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APS physics

Q&A with Nobel Laureate Steven Weinberg
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# REVIEWS OF MODERN PHYSICS

## Synthesizing Current Research Succinctly and Elegantly

*By Randall Kamien*

Ninety years ago the editor of the *Physical Review*, John T. Tate, proposed "a new type of journal in Physics—a journal in which would appear reports and critical comments on the various branches of current thought and research." He continues, "[w]e recognize the value of this kind of thing in so many ways—in the symposia we have at our meetings—in the seminars we hold in our research laboratories and universities. I would hope that this journal would extend the advantages of that sort of discussion to a much wider audience."

Endorsed by a few dozen prominent physicists, a supplement to the *Physical Review* was created, now known as *Reviews of Modern Physics*. Long before the arXiv, fax machines, and express mail, this was a timely way to disseminate and educate. The very first article, on the probable value of the physical constants by Raymond Birge in 1929, was the forerunner to the Particle Data Group's ongoing mission. Hans Bethe, with collaborators, published a series of review articles on nuclear physics in the 1930s that came to be known as the "Bethe bible." In 1948, Richard Feynman published his article on the path integral approach to quantum mechanics. Over the years, David Mermin has published any number of insightful reviews, and the list goes on. Articles that are over 50 years old are still a delight to read and can teach us much, from physics to pedagogy.

REVIEWS OF MODERN PHYSICS
90 YEARS

Why can't we replace this with video recorded lectures and disseminate ideas *à la* social media with hyperlinks serving up every definition and acronym, and routing us down every rabbit hole? Because good writing begets good reading, and good reading is a deliberate exercise, not a Sunday

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## APS Bridge Program and the National Mentoring Community Visit Google HQ

*By Leah Poffenberger*

From November 16 to 18, 2018 the APS Bridge Program and the National Mentoring Community (NMC) held a joint conference for the first time, drawing the highest number of undergraduates, graduate students, and faculty mentors to date. More than 200 attendees spent a day at the Google Headquarters and another two days at Stanford University learning about physics career opportunities.

The APS Bridge Program and the NMC partnered up for this conference to further the goal of increasing diversity of students in physics. The Bridge Program helps undergraduate students from underrepresented minorities enter graduate school, and the mentoring program helps ensure student success.

A large draw for this year's record-setting attendance was the chance to visit Google's headquarters in Mountain View, CA. The trip to Google focused on ways students can prepare for and succeed in physics careers in industry. Google employees were on hand to talk with conference attendees and show them around the company's campus.

"I didn't know what to expect from the Google meeting since I assumed they only hired computer science degrees. It was super exciting to see physics representation at high-level positions at Google, and

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## APS Membership Unit Profile: The Topical Group on Medical Physics

*By Abigail Dove*

With over five hundred members and counting, the APS Topical Group on Medical Physics (GMED) explores the physics underlying human health and disease—from modeling the physics of disease states to the development and optimization of medical technologies and interventions. Established in 2016, GMED is one of the newest topical groups at APS, but the tradition of physics in medicine dates back to discovery of radioactivity and emergence of technologies such as radiology and radiotherapy in the 19th century. Decades later, some of today's hottest topics include particle transport (in scanners and tissue alike), modeling of tumor origins, development of and response to different kinds of therapies, and extrapolating the causal factors that lead to disease.

The founding of GMED began with a conversation between Princeton's Bob Austin (outgoing chair) and University of Wisconsin's Robert Jeraj (incoming chair), who recognized the need for an organization that brings together physicists working on questions relevant to medicine. This realization was sparked in part by the National Cancer Institute's (NCI) Physical Sciences Oncology Centers, a network of twelve research centers established in 2009 to bring together a diverse array of scientists (and particularly physicists) to rethink cancer. Austin, who headed the

Robert Jeraj

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## One if by Land, Qubits by Sea: The 2019 APS March Meeting heads to Boston

*By Leah Poffenberger*

The world's largest physics meeting will see more than 11,000 attendees, including over 1,000 invited speakers, flocking to Boston to share research, network with future collaborators, and attend many events and workshops. The APS March Meeting will run March 4–8 at the Boston Convention and Exhibition Center (BCEC).

The 2018 Nobel Prize in Physics winners Gérard Mourou (École Polytechnique and the University of Michigan, Ann Arbor) and Donna Strickland (University of Waterloo) will speak at a special Nobel Prize session on Thursday, March 7 (5:45–6:30 PM). They will discuss the development of chirped pulse amplification, which paved the way for improved laser technology and secured them half of the Nobel Prize.

This year's Kavli Foundation Special Symposium, themed "from unit cell to biological cell" will feature five distinguished speakers on March 6 (2:30–5:30 PM). Claudia Felser (Max Planck institute for Chemical Physics of Solids) will speak on magnetic materials called Heusler compounds and their wide range of uses. Philip Kim (Harvard University) will share research on the emerging new physics of atomically thin structures made by stacking 2D quantum materials. A method of creating ultra-stable glass comes from research done by Mark D. Ediger (University of Wisconsin, Madison). Sharon Glotzer (University of Michigan) will introduce the notion of the entropic bond in her talk "Colloidal Crystals, Quasicrystals and the Entropic Bond." Clifford Brangwynne (Princeton University) combines biology and soft matter physics in an exploration of self-assembly of biological materials.

The March Meeting officially begins on Monday, March 4, but a number of pre-meeting activities are available on Sunday, March 3, including an orientation session for first-time March Meeting attendees (5:00–6:00 PM). A special workshop, Get the Facts Out: Changing the Conversation Around STEM Teacher Recruitment, aimed at addressing misconceptions that discourage students from pursuing careers as physics teachers, will also be held in partnership with the 2019 PhysTEC conference (2:30–5:00 PM). A Wikipedia Edit-a-thon to create Wikipedia pages for female and underrepresented minority physicists rounds out the night (6:00–9:00 PM).

The APS Prizes and Awards Ceremony will be held Monday evening (5:45–6:45 PM) followed by a welcome reception. A special outreach session on quantum information science policy "Enabling Quantum Leap: National Quantum Initiative" will also follow the Prizes and Awards Ceremony (7:30–9:40 PM).

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it was very inspiring," said Marcus Dupont, a senior at Florida State University. "I know that if I decide to go into industry after my PhD, Google is the first place I 'm applying. The conversations were very fruitful there."

Stanford University hosted the rest of the conference, which included a number of workshops for students as well as mentors attending the conference as part of NMC. Around 40 student attendees also participated in a poster competition for both undergraduate and graduate students.

The conference also included six plenary sessions covering important topics in physics education including retention of students, mental health in graduate education, and how mentors can better support their students. At one of the plenary sessions, Theodore Hodapp, APS Senior Advisor to Education and Diversity programs, spoke on the Inclusive Graduate Education Network, an alliance between APS and four other scientific societies—the American Chemical Society, the American Geophysical Union, the American Astronomical Society, and the Materials Research Society—set to expand the Bridge Program into fields beyond physics.

"The conference was very successful at helping physics students from underrepresented groups make important connections and learn strategies for thriving in physics," said David May, Diversity and Education Programs Manager at APS. "In addition, APS strengthened its valuable connections with NSBP [the National Society of Black Physicists] and the NSHP [National Society of Hispanic Physicists] and is looking into running a joint conference with NSBP and APS's NMC program in 2020."

