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APS NEWS

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A Message from the APS CEO and the APS President

Kate Kirby

Philip Bucksbaum

We face a time of extraordinary challenges. We know, however, that our physics community will be resilient and resourceful in the face of crisis as the world confronts the coronavirus pandemic. We saw this in Denver following the sudden cancellation of the March Meeting, as many members stepped forward to schedule and conduct online sessions to ensure the continuity of scientific exchange. APS staff worked tirelessly to support, encourage, and enable these sessions, but the drive to push so much online so fast came from the March meeting physicists.

This spirit is also seen in physics departments and labs worldwide, where physicists have suspended research with almost no prior warning, and students and staff have dispersed. Now and in the coming weeks, we will all be called upon to do what we can to keep our communities healthy, keep our research and education missions alive, and prepare for an uncertain future.

As a result of the coronavirus, APS—like most other professional societies around the world—has canceled conferences and requires staff to work from home. APS has prepared for this, and thus far the staff have maintained most core activities as usual. Research meetings have been affected profoundly, however. APS meetings are essential to our worldwide physics community, and so we have taken several steps:

- The APS Board Executive Committee agreed that the April Meeting, originally to be held in Washington, DC, is canceled as an in-person meeting, but will be held online to the greatest extent possible. The April Program Committee and APS IT support are working together to implement a robust virtual meeting.
- All spring section meetings have been canceled.
- DAMOP leadership will make a decision about their June meeting soon.
- APS is supporting several community-driven efforts to continue to place many of the planned March Meeting sessions online. We are all exploring new ways to disseminate scientific information and interact with our colleagues. You can read more about this on the March Meeting website.

The APS's Office of Government Affairs (OGA) has focused on ensuring that our graduate students and postdocs continue to receive support, despite the shutdown of labs and universities across the country. Through a grassroots-driven partnership with the Forum on Graduate Student Affairs, APS OGA is urging federal agencies to continue to provide salaries and benefits. In addition, in preparation for any future phase of federal economic stimulus to respond to COVID-19, OGA has prepared a proposal for including scientific infrastructure in the funding package.

We acknowledge the stress so many in our community are experiencing as they close down research experiments and laboratories and pivot to teaching all courses online and hold office hours in cyberspace. The April *APS News* Back Page article contains some suggestions regarding successful transitioning to online teaching. In addition, we must especially look for ways to help our early career and student members, whose lives have been upended as institutes are shuttered and campuses are closed.

Other actions, both large and small, are taking place throughout our community to address critical needs resulting from the pandemic. Physics labs across the country are donating much- needed personal protective equipment to local hospitals. Several groups engaged in biological and medical physics are busier than ever, racing to develop knowledge that could lead to effective treatment. Although many national laboratories are temporarily shut down, some beamlines at synchrotrons such as SSRL at SLAC remain open for important research related to the COVID-19 virus.

Like other global threats our society has faced, from world wars to national disasters (both natural and man-made), this current situation is an existential challenge, which can accelerate positive change, spur innovation, and make us stronger and more resilient. APS exists to serve its members, the physics community, and society broadly. Learn more about our efforts on our COVID-19 response page. If there are additional actions you think we should be taking at this time, please let us know (exec-office@aps.org).

We send all best wishes to you and your families, and hope that you are able to stay healthy and strong.

Sincerely,

Kate P. Kirby
APS CEO

Philip H. Bucksbaum
APS President

Physicists and COVID-19: *APS News* and *Physics Magazine* would like to hear from you. How are you carrying out your research? How are you moving your classes online? How are you using your physics training during the pandemic? Please send your story to letters@aps.org.

COVID-19: APS Actions and Resources

APS understands that our members and the physics community are under considerable stress at this time. Please be assured that we will continue to do all that we can to support you and the physics enterprise. If you have any questions or concerns, please let us know via the form at aps.org/about/contact/.

APS has created a central website with updated information about Society activities during this time. Please check the website regularly: **aps.org/about/covid-19/**.

***Physical Review* Journals**

The APS and the *Physical Review* editorial office are fully equipped and actively working to support researchers by continuing to carry out all editorial and peer-review functions and publish research in the journals as well as minimizing disruption to journal access.

Remote Journal Access. Many researchers now find themselves working away from their institutions and may have trouble accessing the *Physical Review* journals. To address this, we are facilitating access via several different mechanisms: Google Scholar CASA, Go Mobile, and Shibboleth. For full details visit: journals.aps.org/remote-access.

For any questions, please contact our journals Help Desk at help@aps.org.

COVID-19 CONTINUED ON PAGE 7

Resources for Online Physics Instruction

BY MONICA PLISCH

Many physics departments have quickly moved their courses online in response to the COVID-19 pandemic. Some leading resources include:

- **PhysPort (physport.org)**—APS Fellow Sam McKagan is founder and director of this user-friendly web portal hosted by AAPT that supports physics faculty in implementing research-based teaching practices. The Expert Recommendations tab has a well-developed page titled "I suddenly have to move my face-to-face physics/astronomy course online! What should I do?" Sourced from dozens of experts, this vetted page includes ideas and links from how to structure your class, to group work online, to online teaching resources.
- **PhET Simulations (phet.colorado.edu)**—Winner of the 2018 APS Excellence in Education Award, this website hosts over 100 interactive simulations of physics phenomena. Most simulations can be run on the web and all can be downloaded. Curricular materials are available for most sims, which can be used to supplement or substitute for hands-on laboratory exercises.
- **Virtual Chairs Meeting**—APS and AAPT jointly organize the Physics Department Chairs Meeting and will be holding a shortened version of this meeting online, likely on June 19. Chairs and other department leaders are welcome to attend and discuss lessons learned from the unexpected experiment with online education, among other topics. Look for announcements on the APS Education Programs page (aps.org/programs/education) to stay in the loop.

Please contact us at education@aps.org if APS staff can be of assistance regarding questions with online education. Also see the *APS News* Back Page article by Chandralekha Singh in this issue for additional links.

The author is APS Director of Programs.

Revised 4/20/20

MEMBERSHIP

APS Student Ambassadors Engage with Units

BY LEAH POFFENBERGER

The APS Annual Leadership Meeting (ALM) in Washington, DC, held at the end of January is an important resource for connecting leaders of APS membership units to APS staff and leadership, and this year it also acted as a training ground for a new type of APS leader: the APS Student Ambassadors. APS Student Ambassadors are undergraduate and graduate physics students who have committed to acting as APS representatives for their fellow students in their home institutions.

The Student Ambassador program was first launched in Spring of 2019, and now has 20 ambassadors at 18 institutions who inform their peers about APS and its resources. Ambassadors are provided with materials about APS programs and support from APS staff to act as a valuable bridge between students and APS.

"APS is almost 50% students, and APS is definitely making a big push to help support students and early career scientists more—[the Student Ambassadors Program] is part of that," says Sarah Monk, Unit Operations Coordinator at APS. "The Student Ambassadors serve as representatives of APS at their institution, so if students have questions about APS, they can go to that representative who can answer their questions or put them in touch with a person at APS who can help them."

As part of the program, student ambassadors are given free APS memberships, as well as unique opportunities for career growth. Seven student ambassadors representing five institutions attended ALM, and participated in all ALM has to offer, from being a part of Congressional Visits Day (see p. 4) to ramping up their skills at a special professional development workshop.

"Part of the Ambassador program is providing professional development and networking opportunities for these ambassadors, and we thought ALM would be a really great opportunity for them to learn a lot more about APS," says Monk. "At the ALM, we paired each of the student ambassadors with a unit leader as their mentor for the whole meeting, so they had that unit leader to answer questions for them or talk about their career path, whatever they needed."

