physics (IHEP) in Protvino, about 100 km south of Moscow. Darrell Drickey of UCLA and Edouard Tsyganov of the Joint Institute for Nuclear Research (JINR) led the project (see PHYSICS TODAY, September 1970, page 18). I was a young postdoc in the UCLA contingent, which included six scientists and their families, several with young children. The Soviet group included Russians, Uzbeks, Poles, and a Romanian. We Americans lived in Protvino for six months, working through the long Russian winter, forming friendships, and creating indelible memories. Some of the participants got together a few years later at Fermilab to repeat the experiment.

The joint scientific endeavor was in the spirit of détente a full two years before Richard Nixon's 1972 meeting with Leonid Brezhnev, which Sher refers to as the start of détente. At the time, the IHEP proton accelerator was the highest-energy machine in the world, and the Soviets were keen to provide visibility for their scientific achievement and the science city constructed to house workers and guests.

As a junior member of the US group, I was not party to the behind-the-scenes negotiations to create the collaboration, which the 1970 PHYSICS TODAY report describes as a years-long effort between the US Atomic Energy Commission and the USSR State Committee for the Utilization of Atomic Energy. I was told at Panofsky's memorial symposium at Stanford University in 2010 that he also was involved.

The story behind the UCLA–JINR partnership and the topic of US–USSR particle-physics collaborations would have added an important piece to the history that Sher endeavors to cover in his book.

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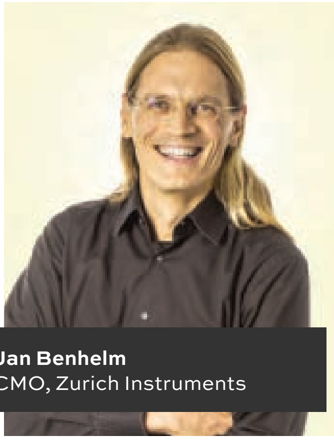
Zurich Instruments introduces next-generation Quantum Computing Control System



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Zurich Instruments is a test and measurement company whose mission is to provide the best tools for scientists and engineers. The company was founded in 2008. At the time, the price-to-performance ratio of FPGAs, DACs, and ADCs had fallen to the point that it became attractive to develop a new generation of instruments with new functionalities. We also focused on improving the user experience by providing a novel, Web-based user interface and tools for measurement automation.

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Due in part to our early and continued emphasis on customer care, we have forged close ties with academia and with experimental physicists in particular. Our strong, recent commitment to quantum computing has led us to team up with two of the top research groups working with superconducting qubits: one headed by Leo DiCarlo at Delft University of Technology, the other by Andreas Wallraff at ETH Zurich. Since 2015, our joint projects have pushed forward the instrumentation and firmware to link qubits with higher-level software. As a result of those efforts, we launched the first generation of Zurich Instruments' Quantum Computing Control System (QCCS) in 2018. The QCCS concept has already helped our customers achieve significant scientific results.

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Building useful quantum computers is a strategic goal of several big tech companies and national governments. Fueled by increasing investments, setups have grown in size and complexity. For the field to progress quickly, reliable and commercially available control electronics and software are essential. The availability of innovative hardware and software solutions also lowers the entry barrier for new players and, in turn, will increase the variety of promising qubit technologies.

Zurich Instruments also supports the quest to scale up to ever larger numbers of qubits. Indeed, we envision our technology supporting 100 qubits and more. With scalability and higher levels of integration in mind, we have just launched a new quantum analyzer, the SHFQA. As part of the next-generation QCCS, the SHFQA includes microwave generation and offers previously unseen signal-to-noise ratios. Measurement times are reduced, and the need for time-consuming calibration is eliminated. A single SHFQA can measure up to 64 superconducting qubits in parallel or staggered formations, effectively combining the functionality that used to require half a rack of space and dozens of cables.

The first experiments have been carried out with this new instrument. With other innovations in the immediate pipeline, we are confident that our customers will make major contributions to the field in the near future.

Compressibility measurements reach white dwarf pressures

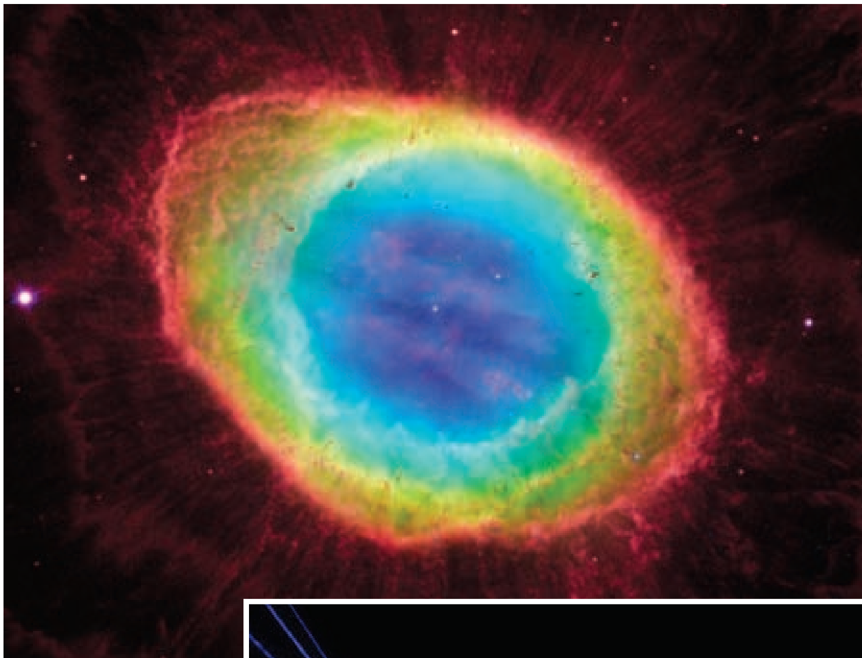
With spherically converging shock waves, researchers can probe material properties under extreme conditions.

Humans have never visited Earth's core or been to the stars. Most of what we know about those exotic environments comes from observations made on or near Earth's surface. We've learned a lot about what's inside our own planet from seismic waves, which propagate differently through the rocky crust and mantle, liquid outer core, and solid inner core. (See, for example, the article by Bruce Buffett, PHYSICS TODAY, November 2013, page 37.)

Stars, too, are seismically active, and the pressure and gravity modes that pulse through a star can reveal themselves as periodic brightness variations that, though subtle, are visible from Earth. By analyzing those oscillations, asteroseismologists reconstruct stars' compositions, internal structures, and even evolutionary dynamics. (See the article by Conny Aerts, PHYSICS TODAY, May 2015, page 36.)

But much of the matter inside planets and stars exists in forms unlike anything we encounter on Earth's surface. Chemical bonds start to be ripped apart at pressures above 1 Mbar (a million times the atmospheric pressure at Earth's surface, but less than a third of the pressure at the planet's core, and an even smaller fraction of the pressure inside a star). Above 100 Mbar, or 10 TPa, atoms of carbon and its neighboring elements start to lose even their core electrons. Those changes inevitably influence material properties, such as how much a material compresses in response to additional pressure, and thus complicate the interpretation of asteroseismology measurements.

Now, for the first time in a laboratory experiment, researchers working at Lawrence Livermore National Laboratory's National Ignition Facility (NIF) have measured material compressibility[1] at pressures exceeding 100 Mbar. The team used NIF's powerful lasers (the blue beams in the lower panel of figure 1) to deliver a megajoule of energy in a 5 ns pulse to a solid sphere 2 mm in diameter. The lasers launched a spherical shock wave that converged on the sphere's center and reached pressures up to 450 Mbar.



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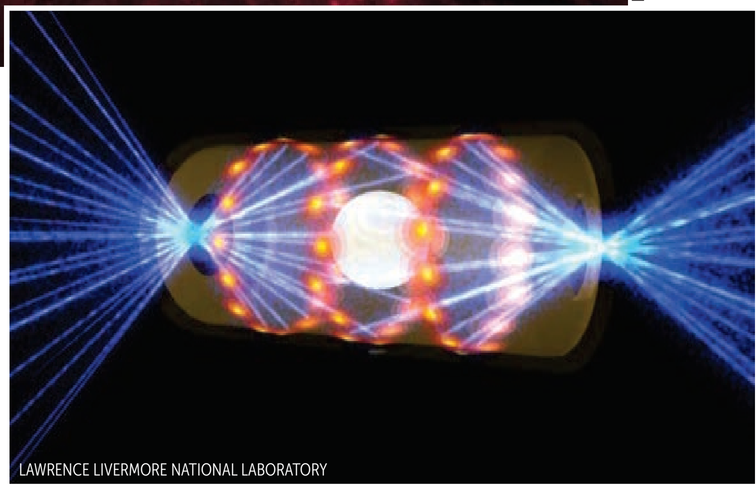

LAWRENCE LIVERMORE NATIONAL LABORATORY

FIGURE 1. THE PALE DOT at the center of the upper image is a white dwarf, the hot, dense ball of mostly carbon and oxygen left behind when a dying star sheds its outer layers. The National Ignition Facility re-creates white-dwarf conditions in the lab by using lasers (blue beams in the artist's rendering in the lower image) to deliver hundreds of kilojoules of energy to a centimeter-long cavity (dull gold) containing a solid sample (white).

Because the sphere was made of a carbonaceous material, its compression mimicked the conditions in the outer envelope of a carbon-rich white dwarf—the faint, dense remnant of a main-sequence star that has exhausted its hydrogen fuel but has insufficient mass to fuse carbon and oxygen into heavier elements. Like other stars, white dwarfs can pulsate and be probed by asteroseismology (see PHYSICS TODAY, March 2018, page 16), and the convective outer envelope is the region most responsible for their pulsation modes.

Consider a spherical shock wave

Shock-wave experiments have long been used to study materials under extreme

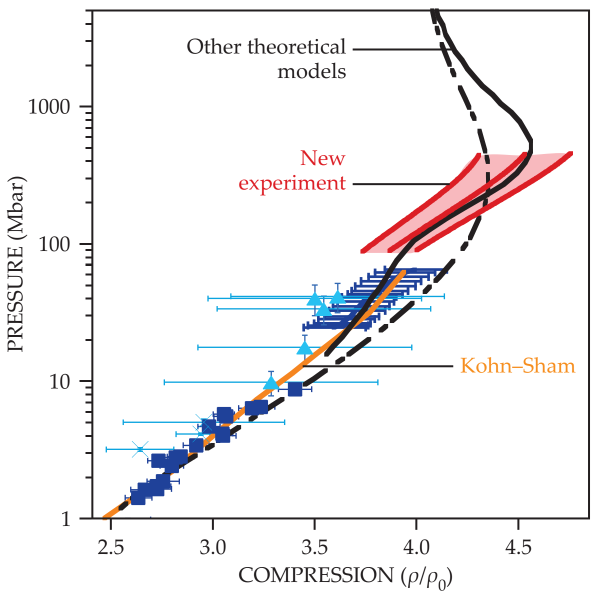

FIGURE 2. SHOCK-WAVE EXPERIMENTS on a hydrocarbon solid show how the material's compression (mass density ρ divided by initial density ρ_0) varies with pressure. Light- and dark-blue data points show the results of previous experiments, mostly based on planar shock waves and in good agreement with Kohn–Sham density functional theory (orange). Above 100 Mbar, carbon starts losing its core electrons, and only other, computationally cheaper theoretical models are feasible (black curves). New work using spherical shock waves, the results of which are shown in red, is the first lab measurement of compressibility in that high-pressure regime. (Adapted from ref. 1.)

conditions. (See the article by Paul Drake, PHYSICS TODAY, June 2010, page 28.) Shock waves—created by lasers, magnets, explosives, or other means—concentrate energy in time, so they can access higher pressures than is possible with static compression. And their behavior is well understood: Conservation of mass and momentum straightforwardly relate the shock propagation speed to the pressure and density of the shocked material. If any two of those three quantities are known, the third can be calculated. Most experiments to date have used planar shock waves that propagate uniformly through a material, so that their speeds, for example, can be extracted from their total transit time over a known distance.

NIF was designed for research on inertial confinement fusion: using lasers to heat and compress a small capsule of frozen hydrogen in the hope of inducing a nuclear reaction that yields more energy than was used to trigger it. Although that mission has yet to succeed, the laser setup is ideal for studying matter at high energy density (see PHYSICS TODAY, February 2017, page 33). And it's already optimized for a spherically symmetric geometry, because the fuel capsules need to be irradiated with equal intensity from all directions. To study spherically converging shock waves, just swap the spherical fuel capsule for a spherical solid sample.

Spherical shock waves have some advantages over planar ones. For one thing, they can reach higher pressures as the shock waves converge on a progressively smaller volume. For another, they make it possible to probe a range of pressures with a single laser shot—and because NIF laser shots take hours to prepare and are in high demand, it's important to get as much information as possible out of each one. On the downside, the shock speed, pressure, and density are all functions of time, so they need to be measured as instantaneous quantities rather than time averages. For a shock wave that takes just 9 ns to traverse the sample's 1 mm radius, that's not easy.

The researchers use x-ray streak radiography to record the x-ray transmission, with the necessary time resolution, through a thin slice across the center of the sphere. Because compressed material blocks x rays more effectively than uncompressed material does, the shock wave's progress is traceable as it closes in on the center of the sphere. From the details of the transmission profile, the researchers solve for the mass density just behind the shock front; from that, they extract the pressure and thus the compressibility curve.

Stars in the lab

Two years ago the NIF researchers published spherical-wave compressibility measurements[2] up to 60 Mbar. For that work, they limited the laser energy to 311 kJ, which simplified the experiment in several ways. Now, to advance to higher pressures, they've tripled the pulse energy—and introduced some experimental complications. For example, they can no longer assume that x-ray attenuation is proportional to mass density. Carbon atoms block x rays because the x rays excite the atoms' core electrons into higher-energy states. But when the pressure rises above 100 Mbar, the atoms start to lose their core electrons, and the x-ray absorption grows less efficient. The researchers had to account for that dependence when solving for the shock-wave pressure and density.

Figure 2 shows the compressibility results. Data from a collection of previous experiments are depicted in light and dark blue. Because most of those experiments used planar shock waves, which probed one pressure at a time, their results are shown as discrete data points, with individual error bars for each. The new spherical-wave experiment measures a range of pressures in a single shot, so its results are shown as a continuous trace surrounded by an error band.

The experiments help to benchmark the theoretical models that researchers currently use to estimate compressibility at high pressures. Kohn–Sham density functional theory, whose compressibility curve is shown in orange, is highly accurate but too computationally costly to use in the pressure regime of the new experiment. At higher pressures, researchers often resort to more approximate models, two examples of which are shown in black. The solid black curve is from a model, also based on density functional theory, that accounts for the electronic shell structure of atoms; it reproduces the experimentally observed inflection point at around 100 Mbar, where core ionization begins. The dashed black curve, from a model that lacks a representation of electronic shells, doesn't agree well with the data.

Even under the high pressure generated in the NIF experiment, the hydrocarbon sample was compressed by less than a factor of five relative to its ambient-pressure density. It's a long way from studying the conditions in the core of a white dwarf, which is orders of magnitude denser than any ordinary solid and resists further compression only through electron degeneracy pressure.

But pinning down the properties of the white dwarf envelope, where electron degeneracy has a more modest influence and densities are closer to those of earthly solids, can still help advance the understanding of the star's interior. Like sound waves in a whispering gallery, seismic waves spend much of their time near the surface of their star or planet. Knowing the material properties of that near-surface region is essential to correctly interpret the signals from those waves in order to probe the internal structure.

Johanna Miller

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One photon's transmission usefully controls another

To preserve the quantum correlations between two particles of light, researchers mapped the scattering that a photon experienced onto the entangled state.

Prime numbers are the keys to encrypting sensitive information (see the Reference Frame by N. David Mermin, PHYSICS TODAY, April 2007, page 8). If an adversary wanted to decipher a message protected by today's most often-used encoding method, known as RSA encryption, they would need to identify the prime factors of numbers with thousands or tens of thousands of digits. That feat is beyond the capability of classical computers, although not for quantum-based ones.[1]

In a quantum computer, the information stored as zeroes and ones in classical bits can be encoded as a superposition of quantum states in various physical systems, such as trapped ions and large groups of cold, neutral atoms (see the article by Ignacio Cirac and Peter Zoller,

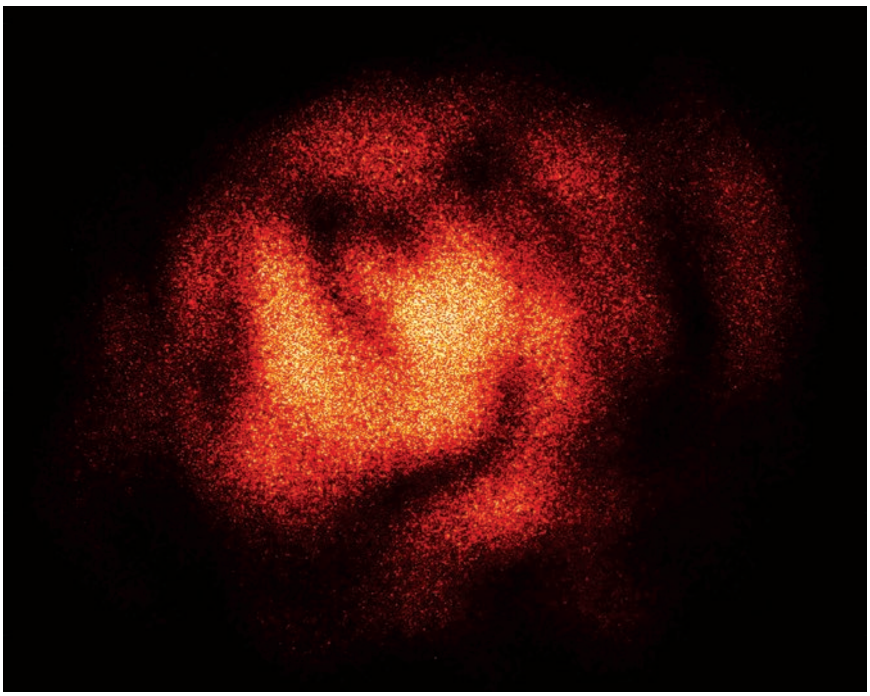

FIGURE 1. THE RED–YELLOW SPECKLE PATTERN formed from light that interferes with itself as it travels through a multimode fiber-optic cable. The effects of such scattering must be corrected for an entangled state to transmit error-free information in a quantum computer. (Image courtesy of Mehul Malik.)

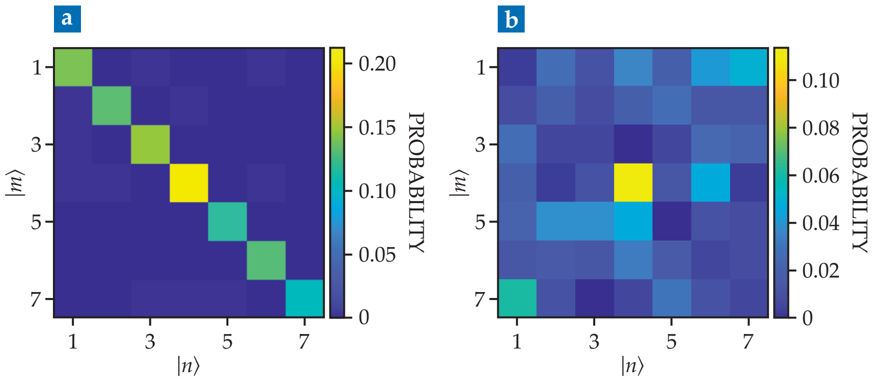

FIGURE 2. PRESERVING ENTANGLEMENT. The position and momentum patterns of two entangled photons $|m\rangle$ and $|n\rangle$ were measured in seven dimensions. **(a)** The quantum correlations of the spatial modes for the system were preserved before one of the photons was transmitted through a two-meter-long multimode fiber-optic cable. **(b)** Scattering of the transmitted photon in the fiber destroyed the correlations, as shown here. By mapping that scattering onto the two-photon correlations, the researchers restored the system's entanglement. (Adapted from ref. 4.)

PHYSICS TODAY, March 2004, page 38). A qubit stores more information than a classically equivalent bit, and a unitary transformation of a qubit can operate on all the information simultaneously. With that parallel processing power, quantum computers could deploy brute-force techniques or other, more clever algorithms to efficiently solve the prime factorization problem.

Much like energy, mass, and other physical quantities that obey the conservation laws, quantum information can neither be created nor destroyed. But when, for example, quantum information encoded in a photon's transverse position travels some distance through a fiber-optic cable, stray light destroys the correlations in the quantum system. "Noise that destroys quantum resources is one of the most important issues which hinder a practical and large-scale development of quantum technologies," says Rosario Lo Franco, a physicist working on quantum systems at the University of Palermo in Italy.

Recovering the original quantum state would require a quantum-error correction (see PHYSICS TODAY, February 2005, page 19, and the article by John Preskill, June 1999, page 24). One approach to limit the effects of noise, or decoherence, uses a qudit, which is a generalization of the two-level qubit to systems with *d* levels. A variable such as the spin of an electron can only take one of two values, but the position or momentum of a photon is continuous and can have many values, the number of which depends on the capabilities of the measuring device. A high-dimensional quantum state, such as one in which the various spatial patterns of a two-photon system are entangled, can carry a lot more information than zeroes and ones in its spatial and temporal structure.

Such a state is also more resistant to decoherence than ones based on light polarization or electron spin. That's because the information encoded in the position and momentum of photons is discretized across more dimensions than a binary quantum state, and the environmental noise is consequently diluted across the additional quantum levels.[2]

Physicists have demonstrated that the correlations in a photon pair with position–momentum entanglement can be maintained while being transported up to 300 km through a single-mode fiber, which acts as a waveguide that only allows one light pattern through.[3] An approach with more storage capacity would use hundreds of light modes, each carrying unique bits of information, that could be transported through a multimode fiber-optic cable. Maintaining the entangled light state in such a noisy environment is challenging because of the scattering and interference the light experiences. Figure 1 shows a typical pattern.

Now Natalia Herrera Valencia and Mehul Malik, both of Heriot-Watt University in Edinburgh, and their colleagues have demonstrated that they can preserve the quantum correlations of two photons in a multimode fiber-optic cable. They do so by determining how the transmitted photon was scattered from the entangled quantum state itself.[4]

Seen in a quantum light

The researchers take advantage of a process called spontaneous parametric down-conversion, which transforms a higher-energy photon into a pair of lower-energy ones by splitting the photon beam from a UV laser with a nonlinear crystal. That optical process entangles the pair such that the position–momentum of each photon is linked: Because of the conservation of momentum, measuring one photon's momentum affects the entire quantum state and reveals that of the other.

After the two photons are produced, a polarizing beamsplitter separates them: One is measured locally, and the other is sent through a two-meter-long multimode fiber-optic cable. In the experiment, two spatial light modulators display the modes of each photon's quantum state as seven individual pixels on various holograms, which the researchers examined to determine the particular spatial modes of light.

The position–momentum state of the photon pair was then measured by the light intensity of each pixel to determine how the fiber scattered the transmitted photon. Those data and phase information retrieved from a copropagating reference mode are contained in the transmission matrix—an array of complex numbers that connects the transmitted photon's input modes to the set of observed output modes.

Figure 2a shows the seven-dimensional correlations in position and momentum of the entangled quantum state; figure 2b shows the decorrelation as a result of the transmitted photon traveling through the multimode fiber-optic cable. Those decorrelations contain information, in the form of a transmission-matrix image, that describes the scrambling process inside the fiber.

To remove the decoherence caused by that noisy environment, the researchers used the transmission matrix to define an operator that scrambles the untransmitted photon. Then they tested the post-transmission quantum state for entanglement, although some problems, such as matrix-inversion issues and measurement uncertainty, prevented them from verifying the presence of a 7D entangled state.

Despite those issues, the researchers demonstrated that a 6D entangled state of light could be maintained through a multimode fiber-optic cable with an accuracy of 84%. "We were very surprised when it worked right away," says Malik. "I just started my group two years ago, and this was the first big experiment that we had set up." That accuracy is good enough to show that the technique works, and the group is striving to improve the process. Lo Franco says, "The next goal is to further develop quantum information protocols that make use of high-dimensional states."

More modes, larger spaces

The researchers could have mapped the inverse of the transmission matrix to the transmitted photon to restore the entangled state. But in a quantum communications scenario in which a secure key is established between two parties via the entanglement shared between them, one party could use the transmission matrix on its part of the entangled state to undo the noise effects experienced by the other. The person receiving the scrambled photon would not need any specialized equipment or resources.