Links: APS Bridge Program: aps.org/programs/minorities/bridge/

National Mentoring Community: aps.org/programs/minorities/nmc/



# This Month in Physics History

## February 6, 1970: Luis Alvarez's paper in *Science* on cosmic rays and pyramids

When archaeologists confirmed their discovery of a hidden burial chamber in an Egyptian pyramid in 2017, it was in some respects the culmination of a project undertaken in the 1960s. A physicist named Luis Walter Alvarez came up with the idea of using cosmic rays to map dense structures like the Great Pyramid of Giza.

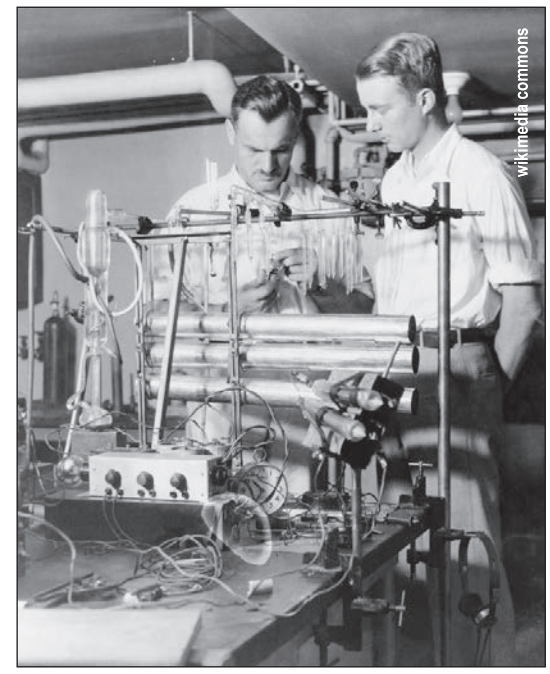
Alvarez was born in 1911 in San Francisco. His father and grandfather were both physicians, and his Aunt Mabel was an artist. When his father took a job at the Mayo Clinic, the family relocated to Minnesota for young Luis's high school years. He attended the University of Chicago, ultimately earning his PhD in physics in 1936. During his graduate studies, he built a cosmic ray telescope out of Geiger counter tubes and used it to determine that primary cosmic rays had a positive charge.

Alvarez's sister, Gladys, worked as a secretary for Ernest Lawrence, so after getting his PhD, he asked if there were any job openings at Lawrence's laboratory. Lawrence offered him a job, and Alvarez joined the University of California in Berkeley to work with the cyclotron. He designed experiments to study radioactive nuclei, specifically the detection of soft x-rays from a particular type of beta decay that had been predicted but not yet observed.

During World War II, Alvarez joined the newly formed Radiation Laboratory at MIT, where he developed military applications for microwave radar. He worked on several radar projects while there, and is best known for the Ground Controlled Approach (GCA) system, which used a dipole antenna for improved resolution. Even untrained pilots could be guided through a runway landing by ground-based operators using the GCA system. It was still in use in some countries as recently as the 1980s. While testing the GCA in England in the summer of 1943, Alvarez met a young Arthur C. Clarke, then a radar technician with the Royal Air Force, and they struck up a years-long friendship.

That fall, Alvarez joined the Manhattan Project. One of his first tasks was to find a means of discovering whether the Germans had any nuclear reactors in operation. Alvarez outfitted an airplane with a system capable of detecting the radioactive gases such reactors would produce. Germany didn't have any reactors at the time, so the mission found no such evidence, but the approach would prove to be extremely useful for intelligence gathering in the post-War era. His final task on the Manhattan Project: designing small instruments to measure the strength of the shock wave from an atomic bomb. He was present at the Trinity Test in 1945 and used his instruments aboard a B-29 to measure the blast energy of the atomic bombs dropped on Hiroshima and Nagasaki.

After the war, Alvarez applied his radar expertise to improve particle accelerators, leading to the construction of the Bevatron in 1954. Alvarez's contribution was to adapt a bubble chamber so that it could work with liquid hydrogen, the better to image particle interactions. He received the Nobel Prize in Physics in 1968: "For his decisive contributions to elementary particle physics, in particular the discovery of a large number of resonant states, made possible through his development of the technique of using hydrogen bubble chambers and data analysis."




Nobel Laureate Arthur Compton, left, with young graduate student Luis Alvarez at the University of Chicago in 1933

His earlier cosmic ray research eventually led to his 1965 proposal that one could use muon tomography to hunt for previously undiscovered chambers in Egyptian pyramids. Alvarez and his interdisciplinary team of physicists and archaeologists placed spark chambers in a known chamber beneath the second pyramid of Chephren to detect incoming cosmic rays and measure their deflections as they hit the solid bricks of the structure. The muons would pass right through a chamber, however, registering a void in the resulting image.

The Arab-Israeli Six Day War of 1967 interrupted the experiment briefly, but things resumed soon after, and Alvarez's team continued taking cosmic ray data for the next two years. At a 1969 APS meeting, Alvarez reported that they had successfully surveyed about 19 percent of the pyramid, but had found no hidden chambers. He and his colleagues also published a paper in *Science* to that effect in February 1970.

Alvarez's natural curiosity often took him well outside the physics laboratory. When *Life* magazine published photographs in 1966 of President John F. Kennedy's assassination, Alvarez applied his expertise in optics and photo-analysis to the images. His conclusions, outlined in an informal tutorial paper, went against many of the conspiracy theories circulating at the time. For instance, he found that the backward snap of Kennedy's head is what would happen with a shot from behind and pointed

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**Editor** ........ **David Voss**
**Staff Science Writer** ........ **Leah Poffenberger**
**Contributing Correspondent** ........ **Alaina G. Levine**
**Design and Production** ........ **Nancy Bennett-Karasik**

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# Impact of Women in STEM Roadshow in India

*By Sultana N. Nahar*

The US Department of State funded project "Women in STEM Roadshow" (WSR), which ran from October 1, 2017 to September 30, 2018, was a huge success and made an enormous impact on the young inquisitive minds of female students from minority and disadvantaged groups in India. The project focused on inspiring students to choose STEM (science, technology, engineering, and mathematics) fields for their education and research, study in US universities for higher degrees, and use their knowledge for the development of India.

The goals of the WSR were to strengthen ties between people in the United States and India through exchanges of information, experiences, and expertise; support economic growth and development by creating awareness of higher education opportunities in STEM fields among girls and young women; and encourage more Indian students to consider higher education opportunities in the United States by interacting with alumni from US universities in India and promoting the EducationUSA network (educationusa.state.gov) that provides information on various US educational institutions and how to study at one of them.

WSR was structured around nine workshops, each two days long, in six cities in India—Delhi, Hyderabad, Kolkata, Aligarh, Kurnool, and Patna—and included a year-long monitoring period to evaluate its impact. In total, the WSR reached 388 participants, most of whom were undergraduate students, a number of high school students, about 25 teachers, and 10 alumni from US institutions. The number of applications overall was higher than expected in most places, and the number of Muslim student applications was significantly higher than other groups.

Sabiha Parveen, one of the US graduates, wrote that she learned about the increasing need

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Workshop participant S. Nabiha (left) achieved Rank 1 position in the B.Sc. exam and is planning on further study after her M.Sc. She received her certificate from Sultana Nahar (right).



# Fuzzy Fluid Dynamics: Bats, Fruit Flies, and Wombats

*By Leah Poffenberger*

The 71st Annual Division of Fluid Dynamics (DFD) Meeting in Atlanta last year had its fair share of sessions on topics most people would associate with fluid dynamics: bubbles, drops, turbulence, and flows. But intermixed with research on fizzing fluids or whimsical waves was the science behind the curiosities of creatures. A number of talks covered research into how animals and insects use fluid dynamics, including how bats suck up nectar, how fruit flies fly, and how wombats create their unique cuboidal feces.


