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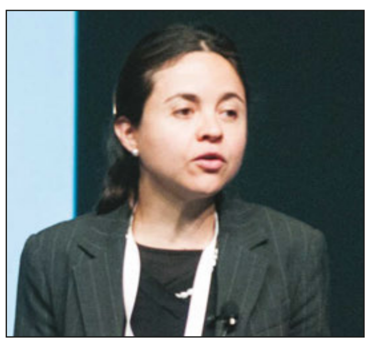
Industrial Physicists Mentor Ph.D. Students, See page 5

Kavli Session Speakers Discuss Physics Frontiers

By Emily Conover

2016 APS March Meeting

Each year during its Kavli Symposium, the APS March Meeting features speakers from the forefronts of their fields. The 2016 symposium showcased a broad range of topics, from super-resolution microscopy and its biological applications, to the precise formation of liquid droplets, to the detection of gravitational waves.



Ken Cole

Ana Maria Rey

Ken Cole

Xiaowei Zhuang

Ana Maria Rey of JILA and the University of Colorado Boulder discussed her work with ultra-cold atoms, including atomic clocks that use alkaline earth atoms such as strontium. Rey's work helped to improve the timing of atomic clocks formed from atoms trapped in an optical lattice, by enabling scientists to understand and control the interactions that occur between atoms in such clocks, which can degrade their precision.

Rey's research also spans related subjects, from quantum simulation, to forming new materials that are not accessible in nature, to constructing quantum computers. "I think there is a great vista ahead," Rey said. "These atomic systems are such that they are opening the possibility to see very exotic behavior."

Xiaowei Zhuang of Harvard University discussed methods for seeing the very small. Her group developed the method of stochastic optical reconstruction microscopy (STORM), which can image structures smaller than the diffraction limit that is set by the wavelength of light.

In traditional optical microscopy, objects smaller than a few hundred nanometers will show up as a blur in standard microscope images, thanks to diffraction. Zhuang and others seized on the

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Battling the Emperor of Maladies

By Gabriel Popkin

2016 APS March Meeting

This conference features studies of transitions: liquid to glass, disordered to crystalline, ordinary material to superconductor.

To those classic phase transitions, add this one: What causes cells to convert from well-behaved constituents of bodily tissues to out-of-control and potentially deadly cancers?

The question is central to understanding and fighting one of the world's biggest killers, and the need for new approaches is clear, Kenneth Pienta, an oncologist at Johns Hopkins University, told attendees at an invited session: Globally, more than 14 million people get cancer and more than 8 million people die of it each year. And despite decades of research and limited successes against some types of cancer, overall numbers are growing, not shrinking, as populations get older.

Pienta studies metastasis, the process by which cells leave a tumor, enter the bloodstream and spread throughout the body. Once a tumor metastasizes it becomes far more difficult to treat — and far more deadly. "Metastasis is the lethal event," Pienta said. To better understand the process, he teamed with two theoretical physicists Herbert Levine of Rice University in Houston and the late Eshel Ben-Jacob of Tel Aviv University in Israel. The physicists analyzed studies of proteins in cells transitioning from being stationary epithelial cells, which line blood vessels and organs throughout the body, to more mobile mesenchymal cells, which are often associated with metastasis. Levine and Ben-Jacob then predicted that interme-

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Physics Prospects in Cuba

By Emily Conover

2016 APS March Meeting

The historically icy relationship between the U.S. and Cuba has begun to thaw, making scientific collaboration between the U.S. and its southern neighbors more feasible, thanks to eased constraints on travel and the loosening of certain financial restrictions. In December 2014, President Obama announced that the U.S. and Cuba would work to normalize relations, and this March, President Obama visited Cuba — the first visit by a sitting U.S. president in almost 90 years.

The U.S. embargo of Cuba, which has been in place for more than 50 years, has made doing science in the country a challenge, said Fidel Castro Díaz-Balart — the son of Cuban revolutionary Fidel Castro — at a session at the APS March Meeting on physics in Cuba.

In spite of the conditions, scientists in Cuba have soldiered on. Now, Castro Díaz-Balart said, "The normalization of relations with the United States certainly will provide grounds for improving the conditions in the research in the field of physics, because we had had a lot of problems to acquire the newest technology in the labs and to train our undergraduate and postgraduate students."

Cuba is home to around 1800 physicists, said Castro Díaz-Balart. Around two hundred of those physicists have Ph.D.s — with the majority in solid-state physics and nuclear physics — and around 800 physicists are active in research.

Castro Díaz-Balart is himself a physicist; he earned his Ph.D. from the Kurchatov Institute in Moscow. He is the vice president of the Cuban Academy of Sciences, and serves as scientific advisor to the state council of Cuba.

Cuba's scientific strengths lie largely in biotechnology and the medical and pharmaceutical sciences, said Castro Díaz-Balart. The country boasts six doctors for every thousand inhabitants, and the population has a life expectancy similar to the United States. Cuban scientists have developed vaccines against hepatitis B and meningococcal meningitis B and C, and other drugs, including a treatment for diabetic foot ulcers. And Cuba's Pedro Kouri Institute of Tropical Medicine has worked on the front lines in efforts against diseases like Zika, dengue, and Ebola.

The country is also strong in the nuclear sciences. In the 1980s, the country worked toward establishment of its first nuclear power plant. However, the U.S. embargo eventually forced Cuba to abandon these plans. In the late 1990s, nuclear research in Cuba began to be redirected to non-energy applications, including medical physics and theoretical nuclear physics.

Cuban physicists are involved in a number of international collaborations, at the ALICE experiment at CERN, with the Joint Institute for Nuclear Research in Dubna, Russia, and the International

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Physicists, the Brain is Calling You

By Gabriel Popkin

2016 APS March Meeting

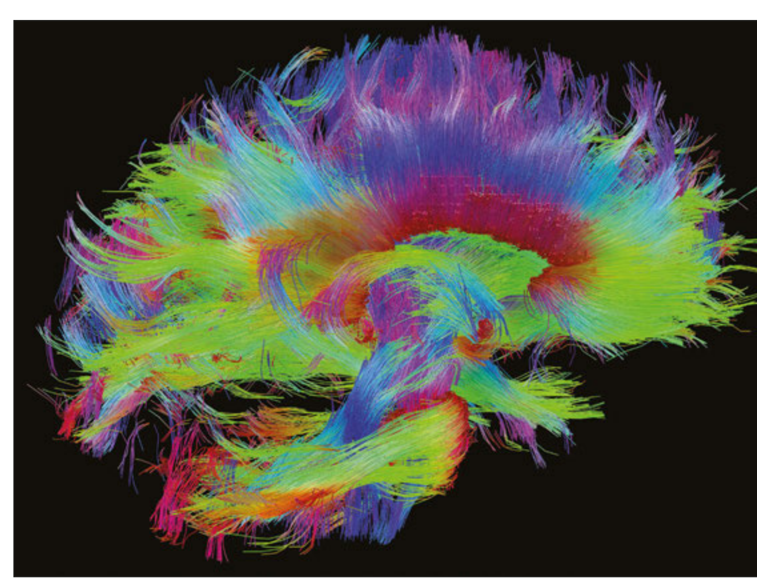
From modeling the biomechanics of brain development to improving neuroimaging techniques to processing and analyzing the data from studies using those techniques, physics expertise is urgently needed in all areas of neuroscience, presenters at the 2016 APS March Meeting said. They urged physicists to get involved.

The potential reward is a deeper understanding at one of science's biggest frontiers — the few-pound lump of grey matter that makes us who we are, yet whose functioning has remained largely a mystery despite more than a century of study.

The brain is, of course, not new ground for physicists. Two biophysicists, Aaron Lloyd Hodgkin and Andrew Huxley (with John Eccles), shared the 1963 Nobel Prize in Physiology or Medicine for discovering how the neuron, the brain's basic cell, transmits signals. And the groundbreaking theoretical model of neural networks emerged from work by physicist (and APS past president) John Hopfield and others, some of which was presented for the first time at March meetings in the early 1980s.

Mapping the brain

Those early advances have now re-emerged as important driving forces for major new initiatives aimed at pushing brain science forward. In an invited session on large-scale neuroscience projects, Miyoung Chun, a geneticist and executive vice president of science programs at the Kavli Foundation, described discussions the Foundation held beginning in 2011 on a "Brain Activity Map," which eventually morphed into the Obama administration's Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative. Physical scientists were so heavily involved in the planning, Chun said, that "it was a bit of a problem when the BRAIN Initiative was announced, because many of the neuroscientists [said], 'who are these people, and how are they representing our field?'"



NIH Laboratory of Neuro Imaging and Martinos Center for Biomedical Imaging

Wiring diagram of a human brain created by tracking the movement of water molecules with magnetic resonance imaging.

The initiative represents a major injection of funding into exactly the kind of science that physicists have long excelled in: tool development. One of the major challenges for neuroscience has been figuring out how to "see" what is happening inside the living brain, which is opaque and, in the case of most vertebrates, encased inside the skull. Since 1990, functional magnetic resonance imaging has enabled researchers to detect activity in specific regions of the brain, and scientists continue to push the technique toward higher power and resolution.