Student Ambassador Huei Sears

In a student-ambassadors-only session at ALM, the ambassadors were given resources, both for their own career growth and for their work as representatives for APS. A workshop titled "Finding Your Voice: On Campus and Off" helped give the students tools to better communicate about themselves, their research, and as APS representatives. Crystal Bailey, Head of Career Programs at APS, headed up a careers roundtable, sharing the resources APS has for students and early career scientists, and Monica Plisch, APS Director of Programs, provided information on Society efforts dedicated to education, diversity, and inclusion. Monk led a training session, ensuring the ambassadors had all the tools they need to be successful representatives to fellow students.

"It was very useful to have a semi-informal presentation of all the resources APS has to offer," says Huei Sears, a graduate student at Ohio University and one of the Student Ambassadors who attended ALM. "I know that joining APS allows students to present at APS conferences for an affordable price, but I've struggled in finding reasons to join APS for students who maybe aren't ready to present yet. This presentation gave me that information, and I now feel prepared to encourage all graduate students to join [APS]."

Both undergraduate and graduate students can become Ambassadors upon nomination from the chair of their physics department or from other faculty members. Students will also be able to apply to be an Ambassador online starting August 1, 2020.

AMBASSADORS CONTINUED ON PAGE 3

THIS MONTH IN

Physics History

April 13, 1942: Death of Annie Jump Cannon

Astronomer Annie Jump Cannon was a rare creature for her time, when most women did not receive higher education, and were expected to pursue traditional domestic priorities. She defied those societal expectations and gave us a star classification system still in use today.

Born in December 1863, Cannon's father was a shipbuilder in Delaware and a former state senator. Cannon recalled being fascinated by the glass prismatic pendants in the family candelabra, detaching them occasionally to catch sunbeams and play with the light. It was her mother, Mary Jump, who encouraged young Annie's interest in the stars, observing them from the family attic. She learned about the constellations with the help of an old astronomy textbook. "Stars and prisms!" Cannon later said. "How prophetic was this baby amusement of the profession which was destined to fill my life.

Cannon's mother also pushed her to study math and the sciences at what is now Wellesley College. Her mentor was Sarah Frances Whiting, a rare woman physicist in the US at the time. Cannon excelled academically and graduated with a degree in physics in 1884, serving as valedictorian of her graduating class.

Cannon did not immediately pursue a career in science after leaving Wellesley, returning to her Delaware home instead, where she worked as a tutor in math and history. She also developed a great deal of skill in photography, even traveling throughout Europe taking pictures with a box camera. She published a pamphlet of her photographs from Spain in 1893, which was distributed at the Chicago World's Columbian Exposition that year.

Sometime during these years, Cannon had survived a bout with scarlet fever, but the illness left her mostly deaf. Then her mother died in 1894, and Cannon found herself at loose ends and desiring change. She wrote to Whiting asking about a job opening, and her former mentor hired her as a junior physics teacher. This also enabled Cannon to pursue graduate studies in physics and astronomy, and begin to learn about spectroscopy. Eventually she enrolled at Radcliffe College, with the aim of gaining access to a better telescope, as well as the Harvard College Observatory.

In 1896, the director of the observatory, Edward Pickering, hired Cannon to join his "Harvard Computers," thanks to her academic background and considerable experience with telescopes. Their task was to help complete the Henry Draper Catalog and to map and define every star in the night sky by their optical spectra. Male astronomers handled the telescope observations and took the photographs; the tedious task of painstakingly sifting through each plate; measuring brightness, position and color; and classifying the stars fell to the women in Pickering's employ.

Annie Jump Cannon

At the time, Harvard astronomers used a prism placed in front of a telescopes eyepiece to observe a star's spectrum, and then drawing that spectrum by hand. Eventually, they began using one-inch square photographic plates to record the spectra. Pickering was able to speed up the process even more by placing the prism at the gathering end of the telescope. This enabled astronomers to image more than a single star at a time. Any star within the telescope's view could be captured on 8"x10" photographic plates.

Cannon spent many nights scanning the night sky at the observatory, recording all the tiny fluctuations in the brightness of various stars, as well as synthesizing data from citizen scientists making their own observations around the globe. But she particularly excelled at classification, able to classify spectra in as little as three seconds. She would place each plate on a stand, and a mirror at the base would catch the sunlight to illuminate the horizontal spectral bands on the plate. Then she used a microscope to determine the spectral patterns and verbally communicate the classification to an assistant.

Two of Cannon's fellow computers, Williamina Fleming and Antonia Maury, had devised competing classification schemes. Fleming's system divided stars into 15 spectral categories, depending on how strong their hydrogen lines were. There were 22 categories in Maury's more complicated system, based on the helium lines of a given star.

Cannon devised her own compromise classification scheme that is still used today, preserving some elements of both, which (we now know) essentially ranked stars in terms of temperature, from hottest to coldest. She based her scheme on how strong the Balmer absorption lines were for each star, dividing them into the spectral classes

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MEMBERSHIP UNITS

The Division of Atomic, Molecular, and Optical Physics

BY ABIGAIL DOVE

The Division of Atomic, Molecular, and Optical Physics (DAMOP) is a home for physicists engaged in fundamental research on atoms, molecules, photons, and their interactions. These researchers investigate a wide range of phenomena, including ultrafast and strong field physics, collisions and spectroscopy, quantum optics, plasmas, and precision measurements.

Founded in 1943 as the "Division of Electron and Ion Optics," DAMOP has the distinction of being the oldest division in APS. It evolved over the years into the "Division of Electron Physics" in 1947 and became the "Division of Electron and Atomic Physics" in 1966, finally becoming DAMOP in 1986.

As the first APS division, DAMOP led the way for other specialized units within APS, which since its founding in 1899 had been a single body with no internal subdivisions. Just one year after DAMOP's establishment the Division of Polymer Physics (DPOLY) was formed in 1944, followed by the Division of Condensed Matter Physics (DCMP) in 1947 (see *APS News* April 2019).

The move toward subdivisions was initially met with some skepticism from some in the physics community, who feared that it would incite too much fragmentation in what was then a much smaller field. On this issue, Karl Darrow, the Secretary of APS at the time, noted in 1943 that "The natural tendency of any growing science is to subdivide itself. Paradoxical as it may sound, this is regarded by [...] the Society as a step in the direction of unity and not disintegration." He emphasized that APS benefits from the emergence of specialized subdivisions because it ensures that everyone in the physics community, no matter how different their academic interests, can "continue to regard themselves and to be regarded as being physicists and members of a society of physicists."

Almost 80 years later, this has proven to be the case: Today APS has 17 divisions, 13 topical groups, 10 geographical sections, and 9 forums, all operating synergistically with ample crosstalk and collaboration.

In addition to being the oldest, DAMOP also ranks among the largest units at APS, approximately 3,200 members strong. Notably, over 40% of DAMOP members are students, underscoring the vibrancy of this rapidly developing field and reinforcing what DAMOP chair John Bollinger (NIST) characterized as "a culture of sharing, support, openness, and scientific curiosity."

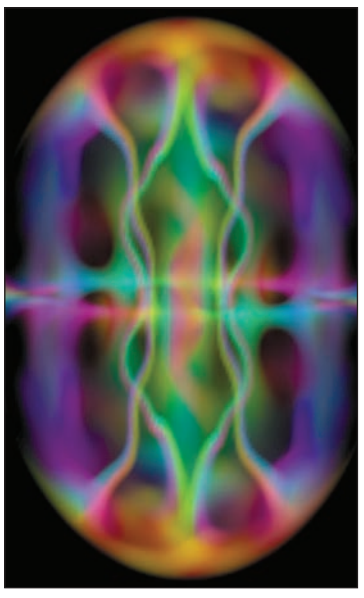
Fundamental research in the domain of atomic, molecular, and optical – or "AMO" – physics has been instrumental in the development of methods for the control and manipulation of atoms, molecules, charged particles, and light. As DAMOP Past Chair Marianna Safronova (University of Delaware) explained, the natural synergy between these aspects of fundamental AMO research and other areas of physics has enabled close relationships and collaborations with several other APS units, including the Divisions of Quantum Information (DQI; see *APS News* December 2019), Laser Science (DLS), and Nuclear Physics (DNP), and the Topical Group on Precision Measurement and Fundamental Constants (GPMFC).