Itai Cohen demonstrates how fruit flies can be so acrobatic.

## Bats battling drip

Anette Hosoi (Massachusetts Institute of Technology), recipient of the 2018 Stanley Corrsin Award, brought "Hairy Hydrodynamics" to DFD with her research on bats, specifically how nectar-eating bats manage to drink their dinner. The secret is tiny hair-like structures that trap nectar, but in Hosoi's lab, the research team wanted to know more about how these structures work: What properties allow the flying-feasters to optimize the amount of nectar they can grab?

Researchers created rubbery faux bat tongues with different densities of bristles to see their effects on trapping nectar: Too few, and the nectar can flow down and off the tongue, but too many and there isn't enough space between the structures to capture much nectar at all. Bats, as it turns out, have just the right number of bristles to combat the drip and can pick up 10 times more nectar than if their tongues were smooth. Certain types of parrots, a tiny Australian marsupial called a honey possum, and honey bees all use similar hair-like structures to help slurp up their food.

Hosoi's group has also used the materials they developed to mimic bristles on bat tongues to study the effect of flexible hairs on the flow of fluid. The subsequent findings, where shape of the flexible hairs creates drag, matches findings from previous researchers, including Stanley Corrsin, who studied placental blood flow through finger-like structures called villus trees in 1977.

## Acrobatic flies

The fast-flying antics of fruit flies may make them a nuisance to many people, but Itai Cohen (Cornell), an invited speaker at DFD and former chair of the APS Forum on Outreach and Engaging the Public, finds them fascinating. In an invited talk, Cohen explained—and at times demonstrated with his own pair of scaled-up fly wings—how flies are able to make quick adjustments in the air.

Due to their small size, fruit flies have to adjust their motion up to 100 times faster than a larger animal to deal with aerodynamic instabilities, beating their wings in elegant figure-8 motions up to 30 times in the blink of an eye. To figure out how it is flies achieve this, Cohen had to slow them down: By taking slo-mo video of flies and using an algorithm to reconstruct the image frames, the researchers could pinpoint what allows these adjustments.

The research team's results identified the biggest factor for flight control in fruit flies: The pitch, or angle, of the wings. Smaller pitch, and the fly can generate more forward thrust. These pitch adjustments allow flies to pirouette and self-correct in mid-air, but these adjustments can only be made thanks to two specialized structures on the fly: a pair of organs called halteres that act as a kind of vibratory gyroscope, and a specific muscle that, when genetically silenced, leaves flies unable to make adjustments.

## Wombats going cubic

Patricia Yang, a postdoctoral fellow at the Georgia Institute of Technology, along with her colleagues Miles Chan, Scott Carver (University of Tasmania), and David Hu, set out to solve one of the animal kingdom's odd mysteries: How do wombats, a type of marsupial from Australia, make cube-shaped poop? Yang's studies of the hydrodynamics of fluids in the bodies of animals sent her searching to see how the soft tissues in the wombat's digestive system could compact fecal matter into the odd shapes wombats leave behind.

Wombats create cubed poop to mark their territory and communicate with other nearby wombats—and the cube shape keeps the scat from rolling away, unlike the spherical or cylindrical shapes from other animals. Yang obtained intestines from Tasmania that had been collected from wombats after unfortunate run-ins with vehicles. After studying the properties of large intestines, still full of feces, Yang determined that points of varying elasticity in the intestinal wall compressed the fecal matter as it passed through, creating the cubed shapes.

Cubes are difficult shapes to create organically, and in manufacturing, cubes are generally only made by molding or cutting materials into a cube. Yang's discovery into how wombats can naturally create cubes by compressing material may eventually lead to new methods in manufacturing.

# Q&A with Standard Bearer Steven Weinberg

*Editor's note: This interview first appeared in* Physics *(physics.aps.org/articles/v11/134).*

*By Michael Schirber*

Steven Weinberg is well-placed to tell the story of the standard model of particle physics. In 1979, he was awarded the Nobel Prize in physics, along with Abdus Salam and Sheldon Glashow, for the unification of the weak and electromagnetic forces. Their "electroweak theory," which became the first pillar of the standard model, assumed a symmetry between photons and vector bosons, the force carriers of the weak interaction. That symmetry, Weinberg proposed, is "spontaneously" broken as a result of interactions with other fields, making it unobservable. His theory explained several puzzles in the field, including why the weak interaction differs for left- and right-handed particles (parity violation).

In a recent essay published in *Physical Review Letters*, Weinberg recounted the excitement surrounding the standard model during its development in the 1960s and 1970s. Now, in an interview with *Physics*, Weinberg explains initial reactions to the model and why it was called "standard." He also offers advice to the current generation of particle physicists as they attempt to build a model that goes beyond the one that he helped build.

**Your 1967 paper, "A model of leptons," was a significant step in the standard model's development. At the time, did you have a sense that your theory would be so transformative?**

I thought it might be. I really felt that I was proposing the kind of theory that might be right and that might solve the outstanding problems of the weak interactions. There were other ideas around at the time, but I was convinced that the way forward was with a gauge symmetry that was spontaneously broken.

Steven Weinberg

**What was the reaction to your idea?**

Just before the paper published, I spoke about the theory at the

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# The APS Office of Government Affairs

## 2018: OGA Worked with APS Members to Effectively Advance Science

*By Tawanda W. Johnson*

The APS Office of Government Affairs (OGA) worked with APS members throughout 2018 to successfully advocate for physics and physicists, and to amplify their voices for science.

OGA facilitated more than 4,000 APS member contacts with Congress—through op-eds in key states and districts, emails, meetings, tweets, and phone calls—to advance the interests of the physics community. In particular, the office worked with APS members who authored opinion pieces that appeared in various media outlets in key states across the country including: Kristan Corwin (Kansas); Shua Sanchez (Washington); Justin Powell (Tennessee); Mike Tamor (Arizona); Don Q. Lamb (Illinois); and Sarit Dhar (Alabama).

Of particular note in 2018, OGA collected more than 1,300 signatures on a petition that successfully opposed the PROSPER (Promoting Real Opportunity, Success and Prosperity through Education Reform) Act, which would have decreased the quality and accessibility of student loans. Students delivered the petition to key senators in their states.

"We are proud of the work OGA is doing to help our members make a difference in achieving policy goals that strengthen the scientific enterprise," said APS Chief Government Affairs Officer Francis Slakey.

Throughout 2018, OGA surveyed APS members at meetings to determine the issues that the physics community was most concerned about, and OGA developed strategies to respond to their needs.

**Federal Research Funding:** In an ongoing effort to achieve sustained and robust support for federal science agencies, OGA working with APS members, and coordinating with other science and technology organizations, advocated for increased funding through APS member op-eds and meetings with congressional offices. The result: key science agencies saw increases from fiscal year 2018 to 2019. For example, the Department of Energy Office of Science's budget increased by 5%. Additionally, the president signed the National Quantum Initiative Act into law, which authorizes $1.2 billion over the next five years for new quantum information science research programs at the National Science Foundation, National Institute of Standards and Technology (NIST), and the Department of Energy. The act also establishes a National Quantum Coordination Office within the White House Office of Science and Technology Policy and promotes the commercialization of research breakthroughs during the next decade.