But much of the action today involves technologies that record the activity of single neurons, potentially allowing researchers to map out entire brain circuits and explore the brain's computational code. As an example, Chun described BRAIN Initiative-funded research by Chris Xu at Cornell University, who used ideas from adaptive optics originally developed for astronomy research to

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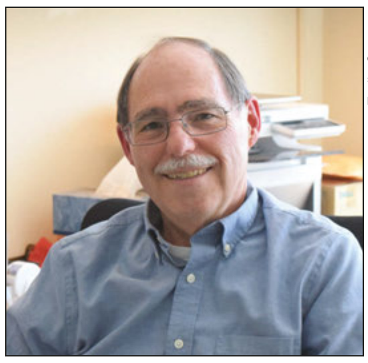
Inside APS

Ken Cole, Corporate Secretary



Emily Conover

Ken Cole

In this series of articles, *APS News* sits down with APS employees to learn about their jobs, their goals, and the things that make them tick. This month we chat with Corporate Secretary Ken Cole. He discusses APS governance and how his role has changed under last year's corporate reform.

What does the corporate secretary do?

The corporate secretary basically is responsible for anything governance: dealing with the various committees — which of course includes the Board of Directors, the Council of Representatives, and most of their subcommittees, most importantly the Board Executive Committee and the Council Steering Committee — and just being the administrative support and the person who helps keep them together and keeps them moving.

This title was created during the APS corporate reform. How is it different from your previous role?

I've been telling people 95 percent of it is old and 5 percent is new. My previous title was special assistant to the executive officer, and most of that transferred over to the corporate secretary. But the Council Steering Committee and the Board Executive Committee are new, so that's a little bit of additional responsibility.

Why did your title change?

For us to become reincorporated, the DC law required us to appoint someone as a corporate secretary to do the things that I was already doing, but I just didn't have the title. So now we've fulfilled that requirement.

What kind of things do you do to help the different committees?

I do a lot of meeting logistics. That includes working with the chairs — or whoever's in charge of the meeting — to work up agendas, to record minutes, and to make sure that any action items are followed up on, coordinating closely with the CEO.

What work do you do with APS elections?

The general membership election starts with the Nominating Committee. My role includes getting the Nominating Committee together, collecting nominations from the membership, giving the committee historical information so they know who has run, who has been elected, who hasn't been elected, so they'll have all that background. Once they meet and produce a slate of candidates, their job is pretty much done, and I carry on by contacting the candidates, getting their biographical information, setting up the actual election, and running that. And then afterwards, in conjunction with the CEO, contacting the winners and getting them oriented and ready to do their jobs.

Do you have any resources for members who are interested in APS governance?

All of our governing documents are up on the website. We have meeting minutes that go all the way back to when I first started doing the job; they go back to 2000. All of our Board and Council meetings are open to APS members except when the meetings go into executive session.

We have an annual business meeting now — under corporate reform we're required to have that. We had one last year, and we're organizing the second one now. It will be at the 2016 April Meeting. People are encouraged to attend in person, but we are also streaming it live, and we are taking live questions. It will be recorded and posted; in fact the 2015 meeting is currently posted and the 2016 meeting will be afterwards.

How long have you been at APS?

I've been at APS 21 ½ years. When I came to APS I was the administrator for prizes and awards. I did that for six and a half years, and then I started working for former Executive Officer Judy Franz, in the role I have now.

Have you liked it?

It's been wonderful. I have

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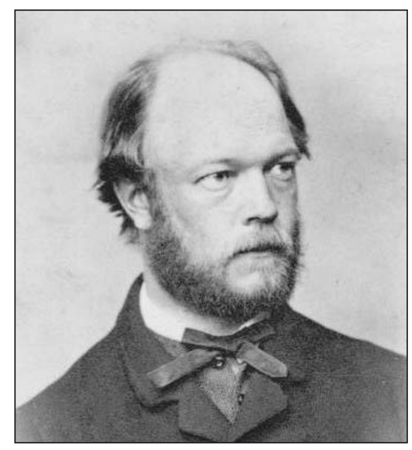
This Month in Physics History

April 28, 1831: Birth of Peter Guthrie Tait, Pioneer of Knot Theory

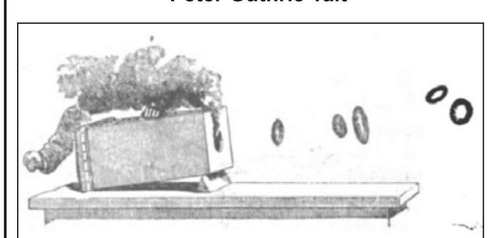
Mathematicians have been fascinated by topological knots for centuries, ever since 1833 when Carl Friedrich Gauss figured out how to compute the number of times two interlinked knots wrap around each other. But the field didn't gain true prominence until the turn of the century, after a Scottish mathematician named Peter Guthrie Tait conducted experiments with smoke rings.

Born in 1831 in Dalkeith, Scotland, Tait lost his father at the age of six, and the family relocated to Edinburgh to live with his uncle, a banker named John Ronaldson. Ronaldson's side interests — including astronomy, geology, and photography — inspired young Peter to pursue similar scientific interests. He proved an apt pupil, ranking at the top of his class for all six years he studied at the Edinburgh Academy, with a strong proficiency in mathematics. Among his classmates was James Clerk Maxwell; their paths would continue to cross for the rest of their lives.



wikimedia commons

Peter Guthrie Tait



Tait Lecture 1878

When Tait tapped on the back of a box filled with thick smoke, vortex rings shot out from a hole in the front.

Along with Maxwell, Tait went on to study at the University of Edinburgh, although he transferred to Peterhouse College, Cambridge, the following year. He graduated with top honors in mathematics and became a Peterhouse Fellow, coaching undergraduates and writing a textbook, *Dynamics of a Particle*, with his colleague William Steele. In 1854, he became a professor at Queen's College in Belfast, conducting his first experiments (with Thomas Andrews) on measuring the effects of electrical discharges in various gases. Five years later, he beat out Maxwell for the chair of natural philosophy at the University of Edinburgh, in part because of his superior teaching skills.

Back in 1858, Tait had read a paper by Helmholtz on the motion of a perfect fluid, which he translated in 1867. Among the phenomena described was the unusual behavior of vortex rings. Helmholtz suggested that two such interacting rings would retain their shape even though their size and velocity might change. Tait set out to verify this theoretical prediction experimentally with smoke rings.

He took a pair of cardboard boxes with a circle cut out in front, and covered the back with a rubber diaphragm. Inside the boxes he placed a mixture of ammonia, salt, and sulfuric acid, producing a thick smoke. Punching the diaphragm at the back of the box forced the smoke inside through the circular opening in the front, creating perfectly formed smoke rings. Tait noted that they looked like "rings of solid India rubber." He even managed to make smoke rings bounce off each other, just like rubber. And he noticed the smoke rings were remarkably stable, traveling across the room without dissipating. So Helmholtz's theoretical prediction seemed correct. Rings made of an ideal fluid, with no friction, should, in theory, last forever.

Tait showed his smoke ring experiment to William Thomson (Lord Kelvin), who was pondering the problem of the atom: namely, there were many competing theories about what atoms might look like, and how one might account for different elements. Tait's smoke rings inspired Kelvin to devise a radical new theory: Perhaps atoms were actually knots of swirling vortices in the luminiferous ether, which scientists at the time thought existed as an invisible medium through which light moved. Different kinds of linked vortex knots would be stable, and would correspond to different chemical elements — specifically, to their particular emission spectra. The heavier the element, the more complicated the knot.

Tait was initially skeptical of the idea, but he soon warmed to the challenge of creating a knot-based periodic table of elements, by drawing many different kinds of knots and trying to match them to specific emission spectra. Even Maxwell became fascinated with the vortex theory, enthusiastically writing to his two friends, "May you both prosper and disentangle your formulae in proportion as you entangle your [vortices]."

Alas, the famed Michelson-Morley experiment in 1887 proved there is no such thing as the luminiferous ether, and without that medium, Kelvin's vortex theory of atoms simply couldn't work. But his work with Tait and Maxwell helped establish knot theory in mathematics, helping to rediscover the work of Gauss and Johann Benedict Listing 20 years before.

Tait went on to become a leading topologist, formulating a series of conjectures on alternating knots that mathematicians finally proved in the 1990s. Knot theory continues to be an active and exciting area of research, both fundamental and applied. In the 1980s, for example, mathematicians found several solutions to Maxwell's equations describing objects in free space that were decidedly knot-like.

Over the last few years, physicists have suggested the possibility of tying real knots in light fields, and successfully tied the first "quantum knots" in

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Inside the Beltway

Mandatory Science Spending: What's That?

By Michael S. Lubell, APS Director of Public Affairs

A week before President Obama released his budget request for the coming fiscal year, the White House leaked word that his plan would include mandatory spending for science. My first reaction was, "Huh?"

By the time the Administration rolled out the budget on February 9, I had reached the conclusion that the plan was pretty much a gimmick. Boxed in by the two-year budget accord he had agreed to last fall with congressional Republicans, the president wanted to make a statement about urgent needs for American science.

