the SPS Observer
Volume XLVIII, Issue 4
Winter 2014–15

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SOCIETY OF PHYSICS STUDENTS

One Physics Ellipse
College Park, MD 20740
301.209.3007 (tel)
301.209.0839 (fax)
sps@aip.org
www.spsnational.org

Find SPS on:
www.spsnational.org

Freedom and Physics for All

by Sean Bentley
Director, Society of Physics Students and Sigma Pi Sigma

As a professor at Adelphi University in Garden City, New York, I enjoyed teaching introductory physics, math methods, and quantum mechanics. However, the most important class I taught focused on physics in society. It explored energy, security, climate, medicine, transportation, and many other topics in the world around us affected by the physical sciences.

Physics is not some esoteric subject to be studied only by those who want to simultaneously tackle intense mathematics and challenging philosophical questions. A basic understanding of physics is now central to being an informed member of society.

Being well-versed in physics provides you with not only an opportunity but also a duty. "With great power comes great responsibility," stated Voltaire (though the quote is now more commonly attributed to Peter Parker's Uncle Ben). You understand concepts connected to major societal issues and have a unique toolbox of wonderful

> "Activism"
> IS NOT A DIRTY WORD!

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problem-solving skills. The world needs this combination as we address the challenges that face us. In all that you do, you can be an advocate for science and rational thought. You can have a positive impact through small actions.

Unfortunately, many in physics do not get actively involved in advocacy. When people think of policy and advocacy, they often picture either someone wearing a suit and working "inside the Beltway" or someone marching and carrying a picket sign. Professional policy careers and public protests may not be right for you, but you still can and should be actively involved in policies that touch aspects of your professional and personal lives.

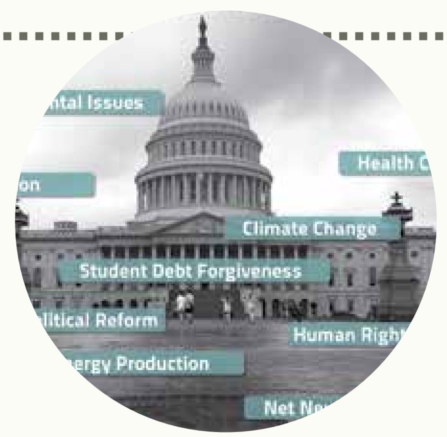
Start by carefully exploring issues of interest to you and weighing all the factors related to those issues—factors related to science, culture, economics, the environment, and so on. Realize that societal problems, much like real physics problems, often do not have simple analytic solutions. If they did, we would be living in a utopia by now! Listen to everyone's opinions, examine the evidence critically, and make an informed choice.

Then act on your decision. Vote. Write letters to elected officials. Engage in public outreach. Don't be passive—"activism" is not a dirty word! //

THE AUTHOR visits the Liberty Bell in Philadelphia. Photo courtesy of Sean Bentley.

FOR MORE ON THIS TOPIC

See the feature stories starting on p. 14.



ON THE COVER
This fall we asked you, the SPS community, to vote on what issues are important to you. See p. 15 for your responses.
Photo by Courtney Lemon.

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The American Institute of Physics is an organization of scientific societies in the physical sciences, representing scientists, engineers, and educators. AIP offers authoritative information, services, and expertise in physics education and student programs, science communication, government relations, career services for science and engineering professionals, statistical research in physics employment and education, industrial outreach, and the history of physics and allied fields. AIP publishes *Physics Today*, the most influential and closely followed magazine of the physics community, and is also home to the Society of Physics Students and the Niels Bohr Library and Archives. AIP owns AIP Publishing LLC, a scholarly publisher in the physical and related sciences. www.aip.org

AIP Member Societies: American Association of Physicists in Medicine, American Association of Physics Teachers, American Astronomical Society, American Crystallographic Association, American Meteorological Society, American Physical Society, Acoustical Society of America, AVS–The Science & Technology Society, The Optical Society, The Society of Rheology

Other Member Organizations: Sigma Pi Sigma physics honor society, Society of Physics Students, Corporate Associates

AIP | American Institute of Physics

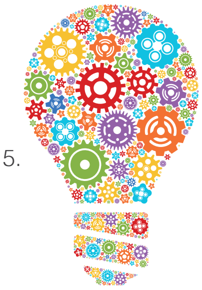
Physics Promoters

2014–15 FUTURE FACES OF PHYSICS AWARD RECIPIENTS

Future Faces of Physics Awards are made to SPS chapters to support projects that promote physics across cultures. The goal of the Future Faces of Physics Award is to promote the recruitment and retention of people from groups historically underrepresented in physics. Congratulations to the 2014–15 recipients, who will each receive up to $300 in project funding.

HAVE A GREAT OUTREACH PROJECT IDEA?

Consider applying for a 2015–16 Future Faces of Physics Award. Proposals are due November 15, 2015. To learn more, visit www.spsnational.org/programs/awards/futurefaces.htm.



Abilene Christian University

WISE STEM Camp for Girls
The SPS chapter at Abilene Christian University will partner with the Women in Science and Engineering branch of their SPS chapter to put together a hands-on camp to foster creativity in female middle school students.
Project Leader: Megan Cromis
SPS Advisor: Darby Hewitt

Colorado School of Mines

Program for the Inspiration of Physics Students
The Colorado School of Mines SPS chapter will promote the study of physics and STEM fields as fascinating, practical, and realistic options through an exhibit-style arrangement of small, interactive demonstrations. They will close the event with a large stage show. The event will be tailored to students at local urban and rural schools.
Project Leader: Jordan Diemer
SPS Advisor: Chuck Stone

Drexel University

A Continued Effort to Patch the Pipeline
Drexel University's SPS chapter will continue its partnerships with a local all-girls Catholic high school and a local after-school science club, and will focus on electrodynamics and thermodynamics this year.
Project Leader: Cameron Petersen
SPS Advisor: Luis Cruz Cruz

Indiana Wesleyan University

Promoting the Physics of Renewable Energies
Indiana Wesleyan University's SPS chapter will host an event at a local high school with a high number of minority students. The event will focus on types of renewable energy production and storage and will include hands-on experiences and a variety of stations.
Project Leader: Alexander Waters
SPS Advisor: Roberto Ramos

Mount Holyoke College

Redefining Physics: Adding Women and Minorities to the Equation
The SPS chapter at Mount Holyoke College will run a photo campaign aimed at students who have not yet declared majors, displaying reasons why current majors and physics faculty chose physics and showing how women and minorities are important to the field.
Project Leader: Husna Anwar
SPS Advisor: Kerstin Nordstrom

Sonoma State University

SSU SPS/MESA Skills Lab: RedBoards, Soldering, PCBs, Oh My!
Sonoma State University's SPS chapter will continue its successful partnership with the Math, Engineering, and Science Achievement (MESA) program on campus, which focuses on educationally disadvantaged students. This year the chapter will lead a workshop on soldering and printed circuit boards, building on a lab that teaches microcontrollers with RedBoard starter kits.
Project Leader: Amandeep Gill
SPS Advisor: Hongtao Shi

United States Air Force Academy

Expanding the Universe!
The United States Air Force Academy's Falcon Physics group, a female cadet-led physics outreach team, will provide observatory tours and interactive demonstrations to local schools.
Project Leader: Anita Dunsmore
SPS Advisor: Devin J. Della-Rose

University of Central Arkansas

The Signs of Physics
The SPS chapter at the University of Central Arkansas plans to work with certified American Sign Language linguists to deliver an engaging physics demonstration show to students of the Arkansas School for the Deaf.
Project Leader: Maxwell Milan
SPS Advisor: Will Slaton

University of Oregon

Light on Science
The University of Oregon's SPS chapter will be partnering with the local chapter of The Optical Society on an outreach event for a Title I-A school. The event will be inspired by the International Year of Light.
Project Leader: Teiler Kwan
SPS Advisor: Stan Micklavzina

SPRING

AWARD OPPORTUNITIES

FOR

Society of Physics Students & Sigma Pi Sigma CHAPTERS

APPLY TODAY!