**Visas & Immigration:** Alerted by APS members, OGA carried out a survey of graduate programs that showed there was an alarming 12% decline in international applications to US institutions, from 2017 to 2018. OGA responded, in part, by urging Congress to make the F-1 visa "dual intent"—giving international students the opportunity to simultaneously study and apply for citizenship in the United States. APS leaders, physics department chairs, and members participated in numerous meetings in their states and on Capitol Hill. During 2019, the office plans to expand the goal to address the broader issue of scientific mobility.

**STEM Education**: US Rep. Joaquin Castro (TX-20th) and former US Rep. Barbara Comstock (VA-10th) co-sponsored a bipartisan resolution recognizing the importance of the APS Bridge Program in helping underrepresented minorities in STEM earn PhD degrees in physics. The resolution followed the visits of several Bridge students who met directly with some members of Congress and shared their compelling stories

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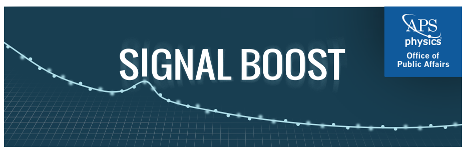


Signal Boost is a monthly email video newsletter alerting APS members to policy issues and identifying opportunities to get involved. Past issues are available at go.aps.org/2nr298D. To receive Signal Boost and learn more about grassroots activities, contact the Office of Government Affairs at oga@aps.org.

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# FYI: Science Policy News From AIP

## Five Science Policy Stories to Watch in 2019

*By the FYI Team*

A measure of predictability returned to federal science policy in 2018 as Congress decisively rejected the Trump administration's proposed budget cuts. However, the partial government shutdown that ensued at year's end serves as a sobering reminder of the current political era's volatility. In addition, the sudden surge of interest in subjects such as quantum information science and technological competition with China demonstrate just how quickly the science policy landscape can change. Based on current trends, the new year is set to be an eventful one. Here are five stories to watch in 2019.

### Budget battles on horizon as spending caps return

A deal reached in early 2018 that raised caps on federal spending enabled Congress to provide many science agencies substantial budget increases. Nevertheless, some agencies were caught in the partial government shutdown and uncertainties are likely to deepen because the budget cap deal expires this fall. Congress could agree to keep the caps high, but the budget deficit or other politically volatile issues could make it difficult to strike a new deal, threatening the return of tighter budgets and perhaps further shutdowns.

### US–China tensions reverberating across research enterprise

The US government embarked on a campaign last year to raise awareness about illegal and legal methods that it alleges the Chinese government uses to obtain foreign technologies. Based on concerns about espionage, the Trump administration also implemented new visa screening measures for Chinese nationals and has reportedly considered more aggressive measures such as putting stricter limits on student visas. It also plans to establish export controls on certain "emerging and foundational technologies." However, such measures also run the risk of harming the US economy, stifling scientific collaborations, and creating bias against Chinese researchers.

### National Quantum Initiative ramping up

With the National Quantum Initiative Act now signed into law, federal agencies will work to implement its provisions. The Department of Energy and National Science Foundation will begin to establish between two and five research centers each, and the National Institute of Standards and Technology will convene a consortium of stakeholders to assess research needs. The White House will also stand up a national coordinating office and empanel an advisory committee to oversee the initiative. These activities will build on efforts already underway to establish a national infrastructure of quantum computing testbeds, prototype communication links, and device "foundries."

### Climate change back in spotlight

The release last fall of major climate change assessments brought renewed attention to President Trump's rejection of the scientific consensus on the subject.

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Princeton center, recalled, "At the time it seemed crazy that the NCI centers weren't interacting more with the American Association of Physicists in Medicine (AAPM)." That said, AAPM, the largest medical physics professional group in the US, focuses primarily on the physics of radiation therapy and medical imaging and was therefore not a natural home for physicists at the broadly research-focused NCI centers. Enter GMED, which prioritizes implementing physics to understand and treat disease in addition to imaging it—in oncology and beyond.

It's clear that GMED occupies a unique niche in the physics community. In addition to being distinguished from AAPM in its wider lens on modeling and interventional research, within the APS umbrella GMED differentiates itself from the similarly research-oriented Division of Biological Physics (DBIO) by having a specific focus on human health and disease, as opposed to fundamental biological processes writ large. Roughly this also breaks down as research predominantly at the level of organs or tissues in GMED vs. cells and molecules in DBIO.

GMED's member base, though relatively new, already represents nearly every major area of physics within APS—from biological, computational, and nuclear physics to particle, plasma, and high energy physics. This bodes well for GMED's hope of reaching across APS divisions and getting physicists from different disciplines to "share notes," in Austin's words.

To this end, in 2019 GMED will hold sessions at both the APS March Meeting in Boston and the APS April Meeting in Denver. Sessions at the upcoming March Meeting offer a deep dive on acquisition geometries, radiation sources, hardware, and algorithms for medical imaging and address recent advances in the use of biomedical magnetic resonance for understanding disease pathophysiology. Additionally, there is an entire session dedicated to computational modeling, spanning everything from immuno-, chemo- and radiotherapy treatment response to the progression of atherosclerosis to improving influenza vaccine development. Although GMED has a historical grounding in oncology, neurology and cardiology are widely represented as well.

Notably, this diversity of research topics is also mirrored in the diversity of GMED's membership. The division impressively demonstrates the highest proportion of women (30%) in any topical group, forum, or division at APS. Diversity also exists at the scientific level in GMED, given that most medical physicists work among extremely interdisciplinary teams.

Beyond the vibrant community, Austin and Jeraj highlighted the intellectual opportunities associated with GMED as the group's biggest draw. While the problems in medical physics are similar in principle to those in traditional physics, they have an extra dimension of intrigue given the challenges that come with complex

Bob Austin

biological systems and their many variables. Furthermore, physicists interested in machine learning, modeling, and other computational work find it compelling that the medical field is one of the most prolific generators of data; there is a wealth of possibility in these complex and multifactorial but also highly organized data sets. Added Jeraj, "Many physicists may not know that their work can be translated into a medically useful finding. It's a very natural convergence point for many areas of physics."

For junior physicists still in training, GMED additionally offers valuable practical insight into the unique career possibilities that exist in medical physics. Beyond the traditional paths in research, academic training, and industry, medical physics also offers a wide menu of options in the clinical world—a setting that is likely unfamiliar to students and early career scientists. Outlining these options is a major focus of GMED workshops and information sessions for younger APS members, and beginning with the upcoming APS March Meeting GMED is arranging a tour of the medical physics research facilities at local Boston hospitals to bring this unique dimension of the field to life.

At an even earlier level, cultivating strong education around medical physics is a key element of GMED's vision. Given the decades-long tradition of physicists generating advances in medicine, it may come as a surprise that most physics curricula lack a dedicated medical physics specialty or even medical physics elective courses. Jeraj explained that a major goal for GMED as the organization expands and matures is to play a leading role in promoting more explicit education and training in medical physics specifically. He envisions a future where undergraduate or graduate school programs can reach out to GMED for resources and support in developing either a comprehensive medical physics program or some elective courses in biomedical physics.

Overall, GMED stands out as an ambitious group with a bright future, and one whose contributions to scientific knowledge are matched by contributions to human health. More information on this topical group can be found here: aps.org/units/gmed/

*The author is a freelance writer in Helsinki, Finland.*

# The Dark Energy Survey's Six-year Exploration Comes to an End

*By Leah Poffenberger*

**The Dark Energy Survey camera is mounted on the Blanco Telescope (center) at the Cerro Tololo Inter-American Observatory in Chile.**

Six years ago, astronomers placed the 520-megapixel Dark Energy Camera (DECam) onto the 4-meter Blanco telescope at Cerro Tololo Inter-American Observatory in Chile. From this perch, it began a mission to map a portion of the sky with unprecedented detail and to better understand dark energy, the mysterious accelerator of the expansion of the universe. On January 9, 2019, this project, known as the Dark Energy Survey (DES), completed its data collection after gathering light from more than 300 million distant galaxies over 758 nights.