He knew that Congress would never agree to put any portion of science spending on a par with mandatory programs, such as Social Security and Medicare. These programs are funded by their own special laws, outside and untouchable by the normal annual appropriations process. He was simply setting down a marker and leaving the nuts and bolts of negotiations over science spending for a future president at a future date.

The science budget roll-out, which the White House held at the headquarters of the American Association for the Advancement of Science, confirmed my supposition. In response to a question from *Science* journalist Jeffrey Mervis, President Obama's science adviser, John Holdren, and OSTP analyst Kei Koizumi indicated that the president tried to circumvent the sequestration budget caps by including a supplemental budget that expanded research support. It didn't work, so this year Koizumi said the administration decided to try something different.

I followed up Mervis's question by asking Holdren one of my own: "What strategy had the White House cooked up to convince Congress that mandatory science spending made sense." I got the same answer Jeff had received moments earlier.

It was clear there was no rationale, strategy or play plan. Like the famed Hail Mary pass in football, the mandatory request was little more than a wild, last ditch effort as the White House game clock was ticking down.

But the more I thought about it, the more I became convinced there is a serious rationale for assigning a small portion of the science budget to the mandatory spending category.

As I've written many times before, there is ample evidence that science is the underpinning of the 21st century American economy. Those economists who have studied the relationship between research and development and growth of the gross domestic product have estimated that at least 50 percent and perhaps as much as 70 percent of GDP increases come from STEM (science, technology, engineering and math).

There is also ample evidence that U.S. innovation has begun to lag the performance of other developed nations. The 2015 Global Innovation Index compiled by the world business school INSEAD, in collaboration with the World Intellectual Property Organization known as WIPO and Cornell University, ranks the United States 5th. And the Information Technology and Innovation Foundation (ITIF), in its 2016 report, "Contributors and Detractors: Ranking Countries' Impact on Global Innovation," places the U.S. 10th, in part because of very tepid growth in government support of R&D and weak numbers in STEM college graduates.

A robust innovation enterprise that relies on government support for long-term research needs funding that not only is sufficient but also reliable. For much of the last two decades, gridlock and hyper-partisanship have stymied the appropriations process to the point where last-minute patchwork "continuing resolutions" have become more the rule than the exception.

The annual ritual of appropriations stalemates wreaks havoc with many federal programs, but its effect on science activities is particularly pernicious. Continuing resolutions inject uncertainties into agency planning and execution, prohibit the start of new projects, and send a strong message to young scientists that the United States might not be the ideal place for pursuing a scientific career.

A quarter of a century ago, our nation might have been able to weather such annual budget disruptions, but today there are too many nations that can take advantage of our inability to keep our scientific engine well lubricated and well fueled.

Using mandatory accounts to support a small portion of the federal research budget could provide a buffer against the damaging effects of continuing resolutions that often extend for three months or more and against shorter-term government shutdowns that result in furloughs or layoffs at national laboratories and damage to critical scientific infrastructure.

How large the mandatory spending crutch should be is a matter for serious analysis and debate. But if a typical continuing resolution lasts three months, and if a quarter to a half of federally supported scientific activities are jeopardized during that period, mandatory accounts covering five to ten percent of the federal scientific budget would suffice.

Although I haven't spoken much to Pete V. Domenici (R-N.M.) since his retirement from the Senate in 2009, I think he would find the proposition intriguing, based on conversations we had while he was still in office. Domenici was one of the Senate's gurus on budgets, appropriations, and energy policy. And as a staunch advocate for science he used to bemoan the problems that the annual appropriations process created for research – and that was in the days when continuing resolutions were still not the norm.

President Obama might have proposed mandatory spending as a gimmick, but in reality he has opened the door to a discussion on something far more substantive.

Campaigning Like a Physicist

By Emily Conover

When plasma physicist Andrew Zwicker ran for a seat in the New Jersey General Assembly last November, he approached the challenge like a physicist, employing a powerful trick from the scientist's toolkit: a statistical model. Using data about constituents in his district, he worked with Sherrie Preische, a physicist who now works on election modeling, to pinpoint the voters most likely to help tip the balance in his favor, and reach out to them.

Zwicker was facing an uphill battle, running as a Democrat in New Jersey's 16th district, which had a 40-year streak of electing Republicans. But the method apparently worked: Zwicker pulled off an upset victory — by a hair. He won by just 78 votes, defeating the incumbent, Donna Simon, 16,308 to 16,230.

In 2012, the Obama campaign successfully employed a similar strategy on a larger scale. The technique, known as micro-targeting, aims a candidate's messages at narrow slices of the voting population, even tailoring communication to individual voters. Until recently, such modeling has been out of reach to all but the biggest, wealthiest campaigns, Preische says. "My approach has been to try to make it available to smaller campaigns, and particularly close [races] where it can make a real difference."

The model Preische developed for Zwicker assigned registered voters a "support" score representing the probability they would support Zwicker, and a "turnout" score representing the probability they would show up at the polls on election day.

To most effectively reach out to the 150,000 registered voters in the district, the campaign tailored its communication efforts according to these scores. Voters with a high support score and a low turnout score might be contacted by a volunteer encouraging them to vote, while voters that the model predicted were likely to vote, but were on the fence about whom to

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gather images from more than a millimeter deep in a mouse brain.

Since Barack Obama's 2013 announcement of the initiative, federal investment has increased severalfold, with the National Science Foundation and the National Institutes of Health each contributing around $150 million in 2016, and other agencies putting in smaller amounts. Meanwhile, private foundations are partnering with the federal agencies, collectively contributing more than $300 million in 2015, according to data Chun showed. With the influx of funding, Chun said, "I think the physics community has a great opportunity for really solving these complex questions."

States of mind

Molecular biologist David Tank of Princeton University, who early in his career helped Hopfield develop neural network theories, described recent research funded by the Simons Collaboration on the Global Brain, which aims to quantify neural states in a brain actively doing tasks. "These ideas have been explored theoretically and in psychology for centuries," he said, "but now we really are beginning to have tools that allow us to probe them in the awake brain."

To study those neural states, Tank and his colleagues developed a two-dimensional virtual reality headset for a mouse. The device allows the researchers to measure neuron firing while the mouse explores a complex environment, without technical challenges that would accompany such measurements if the mouse were moving around in real space. The rich datasets that are emerging present tantalizing evidence that spatial neurons are encoded according to a theoretical model called an attractor manifold, a concept that emerged in the 1960s and 1970s from chaos theory, and is now resurging, Tank said.

Techniques to record the activity of large numbers of neurons are enabling powerful insights, but they are also generating much larger volumes of data than neuroscientists are used to, Tank cautioned. "Large-scale recording technologies really are transforming neuroscience. We will soon be swamped with neural activity data," he said. "We need the brightest minds and the best mathematical tools to make sense of these data."

And physicists are the experts at crunching huge datasets, having cut their teeth on the original big data from telescopes like the Hubble Space Telescope and particle colliders like the Large Hadron Collider, Chun added. "We hope that neuroscience can take advantage of what's already happened in other fields like astrophysics," she said. "The BRAIN initiative will be successful only if physicists join in."

Theoreticians are also needed to place the insights from modern experiments into a coherent theoretical framework, added Terry Sejnowski, a neuroscientist at the Salk Institute for Biological Studies in La Jolla, California, and another early pioneer of neural networks. "I don't think we have a theory of the brain that's anywhere near the level [of the theories of evolution or DNA]. But we need it."

At another invited session, physicists discussed such theoretical issues, including how to use statistical mechanics to analyze data from retinal neurons, what the dimensionality of neural data is, and how networks of neurons predict the future based on present stimuli. "These are the kinds of things that physicists would be worried about," and that might seem out of place at a traditional neuroscience meeting, said session chair William Bialek, a physicist at Princeton University. He added that the APS March Meeting is providing an important space for community-building among people wanting to approach biological topics through physics, without regard to traditional disciplinary boundaries. "Where do you go as a physicist to talk to other physicists who are interested in other parts of biology? It looks like APS is going to be the answer."

How the brain folds

An example of such a cross-disciplinary approach was provided by an invited session on quantifying the forces that give the part of the brain known as the cortex its complex folded shape. Researchers studying the brain's material properties have developed two main hypotheses for cortical folding: that tension in neurons' long, threadlike axons pulls the developing brain into its folded configuration, and that the brain buckles as different parts grow at different rates inside the skull.

David Van Essen, a neuroscientist at Washington University in Saint Louis, led off the session by describing evidence for his hypothesis, originally published in 1997, that axonal tension plays a dominant role. The hypothesis could help explain how the brain is wired, Van Essen said, but added that neuroscientists like him need physicists to add quantitative rigor to their anatomical models. "There's room for dramatic progress, and it will accelerate if we bring in more well trained and well integrated talent from physics," he said.

One physicist who is contributing is Jennifer Schwarz of Syracuse University in New York. She presented a model that builds on Van Essen's hypothesis to make testable quantitative predictions about parameters such as the axons' spring constants and elastic moduli. Brain biomechanics is well outside what most mainstream neuroscientists are interested in, and probably won't be funded by large-scale efforts like the Brain Initiative, Schwarz said. But understanding how the brain gets its shape is crucial to understanding how it's wired, and ultimately how it works. "I'm hoping to help neuroscientists ultimately … understand structure and function" she said. "I'm hoping [brain biomechanics and functionality] will eventually converge — that's my goal."