A particular point of pride for DAMOP is its long-running Annual Meeting. With a typical attendance of 1,000 to 1,200 people, this meeting provides a more intimate forum to discuss AMO physics specifically—itself already a broad field. Besides a large selection of invited talks (the topics of which are proposed by the broader AMO community), the meeting also includes graduate student symposia, career development events, and an annual workshop on precision measurement and fundamental concepts from APS' GPMFC (which rotates between the DAMOP Annual Meeting and the APS April Meeting).

"It's the best conference on AMO physics in the United States to see the perspective of the entire field," noted Safronova, "I would encourage even first year graduate students to attend."

Echoed Bollinger, "AMO science has undergone much growth during the last 30 years, and this has produced a proliferation of smaller topical meetings. DAMOP, in particular through its Annual Meeting, brings together the different topical areas of research. One of my biggest aspirations is to keep these connections healthy and vibrant because scientific diversity is important for progress to be made."

Looking to the future, Bollinger's top priorities for DAMOP are two-fold – to "build connections



Computer simulation showing tornado-like vortices forming within a spinning Bose-Einstein condensate of ultracold atoms. IMAGE: NIST

DAMOP CONTINUED ON PAGE 7

APS Members Named "5 Sigma Physicists" for Outstanding Advocacy

BY TAWANDA W. JOHNSON

They wrote op-eds that appeared in top media outlets throughout the country, participated in meetings with congressional staff, and one even used her expertise to testify during a hearing on Capitol Hill. As a result of their outstanding science policy advocacy throughout 2019, APS has selected 16 members to receive the 5 Sigma Physicist Award.

Awardees are honored for participating in high-impact advocacy activities with the APS Office of Government Affairs (APS OGA) and for maintaining communication with the office throughout the year.

This year's awardees requested that members of Congress: support the Combating Sexual Harassment in Science Act; cosponsor the Keep STEM Talent Act; introduce legislation to keep the Federal Helium Reserve open and create a robust helium recycling program; and raise the budgetary caps on the FY21 federal budget.

"The advocacy that I've been able to do this year with the help of the APS Office of Government Affairs has been its own reward," said Stephen Albright, a PhD physics student at Yale University, who helped urge US Rep. DeLauro (CT-3rd) to support the Combating Sexual Harassment in Science Act and the Keep STEM Talent Act. More specifically, Albright organized a team of advocates who met with US Rep. Rosa DeLauro's staff in support of both pieces of legislation. Those efforts paid off: DeLauro became a co-sponsor of the Combating Sexual Harassment Act shortly after meeting with Albright's team.

Tiffany Nichols, Kevin Nuckolls and Midhat Farooq, leaders of the APS Forum on Graduate Student Affairs (FGSA), were lauded with the award after working with APS OGA to organize a 12-week, letter-writing campaign on the Combating Sexual Harassment in Science Act. The result of their work: The US House of Representatives passed the legislation within eight months from the time of introduction.

Kevin Nuckolls, a PhD physics student at Princeton University, said, "There's still a lot we must do to further combat sexual and gender harassment in the STEM community, but I believe the passage of HR 36 [the bill in the House of Representatives] marks a concrete step in the right direction toward transparency and inclusivity."

Added Tiffany Nichols, an attorney and a doctoral candidate in the history of science/physics at Harvard University, "I hope to continue devoting my time and efforts to program development and activism that make physics and related fields more inclusive, equitable, and diverse. We are better together."

Being selected for the 5 Sigma Physicist Award was a "pleasant surprise," said Midhat Farooq, APS Careers Program Manager and former member-at-large of FGSA.

"Advocating for sound policies supported by science is a responsibility that falls on many, including APS and its members. What makes me truly happy is that APS goes one step further and advocates for policies that affect the people doing the science, such as tackling topics like sexual harassment and immigration. I think these social issues are just as important as research funding, and I am glad to see APS addressing them," said Farooq.

Nadia Fomin and Christine Nattrass, assistant and associate physics professors, respectively, at the University of Tennessee, Knoxville (UT Knoxville), joined Elizabeth Mae Scott, a graduate student at UT Knoxville, to advocate for the Combating Sexual Harassment in Science Act. They participated in meetings with staff representing US Sens. Lamar Alexander and Marsha Blackburn.

"These meetings took a lot of work, but they are important first steps in knocking down barriers to sexual harassment in STEM," said Nattrass.

Amber Lauer, physics postdoctoral associate at Duke University, and Saeed Pegahan, PhD physics student at North Carolina State University, teamed up during a meeting with Sen. Thom Tillis' staff in support of the Keep STEM Talent Act. Pegahan also arranged a lab tour for Tillis' staff, and during the tour, he underscored the case for keeping international talent in the US.

Lauer wrote an op-ed in *The Raleigh News & Observer* newspaper in support of the bill, which would enable high-skilled international graduate students to both study at US universities and provide a path to a green card if they secure job offers from US employers after graduation.

Pegahan pointed out that he was elated to advocate for the Keep STEM Talent Act.

"Thanks to all the amazing APS Office of Government Affairs staff, I am glad that I had an opportunity to speak with staff in the sena-

5 SIGMA CONTINUED ON PAGE 6

AMBASSADORS CONTINUED FROM PAGE 2

When asked what she would tell students who may be interested in joining the program, Sears' advice is simple: "Jump right in & join," she says. "I've learned a lot about APS (and the physics community in general) during my time as a Student Ambassador, and I greatly enjoyed attending ALM. If you have any questions or concerns don't hesitate to reach out and ask—APS wants the best for the physics community, and including students is imperative in securing a bright future."

Applications for the Student Ambassador program open August 1, 2020: go.aps.org/ambassador2020

GOVERNMENT AFFAIRS

APS Members Take to Capitol Hill to Make Case for Science Policy Issues

BY TAWANDA W. JOHNSON

Nearly 70 APS members recently advocated for the Society's policy priorities on Capitol Hill during APS's annual Congressional Visits Day (CVD), and based on their feedback, the experience was positive and productive. The event was held just before the start of the APS Annual Leadership Meeting at the end of January.

Representing 26 states across the country, groups of these volunteers participated in nearly 100 meetings to make the case for science policy priorities determined by APS members and leadership. During the meetings, APS volunteers requested that members of Congress: support the Combating Sexual Harassment in Science Act; cosponsor the Keep STEM Talent Act; preserve methane emissions regulations for the oil and gas industry; introduce legislation to keep the Federal Helium Reserve open and create a robust helium recycling program; and include funding increases of at least 4 percent real growth for key science agencies during the fiscal year 2021 appropriations process.

During the Capitol Hill meetings, leaders of APS membership units shared personal stories related to these science policy issues and explained to the staffers how those stories affected their congressional members' districts and states. Thirteen sitting members of Congress participated in the meetings—a record number for the APS CVD.

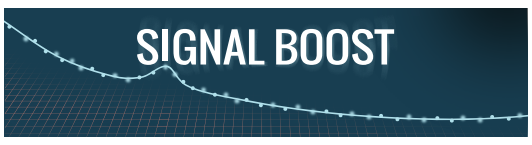
Almost 70 APS members from 26 states in the US visited Capitol Hill during APS Congressional Visits Day.