SPS Award for Outstanding Undergraduate Research

Awarded to one or more members for outstanding research done as an undergraduate

Deadline: March 15*
Amount: $500 for winner, $500 for chapter, and an all-expenses-paid trip to the 2015 International Conference of Physics Students (ICPS) in Zagreb, Croatia

Helen Meskhidze from Elon University received a 2013–14 SPS Award for Outstanding Undergraduate Research for her work modeling the composition and emissions of gamma-ray burst jet cocoons. Zoey Warecki from Towson University received a 2013–14 SPS Award for Outstanding Undergraduate Research for her work on the structural and electrical properties of electron-doped $CaMnO_3$ thin films. Both attended the 2014 ICPS and presented their work at the meeting. *Image credit: Daniel Matias Ferrer*

Blake Lilly Prize

Awarded to chapters and/or individual members who make a genuine effort to positively influence the attitudes of school children and the general public about physics

Deadline: April 15*
Prize: *The Feynman Lectures on Physics* (three-volume set)

The University of Central Arkansas was recognized with a 2013–14 Blake Lilly Prize for its outreach activities. Known throughout the region for its popular science demo shows and planetarium shows, the chapter hosts elementary school students on campus and brings demo shows to schools as well. Other highlights include public showings of the television show Cosmos, interactive SPS booths in multiple campus fairs, and "Science Nights" at local elementary schools.

SPS Outstanding Chapter Advisor Award

Awarded to a chapter advisor on the basis of the leadership, student leadership development, support, and encouragement the advisor has provided to the chapter

Deadline: April 15
Amount: $5,000 to be divided three ways: 60% to the advisor, 20% to the chapter, and 20% to the department

Dr. Randy Booker from the University of North Carolina at Asheville received the 2013–14 SPS Outstanding Chapter Advisor Award. Dr. Booker has been a tireless champion for SPS at the University of North Carolina at Asheville and in his service on the SPS National Council. Through his teaching and mentoring, he has impacted the lives of his students and has seen his SPS chapter recognized for excellence repeatedly.

SPS Outstanding Chapter Awards

Awarded to multiple chapters on the basis of SPS involvement at the local, regional, and national levels as demonstrated in the annual chapter report

Deadline: June 15
Prize: National recognition

The University of Texas at Brownsville received an SPS Outstanding Chapter Award for 2013-14, along with about 60 other chapters.

SPS Scholarships

Awarded to multiple members on the basis of scholarship, SPS participation, and additional criteria as outlined in the scholarship descriptions (such as teaching career objective, attendance at a two-year college, or underrepresented status). For details visit www.spsnational.org/programs/scholarships.

Deadline: February 15*
Amount: $2,000–$5,000

SOCIETY OF PHYSICS STUDENTS

For details and spring award deadlines, visit www.spsnational.org/programs/awards/.
**When an award deadline falls on a weekend, the deadline is moved to the following Monday.*

Know Thyself

A PHYSICIST REWRITES HER STORY AND FINDS A CAREER IN POLICY

by Anna Quider, Director of Federal Relations, Northern Illinois University, DeKalb

QUIDER speaks at the Global Entrepreneurship Summit in Kuala Lumpur, Malaysia. Photo courtesy of Anna Quider.

I was halfway through my astronomy PhD at the University of Cambridge, and I was confused—not by my research, which was going well, but by my waning desire to do research.

I thought I'd work hard and become a professor. I had dreams of becoming the first woman in decades to win a Nobel Prize in Physics. I thought that's just what all physicists *should* want to do. So what was wrong with me?

To jump to the punch line: nothing. I was just starting a different journey to becoming one of the thousands of physicists each year who pursue career opportunities other than academic research. Now I am the director of federal relations for Northern Illinois University (NIU) in DeKalb. I am the bridge connecting students and faculty at NIU to government officials in Washington, DC, and I have the privilege of advocating every day for education, research, economic investment, the arts, innovation, and many other topics that are important to my university community and our nation.

If I could hop in Dr. Who's time machine, the TARDIS, and visit my undergraduate self, I think she would stare in disbelief at her future self. As an undergrad, I didn't even know that careers like mine exist!

ASK THE HARD QUESTIONS

So how did I get here? The ancient Greeks got it right with the aphorism "Know thyself." To get a sense for what my life could be like as a researcher, I read biographies of academic physicists. Then I branched out to politicians, social activists, artists, and others outside of science.

I began to ask myself hard questions. What did I want the story of my life to say? What did I genuinely enjoy doing? What was I *actually* good at? Then came the realization that changed my life: I wanted my life story to read more like that of Hillary Clinton than that of Marie Curie. Then came the guilt (I'll let everyone down! I'm abandoning science!), the fear (What am I going to do with my life now?!), and the relief (I can have a fulfilling career without writing computer code for the next 40 years!).

LEFT: Anna explains the historical Northumberland Telescope at the at the Institute of Astronomy of the University of Cambridge. Photo by Amanda Smith, Institute of Astronomy, University of Cambridge.
ABOVE: The author takes a selfie with the U.S. Capitol Building (left); Quider laughs with students in Dar es Salaam, Tanzania. She visited to discuss women in science and science careers with the teenagers. Left photo courtesy of Anna Quider. Right photo courtesy of the U.S. Embassy, Dar es Salaam.

THE QUESTION IS NOT WHETHER YOU CAN GET A JOB,

but how to get a job you will be happy doing.

You don't have to read a dozen biographies to see the possibilities. There are tools to help you along the process of self-reflection and career exploration, such as the Careers Toolbox for Undergraduate Physics Students (http://www.spsnational.org/careerstoolbox/). Find out about people whose careers you admire or people you hear about in the news. Read their Wikipedia pages or websites, and don't be shy about asking them for an informational interview.

By turning the lens on myself, I realized a number of things. My favorite thing to do is public speaking. Learning is critical to my happiness, but discovery is not. I am not a talented computer programmer. I am a "people person" who thrives on working with others. I enjoy leadership positions. I am very good at networking and building relationships. I prefer working on multiple projects at once. I enjoy teaching.

EXPAND YOUR HORIZONS

Physicists regularly place at the top of employability surveys. The question is not whether you can get a job, but how to get a job you will be happy doing. The world is much bigger than you think, and physicists are working pretty much everywhere. Start expanding your horizons by going to talks in other departments and volunteering.

Interested in policy, specifically? Follow FYI from the American Institute of Physics (read a story from its primary author, Richard Jones, on p. 16). Check out the American Physical Society's Forum on Physics and Society and follow the meetings of the Public Outreach and Public Affairs Committees. Do the things a political science student does: help out with a political campaign, run for student government, or join discussion groups on current events. Firsthand experience looks great on a resume and should help you figure out if you want to pursue a career in policy. Even if you decide that your interests lie elsewhere, the experience will make you a better citizen and more effective advocate for things you care about (such as science research and education).

While in graduate school I began attending events at the Cambridge Centre for Science and Policy, a then–newly established organization linking Cambridge scientific expertise with UK policy makers. I vividly recall when one member of Parliament spoke about a colleague who believed that since one in ten unvaccinated children was expected to fall ill to a certain ailment, scientists should just find and vaccinate that one child likely to fall ill. Misconceptions like this put in stark relief the need for scientists to work with policy makers. They also make the case for a robust basic education in science and mathematics.

I learned firsthand about small-scale policy making after I was elected to my graduate student council and to Cambridge's Faculty Board of Physics and Chemistry. Working to create and enact policies that affected the lives of over a thousand students was at times daunting yet always rewarding. I also honed my communication skills by volunteering for public lectures, school visits, and the Cambridge astronomy podcast.