The emphasis on neuroscience at this year's March Meeting resulted partly from organic growth in the field, but was also partly intentional, said Ilya Nemenman, a biophysicist at Emory University, who as incoming Division of Biological Physics chair oversaw the division's meeting programming. "Computational neuroscience in some sense started here at the APS meeting … and then people migrated out to neuroscience meetings," he says. "We made the decision a couple years ago that we wanted to bring physical scientists back."

"I think one of the impacts this will have is to get what are still some of smartest kids who go to physics," he added, "and actually tell them that now you can use that sort of training to solve the brain."

A Medley of Metamaterials

By Emily Conover

Metamaterials — specially designed, structured materials with counterintuitive properties — can do amazing things. Among the most dramatic are "invisibility cloaks" that hide objects by steering light around them. But another kind, known as a mechanical metamaterial, is structured to tweak mechanical — rather than optical — properties, producing materials that are ultralight, yet strong, for example.

The weird substances were the topic of several sessions at the 2016 APS March Meeting. Researchers drew inspiration for the materials' designs from art, from nature, and even from the toys they played with as children.

Expanding horizons

When you stretch a rubber band, it gets thinner — it shrinks in the dimension perpendicular to the force applied — as do most materials. But one class of metamaterials bucks the trend: Auxetic materials instead get thicker.

A new type of auxetic material, designed by Ahmad Rafsanjani of McGill University, was inspired by ancient Islamic art. Rafsanjani used geometric patterns from the Tomb Towers, which were built almost a thousand years ago in Kharraqan, Iran, and which display 70 different tessellations and patterns on their walls. Interestingly, Rafsanjani said that two of the patterns are auxetic when made into physical materials. His materials also have the advantage of bistability — they snap into place and hold their deformed shape once they are stretched, rather than relaxing back to their original shape.

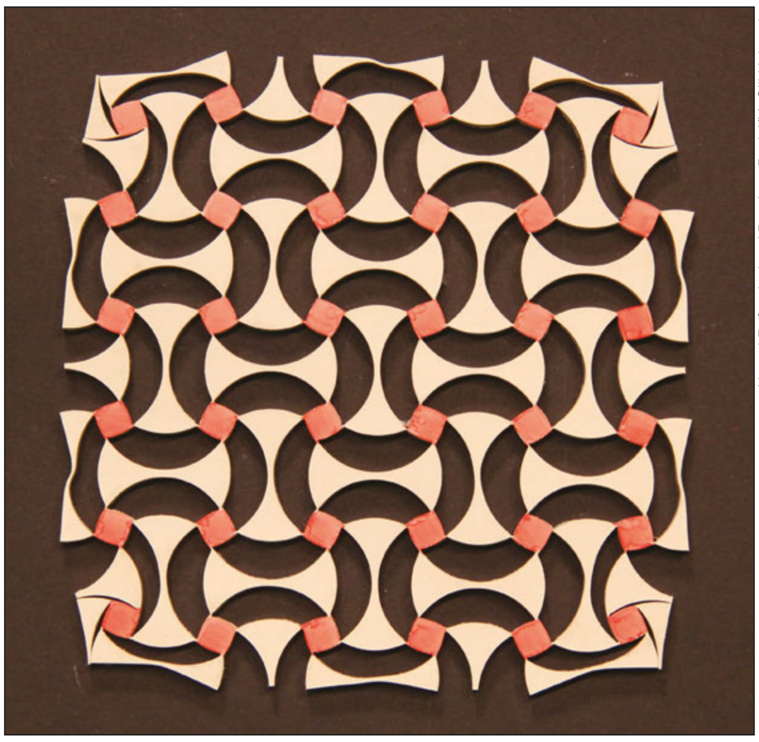
The materials, Rafsanjani said, can be easily fabricated on rubber sheets using a laser cutter, and the designs could be useful in devices that need to expand and stay put, like medical stents or solar panels on spacecraft.

Good to the bone

Bone structure was the inspiration for Ahmed Elbanna of the University of Illinois Urbana-Champaign. He designed a material that becomes corrugated when stretched, and which can be tuned to produce different patterns of corrugation.

Bones are composed of soft collagen reinforced by stiff hydroxyapatite. "They are built like brick-and-mortar," Elbanna said. So Elbanna designed a beam of soft material with staggered stiffer pieces embedded. When the beam is stretched, it forms wiggles, or corrugations, on its surface. "Your surface could initially be flat," said Elbanna, "and then you stretch it, you can create surface roughness that's variable as a function of the stretch."

Such structures could be formed from a variety of materials and in a range of sizes, and the corrugation can be tuned by modifying the ratio of the stiffness between the two components of the material. The material can also be layered, using different patterns of stiff reinforcements to obtain different results, including creating small channels in the material, or corrugation shaped like egg cartons. The material can also be tuned to prevent sound of certain wavelengths from propagating through it, which could be useful for sound isolation.



Ahmad Rafsanjani and Damiano Pasini/McGill University

These metamaterials, inspired by patterns in Islamic art, expand in both directions when stretched, and stay locked in their stretched position.

Building metamaterials brick by brick

Paolo Celli of the University of Minnesota grew up playing with LEGOs, and his childhood playthings inspired him to create metamaterials that can be changed just by snapping the plastic pieces into place, to provide a platform for easily testing proof-of-concept metamaterials designs. Additionally, Celli said, the system will be a useful science outreach tool. "We were also looking for something that people could relate to, something that would make our life easier when trying to explain to people what our research is about."

Because of the complex geometry of metamaterials, fabrication is expensive and slow, so it's not possible to quickly and easily test new ideas and different designs. 3D printing is one possible solution, but it is more expensive and slower than rearranging blocks. Additionally, many of the materials commonly used for 3D printing tend to damp waves that travel through them, Celli said. In contrast, LEGOs are made of ABS plastic, which is very stiff and allows waves through without damping.

Celli placed plastic posts in a grid formation on a flat LEGO base plate. He vibrated the material using a shaker located on the plate, and measured the resulting shaking across the plate. Celli found that vibrations within certain frequency ranges wouldn't travel through his material, thanks to destructive interference and energy trapping. The blocked frequency intervals, known as "band gaps," changed when Celli altered the configuration of the plastic posts.

Spinning a new metamaterial

Rapidly spinning gyroscopes were the basis for another unusual metamaterial. Lisa Nash and her colleagues at the University of Chicago created a metamaterial composed of an array of 54 hanging gyroscopes, which interact with one another via attached magnets. The behavior of the material is unique, because the gyroscopes react perpendicularly to applied forces (just as a top precesses in a gravitational field rather than falling over).

The resulting structure has unusual topological properties: When a gyroscope on the edge is excited with periodic bursts of air at certain frequencies, the resulting disturbance travels along only the edge of the array, leaving gyroscopes in the center untouched. The disturbance also travels in only one direction around the edge. The preferred direction depends on the spinning direction of the gyroscopes and the shape of the lattice.

The system could be a step toward creating one-directional waveguides, Nash said. And, since these types of topological effects are more well known in quantum mechanical systems, "It's also just interesting that you can see this phenomenon in a mechanical system like this."

Sweating the small stuff

So what's the next frontier in metamaterials? It may be the super-small, according to Itai Cohen of Cornell University. Cohen favors origami metamaterials, which are formed out of thin sheets that can fold and unfold in complex patterns. "You can make very complicated patterns with origami," said Cohen. And importantly, he noted, it is scalable, so the rules of origami remain the same on the tiniest scales. So Cohen focused on the thinnest sheets available: graphene — a one-layer-thick sheet of carbon atoms.

"We want to start thinking about graphene not just as a two-dimensional material, but as a two-dimensional material that you can ... build things out of in 3D," said Marc Miskin, a member of Cohen's research group.

By layering graphene with a thin sheet of glass, Miskin created a sheet that bends when heated, for example, as the glass and graphene expand and contract in different amounts in response to changing conditions. When Miskin heats up the graphene-glass sheet, it curls up into a tiny helix. "We are interested in the ultimate limit of this technology," Miskin said.

CAMPAIGN continued from page 3

vote for, might merit an in-person visit from Zwicker himself.

"Every piece of mail we sent out, every phone call we made, and every door we knocked on was guided by the model, and we had to be incredibly disciplined to do that," Zwicker says.

To create such models, Preische uses public information, like a voter's registration as a Republican, Democrat, or independent; whether the voter cast a ballot in a given election; political donations; the results of elections by precinct; and census data. She combines this with consumer data that companies gather about individuals, which are available for a price. Such data range from the type of car you drive to the shows you watch on television. "There's thousands of pieces of information," Preische says.

To create the model for Zwicker's campaign, Preische combined these methods with data from a phone survey, in which voters responded to questions relevant to Zwicker's candidacy — for example, how they felt about a scientist running for office, or whether they supported Zwicker.

Presiche then used machine-learning algorithms to look for correlations between the public data and the survey responses, and used the results to build a model that could make predictions for voters who hadn't been surveyed.