"APS is once again elated to have our members advocate on crucial science policy issues that are not only beneficial to the physics community but to society as a whole. We are committed to being the leading voice for physics in the US, and that means supporting member engagement in effective science advocacy to help shape federal science policy," said APS President Phillip Bucksbaum.

Shannon Swilley Greco, a science education senior program leader at Princeton Plasma Physics Laboratory, said she appreciated the opportunity to be "civically engaged." She added, "I think I am a good ambassador for these issues, and I'd like to think I'm effective. And the experience helped me hone my communication skills."

Leslie Atkins Elliott, professor of curriculum, instruction, and foundation studies at Boise State University, said she was drawn to

CAPITOL HILL CONTINUED ON PAGE 7



Signal Boost is a monthly email video newsletter alerting APS members to policy issues and identifying opportunities to get involved. Past issues are available at go.aps.org/2nr298D. **Join Our Mailing List: visit the sign-up page at go.aps.org/2nqGtJP.**

FYI: SCIENCE POLICY NEWS FROM AIP

Proposals Proliferate to Inject Billions Into R&D Programs

BY ANDREA PETERSON

An R&D spending surge could be on the horizon, if senior Democrats and Republicans follow through with proposals to channel billions of dollars into fields they deem critical to national interests. The proposals circulating on Capitol Hill differ widely, but all cite either climate change or competition with China—or both—as justification for turbocharged funding.

In January, Republican members of the House Science Committee introduced the Securing American Leadership in Science and Technology Act, a sweeping policy bill that recommends roughly doubling the budgets of select science agencies over ten years. Among those included are the Department of Energy Office of Science, the National Science Foundation, and the National Institute of Standards and Technology.

Committee Ranking Member Frank Lucas (R-OK) has said he hopes the bill will "start a bipartisan conversation about what we need to do to ensure America's lead in the technological revolution of the 21st century." Commenting on the legislation, Committee Chair Eddie Bernice Johnson (D-TX) said she is pleased with its call to put science agencies on a sustained growth path and that she will look to incorporate ideas from the bill into bipartisan legislation Democrats hope to introduce later this year.

In the Senate, interest has begun to coalesce around the five "Industries of the Future" the White House has identified as key to US global competitiveness: artificial intelligence (AI), quantum information science (QIS), 5G telecommunications, advanced manufacturing, and synthetic biology.

In January, a bipartisan group of senators led by Commerce, Science, and Transportation Committee Chair Roger Wicker (R-MS) introduced the Industries of the Future Act, which would direct the White House to sketch out its vision for these areas. It would also require the administration to develop plans for doubling civilian agencies' annual spending on QIS and AI over the next two years and for scaling up their investments across emerging technology areas to $10 billion annually by 2025.

Senate Minority Leader Chuck Schumer (D-NY) has floated a separate proposal to create a new funding entity that would channel $100 billion over five years into "basic research" in areas such as AI, quantum computing, robotics, and 5G. Schumer has not yet introduced legislation for the proposal,

but he reiterated his interest in the idea in a recent letter to the White House encouraging it to significantly increase funding for NSF and NIST in its latest budget request. The administration ultimately proposed steep cuts to both agencies, though it did propose ramping up spending on QIS and AI.

Proposals for bolstering R&D spending to address climate change have likewise proliferated in Congress. The House Republican bill is part of that party's new effort to develop an innovation-centered climate policy, but a similar idea was articulated a year ago by Sen. Lamar Alexander (R-TN), who called for doubling energy research funding over five years as part of a "New Manhattan Project for Clean Energy."

Although his proposal has not been embodied in legislation, from his position as chair of the Senate appropriations subcommittee

R&D CONTINUED ON PAGE 5

MEETINGS

Using Autonomous Vehicles for Agriculture, Environment, and Infrastructure Monitoring

BY LEAH POFFENBERGER

Technologies that are putting self-driving cars on the road, such as laser sensors and multi-spectral cameras, are now enabling a different type of autonomous vehicle: self-flying drones. Researchers like Pratap Tokekar, an assistant professor at the Maryland Robotics Center at the University of Maryland, are developing small, unmanned aerial vehicles (UAVs) that can be deployed as tools to improve agriculture, inspect infrastructure, and monitor the environment.

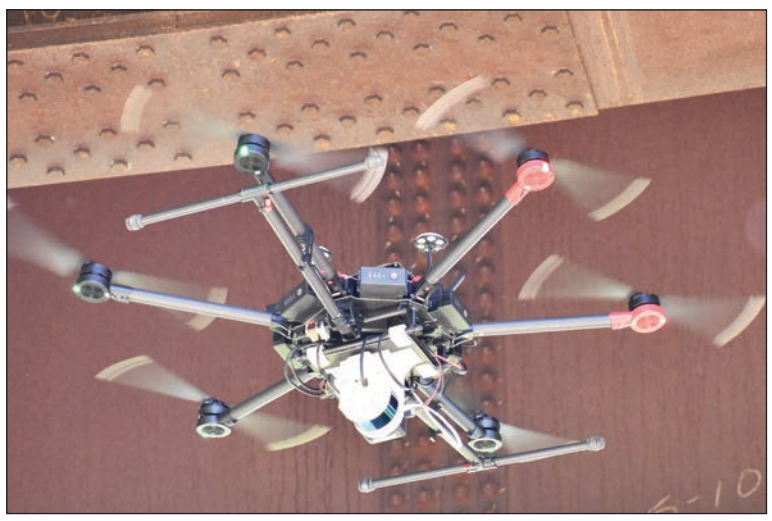
Tokekar described his research at the September 2019 Frontiers in Optics/Laser Science meeting, organized by the Optical Society and the APS Division of Laser Science. His work was done while at Virginia Tech and focuses on precision agriculture, which uses technology to improve crop yields. UAVs are great for applications outside of farms, such as bridge inspection and aquatic pollution tracking. However, UAVs are especially well-suited to agriculture because of the nature of the work and the relatively safe flying environment.

"The goal of UAVs is really to do any task that is dull, dirty, and dangerous," says Tokekar. "In terms of agriculture, there are certainly a lot of tasks that are dull, such as going and taking images of all the plants on your farm…this is something that is easily automated with robots that can help us improve the efficiency of our farming in general, using data-driven techniques."

Tokekar's use of UAVs for agricultural monitoring was made possible about eight years ago, thanks to advances in battery life and improved GPS technologies. Since farms are relatively free of aerial obstacles, vehicles equipped with onboard GPS and inertial measurement units for navigation can be deployed to begin collecting data with relative ease.

"The agricultural domain was the perfect fit because it's structured enough that the UAVs can navigate easily in the environment and focus on the more interesting data collection aspect and not worry about things like obstacle avoidance or safety as one would for self-driving cars," says Tokekar.

UAVs deployed in other applications, such as infrastructure inspection, might operate in areas where GPS signals may be interrupted, so they are equipped with other navigational tools like cameras and LiDAR—a laser sensor that allows the vehicle to build a 3D map of its environment. Such UAVs are ideal for inspecting bridges, a dangerous job for humans. In particularly tricky flying conditions, some UAVs are mixed autonomy and can be guided by a remote pilot.



Unmanned Aerial Vehicles loaded with sensors are providing new eyes on agriculture and infrastructure.

In addition to navigational instruments, UAVs can be loaded up with a number of different scientific sensors, depending on the task at hand. For precision agriculture, the UAVs are typically equipped with thermal cameras, multi-spectral cameras, and temperature sensors. Data from these sensors can show whether some plants on a farm, like a new genetic variant, are growing better than others, providing farmers with information on what crops will be most profitable to plant.