DES concluded its data taking with plenty to show for it: nearly 2,000 terabytes of raw data that collaborators can now comb through to look for clues about the nature of dark energy. The National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign has the task of storing the massive amount of data for analysis. The first step to using all that information, especially to pinpoint dark energy, is getting rid of all the noise that inevitably comes with detailed data collection.

"We're trying to tease out the signal of dark energy against a background of all sorts of noncosmological stuff that gets imprinted on the data," said Josh Frieman, former DES director. "It's a massive ongoing effort from many different people around the world."

DES has already yielded more than 200 academic papers on a variety of cosmological phenomena, thanks to the versatility of the DECam as a tool for discovery. The goal of the project was to carry out the largest galaxy survey ever, covering 1/8th of the sky. During its run, DECam was the first experiment to be able to use four methods to probe dark energy by studying galaxy clusters, supernovae, the clumpiness of galaxies, and gravitational lensing.

In 2017, DES produced a number of remarkable results, including a measurement of the dark matter structure of the universe and detecting the most distant supernova to date. DES was also one of the sky surveys that spotted the visible counterpart of gravitational waves caused by the collision of two neutron stars, helping the LIGO/Virgo collaboration usher in the era of multi-messenger astronomy.

The DECam was constructed at Fermi National Laboratory in Batavia, Illinois, before taking the trip to the NSF-funded Cerro Tololo Inter-American Observatory in Chile. The DES collaboration includes more than 400 scientists from 26 institutions in seven countries. And in 2018, the first three years of DES data was publicly released, allowing amateur astronomers from anywhere with an internet connection to analyze the data.

"Working with DES has put me in contact with many remarkable scientists from all over the world," Antonella Palmese, a postdoctoral researcher at Fermilab said. "It's a special collaboration because you always feel like you are a necessary part of the experiment. There is always something useful you can do for the collaboration and for your own research." Palmese began working on DES as a graduate student in 2015.

The DECam is expected to continue its survey of the night sky for another ten years, continuing its usefulness for a variety of astronomical observations.

"Although the data-taking for DES is coming to an end, DECam will continue its exploration of the universe from the Blanco telescope and is expected remain a front-line 'engine of discovery' for many years," Cerro Tololo Inter-American Observatory Director Steve Heathcote said.

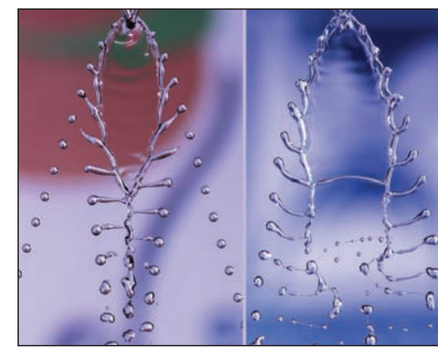
With the launch of DES six years ago, James Siegrist, associate director of science for high energy physics with the U.S. Department of Energy expressed the potential of the project. "The results of this survey will bring us closer to understanding the mystery of dark energy, and what it means for the universe," said Siegrist.



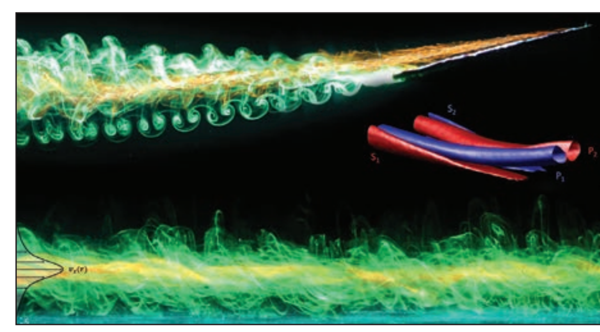
# The 2018 Gallery of Fluid Motion Poster Winners

The Division of Fluid Dynamics meeting celebrates the interface of science and art through the Gallery of Fluid Motion, a yearly showcase of visually stunning fluids research. A panel of judges assessed this year's entries, selecting the top video and poster submissions that will be published in *Physical Review Fluids* in 2019. The poster winners of the 2018 Milton van Dyke Award and the APS/DFD Gallery of Fluid Motion Award listed here, along with the video winners, can be viewed at gfm.aps.org

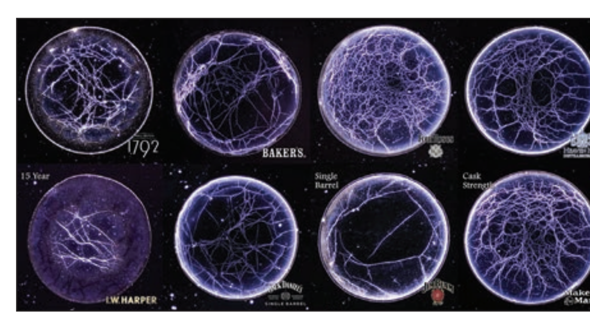
## 2018 Milton van Dyke Award Poster Winners



***Viscoelastic Fishbones (P0045) by Bavand Keshavarz, Michela Geri, and Gareth McKinley, Massachusetts Institute of Technology.*** **Colliding fluid jets form a blurred liquid fan, but when illuminated with an electric spark flash the pattern is frozen in time.**

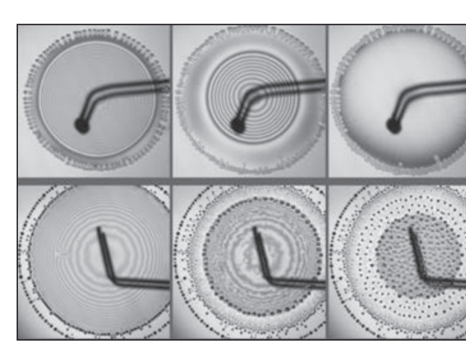


***Delta Wing Vortices (P0020) by Sarah Morris and C. H. K. Williamson, Cornell University.*** **Although seemingly simple, counter-rotating vortex pairs created by a wing surface moving through a fluid can produce complex three-dimensional dynamics.**

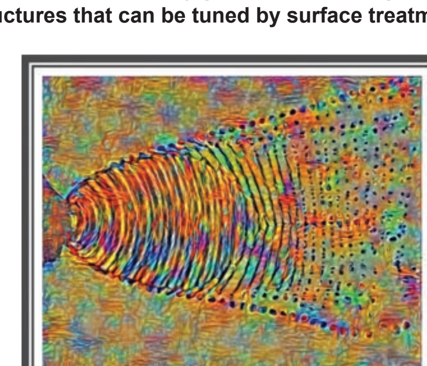


***Whiskey Webs (P0002) by Stuart Williams, Martin Brown, and Adam Carrithers, University of Louisville.*** **Bourbon whiskey is a colloid and as the ethanol evaporates, maturation-derived polymers and surfactants cause erratic fluid motion, leading to unique deposited structures.**

## 2018 APS/DFD Gallery of Fluid Motion Award Poster Winners



***Liquid Deposition through Evaporation (P0056) by Asher Mouat, Clay Wood, Justin Pye, and Justin Burton, Emory University.*** **As binary liquid mixtures evaporate, they generate spreading patterns and leave behind structures that can be tuned by surface treatment.**



***Painting Fluid Motion (P0004) by Maxime Bassenne, Andrew Banko, Sadaf Sobhani, Stanford University.*** **In 1982, Milton van Dyke published *An Album of Fluid Motion*, a unique collection of over 300 black-and-white photographs illustrating a diverse set of fluid phenomena. Neural networks can combine the content of these photographs with the style of a timeless painting.**

ALVAREZ continued from page 2

out several errors or omissions in the FBI's official analysis.