On election night, the outcome was so close that the Associated Press initially called the election for his opponent, and Zwicker conceded. But it soon became clear that the final results would have to wait for every last ballot to be counted, which took two weeks. In fact, Zwicker says, he was at the 2015 APS Division of Plasma Physics Meeting in Savannah, Ga. when he got a phone call informing him that he won.

Zwicker says that the model alone wasn't enough to tip the balance in the election: "We outworked them — that's the only reason why I won," he claims. "Altogether, we knocked on 22,000 doors; we made 78,000 phone calls; and we sent out many pieces of mail. So the model just guided it."

Zwicker campaigned with the promise that he would use evidence to make decisions. When he knocked on doors of voters with this line, Zwicker says, "They would laugh sort of cynically, like 'good luck with that.'" But, Zwicker says, many voters, although they didn't necessarily promise to vote for him, said they were intrigued. "That happened over and over and over again."

Now, in his first months on the job, Zwicker is sticking with the strategy. "If I don't agree with your position, show me the evidence, and I have to do what I promised to do — what any good scientist would do. I cannot stick to only ideology," Zwicker says. "People respond to that, because they say to me,'We may not agree but at least I understand where your position comes from.'"

Zwicker is enjoying his new role as an assemblyman. "I feel incredibly honored to have this opportunity," he says. He is splitting his time between the assembly and his job at Princeton, where he is head of science education at the Princeton Plasma Physics Laboratory (PPPL). Zwicker says his fellow assembly members have responded well to his scientific approach, and he is serving on three committees: telecommunications and utilities, environment, and judiciary.

Preische notes that in previous micro-targeting campaigns, her model has proven to be "amazingly accurate," when its predictions are compared to election outcomes. Preische notes that as a physicist she predicted the behavior of electrons instead of people. "People are less predictable," she says, but "people are more predictable than they think they are."

Preische got involved in politics when she left a career in plasma physics to work on another physicist's election campaign: former U.S. Representative Rush Holt (now the CEO of AAAS). She now is a partner in the political consulting firm FiftyOne Percent, where she works on election campaigns and advocacy campaigns for organizations. She previously employed a micro-targeting strategy for U.S. Representative Bonnie Watson Coleman, in a heavily contested 2014 New Jersey Democratic primary race for Holt's former seat, which was left open after he announced he would not seek reelection. Zwicker also ran in this race, unsuccessfully.

Preische knew Zwicker from PPPL when she was a graduate student and he was a postdoc. Holt himself was previously the assistant director of PPPL. Sources were unable to confirm whether there's something in the water at PPPL that motivates physicists to go into politics.

As for Zwicker, he says Holt was part of his inspiration to get into politics, but he also grew up in a politically active family, and his parents volunteered on local campaigns. "My mom, at 83, still reads the paper every day and wants to talk about politics all the time," he says. Zwicker was also frustrated at the politicization of science, and felt that as a scientist he could help steer his state toward economic prosperity. "We know historically that investment in science comes back multiple-fold in terms of economic activity," he says.

"New Jersey has real economic challenges — our economy has not recovered as fast as our neighboring states. And we have this rich, rich history of scientific innovation." Zwicker believes science is the way to turn his state's economy around. "Who better than myself as a scientist and as a science educator to try to do that?"

Diversity Update

New Report on How APS Can Be More Inclusive of LGBT Physicists

The APS Ad-Hoc Committee on LGBT Issues released a report on "LGBT Climate in Physics: Building an Inclusive Community" at the 2016 APS March Meeting in Baltimore, MD. Findings include: LGBT physicists experience workplace pressure to “not act too gay”; those with additional marginalized identities face greater discrimination; and transgender individuals experience the most hostile climate. Over a third of LGBT physicists surveyed considered leaving their department in the last year. The report recommends specific ways for APS to make the physics community more inclusive and safe, including establishing a broad-based Forum on Diversity and Inclusion. The report will also be presented in a session at the 2016 APS April Meeting in Salt Lake City, Utah, and is available to view on the APS website at go.aps.org/lgbtphysics

The National Mentoring Community at the 2016 APS April Meeting

The APS National Mentoring Community (NMC) provides support for successful mentoring relationships between physics faculty and African American, Hispanic American, and Native American undergraduate students. On the evening of April 15, prior to the 2016 APS April Meeting in Salt Lake City, the NMC will offer a workshop for mentors to aid the development of their mentees' research self-efficacy, or belief that they “can do it.” For more information, visit aps.org/meetings/april/events/nmc-workshop.cfm

Network with other physicists on LinkedIn

Join the LinkedIn groups for Minorities in Physics (go.aps.org/minoritiesinphysics) and for Women in Physics (go.aps.org/womeninphysics) and start networking today!

Save the date!

The 2017 APS Bridge Program Conference will be held in conjunction with the third APS / American Association of Physics Teachers' Graduate Education Conference in College Park, Md., on February 10 - 12, 2017. More details coming soon.

NMC Conference — October 21 - 23, 2016; Registration Open April 6

The annual National Mentoring Community Conference will be held on October 21 - 23 at the University of Houston, and will highlight the importance of mentoring and research experiences for undergraduate students. The agenda will include a research experience for undergraduates and a graduate school fair, mentoring workshops for both students and faculty, plenary talks on supporting underrepresented students in physics, a research poster session, NASA tours, and more. NMC mentors and mentees receive special discounted rates and are eligible for travel funding to attend. Visit go.aps.org/nmc-conference to register and learn more.

Physics Grading Biased Against Women

By Emily Conover

A complex array of factors seems to be holding women back from the field of physics, and now it appears that grading biases may play a part. A recent study performed in several German-speaking countries indicates that physics teachers give better grades to male students than female students — even when their answers are identical. However, this bias disappears as teachers become more experienced. In Switzerland and Austria, secondary school teachers of both genders gave lower grades to female students, while in Germany, female teachers displayed the same bias. Surprisingly, male German teachers were an exception to the pattern, grading students equivalently regardless of gender.

The study focuses specifically on physics teachers, but such biases have already been shown to be present in science education in general. “The fact that teachers unknowingly evaluate students differently as a function of stereotypes about who is supposed to be smart and good at a given subject is pretty well established,” says Nilanjana Dasgupta, a professor of psychology at the University of Massachusetts at Amherst, who was not involved with the study.

“What's new in this is the effect of teacher experience, which I thought was really interesting,” Dasgupta says. “It makes sense that as teachers become more experienced … that's when their gender bias in student evaluation goes away.”

The researchers asked 780 physics teachers to grade a simple exam question, answered by a fictional student. The question was a conceptual Newtonian mechanics problem, which asked students to explain in words what would happen to two skateboarders, each holding one end of a rope, when one skateboarder pulled on the rope.

The choice of such an open-ended question was intentional, says Sarah Hofer of ETH Zürich, the author of the paper, which was published in the *International Journal of Science Education*. “Such [questions] are more prone to biases or to stereotypes because stereotypes particularly take effect in situations that are ambiguous.”

Each teacher was presented with the same student answer, which showed some understanding of physics concepts, but was not fully correct. The student's gender was randomly listed as either male or female. The student's academic focus — languages or sciences — was also randomly assigned.

For newbie teachers at the beginning of their careers, the fictional boy who answered the question had a statistically significant advantage over the fictional girl, even though their responses were identical. For example, in Switzerland, where grades range from 1 to 6, the mean grade difference was 0.7, meaning that a girl might get a 4.8, while a boy got a 5.5 for the same answer. This bias gradually decreased with teaching experience, disappearing for teachers who had taught for at least ten years. The student's academic focus had no influence on the grade the student received.

The only exception to this pattern was male German teachers, who graded boys and girls equally. The explanation for this difference is unclear. “It was really surprising because all other teachers really behaved the same; only this group was different,” says Hofer. She speculates that the difference could be due to programs in Germany that attempt to sensitize teachers to gender issues in physics. “Perhaps this was effective, but especially for the male German teachers,” Hofer says.

Because the finding was unexpected, in order to conclude there's really a difference in male German teachers, “The thing to do would be to see if you can replicate this effect,” says Dasgupta. “If you get it more than once, then you begin to believe it's a real thing, and not just something fluky.”

The importance of experience for reducing stereotyping can be understood in the context of previous research on biases, Hofer says. “Stereotypes may influence the judgment process, particularly in situations that are cognitively demanding and provide the weakest information,” she says. “With increasing experience, teachers can be expected to develop all the cognitive resources that are necessary to avoid the influence of biases on the judgment process.”

Alternatively, the effect may be due to the repeated exposure to female students who are good at physics, which contradicts the teachers' implicit biases, Hofer says. “So the stereotype itself disappears.”

Luckily, the problem has potential solutions, researchers say. For example, grading can be done using student ID numbers instead of names, so that the student's gender is unknown to the grader. “I do that routinely and I find it an interesting experience,” says Dasgupta. “Often I'm surprised that my initial impression of a student in class doesn't match the grade I give them on an assignment.”