However, UAVs can't carry an unlimited sensor package: even with the best battery technology, the vehicles have a short time in the air. "Ten to 30 minutes may not be enough for what you want to do, and so you have a trade-off: if you want to put more interesting scientific sensors on a platform, you are reducing the flight time you have," says Tokekar. "This is, in some sense, good for us as robotics researchers because now we have a constrained platform. Instead of just flying everywhere in the environment, now it is upon us to find the most interesting locations in the environment to collect samples from."

To meet the challenge of short battery life in aerial vehicles, Tokekar's team has been working on algorithms that can coordinate teams of vehicles, both aerial and ground, to maximize the amount of time UAVs spend in the air in interesting locations. Unmanned ground vehicles (UGVs), which have much longer battery lifetimes, can be used to transport UAVs to areas of interest and act as charging stations, where a depleted UAV could land and recharge before completing its mission.

"If you have one vehicle that has only 10 minutes, then the solution is to have multiple vehicles that can all operate simultaneously: you can have a swarm or collection of aerial vehicles all going and doing data collection, but that introduces newer challenges now because now you need these vehicles to coordinate with each other," says Tokekar. "Then the questions become: How do you coordinate the actions between these aerial and ground vehicles? How do you get few ground vehicles to support a larger fleet of aerial vehicles? That's something that we've actively been working on."

Coordination between different types of vehicles is also important for UAV applications in aquatic environments where UAVs and robotic boats can be deployed together in response to oil spills or other pollutants in a body of water.

"We're been working on developing algorithms to use a team of aerial robots with aerial sensors that can quickly disperse in the environment and map the extent of a pollutant, find the source of a pollutant, and then coordinate with a robotic boat that can go and collect physical samples," says Tokekar.

As autonomous vehicles like UAVs improve and become more widespread, robotics researchers like Tokekar recognize the potential for such technologies to impact the workforce. Tokekar has been involved with a research project, as part of the National Science Foundation's Future of Work program, to study the intersection between UAV technology and workers. One focus was on how using UAVs will impact infrastructure inspectors.

"We are not only improving the technology [for infrastructure inspection], but also working with stakeholders: This includes government agencies as well as inspection companies, and economists too, to see what the workforce [requirements] would look like if such a technology would become feasible in the near future," says Tokekar. "How would training requirements change, would inspectors need to also be pilots and so on and so forth. It's an interesting program, but I think this is something that can have a tangible impact."

R&D CONTINUED FROM PAGE 4

for DOE, Alexander marshalled a funding boost for the current year that aligns with his doubling goal. However, he is retiring at the beginning of 2021, leaving the matter in his hands for only one more budget cycle.

With the election season now well underway, time is short to assemble a major legislative push this year. Efforts could continue into the next Congress, perhaps under significantly different circumstances should there be a new occupant of the White House. Joe Biden and Bernie Sanders have both included major energy innovation pushes in their platforms and could also prove receptive to the ideas in Congress.

The author is a science policy reporter for FYI.

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MARCH MEETING

How To Protect A Quantum Computer From Itself

BY SOPHIA CHEN

The race to build the first useful quantum computer is on. In the last year, researchers have announced a flurry of results: in October, a team at Google reported that they'd demonstrated the first task, in which a quantum computer beat a conventional one in solving an abstract math problem. Meanwhile, IBM's quantum team solved simple problems relevant to chemistry and finance on prototype quantum hardware that, if scaled up to future larger machines, may offer utility beyond classical computing. This March, Honeywell claimed they'd built the most powerful quantum computer yet, a machine made of trapped-ion qubits.

However, existing quantum computers cannot run arbitrarily complicated tasks because the hardware works imperfectly. These errors arise from external interference—changes in Earth's magnetic field, for example, that might change a qubit's quantum state—and from mistakes inside the

Scientists Hanhee Paik (left) and Sarah Sheldon (right) examine the hardware inside an open dilution fridge at the IBM Q Lab at IBM's T. J. Watson Research Center in Yorktown, NY. IMAGE: IBM

QUANTUM CONTINUED ON PAGE 6

5 SIGMA CONTINUED FROM PAGE 3

tor's office, and the discussion on immigration policies for physics graduates at North Carolina State University was a great chance to share our thoughts."

James Vary, physics professor at Iowa State University; Klaus Bartschat, physics professor at Drake University; and Wayne Polyzou, physics professor at the University of Iowa, attended meetings with staff in the offices of US Sens. Joni Ernst and Chuck Grassley concerning the Keep STEM Talent Act.

Vary also wrote an op-ed in the Cedar Rapids *Gazette* about the Keep STEM Talent Act. In his piece, he stated, "Our nation's role as a global leader in innovation, however, remains in jeopardy as the number of international students applying for physics PhDs at essential US institutions [is] experiencing a major decline…Fortunately, our US Sens. Joni Ernst and Chuck Grassley are in a position to help by co-sponsoring the Keep STEM Talent Act, which would enable high-skilled international graduate students to both study at US universities and [would] provide a path to a green card if they secure job offers from US employers after graduation."

Bartschat said he was pleased to be among the 5 Sigma Physicist awardees.

"When I looked at the list of awardees from recent years, I recognized some of them, and I am very happy to be in such distinguished company," he said. "I am certainly determined to keep doing what I can, and I hope that more of my colleagues will devote some energy to support the efforts of APS."

Added Polyzou, "Today, with tight budgets, and some public skepticism about science, it is important for all scientists to try to educate the public, and in particular, lawmakers about the impact that science and science policy has on society."

Raju Ghimire, a PhD student focused on nanoscience and microsystem engineering at the University of New Mexico (UNM) and a visiting PhD student at the University of Texas at Austin (UT Austin), pointed out, "As scientists, we have the knowledge and expertise to serve as crucial advisers to lawmakers to ensure that their policies are supported by sound, scientific data." Ghimire helped design and implement a survey of international physics graduate students on their experiences with US visa processes and their perceptions of the US as a destination to study and work. He said his advocacy work would not have been possible without the support of his advisers Mehran Tehrani (UT Austin) and Yu-Lin Shen (UNM).

Sophia Hayes, chemistry professor at Washington University in St. Louis, said she was "both honored and humbled" to receive the distinction. Hayes used her expertise on helium during a Capitol Hill hearing. She was also widely quoted in media articles on the topic.

"We scientists often have specialized, detailed knowledge at times, and if that can be put to good use outside the lab for the betterment of society, then it's a tremendous opportunity," she said.

Joseph DiVerdi, chemistry professor at Colorado State University, published an op-ed in *The New York Times* about keeping open the Federal Helium Reserve beyond its 2021 closure date and creating a helium recycling program modeled after one sponsored by the National Science Foundation.

"Advocating for and helping to shape science policy assists the current generation of scientists to further and deepen our understanding of ourselves, our world and our universe. It also contributes to the process of mentoring the next generations of scientists, so that ours will not be the last," said DiVerdi.

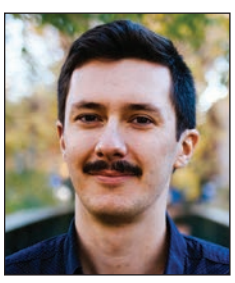
Dany Waller said "wow" after receiving word that she had been selected for the award. She wrote an op-ed in *The Louisville Courier Journal* that asked congressional leaders to lift budgetary caps to promote investment in scientific research and STEM job growth.

"I'm so honored to be recognized for my work. Collaborating on an op-ed really spurred me to stay involved at a local and national level at a time when I was considering disengaging from advocacy entirely," said Waller, former president of the University of Kentucky's Association of Women in Mathematics and Physics. "We can't expect the public and policymakers to support our work if we are not putting in the effort to convince them of its impact."