Alvarez's son, Walter, became a geologist, and became intrigued by a thin layer of clay in the strata of a limestone gorge in central Italy—marking the point where the dinosaurs went extinct, right at the Cretaceous-Paleogene boundary. Alvarez and his son collaborated with nuclear chemists at LBL on a controversial 1980 paper suggesting an extraterrestrial cause, such as an asteroid, for that extinction event.

Geologists were sharply critical, but subsequent analysis of the clay showed that it contained shocked quartz crystals, tiny diamonds, and rare minerals that only form under high pressure and temperatures. Ten years after Alvarez died, scientists discovered the Chicxulub impact crater off the coast of Mexico, lending even more support to the theory. By 2010, scientists had largely reached a consensus that this asteroid impact did indeed trigger the mass extinction that wiped out the dinosaurs.

Alvarez died in 1988 from complications of surgery for esophageal cancer. But his legacy in pioneering cosmic ray imaging techniques continues to bear fruit. In addition to Egyptian pyramids, cosmic rays have been used to map lava channels in volcanoes (like Mount Vesuvius) and on other archaeological sites, and to probe the structure of Brunelleschi's dome in Florence, Italy.

### Further Reading:


Alvarez, L.W., "Search for Hidden Chambers in the Pyramids," *Science* **167**, 832 (1970).

Alvarez, L.W. *Alvarez: Adventures of a Physicist* (Basic Books, New York, 1987).

Wohl, C.G.,"Scientist as detective: Luis Alvarez and the pyramid burial chambers, the JFK assassination, and the end of the dinosaurs," *American Journal of Physics* **75**, 968 (2007).


ROADSHOW continued from page 3

to encourage students to pursue careers in STEM disciplines. "In India, women in STEM fields lag far behind their male counterparts, and the problem is acute for women from minorities and disadvantaged groups," she said. "They are interested in STEM, we just need to provide a spark for them."

A team of four led the WSR workshops: Anil K. Pradhan (atomic astrophysicist and Director of Indo-US STEM Education and Research Center at Ohio State University(OSU)), Karen Irving (PhD in Chemistry and STEM Education at OSU), Nasreen Haque (a physicist by training and President of Intalage Inc. USA, involving teachers and students in the USA for STEM Education), and myself (physicist and founder of STEM education and research programs in many institutions in several countries and Director of WSR, OSU).

We had a dedicated and efficient Indian team of local experts, local contacts, and student volunteers in each location. Each local expert presented STEM contributions by women and the need for more women participating in STEM fields in India.

Swaleha Naseem, a local expert in Aligarh, wrote that "after attending the workshop, the students found themselves more confident and motivated about their fields. They acknowledged all the speakers at the workshop for their guidance on how to improve their CVs and how they can apply to US universities for their higher education in STEM fields."

US Consulate officials also joined us and presented inspiring stories in the Delhi, Kolkata, Hyderabad, and Kurnool workshops, while one representative spoke on EducationUSA. The US alumni shared their experiences and spoke on the benefits of studying at a US university. We invited one dedicated activist for education of women to be a chief guest in each workshop. The most notable one was the Governor of Manipur and Chancellor of Jamia Millia Islamia (a central university in Delhi), Najma Heptullah, who received her PhD in zoology and became a faculty member at age 22 before moving into government and bringing about scientific and technological changes in India.

The impact of the workshops was extremely positive for the participants: In follow-up reports on the impact of WSR, many participants enthusiastically shared their academic progress reports to show how well they were doing in their pursuit of higher degrees in STEM fields. Most of them are achieving excellent GPAs—several ranking at the top of their class—attending and volunteering at conferences, preparing for graduate school entrance exams, and participating in (and winning) science competitions.

"The experience of meeting such great personalities was very inspirational especially for myself," wrote a student from Aligarh. "The speeches delivered by Nahar, Anil and others were very inspiring and built up the students' confidence, knowledge, and the enthusiasm to explore the world."

*APS Fellow Sultana Nahar is professor of astronomy at Ohio State University, co-director for the Research and Liaison Office of the STEM ER Center, and adjunct professor of physics at AMU.*



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about how their lives were changed by the Bridge Program. Brian Zamarripa Roman, Michelle Lollie, and Dylan Smith met directly with Comstock and Castro. They also visited other congressional offices.

**Non-Proliferation:** Commissioned by the APS Panel on Public Affairs, the report, "Neutrons for the Nation," was released. The report urged the Trump Administration to begin an effort to design and build a new research reactor for neutron research and development to maintain US leadership. That goal has now been publicly embraced by NIST. The report continues to yield positive responses following an op-ed authored by the study's Co-Chairs Julia Phillips and James Wells. *The Hill* newspaper, a major Capitol Hill publication, published their op-ed.

**Climate Change**: APS released its full greenhouse gas emissions (GHG) report, becoming the first scientific organization to broadly assess and publicly post results of GHG emissions. Based on the report's recommendations, APS took steps to help its members mitigate their GHG emissions from traveling to APS meetings by offering them an opportunity to donate to an environmental organization of their choice. APS unveiled the pilot campaign in November by providing the Division of Fluid Dynamics (DFD) members the ability to mitigate the effect of their travel to and from the DFD annual meeting in Atlanta.

"A key APS goal for 2019 is to make sure all Society members attending the organization's largest national meetings have an opportunity to mitigate their GHG emissions," said Mark Elsesser, APS OGA Manager of Science Policy.

"The environmental donation campaign will be an ongoing activity at APS's major meetings in 2019 and beyond. We hope our meeting attendees take advantage of the opportunity," he said.

*The author is the APS Press Secretary.*

STORIES continued from page 4

Democrats are now making the issue front and center. They have established a "Select Committee on the Climate Crisis" in the House of Representatives, and several other House committees are planning to hold hearings on climate change early this year. There also are signs the political contours of the subject are changing. Some Republicans are now proposing actions such as innovation-centered policy solutions or a carbon tax, while some Democrats are advocating for aggressive action via a "Green New Deal."

### More action expected against sexual harassment

Efforts to combat sexual harassment in the sciences that gained momentum last year are set to continue in 2019. Leaders of the House Science Committee have introduced bipartisan legislation that would direct federal science agencies to adopt uniform policies for addressing the problem. The newly confirmed director of the White House Office of Science and Technology Policy, Kelvin Droegemeier, has also expressed support for pursuing a cross-government effort. Meanwhile, scientific societies have been revising their codes of conduct. For instance, the National Academy of Sciences is expected to advance a policy that enables it to expel members.

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Solvay Conference in Brussels. My talk aroused some interest, but I wasn't carried around the room on people's shoulders. At the time, even I knew the theory wasn't complete. One missing element was the proof that the theory really was renormalizable, that is, that the infinities in the calculations could be eliminated. (That proof came in 1971 from Gerard 't Hooft and others.) The other missing item was experimental verification, which started to happen in 1973 with the discovery of neutral currents in weak interactions. Also in 1973 came a theory of the strong force, called quantum chromodynamics. Those two pieces: the electroweak theory and the strong theory formed the standard model.