FELLOW, INTERN

Fellowships and internships can be a great way to explore using your physics training in creative ways. Check out the SPS internships, especially the AIP Mather Public Policy Internships. Corporations, nonprofits, and even lobbying firms also offer summer internships—think outside of the box!

Upon earning my PhD, I was incredibly fortunate to receive the 2011 Congressional Science Policy Fellowship from the American Physical Society. I had a fabulous year working for Representative Russ Carnahan on issues ranging from education to telecommunications. From 2012–2014 I was a Science and Technology Policy Fellow at the US Department of State supported by the American Association for the Advancement of Science (AAAS). The experience of managing a science and technology program operating in 54 countries and helping people realize their potential was equal parts fulfilling and inspiring.

Opportunities exist at the intersection of your values, interests, skills, and education level. Working in policy has united my passion for science and learning with my love of communicating. I see myself as a physicist and an educator who oversees an unorthodox classroom.

There aren't right or wrong choices for how to use your physics training, just choices that will be better fits for you. During a job interview in graduate school I was asked where I saw my career going in 20 years. I said, "I don't know . . . but I know I will be happy." I did not get the job, but I stand by my answer.

My career so far hasn't followed a linear trajectory with an *a priori* endpoint; it has been an organically evolving adventure driven by curiosity, passion, and personal growth, mixed with a bit of chance. I wish you well on your own journey! //

GET INFORMED

AIP Career Pathways Project at www.spsnational.org/cup/careerpathways/

National Science Policy Group at http://natscipolgroup.org

Mirzayan Science and Technology Policy Graduate Fellowship Program at http://sites.nationalacademies.org/pga/policyfellows

American Physical Society's Congressional Policy Fellowships at www.aps.org/policy/fellowships/congressional.cfm

Science and Technology Policy Institute's Policy Fellowship Program at www.ida.org/STPI/STPIResearchStaff/FellowshipProgram.aspx

American Physical Society Forum on Physics and Society at www.aps.org/units/fps/

Through Thick and Thin

A STUDY OF METAL OXIDES

by Zoey Warecki
Class of 2015, Towson University, MD

My interest in perovskite metal oxides started with their potential applications in renewable energy devices such as photovoltaics and photoelectrochemical cells. Made of rare earth elements and alkaline and/or transition metals, the materials could contribute to the clean energy revolution and reduce the world's current dependence on harmful and limited resources.

Another reason to be interested in the oxides is that they have a reputation for being unpredictable. Will a perovskite be a metal or an insulator? Magnetic or not? They seem to have trouble making up their minds because their properties are extremely sensitive to variations in structure and composition.

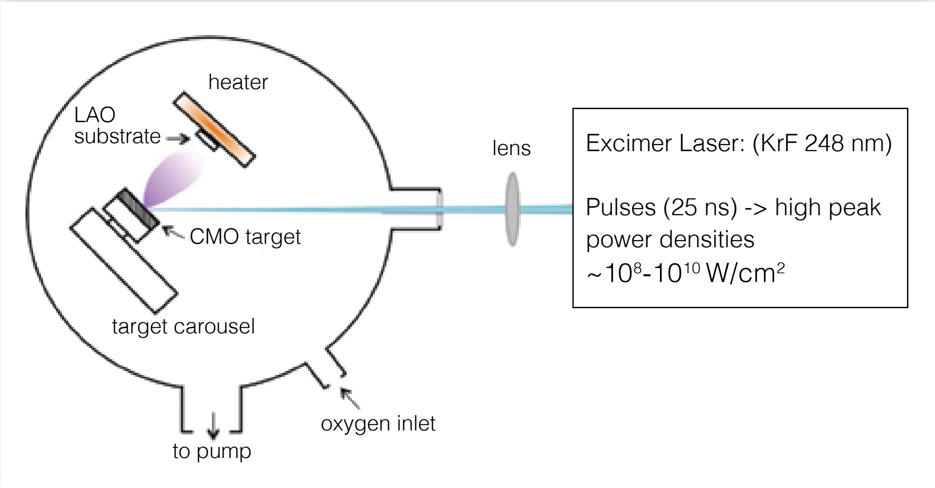
When prepared as thin films or other nanostructures, for instance, perovskites display behaviors not observed in their bulk form. Some perovskite thin films possess colossal magnetoresistance, which means they drastically change their resistance to the flow of electricity in the presence of a magnetic field.

Our specific project was born out of a desire to fabricate thin films of calcium manganese oxide (CMO) with low resistance. CMO, like other perovskites, is in bulk an insulator with such high resistance that it is sometimes inconvenient or nearly impossible to accurately measure. Thin CMO films, on the other hand, have measurable resistances and can be fabricated with various deposition methods.

Each of the many deposition techniques for making a thin film in a laboratory has its advantages. Some are cheaper or quicker; others are more reliable or scalable. One of the coolest methods with one of the coolest names is pulsed laser deposition (PLD). It is an expensive method, but it allows the fabrication of thin films of materials with complex structures, such as $CaMnO_3$. The thickness of a sample made with PLD can range from hundreds of nanometers to a few atoms.

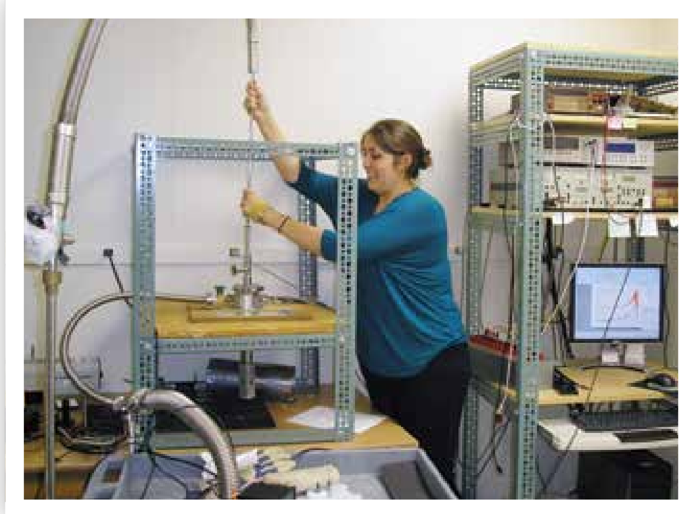
We began making CMO thin films with PLD and found that the resistance of the film depended on its thickness. This was due to the difference in size between the crystals in the thin film and the crystals in the substrate on which the film was grown, lanthanum aluminate (LAO). The thinner you make the film, the more CMO has to strain to match its lattice structure to the substrate's. We then changed our question from "Can we make low-resistance films?" to the more interesting "What role does strain play on these thin films?"

We investigated the size of the unit cells comprising the films and the resistivity of the samples. To measure the di-



LEFT
To create thin films, the author vaporized CMO with a pulsed laser, as shown in this illustration.

RIGHT
The crystal structure of CMO is composed of a manganese atom inside a tetrahedron of oxygen atoms nested within a cube of calcium atoms. Images by Zoey Warecki.



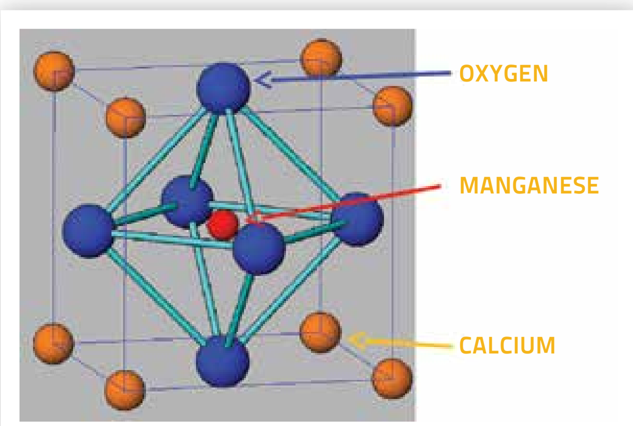
LEFT
The author poses for a snapshot in her lab at Towson University.