Francis Slakey, APS Chief Government Affairs Officer, said the 5 Sigma Physicist awardees represent the best of the best in science policy advocacy.

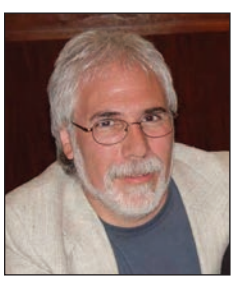
"APS greatly appreciates the time and effort these volunteers committed to advocacy initiatives that benefit not only the physics community but society as a whole. They set the standard for outstanding advocacy, and we look forward to working with them and many other APS members who are determined to let their voices be heard on crucial science policy issues," he said.

The author is APS Senior Press Secretary.



Stephen Albright

Klaus Bartschat



Joseph DiVerdi

Midhat Farooq

Nadia Fomin

Raju Ghimire

Sophia Hayes

Amber Lauer

Christine Nattrass

Tiffany Nichols

Kevin Nuckolls

Saeed Pegahan

Wayne Polyzou

Elizabeth Mae Scott

James Vary

Dany Waller

QUANTUM CONTINUED FROM PAGE 5

machine itself, such as imprecisely calibrated lasers.

So one major hurdle on this decades-long track is to build a machine capable of correcting hardware errors in real time. "Quantum error correction is how we're going to turn the noisy qubits we have right now into actual devices capable of solving real-world problems," says Ted Yoder, a theorist working at IBM.

This year's cancelled APS March Meeting was to feature presentations from researchers across both academia and industry on the latest research in quantum error correction. While theorists began considering quantum error correction more than two decades ago, researchers have only recently begun to move toward actual experiments. "We're transitioning from being mostly a theorist's playground to actual practical implementation," says Yoder.

A collaboration between IBM and Raytheon, for example, has recently reported a demonstration of error correction in real time using five qubits. Meanwhile, on the theoretical side, researchers continue to optimize existing codes and develop mathematical formalism to better understand how the algorithms work. Another active area of research is how to apply theoretical insights to existing quantum hardware.

The basic task of quantum error correction can be broken into two steps: first, to detect errors that occur during computation, and second, to undo those errors. These errors arise for a variety of reasons: operations on one qubit may unintentionally alter an adjacent qubit's state, for example, which is a specific error known as crosstalk. Researchers working on error correction develop algorithms that are robust to these unintended hardware errors.

Quantum errors present physicists with unique challenges. Classical algorithms correct errors in part by duplicating data. For example, in so-called classical repetition codes, a classical computer works with multiple copies of the same bit, so that if one bit is somehow flipped in transmission, the computer can apply a "majority rules" algorithm to correct that error. But this code doesn't translate to a quantum computer because qubits are restricted by the so-called "no-cloning theorem," which prohibits the duplication of a quantum state.

Summed up broadly, "in order to do quantum error correction, I need to check the state of the system without directly measuring it," says Natalie Brown of the Georgia Institute of Technology, who is slated to start work at Honeywell this summer.

One popular strategy is to employ a constellation of "physical" qubits—multiple trapped ions or superconducting circuits, for example—to collectively work as one "logical" qubit of information. In this scenario, several "data" qubits hold the information being computed, and it is coupled to supporting qubits known as "ancilla" qubits. The computer infers errors by directly measuring the ancilla qubits, but it leaves the data qubit untouched, preserving its quantum state. Yoder has recently shown that a class of error correction codes require a fraction of the qubits needed relative to one commonly used code. "We should be optimistic about the resources required for error correction," he says.

Still, an error-corrected quantum computer will require lots of qubits. The computer that Google used in its widely reported experiment, for example, consists of 54 superconducting circuit qubits. To perform error correction, most of those are ancilla qubits, with only a few participating in the main computation task. Because existing hardware contains relatively few qubits, it has thus far been difficult to implement error correction algorithms. "We're just now getting to the point of having enough qubits to do error correction," says Brown.

Brown, who recently defended her PhD, has used simulations of a 36-qubit computer to study a particular type of error known as a leakage error. These errors arise because qubits are not perfect two-state systems; they can include third, fourth, or more energy levels, and a so-called "leakage" occurs when the qubit is accidentally put in one of these higher states. In an analysis of these errors, Brown found that leakage errors in ancilla qubits were much more damaging than those in data qubits.

Brown's project was funded through the Quantum Information Science and Engineering Network (QISE-NET), a new NSF-funded fellowship that began in 2019, associated with the University of Chicago and Harvard University. The fellowship, geared toward graduate students in fields related to quantum technology, facilitates a project among the student, academic adviser, and an industry partner. Brown's industry partner was IBM.

Both Brown and Yoder work on undoing errors with software. Michael Biercuk of the University of Sydney, on the other hand, has founded a startup company called Q-CTRL (pronounced "cue control") that sells machine learning-driven tools to identify and minimize hardware errors in the first place. Q-CTRL's customers include quantum computing startup Rigetti, the Massachusetts Institute of Technology, and the University of Southern California.

This design approach is called "control engineering," and is inspired by the way the Wright brothers invented the first airplane. Prior to the Wright brothers, airplane developers avoided giving pilots much control over the aircraft, instead trying to make an airplane that flew mostly on its own. "The Wright brothers said, 'Forget that,'" says Biercuk. "They were bicycle engineers. They knew that you can ride a bicycle upright down the street with a lot of control. They took that mindset and applied it to the development of aircraft." Most famously, the Wright plane flew with deformable wings whose shape the pilot could control.

This hardware approach, combined with quantum error correction, could lead to useful quantum computers. "Within this decade we feel like we can see a quantum advantage, and error correction will be part of it," says Yoder.

The author is a freelance writer in Tucson, Arizona.

CANNON CONTINUED FROM PAGE 2

O, B, A, F, G, K, and M. Astronomy students still use a handy mnemonic to remember the classifications: "Oh Be A Fine Girl, Kiss Me." Her scheme was formally adopted by the International Astronomical Union on May 9, 1922. That same year, Cannon spent six months photographing stars in the Southern hemisphere in Peru.

The nine volumes of the Henry Draper Catalog were published between 1918 and 1924, and when Pickering died in 1919, Cannon took over the oversight for the remaining six volumes. She also contributed to the Henry Draper Extension Charts, the first part of which was published in 1937. The full extension charts were published in 1949.

Cannon was the first woman to receive an honorary doctorate of science from Oxford University, and the first woman to receive the National Academy of Science's Henry Draper Medal, thanks to a nomination by Pickering's successor, Harlow Shapley.

She also established the American Astronomical Society's Annie Jump Cannon Prize. Astronomer Cecilia Payne-Gaposchkin, who used Cannon's data to prove that stars were mostly made up of hydrogen and helium, was the first honoree, and received a gold pin in the shape of a spiral galaxy. "Isn't it the first universe ever made by a woman?" Cannon remarked when she saw the pin. Prizewinners still receive a handcrafted piece of jewelry to this day.

In 1938, Cannon became the William C. Bond Astronomer and Curator of Astronomical Photographs, a position she held until her death on April 13, 1941, at the age of 77. She catalogued some 350,000 stars in her lifetime, discovering 300 variable stars, five novas, and one spectroscopic binary star in the process.

Further Reading:

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Greenstein, George. (1993). "The Ladies of Observatory Hill," *American Scholar* 62(3): 437-446.

Sobel, Dava. *The Glass Universe: How the Ladies of the Harvard Observatory Took the Measure of the Stars*. New York: Penguin, 2016.

DAMOP CONTINUED FROM PAGE 3

with other divisions and units in APS" and to "increase the diversity of the DAMOP membership" (currently >80% male). Safronova also emphasized the importance of increasing international collaborations. She elaborated that with largely table-top research, international collaboration wasn't an intrinsic requirement part of AMO physics historically, but that is beginning to change – most notably in subfields such as atomic clocks, which involve a geographically distributed network of clocks.