Malik and his team also showed from theoretical calculations that each photon could travel through its own independent scattering channel and have the noise effects removed by performing a correction operation on only one photon. That possibility and the observed results would help make it feasible for a sender to preserve the quantum correlations of an entangled state even without having physical access to both photons.

The experiment used 7 of the approximately 400 modes of light that are supported by the multimode fiber, and Malik's group is currently working on exploring the full number of available modes. But reconstructing large quantum states is difficult because of the many measurements that need to be made and the time it takes to process those data. "Just characterizing this (100 × 100)-dimensional Hilbert space is quite challenging," says Malik. "It shows you that we as classical beings have a big challenge ahead of us to characterize the quantum world, even on the level of a few qubits or a fiber."

Alex Lopatka

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Tropical soils could be accelerating global warming

A field study challenges climate simulations by showing increased carbon loss from warmed low-latitude soils.

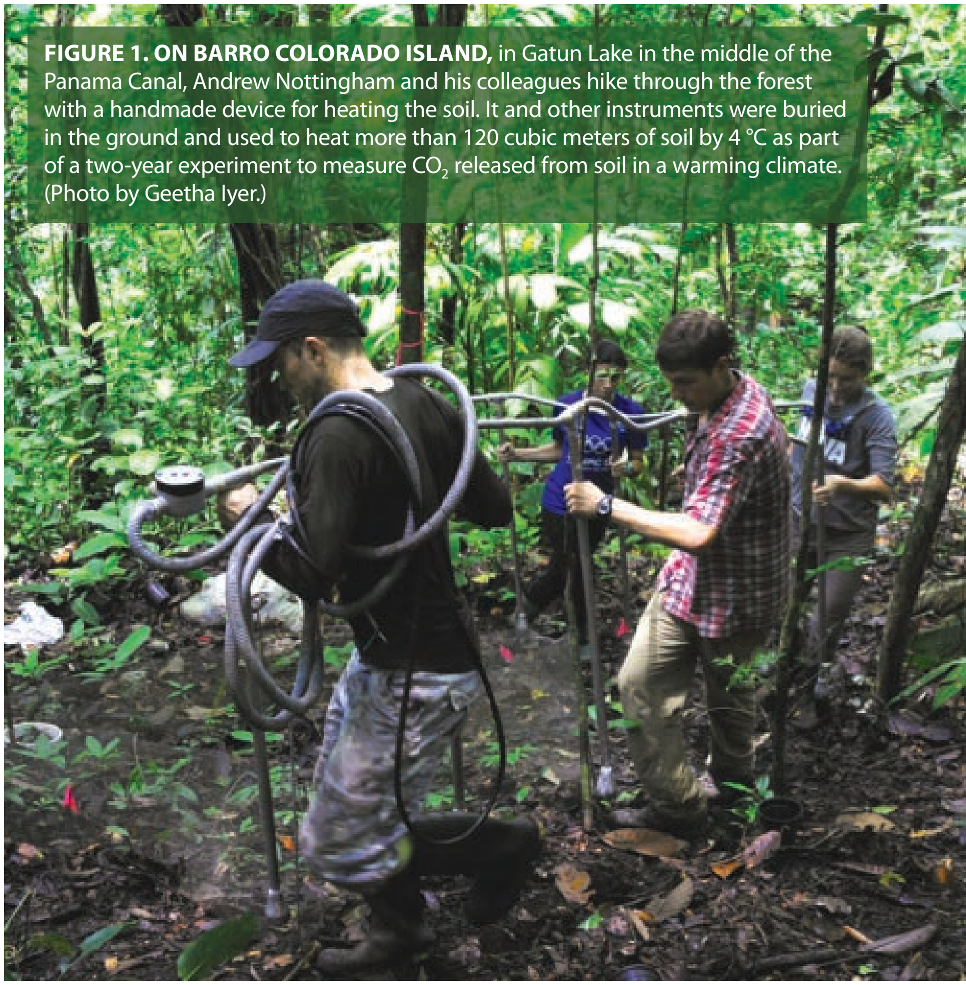

FIGURE 1. ON BARRO COLORADO ISLAND, in Gatun Lake in the middle of the Panama Canal, Andrew Nottingham and his colleagues hike through the forest with a handmade device for heating the soil. It and other instruments were buried in the ground and used to heat more than 120 cubic meters of soil by 4 °C as part of a two-year experiment to measure CO_2 released from soil in a warming climate. (Photo by Geetha Iyer.)

Earth's soils store about 1.5 trillion metric tons of organic carbon—more than is contained in the planet's vegetation and atmosphere combined. But that soil carbon isn't necessarily a permanent fixture: It can be lost when microbes digest it and respire CO_2. In a mature forest in a stable climate, carbon released from the soil to the atmosphere is in equilibrium with carbon absorbed from the atmosphere. In a world warmed by climate change, though, the balance may tip.

Generally, an increase in soil temperature accelerates the rate of microbial respiration and therefore the rate of CO_2 release to the atmosphere. However, climate models struggle to predict how much more CO_2 soil microbes release in response to rising temperatures and that uncertainty is amplified by differences in the mean annual temperatures for different latitudes. Measurements in temperate and Arctic forests have shown that high-latitude soils—including permafrost—that contain vast amounts of carbon are part of a positive feedback mechanism that enhances global warming. That warming may cause increased CO_2 emissions and yet more warming.

Partly because the tropics are warming more slowly than higher-latitude regions and their soils contain less carbon, Earth system models predict smaller relative increases in carbon emissions from tropical soils than from soils at higher latitudes. But those models remain untested, and they may underestimate a significant source of atmospheric CO_2.

The tropics account for 30% of the world's soil carbon—an amount approximately equivalent to the carbon contained in vegetation worldwide. Half of the world's annual carbon exchange between ecosystems and atmosphere comes from tropical forests, and the processes of carbon exchange in the tropics dominate the interannual pattern of atmospheric CO_2 concentrations.

Now, in a challenging two-year field experiment, Andrew Nottingham (University of Edinburgh) and colleagues provide evidence that warmed tropical soils may release as much, if not more, of their stored carbon than do temperate soils.[1] The findings suggest that tropical soils are less stable carbon stores in a warming world than previous expectations based on thermodynamic models. A relatively small perturbation to tropical forest carbon stores could have significant consequences for the concentration of atmospheric CO_2.

Temperatures rising

Climate models predict that by the end of the 21st century the tropics will be 2 °C to 5 °C warmer than they are in 2020. Knowledge of how that warming affects microbial-respiration reactions in the soil is limited to laboratory experiments and theoretical predictions, which do not translate precisely to real-world settings.[2] Until now, no *in situ* experiments have tested the resilience of tropical soils and their huge stores of carbon to that expected amount of warming. Carrying out field studies in the tropics presents challenges due to the logistics of working in remote, dense forests and establishing electrical infrastructure. In addition, electronics are easily damaged by the tropical heat and humidity, and the clay-rich soils often found in tropical forests are difficult to dig into and manipulate.

In an experiment that took two years to design and build, Nottingham and his colleagues overcame those challenges. They travelled to Barro Colorado Island, Panama, a nature reserve covered with tropical forest, shown in figure 1. By burying 1.2-m-long electrical rods in the soil, arranged around the perimeters of five 2.5-m-radius circular plots, they warmed each plot by 4 °C above the ambient soil temperature of 26 °C. "We heated the soil in the same way a football pitch is heated during the winter, although heating to depth and doing it in a tropical forest environment makes it a little more complicated," says Nottingham. Using a common forestry technique of placing mesh constructions in the soil, the researchers carefully guided plant roots to grow in specific areas and thus isolated the effects of microbial soil activity from other plant-derived sources of CO_2.

For two years, instruments placed in weatherproof boxes recorded the CO_2 output over the warmed plots and nearby ambient-temperature control plots. The researchers found that the CO_2 release rate increased substantially, shown in figure 2, as a result of increased microbial respiration. The warmer soils emitted 55% more CO_2 than the control plots and lost a total of 13% of their initial carbon.

For comparison, an experiment that used the same method in a temperate forest in northern California found a 35% increase in emissions from heated soils.[3] The regular soil sampling and analyses by Nottingham's team also provided information about the nutrient availability, carbon content, moisture, and microbial mass and enzymes in the soil.

Those analyses showed that carbon in the warmed soil was digested by microbes faster than in the ambient-temperature soil. But the microbes showed no chemical signs of compensating for the temperature change—for example, by changing enzyme activation energy or metabolic efficiency.

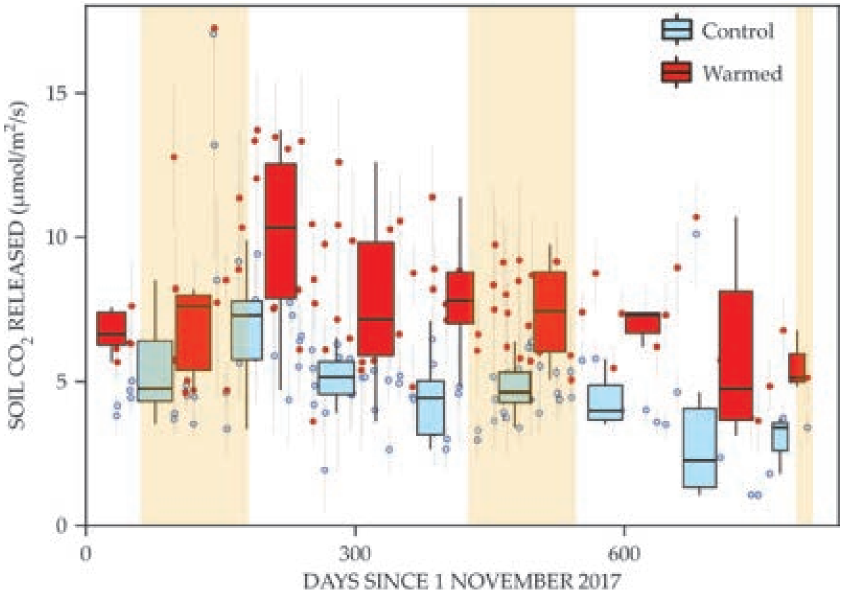

FIGURE 2. TROPICAL SOILS EMIT CARBON DIOXIDE as a result of microbial respiration. In a two-year field study, instruments measured the CO_2 released from five plots warmed to 30 °C (red) and from five plots kept at 26 °C (blue). Heating began in full on 1 November 2017 after several months of testing. The boxes represent temporal variation in the CO_2 release rate over sequential 100-day periods and indicate seasonal dynamics. The yellow shaded areas indicate dry seasons. The soil CO_2 release rate was significantly higher in the warmed plots than in the control plots over the two-year period, and for the dry and wet seasons individually. (Adapted from ref. 1.)

Carbon complexities

Nottingham's results came as a surprise. The rate at which microbes metabolize and respire soil carbon depends on the rate at which enzymes break apart organic molecules. In Earth system models, that rate is governed by various versions of the Arrhenius equation. Proposed in 1889, the equation describes the dependence of chemical and enzymatic reaction rates on temperature. According to that equation, soil microbial respiration should increase more slowly in the warmer tropics relative to cooler, more northerly regions.[4]

But Nottingham's observations—that warm-climate soils increase the rate of release of their carbon stores more than do soils from cooler climates exposed to the same 4 °C warming—do not necessarily contradict the basic equations commonly used to describe enzymatic activities. Rather, the finding highlights the complexity of tropical forest soil ecology and the need to tease out other factors that may boost CO_2 release in real-world conditions.

One possibility is that microbial communities grow quickly in warm soils. Emerging experimental evidence shows that describing soil warming processes will require complex models that incorporate microbial responses to temperature.[5] Nottingham's soil sampling results contribute to that evidence by suggesting that the biomass of the microbes increases with warming, perhaps because certain types of detritus-eating microbes thrive at warmer temperatures.

Still, the measured increase in emissions should not be expected to continue indefinitely. Studies of temperate-forest warming suggest that increased emission rates may take a decade to decline. The observed lost carbon may represent a small, easily decomposable fraction of the entire carbon stock. Once that's gone, the microbes may be unable to break down more stable organic matter. Alternatively, nutrients such as nitrogen or phosphorus might limit the activity of microbes at warmer temperatures. Or microbes may start to adapt to warm temperatures and decrease their carbon usage rate. The response of soil carbon to warming also depends on how vegetation responds to higher temperatures.

When using Nottingham's findings to estimate large-scale effects by adapting climate models to represent global tropical soil contributions, one must consider differences in soil composition. In the short term, the results suggest that climate warming could lead to large additional CO_2 emissions to the atmosphere, but the researchers cannot yet predict the long-term effects of warming. They are continuing their experiment in Panama to explore that uncertainty. Human development, such as new agricultural methods and changes in land use, should also be carefully evaluated to understand their impact on such vulnerable soils, especially in the context of future climate change.

Rachel Berkowitz

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PhD student–adviser pairing is critical, but in US physics departments it's often haphazard

Scientific interests, personal chemistry, and mentoring styles go into choosing an adviser. The best way to know if a match will work is to try it out.

Back when Dan Stamper-Kurn, now a physics professor at the University of California (UC), Berkeley, headed to graduate school at MIT, he got two bits of advice that were "right on." A researcher with whom he had explored the effects of urban heat islands on energy use told him to work "in the most fundamental science" possible so as to gain a strong foundation. The other piece of advice came from a graduate student, who told him, "Don't work for a jerk."

Since then Stamper-Kurn, whose research focuses on ultracold atoms, has mentored dozens of PhD students. Choosing an adviser is the most important decision a graduate student makes, he says. The relationship continues after a student gets their PhD. It is personal. It has a power dynamic. And both parties need each other for their careers.

Yet adviser–advisee relationships tend to form with minimal information. The process involves institutional structures, funding, individual initiative, trial projects to sample research interest and work styles, and compatibility. "There is no formula," says Stamper-Kurn. "I have to think it will be possible to turn [the student] into a kick-ass scientist."

Open houses and pizza lunches

At many US universities, the admissions process paves the way for pairing faculty with PhD students. Faculty members are polled to see who wants to take on new students, and applicants are asked to list their areas of interest. The aim is to engineer an incoming class whose interests roughly line up with the available research spots.

ILYA VEKHTER

PROSPECTIVE GRADUATE STUDENTS at the Louisiana State University physics department's 2017 open house, which coincided with a local St Patrick's Day parade. Now working on their physics PhDs at LSU are Tej Poudel Chhetri (far left), Thomas Ruland (red shirt), Frank McKay (light blue shirt), and Scott Mullen (maroon shirt). Madeleine Miora (second from right) earned her master's at LSU; the other students went to other universities.

BRIAN STAUFFER, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

GROUP DYNAMICS can be an important factor in choosing a research adviser. At the University of Illinois at Urbana-Champaign, Jessie Shelton (right front) and other professors in high-energy theoretical physics hold joint group meetings.

Prospective students and advisers meet during campus visits. That's how Rachel Nguyen, now a second-year graduate student in dark-matter theory at the University of Illinois at Urbana-Champaign (UIUC), found her adviser. "I had a large list of universities I was interested in, and for each one that I was accepted to I tried to identify several professors that I thought I would be happy working with," she says. The person who became her adviser was not on her spreadsheet—he was a new hire and was not yet featured on the department's website. "His interests matched mine, so the department put him on my schedule for visitors' weekend," she says. Afterward, he followed up with email messages and a Skype call.

Rachel Malecek didn't know what research area she wanted to pursue. At the Louisiana State University (LSU) physics department's open house in spring 2017, she attended talks by several professors and chatted with them and their students. "I'd never considered nuclear as an option because I hadn't had a class as an undergraduate," she says. "But from the short talks, it sounded cool. The nuclear-physics group seemed like a nice, tight-knit group." Malecek later sent an email to one of the nuclear physicists and asked if he was looking for graduate students. He was, and she joined his group.

Once students are accepted to UC Berkeley, Stamper-Kurn reaches out to those who express interest in atomic, molecular, and optical physics. "I encourage them to come to our open house. I show them around the labs and talk to them about Berkeley and our group." At Berkeley and other state schools, departmentally funded fellowships are scarcer than at some of the private schools that the students may be looking at, he says. "One tool I have in my arsenal is to offer students a spot in my group right off." If they want to do research and not have to work as a teaching assistant, he says, "that can be a powerful incentive."

Faculty members who want to take on students typically present departmental talks. For first-year students in the Yale University physics department, for example, Friday pizza lunch is a *de facto* required class. "Students learn about potential advisers, and it gives them a sense of research in the department," says Sarah Demers, whose group focuses on using muons and tau leptons to investigate physics beyond the standard model. "It's a great recruiting opportunity."

Some departments offer rotations, in which students join different research groups for up to a semester each. Official rotation programs are rare in physics—they are common in biology and chemistry—but often students can create their own rotation schedules. The physics department at UC Berkeley, for example, encourages students to do that. Heather Gray is an assistant professor at the campus who studies the Higgs boson. "In high-energy physics, we work in enormous collaborations," she notes. "The rotations are an opportunity to see if the personalities work together. The PhD is long, and there is no purpose in being in a group where you are unhappy."

"Motivation any day"

So what do faculty look for in advisees? Passion and excitement about the specific research topic are often critical. "I don't look for just experience and talent," says MIT's Nergis Mavalvala, who works on the Laser Interferometer Gravitational-Wave Observatory. "I look for interest. I can teach a student the tools of my trade, but I can't teach them to be excited about what I do."

Professors also look for dedication, motivation, creativity, a willingness to ask questions, the ability to recognize when a line of inquiry hits a wall. Frank Würthwein of UC San Diego searches for new high-energy phenomena at the Large Hadron Collider. "Each faculty member has a different set of criteria," he says. Theorists are more interested in what students know, he observes, while experimentalists are typically more interested in what skills they have. He pays attention to the questions students ask and to whether they are self-critical.

Würthwein likens his group to a small business, in which his investment in students should pay off. "There is real money in the game," he says. "I want to make sure students are productive."

David Gerdes, physics chair at the

University of Michigan, asks prospective students, "What are your goals? What is your perfect day?" Some students are software oriented, some like analyzing data, some want to fiddle with lasers or other hardware, some like higher-level interpretation. Sussing out a student's interests is important to match them with a project, Gerdes says. "There's an axis of skills and abilities, and an axis of motivation, persistence, and enthusiasm. Ideally, someone has both. But if I have to pick, I'd pick motivation any day."

A common approach for faculty is to invite students to work with them on a provisionary basis so both parties can test the fit. Lars Bildsten, director of the Kavli Institute for Theoretical Physics at UC Santa Barbara, says that to onboard students he works with them intensely, usually after their first year of graduate school. "By the end of the summer, I'll say 'yes, great,' or 'no, this isn't working.' " A no is better earlier than later, he notes, and usually it's no surprise to the student. "If they don't have that fire in the belly for the specific research problem, it comes through quickly," says Bildsten. Usually, he adds, the student finds a research area, adviser, and group that are a better fit.

James Sethna, a Cornell University theorist in statistical physics, says he works with students for a summer or semester before committing to take them on for their PhD. "It's not just how smart they are, or how much overlap of interest we have. It's also personal chemistry." Theory tends to attract more students than departments can support, he notes, so student initiative is important. "The ones who are aggressive end up getting more attention." But Sethna says he avoids snap judgments. He recalls one student whose persona was "very nonthreatening. You didn't find out how really amazingly smart she is until you worked with her for a while. I was really pleased I didn't make the decision right away. I grew to appreciate how talented she was."


ADMX COLLABORATION

MEMBERS OF THE AXION DARK MATTER EXPERIMENT lower the deep cryogenic detector into the bore of a superconducting magnet. Shown are ADMX lead scientist Leslie Rosenberg (yellow hat), graduate students Nick Du (white hat) and Michael Hotz (green hat), and Cliff Plesha (no hat) and another undergraduate (orange hat), all of the University of Washington.

Elements of style

Grades and GRE scores, many professors say, are not a factor for taking on a student. For one thing, by the time students are in a position to join a research group, they have been admitted to the department. Getting into Harvard University is competitive, so students' grades have to be good, notes Melissa Franklin, who studies proton–proton collisions at the Large Hadron Collider. Professors look at research experience and letters of recommendation, she says.

Karen Daniels, a soft-condensed-matter experimental physicist at North Carolina State University, says that for her, "grades and prior lab experience are just part of the picture." She has mentored students who had good grades and others who had mediocre grades; students with skills in electronics, coding, and writing prose and others who lacked those skills. "It's hard to predict which students will emerge with a rewarding PhD," she says. "It's best correlated with whether they want to work on the skills they need. If so, they will be successful."

Professors, for their part, have different mentoring styles. They can be hands on or let students flounder. They may insist that students be in the lab on weekends and evenings. "It's fascinating to see how people gravitate to work with one sort of professor or another," says Franklin. In looking for a good fit, she says, "I ask students, 'What book are you reading now?' You can get a sense of who they are intellectually."

Group dynamics is precious, says Yale's Demers. "Graduate school is a challenge, and the relationships among students, postdocs, and myself have to be functional." And, she adds, "I want students who are kind and respectful. I don't want arrogant or overconfident. I want someone who sees doing a PhD as not a waste of time, regardless of what they end up doing."

Sometimes faculty members don't have much choice about whom to take on. "I am a recruiter," Demers says. "I don't have people banging on my door. When the new class is admitted, I go to them." Likewise, Vernita Gordon at the University of Texas (UT) at Austin says her department has a tough time wooing would-be biophysicists. And Jeffrey Wilkes, a professor emeritus who works in high-energy neutrino and cosmic-ray astrophysics at the University of Washington, says he's taken on "mediocre students because I needed someone, and no one was available who I thought would do the best job."

Attracting students can be especially hard for new faculty, who urgently need students but haven't yet built up a reputation for either their research or their mentoring style. But assistant professors also have advantages, says Jack Ritchie, chair of physics at UT Austin. Graduate students can find them less intimidating, he notes. "And young faculty often work in hot new areas."

Vladan Vuletić, an MIT professor who creates and studies entangled many-body states, says he relies heavily on the students and postdocs in his group to assess whether potential recruits would fit in well. "Peers are a really good judge," he says. "Students may be less shy and show their knowledge and personality."

Whisper networks

For students, too, talking to other students can be helpful in selecting a research adviser and group. LSU's Malecek says senior graduate students "gave me the inside scoop on their advisers." Karmela Padavić-Callaghan, who recently earned her PhD in condensed-matter theory at UIUC, says she knew when she entered graduate school that she wanted to be a theorist, and she knew the field was male dominated and competitive. "I didn't want to work with someone who would make me feel small if I didn't know things," she says. She chatted with graduate students because "they don't have a reason to lie. They warn you, and if you ignore those warnings, it's not ideal." She sought out a research group mainly based on topic, but it was also important to find a female adviser "for the shared lived experience."

Women tend to be less assertive, she notes, and they are more likely to have family responsibilities than men. Students from other countries may be accustomed to more formal and deferential interactions with senior scientists, continues Padavić-Callaghan, who is originally from Croatia. As a result, women and international students "may not have as much of a shot at getting into certain groups, even if they are interested in the research and have great skills." Such cultural issues "can be a big factor in what a student ends up doing during their PhD," she says.

"I had spoken to graduate students who seemed burned out," says Mariel Pettee, who will graduate next spring from Demers's group at Yale. "I wanted to pick a place where I could be happy as a whole adult."

Sergio Cantu, an American of Mexican heritage, joined Vuletić's lab after spending a year at MIT in a bridge program that helps students from underrepresented groups transition to graduate school. "I shopped around," says Cantu. "But I kept going back to him because he was welcoming. And once I started working in his lab, I noticed he would say things like 'your lab' and 'your experiment.' That gave me ownership and made me feel empowered."

When it doesn't work out

No reliable statistics exist, but several faculty members interviewed for this story estimated that 10–20% of PhD students switch groups. The main reasons are that students find a topic they are more excited about, they clash with their adviser, or their adviser runs out of funding. When the switch happens relatively early, say by the end of the second year, it tends to go smoothly, students and faculty members report. Switching later is trickier, and it often adds time to finishing a degree.

Joel Moore, a theorist who studies quantum materials at UC Berkeley, says that one of the hardest things he's had to do was tell a student after six months that it wasn't working out because they weren't making enough progress. "They were still excited about the project, but I felt I was not the right adviser for them to succeed."

"I've asked someone to leave," says a professor who didn't want to be named to protect the student. "It had become toxic. The student had alienated almost everyone in the group."

Sonia Paban, a cosmologist and particle theorist at UT Austin, says that ousting a student is "not a decision [made] in one day. It's a process." Harold Johnson, now a third-year graduate student, switched to Paban's group from an astronomy group because both the research and the work environment were more inspiring to him. When Johnson approached Paban about joining, he says, "she gave me some work to read, and I knew I wanted to be her student."