Industrial Physicists Mentor Young Scientists

By Emily Conover

When Edward Chen entered graduate school at the Massachusetts Institute of Technology, he planned to go into academia, like many of his peers. But as he neared the end of his education, he learned that an academic postdoc was far from the only option for a Ph.D. physicist. “The possibilities are enormous,” he says — from working in government to doing research in industry.

But, Chen says, the job market is difficult to navigate for students who consider venturing beyond the familiar halls of academia, and he was unsure whether he should start a postdoc, or dive into the private sector. “I've sort of been grappling in the dark the last half year, just trying to make sense of what a Ph.D. means, and what you can do with a PhD, and what I wanted to do for the next 5 or 10 years of my professional career.”

Fewer than 20 percent of physics Ph.D.s become permanent academic faculty, says APS Careers Program Manager Crystal Bailey, and more than half of physics PhDs eventually wind up in the private sector. Despite that, many students struggle with lack of access to information about industrial careers, says APS Industrial Physics Fellow Steven Lambert, because “they're surrounded by academics.”

To address this knowledge gap, APS has created a new program, called Industry Mentoring for Physicists (IMPact). “Students are aware that they won't all get academic jobs, and many of them don't want academic jobs,” Lambert says, but “they have no example of what it's like to work in industry.”

The program pairs graduate student or early career APS members with experienced mentors in industrial physics for a short-term mentoring relationship. Prospective mentors and mentees fill out a short profile through the IMPact website, and the mentees are matched up with potential mentors based on area of interest, geography, or the questions they want answered.

Once connected, the mentor and mentee can proceed however they like — IMPact program guidelines recommend four discussions over three months, usually by phone or video conference. Students can have up to two mentors at a time, and mentors can have up to two mentees.

Since November 2015, APS has gradually rolled out the program to larger numbers of physicists. It is now open to all graduate student and early career members of APS in the U.S., and industrial physicist members. Although the program is not yet open to undergrads or to members in other countries, Lambert hopes to expand the program in the future. “We're trying to have a successful program with a limited audience at the present time.” As *APS News* went to press, 95 mentors and 207 mentees had signed up on the website,and 40 matches had been made.

When he heard about the program, Chen says, “I knew it was something I needed.” His mentors shared their experiences, helped him make contacts with other industrial physicists, explained the reputations of various companies, and discussed the implications of taking a postdoc before moving to industry.

“You won't get this kind of advice from your professors because your professors have lived in this academic bubble their entire careers,” Chen says. “They don't really know what it means to work in a government lab or work in a for-profit research lab.”

Given that only a small fraction of Ph.D. students will find permanent jobs in academia, says Matthew Thompson of Tri Alpha Energy, “I personally have noticed a big need for advice and training.” Thompson has mentored over a dozen students during his career, and he helped spark the IMPact program by proposing an industrial physics mentoring program at the 2014 APS Workshop on National Issues in Industrial Physics. Thompson is now participating in IMPact as a mentor.

“If you connect a student who's done nothing but been in school, probably their whole lives, with someone who is out and having a successful career in industry, that gives them the existence proof,” says Thompson. Mentoring is “great for their morale and their options for the future.”

Walter Buell of the Aerospace Corporation was one of the first mentors to participate in the program. He says that he would've found the program useful if it had been available when he was a student.

“It certainly would have gotten my brain thinking in a different way and it would have gotten it thinking in that way earlier,” Buell says. “When I finished graduate school I was pretty sure I knew exactly what my career was going to be: I was going to go off and do my one postdoc and become a professor, because that's what one did.” Instead, he ended up taking the one nonacademic position he applied for.

Now, Buell hopes to help students be better prepared for nonacademic careers and the job hunt. “In addition to telling the background story of how I got into a nonacademic position and what sort of preparation would have been useful, a lot of the other pieces have been helping with networking ideas,” says Buell. He has put mentees in touch with contacts at companies they are interested in, or with industrial physicists who started off in the mentee's field in graduate school.

Even if mentees ultimately go the academic route, Buell says, the program is “a good introduction to networking,” and the mentees can forge connections that may be useful in their academic careers.

Buell says he's found mentoring to be an interesting experience. “I can draw on some of the conversations to help in my own recruiting efforts as well,” for example, to understand “the sorts of things that newly minted PhDs are thinking about.”

Chen finally decided, with the help of his mentors, to forego a postdoc and instead take a position working in the defense industry. For most Ph.D.s, who often have spent most of their lives as students, Chen says, “It's very scary to jump from a university setting to all of a sudden a non-university setting.” But, Chen says, participating in IMPact has strengthened his confidence in his decisions.

To learn more about IMPact and sign up to be a mentor or mentee, visit impact.aps.org.

COLE continued from page 2

absolutely enjoyed it. I think getting to know some of the brightest, most capable and accomplished scientists in the world — and getting to know them personally, on a first-name basis — has been the biggest kick.

I can remember picking up the phone, and someone says, "Hi Ken, this is Jerry Friedman." Someone of his stature and his accomplishment [Friedman is a Nobel Laureate] to pick up the phone and call you and chat, that was a real kick. I've gotten to know all of the APS Presidents quite well, and they are just top of the top.

Did you have any experience with physics before you came to APS?

No, I took one semester of physics 101, and I said, "This is not for me." So I switched my second semester to biology and did much better. I've always had kind of an interest in science and technology, but never really pursued it. My bachelor's degree is actually in psychology.

What are your hobbies?

My serious hobby is photography, and I've been doing meetings photography for APS for quite a while now [*Editor's note: for example, see the photos on page 1*], especially the prizes and awards ceremonies and presidential receptions, that sort of thing. And I've kind of made that into a side business, and want to do more with that as I get more time down the road.

Anything else?

I will guarantee you, without doing any research, that I am the only person that has an actual speed bump in their office, in the whole world. [Cole points to a yellow speed bump on the floor of his office, which previously slowed traffic on Physics Ellipse, the road surrounding the American Center for Physics in College Park.] And I'm about to add another speed bump, because there are chunks of one out there in the parking lot. It's the asphalt that broke away when they were plowing from the last snowstorm. So we have a speed bump circa 2007; we're going to have circa 2016 soon.

This interview has been edited and condensed.

CUBA continued from page 1

Center for Theoretical Physics in Trieste, Italy.

Sustaining scientific progress remains a priority, said Castro Díaz-Balart, and Cuban scientists are now looking to expand their expertise: "Cuba has identified nanotechnology as an emerging field that is relevant to the future economic [competitiveness] and development of the country," said Castro Díaz-Balart. The creation of a new nanotechnology R&D center, the Cuban Center for Advanced Studies (CEAC), is one effort to enhance Cuba's nanotechnology standing. "It will be an open institution, part of an extensive network of national and international collaboration," said Castro Díaz-Balart.

Current nanotechnology research in Cuba overlaps closely with the country's expertise in biopharmaceuticals, and includes working on nanovaccines for diseases from cancer to dengue, using nanotechnology to improve drug delivery and diagnostics, and studying the impacts of nanoparticles on the environment and on human health.

The country's achievements thus far in nanotechnology are the result of creating "a vision and strategic planning," Castro Díaz-Balart said. "We built our development on the existing strength in medical and biopharmaceutical industries." Some of the necessary equipment for such research was already available, for example.

Nobel laureate David Gross, another speaker at the session on physics in Cuba, noted the unique role that science can play in promoting cooperation between countries. "My experience is that with all the barriers that bureaucracies and governments put up, scientists find some way to go around them, and have an enormous desire to interact with other scientists," Gross said.

Despite having been isolated by the U.S. embargo for so long, Gross said, "Cuba has a vibrant scientific community with very ingenious people who have managed to create a lot in spite of enormous difficulty."

After the recent steps to normalize relations, logistics will be easier for U.S. and Cuban scientists who wish to spend time in each others'countries, said Deputy Science and Technology Adviser to the Secretary of State Frances Colón, who also spoke at the session. "I do see more and more requests from scientists on both sides to spend time in each other's research institutions."

"Cuban science is open for business and they want to collaborate with you," said Colón. "Give it a closer look."

TAIT continued from page 2

a Bose-Einstein condensate. And with the advent of string theory, physics has in some sense come full circle: fundamental particles and forces arise from the vibrations of one-dimensional bits of string, sometimes taking the form of closed loops ("un-knots").

Tait's scientific interests spanned a broad range, from thermodynamics and the motion of iron filings on a vibrating plate, to a classic paper on the trajectory of golf balls, inspired by his son Frederick's love for the sport. Frederick was a leading amateur golfer, but gave up the sport to fight in the Boer War. He was killed in 1900. Tait himself died the very next year.

Kelvin spoke fondly of his friend's passionate nature, recalling that Tait once declared that nothing but science was worth living for. And yet Tait had been a voracious reader with a prodigious memory. "What he once read sympathetically, he ever after remembered," Kelvin recalled. "Thus he was always ready with delightful quotations, and these brightened our hours of work."

Further Reading:

Silliman, Robert H., (1963) "William Thomson: Smoke Rings and Nineteenth-Century Atomism," Isis 54(4): 461–474.

Silver, Dan. "Knot theory's odd origins," *American Scientist* 94(2): 158–165.

Thomson, Sir William (Lord Kelvin). (1867) "On Vortex Atoms," *Proceedings of the Royal Society of Edinburgh VI*: 94–105.