Overall, over 77 years and counting, DAMOP has proven itself as a major cornerstone of APS as a whole, and a leader among divisions toward openness and collaboration. More information on this unit can be found here: aps.org/units/damop.

The author is a freelance writer in Stockholm, Sweden

CAPITOL HILL CONTINUED FROM PAGE 4

the APS CVD because she "knew very little about how groups like APS help shape policy decisions." Elliott continued, "I enjoyed the insights into that process and thinking about how science isn't serendipity, but the outcome of deliberate actions by scientists and lawmakers."

The APS CVD experience was "quite positive," said Pushpa Bhat, senior scientist at Fermi National Accelerator Laboratory.

She noted that congressional staffers were "supportive of attracting the best and brightest" students to study and work in the US—a primary goal of the Keep STEM Talent Act.

"It doesn't make sense to have these students trained here and then have them leave," she explained.

Much to the delight of Jason Fry, assistant professor of physics and astronomy at Eastern Kentucky University, he received great news about the Keep STEM Talent Act during his meetings.

"US Rep. Tim Burchett (TN-2nd) and US Rep. Andy Barr (KY-6th) both said they would like to co-sponsor it," he said, excitedly. "Everyone we talked to said it sounds like a good idea."

APS CVD continues to be a highlight event for APS members and the Society's advocacy efforts, said Callie Pruett, Senior Strategist for Grassroots Advocacy in the APS Office of Government Affairs (APS OGA).

"We equipped nearly 70 APS members to confidently go into meetings and speak on five key issues. And we strengthened our coalition of APS members who have already taken an active role in advocating for the future of science," she said.

APS members provided good feedback about their meetings on Capitol Hill, added Pruett.

"There are new avenues now open with congressional offices to help advance the Keep STEM Talent Act and the Combating Sexual Harassment in Science Act, address the helium crisis, counter the proposed rollback on methane emissions, and increase the federal research and development budget," she explained. "Our teams were well-prepared, organized, and on their A-game, and the feedback from the offices reflected that."

Following the CVD, Pruett said US Sen. Chris Van Hollen (MD) and US Sen. Dianne Feinstein (CA) signed on to co-sponsor the Combating Sexual Harassment in Science Act in the Senate. Additionally, US Rep. Himes (CT-4th) and Van Hollen have both added their co-sponsorships the Keep STEM Talent Act in the House and Senate, respectively.

"These legislative developments have a direct connection to APS's advocacy efforts. As follow-up and communication continues, we aim to see more results and co-sponsorships," said Pruett.

"CVD is a great example of APS staff across departments and locations working together to provide a unique opportunity for APS members," said Mark Elsesser, Associate Director of Government Affairs in APS OGA. "The day continues to be a success because of the strong coordination between several APS departments, including OGA, Communications, and Membership," he said.

Keeping members engaged on important science policy issues is a key goal of APS OGA, explained Francis Slakey, APS Chief Government Affairs Officer.

"We want to make sure our members are fully equipped to take advantage of as many opportunities as possible to make their voices heard on crucial science policy issues that impact the physics community and scientific enterprise," he said.

The author is APS Senior Press Secretary. To get involved in APS's grassroots advocacy initiatives, contact Callie Pruett, Senior Strategist for Grassroots Advocacy, at pruett@aps.org.

COVID-19 CONTINUED FROM PAGE 1

APS Meetings

The in-person APS March and April Meetings have been canceled. APS is supporting virtual access to March Meeting presentations and is working actively to provide a virtual April Meeting.

Virtual content from the March Meeting. There have been a number of spontaneous initiatives by individuals and small groups of researchers aimed at enabling the sharing of research that would have been presented at the March Meeting. A number of March Meeting units and attendees have organized virtual March Meeting sessions. Check march.aps.org/about/sharing-your-research/ regularly for updates.

Virtual April Meeting Confirmed. APS is excited to announce that the April Meeting will be the inaugural APS Virtual Meeting, taking place over the same dates (18–21 April 2020). APS staff have selected a third-party virtual meeting platform that supports live sessions, recording of and technical support for live sessions, and pre-recorded talks. The platform also will allow small groups of participants to interact directly with each other and exhibitors. For the latest visit april.aps.org.

Registration refunds. APS has processed the majority of the March Meeting registration refunds. Upon processing the refund, it will take up to three days for the credit to appear on the credit card from which the payment was initiated.

In addition, each registrant should receive an email from meetings-refunds@aps.org that includes a copy of the refund invoice. It is each registrant's responsibility to provide a copy of the refund invoice to the party who paid for their registration, as applicable.

If you have not received an email from meetings-refunds@aps.org or do not see the credit on your statement, please check your APS account at my.aps.org under My Orders or feel free to contact meetings-refunds@aps.org and include the following information so we can investigate:

Registrant Name

Registrant ID number

Credit Amount Expected

Last four digits of credit card number (if known)

APS has started processing meeting registration refunds for the April meeting and will follow a similar process.

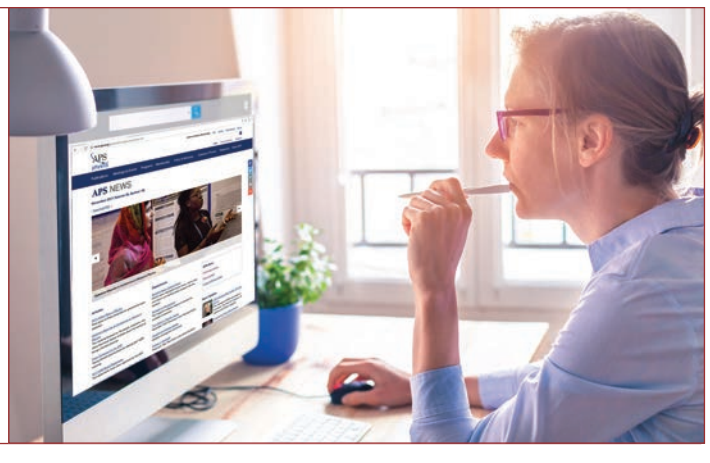
Note: Some funding agencies permit investigators to use grant funds to pay for nonrefundable travel costs resulting from cancellations. Among these are the DOE Office of Science and NSF. Visit energy.gov/science and nsf.gov for more information and check with your program manager or agency contact to verify eligibility.

APS News and *Physics Today*

APS members will continue to receive print copies of *APS News* and *Physics Today*. If you currently receive them at your workplace, you may go to your my.aps.org profile to add a delivery address to receive them at home. We would also like to remind everyone that they can read all the articles published by *APS News* free online: aps.org/apsnews.

Membership

APS extends thanks to all members who continue to demonstrate support of the Society by renewing their membership. Processing of new memberships and renewals is functioning as usual. If you have any questions about your membership status, unit membership, or other details, you can contact APS Member Services at aps.org/membership.