Transitions are not always easy, says MIT's Mavalvala. "They are not always mutual. If a student needs a new research group, they can typically work as a teaching assistant to tide them over, so they don't feel trapped." She has never asked a student to leave her group. "When I get to the place where I think a student is not working out, I force myself to write down their strengths and weaknesses," she says. "And then I try to point them in the direction of their strengths."

When their chosen group doesn't work out, some students leave with a master's degree. Those that stay may have a hard time finding a new adviser. But, says Mavalvala, "the stigma goes in both directions. It's not just the student who is tainted. If there is a pattern, the faculty member gets a reputation for being hard to work with."

Senior faculty members say that students who have had trouble working with someone should work with tenured professors. "When young, an adviser should focus on finding students that can be beneficial to their research," says Cornell's Sethna. "After they get tenure and are secure, they can aim in large part to benefit the students."

Toni Feder

The Great Lakes are filled to their brims, with no signs of receding

Experts see the fingerprints of climate change on the lakes' record high water levels.

US ARMY CORPS OF ENGINEERS

EROSION CAUSED BY HIGH WATER LEVELS has eaten away bluffs and beaches along the eastern shore of Lake Michigan.

Seven years ago, Ron Wilson's son was married on the beach in front of his cottage on the eastern shore of Lake Michigan. Were the couple to renew their vows today in the same spot, they'd be standing in nearly two meters of water. The 18-meter-wide beach has vanished, and the lake is now lapping at a steel seawall Wilson erected last winter to keep storms away from his foundation.

A few miles down the shore, Senator Debbie Stabenow (D-MI) is also losing ground to the water. Her property is on a bluff, so seawalls or other shoreline defenses to prevent further cave-ins must be installed either from a barge or after a path is cut for heavy equipment to gain access. Either will make the cost enormously higher than the $3000 per meter that Wilson says he had to pay for the work he had done. "It's pretty scary and pretty horrifying, and I wish there were an easy solution," Stabenow told an August virtual meeting of the Great Lakes Coalition, a nonprofit association of shoreline property owners. Wilson is the coalition's president.

Water levels have always fluctuated on the Great Lakes, but the recent extreme seesawing, particularly on the upper lakes—Superior, Michigan, and Huron—is unprecedented in the century that records have been kept (see charts). Michigan and Huron, which are linked and share the same level, stood at record highs in August, 84 cm above their historic average. The two lakes bottomed out at record lows in 2013. Although a relatively modest 25 cm above average, Superior in 2020 was just 5 cm below its record peak for August set a year ago.

Along all the Great Lakes, storm-driven waters are eroding public beaches, washing away sand dunes and bluffs, and damaging roads and other infrastructure. Michigan agencies estimate that shoreline repairs in cities and public parks will cost up to $250 million. In Detroit, pumps first have to push out water entering Detroit River outfalls before they can move stormwater from drains.

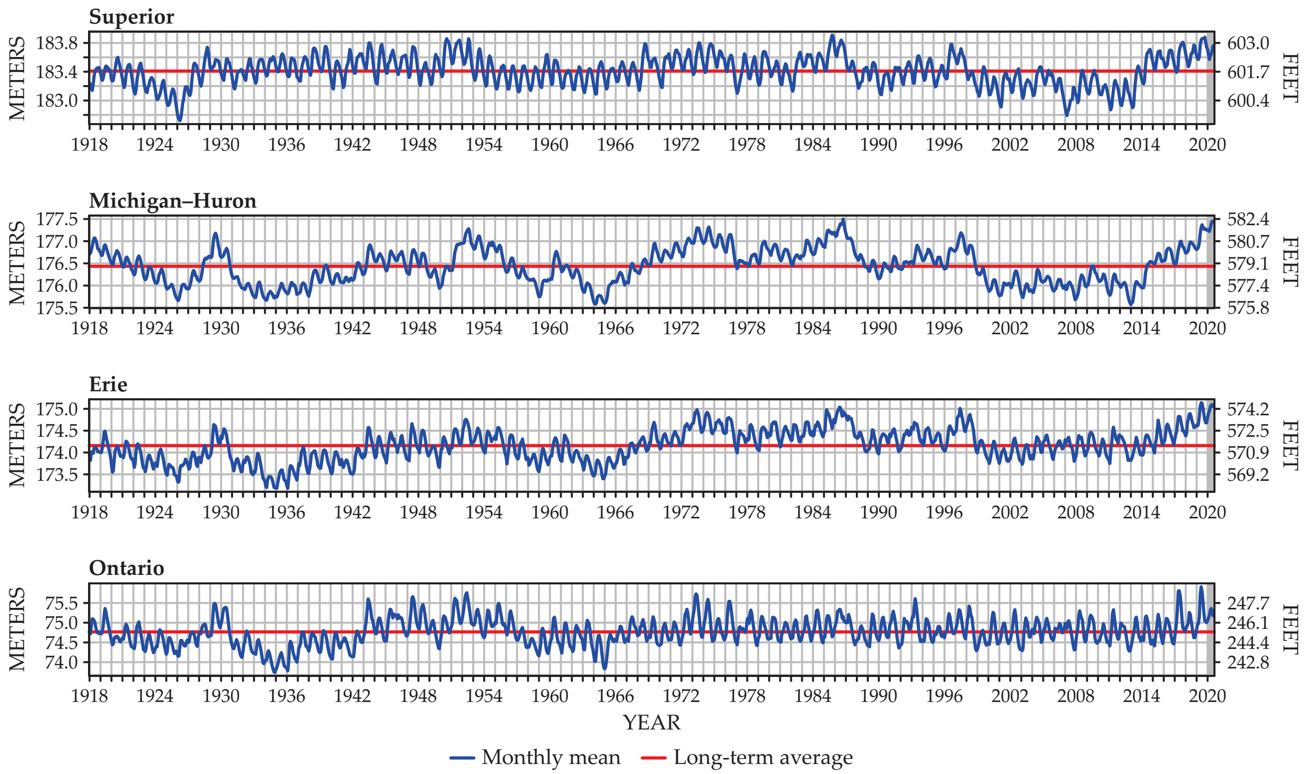
The Great Lakes system holds 21% of the world's surface fresh water, enough to cover the continental US to a depth of 3 m. Lake levels fluctuate according to changes in the balance between rainfall, snowmelt, and runoff in the watershed on the one hand, and evaporation and outflows on the other. Outflows from the five lakes are more or less constant. Evaporation, though, varies widely in response to air and surface water temperatures, and a good deal of the water vapor returns to the lakes as rainfall and lake-effect snows. Due to their vast volumes, the lakes cool slowly through the fall, when evaporation increases into the cooler, drier air. Ice cover, which varies from year to year, curbs evaporation during the cold months.

Signs of climate change

The past 10 years have been the wettest on record for the Great Lakes watershed. Andrew Gronewold, associate professor for environment and sustainability at the University of Michigan, says the rainy years began well before the 2013 ebb in the upper lakes. An extended period of excess evaporation that started in 1998 more than offset the added precipitation until the polar vortex event in early 2014 caused most of the lakes to freeze over. Since then, water supply has exceeded evaporation, partly because of several especially cold winters, Gronewold says. He adds that the 2014–17 period saw the fastest three-year increase in water levels since record-keeping began.

Donald Wuebbles, professor of atmospheric science at the University of Illinois at Urbana-Champaign, says precipitation over the watershed has risen 10% over the past century and is expected to grow another 10% over the next. Precipitation in the Great Lakes region is increasingly occurring in larger events, researchers say. As a result, more rainfall runs off into streams and rivers feeding the lakes instead of being absorbed in soils. The lakes themselves make up a major portion of the watershed.

"The rate at which precipitation has changed over the past decade simply cannot be explained by historical variability alone," says Gronewold. "The best



WATER LEVELS ON THE GREAT LAKES have fluctuated irregularly over the past century. The peaks and troughs on Lakes Michigan and Huron have been especially pronounced. From a record low in 2013, they have surged to record highs this year. (US Army Corps of Engineers.)

explanation is a warming atmosphere and warming global temperature." Deborah Lee, director of NOAA's Great Lakes Environmental Research Laboratory, notes the impact of warming oceans and changing circulation patterns. She and her colleagues have identified correlations between lake levels and the Pacific Decadal Oscillation, the North Atlantic Oscillation, and the Arctic Oscillation.

The rapidly warming Arctic has caused the polar jet stream to meander more than usual, bringing down frigid air to the lakes. But Wuebbles says the jet stream is expected to lose its influence in the coming decades as the difference narrows between Arctic and midlatitude temperatures.

Other regional factors could also be contributing to the fluctuations. Gronewold and others have theorized that during the 15 years of high evaporation, a feedback mechanism developed in which clouds dissipated over the lakes to an unusual extent and allowed more solar heating of the lakes. That mechanism may have led to the 2013 lows. He's unsure if an opposite feedback loop has been involved in the current highs.

The lakes' surface temperatures have been higher than normal this summer, which should intensify evaporation. But Gronewold cautions not to read too much into news reports of record high temperatures in some places. "There is a lot of variability in response to wind and circulation with the subsurface, but the question is, What's the heat content of the lake? How does the temperature stratify as you go down? That's the kind of heat that would carry over into the fall."

Managing lake levels

Over the decades, human-made diversions have affected lake levels to varying degrees. Wilson advocates changing those interventions to mitigate the high water. One measure would be to increase the outflow of an existing Chicago diversion. The Chicago River used to empty into Lake Michigan, but in 1848 it was redirected to flow into the Illinois River, which drains to the Mississippi River. The waterway was expanded around 1900 into what is now the Chicago Sanitary and Ship Canal. Its rate of flow was established by the Supreme Court in 1967 after several states and cities brought litigation to limit the diversion. But Lee likens the existing diversion's effect on lake levels to a pinprick on a gallon jug.

Wilson also urges shutting off the extra inflow to Lake Superior from two Ontario rivers that were diverted away from Hudson Bay in the 1940s. He says the Ontario utility responsible for those diversions already produces more hydroelectric power than the province needs.

Experts say such measures would accomplish little. Lee has participated in studies over 35 years that have examined possible interventions; she says lowering Lakes Michigan and Huron would require excavating a new channel that could carry the same flow as the St Clair and Detroit Rivers, which drain Huron into Lake Erie. Even if that were feasible, the scheme could fail because the lakes' water supply accumulates on annual, interannual, and decadal time scales. "You'd still have to have the ability to make forecasts far enough into the future to know when to open and close [the canal]," she says. Moreover, the channel would relocate flooding to the lower lake into which it dumps.

The International Joint Commission

THE GREAT LAKES SYSTEM holds about one-fifth of all surface fresh water on the globe.

(IJC), a Canadian–US body, regulates the flow of water from Lake Superior to Michigan and Huron through dams on the St Marys River. Following the previous high-water record in the 1980s, the IJC studied the hypothetical effects of increasing the Chicago diversion to its theoretical maximum flow and shutting off the two Canadian rivers. The commission's 1992 report found that those measures would lower Lakes Michigan and Huron by just 9 cm after two years and by 21 cm after five years.

Some of the same groups now calling for intervention were demanding action to restrict the flow out of Michigan–Huron during extreme low-water periods, says IJC spokesperson Frank Bevacqua. In a 2012 study, the IJC explored the possibility of installing contrivances such as inflatable weirs and flap gates on the St Clair River to slow its flow. The report noted that any of the structures would take up to a decade to achieve the desired effect. It estimated the cost of building new controls for Lakes Michigan, Huron, Erie, and Ontario at $27 billion. The report did not recommend they be built, but instead called for further studies by the Canadian and US governments. Those studies were never carried out, Bevacqua says.

The IJC also controls the flow into the St Lawrence River from Lake Ontario, the smallest of the five lakes by area. The river, which drains the Great Lakes to the ocean, was widened in the 1960s, when the Moses-Saunders Power Dam was built to help limit water-level fluctuations on the lake. The dam can only do so much, however, and it was unable to prevent the lake from reaching a record high in 2019. An IJC spokesperson says the flow released by the dam is restricted by international agreement to prevent flooding in Montreal.

There are environmental considerations to altering water levels, says Lee, including harmful effects to coastal wetlands and biodiversity. The natural, cyclical rise and fall of the lakes keeps wetlands healthy, limits invasive species, and prevents upland vegetation from moving downslope. "You need a mix of vegetation types—from submergent, to emergent, to upland. Fluctuating water levels cause that to happen on the decadal time scale," she says. Keeping the invasive Asian carp out of the lakes argues against increasing the flow rate of the Chicago diversion, says Lee.

Quo vadis?

Water levels are likely to decline somewhat in the next several months, as part of the usual seasonal cycle. But Gronewold cautions that soil moisture remains high in the upper lake basins, and he notes that even under dry conditions, it will be a couple years before the lakes would return to more typical levels.

Longer term, it's anyone's guess where lake levels are headed. The range of possibilities in the six-month forecasts by the

RON WILSON

EIGHTEEN METERS OF BEACH lay in front of Ron Wilson's cottage on Lake Michigan as recently as 2013. Last fall, the lake was lapping at the cottage's structure.

US Army Corps of Engineers is so broad in the latter months as to be of little use, researchers say. Two- to five-year forecasts would require an ability to predict such mesoscale phenomena as polar vortices and El Niño–Southern Oscillation cycles. For his part, Wilson is hoping for a La Niña event, which he says would likely bring colder than normal temperatures to the lakes this winter and boost evaporation.

"The lakes are very complicated, and it's not easy to forecast how they behave," says Lee. "They are at the crossroads of global circulation patterns, and there are local effects because the lakes have thermal memory and water levels take quite a while to drain from lake to lake."

Wuebbles is working with Argonne National Laboratory to refine a regional North American climate model to run at 4 km resolution. That should enable the simulation of clouds and convection needed to visualize precipitation trends. The model will be paired with the National Hydrologic Model. "If you were to ask me four or five years from now," Wuebbles says, "I'd be in much better shape to tell you what's happening to the lakes."

For now, adaptation is the only solution to high water. Stabenow says she is working to free up assistance from the Federal Emergency Management Agency and the Corps of Engineers, which are geared to respond to sudden disasters such as hurricanes but not to more gradual events such as erosion. Federal assistance should be provided to shore up states' shoreline protection efforts, she says, since their own budgets for that purpose had to be tapped to fight the coronavirus pandemic.

Gronewold thinks the solution is "to be careful where you build things near the shoreline, and be cautious about setback distances." That's not an option for people like Wilson, whose cottage has been in the family for generations.

"We want to get the politicians to understand that [high water] may be permanent with climate change," says Wilson. "Then where do we go? The cities will flood."

David Kramer PT

Omar Magaña-Loaiza is an assistant professor of physics at Louisiana State University in Baton Rouge.

Reflections on an ACADEMIC JOB SEARCH

Omar S. Magaña-Loaiza

The road from reading a job posting to signing a contract is long and involved. Advice from a recently hired professor may smooth the path.

I have always favored learning through experience, which might be why I am an experimental physicist. I used that approach when I decided to apply for jobs in academia. But my plan wasn't always to become a professor: In 2016, after I completed my PhD in quantum optics at the University of Rochester in New York, I became a research associate at NIST in Boulder, Colorado. I chose that path because I loved doing research, and at NIST, I could devote all my time to being a scientist.

Despite the amazing facilities and opportunities there, I missed the freedom I had in academia to explore new research trajectories. National research facilities support specific missions, so it's difficult for their scientists to change direction after making unexpected discoveries. As an assistant professor of physics at Louisiana State University (LSU; see figure 1), I lead the quantum photonics group. Our work ranges from basic "blue-sky" research to the development of photonic devices.

When I decided to move back to academia only a year after obtaining my PhD, I was aware of the challenges an academic job hunt presents and how long it might take. The probability of my finding a position was low; newly hired tenure-track faculty members are most likely to come from postdoc positions (see figure 2), and those typically last two or more years. But I thought that I had the requisite experience to join the academic ranks: I had trained and advised younger investigators, I had

ISTOCK.COM/PEOPLEIMAGES; ADAPTED BY DONNA PADIAN always enjoyed teaching in academic environments, and I was ready to establish and run an independent research program.

It can take months or even years to find a suitable academic job, even for experienced applicants. I familiarized myself with the job-hunting process by giving invited talks and having discussions with faculty members who attended the events. I also learned from experience: Interviews for other faculty positions earlier in my job search prepared me for my interview at LSU. As a new professor, I'd like to share my experiences with the hiring process and provide advice for young scientists considering an academic career.

The job-hunting process can be grouped into four parts: the application package, the online interview, the on-campus interview, and the negotiation of job terms. Below, I discuss relevant and sometimes unintuitive aspects of each of them.

In the past, an academic job search might have started by combing periodicals for job postings (see the article by Matt Anderson, PHYSICS TODAY, April 2001, page 50); now it starts online. I began exploring academic positions using PHYSICS TODAY Jobs, a valuable website with an extensive listing of positions for physicists and engineers; it's also where I found the advertisement for my current position at LSU (see figure 3). Additional websites with academic job postings can be found in the online resources box on page 35. Some sites will send users daily or weekly newsletters with alerts about new postings. The guidance provided by such sites is usually general rather than tailored to physics positions, but it can still help candidates identify and understand the necessary materials for preparing an application package.

From start to finish, my hiring process took approximately six months: two months to prepare the application package and four months to have the interviews and negotiate the terms of employment. Each institution's application package will be different, especially if you're considering both large research universities and primarily undergraduate institutions (PUIs), so you should tailor your submission to each one.

PALOMA YBARRA

FIGURE 1. THE AUTHOR, in his interview clothes, stands outside Louisiana State University's quantum photonics laboratory. He now leads the lab as a faculty member in the physics department.

Application assembly

Search committees will almost certainly request the following documents: a cover letter, a curriculum vitae (CV), teaching and research statements, and references. The first four documents should convey a general idea of your background, credentials, achievements, and research plans. Institutions usually request three recommendations, so you should include contact information for three references or arrange for the letters to be sent on your behalf. It's appropriate to ask your PhD adviser and postdoc supervisor to be references, and the third should be a senior colleague, such as another supervisor, a collaborator, or a member of your PhD thesis committee.

The search committee may also ask for a writing sample. Most applicants submit one or two of their best publications, but you could also pair a research paper with a less technical article if you've written one. Institutions are becoming increasingly likely to request a diversity statement, which describes your experiences working with people from different backgrounds, and you may be asked for a teaching portfolio, especially by PUIs. All application documents should use clear, accessible language for nonexpert scientists.

The cover letter's purpose is to provide a broad description of your research and other professional achievements. It should briefly outline your current and past positions. Cover letters usually run less than one page, although keeping it to that length can be a challenge given the breadth of information you may want to include. A good way to tell your story concisely is by featuring one or two high-profile research projects. Trying to squeeze in more could distract and overwhelm the hiring committee. The letter should also note your main research results and discuss how your previous research will influence future work.

Every application should be tailored to a particular job, and the cover letter should describe how you meet the job requirements in the posting (see figure 3). It should also discuss the aspects of the hiring institution that motivated you to apply. I recommend highlighting how your expertise will be a good fit for the department advertising the position. That effort requires learning about the department and understanding its ongoing research and teaching efforts, which will also help to clarify which of your own potential contributions should be highlighted.

While learning about each department, it's a good idea to identify similarities and differences between yourself and current faculty members. That comparison may help you suggest possible paths for future synergistic collaborations. However, because you won't know who might be leaving or retiring, it

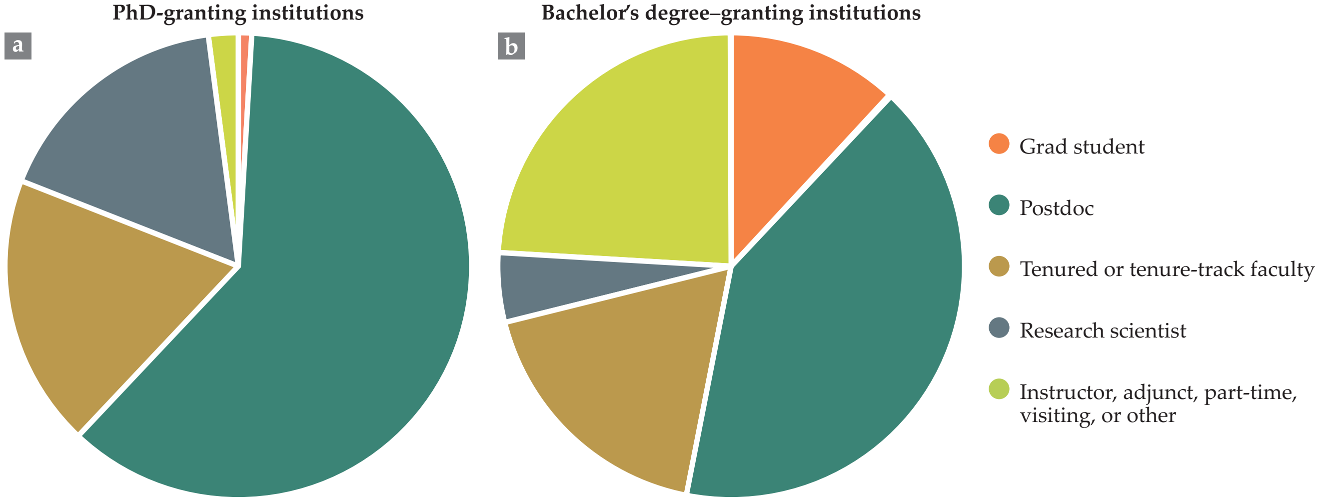


FIGURE 2. NEW TENURED OR TENURE-TRACK PHYSICS FACULTY at PhD-granting institutions **(a)** in the 2017–18 academic year were most likely to come directly from a postdoc position. Career trajectories are more varied for faculty at bachelor's degree–granting institutions **(b)**, but postdoc was still the most common previous position for new hires. (Adapted from ref. 3.)

might be safer to focus on broad research directions rather than mentioning specific faculty members.

In my case, I knew that the physics department at LSU had a strong theory group that was developing quantum optical technologies. Multiple senior faculty members had also conducted seminal research in the foundations of quantum theory. Thus I saw a role for myself in supplementing their expertise with my experimental skills. I tried to convey that vision in my cover letter. I also described how my joining the department could be mutually beneficial—I could contribute to the development of the department, and the department could help my academic career grow.

Next in the application package is the CV. Although it can be long and dense, the CV should be organized and provide additional details and references related to claims made in the cover letter and in the teaching and research statements. It should list research interests, academic positions, other relevant work experience, education, and teaching experience. You should also include peer-reviewed publications, conference papers, invited talks, media coverage, honors and awards, collaboration with industry, skills, and service. The order in which the information is presented and what is highlighted should be informed by the institution's focus and the position of interest—for example, teaching experience should likely be emphasized for PUIs, whereas research is often more relevant at larger universities.

Although it may feel superfluous, don't neglect the service section: Activities such as mentoring, engaging in educational outreach, and peer-reviewing journal articles are valuable experiences that can help a candidate stand out.

A teaching statement should outline your instructional goals and describe your philosophy. It should be approximately two pages and should describe your experience teaching at different levels, which should include your work as a teaching assistant during graduate school. The statement is also a place to discuss your teaching methodologies. It can be enriched by including pedagogical techniques such as active learning,[1] which has recently received a lot of attention.

Your teaching statement should also describe new courses you could design that would enhance the department's existing curriculum. In my case, I applied only to research universities, so I created my teaching statement to complement my research statement. For example, I briefly discussed how the equipment in my research laboratory could be used to perform hands-on demos for various specialized courses. But teaching and research statements can be independent, especially if the institution of interest is primarily a teaching university.

A good research statement should be four to five pages of information on your past, current, and future scientific work. The discussion should be general, and it should highlight the potential relevance of your research for the department. From the search committee's perspective, the most important part of the document is your plan for future research, and it must be supported by your past achievements, publications, and experience. It should also address funding. I highly recommend discussing funding opportunities that could eventually support your research program. Including potential funding sources in your research statement will allow you to convey a clearer and more comprehensive plan to the search committee.

Some search committees may ask experimentalists to include a startup budget with their application. That information will help the committee understand the infrastructure and initial support that your research program might require. Your budget proposal should consider the institution's available infrastructure and research priorities, and it should identify both the basic equipment needed for the experimental research being proposed and any associated costs. The budget may also contain information regarding potential collaborations that could help reduce startup costs. A basic plan can be easily adapted for different institutions.

A diversity statement, typically one page, should describe your past experiences with diversity and how it has influenced your personal and professional growth. It should reflect your desire to be inclusive and your willingness to boost and stimulate academic collaborations among people of different cultural backgrounds, nationalities, and beliefs. The positive aspects of your past collaborations may help you establish a strategy to improve inclusiveness in academic environments. Furthermore, recognizing the challenging aspects of those collaborations can help you set goals and identify possible solutions.