RIGHT
Warecki tests the properties of thin film samples. Photos courtesy of Zoey Warecki.

mensions of the cubelike cells, we used x-ray diffraction (XRD), which determines how the planes are arranged in a crystal based on the diffraction angles of x-rays. Then we used a liquid nitrogen cryostat to measure the temperature-dependent resistivities of our samples. These two different measurements, one structural and one electrical, began to hint at the same story: the thinner samples (i.e., the ones with more strain) were more susceptible to the formation of oxygen vacancies, holes in the crystal structure next to oxygen atoms. Understanding how oxygen vacancies change the electrical properties of CMO could help engineers to create new oxygen sensors and other devices.

One particular challenge we faced when first beginning this work was that the resistances of the CMO samples changed over the course of a few days to a week. We needed to organize the experiment in such a way as to minimize any time effects. This seems easy but can often be difficult when equipment, like the XRD, shuts down and needs to be repaired. Experimental physicists must be very patient, or they will become frustrated by interruptions to their work.

I was lucky to have a good advisor who was motivated, passionate, and supportive. He encouraged me every step of the way and pushed me to do good, meaningful work. In my early years of research I made the mistake of not asking questions because I was afraid of looking foolish. I have seen others fall into this dangerous trap. Now I know that fulfilling research starts not with already knowing the answers, but with our ability to ask meaningful questions. //



Experimental physicists must be very patient, OR THEY WILL BECOME FRUSTRATED BY INTERRUPTIONS TO THEIR WORK.

Be Recognized for **Your Research**

Zoey Warecki received a 2014 SPS Award for Outstanding Undergraduate Research for the work highlighted here. Along with the recognition, she received a free trip to present her research at the 2014 International Conference of Physics Students (ICPS) in Heidelberg, Germany; a $500 honorarium; and a $500 award for her chapter. To read about her ICPS experience and the experience of Helen Meskhidze, who also won a 2014 award, visit www.spsnational.org/programs/awards/2014/OSA/.

The 2015 ICPS will be in Zagreb, Croatia, August 12–19. For more information on the conference and the SPS Award for Outstanding Undergraduate Research, visit www.spsnational.org/programs/awards/student.htm. Applications are due March 16.

A Swedish Experience

SCHOLARSHIP SENDS STUDENT ABROAD TO STUDY SUSTAINABILITY

by Lindsay Rothschiller
Class of 2015, Gustavus Adolphus College, St. Peter, MN

I am a city dweller who spent the summer interning in the middle of nowhere, Sweden. When I arrived at the airport, I was picked up by someone I had talked to only once, via FaceTime, the night before. As I was driven farther and farther away from the city, I wondered for a moment if he was taking me somewhere to murder me. There weren't any coffee shops around, or anything familiar at all. I didn't understand what anyone was saying. It was tough at first.

Now that I'm back in the United States, I would absolutely recommend that every student spend time abroad. One way to do this is to study at a foreign university and be surrounded by other students. I did it through an internship in which I experienced the daily life of a nonstudent while doing research. That made it hard to stay in my comfort zone. That's when you really grow. You become more patient and independent. You learn to listen, both to your own thoughts and to other people. You learn to appreciate every moment because you know the moments are only temporary.

I didn't use physics directly, BUT THE PROBLEM-SOLVING SKILLS I HAVE ACQUIRED AS A PHYSICS MAJOR WERE INVALUABLE.

I was able to intern in Scandinavia after being awarded a scholarship offered by my school, Gustavus Adolphus College. Named for Sweden's King Gustav II Adolf, Gustavus offers Swedish courses and has a strong network of alumni and partners in that country. The scholarship, funded by the Wallenberg Foundation, pays for meals, housing, transportation, and a stipend—all meant to provide recipients with a "Swedish experience."

To apply for the scholarship, I had to find a research project. Fortunately, my advisor connected me to Magnus Fredericson, who works for a group of municipalities in Sweden doing research and planning related to sustainable development. He suggested a project on carbon lock-in, which means a society's dependence on energy sources, such as oil and coal, that produce carbon pollution.

I didn't use physics directly in my internship, but the problem-solving skills I have acquired as a physics major were invaluable. Being in physics has taught me to pay close attention to detail and think of everything that could affect an experiment, or in this case, all of the factors involved in carbon lock-in.

During my internship, Fredericson and his family hosted me in their home. I had my own guest cottage, complete with a bathroom and a personal sauna. The family included me in everything, inviting me to come out with them and their friends and even helping me to relearn how to drive a manual car. They made me a part of their family.

There's a special connection that you make with people you meet overseas. You learn to communicate despite the language barrier. You begin to let your guard down and start to realize who you really are, what you value, and who you want to be. //

THE AUTHOR (center) poses for a snapshot with her host family. Photos courtesy of Lindsay Rothschiller.

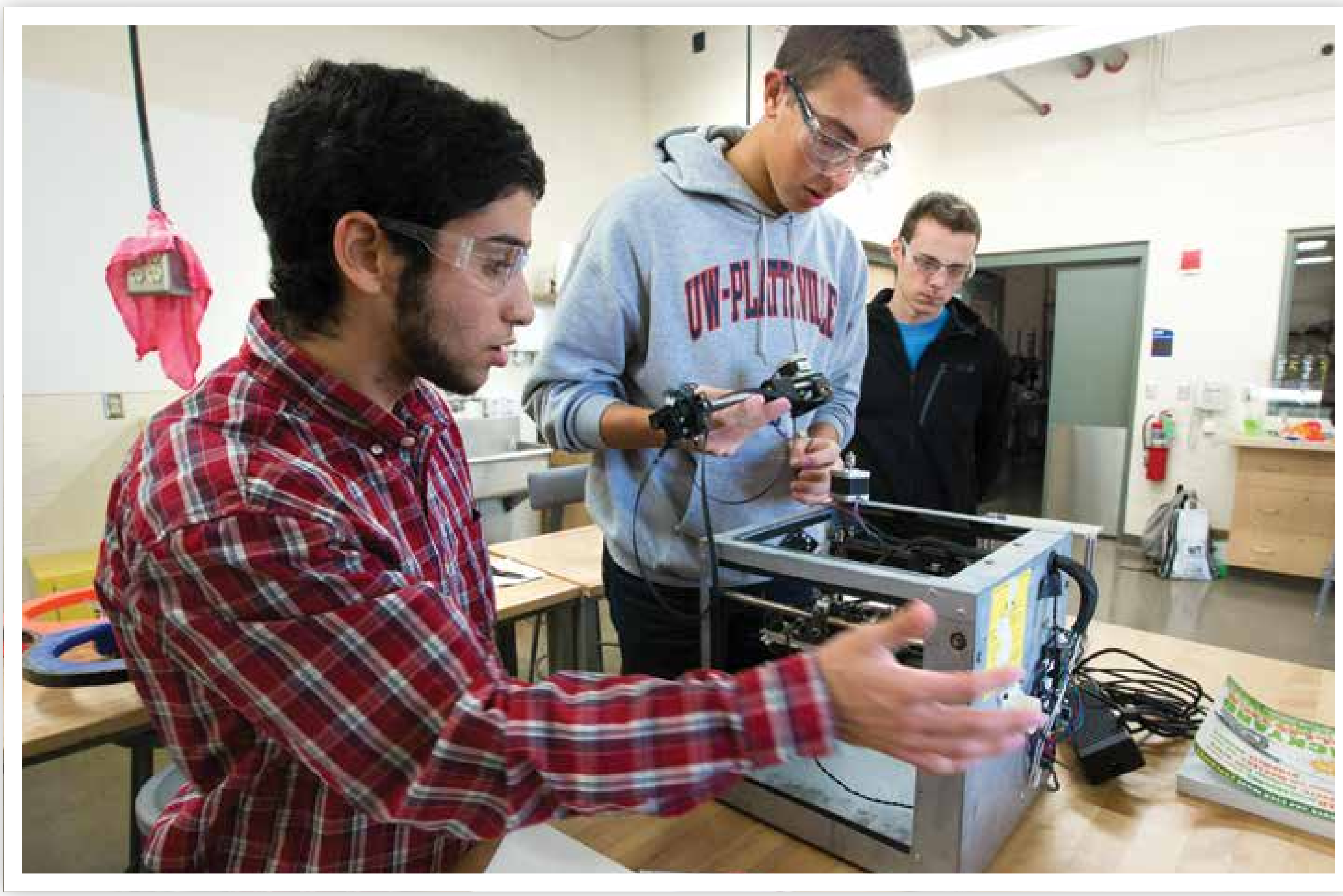
Fall Phenomena

At the University of Minnesota SPS chapter's Liquid Nitrogen Night, balloons dunked in the chilly liquid by the chapter entertained everyone by shrinking very quickly.
Photo courtesy of Jacquelyn Smale.