**When did people start calling the whole thing the standard model?**

I don't know exactly, but I remember using the name in 1973 during a talk in Aix-en-Provence in France. I wanted to point out to my audience that we physicists had a pretty good picture of elementary particles by then, and we could use this "standard model" as a device for interpreting experiments.

**Did having "standard" in the name imply certainty for you?**

I was confident that the theory was right, but my confidence was partly shaken by data from a number of experiments in 1976 and 1977 that were hard to make sense of within the standard model. In the spring of 1977, I ended up canceling a trip I had planned with my wife and daughter to go to Yosemite. Instead, I spent that time working with my friend Ben Lee trying to find an alternative theory that could account for the experiments. I'm proud to say we failed, as it later turned out that the experiments were wrong.

In the end, the issue was settled by a 1978 experiment at SLAC that confirmed the prediction of parity violation in the interaction of electrons with nuclei. After that, I think everyone was convinced that the standard model was correct.

**In your PRL essay you describe some of the twists and turns in the standard model's development? Do you see a benefit in revisiting that complicated history?**

I think that by studying the history of physics we can learn about the judgments—and misjudgments—that all physicists make. History can also be a source of motivation: By knowing the story behind our theories, we, as physicists, can feel part of a great historical progression. That sense of motion keeps us at our desks and in our laboratories.

**Where is that progression taking particle physics?**

I think the goal is a "final theory" that explains all forces and particles. But its form is very cloudy. At this point, such a fundamental theory seems farther away than ever, as there are hints that the required energies for seeing it are beyond our reach. It's just a pity that the accelerator experiments haven't yet revealed anything beyond the standard model, with the one exception of the neutrino masses.

**Do you think the problems faced by particle physicists today are different from those that you faced as a young scientist?**

I do. It was a different situation 50 years ago. Back then, we had experimental data coming out of our ears, and a lot of it didn't seem to fit any pattern. The problems seemed formidable, but there were so many ways to go with new theories. It really was a thrilling time to be a physicist.

Nowadays, it's very hard to think of a challenge that we can get our teeth into. The current puzzles don't offer theorists many opportunities to propose solutions that can be tested experimentally.

**Do you have any advice to offer the next generation?**

Winston Churchill had a motto at the beginning of World War II: "Keep buggering on." In that spirit, I think it's better to do something than to do nothing. My advice is to try crazy ideas and innovative experiments. Something will come up.

*Michael Schirber is a Corresponding Editor for* Physics *based in Lyon, France.*

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matinee. Joyce Carol Oates argues "that serious reading is as sacramental an act as serious writing…" [1]. In a perfect world, everything we read and write would live up to this ideal.

Fortunately, *Reviews of Modern Physics* has been and remains a small, curated journal with about 11 articles per quarter: when the authors, referees, editors, and referees (the referees are *very* important and appreciated—two mentions may not be enough!) are giving their all, it is possible to aspire to this level of communication. *Reviews of Modern Physics* should be a pleasure to read on all levels: the articles should have strong and clear introductions to bring the reader up to speed; the content should not only be relevant but also elegantly and succinctly presented when possible; and there should be something for everyone in every issue.

Indeed, as the scope of APS expands through its membership, its publications, and its role in scientific outreach, *Reviews of Modern Physics* is taking steps to broaden the definition of "Modern Physics." We have appointed an editor to cover climate science, we are expanding to solicit articles on fluids, applications, and materials, and we continue to expand into new areas, "physics broadly construed." We have the distinct advantage that we are a journal that can plot our own course – we need not be swayed by the desire to promote our articles to the popular media and we can publish articles for our true constituents. Our sincere thanks go out to the authors, referees, and editors who continue to make this possible.

*Randall D. Kamien is the Lead Editor of* Reviews of Modern Physics *and Vicki and William Abrams Professor in the Natural Sciences in the Department of Physics and Astronomy, University of Pennsylvania.*

**Reference**

1. Joyce Carol Oates, "Literature as Pleasure, Pleasure as Literature," in *Woman Writer: Occasions and Opportunities* (Dutton, 1988).

For more on the history of *Reviews of Modern Physics*, see the February 2019 special issue of Physics Today (physicstoday.org).

At both the March and April Meetings this year, *Reviews of Modern Physics* will host special symposia to encourage excellent scientific communication, celebrate our 90th anniversary, and look forward to the Reviews of the Future.

APS March Meeting - *Reviews of Modern Physics*: The First 90 Years, Tuesday, March 5, 7:30 – 9 PM, Grand Ballroom A, Westin Boston Waterfront. For the latest information on the APS April Meeting sessions, see aps.org/meetings/april/

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As with previous APS Meetings, a number of diversity events are scheduled, including an LGBTQ+ roundtable discussion (Wednesday, 4:00–5:00 PM), the National Society of Black Physicists meetup and reception (Wednesday, 5:00–6:00 PM), and the National Society of Hispanic Physicists meetup and reception (Wednesday, 6:00–7:00 PM). Also on Wednesday, there will be an Education and Diversity reception (7:00–8:00 PM).

On Tuesday, March 5, *Reviews of Modern Physics* (RMP) celebrates 90 years with talks from the authors of popular RMP papers and a champagne toast (7:30–9:00 PM). Editors from all APS journals will also be available Tuesday from 4:30–6:30 PM to answer questions and discuss the *Physical Review* journals.

Also on Tuesday, March 5, APS President David Gross and CEO Kate Kirby will host a Town Hall session on the Society's newly developed strategic plan (2:30–3:30 PM). The strategic plan lays out APS goals and priorities for the next several years. Copies of the strategic plan document will be available.

Extra physics fun comes in the form of a quantum-themed physics escape room, brought to the March Meeting by the Forum on Outreach and Engaging the Public. LabEscape will be open from March 3 to March 8 for both meeting attendees and the public. On Wednesday, March 6, Imaginative Performances: Quantum Voyages and the History of Physics in 13 songs (7:00–8:30 PM) showcases events created by collaborations between physicists and artists. A Rock-n-Roll Physics Sing-along—a March Meeting tradition—will follow (9:00–10:30 PM).

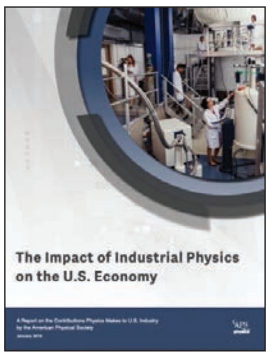
Future of Physics Days events, sponsored by APS and the Society for Physics Students, will offer unique opportunities for undergraduate students to present research, explore graduate school and career options, and network with peers and senior scientists. An interactive workshop on Monday (6:00–7:00 PM) will seek to give students the tools to transition into a physics career, and a graduate school fair on Tuesday (10:00 AM–5:00 PM) will provide an opportunity for students to meet graduate school representatives and learn about programs.

The March Meeting will include many more special events, sessions, and opportunities to network. Visit the meeting website for the full schedule of events: aps.org/meetings/march/.

# The Back Page

## Where Would We Be Without Industrial Physics – Today and Tomorrow?

*By John Rumble, Steven Lambert, and Robert Doering*




As we contemplate our world today and its future, we cannot help but marvel at the incredible changes in our daily lives brought about by industrial physics. A quick glance around an office reveals a smartphone, computers, printers, LED lights, digital sound systems, flash drives, with microelectronics, nanomaterials, lasers, and micro-magnets. These are transformative technologies and have created the 21st Century as we know it. How has this happened and what role does industrial physics play? To help answer these questions, the APS Industrial Physics Advisory Board has just released its report on *The Economic Impact of Industrial Physics on the U.S. Economy*, available at aps.org/programs/industrial/impact-economy.cfm.