Search committees won't always request a diversity statement, but it's helpful to write one anyway. During your interview, the committee is likely to initiate a discussion related to diversity and inclusion efforts, so you should be well prepared from having written about your experiences and initiatives.

Getting personal

The documents described above help search committees decide which candidates will move on to the next stage: interviewing. A first round of interviews typically takes place online as a teleconference with a subset of the committee. It may also include administrators, faculty members responsible for shared facilities and teaching, and faculty members from other research areas or even other departments. The meeting typically takes about an hour, but could take anywhere from 20 minutes to 2 hours.

First-round interviews require you to be focused. The faculty panel may ask questions on a wide range of topics, including teaching, research experience, research plans, teaching philosophy, contributions to diversity, and service. The questions can jump quickly from one topic to another, which I found challenging. In one interview, for example, a question about the estimated budget to build a laboratory was followed by one related to the qualities of a good teacher and another about how to explain quantum interference to undergraduate students. Often the committee members use a set list of questions that will be asked of all candidates. The process ensures fairness, but can make the interview feel stiff and formal.

Before each interview, think about possible teaching and research questions that the search committee might ask. One question you should always be prepared to answer is, Why are you interested in working with the faculty at the interviewing institution? (See the online resources box on page 35 for more information on interview questions.) You will also have an opportunity to ask questions during the interview; posing thoughtful questions is one way to show that you've put time into learning about the department, its research, and the institution. Good preparation of both questions and answers will also help avoid uncomfortable silence during the meeting.

Some candidates will be filtered out in the online interview stage, and typically only three to five candidates are invited for a subsequent on-campus interview. The interview is an opportunity to demonstrate your communication skills and teaching abilities. It's also a chance to learn more about the university, the city, the department's culture, and the people who may become your long-time colleagues! The multiple meetings with faculty members will be long, exhausting, and at some points maybe even boring. Regardless, you should exploit the opportunity to learn more about the university's expectations and to assess the positive and negative aspects of potentially relocating your life and career there.

It's a good idea to prepare questions for the faculty members and administrative staff you will be meeting. My campus visits each consisted of one long day, but some last for two days, and they can occasionally be as long as four. You should focus your energy on engaging in one-on-one interviews, delivering an exciting talk, and learning as much as you can. Be prepared for the possibility that your interview will include breakfast, lunch, and dinner. That may make it feel endless and without respite, but it's a common practice used to get to know candidates in more informal settings and to optimize time.

Vying for a faculty job is a competition, so it's important to make yourself stand out. The on-campus interview is an opportunity to do that—particularly during the job talk, which is a seminar or colloquium based on your research. There's more than one way to design an interesting and engaging talk, but I suggest focusing on a single topic or paper. That way you can provide the audience with enough background information that they can understand the significance of your research. To make sure things go smoothly, rehearse your talk a few times for your colleagues and incorporate their feedback.[2] (See the article by Stephen Benka, PHYSICS TODAY, December 2008, page 49.)

It may be tempting to try to impress the search committee

Louisiana State University

Assistant Professor of Experimental Quantum Optics or AMO Physics (Tenure-Track)

The Department of Physics and Astronomy at Louisiana State University invites applications for a tenure-track Assistant Professor position in experimental quantum optics or atomic, molecular and optical (AMO) physics starting Fall 2018. The faculty in LSU's Quantum Science and Technology (QST) group include Thomas Corbitt, Jonathan Dowling, Hwang Lee, Ravi Rau, Georgios Veronis and Mark M. Wilde. The group carries out an active research program in quantum optics theory, as well as the quantum optics experimental activity of Corbitt. The QST group forms half of the Hearne Institute for Theoretical Physics, with the other half comprising the experimental and theoretical general relativity group, whose faculty members consist of Ivan Agullo, Thomas Corbitt, Peter Diener, Joseph Giaime, Gabriela Gonzalez, Warren Johnson, Robert O'Connell, Jorge Pullin, and Parampreet Singh. The experimental component is largely part of the LIGO Scientific Collaboration, with an extensive presence at the LIGO Livingston Observatory situated 24 miles from campus. LSU also hosts a theoretical attosecond theory group including Mette Gaarde and Ken Schafer.

The Department of Physics and Astronomy at LSU has strong research efforts in particle physics, including nuclear and neutrino physics, space physics, condensed matter physics, medical physics, and astronomy and astrophysics.

Details

Posted:
November 1, 2017

Location:
Baton Rouge, Louisiana

Salary
Open

Level:
Experienced

Sector:
Academic

Work Function:
Faculty 4-Year College/University

Discipline:
Physics: Atomic and Molecular,
Physics: Optics and Laser,
Physics: Quantum

Responsibilities

Teach at the undergraduate and graduate levels; supervise graduate students' research and dissertations; establish a vigorous research program in experimental quantum optics or AMO physics; and service to the university.

Minimum Qualification

PhD degree in Physics or a related field (A.B.D. candidates considered but must have PhD by May 2018).

Preferred Qualifications

Preference will be given to candidates working on novel technologies for quantum communication, optical quantum information processing, and quantum optical metrology.

Preferred Education

Doctorate

FIGURE 3. THE JOB POSTING FOR A FACULTY POSITION should guide your application. The qualifications for my current position at Louisiana State University, highlighted in brown, were reflected in my background. My application referenced the job's responsibilities, highlighted in blue, and explained how I would be able to carry them out. Being aware of the department's focus on theoretical research, highlighted in green, helped me envision how my experimental background might complement the existing program. (Adapted from the PHYSICS TODAY Jobs posting.)

ONLINE RESOURCES

- **Some websites that list job postings for physics faculty positions**
  https://jobs.physicstoday.org
  https://academicjobsonline.org
  https://higheredjobs.com
  https://sciences.academickeys.com
- **Advice on writing an academic cover letter can be found at**
  https://owl.purdue.edu/owl/job_search_writing/job_search_letters/academic_cover_letters/index.html
- **An outline for an academic CV can be found at**
  https://academicpositions.com/career-advice/how-to-write-a-professional-academic-cv
- **A list of interview questions that you might be asked—and some you shouldn't be—can be found at**
  https://capd.mit.edu/sites/default/files/career/files/academic-interview-questions.pdf
- **For more guidance on job interviews, see PHYSICS TODAY's Q&A with career consultant Alaina Levine at**
  https://physicstoday.scitation.org/do/10.1063/pt.5.9035/full and /pt.5.9039/full
- **Learn about what salary level to expect as a physics professor at**
  https://aip.org/statistics/salary-calculator

members by presenting multiple papers, but that's not a good strategy. They have already analyzed your CV, and you were invited to the on-campus interview because they were impressed by your achievements. Remember that the purpose of the job talk is to demonstrate your ability to communicate and teach effectively. Picking a single paper or project—if possible, one that can appeal to a broad audience—will help you demonstrate those skills.

I recommend designing your job talk so that it's easy for the search committee to contrast your expertise and plans with those of other applicants. Although you may not know who the others are, most departments have public calendars that list talks by invited speakers. In any case, reviewing recent seminar topics will provide insight into department members' interests, which can help you plan your own talk.

Some universities, particularly PUIs, may request a teaching demonstration in addition to the job talk. In that case, the search committee will assign a topic and request that you teach a 30- to 90-minute lecture, followed by questions from students. The lecture is an opportunity to showcase the various methodologies and pedagogical techniques discussed in your teaching statement. An old-fashioned lecture without interactive components is unlikely to impress the hiring committee.

Going into your job search, you'll likely have experience conducting research seminars and teaching demonstrations. But another potential interview component—the chalk talk—is probably unfamiliar. In a chalk talk, the hiring committee can ask about your research proposal, implementation plan, budget, or anything else, and you have to defend your program. The whole thing takes about 60 minutes, and although it can be done at a chalkboard, it can also be presented with slides or as a combination of the two, depending on what the committee requests.

Nuts and bolts

Following the on-campus interview, you might be contacted by the department chair or the dean to discuss your potential appointment. Negotiating your initial teaching load and startup funds is a necessary part of the hiring process. At some institutions, your salary, the number of students and postdocs you can hire, their salaries, coverage of publishing fees, and travel funding are negotiable as well. Being able to offer generous postdoc salaries can help you attract talented researchers who will speed up the establishment of your research group.

Although you may have a long wish list, it's crucial to identify the bare-minimum resources that you will need to begin a successful research and education program in your area of expertise. Before you bring a budget proposal to a department chair, consider potential barriers to its implementation and formulate possible solutions. The budget should identify any necessary supplies or equipment that the facilities currently lack. Another important consideration is how long it would take to get your lab set up and for your group to start performing new, original research. A careful estimation will inform any negotiations and justify your requested teaching loads and summer salary. Most junior faculty positions cover nine months of salary with the expectation that you will eventually secure funding to cover the three summer months; until that point, you'll need additional support.

Behind every hiring process are departmental and institutional politics that may be invisible to the candidates—and are beyond their control. (See the article by Matt Anderson on page 52 of this issue.) I had a disappointing experience in which I had almost finished negotiating startup funding for a position when the university hired a new dean of science who instated a hiring freeze. Although I believe such setbacks are unusual, they are always possible and can be discouraging. That's why I suggest keeping some emotional distance throughout the stages of the job search and remembering that the hiring process is not finalized until the contract is signed.

In the end, I was fortunate to receive a generous offer only a year after finishing graduate school. But before I received that offer, I had to pass through a series of other interviews for faculty positions. The process presented unexpected challenges and uncovered weaknesses in my job-search approach. I hope that readers who are considering becoming professors can learn from my experience and enter the job market a little better prepared for the challenges ahead.

REFERENCES

1. C. Meyers, T. B. Jones, *Promoting Active Learning: Strategies for the College Classroom*, Jossey-Bass (1993); for other instructional strategies, see National Research Council, *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*, National Academies Press (2012).
2. For help preparing a research seminar, see, for example, N. A. Lewis Jr et al., "Three tips for giving a great research talk," *Science* (17 April 2019).
3. A. M. Porter et al., *Faculty Job Market in Physics and Astronomy Departments: Results from the 2018 Academic Workforce Survey*, Statistical Research Center of the American Institute of Physics (June 2020). PT

UNIVERSITY OF
NOTRE DAME

Tenure-track Professor in Experimental Condensed Matter Physics

The Department of Physics at the University of Notre Dame invites applications for a tenure-track faculty position in Experimental Condensed Matter Physics. Applications from tenured/senior researchers will also be considered. The condensed matter group at Notre Dame consists of 7 experimental and 4 theoretical faculty, doing research in hard condensed matter, quantum materials, complex networks, and biophysics.

We seek faculty members committed to developing and sustaining an environment of inclusive excellence in research, teaching, and service. The successful candidate must demonstrate the ability to develop a highly successful research program, attract independent research funding, teach effectively at both the graduate and undergraduate levels, and engage with students from diverse backgrounds. Applicants must have a Ph.D. or equivalent advanced degree. Salary and rank will be commensurate with the successful applicant's experience and research accomplishments. The expected start date is August 2021.

Applicants should submit a curriculum vitae, list of publications, detailed research plans, and a statement of teaching and mentoring. Candidates must also arrange for at least three letters of recommendation. Review of completed applications will begin on November 1, 2020, with a final deadline of December 31.

Apply at: https://apply.interfolio.com/78640

Tenure-track Professor in Theoretical Nuclear Physics

The nuclear theory group at the University of Notre Dame currently includes three faculty members with broad interests in the areas of nuclear astrophysics and *ab initio* approaches to nuclear structure. Group members actively collaborate with local observers, experimentalists, and theorists and enjoy a close connection to the Notre Dame Nuclear Science Laboratory, an on-campus accelerator facility focused on fundamental and applied low energy nuclear physics (https://isnap.nd.edu).

We seek faculty members committed to developing and sustaining an environment of inclusive excellence in research, teaching, and service. The successful candidate must demonstrate the ability to develop a highly successful research program, attract independent research funding, teach effectively at both the graduate and undergraduate levels, and engage with students from diverse backgrounds. Applicants must have a Ph.D. or equivalent advanced degree. Salary and rank will be commensurate with the successful applicant's experience and research accomplishments. The expected start date is August 2021.

Applicants should submit a curriculum vitae, list of publications, detailed research plans, and a statement of teaching and mentoring. Candidates must also arrange for at least three letters of recommendation. Review of completed applications will begin on November 1, 2020, with a final deadline of December 31.

Apply at: https://apply.interfolio.com/78521

The Department of Phyiscs at the University of Notre Dame is committed to diversifying its faculty and encourages applications from women and members of traditionally underrepresented groups.

The Department of Physics at Notre Dame has 39 tenured and tenure-track faculty; another 21 research, teaching and concurrent faculty; more than 100 graduate students; and about 120 undergraduate physics majors. Additional information about the department and the College of Science can be found at http://physics.nd.edu and http://science.nd.edu respectively.

Equal Employment Opportunity Statement: The University of Notre Dame seeks to attract, develop, and retain the highest quality faculty, staff and administration. The University is an Equal Opportunity Employer, and is committed to building a culturally diverse workplace. We strongly encourage applications from female and minority candidates and those candidates attracted to a university with a Catholic identity. Moreover, Notre Dame prohibits discrimination against veterans or disabled qualified individuals, and requires affirmative action by covered contractors to employ and advance veterans and qualified individuals with disabilities in compliance with 41 CFR 60-741.5(a) and 41 CFR 60-300.5(a).

PRINCETON CENTER FOR COMPLEX MATERIALS
an NSF-supported MRSEC

PRINCETON UNIVERSITY

Princeton Materials Science Postdoctoral Fellowship

The Princeton Center for Complex Materials (PCCM), an NSF-supported Materials Research Science and Engineering Center (MRSEC), announces the 2020 Princeton Materials Science Postdoctoral Fellowship.

These prestigious postdoctoral positions are intended for early-career scientists with a research focus on materials science and engineering. PhD is required. Successful candidates will be appointed in fall 2020 for a full-time, 12 month period as a postdoctoral research associate or more senior, renewable annually for up to three years based on performance and funding.

The selected fellow(s) will join the research group of a current PCCM investigator. The current list of investigators and their areas of research, which include topological quantum matter and harnessing disordered macromolecular structures for living and soft matter, can be found at https://pccm.princeton.edu/research/new-research-groups-2020-2026

Applications must be submitted online at **https://www.princeton.edu/acad-positions/position/17441**. Applications will require curriculum vitae (CV), list of publications, and a statement of your proposed research plans at PCCM, Applicants will need to provide contact information for two references who will be solicited to provide letters of recommendation. **All applications and supporting materials must be submitted by the application deadline date of November 15, 2020, 11:59 p.m. EST.** These positions are subject to the University's background check policy.

Princeton University is an Equal Opportunity/Affirmative Action Employer and all qualified applicants will receive consideration for employment without regard to age, race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability status, protected veteran status, or any other characteristic protected by law.

TENURE-TRACK FACULTY POSITIONS IN PARTICLE PHYSICS AND COSMOLOGY

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

The Department of Physics invites applications for tenure-track faculty positions at the Assistant Professor level in experimental and theoretical physics, with specialty in the areas of **High Energy Theory and Cosmology, Particle Physics Experiment, and Observational Cosmology**.

Appointments at the rank of Associate Professor or above will be considered for candidates with an exceptional record of research excellence and academic leadership. The current faculty at The Hong Kong University of Science and Technology in particle physics and cosmology group include Professor Andy Cohen, Professor George Smoot, Professor Henry Tye, Professor Tao Liu, Professor Yi Wang and Professor Kirill Prokofiev. The department is growing its effort in particle physics and cosmology group by hiring five new faculty in theory and experiment. Further information about the Department can be found at http://physics.ust.hk.

Applicants must possess a PhD degree in physics or a related field. The successful candidates should have a strong track record of research. In addition to pursuing a vibrant research program, the candidates are expected to engage in effective teaching at the undergraduate and graduate levels.

Starting salary will be highly competitive and commensurate with qualifications and experience. Fringe benefits including medical and dental benefits, annual leave and housing benefits will be provided where applicable. Initial appointment will normally be on a three-year contract. A contract-end gratuity will be payable upon successful completion of contract.

Application Procedure
Applicants should submit their applications along with CV, cover letter, complete publication list, research statement, teaching statement, and three reference letters. Separate applications should be submitted online for each position below:

High Energy Theory and Cosmology (PHYS1017H): https://academicjobsonline.org/ajo/jobs/16291
Particle Physics Experiment (PHYS1017P): https://academicjobsonline.org/ajo/jobs/16292
Observational Cosmology (PHYS1017C): https://academicjobsonline.org/ajo/jobs/16293

Screening of applications begins immediately, and will continue until the positions are filled.

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

The Institute for Theoretical Physics of the Department of Physics and Astronomy at Heidelberg University announces an opening for a

FULL PROFESSORSHIP (W3) IN THEORETICAL PHYSICS

We are looking for an internationally recognized theorist working on quantum physics in the context of quantum simulation, physical aspects of information theory, and the foundations of new methods of information processing and computation. The new professor should establish contact to the Heidelberg research groups in experimental and theoretical physics, and in particular provide theoretical perspectives for future experiments. This professorship is a key component in the Heidelberg cluster of excellence **STRUCTURES** and in the newly established focus area physics of information/novel methods of computation at the Department of Physics and Astronomy.

The successful candidate is expected to participate in the teaching program in theoretical physics at all levels and play a leading role in joint grant applications at the Institute for Theoretical Physics.

Prerequisites for application are a university degree and (in accordance with Article 47, paragraph 2 of the Higher Education Law of the State of Baden-Württemberg) a Habilitation, a successfully evaluated junior professorship or equivalent qualification. Heidelberg University seeks to achieve a higher proportion of women in areas where they have not been adequately represented so far. Preference will be given to applicants with disabilities having equal qualifications for the position.

Qualified candidates are invited to submit their application in English including a CV, a list of publications, a list with teaching experience and a research plan in electronic form (pdf) until **October 21, 2020** to the Dean, Prof. Dr. T. Plehn, Department of Physics and Astronomy, Im Neuenheimer Feld 226, D-69120 Heidelberg, Germany (dekanat@physik.uni-heidelberg.de).

Information on the collection of personal data in accordance with Art. 13 DS-GVO can be found on our homepage at https://www.uni-heidelberg.de/datenschutz_personal

UNIVERSITÉ DE GENÈVE

The Faculty of Science at the University of Geneva, Switzerland has an opening for a position as

FULL OR ASSOCIATE PROFESSOR IN OXIDE INTERFACE PHYSICS

The Department of Quantum Matter Physics (DQMP) at the University of Geneva offers a highly dynamic and stimulating environment and is renowned for its research at the forefront of electronic materials.

The department is looking for a highly-qualified and strongly motivated scientist with the ambition to establish a world-class research program evolving around oxide interfaces with innovative electronic properties. The program should address both the growth of heterostrutures and the investigation of their physical properties by means of different techniques. The applicant is expected to have an interest in scientific exchange with other groups working in the field of electronic materials at the DQMP. The successful candidate will benefit from excellent starting conditions, including start-up funds and existing infrastructure and expertise for the growth and physical characterization of oxide heterostructures.

Applications should be submitted exclusively on-line at: **https://jobs.unige.ch** (reference 3839) before **15.1.2021**.

KIAS

ASSISTANT PROFESSOR & RESEARCH FELLOW IN THEORETICAL PHYSICS AT KIAS

The School of Physics at Korea Institute for Advanced Study (KIAS) invites applicants for the positions at the level of KIAS assistant professor and postdoctoral research fellow in theoretical physics. Applicants are expected to have demonstrated exceptional research potential, including major contributions beyond or through the doctoral dissertation.

The annual salary starts from 50,500,000 Korean Won (approximately US$42,000 at current exchange rate) for Research Fellows, and 57,500,000 Korean Won for KIAS Assistant Professors, respectively. In addition, individual research funds of 10,000,000 Korean Won for research fellows and 13,000,000 Korean Won for KIAS Assistant Professors are available per year. The initial appointment for the position is for two years and is renewable once for up to two additional years, depending on research performance and the needs of the research program at KIAS.

Applications are normally reviewed twice a year and the respective deadlines are June 1st and December 1st. In addition, unexpected vacancies may be filled with exceptional candidates throughout the year. Applications must include a curriculum vitae with a cover letter, a list of publications, a research plan, and three letters of recommendation.

Your application materials may be sent to phys@kias.re.kr or submitted via Academic Jobs Online at https://academicjobsonline.org/ajo.

POLYTECHNIQUE MONTRÉAL

The Department of Engineering Physics at Polytechnique Montréal, Canada, has an opening for two positions as

ASSISTANT PROFESSOR (tenure track) IN ENGINEERING PHYSICS

The Department of Engineering Physics at Polytechnique Montréal is recognized for the quality of its teaching and research activities, mainly in the fields of optics and photonics, advanced materials and devices, biomedical engineering, and energy engineering.

Polytechnique is searching for two professors with excellent physics knowledge and training in engineering physics, or any of the other related fields such as physics, electrical engineering, chemistry or material science and engineering. Candidates must have extensive theoretical or experimental research experience, and whose activities align with either those of the Department of Engineering Physics or with any of the other emerging technologies related to health, information, energy or the environment. More specifically, but not limited to, we invite applications in the following priority areas: Micro/Nano-materials and functional materials; Quantum Technologies; Physical Technologies in Health; and in Optics/Photonics.

For more information and application, visit: **www.polymtl.ca/carriere/en/offres-demploi/professors-engineering-physics**

Examination of applications will begin as soon as possible and will continue until the position is filled.

Patrick Mulvey is a research manager in the Statistical Research Center at the American Institute of Physics in College Park, Maryland.

Where do new PhDs WORK?

Patrick J. Mulvey

Survey questionnaire data reveal that recently graduated physics PhDs have a varied set of career options.

We have all heard it. Physics degree recipients are versatile problem solvers who work in all sectors of the economy in all types of positions. For the PhD degree classes of 2017 and 2018, that mantra is as true as it has ever been. Against the backdrop of a strong US economy in recent years, those new physics PhDs secured meaningful employment in a variety of fields. Their specialized training made them strong candidates for specific academic and nonacademic positions, while their general scientific, mathematical, and analytical skills made them attractive hires to a broad range of employers.

ISTOCK.COM/GORODENKOFF; ADAPTED BY DONNA PADIAN

The data about initial employment that form the basis of this article come from 2017 and 2018, the most recent data available from surveys conducted by my colleagues and me at the Statistical Research Center (SRC) at the American Institute of Physics (AIP, publisher of PHYSICS TODAY). The employment outlook for new PhDs from the class of 2020 will assuredly be different. According to the National Bureau of Economic Research, the US entered a recession in February of 2020, ending the longest economic expansion in US history. The recession was caused by the COVID-19 pandemic, which continues to spread. Prospects for the classes of 2021 and beyond may also be different.

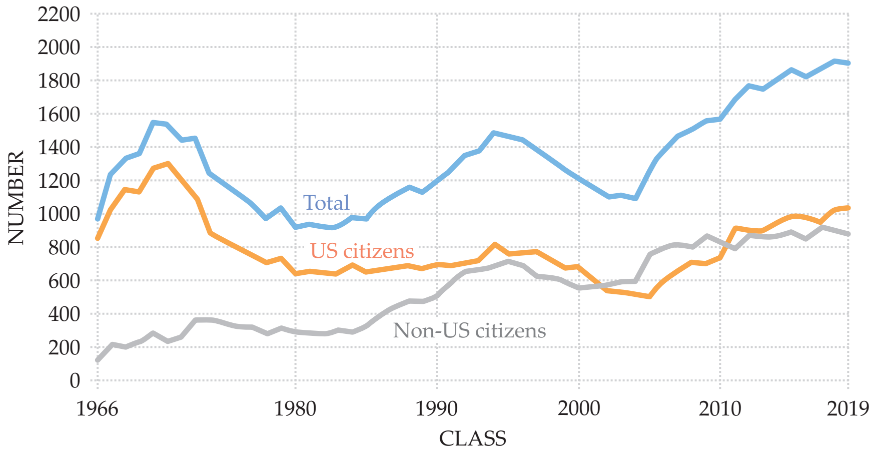


FIGURE 1. NUMBER OF PHYSICS PHDs awarded at US universities, classes of 1966 through 2019. The past 15 years has seen an increase of 175%. (American Institute of Physics, Statistical Research Center, Enrollments and Degrees Survey.)

One consistent element of the job market is that colleges and universities will continue to educate students and fill faculty positions. Companies will continue to need employees, even if new hires will be working remotely. And university and government laboratories will continue to need staff and postdocs to carry out their research agendas. As national economies reopen, a new normal will be established that may or may not resemble the past.