Chico State SPSers explained the law of falling bodies to school children at a theatrical reenactment of Galileo Galilei's legendary demonstrations at the Tower of Pisa. On October 30 they dropped pumpkins off Butte Hall and timed the drops to the cannon blasts of Tchaikovsky's "1812 Overture."
Photos by Jason Halley, university photographer.

At Old Dominion University (ODU) in Norfolk, Virginia, SPSers didn't just drop pumpkins. They tried to save the squashes from squashing. Sixteen teams built devices designed to catch pumpkins that fell nine stories from the Batten Arts and Letters Building. A team of preschool competitors and their teachers from ODU's Children's Learning and Research Center fared particularly well. Photos courtesy of Old Dominion University.

This summer, tornadoes damaged a pair of 3D printers at the University of Wisconsin-Platteville. The SPS chapter there is fixing the machines and plans to print little things for people on campus, such as key chains and nameplates. After they get those projects off the ground, they are planning to help the community by creating objects useful to a nearby hospital. Photo courtesy of Aaron Tarragano.



In September the University of Tennessee's SPS chapter put on a series of physics demos at Market Square, blowing up heads of lettuce and passing around diffraction glasses.

Photos courtesy of Louis Varriano.

On November 6, the Texas Lutheran University physics department held its first Family Physics Night. Dr. Christopher Rogan, a member of the Harvard ATLAS group working at CERN near Geneva, Switzerland, gave a lecture about the subatomic world and the experiments conducted at CERN. Hundreds of attendees had the opportunity to explore physics through interactive experiments that included a bubble chamber, a sunset demonstration, pendulum waves, a Rube Goldberg machine, jumping rings, hand generators, eddy currents, Gak, ferrofluids, chicken cups, light-transmitting sounds, singing glasses, tuning forks, and a big explosive surprise demonstration. Photos by Dustin Wyatt.

Photo by Courtney Lemon.

SPSer Seeks Sustainability

PHYSICIST-POLITICIAN CHAMPIONS FOOD MOVEMENT ON CAMPUS

by Ashley Finger
Fulbright Fellow, University of Luxembourg Laboratory for Photovoltaics and 2014 AIP Mather Public Policy Intern

My introduction to policy had no relation to physics. It grew from my experiences with the Student Government Association (SGA) during my sophomore year at Davidson College in North Carolina, before I had even declared my major in physics. As director of environmental affairs for SGA, my job was to represent environmental organizations and keep student government on track to fulfill promises to the student body related to environmental goals. I met with the administration, petitioned for change, and spearheaded efforts to engage with the greater community.

Our main accomplishment was drafting and passing a resolution that asked dining services to commit to increasing the portion of its budget allocated to local and sustainable foods. While the immediate impact was minor, the resolution demonstrated that students were conscientious about where their food was coming from. This awareness fueled a shift on campus toward a more sustainable food-consumption model, and Davidson ultimately started its own organic farm that supplies produce to the main dining hall.

My activism remained focused on environmental issues, including sustainable food, land conservation, and renewable energy. Until my senior year, physics and political engagement were separate spheres of my life. I dreaded eventually having to prioritize one or the other.

Then, over the course of only a few months, I heard about, applied for, and received a Society of Physics Students AIP Mather Public Policy Internship that allowed me to spend a summer in Washington, DC, where I worked in the House of Representatives for the Committee on Science, Space, and Technology. The committee's broad policy portfolio included issues related to the Environmental Protection Agency, the National Science Foundation, and the Department of Energy. I no longer had the feeling of "having to choose" between my wide range of interests. I had found a niche that brought them all together.

AT HER LAB IN LUXEMBOURG, the author heats thin film solar cells in an oven. Photo courtesy of Ashley Finger.

After my internship, I traveled to Luxembourg on a Fulbright Fellowship to study photovoltaics at the University of Luxembourg for a year. I am passionate about research, but I have realized that it is not something I can see myself doing long-term.

Becoming a lawyer has been in the back of my head ever since I competed in mock trial team in elementary school and high school. During my time on the Hill I was surrounded by people who bridged the gap between science and law, lawyers who got excited about NASA projects and scientists who were actively writing law. My brain, I have learned, seems to be wired to think like a lawyer; I even enjoyed taking the LSAT! Next year I will attend the University of Virginia School of Law, the beginning of a new path to science policy for me. //

The AIP Mather Public Policy Intern Program

John C. Mather, who shared the 2006 Nobel Prize in Physics for his precise measurements of the primordial heat radiation of the big bang, turned his sights to a more earthly ambition when he spent part of his prize money to establish the AIP Mather Public Policy Intern Program.

The program is funded by the John and Jane Mather Foundation for Science and the Arts, and administered by the Society of Physics Students and the Government Relations Division of the American Institute of Physics. Each summer, the program brings two undergraduate physics majors to Washington, DC, to work in congressional offices and experience the political process first-hand. 2015 will be the fifth year of the program.

For more information about applying, visit www.spsnational.org/programs/internships/.

Student Makes a Stand for His Department

PHYSICS UNDERGRADUATE JOINS STUDENT GOVERNMENT, BECOMES AN ADVOCATE

by Frisco D'Lozano
Law Student, Santa Clara University School of Law, CA

POSTERS such as this one promoted D'Lozano's SGA campaign. Image courtesy of Frisco D'Lozano.

When I was a junior at the University of Texas at Brownsville, the university decided to reduce classroom allotments for many departments, including physics. I spent a portion of my summer research hours moving our SPS equipment out of a room we could no longer use. After I dropped our Van de Graaff generator and was nearly run down by our centripetal force demo, I realized we needed better representation in the Student Government Association (SGA). We needed an advocate fighting for sufficient lab space.

So I decided at the beginning of my senior year to run for the office of senator representing the college of mathematics, science, and technology.

It was a close election, but I won. Then I was appalled that the first measure we voted on was a pay raise for the executive officers of SGA. I led a coalition of other first-time senators to oppose this measure. "Student funds should be spent on the students, not their elected representatives," I argued. Though my tendency to filibuster the president's agenda garnered ill will from the longer-serving executive officers, I gained the respect of my fellow nonincumbent senators and became the senator pro tempore, residing over meetings in the president's absence.

My signature piece of legislation focused on increasing the space allotment for my college. It passed, becoming the first bill to overcome a presidential veto. It felt good to fulfill my campaign promise. It felt good to demonstrate that physicists can succeed not only in the lab but in policy positions. Future generations of physicists at my school will now have a place to study and, workload permitting, relax.