**The fascinating findings of the study show that an estimated 12.6% of the U.S. economy can be ascribed directly to the practice of industrial physics, among other impacts summarized below.**

**Defining industrial physics**

- Physicists with degrees in physics who work in industry
- Engineers and other scientists and technical people who employ physical principles in their work
- Use of fundamental physical principles to design and manufacture physical products and systems
- Emerging knowledge of new physical principles that lead to innovative and new products and services

Rather than simply reporting the findings, however, we want to address the larger issue of how the physics community can invest in the future so coming generations can benefit from physics advances being developed on whiteboards and lab benches today.

The economic impact found in the U.S. is broad, affecting many economic sectors, and results from a wide range of contributions from physicists as well as people who understand and use physics in designing, manufacturing, and using today's complex systems, machines, instruments, devices, and materials. We believe the impact is a direct result of the dedication—on the part of industry, academia, and government—to support the richest and most innovative physics community in the world. Below are recommendations designed to continue the impact of industrial physics in the future.

### Recommendations to Physics Communities to Promote the Future of Industrial Physics

#### Academia

APS is in a unique position to influence the U.S.-based physics academic community. These recommendations build on that strength and add focus to improving the readiness of physics-degree students for industrial careers. Our colleges and universities can ensure that all scientists and engineers have strong exposure to physics training as part of their basic requirements. APS can also provide exposure to industrial careers through webinars, national and sectional meetings, and industrial lectures at schools.

- All two-year and four-year colleges should ensure physics classes are available at all levels.
- Strong support should be given for implementation of the recommendations from the J-TUPP/Phys21 report: *Preparing Physics Students for 21st Century Careers*, available at compadre.org/jtupp/report.cfm.
- Internships in industry for undergraduate and graduate students should be encouraged.
- Counseling about industrial careers at all physics degree-granting schools, highlighting excellent career paths and salaries for physics grads at all degree levels should be available.
- Graduate schools should encourage team research; internships; cross-department thesis topics; industrial liaisons; industrial professorships; industrial lectures and recruiting; business courses; career counselling; and LinkedIn pages or similar social media so students can contact previous graduates.
- Post-docs should receive career counseling about industrial careers.

#### Government

The APS Office of Government Affairs has strong interactions with Congress and government agencies that support physics. The following recommendations build on that existing work.

- Hyphenated-physics should be encouraged as industry routinely combines multiple disciplines in developing new products and services.
- Government tech-transfer policies and procedures should be continually reviewed for effectiveness.
- National physics-related facilities should have resources readily available for industrial use, including commercially-conducive intellectual property processes.
- U.S. patent protection procedures should be periodically reviewed for competitiveness.
- SBIR/STTR programs, especially focused on entrepreneurial goals, should be strongly supported.
- Immigration policies should ensure that the brightest students are incentivized to study physics in the U.S. and are able to work for U.S.-headquartered companies after graduation.

#### Industry

Industry can take actions that catalyze the flow of physicists and physics to companies in the future. APS can help to encourage industrial engagement via:

- Improved interactions with two-year, undergraduate, and graduate physics education programs, such as lectures, visiting professorships, participation in thesis committees, talks and attendance at APS Sectional meetings.
- Internships for physics undergraduate and graduate students; industry can work with organizations such as APS to develop guidelines and suggestions for effective programs.
- Involvement in local pre-college STEM efforts, with special emphasis on reducing entry barriers related to minority, gender, or socio-economic status.
- Education of industrial HR departments about capabilities of students with physics degrees and how to recruit them.
- Interactions with major government-industry programs, such as the NIST Manufacturing Extension Partnership (MEP).

**Industrial physics is a major contributor to the economic well-being of the United States.**

- Industrial physics contributes approximately 12.6% of **value added** to the U.S. economy in 2016, about 2.3 **trillion dollars**.
- **Direct employment** related to industrial physics was about **11,500,000 people** in 2016, which accounts for almost 6% of total U.S. employment.
- **U.S. exports** by physics-based sectors are about **1.1 trillion dollars** (2016), which is approximately 20% of the **value added** (GDP) produced by those sectors.
- In the period 2003 to 2016, approximately **70,000 degreed physicists** joined industry
- Between 2010 and 2016, over **340,000 patents** with the classification of physics were granted to U.S. companies
- In 2015, U.S. physics-based companies made **internal R&D investments** of over **150 billion dollars**
- Between 1966 and 2016, the **value added** (contribution to GDP) in the physics-based sectors of the U.S. economy grew by a **factor of 22**. At the same time, the GDP grew by a factor of about 4 (both in 2016 constant dollars).

#### American Physical Society

The following proposed activities align directly with the new APS Strategic Plan goals. The APS Industrial Physics Advisory Board is ready to provide support and additional information as appropriate.

- Make a priority of retaining industrial physicist members, especially early career members.
- Offer 1- or 2-day expert meetings strongly focused on topics of industrial physics interest to address the time and travel constraints of industrial physicists.
- Provide industry-focused publications—peer-reviewed, technical journals as well as popular content such as the now-defunct *Industrial Physicist* magazine.
- Provide career-growth training at major meetings aimed at early-career industrial physicists, such as project management, business basics, and people management.
- Consider establishing a Center for Entrepreneurial and Industrial Physics to foster innovative programs on teaching and promoting entrepreneurship and industrial careers.
- Provide Up-to-Speed physics information—TED© and other online talks, paper bundles; print-on-demand articles and abstracts relevant to hot topics of interest to industrial physicists.
- Encourage sections to involve local industry in their meetings.

#### Students and Practicing Physicists

More than 50% of graduating physicists enter industry to find exciting and rewarding careers. The companies for which they work and the careers they pursue range from highly entrepreneurial technological start-up firms to well-established technology leaders to finance and banking to data analytics. The diversity of possibilities reflects the power of modern physics education, which emphasizes formulating the correct questions and being rigorous in developing answers based on facts. Some suggestions for students to expand their physics horizons include:

- Talk to physicists in industry, and not just technological or scientific industries; hear directly about what working in industry is like, both in terms of rewards and challenges.
- Expose yourself to topics of industrial interest such as new technologies, entrepreneurship, and applied physics; take advantage of APS meeting sessions on industrial and applied physics.
- Pursue internships in industry.
- Take advantage of APS career services for mentoring opportunities, job searches, interview and resume hints and help, and much more.
- Consider taking an introductory business course or two.
- Maintain your APS membership regardless—remember once a physicist, always a physicist!

#### Call to Action

Industrial physics is alive and well and provides innumerable benefits to physics, physicists, and society. It is critical to nurture the industrial physics enterprise and to ensure that it remains a major source of innovation, economic growth, and a positive influence on the future. All physicists, regardless of their interests, can participate in the rich environment. Let's help its continued success.

*John Rumble, Jr. is a chemical physicist and owner of R&R Data Services in Gaithersburg MD. He is also 2019 Speaker of the APS Council. APS Industrial Fellow Steven Lambert is a solid-state physicist who spent 27 years working in the hard drive industry in California. Robert Doering is a senior physicist and research manager at Texas Instruments, Inc. in Dallas, TX and a long-time contributor in physics societies. He is current chair of the APS Industrial Physics Advisory Board.*

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**R&R Data Services, Gaithersburg MD**