Initial employment split

The numbers of recently graduated physics PhDs in the US are at a record high. About 1900 degrees were awarded to the class of 2019 (see figure 1). Since the early 1990s, non-US citizens have accounted for about half of the physics PhDs awarded in the US. The proportion of non-US citizens peaked in 2005 when they represented 60% of the degrees conferred. For the class of 2019, non-US citizens represented 46% of physics PhDs.

The postdegree outcomes for new physics PhDs fall into four main categories: postdoctoral fellowships, potentially permanent positions in academia or the private sector, other temporary positions, and unemployment. For this article, new PhDs are categorized according to the status of their employment in the February following the academic year in which they received their PhD.

> "I love my job and it is a very good position with excellent people and excellent research. However, postdocs are systematically underpaid."

The two most common postdegree outcomes—postdocs and potentially permanent positions—have displayed an inverse cyclical pattern for the past four decades (see figure 2). For most of the past two decades, the prevailing initial employment outcome for new physics PhDs has been a postdoc. Things changed for the class of 2018. More new PhDs accepted potentially permanent positions than accepted postdocs, albeit by only 3%.

The third initial postdegree employment outcome category is other temporary positions. People in those nonpostdoc positions are mostly visiting professors, lecturers, and research scientists at colleges and universities. In recent years, 7–10% of new physics PhDs have accepted such positions. The fourth outcome category, unemployed, has accounted for about 5% of the respondents in recent years.

Not represented in the data shown in figure 2 and in the remainder of this article are the initial outcomes of new PhDs who did not remain in the US. For the classes of 2017 and 2018, about 25% of the non-US citizens and about 10% of the US citizens were either working or seeking employment outside the US in the winter following the year in which they graduated. More than half the non-US citizens and almost all of the US citizens who had left the US indicated they had accepted a postdoc.

The pattern of swings in the proportion of new physics PhDs who accept postdocs or potentially permanent positions is similar for both US and non-US citizens, but there are distinct and fairly consistent differences. Since the class of 2002, the proportion of US citizens accepting potentially permanent positions has been consistently greater than that of non-US citizens. For the combined PhD classes of 2017 and 2018, 47% of the US citizens accepted potentially permanent positions compared with 35% of the non-US citizens. The reverse is true for postdocs, with 40% of the US citizens and 51% of the non-US citizens accepting them.

The postdoc

Postdoc positions provide a temporary period of mentorship during which new degree recipients can either continue to do research and publish papers in the area of their dissertations or pursue other, new areas of research.

Typically two years in length and often renewable, postdoc positions pay less than potentially permanent positions in the private sector. Even so, they are an attractive employment option for many new PhDs. The decision to accept a postdoc is

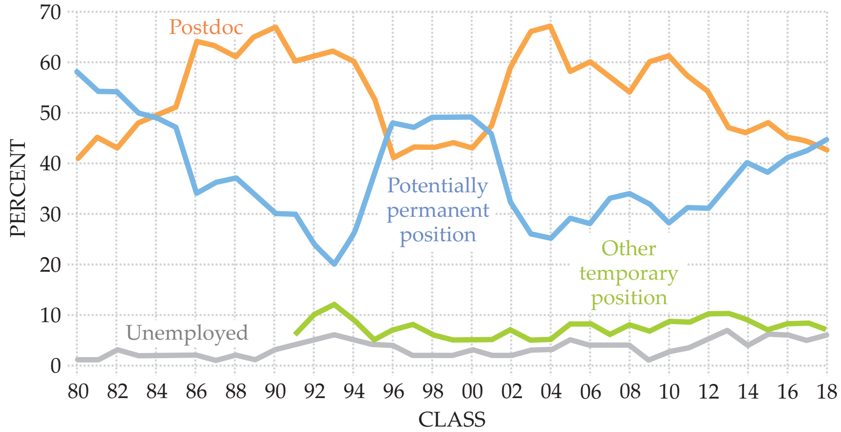


FIGURE 2. INITIAL EMPLOYMENT OUTCOMES of physics PhDs, classes of 1980 through 2018. For the first time since the physics PhD class of 2000, a greater proportion of new PhDs accepted a potentially permanent position in 2018 than accepted a postdoctoral appointment. The category of "other temporary position" was added to the survey instrument starting with the degree class of 1991. (American Institute of Physics, Statistical Research Center, PhD Follow-up Survey.)

influenced by professional goals, personal circumstances, and the realities of the job market. My colleagues and I asked new PhDs who accepted postdocs to indicate to what extent specific factors influenced them. As figure 3 shows, the decision to accept a postdoc is driven not by a single factor but by a combination of them.

> "I am attempting to get a job in data science and finding it very challenging. I was unprepared to translate my skills to a corporate environment and had few connections."

The most cited reason for acceptance was that a postdoc is a "necessary step to get a future position." That finding is not surprising, as completing a postdoc is generally considered a prerequisite to getting a faculty position, especially at a research university. As I discuss below, the notion that a postdoc is a required stepping-stone to a faculty position is corroborated by the hiring practices of colleges and universities. The motivation to "work with a particular scientist or research group" and to "obtain research experience in my field" also influenced new PhDs in accepting a postdoc.

Although the employment prospects and circumstances for non-US citizens differ from those for US citizens, non-US citizens cite many of the same reasons for accepting a postdoc. Non-US citizens often require a change in their visa status if they are to remain in the US after receiving their PhD. Almost half of the non-US citizens who accepted a postdoc in the US indicated that visa restrictions limited their options. Possibly also related to visas is that almost twice as many of the non-US citizens as the US citizens said that they took a postdoc because they "could not obtain a suitable permanent position."

Non-US citizens can obtain a valid visa for a postdoc by getting authorized for Optional Practical Training (OPT). Universities that need postdoctoral researchers are adept at assisting non-US citizens in obtaining the authorization. Because all employment during a period of OPT authorization must be related to the individual's major field of study, the employment options of non-US citizens are more limited than those of US citizens. It is unknown what proportion of the non-US citizens who left the US after receiving their degree did so because of their inability to obtain the necessary visa.

Many of the reasons new PhDs accepted a postdoc centered around gaining valuable additional experience. Indeed, 94% of postdoc holders reported feeling that the knowledge and skills they were developing would help advance their careers. Three-quarters of the postdocs in the classes of 2017 and 2018 were employed at a university. Most of the rest were employed in the government sector, which includes the national laboratories (see figure 4).

Like postdocs, PhDs holding other temporary positions were also primarily (70%) employed in academia. Those other temporary academic positions can provide valuable teaching experience for physicists who hope to continue teaching in a college or university setting. They frequently come with the title of visiting professor or guest lecturer. For some new PhDs, these nonpostdoctoral temporary positions fell short of what they hoped to be doing in the year after receiving their PhD. Not being able to obtain a suitable permanent position was an influential factor for 75% of PhDs who accepted a temporary position. The majority (60%) of nonpostdoctoral positions lasted one year.

Since the PhD class of 2010, the proportion of new physics PhDs in potentially permanent positions has steadily increased. Forty-four percent of the degree classes of 2017 and 2018 accepted such a position. As mentioned above, that development marks the first time in almost two decades that the proportion of physics PhDs accepting potentially permanent positions exceeded the proportion accepting postdocs. The overwhelming majority (73%) of the potentially permanent positions were in the private sector. Companies that employ new PhDs range from the smallest startups to the largest corporations. By contrast, 16% of the new PhDs holding potentially permanent positions worked in an academic setting. Many had job titles such as assistant professor or assistant lecturer.

Many people may not purposefully track the time they spend looking for a job. Nevertheless, the time a person perceives they spent seeking employment can be seen as an indicator of the strength of the job market. New physics PhDs were asked, "How long did you spend actively seeking employment before accepting your position?" Of the PhDs who accepted a postdoc or other temporary position, 20% indicated they spent zero months actively seeking employment. It's likely that some new graduates did not consider the time they spent cultivating contacts and professional connections before receiving their degree as being part of their job search. Of the PhDs holding potentially permanent positions, 12% also indicated spending zero months on job searches. The median length of time that PhDs in all three employment categories searched for employment was three months.

Academic employment

As seen in figure 4, only 16% of PhDs accepting potentially permanent positions were working in an academic setting. That statistic forms only part of the academic employment picture. People who were in postdocs and other temporary positions when they were surveyed will go on to seek new positions. About 60% of the PhDs who held postdocs or other temporary positions indicated a desire to work in academia.

One indicator of potential future openings at physics and astronomy departments is the annual number of hires made. If hiring remains stable, there will not be enough open faculty positions to absorb all the individuals who want one. Nevertheless, a significant proportion of physics PhDs will eventually secure employment of some kind in academia.

Advice for individuals on looking for and obtaining an academic position can be found in two other articles in this month's issue (see pages 30 and 52). Statistical data from NSF and AIP provide a complementary, quantitative look at the hiring practices of US physics departments. According to NSF's 2017 Survey of Doctorate Recipients, about 39% of physics PhDs were employed at an educational institution.[1] NSF includes in that category four-year colleges and universities, medical schools (including university-affiliated hospitals and medical centers), university-affiliated research institutes, two-year colleges, community colleges, technical institutes, precollege institutions, and other educational institutions. As for individuals, NSF considered people who earned their physics PhD in the US, in any year, who were less than 76 years of age, and who were working in the US in 2017.

Data from the 2017–18 AIP Academic Workforce Survey provide insight into the backgrounds of the individuals who are hired into tenure and tenure-track faculty positions at US physics departments. Only 1% of the faculty members hired at PhD-granting physics departments and 12% of those hired by departments in which a bachelor's is the highest degree offered were employed right out of graduate school.[2] The largest proportion (61%) of new academic hires at PhD-granting physics

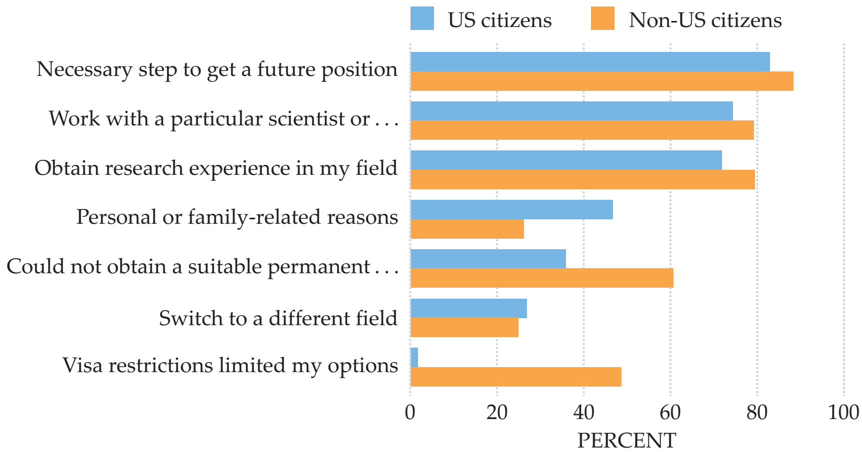


FIGURE 3. SPECIFIC FACTORS THAT LED NEW PHYSICS PhDs TO ACCEPT A POSTDOC. The three most cited influences for taking a postdoc were related to career goals and pursuing research interests. Here, data are limited to PhDs who earned their degree in the classes of 2017 and 2018 from a US university and remained in the US. Respondents were asked to rate the level of influence each statement had on why they took a postdoctoral fellowship. They were presented with a four-point scale that included "very influential," "influential," "of little influence," and "not at all influential." The data in the figure represent the proportion of individuals choosing one of the two positive response choices. (American Institute of Physics, Statistical Research Center, PhD Follow-up Survey.)

FIGURE 4. EMPLOYMENT SECTOR OF NEW PHYSICS PhDs, classes of 2017 and 2018 combined. Three-quarters of new physics PhDs who secured potentially permanent positions were working in the private sector. Here, "other" includes nonprofit organizations, hospitals and medical facilities, and other, unspecified employers. (American Institute of Physics, Statistical Research Center, PhD Follow-up Survey.)

> "I took a lectureship because that's what was available to me given time constraints and opportunities."

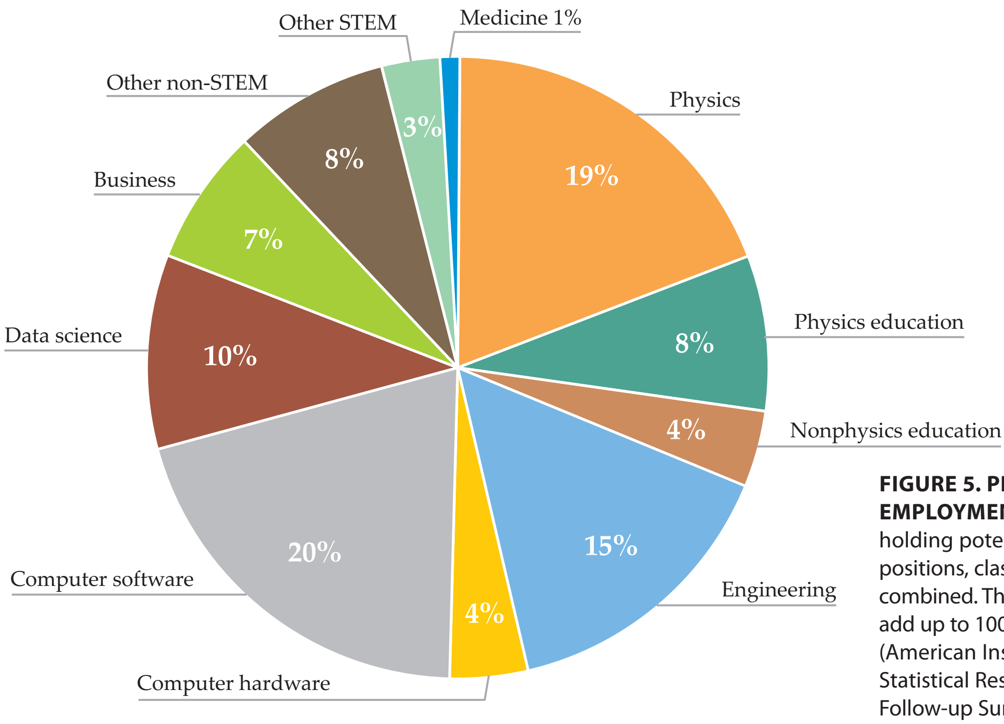


FIGURE 5. PRIMARY FIELD OF EMPLOYMENT for physics PhDs holding potentially permanent positions, classes of 2017 and 2018 combined. The percentages may not add up to 100 because of rounding. (American Institute of Physics, Statistical Research Center, PhD Follow-up Survey.)

departments were individuals who had previously held a postdoc. For new hires at physics departments that offer a bachelor's as their highest degree, 41% had a previous position as a postdoc and 24% had held a nonpostdoctoral temporary academic position.

Competition for tenured and tenure-track academic openings at US physics departments is not just limited to PhDs who earned their degree from a US institution. For the new academic hires in the 2017–18 academic year, 20% at doctoral-granting physics departments and 7% at bachelor's-only departments had earned their PhD outside the US.[2]

Faculty positions for physics PhDs are not limited to physics and astronomy departments. One in five academically employed physics PhDs work in a department other than physics or astronomy, according to a survey conducted by SRC of US-trained physics PhDs who had received their degrees 10–15 years earlier.[3] Clearly, the academic employment possibilities for physics PhDs are broader than just physics departments. The substantial fraction of physicists employed in nonphysics departments exemplifies the interdisciplinary nature of physics and the versatility of physicists.

My colleagues and I asked new physics PhDs what their primary and secondary fields of employment were. If either was in physics, they were also asked if their employment field was the same as their dissertation field. For the most part, PhDs who accepted postdoctoral fellowships not only were working in physics but were also continuing in the area of their dissertation work. New physicists holding nonpostdoctoral temporary positions were fairly evenly split among those working in the field of their dissertation, those working in another area of physics, and those working in a nonphysics field.

The various types of employment that new physics PhDs accept is most prominent among degree recipients who accepted potentially permanent positions. Almost three-quarters (73%) of them indicated that their primary field of employment was in neither physics nor physics education (see figure 5). Recall that most PhDs in potentially permanent positions work in the private sector. Many of them secured employment in the fields of computer software, engineering, and data science. To help better understand which employers hired PhDs into those fields and what skills they use, the SRC has developed an online tool, Who's Hiring Physics PhDs? (see the online resources box on page 46).

Salaries and perspectives

Although most grad students pursue physics because of their interest in discovering how the natural world works, they soon recognize a practical side to a physics degree: supporting themselves financially post-PhD. Starting salaries for the PhD classes of 2017 and 2018 varied by category of position, but the bigger variance came from the sector in which they were employed (figure 6). Physics PhDs who secured potentially permanent positions in the private sector earned considerably more and had a much wider range of salary than PhDs who held other types of employment.

> "I have found employment in the private sector to be more challenging and engaging than I imagined while still in academia."

The median starting salary for physics PhDs working in potentially permanent university and four-year college positions was $60 000, which is about half as much as the median salary for their cohorts employed in the private sector. About half of the PhDs holding potentially permanent positions at universities and four-year colleges reported that their positions were for 9–10 months of work. Those academic salaries were not adjusted for the length of their contract.

Far less striking but still notable is the difference between the salaries of postdocs at government labs and at universities. Physics PhDs who accepted postdocs at government labs had a median salary of $70 000, whereas those with postdocs at universities, which employ the majority of postdocs, had a median salary of $50 000.

The level of monetary compensation for the work one does is important, but other aspects of employment matter as much or possibly more for some individuals. When asked to self-assess how they perceived different aspects of their employment, new physics PhDs in the classes of 2017 and 2018 responded overwhelmingly positively.

The majority (85%) who accepted potentially permanent positions indicated they felt that a physics PhD was an appropriate background for their position. That again speaks well to the ability of physics PhDs to apply their knowledge and skills to the various fields in which they find work. New PhDs were also asked if they considered themselves underemployed; 16% of the individuals who had a postdoc said they were. Of the PhDs holding potentially permanent positions, 20% said they were underemployed. PhDs holding other temporary positions were generally less positive about their employment; 50% felt underemployed.

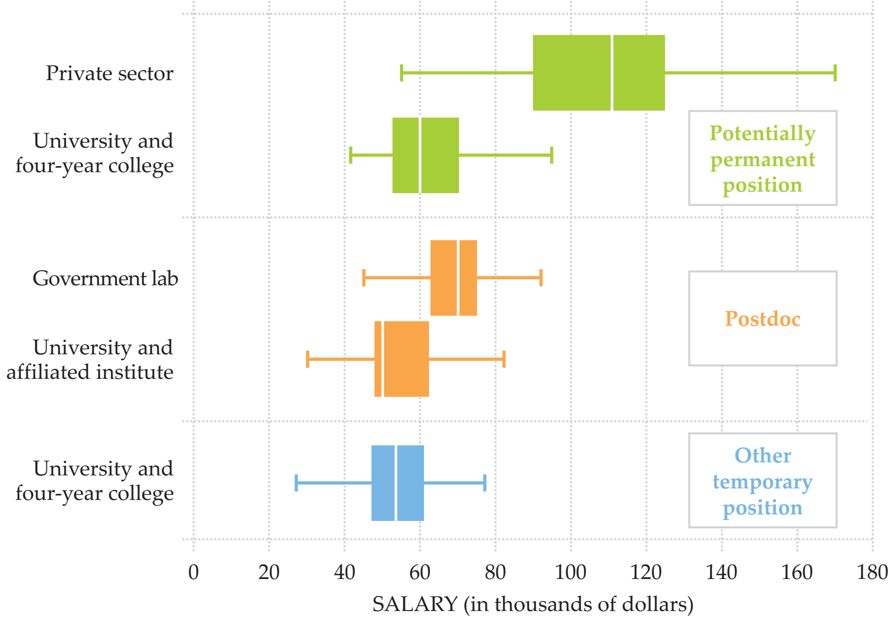


FIGURE 6. MEDIAN STARTING SALARIES for new physics PhDs. For those working in the private sector, it was $110 000 for the combined classes of 2017 and 2018. (American Institute of Physics, Statistical Research Center, PhD Follow-up Survey.)

> “Being employed in industry is so much better than being a graduate student.”

An uncertain future

Predictions by economists of when the economy will recover vary considerably, as do predictions by health-care professionals of when an effective COVID-19 vaccine will be deployed. The timing of both milestones will affect the academic and research environments for physics PhDs.

Compounding the uncertainty, President Trump has suspended various categories of visas through the end of 2020, including the H-1B program. The policy does not apply to the J-1 exchange visitor program used by postdocs and professors or to the OPT program, though some fear those programs may be curtailed through subsequent actions.

But it is clear that physics PhDs are well prepared for a diverse set of career options. Although PhDs will continue to be employed in what was once considered the traditional career path of teaching and research in an academic setting, the majority will continue to find fulfilling employment opportunities in a wide array of other employment sectors and fields.

Regardless of whether they find work directly related to their thesis, in another area of physics, or in a different field, they will be able to leverage their acquired skills and knowledge to obtain professionally challenging, rewarding, and well-compensated positions.

ONLINE RESOURCES

- **Who's Hiring Physics PhDs?**
  www.aip.org/statistics/whos-hiring-physics-phds
  This resource lists the names of employers that hired new physics PhDs into potentially permanent positions by field. It includes job titles, salaries, and skills used.
- **PhD Plus 10 Study**
  www.aip.org/statistics/phd-plus-10
  This resource provides a series of reports exploring the employment of midcareer physics PhDs.
- **Physics Faculty Salary Calculator**
  www.aip.org/statistics/salary-calculator
  This resource lets you explore salaries for physicists by institution type, degree, job title, tenure status, gender, and location.

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2. A. M. Porter et al., *Faculty Job Market in Physics and Astronomy Departments*, American Institute of Physics (2020), tables 5 and 6.
3. PhD Plus 10 Survey, American Institute of Physics (2018), table “Mid-Career PhD Physicists Employed at Four-Year Colleges & Universities.”

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Employer Spotlight

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The Institute of Microengineering in the School of Engineering is soliciting applications for a faculty position at the level of tenure track Assistant Professor in **Integrated Transducers**.

We seek top-level applicants with research interests in the broad area of *integrated* and *miniaturized transducers*, including both *theoretical* and *experimental* aspects. Areas of general interest include *fundamental principles* of sensing and actuating at the *interface* between physical, chemical and biological parameters and electronics (front-end detection). Particular topics of interest include the transducer design, its *micro/nano-fabrication* and *integration* (mechanical, optical, biochemical, magnetic) with the electronics towards scalable (possibly wearable and implantable) smart transducer systems.

Applicants should demonstrate the highest academic excellence with a strong record of high impact publications and show interest in technology transfer and innovation. Candidates with strong academic background, but with few years of experience in industry are welcome.

As a faculty member of the School of Engineering, the successful candidate will be expected to initiate an independent and creative research program and participate in undergraduate and graduate teaching. Internationally competitive salaries, start-up resources, and benefits are offered.

Applications should include a cover letter with a statement of motivation, curriculum vitae, list of publications and patents, and concise statements of research and teaching interests. Applicants should also provide the names and addresses of 3 to 5 referees. Applications must be uploaded in PDF format to the recruitment web site:

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Enquires may be addressed to:
Prof. Philippe Renaud
Search Committee Chair
e-mail: imt-search@epfl.ch

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EPFL is an equal opportunity employer and family friendly university. It is committed to increasing the diversity of its faculty. It strongly encourages women to apply.

Matt Anderson is the Senate Distinguished Associate Professor of Physics at San Diego State University in California.

So you want to HIRE A PROFESSOR!

Matthew E. Anderson

The process for finding a new educator can be daunting, yet nearly every university goes through the same procedural steps. Here's a practical guide from the faculty side.

It's hard to believe that 20 years have passed since I wrote "So you want to be a professor!" (see PHYSICS TODAY, April 2001, page 50). I laid out the procedural steps that one goes through on the way to landing a tenure-track assistant professor position—from reading the ad to signing the offer letter. Much has changed since then, particularly with the shrinking number of tenure-track faculty slots, the rise of video interviews, and the global pandemic of 2020. Nonetheless, I'm still on the physics faculty at San Diego State University. Figure 1 marks the achievement: I'm standing on campus at the same spot I was on 20 years ago in figure 1 of my previous PHYSICS TODAY feature.

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In the article on page 30 of this issue, Omar Magaña-Loaiza provides a compelling upgrade to my original essay, focusing on the hiring process from the applicant's viewpoint. I'm now on the opposite side of the table; here I explain the tenure-track hiring process from the university's perspective. Although it can be extremely varied at different institutions, particularly public and private ones, some threads are common. In most cases, the pressure is not just on the applicant but on the university as well.

FIGURE 1. THE AUTHOR stands in front of Hepner Hall at San Diego State University, his academic home for the past 20 years.