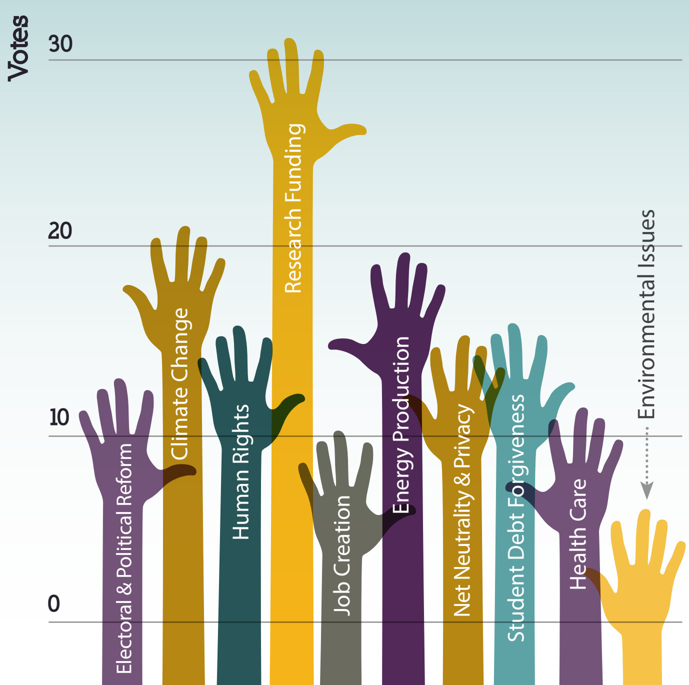
Politics can get dirty, because the laws of humankind are not as clear-cut as the laws of physics. The president knew she couldn't continue her agenda with me around, so she ultimately appointed me to the position of chief justice of the SGA court, a prestigious but largely ceremonial position. Nevertheless, I would still give my wholehearted endorsement to any aspiring physicist-politicians out there. Physics needs advocates. The world needs intelligent leaders who can approach problems objectively and rationally, and this is something physicists do well. //

It felt good to demonstrate that physicists can succeed not only in the lab but in policy positions.

We Asked, You Answered!

SPS asked our Facebook fans to tell us what current issues are important to them, and the responses are in! First we collected free responses, and then we used those responses to generate a poll. The results of the poll are below.

Want to be in on the action? Like SPS on facebook at www.facebook.com/SPSNational.



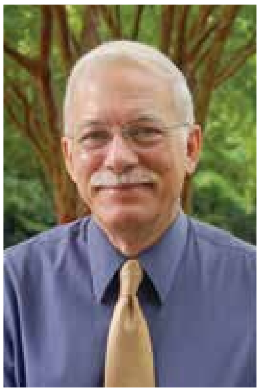


Photo courtesy of AIP.

Communicate with Congress

A CALL TO ACTION

by Richard Jones
Government Relations, American Institute of Physics, College Park, MD

You are needed! Your actions can help influence the amount of money that the federal government provides for physics research at our nation's universities, the policies the government formulates on environmental and health issues, or revisions to student loans.

Every year Congress passes appropriations bills providing research dollars for federal agencies such as the National Science Foundation, the Department of Energy's Office of Science, NASA, the Department of Defense, and the National Institutes of Health. These appropriations bills are "the bills that pay the bills"; they allow science and technology agencies to conduct competitions for research grants and contracts. A professor obtaining one of these grants or contracts can use it to assemble a team (that might include you!) to engage in cutting-edge research.

Federal funding is tight. An agreement between the Obama Administration and Congress has put tough budget controls in place. There are many worthy programs that members of Congress must consider when making decisions about how to distribute money among the appropriations bills. Some programs are visible and easily understood, such as interstate highways or troops based overseas. Others are not as apparent or are thought to benefit interests far away.

That's where you can make a difference. The federal government funds thousands of programs. A big part of the decision-making process that members of Congress use in allocating taxpayer money is based on what they hear from their constituents. A senator or representative who knows of a constituent's interest in a particular program is more likely to support it.

Members of Congress and their staffs are often highly receptive to students. As Eric Beier writes in his adjacent letter, he was able to spend an hour discussing the importance of R&D with a staff member of one of his senators. Members of Congress see R&D as a vital component of America's economic strength, and students as an important part of our nation's future.

> Members of Congress see R&D as a vital component of America's economic strength, and students as an important part of our nation's future.

Get started by learning more about the issues. The American Institute of Physics (AIP) has a science policy bulletin tailored for the physical sciences community that tracks congressional bills and other Washington developments. You can receive "FYI: The AIP Bulletin of Science Policy News," for free by e-mail. It is also posted on the AIP Government Relations site with other science budget and policy information.

To make your voice heard, you might begin your interactions with a member of Congress with a letter. You can also request an in-person meeting, or even work with your university to invite the elected representative to your campus for a lab tour. Seeing something first hand can make a significant impact on a member of Congress. A congressman I worked for many years ago decided to champion funding for a veterans' hospital after visiting and seeing firsthand a thick layer of lint on the walls of the laundry area. "We have to do something about this," he told me at the time, and he did. For guidance on how to communicate with Congress, visit the AIP website (details at left).

Federal support for science and technology is strengthened when relationships like the one Eric describes are formed. Join Eric in working to increase the visibility of federal support for science and technology and the benefits that it brings to your university and to our nation. //

Get informed about the issues

Subscribe to FYI and learn more about communicating with Congress on the AIP website at www.aip.org/policy.

Check out the "Policy and Politics" feed from *Physics Today* at http://scitation.aip.org/content/aip/magazine/physicstoday/news/politics-and-policy.

Change starts with you! Plan your strategy with guidance from Anna Quider (see articles on p. 6 and 19) at www.spscongress.org/change.

Read news and find advocacy resources from the American Physical Society at www.aps.org/policy/.

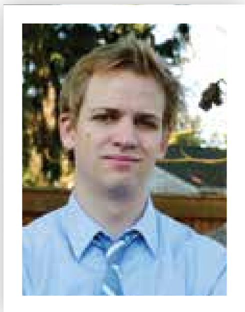


Photo courtesy of Eric Beier.