MALADIES continued from page 1

diate cell types between epithelial and mesenchymal may exist, and could provide a warning sign that a tumor is becoming metastatic.

Inspired by the theorists' prediction, Pienta is now looking for such hybrid cells circulating in the bloodstream of prostate cancer patients. "It has changed the way we as cancer biologists and physicians think completely," he said. "It's changing the field."

The cancer swamp

Pienta is also convinced that, in addition to genetic changes in tumors, researchers should pay more attention to factors in the body that could cause cells to leave a tumor and enter the bloodstream. Inspired by concepts from ecology and the biology of invasive species, Pienta hypothesized that an unfriendly environment—which he called a "cancer swamp"—drives cells to leave a tumor and enter the bloodstream. To make the cancer swamp idea more quantitative, Pienta has joined with physicist Robert Austin at Princeton University, a pioneer in developing microfluidic devices that expose cells to gradients of environmental factors like drugs or nutrients, as they would experience in the body.

Princeton graduate student Ke-Chih Lin, who works closely with Austin, presented a device they call the "death galaxy" — a 2.7-centimeter-diameter, two-dimensional network of 484 connected hexagonal chambers, resembling a miniature silicone beehive. The researchers plan to place cancer cells in the chambers, add chemicals at varying concentrations, and measure how cells respond through microscopy or by sampling the fluid the cells grow in. "We need physicists to help us build artificial environments" like the death galaxy, Pienta said. "That's not something cancer biologists can do."

Metastasis measures

Others presented research on how the matrix of molecules that occupy space between cells in the body could help or hinder cancer cells from invading other tissues. Liyu Liu, a former postdoc in Austin's lab who is now at China's Chongqing University and the Chinese Academy of Sciences in Beijing, described a microfluidic chip he developed to study how cancer cells interact with collagen fibers, a major component of the extracellular matrix. By placing cancer cells and collagen together on the chip, Liu observed fibers lining up in parallel rows, a process that he thinks may help the cells pierce blood vessel membranes. "The cancer cell can construct a highway for invasion," he said.

Meanwhile, for Josef Käs, a physicist at the University of Leipzig in Germany, metastasis is less an errant genetic algorithm than a phase transition. Even the ancient Romans recognized that tumors are stiffer than ordinary tissue. Yet cells that metastasize tend to be soft and pliable. Käs envisions a tumor as a "jammed" material like glass, held together by dense packing of its cells. For metastasis to occur, cells must soften until they're mobile enough to escape the jammed state. "In a nutshell, I'm saying the [epithelial-to-mesenchymal transition] is an unjamming transition," Käs said.

To quantify this idea, he and his colleagues have measured the stiffness of breast and cervical cancer cells using laser-based optical traps, and found that even hard tumors contain some soft cells. When enough of these soft cells are present, they can start to flow — "like ducks in a row," Käs put it, potentially leading to metastasis. He hopes his methods could help oncologists more precisely predict when a biopsied tumor is likely to metastasize, and better plan treatments.

Big data

Many presenters pointed out the challenge of tackling the extreme diversity of cancer, which the National Cancer Institute (NCI) describes as not just one disease but "a collection of related diseases." The genes activated in tumor cells vary widely between people, between types of cancer, and even within a single tumor. As a result, a population of drug-resistant cancer cells usually remains even after treatment, and often gives rise to new, more malignant tumors.

Sui Huang of the Institute for Systems Biology in Seattle is hoping to combine recent big data approaches in biology with research on statistical warning signs preceding tipping points in ecology and other fields to turn cancer's genetic diversity into an asset. Huang measures expression levels of genes in cells of tumors that have been treated, and places them in a high-dimensional state space. His goal is to extract from the population-level data early warning signals that such cells could exit dormancy and start to grow, which could help researchers design drug regimens to prevent recurrence of tumors after therapy.

The idea of identifying a statistical warning sign that a transition is about to occur, rather than focusing on the mechanisms behind that transition, is a radically new approach, Huang said. "It's really a hard sell among biologists," he lamented. "We need a culture change. [Physicists] try to understand general principles, not every step in a mechanism."

A rocky relationship

The culture clash between physics and oncology was a topic of sometimes heated discussion at a session entitled "The War on Cancer: Physics Enters the Fray." In fact, physics had already entered the fray in a big way in 2009, when the NCI launched its Physical Science-Oncology Center program with 12 five-year awards of around $2.5 million per year. Program directors at the time announced ambitious goals of marshalling physicists to create a fundamental theory of cancer, in contrast to their more traditional roles as developers of cancer-fighting technology like radiation therapy and proton beams.

The PS-OC program has catalyzed research into areas such as tumor cell evolution, circulating tumor cells in the bloodstream, and information transfer in cancer, said Anna Barker, a biologist at Arizona State University, who spearheaded the program when she was deputy director for strategic initiatives at NCI, which she left in 2010. "We were funding very few of these fields at the NCI when we started," she said. The agency has "multiple grants in each of them now."

The PS-OC program is now handing out new awards, and many of those funded in the first round have not received additional support, forcing them to look elsewhere to sustain their projects. Some say the NCI's recent awards reflect a turn toward more conventional approaches that have failed to produce major gains. The NCI's review system functions "like the law of mass action," complained Austin, who provided input during the program's conception, and received one of the original grants. "You only end up with the mean." Discouraged that NCI has not funded his more recent proposals, he is now courting private foundations.

NCI officials, however, say they are as committed as ever to bringing methods and insights from the physical sciences, which includes applied mathematics and engineering as well as physics, to bear on cancer. "I think overall, the richness of the network is going to increase well beyond what we had in the first phase," said Michael Espey, a program director in the NCI's division of cancer biology. And there are other avenues of support for physicists looking to study cancer, presenters noted. The National Science Foundation's Krastan Blagoev described the agency's Physics of Living Systems program, which specifically funds theoreticians such as Levine. Presenters also pointed to two relatively new journals — *Convergent Science Physical Oncology*, launched last year by IOP Publishing of Bristol, UK, and *Cancer Convergence*, a Springer-published journal that will begin accepting papers later this year — as evidence that the field is gaining steam.

The APS March Meeting itself also reflects the field's growth, with dozens of talks addressing aspects of cancer — both in standing sessions dedicated to the disease, and in ones on cell motility, active matter, and other topics in biophysics and soft matter. "I can assure you it's going to continue," said Emory University biophysicist Ilya Nemenman, incoming chair of the APS Division of Biological Physics, adding that the meeting venue's proximity to the NCI in Bethesda, Maryland, and Johns Hopkins University in Baltimore helped organizers attract cancer experts.

In the end, progress will come from physicists and oncologists working together, rather than going their own ways, presenters agreed. "This is a complicated subject," Levine cautioned his peers. "Physicists need to make simplifications so they can understand things, but they also then need to be aware of the complications."

Oncologists, meanwhile, desperately need the big-picture insights that only physicists can provide, Pienta added. "There are lots of people who are waiting to partner with you," he said. "This is not a problem that's going away very quickly unless you guys solve

Editor's note: Corrected artiicle posted on April 4, 2016.

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Ken Cole

David Weitz

possibility of beating the diffraction limit by tagging individual molecules and pinpointing the center of a single molecule's blur. Zhuang tagged molecules with fluorescent dyes that can be switched on with light. By turning on a small subset of the dye molecules at a time, she can determine the positions of individual molecules.

"We can not only use the super-resolution approaches to get prettier and sharper pictures, we can actually use that to discover novel cellular structures people didn't even know existed before," Zhuang said. Using this method, her group discovered a skeleton-like structure in neurons, made of actin.

David Weitz of Harvard University spoke about his methods for making extremely regular liquid droplets. Using new microfluidics techniques, Weitz and his group created precisely sized drops with a variety of unique properties. "You can make little Russian dolls of drops — drops inside drops inside drops — in a very, very simple fashion." And by making such liquid drops in air, the researchers formed nanoparticles.

Their materials could be useful for making drugs with enhanced bioavailability, and they've already scaled up their microfluidics processes to make products such as makeup. "This to me is proof positive that not only can you do interesting physics and do interesting science, but you can actually make things in a very practical way," Weitz said.

Naomi Halas of Rice University spoke about her work on plasmonic nanoparticles. Plasmons, the collective oscillation of electrons in a metal, can be excited in plasmonic nanoparticles by hitting them with light, and the particles' responses can be tuned by varying their size and shape. The particles have already turned up in home pregnancy tests and could be useful in applications from color displays to solar cells.

Ken Cole

Naomi Halas

Although such particles have traditionally been made using gold and silver, Halas now favors aluminum nanoparticles, in the interest of sustainability and cost. "I decided to take a lesson from history," Halas said, noting that the first transistor was made of germanium, but the electronics industry soon switched to silicon due to the price and scarcity of germanium.

Halas also uses light-absorbing nanoparticles in water to quickly create steam with the aid of sunlight. The process could be useful for improving the efficiency of processes involving distillation, she says. "Distillation is one of the most energy-consuming processes done by the civilized world," Halas said. "If we can make distillation more efficient, then that's a pretty tremendous goal."