Getting approved

When I joined San Diego State, I was surprised to learn that physics departments around the world are trying to hire new professors every year. In the 2017–18 academic year, for instance, 47% of physics departments in the US hired more than 500 new faculty members. And 45% were planning to hire more faculty members during the next academic year.[1] Even in departments of modest size, a tremendous amount of turnover occurs, driven by retirements, deaths, transfers to other universities, moves to administration, and departures to private industry—often to startups that spring from the professor's research.

If your department wants to hire someone, what steps need to be taken? At the most fundamental level, the chair should get approval from the university, designate a search committee, advertise the position, interview candidates, and make an offer. *Voila*, simple as that. I think not. Each step is vastly challenging and requires effort and commitment.

It's also incredibly time consuming. Hiring a new professor typically takes well over a year and a half—easily stretching from the spring of one year to the autumn of the next, as figure 2 outlines. Getting approval for the hiring is one of the more difficult tasks in the process. The first problem is money. Add up the costs and you quickly reach a few million dollars—enough for startup costs and the likely salary for at least 10 years. Despite record numbers of enrollment, budgets seem to magically shrink each year. What's more, some universities have begun replacing tenure-track instructors and administrators with part-time ones.[2–4]

Nonetheless, several avenues are available for securing the capital. Endowed professorships are one option, but they're atypical. Targeted hires—usually from elite universities—are another; funded by already designated money, they are made simply to bring in the best person for a specific research area. But they also are rare. Here I focus on the much more common process: open search.

Assuming that the budget is intact and the highest levels of administration are motivated to hire, who has the final say? The provost's office typically gives the official approval. It usually announces a fiscal budget or projection that includes a limited number of slots for tenure-track lines and might allocate a certain number to each college in the university. College deans are in charge of how they earmark their allotment. A request for proposal is sent to department chairs when a dean is ready to accept requests for new hires.

The departments submit their best arguments for each position, including the area and level—usually an assistant professor. For physics departments, they should also note whether they want an experimentalist or a theorist. The proposal often sets off a vigorous discussion among faculty members about the wants and needs of the department as a whole. They tend to unite, realizing that getting approved for a position is critical to their success and requires their combined best effort.

So how do you convince the dean that your department deserves a hire? Critical need is one argument. But that usually carries little weight. Departments generally undertake a review every five years, and it includes statements from outside observers—usually professors from other universities—brought in to evaluate the structure and inner workings. As one dean relayed to me, such reviews almost always contain the phrase, "Aggressive and strategic hiring in this department over the next five years is the only way to avoid imminent implosion." Apparently, the statement is true for every single department. And it effectively puts everyone on a level playing field.

Retirement replacement is not usually the most convincing argument. If a professor is approaching retirement, so the reasoning goes, their research is winding down—an indication that it is no longer as fruitful as it once was and the professor is now teaching more classes than their colleagues. You cannot hire a tenure-track professor to replace the retiree who was teaching multiple classes; in recent years administrations have pushed to manage those classes with part-time instructors.

Much more persuasive is to adopt a plan of excellence for the department. To that end, you will need to demonstrate to the dean how the new hire will complement the department's existing research strengths and expand its capabilities. Hot research areas are key. The dean wants to see how quickly the new hire can contribute to the department's research stature by bringing in large grants and publishing influential papers. A

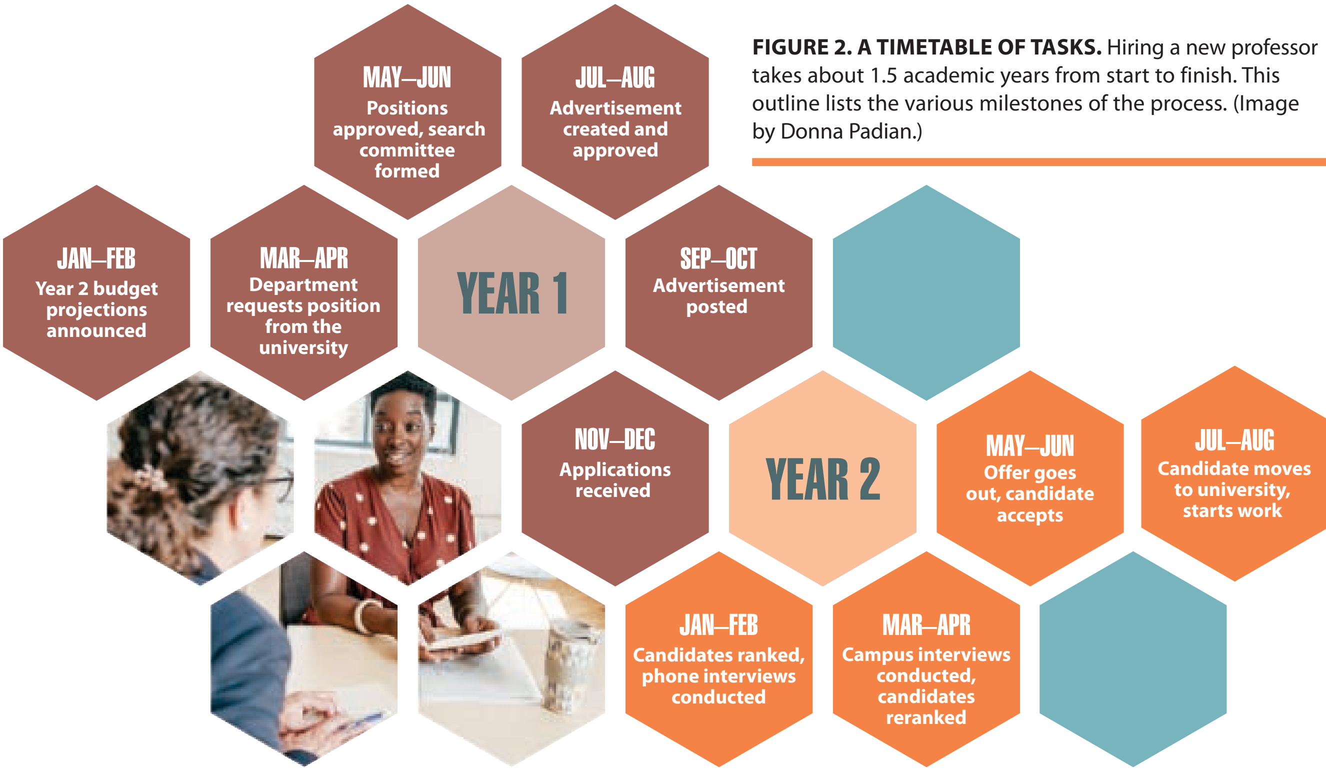

FIGURE 2. A TIMETABLE OF TASKS. Hiring a new professor takes about 1.5 academic years from start to finish. This outline lists the various milestones of the process. (Image by Donna Padian.)

new hire's ability to work within an existing framework and leverage existing equipment and faculty talent are also important arguments.

If a department proposes instead to expand into research areas not currently studied by any of its faculty, solid reasoning must support it. You might argue, for instance, that the rapid increase in scientific discovery and funding in the new research area necessitates that your university get in the game quickly. Then demonstrate how the new hire would complement the research of other principal investigators inside and outside the department.

Whichever approach you pursue, the dean will need answers to other questions. Is there a lab and office space available for a new hire? How much startup money is required? Who will help mentor the new hire on the road to tenure? Interacting with the dean's office on such issues, particularly startup costs, can drag on for a while, so be patient. If you do receive approval, congratulations! The first critical hurdle is over. Take some time to celebrate—like 30 seconds—because now the real work begins.

The search

The first task, usually designated by the department chair, is to form a search committee. It consists of three to five usually tenured professors; some may be from other departments, depending on the nature of the search. The department chair will also designate a committee chair, who will be responsible for setting meeting dates, overseeing production of the advertisement, addressing political bias in the committee, and specifying target dates for the application deadlines, phone interviews, campus visits, and voting decisions. The designated person will serve as a liaison between the committee, the department, and the dean. The committee chair holds incredible power and responsibility, so the department chair should choose wisely.

One surprisingly difficult task is putting together the advertisement. Although the general language—the position, research field, experience, and start date—may be straightforward, the ad itself typically needs to follow strict rules, both in the construction of the language and in its placement. For instance, at many state institutions, stringent guidelines ensure that diversity, equity, and equal opportunity goals are met. The language in the ad must be routed through a specific unit in the university for approval, a process that can sometimes take a long time. Where the ad is placed could also matter; some institutions require that it be published in an international journal.

The nature of the position will have already received approval from the dean. Although departments do hire senior personnel regularly, the most common hire is for a tenure-track assistant professor. For that level, the ad will state what the candidate's experience should include, such as a PhD, which is always required; a postdoc position, which is almost always required; and a second postdoc position, which nowadays is quite common. It will ask for a full curriculum vitae, statements about research and teaching, and three letters of recommendation.

The ad should include a date for when the evaluation of candidates will begin—candidates should read that as a due date. It will also include instructions for how applications should be submitted, typically by email or through a website, so be sure to specify the email or URL address. It is a good idea to inform candidates that they are not to contact members of the department directly, as that usually violates the university's protocol. Faculty will still receive inquiries from candidates directly, and those should be forwarded to the search committee chair, who will likely not reply.

An important logistic aspect of running a search is dealing with the applications themselves. In the olden days, applications were hard-copy printouts mailed to the department. An administrative assistant stored them in a large filing cabinet, and search committee members would review them by checking out files. It was, in retrospect, a bit ridiculous. Nowadays, fortunately, everything is electronic. In fact, your university most likely has a service, such as Interfolio, for receiving applications. It alleviates the burden of organizing them. And if your campus is not using such a service, I highly recommend it.

Weeding people out

After the due date, the committee begins to review the applications. That is a cumbersome task, as the number is routinely 200 or more. The committee's goal is to whittle that down to a number that could be discussed in depth. The first step is to triage the group. The chair will usually assign a subset to each committee member to narrow down the total. Obvious disqualifications help: no PhD, PhD in the wrong field—which happens more than you would think—few publications, and insufficient experience. Those deficiencies remove some 20% of the applicants.

A dividing line to remove others typically centers around number of publications. In search committees I have been a part of, the line is often around 10. Below that number, applicants are rejected. Above it, they stay in the pool. That cut removes the bulk, perhaps another 60%. So, if we started with 200 candidates, we're left with 40 still viable. That's a decent target number for the committee to discuss.

At this stage of the search, the goal changes. Whereas the previous step was designed to weed people out, this next step is to weed them in. The committee wants to identify the strongest candidates. Each member therefore reviews the 40 in depth. They will be using some obvious metrics: publications, grants or grant experience, the strength of the research plan, and teaching philosophy.

But as I stated in my 2001 Physics Today article, postdoctoral experience is the key stepping-stone to landing a tenure-track position, and committees will be swayed by candidates coming from the best research environments. Less obvious metrics include their publication consistency, journal impact factors, and revealing statements—"This person is something special," for instance—found in recommendation letters. After independently reviewing the candidates, committee members reconvene to discuss them collectively. The goal is to identify top contenders, 12 max, who will be asked to give remote interviews either by phone or videoconference. That step can be somewhat contentious, as committee members start to favor certain candidates who don't always make the cut. It is frequently easy to identify the top six candidates; the next six are tougher to find. It may be tempting to interview more than a dozen, but that is ill-advised; each interview takes an hour and is thoroughly exhausting for all parties involved.

Yet the remote interviews are extremely telling. Suddenly the person that you have been evaluating on paper is a real face, a real voice, with real ideas and real drive. Your impressions of the candidates will change after the remote interview, sometimes in dramatic ways. More than once, some of my favorite candidates have fallen out of contention, while others have risen dramatically. The remote interview allows you to dig into their real interests and the clever ideas they might have tucked away for future grant proposals. It also provides the first real glimpse of their personality and allows the committee to consider more personal concerns. Is this someone with whom I could collaborate? Is this someone I would feel comfortable putting in front of students or running a research lab? Does this person convey a sense of enthusiasm so critical for the profession?

It is vital that committee members be aware of and resist their own implicit bias—the notion that we treat others differently on a subconscious level.[5] That behavior, of course, is present in all areas of hiring, but particularly so in the physical sciences,[6] where the historical maleness and whiteness of the academic population are apparent. Scientists tend to think that they can be purely objective and evaluate candidates on their merits alone and that they are not swayed by intangible qualities such as gender, race, or socioeconomic standing. Yet study after study has shown that is not the case.[7]

Intentional or not, the tendency of people is to hire those who look like themselves, a practice that produces homogeneous viewpoints and stifles creative dialog. It is morally imperative, and often legally required, to properly train committee members in how to avoid the pitfalls of implicit bias. Your university undoubtedly has a human resources department that can provide that training. Diversity, equity, and equal representation in hiring is fundamentally important to the future of science. If you want to attract the best minds to our profession, both in the student population and in the professors you hire, you need to expand your phase space to find them. Figure 3 shows Lyuba Kuznetsova, an assistant professor who joined the San Diego State physics department seven years ago.

Campus interviews

Almost always, some candidates check all the boxes, rise well above the competition, and inspire the committee. More than once, I have left a meeting thinking, "We have to get this person." Hopefully, more than one candidate makes you feel that way, because the next step is campus interviews, and the typical number that you can bring in is four—usually a hard limit imposed by the dean.

The top four contenders from the committee's list are invited to campus for a visit, and a series of difficult calendar gymnastics begins. Once everything is set, each candidate performs for two days straight, meeting every faculty member, the committee, the chair, and the dean. They give a colloquium, deliver a closed-door research talk, interact with students, have lunches and dinners with faculty, and wonder whether the university has good coffee. (It does!)

From the committee side of the table, the campus visit is everything. Candidates are invited because they looked good on paper and were great during the remote interview, and the committee suspects that they would be a good fit. But members are not really sure until the campus visit. No single particular aspect of the visit is critical; rather, they all are. Every moment conveys important information, and it is often in the more relaxed downtime that elements of truth emerge. I remember interviewing one candidate, and casually over coffee I asked about a specific lab experience they had mentioned on their CV. The candidate revealed that, in fact, they had only been in charge of running BNC cables from one room to another. Uh, thanks but no. Yet another candidate, whom I had in my mind ranked fourth, suddenly hit it off incredibly well with the students, and I changed my mind and ranked them first.

It's difficult to convey exactly what departments look for during those visits. But if one overarching question pervades

EVA ANDERSON

FIGURE 3. LYUBA KUZNETSOVA lectures during a class at San Diego State University. I was on the search committee that hired her in 2013. She received tenure this year.

the interview process, it would be this: Which of our candidates is most likely to get tenure? We don't want to waste anyone's time going through the selection process if they are not going to get tenure. Indeed, if any doubt about one of the candidates arises, they will be removed from contention.

Universities are critically interested in two things: money and prestige. Will this candidate be able to bring in grant money? Check. Will they elevate the prestige of the university through publications, invited talks, and scholarship? Check. Will they be able to teach classes reasonably well? Check. Will they be a good colleague? Check.

Making an offer

Once all the check marks are in place, the committee reconvenes and ranks the top four candidates. They then present their findings to the chair and the entire department. The process of negotiating with candidate number one ensues. The chair or someone from the dean's office usually reaches out with an acceptance offer by phone. They will mention the salary, startup funds, lab space, and teaching load. Although all of that could be considered negotiable, in practice little of it actually is. Usually, especially at state institutions, the dean's hands are tied on salary. And the space is already designated.

The most wiggle room probably exists within the startup funds and teaching load. The dean will want to know what a new professor really needs to start a research program and whether they could survive when those funds are spread over two years. Most universities will try hard to keep the teaching load light in the first few years because the new hire will be building a lab and launching a research program. Remember, the dean also wants the new person to get tenure, and they know that a high teaching load can impede one's progress.

The chair will need to pressure the dean's office to get the offer to candidate number one as quickly as possible because, unfortunately, there is a high probability they will say no. Often, that's because they are being wooed by other universities. I have been in many search committee meetings in which we recognize that our top candidate may accept another institution's offer. If they do turn us down, we move on to candidate number two as quickly as possible, and the offer process starts all over. All the while, the clock keeps ticking, and people weigh offers from other universities, sometimes getting snatched up before the dean can get to them. It can be an exasperating experience. And sometimes searches simply fail. Convincing the dean to keep the search open for yet another year is, shall we say, challenging.

But more often than not, the process reaches a cathartic conclusion. The university is still interested in a candidate, and the candidate is still interested in the university. It feels right. The dean makes an offer, and the candidate accepts. Now it really is time to celebrate.

After months of wild oscillations, the hiring process finally settles down into a stable equilibrium. The candidate joins the department, and after a few months you don't even remember the other candidates who applied. The person you were looking for all along is exactly the person you found. What was all the fuss about anyway?

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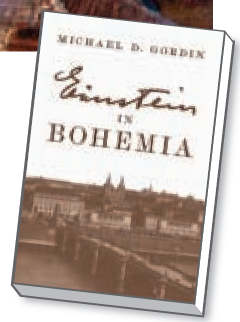
An early 20th-century postcard of Old Town, Prague.

Albert Einstein's year in Prague

Einstein in Bohemia

Michael D. Gordin

Princeton U. Press, 2020. $29.95



Albert Einstein lived in Prague from April 1911 through July 1912, during which time he occupied the chair in theoretical physics at the German University. Perhaps because of the brevity of his tenure in Prague, most of Einstein's biographers give those 16 months short shrift. But it was a critical time in Einstein's life both professionally and personally, not only because the appointment in Prague was his first as a full professor. Giving Einstein's Prague sojourn the full attention it merits is the aim of *Einstein in Bohemia*, the new book by Princeton historian of science Michael Gordin.

It was in Prague in 1911 that Einstein resumed focused work on what would emerge four years later as the general theory of relativity. Einstein had known since 1907 that the equivalence principle—which asserts that gravitational forces are indistinguishable from the effects of an accelerated frame of reference—entailed both a gravitational redshift and the bending of light in a gravitational field. When he returned to those ideas with a more careful exploration of the consequences of coupling a static gravitational field with a nonstatic electromagnetic field, he realized for the first time that the bending of light could be tested not only on a laboratory scale, where the tiny magnitude of the effect makes measurement almost impossible, but also on an astronomical scale, where the effect should easily be observable.

That insight eventually led to Arthur Eddington's confirmation of the light-bending effect with his 1919 eclipse observations and turned Einstein into an international star. Einstein soon recognized the limitations of the so-called static theory, and he was off and running with a clear understanding that Lorentz transformations would not suffice in a fully general theory of relativity. Thus, he was primed to begin what proved to be a crucial collaboration with his mathematician friend Marcel Grossmann when he returned to Zurich in 1912.

Two personal situations came to a head during the months in Prague. First, Einstein's marriage to Mileva Marić, which had been strained for several years, continued to deteriorate. Gordin speculates that the cultural and political situation in Prague played a role in the marital troubles. Einstein moved mainly in a German professional environment and a Jewish cultural milieu in Prague. One example of that was his occasional participation in Berta Fanta's culturally important, weekly salon that drew other prominent German-Jewish intellectuals and writers, such as Max Brod, Franz Kafka, and Samuel Hugo Bergman.

Mileva, a Serbian Catholic, had many friends in the less ethnically charged atmosphere of Zurich; Gordin suggests that she may have felt out of place in Prague, in part due to tensions between Czechs and Serbians. In any case, there is abundant evidence that Mileva was lonely and unhappy in Prague. Albert and Mileva formally separated two years after they returned to Zurich, and the marriage ended in a bitter divorce in 1919.

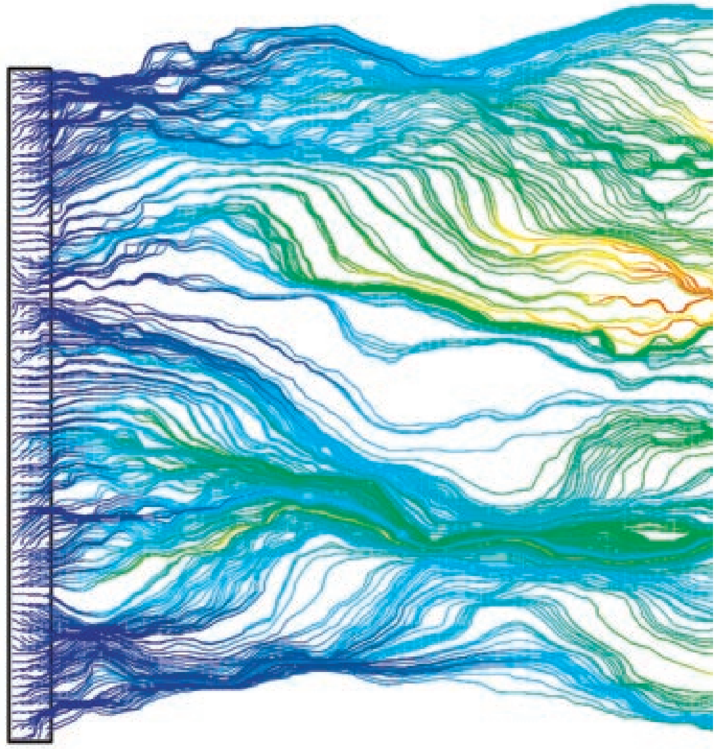
The second situation was that Einstein began to connect more seriously with his Jewish identity. Having turned away from his religious upbringing in his teens, Einstein thought of himself in his Swiss years as someone with no religious affiliation. But in Prague, he found himself in a rich and vibrant Jewish cultural space that included many prominent figures in the Zionist movement. One influential friend was Bergman, an early and ardent member of the Zionist student group the Bar-Kochba Association who later became the founder of the Hebrew National Library in Jerusalem and dean of the Hebrew University. Einstein never supported the establishment of a Jewish national state in Palestine, but within a few years of leaving Prague, he became a prominent supporter of cultural Zionism, as demonstrated by his 1921 trip to the US to raise money for the establishment of the Hebrew University.

Gordin tells the story of Einstein in Prague in much greater detail than any previous writer has done, and he does so with subtlety and nuance. But in order to situate and appreciate this moment in Einstein's life, Gordin does much more than narrate Einstein's story. Readers learn about Prague as the capital of the Holy Roman Empire when Tycho Brahe served as court astronomer to Emperor Rudolf II and Johannes Kepler served as Brahe's assistant. We follow the long and complicated history of Bohemia, the larger region around Prague, and its relations with its national and imperial neighbors. We learn about the religious and ethnic history of Prague and the surrounding region, as the balances shift among the Czech, German, and Jewish inhabitants. Gordin tracks the effects of those demographic developments on politics, which explains, among other things, why during Einstein's time in Prague there was both a German-speaking and a Czech-speaking university.

We learn about philosophy in Prague, from neo-Aristotelian philosopher of psychology Franz Brentano to physicist-philosopher Philipp Frank, a prominent representative of the group known as the Vienna Circle and an advocate for its logical empiricist philosophy of science. Einstein strongly recommended Frank as his successor in Prague, and Frank went on to become one of Einstein's most important biographers after they resumed their acquaintance as émigrés in the US in the 1930s. And we learn about the place the theory of relativity occupied in the charged intellectual and political space of Eastern Europe and the Soviet Union after World War II. By then Czech-Jewish communist and philosopher of science Arnošt Kolman had emerged as a prominent arbiter of the interpretation of relativity in the communist East.

Gordin's *Einstein in Bohemia* affords us a refreshingly different kind of perspective on Einstein in context. The book treats its location in space and time—Prague in 1911 and 1912—not merely as a backdrop, but as an integral part of the drama.

Don Howard
University of Notre Dame
Notre Dame, Indiana



WALT MCNAB

A new favorite textbook on stochastic analysis

Applied Stochastic Analysis
Weinan E, Tiejun Li, and Eric Vanden-Eijnden
American Mathematical Society, 2019. $85.00

The textbook *Applied Stochastic Analysis* by Weinan E, Tiejun Li, and Eric Vanden-Eijnden is a well-thought-out treatment of a range of ideas central to stochastic analysis. The authors, noted experts in the field, use their expertise to show the reader the most important relevant mathematics research. *Applied Stochastic Analysis* might occupy a place on one's bookshelf somewhere near J. R. Norris's now-classic 1997 book *Markov Chains*.

Stochastic analysis has been remarkably successful at revealing the ways in which various random phenomena tend to organize. Energy analyses, limit theorems, Markovian invariant distributions, ergodic measures, and statistical mechanics all provide physicists with powerful tools for understanding the large-scale behavior of microscopically defined random models. *Applied Stochastic Analysis* covers those topics with clear, succinct, and complete proofs when possible and points to standard references for more involved proofs.

The book is divided into two broad sections. The first, Fundamentals, covers topics such as random variables, limit theorems, Markov chains, Monte Carlo methods, stochastic processes, and stochastic differential equations. The second section, Advanced Topics, has chapters on path integrals, random fields, rare events, statistical mechanics, and chemical reaction kinetics.