A Letter to Congress

SPS MEMBER REQUESTS INCREASED SUPPORT FOR SCIENCE FUNDING

by Eric Beier
Class of 2015, Washington State University, Pullman, WA

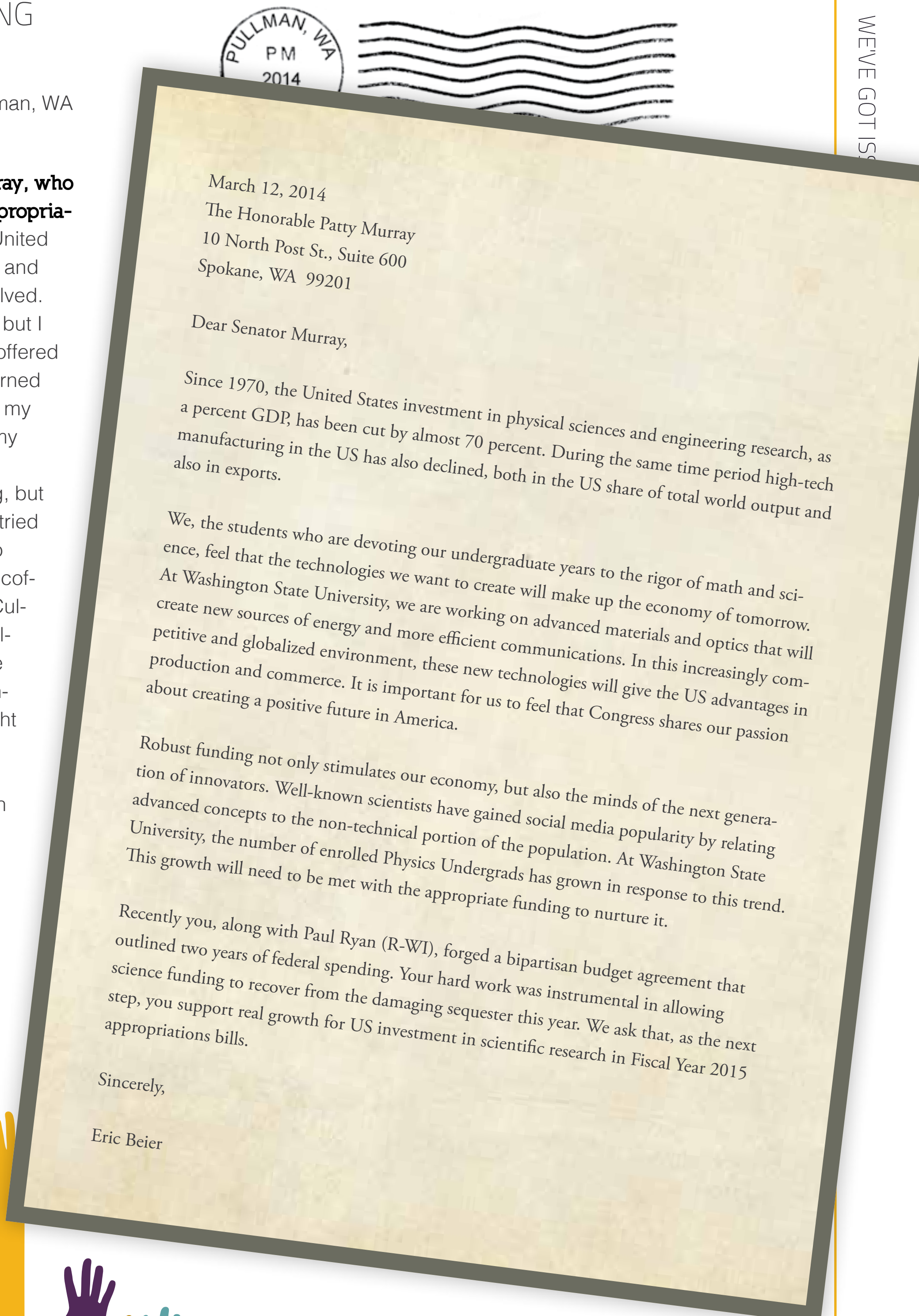
This spring I sent a letter to Senator Patty Murray, who represents my state and sits on the Budget Appropriations Committee. I think it is important that the United States increase its funding for science research, and politics seemed like fun, so I decided to get involved.

Writing a letter fit for a senator was daunting, but I had help. The American Physical Society (APS) offered me advice and reviewed what I had written. I learned to make my argument concise and not try to fluff my language. Senators are busy, and I didn't want my letter to end up in a stack somewhere.

Putting the letter in the mailbox was one thing, but I really wanted to make an impression. So I also tried to schedule a meeting with the senator. After two months of persistent calls, I was able to arrange coffee with her Eastern Washington director, John Culton. We spoke casually for an hour about technology and the internal politics surrounding science policy. He explained Murray's three priorities—infrastructure, education, and research—and taught me the current buzz phrase for science funding, "centers of excellence." Even months after the experience, I still feel like I have a valuable ally in John.

My letter had no instantaneous results, but it helped me to build new relationships with people such as the government relations staff at APS, who provided invaluable guidance. The experience also gave me confidence to move ahead in this field of work. I have since been thinking about ways I could help to promote the benefits of government-funded research to the public.

I strongly believe that this sort of work is valuable to the scientific community and encourage you to reach out. Write a letter. Call the offices of your policy makers. Don't give up until you have scheduled a meeting and made your voice heard! //



March 12, 2014

The Honorable Patty Murray
10 North Post St., Suite 600
Spokane, WA 99201

Dear Senator Murray,

Since 1970, the United States investment in physical sciences and engineering research, as a percent GDP, has been cut by almost 70 percent. During the same time period high-tech manufacturing in the US has also declined, both in the US share of total world output and also in exports.

We, the students who are devoting our undergraduate years to the rigor of math and science, feel that the technologies we want to create will make up the economy of tomorrow. At Washington State University, we are working on advanced materials and optics that will create new sources of energy and more efficient communications. In this increasingly competitive and globalized environment, these new technologies will give the US advantages in production and commerce. It is important for us to feel that Congress shares our passion about creating a positive future in America.

Robust funding not only stimulates our economy, but also the minds of the next generation of innovators. Well-known scientists have gained social media popularity by relating advanced concepts to the non-technical portion of the population. At Washington State University, the number of enrolled Physics Undergrads has grown in response to this trend. This growth will need to be met with the appropriate funding to nurture it.

Recently you, along with Paul Ryan (R-WI), forged a bipartisan budget agreement that outlined two years of federal spending. Your hard work was instrumental in allowing science funding to recover from the damaging sequester this year. We ask that, as the next step, you support real growth for US investment in scientific research in Fiscal Year 2015 appropriations bills.

Sincerely,

Eric Beier

WE'VE GOT IS

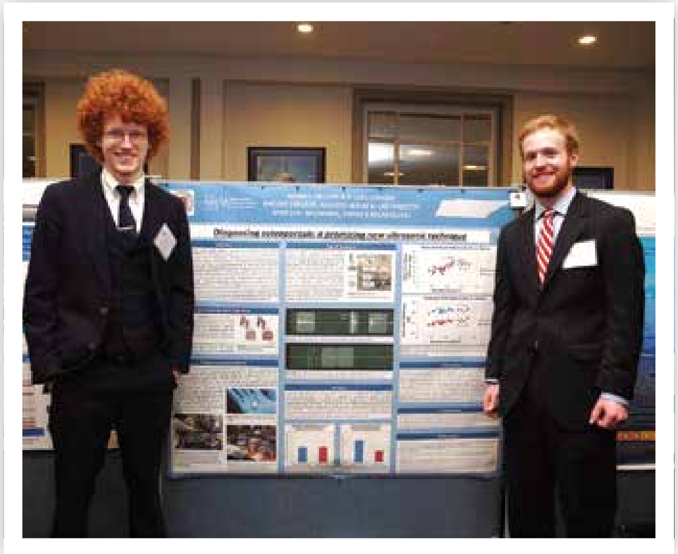
Posters on the Hill and Beyond

EXPERIENCES IN LOCAL AND NATIONAL POLICY KINDLE AN INTEREST IN ADVOCACY

by Mark Sellers
Class of 2015, Rhodes College, Memphis, TN

A project for my AP government class in high school first piqued my interest in politics. It required each student to volunteer with a candidate or political organization to gain firsthand experience of how politics operates at the local level.

I canvassed for Jason Kander, who was then a Missouri state representative and is now Missouri's secretary of state. He talked to me about the importance of rising above partisanship and resisting preconceptions about people's political beliefs. It was an eye-opening experience that caused me to reexamine my binary view of politics.



SELLERS (LEFT) AND HIS COLLEAGUE, LUKE SPINOLO, present a poster on their ultrasound research at Posters on the Hill. Photo courtesy of the Council on Undergraduate Research.

The 2012 Sigma Pi Sigma Quadrennial Physics Congress in Orlando, Florida, rekindled my interest in politics. With the sequester threatening to cut research funding, the conference emphasized political activism in the sciences. After David Mosher, director of the National Security Division at the Congressional Budget Office, and Anna Quider, then–American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellow at the US Department of State, gave a talk about connecting science and policy, we broke into groups to discuss how we would allocate the entire science budget of the United States. I was stunned to hear some group members advocate for reallocating funds for education and human services to high-level research projects at national labs. That's when I realized that effective policy making requires dialogue between scientists, policy makers, and the public. I knew then I wanted to mediate that dialogue.

> [E]ffective policy making requires dialogue between scientists, policy makers, and the public.

Eighteen months later, I traveled to Washington, DC, with my research partner and my advisor to advocate for policies that promote science. At a meeting called Posters on the Hill, hosted by the Council on Undergraduate Research, I was to explain to elected officials and their staff members the significance of my ongoing studies into detecting osteoporosis using ultrasound.

I was nervous. I had never presented research to this kind of an audience; my previous presentations had all been to scientific audiences. During an orientation, the event's organizers calmed those nerves with an advocacy-training workshop offering a simple message: speak clearly and to the point when meeting with your representatives. We scientists must tailor our presentations to our audiences, rather than expecting our audiences to follow us. With the help of our advisor, my partner and I distilled the most salient points from our poster presentation and focused on our overall goal of improving medical technology and quality of life.