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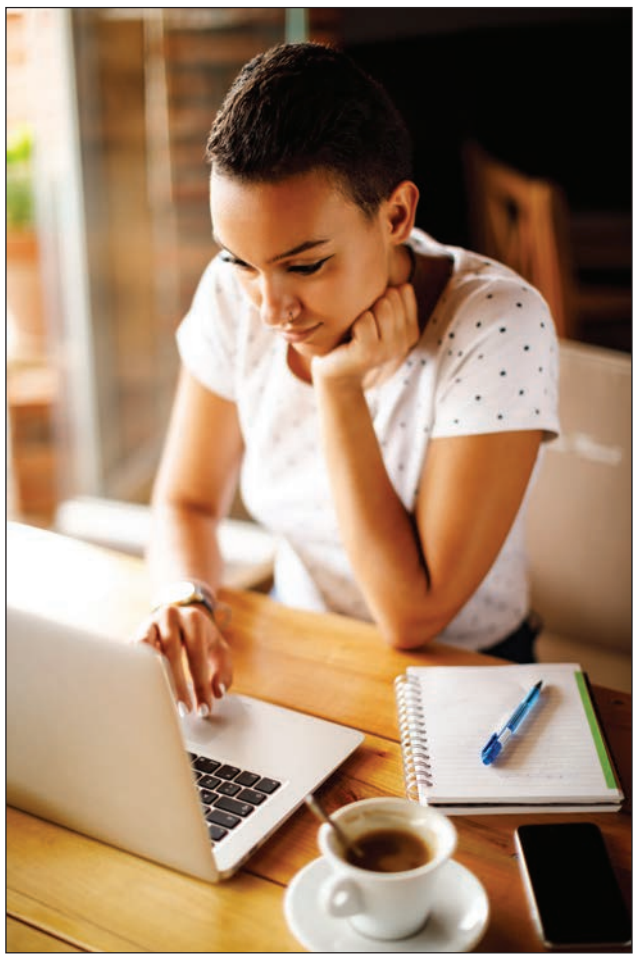
Moving Physics Courses Online on Short Notice

BY CHANDRALEKHA SINGH

In the midst of the COVID-19 pandemic, many physics instructors have suddenly found themselves in an unprecedented situation: their institutions are immediately transitioning to a completely online format. Here are some strategies and resources that can help you and your colleagues in such a situation. Keep in mind that being compassionate and providing maximum flexibility to students is critical, particularly because they did not sign up for an online course and many of them may not have necessary resources, e.g., access to a computer with reliable internet connection or a quiet room at home or required time due to being sick or caring for a sick family member in order to complete all of the requirements of your online course. Everyone is anxious and trying to do their very best, so whatever you and your students can accomplish is good. Communicating frequently and clearly with students is key.

There are many online resources, for example, Linda Strubbe and Sam McKagan's excellent crowd-sourced resources on PhysPort [1], that can be invaluable so you should definitely go over it in its entirety. Below, I summarize seven things to keep in mind while preparing for and executing your online physics courses, including labs:

1. **Keep the focus on the learning goals and objectives of your course.** For example, if your big picture goals are to help students learn to think like a physicist and help them become independent learners and excellent problem solvers, think carefully about strategies for how your online course will accomplish that [2-3]. Reduce the overall content coverage and instead focus on effective approaches to engaging students and assessing their learning.
2. **For lecture-based courses, decide whether it is better to deliver your lectures synchronously or asynchronously.** Synchronous approach involves streaming your lectures live to students, e.g., via Zoom, BlueJeans, Skype or other platforms, and interacting with students as you would do in a brick and mortar classroom. You can record the streamed lecture for students who could not join the live streaming. While the synchronous format allows interactivity, not requiring real-time attendance and posting recorded videos of live streamed sessions is critical for those students who do not have the resources or means to connect live.
3. **Consider establishing virtual office hours** and have them at different times of the day so that students in different time zones can connect with you. These live one-on-one or few-on-one sessions will give your students an opportunity to ask questions after they have had time to reflect on the material and work on homework. A discussion board, e.g., Blackboard or Canvas, where students and you can discuss what students are finding challenging and there is a record of those discussions for all students can be invaluable. Also, using low-bandwidth methods like chat apps may be particularly helpful for students whose internet connections do not reliably support video.
4. **Consider using pre-recorded lectures, created either by you or by others**. This way you can use all of the synchronous time with students for interactions, discussions, and reflections. This approach is common in the "flipped mode" [4] of teaching in which most of the meeting time with students is devoted to activities in the spirit of "Just-in-time-teaching" [5,6]. Students interact with their peers and instructor after having gone over the pre-lectures and the corresponding pre-assessment tasks. Videoconferencing solutions such as Zoom have breakout rooms so that a smaller number of students can work with each other on the physics problems you assign. Then, students can go back into the same virtual room for a general discussion. In large classes, you may poll students by asking multiple-choice questions [7] that focus on your learning goals although it may be more difficult to engage students in peer interaction in this mode. Also, if you are pre-recording your own lectures [8], make sure that you break your lecture into roughly 10-minute sub-lectures and intersperse them with online assessments. This design is conducive to maintaining students' attention and giving them an opportunity to assess their learning between different modules. Each of these pre-recorded sub-lectures can be, e.g., voice over power point or similar to Khan Academy offerings [9] (you will need a laptop or iPad with ability to write on it). Try to incorporate good visuals and if possible lecture demonstrations especially for introductory physics. If you are using pre-recorded video lectures, you can use the existing resources for introductory physics [4], although it may cost money.



5. **For lab courses, take advantage of interactive virtual labs, simulations, and journal articles.** There are many such virtual labs (e.g., see [10-13], some of them are free while others may cost money beyond a 30-day trial period). Articles in the *American Journal of Physics* (AJP) and *The Physics Teacher* (TPT) can be great resources in online teaching not only in lecture-based courses but particularly for your lab courses at all levels. For example, there are many experiments that have been discussed in a pedagogical manner in AJP and TPT. In these articles, e.g., instructors have often shared insights about classic experiments, e.g., single-photon experiments for which video data are available [14], the Millikan oil drop experiment [15], muon decay [16], and many others. You could ask students to read about the experiments and then write about which aspects of those experimental set ups made them effective, how things evolved in that field and how trouble shooting was done, what the experimental errors were, and their implications to physics in general and various other issues based upon your goals. You can have a virtual discussion with the students about what they got out of those papers and assess them on their writings and discussions. If possible, combine these tasks with interactive simulations and data analysis. Similarly, for upper-level lecture classes, AJP and TPT articles often provide nice overview of a field including common student difficulties that can make it easier for students to understand the concepts. This can help students learn to read and reflect upon journal articles (good for becoming a lifelong learner) and enjoy the whole experience.
6. **Remind yourself that these are extraordinary circumstances and feel free to change assessment approach and be considerate.** It is ok to change assessment strategies as well as grading rubric and adjust the emphasis before and after going online. For example, it is ok for you to reduce the weight on the final exam or even eliminate the traditional final exam in favor of many low-stakes assessments, final projects, and online presentations (that can be pre-recorded or can be synchronous so that students can field questions from their peers and you). Students should be allowed to work in groups on these projects to reduce isolation (particularly because isolation can increase anxiety) and to benefit from interactions. You can come up with novel group projects that meet the goals of your course in lieu of the final exam especially for your upper-level courses that require students to work in groups but have some individual accountability built into them (e.g., all students must present some part of their project individually and answer questions by peers and instructor). If you must give final exams that students will do at their own pace at home, use an honor code. Try to be especially considerate to students who may not have resources at home to take advantage of the full online learning environment. Be inclusive and think about whether it is appropriate and equitable to give students who cannot do the work due to constraints an incomplete so they can make up later or modify requirements for them commensurate with their constraints so that they can finish with everyone. Consider not giving a grade lower than what they would have gotten based upon their performance on the course thus far before going online.
7. **Remember that technology is a tool and not the goal.** Make sure the focus is always on your students and their learning based upon your course goals and personalize learning as much as possible in this online environment so that students who are already disadvantaged in many ways are not penalized further. Share your ideas with your colleagues and help each other. We will learn a lot about online learning at the end of this challenging period!

Chandralekha Singh is a professor in the Department of Physics and Astronomy at the University of Pittsburgh. She is a past chair of the APS Forum on Education and is currently the President of the American Association of Physics Teachers.

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