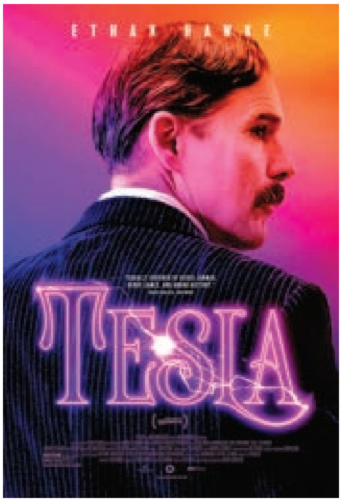
Most of the applied material promised in the title is contained in the second half of the book, which is oriented toward physical and chemical systems. Theory and applications have had a long interplay in the study of such systems. The authors review some basic results in statistical physics and chemical kinetics to give the reader an understanding of how stochastic tools can lead to meaningful conclusions and descriptions. Almost all readers will find a novel calculation or approach in the material.

One revealing perspective of a given graduate-level text is the last chapter, in which the authors usually open the throttle on a subject of their interest. In *Applied Stochastic Analysis*, the last chapter is an introduction to chemical kinetics. E, Li, and Vanden-Eijnden introduce the major ways that the formalism of stochastic processes can be used to create macroscopic dynamical models of interacting chemicals. The authors cover macroscopic ordinary differential equation models and then develop Poisson-driven stochastic differential equations to model individual molecule counts before moving on to cover diffusion limits. They then bring the theory of stationary distributions to bear, followed by a multiscale analysis. The time spent understanding the entire presentation is well worth it. Stewart Ethier and Thomas Kurtz's definitive 1986 book *Markov Processes: Characterization and Convergence* develops a lot of machinery used in this chapter; *Applied Stochastic Analysis* shows why that machinery is important.

This book gives students of stochastics or mathematical physics a wonderfully solid starting point and is likely to be a favorite among physicists. By the end of it, readers should have a solid understanding of core tools in stochastic analysis.

Richard Sowers
University of Illinois
Urbana

NEW BOOKS & MEDIA



Tesla

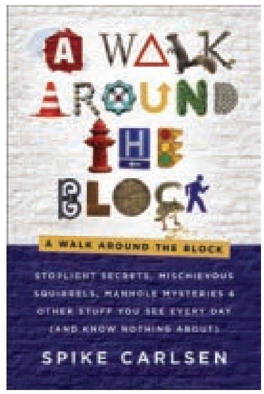
Michael Almereyda (writer, director, and producer)
IFC Films, 2020

Starring Ethan Hawke as the titular character, *Tesla* centers on the conflict between inventors Nikola Tesla and Thomas Edison over which electricity supply system should prevail: AC or DC? Although nominally a biopic, director Michael Almereyda's version is decidedly quirky, with J. P. Morgan's daughter Anne (Eve Hewson) using a laptop to pull up Google search results on Tesla and Hawke as Tesla at one point singing the Tears for Fears song "Everybody Wants to Rule the World." Winner of the Alfred P. Sloan Feature Film Prize at the 2020 Sundance Film Festival, *Tesla* is an intriguing take on the enigmatic inventor. –CC

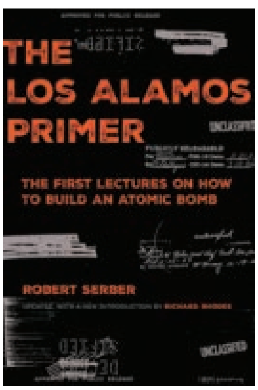
A Walk Around the Block

Stoplight Secrets, Mischievous Squirrels, Manhole Mysteries and Other Stuff You See Every Day (and Know Nothing About)

Spike Carlsen
HarperOne/HarperCollins, 2020. $24.99



Inspired by frozen pipes one winter to learn where the water in his home comes from, author Spike Carlsen embarked on a quest to learn about the world outside his front door. Carlsen, a former carpenter, has since descended into sewers, toured electricity-generating plants and recycling centers, visited a US Postal Service processing and distribution center, and performed numerous other investigations into such everyday things as bicycles and asphalt. A mix of history, technology, personal profiles, and even the etymology of terms, including "fire plug" and "Bluetooth," *A Walk Around the Block* is an entertaining and informative read aimed at a general audience. –CC



The Los Alamos Primer

The First Lectures on How to Build an Atomic Bomb

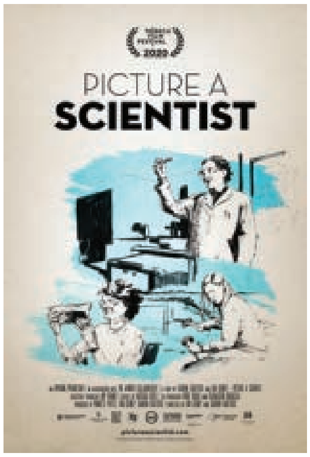
Robert Serber
U. California Press, 2020. $17.95 (paper)

In 1943, at the newly constructed Los Alamos Laboratory, physicist Robert Serber presented a series of lectures on the cutting-edge physics and engineering required to build a nuclear weapon. Fellow physicist Edward Condon took notes, which became known as *The Los Alamos Primer*. Classified until 1965, the information was first published in book form by the University of California Press in 1992, along with extensive annotations by Serber and an introduction by Pulitzer Prize–winning historian Richard Rhodes. Almost three decades later, this seminal work has been updated and reissued in paperback, with a new introduction by Rhodes. –CC

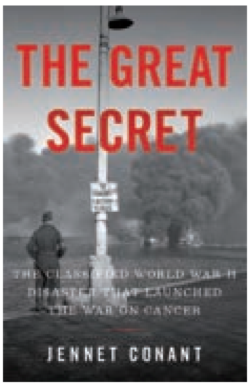
Picture a Scientist

Sharon Shattuck and Ian Cheney

Uprising Production/Wonder Collaborative, 2020.



Most image searches for “scientist” return variations on the same theme: a man in a white lab coat. This engaging documentary tells the story of three women who break that mold. Molecular biologist Nancy Hopkins, chemist Raychelle Burks, and geologist Jane Willenbring share the joy of their scientific work and the problems they have encountered as women in male-dominated fields. The three are candid and powerful as they describe their experiences of discrimination. The most painful story is Willenbring’s; her graduate adviser viciously harassed her while doing fieldwork in the Antarctic in the early 2000s and did not face consequences for nearly two decades. Visit http://pictureascientist.com for more information on viewings and screenings. —MB



The Great Secret

The Classified World War II Disaster that Launched the War on Cancer

Jennet Conant

W. W. Norton, 2020. $27.95

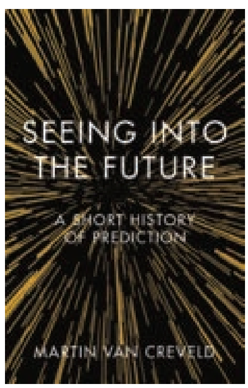
On 2 December 1943, Germany launched a devastating air attack on Allied forces at the port of Bari, Italy. Among the vessels destroyed was an American ship that carried a secret load of mustard gas; the deadly chemical poisoned hundreds of people. Although British and American officials initially denied the presence of mustard gas, whose use was barred by the Geneva Protocol, Lieutenant Colonel Stewart Francis Alexander, an American doctor and chemical-weapons expert, discovered the truth. *The Great Secret* tells the riveting story of Alexander’s investigation of the Bari incident, his revelatory research regarding mustard gas’s destruction of white blood cells and potential use in chemotherapy, and the efforts to act on those findings by American oncologist Cornelius Rhoads, who in 1945 became director of one of the most advanced cancer centers in the world, the Sloan Kettering Institute. —CC

Seeing into the Future

A Short History of Prediction

Martin van Creveld

Reaktion Books, 2020. $24.00



What will the weather be like tomorrow, next week, next year? Will there be another war, famine, global pandemic? Will the stock market rise or fall? In *Seeing into the Future*, military historian and theorist Martin van Creveld provides an overview of some of the myriad methods humans have devised over the millennia to foretell what is to come, from the ancients’ use of prophecy and astrology to today’s mathematical algorithms. In addition to delving into when, where, why, and how those techniques originated, he discusses such questions as why prediction is so difficult, whether modern humans are any better at making predictions than our ancestors were, and whether knowing the future is a good thing. —CC PT

Focus on materials, semiconductors, vacuum, and cryogenics

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

Quiet, dry vacuum pumps

The HiScroll models from Pfeiffer Vacuum's new range of scroll pumps are oil-free, hermetically sealed vacuum pumps with high nominal pumping speeds of 6–20 m^3/h. The compact devices offer quiet, low-vibration operation with less than 47 dB(A) and less than 42 dB(A) in standby mode. The two-stage gas ballast increases the pumps' water vapor tolerance and helps avoid condensation in the vacuum. Active temperature control ensures optimal cooling and the lowest noise emissions in their class, according to Pfeiffer Vacuum. The powerful motor—up to 15% more efficient than conventional drives, the company claims—ensures optimal performance while also keeping temperatures low. The pumps are suitable for many applications in R&D, analytics, biomedicine, and pharmaceuticals. They can be used in mass spectrometry, electron microscopy, surface analysis, accelerators, laboratory applications, the semiconductor industry, coating processes, and gas recovery. ***Pfeiffer Vacuum Inc***, *24 Trafalgar Sq, Nashua, NH 03063, www.pfeiffer-vacuum.com*

Compact sensor head

With its advanced space-saving design, the Intlvac Multi Crystal Sensor Head can fit through a ConFlat flange measuring 1–2¾ inches. The unit is compatible with existing thin-film deposition controllers from Inficon, Sigma, and Maxtech, which reduces costs. The sensor head can be programmed to operate fully automated through the input–output port. Necessary crystal changes can be signaled via users' thin-film monitor or controllers; a load option on the sensor controller allows for manual operation. Crystal sensors can be replaced as necessary during a deposition run. The unit is suitable for use in precision organic LED and molecular-beam epitaxy applications. ***Intlvac Thin Film Corporation***, *1401 Duff Dr, Unit 600, Fort Collins, CO 80524, https://intlvac.com*

Superconducting magnet system with diamond windows

Cryomagnetics' C-Mag Vari-7S-Optical, a 7-tesla split-pair superconducting magnet system, is cryogen-free: A Sumitomo 1.0 W single-pulse tube cryocooler conductively cools the magnet, the cryostat, and a secondary closed-loop helium circuit used to control the sample temperature. Optical access—both axial and perpendicular to the magnetic axis—features diamond windows for measuring over a wide spectral range. A bottom-mounted window allows for access to the *z*-axis. The system features an f2.4 axial and an f3.1 perpendicular optical path, a 38 mm i.d. sample space less than 1.6–300 K, and ±0.3% homogeneity over 1 cm diameter of spherical volume. The cryostat cradle is designed for precision alignment on optical tables. ***Cryomagnetics Inc***, *1006 Alvin Weinberg Dr, Oak Ridge, TN 37830, www.cryomagnetics.com*

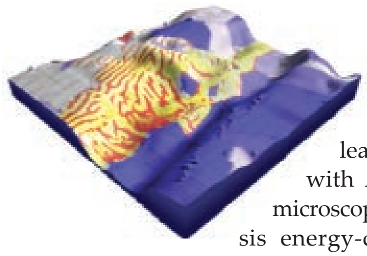
Water vapor desorption system

The VB series vacuum chamber bakeout package now available from RBD Instruments combines the company's BC-3 controller and IRB-600 shortwave IR emitter. According to RBD, it effectively reduces water vapor in vacuum chambers. Users are able to set the heating power and bakeout time. Additional features include thermocouple feedback to regulate temperature and vacuum interlock feedback to maintain vacuum chamber pressure. The IRB-600 emitter provides 600 W of IR power in a small form factor. The BC-3 controller can drive up to two IRB-600 emitters or heating tapes. The VB series is easy to operate and a safe alternative to the Variac controllers, which are no longer allowed in many government laboratories. ***RBD Instruments Inc***, *2437 NE Twin Knolls Dr, Ste 2, Bend, OR 97701, www.rbdinstruments.com*

Turbomolecular pumps

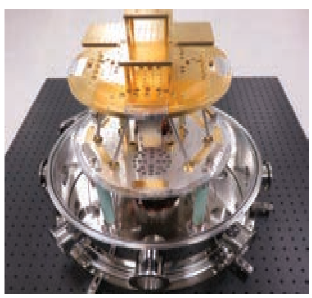
Edwards has launched two larger variants of its nEXT mechanical turbomolecular pump range: the nEXT730 and nEXT930, with pumping speeds over 700 l/s and 900 l/s for nitrogen. They are designed to make the range suitable for new applications, including specialty coating, heat treatment, furnaces, electron-beam welding, ion implantation, degassing, and cylinder evacuation. The pumps are rated IP54 as standard to further support those applications. According to the company, the nEXT730 and nEXT930 pumps offer improved performance and cycle times and reduced operational pressures. They function in any orientation and are easy to install because of their compact design and integrated controller. Their compatibility with Edwards TIC and TAG controllers and Support PC software for monitoring, configuration, and control facilitates their integration into new or existing vacuum systems. ***Edwards Ltd***, *Innovation Dr, Burgess Hill, West Sussex, RH15 9TW, UK, www.edwardsvacuum.com*

Software for correlative imaging



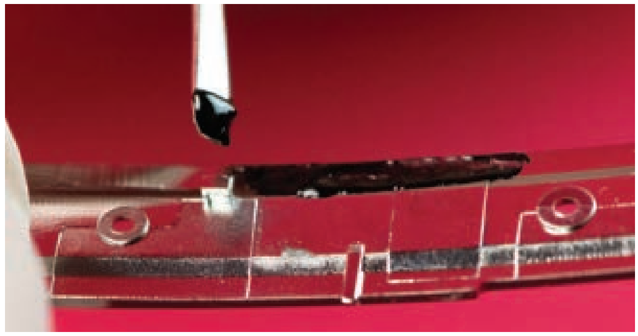
Oxford Instruments Asylum Research has released its Relate software for correlative imaging with Asylum Research's electron and atomic force microscopes (AFMs) and Oxford Instruments' NanoAnalysis energy-dispersive-spectroscopy (EDS) and electron-backscatter-diffraction (EBSD) detectors. According to the company, the software simplifies the correlation, visualization, and analysis of the numerous image data types generated by those techniques. It uses the combined information they provide for applications in semiconductors, metallurgy, energy storage, and generation materials. The Relate software works by importing data files in the native formats used by the AFMs and the EDS and EBSD detectors. It lets users correlate data from the same region of interest and prepare composite 2D and 3D images. Unlike simplistic image overlays, Relate maintains the underlying data structure of each layer, which enables not just visualization but true quantitative analysis of the combined data sets. ***Oxford Instruments America Inc***, *300 Baker Ave, Ste 150, Concord, MA 01742, www.oxinst.com*

Low-vibration cryogenic probe station

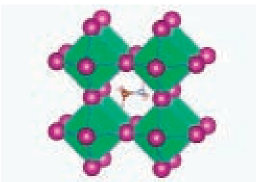


According to High Precision Devices, its cryogen-free model 125 probe station can test silicon chips at 4 K. It does so by combining the benefits of low-vibration, liquid-helium dip probes and cryogen-free systems that rarely achieve such low temperatures when used alone. When using electrical probes to test chip samples, it is important to reduce vibration levels between the probe and the device under test. The model 125 does that by mechanically isolating the experimental space and insulating it from the cryocooler's impulses. The probe station can be configured to host either individual chips or whole wafers. Other options include translations up to the full diameter of the wafer, window shutters, coaxial cables, and sample magnets. Its low vibration level makes the model 125 suitable for scanning probe microscopy research, including SQUID studies and atomic force and scanning tunneling microscopy, and for superconducting logic functions, metrology, and quantum sensing and communication. ***High Precision Devices Inc***, *4601 Nautilus Ct S, Ste 100, Boulder, CO 80301, https://hpd-online.com*

Medical-grade epoxy



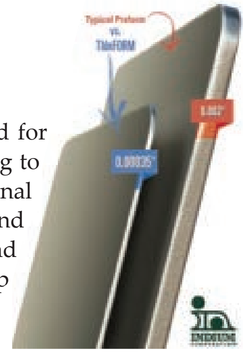
Master Bond's EP42HT-4AOMed Black two-part epoxy offers thermal conductivity and electrical insulation. Created for medical-device manufacturing, it is biocompatible and noncytotoxic, passes USP class VI and ISO 10993-5 certifications, and withstands aggressive chemical sterilants, radiation, and repeated cycles of autoclaving. EP42HT-4AOMed Black offers cryogenic serviceability and heat resistance. It has a service temperature range of 4–477.6 K, thermal conductivity of 1.30–1.44 W/m·K, and volume resistivity greater than 10^{14} Ω-cm. A filler in the epoxy system contributes to its high strength profile and dimensional stability. Once mixed, it has good flow properties and is suitable for bonding, sealing, and coating applications. It bonds well to metals, composites, glass, ceramics, rubbers, and plastics. The epoxy can cure at room temperature, but the process can be sped up through the application of heat. ***Master Bond Inc****, 154 Hobart St, Hackensack, NJ 07601-3922, www.masterbond.com*



Perovskites for optoelectronic applications

Goodfellow now offers a new range of perovskites, a group of materials that, according to the company, demonstrate excellent potential for optoelectronic applications. Many perovskites occur as oxides (ABO_3), where A and B are typically metal cations. Due to their lattice structures, those materials are characterized by properties such as superconductivity, magnetoresistance, piezoelectricity, and dielectric and pyroelectric behavior. They are therefore good candidates for multilayer capacitors, including fuel cells, solar cells, sensors, and electric batteries. They may also be suitable for use in next-generation display screens, LEDs, memory devices such as RAM, and high-temperature superconductors. Goodfellow's perovskite range includes powder and solid forms of barium titanate, bismuth aluminate, bismuth titanium oxide, calcium titanate, copper tungsten oxide, lithium titanate, lead titanium oxide, lanthanum titanate, and samarium ferrite. ***Goodfellow Corporation****, 125 Hookstown Grade Rd, Coraopolis, PA 15108, www.goodfellow.com*

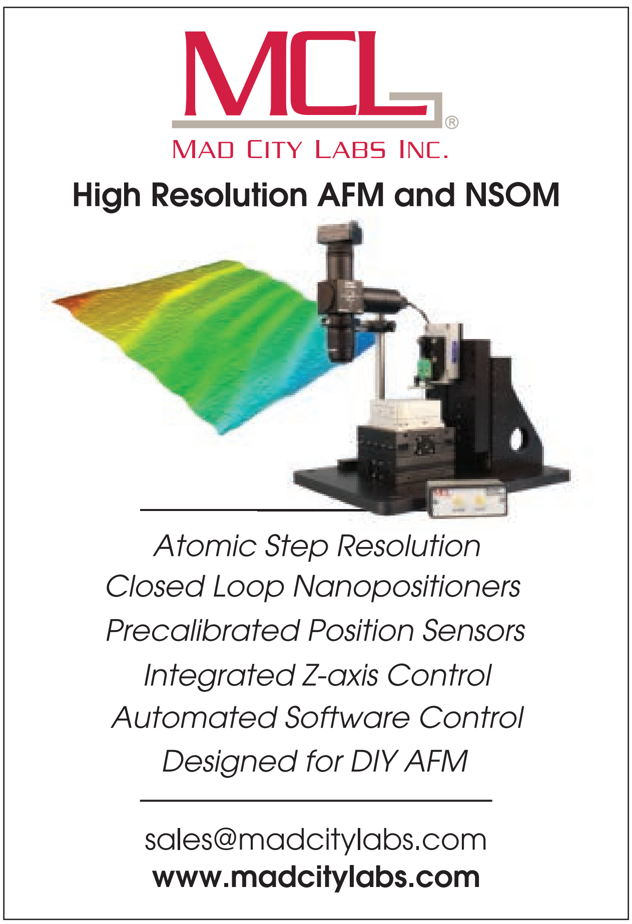
Ultrathin gold–tin preform

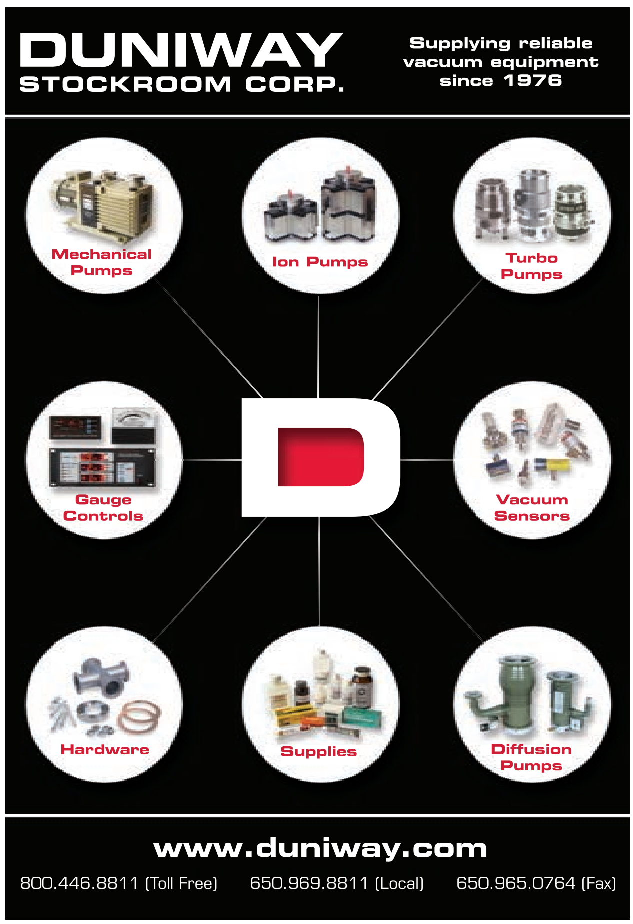


Indium has expanded its portfolio of precision preforms with an ultrathin gold–tin layer designed for semiconductor-laser manufacturing where thermal management has become a challenge. According to the company, the AuLTRA ThInFORMS, which are just 8.89 μm thick, improve the overall operational efficiency of high-output lasers by helping to combat common issues such as poor thermal transfer and shorting. The ultrathin preform reduces bond-line thickness and thus improves thermal transfer and increases the longevity and performance of the device. Reduced solder volume inhibits wicking up the die and minimizes the risk of shorting. ***Indium Corporation***, *34 Robinson Rd, Clinton, NY 13323, www.indium.com*

Cost-effective EBSD detector

Bruker claims that its new e-Flash XS is the first electron backscatter diffraction (EBSD) detector to enable the characterization of the microstructure of crystalline materials in tabletop and other small, entry-level scanning electron microscopes (SEMs) in research and industry. The e-Flash XS is the smallest and lightest EBSD detector currently available, but it offers excellent performance, according to the company. That makes the instrument suitable for routine EBSD analysis in applications that do not require the use of high-end field-emission SEMs. The e-Flash XS is powered by a state-of-the-art CMOS camera with 720 × 540 pixels of native resolution. Coupled with an innovative optical system for maximum light transmission and a high-performance, user-replaceable phosphor screen, the camera can acquire patterns at a speed of up to 525 fps even at moderate electron probe currents. ***Bruker Nano Inc***, *5465 East Cheryl Pkwy, Madison, WI 53711, www.bruker.com*





Laser particle sizer

With an extra-wide measuring range of 0.01–3800 μm, the Analysette 22 NeXT Nano from Fritsch performs automatic particle size analysis down to the nanoscale. According to the company, it offers high precision and sensitivity for the smallest particles. It is compact and solid, has few moving parts, and is low maintenance. The Analysette 22 NeXT Nano operates with only one laser and does not need an additional light source, even for backward scattering. The entire measuring range is recorded with one scan; most measurements take less than a minute, including a reliably residue-free cleaning. The analyzer is suitable for measuring particle size distribution of suspensions in R&D, production and quality control, and controlling manufacturing processes. ***Fritsch GmbH–Milling and Sizing**, Industriestrasse 8, 55743 Idar-Oberstein, Germany, www.fritsch-international.com*

Semiconductor leak testing

Inficon has unveiled the latest generation of its leak detectors for checking complex, ultraclean vacuum units. With the UL3000 Fab Ultra, the company has refined the detector to adhere to the special requirements of equipment used to manufacture semiconductor chips, solar cells, and flat-panel displays; of glass and plastic foil coating; and of vacuum process equipment. The UL3000 Fab Ultra is slim, mobile, robust, and intuitive to operate. It uses the vacuum method with helium as the tracer gas in order to safely detect the smallest leaks. A high-performance, low-maintenance roots pump replaces the scroll pump used in previous models. The efficient roughing pump allows the UL3000 Fab Ultra to more quickly evacuate production equipment being tested—especially when it is very large—and thereby reduce downtime in facilities. The detector can identify leak rates of down to 5×10^{-12} mbar·l/s when testing the vacuum in wafer chambers. ***Inficon**, 2 Technology Pl, East Syracuse, NY 13057, www.inficon.com* PT

Mark Yakovlevich Azbel

Condensed-matter theorist Mark Yakovlevich Azbel passed away on 31 March 2020 in Petah Tikva, Israel. Azbel was a major figure in the development of the modern electron theory of metals. Most notably, his work showed how features of a metal's Fermi surface can be manifest in various experimental measurements. Experiments based on the Azbel–Kaner cyclotron-resonance effect were, for many years, among the most powerful ways to study the Fermi surface of metals.