Duncan Brown of Syracuse University discussed the recent observation of gravitational waves by the LIGO experiment. 1.3 billion years ago, two black holes spiraled around one other, orbiting closer and closer until they violently merged, emitting three solar masses-worth of energy in gravitational waves. LIGO detected these gravitational waves last September, Brown recalled, just after the upgraded version of the experiment, Advanced LIGO, turned on for the first time. The signal was "absolutely beautiful," Brown said, and it was easily visible above LIGO's ever-present background noise. "I did not expect this," he said.

Ken Cole

Duncan Brown

When one eager physicist asked when to expect a second detection, Brown pointed to the second strongest event reported in the detection paper — a 2-sigma result, which was not significant enough to report as a detection — saying that it "quacks like a duck," and added, "If you ask me, this little guy here looks like a weak binary black hole merger." Either way, Brown said, LIGO is currently analyzing two more months of data, and should have results soon. And LIGO will begin taking more data in late summer or fall. "We won't have to wait too long," he predicted.

The Back Page

In the Matter of *Minority Physics Students v. Chief Justice Roberts*

By Chandralekha Singh

On December 9, 2015, Chief Justice Roberts asked the question "What unique perspective does a minority student bring to a physics class?" during the discussion of a case on affirmative action at the university level. It appears that he chose a physics class because he felt that this discipline definitely does not need diverse perspectives. As a female physicist who has been teaching at the University of Pittsburgh for two decades, I feel that the Chief Justice's question suggests a lack of familiarity with urgent issues in education that must be addressed to maintain U.S. competitiveness.

The question first implies that it is the perspective of the minority student that is the critical feature rather than the presence of the minority student in the physics class. We need to attract minority students to disciplines that need their talents. Currently, approximately 20 percent of undergraduate and Ph.D. students in physics programs across the U.S. are females, which is significantly lower than the percentage in many European and Asian countries. What is perhaps more alarming is that only about 9 percent of physics undergraduate degrees and 6 percent of Ph.D. degrees are awarded to students from underrepresented races and ethnicities. According to the AIP Statistical Research Center, while the number of students obtaining a bachelor's degree in physics increased by 58 percent from 2003-2013, the increase for the African-American students was only 1 percent [1]. In addition, the minority population is projected to become the majority in the U.S. in a few decades. The students from the minority groups are often from economically disadvantaged families, who are often denied the opportunities to get ahead that children from families without economic concerns typically receive. Moreover, there are other barriers due to societal stereotypes and implicit bias that impact the advancement of various underrepresented groups in physics including women and those from underrepresented races and ethnicities. There is an urgent need to engage and increase the participation of these traditionally underrepresented students, whose talents in physics have largely been untapped. These students will be attracted to the beauty of physics if they are supported and encouraged early and often, and have role models.

In response to the Chief Justice's question, the APS President Sam Aronson released a statement on diversity which notes, "One physics student from a minority community disparaged and feared at the time – the Jews of 19th century Germany – was Albert Einstein, whose unique perspective transformed the world." One of my colleagues, who was a Ph.D. student of Manhattan Project leader J. Robert Oppenheimer, told me that he had wanted to major in math but the chairman of the math department at the time blatantly told him and others that Jewish students majoring in math would not find decent math related jobs. Therefore, he majored in physics! Although one may feel relieved now that we do not have this level of explicit discrimination against underrepresented groups, it is important to understand that stereotypes and implicit biases persist and can negatively impact the advancement of underrepresented groups.

My two children attended a public high school in which half of the students were African American, Hispanic, or multi-racial and the other half were white. This school appeared to be "well-integrated" in terms of providing equal education to students with ethnically and racially diverse backgrounds. The reality was different. While my children and many white students took advanced classes in the gifted or honors track, a large number of minority students were in the lowest tier called "main stream." A major reason for the difference is that some children were privileged and had the resources to succeed. Talented minority students with less than optimal resources and support from various societal stakeholders (including school counselors) are unlikely to perform as well as privileged children in seemingly "integrated" schools. They are less likely to get into top colleges and live up to their potential unless we give them adequate opportunities and support.

Now let's go back to the question of the "unique" perspectives of students in a physics class. I wonder if the Chief Justice is assuming that all physics instructors must be a "sage on a stage," and that students have nothing to contribute to the classroom dynamic. Research in physics education, including my own, shows that teaching by telling does not work for a majority of students; rather the physics instructor must actively engage students in the learning process in order for learning to be meaningful. For example, the photos above show students at Chicago State University, a minority serving institution on Chicago's South Side, engaged in active learning environments that have been shown to aid minority students develop a deep understanding of physics [2]. The chart above shows the average scores of matched students before (pre) and after (post) instruction on a well-known standardized physics test called the Force Concept Inventory (FCI) for Modeling Instruction (a research-based approach to helping students learn in which students work in groups and build models to develop a good grasp of physics) and traditional lecture classes at Florida International University, also a minority serving institution [3]. The chart shows that the average raw learning gains from pre-instruction to post-instruction on concepts related to force is significant higher for Modeling Instruction than for lecture classes. As the director of a center that focuses on supporting teaching innovation in the nine natural sciences departments at the University of Pittsburgh, I support faculty members who are excited about developing a classroom culture in which students are engaged in discussions with the instructor and their peers [4].

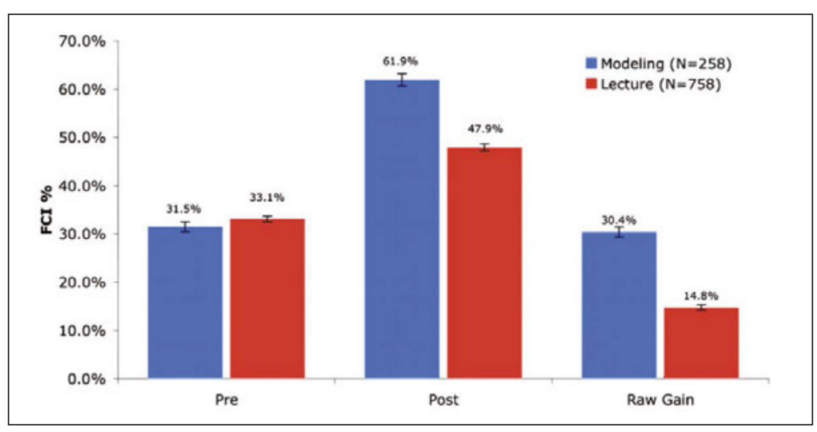
The Chief Justice may also be assuming that physics is just a collection of facts and equations and discussions of societal and real world issues do not have relevance in physics classes, so there would not be any need for a diversity of perspectives. This assumption is not correct. More than ever, physicists are focusing on the implications of their research to society and these thought processes are impacted by the perspectives of scientists with diverse backgrounds. For example, physicists from third world countries are more likely to be inspired to develop improved stoves, solar cells, water purification systems, or solar powered lamps [5].

Moreover, physics as a discipline prepares students for diverse careers and a majority of physics undergraduate majors who do not pursue a higher degree in physics typically find employment in diverse fields such as government, industry, K-12 education, or they pursue higher degrees in engineering, law, business and medicine. In fact, in the last few decades, a majority of physics Ph.Ds. (approximately 70 percent) have found employment outside academia. The enriching perspectives that diverse groups of students bring to physics classes shape the thought processes of all students who go into varied careers and impact innovation and progress in every walk of life [3, 6, 7].

We should all focus our effort on providing greater opportunities to students from underrepresented groups. Without figuring out ways to tap the potential of this large number of talented students, we risk losing our competitive edge.

Chandralekha Singh is a professor of physics and the founding director of the Discipline-Based Science Education Research Center at the University of Pittsburgh. She was in the chair line of the APS Forum on Education from 2009 to 2013. She was the chair of the 2013 APS / American Association of Physics Teachers Graduate Student Conference in physics, which especially focused on embracing diversity to sustain thriving physics programs for the 21st century. For more information about her work, please see sites.google.com/site/professorsinghswebpage/

Photos at left show students at Chicago State University (CSU), a minority serving institution on Chicago's South Side, engaged in active learning environments that have been shown to aid diverse groups of students develop a deep understanding of physics. In top photo Ebony Spells, Angela Moore, and Sharif Onihale work on a physics lab experiment. In middle photo Mike Tyler, Ruth Osborne, and Louis Isaac tackle a classroom exercise. CSU is one of the larger producers of African American physics graduates. It is projected to graduate six black physics majors this year (Fall 15 & Spring 16). According to APS, only two of the roughly 750 colleges and universities that grant this type of degree graduate more than six African American physics majors. Illinois is currently in its eight month without a budget and universities in the state will need to make some very difficult decisions about program cuts and elimination. Physics programs, such as the one at CSU, which the state classifies as low producing, are in danger.



The chart at left shows pre-instruction (Pre) and post-instruction (Post) Matched Force Concept Inventory (FCI) scores for Modeling Instruction and lecture classes at Florida International University, a minority serving institution. The raw gains from Modeling Instruction are substantially higher compared with traditional lecture techniques. Reprinted from Brewe et al. [3].

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The Back Page is a forum for member commentary and opinion. The views expressed are not necessarily those of APS.

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