Azbel was also known for his role as a leader of the "refusenik seminar" in Moscow during the mid 1970s. The refuseniks were scientists in the Soviet Union who expressed a desire to emigrate to Israel, as was their right under the law, and were fired from their jobs while being refused permission to leave the country. The weekly seminar, often held in Azbel's apartment, kept alive the hopes of its refusenik participants, and it served to keep them informed of continuing developments in a wide range of scientific fields. It also attracted attention in the West and was an important factor in the outpouring of Western support for the refusenik cause.

Born on 12 May 1932 in Poltava, Ukraine, Azbel earned an MS in physics in 1953 and a PhD in theoretical physics in 1955, both from Kharkiv State University. He researched his thesis on the kinetic theory of conductivity in metals under the supervision of Ilya Lifshitz. In 1956 a pair of papers by Lifshitz, Azbel, and Moisei Kaganov on the behavior of metals in a strong magnetic field was one of the first demonstrations of the important effects that Fermi surface topology has on properties of metals. Thus, in a high magnetic field, a metal whose Fermi surface allows open electronic orbits—stretching to infinity when plotted as a function of momentum in the repeated Brillouin zone scheme—can have an electrical conductivity tensor that depends sensitively on the direction of the magnetic field relative to the crystal axes.

Azbel's career had a meteoric beginning. Azbel and Emanuil Kaner published their paper on cyclotron resonance in 1957. Lev Landau highly appreciated Azbel's work, and in 1957 Landau and Pyotr Kapitsa supported awarding a doctor of science degree, equivalent in the Soviet Union to the rank of a full professor, to the 25-year-old researcher. In 1960 Azbel showed how cyclotron resonance in a metal at high frequencies could lead to spikes in the AC electromagnetic field at positions much farther from the surface than the classical penetration depth. And in 1963 he elucidated singular features of the energy spectrum of an electron in a magnetic field and a periodic potential.

Azbel was invited in 1964 to join the physics department at Moscow State University, and when the L. D. Landau Institute for Theoretical Physics was created in 1965, he headed one of its eight research groups. His extraordinary chain of success was broken, however, by his application in 1972 to emigrate to Israel. Permission was withheld for five years, and it was during that period that Azbel helped organize and host the refusenik scientific seminar. Two of us (Halperin and Langer) had the privilege of attending the fifth-anniversary convocation of the seminar series in May 1977, where we observed firsthand Azbel's powerful leadership. Particularly striking was his ability to provide concise summaries in English of talks given by Russian scientists on various topics and to provide lightning summaries in Russian of talks given by the Western participants.

ROMAN MINTS

Mark Yakovlevich Azbel

In July 1977 Azbel was finally allowed to leave Moscow and meet the students and faculty of Tel Aviv University, where he had been appointed a professor in 1973. His association with the university lasted 47 years. He was a brilliant lecturer. His scientific work included contributions to the theory of mesoscopic electron systems and thought-provoking speculations on such diverse topics as the physics of DNA, aging, and evolution. In addition to an academic career in Israel and abroad, Azbel enjoyed an active role in Israeli radio and newspapers. His 1981 book *Refusenik: Trapped in the Soviet Union* described the history of his struggles to obtain permission to emigrate to Israel and to coordinate the work of the seminar.

Those of us who knew Azbel as a young researcher, a famous professor, or a senior statesman at Tel Aviv University will always remember his contributions to physics, his originality and inventiveness, his spirited temperament, his appetite for discussions, and his passion for thinking about the world in new ways. Life in his presence was never dull.

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Roberto Daniele Peccei

Particle physicist Roberto Daniele Peccei died in Los Angeles on 1 June 2020 of complications of a broken hip. Although he was challenged by health issues in his last 10 years, his enthusiastic approach to life hid them from most of us. Roberto was a man of vision and humanity: a theoretical physicist who asked deep questions and collaborated with others to answer them; a departmental and university administrator who found ways to support and expand the opportunities for science at UCLA; and an inspired teacher, mentor, and friend to young physicists from all over the world and to his more senior colleagues. His wife, Jocelyn, fondly called him Zeno, his MIT ski-team nickname after a great Italian skier, but the reference to the paradox also suited him—he never stopped halfway to anything!

Born in Turin, Italy, on 6 January 1942, Roberto grew up in Buenos Aires, Argentina. He went to the US to attend MIT and graduated with a BS in physics in 1962. After getting a master's of science from New York University in 1964, he returned to MIT and completed his PhD in high-energy physics in 1969. He worked at the University of Washington, Stanford University, the Max Planck Institute in Munich, and the German Electron Synchrotron (DESY) in Hamburg and then returned to the US in 1989 as a professor at UCLA, where he stayed the rest of his career. Wherever he went, he was a respected colleague and made lifelong friends.

Roberto was a natural leader. He went to DESY in 1984 to head its theory group. Not long after joining UCLA, he became department chair, and in 1993 he was appointed dean of physical sciences. He eventually served as vice chancellor for research from 2000 to 2010.

Through both hard times and times of growth, Roberto was a skilled and highly respected administrator. He advised many other institutions on their


UCLA

Roberto Daniele Peccei

physics and institutional policy, and he followed his father's footsteps as a director of the Club of Rome, which looks for comprehensive solutions to the world's interconnected problems. He was in demand for his wisdom and good judgment and for his keen research insight. He was sought after as a teacher, both at UCLA and at the many international physics schools where he was invited to lecture.

I collaborated with Roberto at Stanford in 1976 and 1977. We had fun doing physics together. He set the agenda for our work by asking good questions, the hardest part of doing good research. Our initial attempts to understand instantons, newly recognized as a property of quantum chromodynamics, led directly to what's now known as Peccei–Quinn symmetry, for which we shared the American Physical Society's J. J. Sakurai Prize for Theoretical Particle Physics in 2013.

We sought to explain how the strong interactions could maintain symmetry with respect to *CP*, the combined operators of charge conjugation and parity. Instantons introduce a *CP*-violating Lagrangian term with an angle-like coefficient, θ. The measured upper limit on the electric dipole moment of the neutron required that θ be tiny, less than 10^{-10}. Roberto asked, Can we make it automatically be zero? Our answer came after some stumbling. It confused us that θ is irrelevant—readily set to zero by axial rotation of any quark field—when quarks are massless in the very early universe but that θ becomes relevant when the Higgs mechanism imbues them with mass as the universe cools. How could that be?

A conversation with Steven Weinberg set us on the right track. He reminded us that even when the quarks are massless, Higgs–quark coupling phases are changed by the axial rotations to make θ vanish. Our question became how could all those phases conspire to give real quark masses and zero θ when the Higgs field vacuum value arises? Our symmetry, and the extra Higgs-type fields needed to achieve it, provided an answer.

Suspecting that the simplest model to realize the symmetry would quickly be ruled out (as indeed it was), we included no discussion of phenomenology when we shared our idea. But, as Weinberg and Frank Wilczek pointed out, one aspect of the phenomenology is generic. Even in the more complex models, the broken pseudosymmetry implies a pseudo-Goldstone boson, the axion, that has so far survived experimental constraints. For some models, the axion is a candidate dark-matter particle. Unfortunately, Roberto left us before learning whether axions solve the puzzle of dark matter, although searches are now sensitive enough to begin revealing that answer.

The qualities Roberto brought to our work were on display throughout his research career. For example, in Munich he investigated spontaneous breaking of lepton number symmetry, which would introduce another possible pseudo-Goldstone boson, the majoron, and a mechanism for producing Majorana mass terms for neutrinos. And at DESY he calculated angular distributions for $e^+e^- \rightarrow W^+W^-$ and provided guidance for detailed study of weak couplings in experiments there and elsewhere.

The large attendance and comments made at a UCLA-organized memorial symposium for Roberto were a testament to how well respected and liked he was by his students, his physics colleagues, and those who knew him as a university administrator. His voice will be missed by many of us.

My thanks to Graciela Gelmini for her help and advice in compiling this obituary.

Helen Quinn
Stanford University
Stanford, California

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QUICK STUDY

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Where does outer space begin?

Jonathan McDowell

As suborbital space tourism gears up, the decades-old debate about the boundary of Earth's atmosphere continues.

We are entering a new phase of the space age. The era of superpower rivalry has been replaced by intense commercial activity in orbit and by new types of vehicles operating at the margins of space. Virgin Galactic and Blue Origin are about to start flying tourists in those margins, while militaries are experimenting with hypersonic flight in the upper atmosphere and hucksters are advertising high-altitude stratospheric balloon flights at the edge of space. As a result, the six-decade-old delimitation question has gained renewed relevance: Where does outer space begin? How high do you have to fly to be a space traveler?

Of course, Earth's atmosphere has no sharp edge. Its density decreases exponentially with altitude, and it slowly becomes largely ionized but still detectable even 1000 km above Earth. Interplanetary space itself is not a perfect vacuum, and one could argue that the boundary of our atmosphere is the magnetosphere bow shock, where the flow of the solar wind around our planet interacts with the gas that is loosely bound to Earth. But in practice everyone agrees that you are in outer space well before you reach the tens of thousands of kilometers to which the magnetosphere extends.

At the other extreme, some have argued for the so-called Armstrong limit at an altitude of only about 19 km, where water can boil at normal body temperature and an unprotected human cannot survive even with an oxygen supply. (The limit is named after Harry Armstrong, a major general in the US Air Force and unrelated to astronaut Neil.) But the ability of airplanes and balloons to fly well above that limit makes it implausible to assert that 20 km is in outer space.

The Kármán line

Aerospace pioneer Theodore von Kármán argued that the point where orbital dynamics forces exceed aerodynamic forces is a sensible place to set the limit—now known as the Kármán line (see figure 1, in which $k = 0$ defines the Kármán line height). His proposal is the most widely accepted definition of outer space and was originally popularized in 1963 by space lawyer Andrew Haley. (At the time, space law dealt mostly with international treaties; now it's also about licensing commercial satellites.)

Modern commentators often assume that the order-of-magnitude estimate of 100 km for the Kármán line's altitude is actually its definition. But that assumption is not historically correct. In a 2018 paper in *Acta Astronautica*, I showed that von Kármán's argument places the line close to 80 km, largely independent of atmospheric variations and satellite properties.

Von Kármán's original point was that an altitude exists where generating lift with a wing is impossible. That's because you would have to fly so fast in the thin atmosphere that you'd exceed the Keplerian velocity, the speed at which a satellite flies in a circular orbit at that height. But a basically identical calculation shows that drag dominates gravitational forces on an orbiting satellite at a similar height. The result depends a little on the mass-to-area ratio of the spacecraft—whether it's a balloon, say, buffeted by the thin wind or a dense object plowing through the exosphere. The effect is captured by a quantity known as the satellite's ballistic coefficient, essentially its drag per unit mass, which varies from 0.005 m^2/km to 0.05 m^2/km for the majority of spacecraft.

Nevertheless, the atmospheric density falls off so rapidly in the 70–100 km region that the location of the effective Kármán line doesn't actually change much for the different cases. At higher altitudes, the atmospheric density is highly sensitive to solar activity; below 100 km it's much less sensitive. The upshot is that using von Kármán's criterion, the theoretically cal-

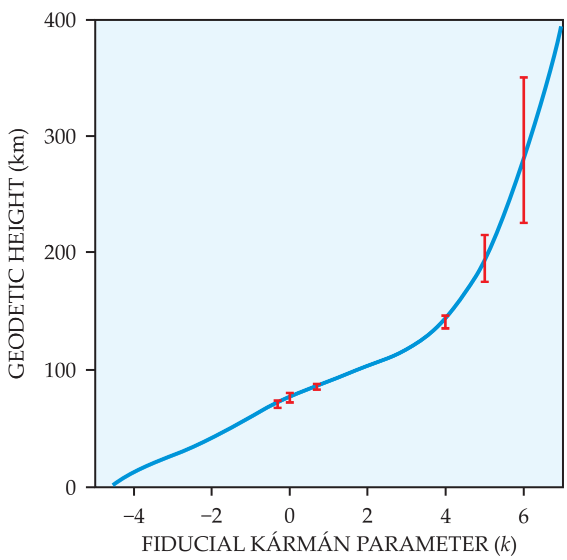

FIGURE 1. THE FIDUCIAL KÁRMÁN PARAMETER *k* is the logarithm of gravitational force divided by aerodynamic force. The plot illustrates how that ratio rapidly changes with altitude for a typical satellite and for a density profile defined by the 1976 US standard atmosphere. The point $k = 0$ corresponds to the effective Kármán line at about 80 km, where gravity and aerodynamics balance. Error bars indicate variations due to realistic atmospheric conditions. (Adapted from J. C. McDowell, *Acta Astron.* **151**, 668, 2018.)

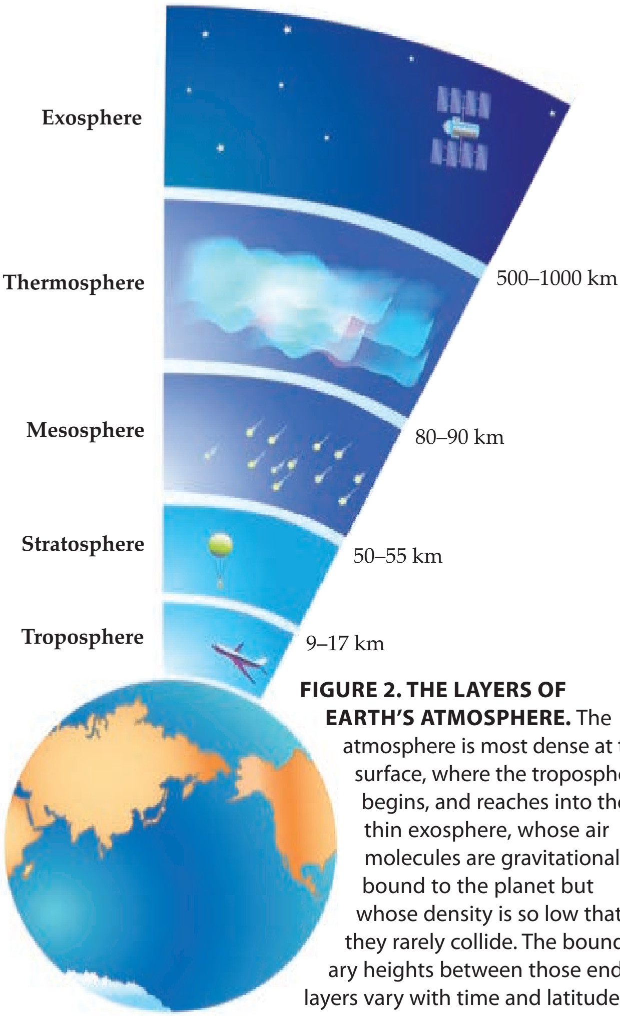

FIGURE 2. THE LAYERS OF EARTH'S ATMOSPHERE. The atmosphere is most dense at the surface, where the troposphere begins, and reaches into the thin exosphere, whose air molecules are gravitationally bound to the planet but whose density is so low that they rarely collide. The boundary heights between those end layers vary with time and latitude. See the Quick Study by John Emmert, PHYSICS TODAY, December 2008, page 70. (Adapted from the Center for Educational Technologies.)

culated boundary is always between 70 km and 90 km, with 80 km being a reasonable representative value. Because drag is proportional to atmospheric density and to the square of the satellite's velocity, the large density causes rapid deceleration below that height and makes the satellite fall out of orbit. The strong braking also generates extreme heating, and in the absence of a heat shield, the satellite quickly breaks apart and melts.

Practical, historical, physical

Practical evidence suggests that the 80 km line is a reasonable boundary. An analysis of 60 years of archival satellite orbital data shows that elliptical-orbit satellites can survive for days or weeks with a perigee (low point of the orbit) between 80 km and 90 km. At each perigee, the braking effect of the upper atmosphere reduces the satellite's velocity and causes the height of the next apogee (orbital high point) to be somewhat lower. Once the perigee drops below 80 km, however, the satellite does not survive more than one orbit.

Satellites with perigees in the 80–90 km range drop below 100 km every few hours. If you regard 100 km as part of outer space, keep in mind that the satellites would leave space, briefly pass through some country's airspace, and then return quickly to outer space. That implication is inconvenient and impractical. When objects are in orbit traveling at more than 400 km/min and crossing national boundaries every few minutes, we must conclude they are in outer space.

The 80 km boundary also has historical resonance: It is closely equal to 50 statute miles, the boundary used since 1961 to award "astronaut wings" to US military pilots, including several who flew the X-15 suborbital space plane. Pilots have made 8 suborbital flights above 100 km and another 14 above 80 km, most recently the flights by *SpaceShipTwo* and the emergency abort of the *Soyuz MS-10* launch.

The 80 km boundary corresponds reasonably well with the typical altitude of the mesopause, which is the highest well-defined boundary in the atmosphere and thus provides a physical reason for the choice. Most of us live in the troposphere, below about 12 km, although academics like me tend to spend too much time at the upper edge of that region, where commercial jets fly. (See figure 2.) All vehicles that need aerodynamic lift to remain aloft are restricted to the stratosphere, whose ceiling, the stratopause, is at about 50 km. The jet altitude record remains a mere 38 km.

Above the stratopause is the mesosphere region between 50 km and 80 km. That is a forbidden zone, where neither aircraft nor satellites can fly. It is visited for only a few minutes at a time by sounding rockets, reentry vehicles, and rocket stages, which complete a partial orbit. Starting with work by international space lawyer Bess Reijnen in the 1970s, various authors have suggested that the mesosphere could be regulated as an intermediate region—neither airspace nor outer space—but no consensus has been reached to date.

At the United Nations and in other international forums, Russia and other spacefaring countries have repeatedly suggested adopting the 100 km boundary, or something near it. The US government, though, has long resisted any official legal definition of space. Instead, US officials argue for a functional definition, in which different rules would apply to different kinds of vehicles, but they ignore the issue of what happens when vehicles interact.

As traffic in the liminal region increases, I believe that some legal rule will eventually be necessary to specify where a national airspace becomes a global, international space. In the meantime, those of us who make lists of astronauts or of suborbital space launches have to adopt some choice for what to include or exclude. I advocate using 80 km as that boundary.

Additional resources

▶ J. C. McDowell, "The edge of space: Revisiting the Karman line," *Acta Astron.* **151**, 668 (2018).

▶ R. F. A. Goedhart, *The Never Ending Dispute: Delimitation of Air Space and Outer Space*, Editions Frontières (1996).

▶ Committee on the Peaceful Uses of Outer Space, *Historical Summary on the Consideration of the Question on the Definition and Delimitation of Outer Space*, report A/AC.105/769, United Nations (2002).

▶ J. M. Picone et al., "NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues," *J. Geophys. Res. Space Phys.* **107**, 1468 (2002).

▶ T. Gangale, "The non Kármán line: An urban legend of the space age," *J. Space Law* **41**, 151 (2017).

Nanopainted art

Dutch artist Johannes Vermeer painted *Girl with a Pearl Earring* around 1665. To mix his colors, Vermeer relied on pigments made of varying amounts of chalk, ochre, charcoal, and other materials. Pigments produce color through selective absorption, although color can also be made through the selective scattering of light waves by microscopically altered surfaces. Researchers have already produced several kinds of metasurfaces capable of generating a large color range. Now Nanjing University researchers Pengcheng Huo, Yanqing Lu, Ting Xu, and their colleagues have produced a metasurface that generates a full range of visible color on which they can simultaneously adjust the brightness.

As a proof of concept, the researchers reproduced Vermeer's masterpiece, shown here. They designed a dielectric metasurface composed of pillars hundreds of nanometers in size and made of titanium dioxide, a material with a high refractive index. When visible light falls on the metasurface, each nanopillar acts as a waveplate. At a specific wavelength, a nanopillar rotates the polarization of the light, which yields a color. The independently tunable orientation angle of each nanopillar relative to an applied electric field determines a color's brightness. Vermeer's original canvas measures about 1700 cm^2. The nanopainted copy is approximately 0.65 mm^2. (Image courtesy of Ting Xu; P. Huo et al., *Optica* 7, 1171, 2020.) —AL

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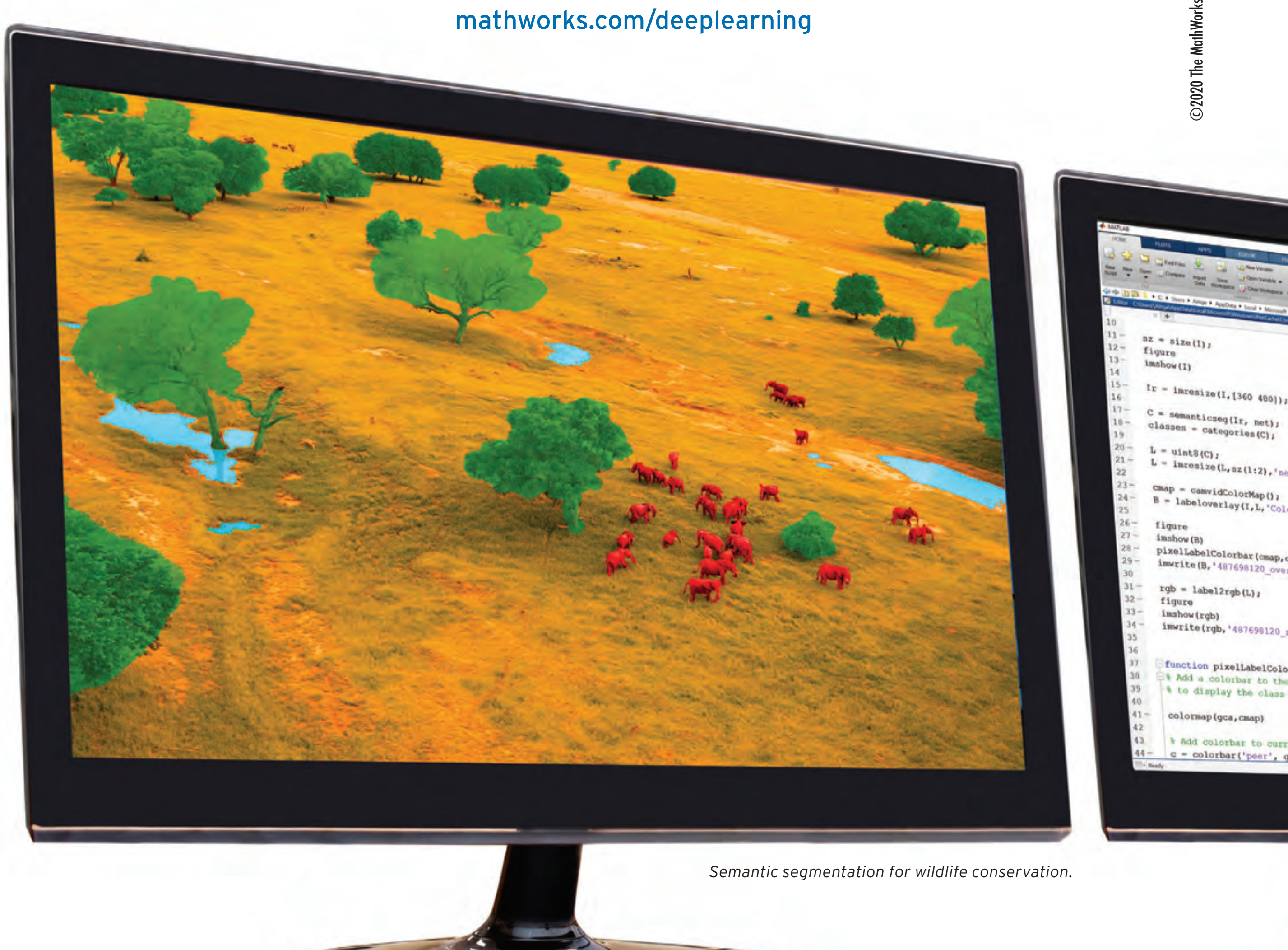

Semantic segmentation for wildlife conservation.