The next day, we met with Representatives Emanuel Cleaver (MO-5), Stephen Fincher (TN-8), and Steve Cohen (TN-9), as well as Senator Bob Corker (TN) and members of Senator Lamar Alexander's (TN) staff. They were intrigued by our research and its potential benefits. I felt like I belonged in those meetings, as the topic at hand was the importance of science and its relevance to policy, not partisanship.

A month later, I returned to Washington, DC, for an

SPS summer internship that involved designing the 2014–15 SPS Science Outreach Catalyst Kit (SOCK). My goal was to improve public awareness of science to encourage better political decisions. I tested and created outreach activities, helped organize events, and assisted with the National User Facility Organization's 2014 Exhibition at the Rayburn House Office Building. Along the way, I met scientists, advocates, professionals, and policy makers who were eager to promote science policy.

All of these experiences have reinforced a single message: Good communication and good relationships open doors to bigger and better opportunities in policy and in physics. //

Dig deeper

For more information on Posters on the Hill, visit the Council on Undergraduate Research at www.cur.org/.

To see more about the 2014–15 SPS SOCK and request a free one for your chapter, visit the SPS website at www.spsnational.org/programs/socks/.

Photo by Courtney Lemon.

Change Starts with YOU!

When thinking about federal science policy, you may feel like your voice is only a tiny drop in the vast ocean of opinions, policies, and regulations. But you can be an agent for change on the issues that matter most to you. The suggestions below will help get you started and take part in our nation's science policy dialog. Visit www.spscongress.org/change for even more suggestions.

01 WRITE YOUR MEMBER OF CONGRESS

This may seem like a cliché, but in reality only a very small percentage (<5%) of Americans write to their member of Congress every year. Many members of Congress consider responding to constituent mail to be a very important part of their job. Tell them what's important to you!

02 MOBILIZE OTHER PEOPLE FOR YOUR CAUSE

The old adage "the more the merrier" has never been truer than in the case of writing to your member of Congress. How can your members of Congress represent their community if they don't know what you think about issues that are important to you? Start a chain reaction of science advocacy!

03 MEET YOUR MEMBERS OF CONGRESS OR THEIR STAFF

Get to know the people who are your official voice in national affairs. Help them put a face to your name and tell your story in person. This will help your elected representatives more effectively speak for you. You may meet their staff instead. That's okay. Staff members can help you get your message to their boss.

04 DO A POLICY-RELATED INTERNSHIP

Learn about the policy-making process from the inside. Broadening your understanding of science policy decision-making will make you more effective as a citizen-advocate and as a scientist who will have to interface regularly with the federal government.

Do not underestimate the value of being in Washington, DC, and networking with the many people who work in science policy. Regardless of what career path you choose, it will likely be to your advantage to know a wide range of people embedded in the science policy infrastructure of the United States.

05 STAY INFORMED!

Keeping up to date on what's happening in Congress and in the president's administration will help you determine effective actions you can take to promote your views. //

This call to action was originally drafted by Anna Quider (see article on p. 6) to accompany the workshop she co-led at the 2012 Quadrennial Physics Congress.

Give Counsel to the National Council

JOIN THE CONVERSATION, INFLUENCE SPS POLICY

by the SPS National Office staff with Earl Blodgett, SPS Historian and Professor of Physics at University of Wisconsin—River Falls

In 1999 the Kansas State Department Board of Education voted to strip evolution, the age of the Earth, and big bang cosmology from the public school science curriculum. In response, the Society of Physics Students took action and that year released its first-ever policy statement.[1] "Ideas about the structure and evolution of the universe, including Earth and its life forms, are unifying concepts in science," we proclaimed. "The development of students' informed views about these concepts is essential to a knowledge of science."

This was a bold and unprecedented step for the society, which had largely stayed out of politics. Some members of the National Council questioned whether SPS had any business getting involved, but the overwhelming majority felt it was appropriate to take a stand.

Building on that first leap, SPS has become a more outspoken voice on issues important to the undergraduate physics community. Since 1999 SPS has released or signed on to policy statements related to increasing investments in education, incorporating discussions of professional conduct into the physics curriculum, encouraging undergraduate research, making physics more accessible to everyone, and most recently, encouraging undergraduates to participate in science outreach. SPS has also sent position letters to national funding agencies, participated in the Science, Engineering, and Technology Congressional Visit Day, and created the American Institute of Physics Mather Public Policy Internship in collaboration with the John and Jane Mather Foundation for Science and the Arts.

As a grassroots organization, SPS's strength comes from the diverse perspectives of its members. Every September, elected student and faculty representatives from each of the 18 geographic zones of SPS come together to decide on priorities and vote on the actions we should take together. These representatives, along with a small executive committee, make up the SPS National Council. The council continues its work throughout the year, primarily through topical committees, and reconvenes via webinar in April. The National Council represents you and wants to hear from you!

> What issues are you passionate about? What problems should we tackle together?

What issues are you passionate about? What problems should we tackle together?

Are you concerned about the state of science funding, like Eric Beier? (See his letter to Congress on p. 17.) Maybe you want to improve communications between SPS chapters. Or perhaps you are looking for allies as you address difficulties closer to home in your physics department. (See Frisco D'Lozano's story on p. 15.)

[1] The text of the full statement is available on the SPS website; see www.spsnational.org/governance/statements/2003evolution.htm.

So You Want to Be an AZC?

Join the SPS National Council!

The SPS National Council is looking for students to run for Associate Zone Councilor (AZC), student representative, in each of the 18 SPS geographic zones. Nominations are due February 16. For details, visit www.spsnational.org/governance/elections/.

Reflections from AZCs, past and present:

PETER NGUYEN

Graduate Student, University of Florida, Gainesville
AZC from Zone 6, 2010–12
Student Representative to the SPS Executive Committee, 2011–12

My time on the SPS National Council was definitely one of the best experiences of my undergraduate career. It was great getting to meet fellow students who are just as passionate about science as I am. Even though we only spent a few days together, I made some lifelong friends among my fellow council members.

KELBY PETERSON

Class of 2015, Utah State University
AZC from Zone 15, 2014–15

Being a part of the SPS National Council has given me invaluable insight into how SPS is organized. Meeting physics students from across the nation has been an awesome experience, and I now understand the foresight and thought that goes into SPS initiatives. Being on the council has also helped me figure out what I want my role to be in the greater physics community as I further my academic pursuits.

BRENDAN DIAMOND

Full-Time Teaching Faculty, Tallahassee Community College, FL
Graduate Student, Florida State University, Tallahassee
AZC from Zone 18, 2007–2009
2008 Sigma Pi Sigma Congress Planning Committee

By becoming an AZC, I was able to help plan the 2008 Congress. I hope it inspired the next generation of physicists and leaders.

DAYTON SYME

Graduate Student, Florida State University, Tallahassee
AZC from Zone 15, 2011–13

My fondest memory of being an AZC was my first visit to the headquarters of the American Institute of Physics. It was glorious to see the place where fantastic physics organizations come together to plan and build a better future for science across the United States (if not the world). Although the Society of Physics Students, the American Association of Physics Teachers, and the other organizations housed in this building each have a different expertise, they share the goal of advancing physics. I got to be a part of that goal.

RICHARD PRINCE

Class of 2014, University of Tennessee, Knoxville
AZC from Zone 8, 2011–13
AZC Representative to the SPS Executive Committee, 2012–2013
2016 Sigma Pi Sigma Congress Planning Committee

The most valuable experience I gained from being on the council was the exposure to parts of the scientific community that weren't research. Scientists have roles to play in many aspects of society, and the National Council introduced me to those other roles through such experiences as the congressional visits.

(continued on p. 22)

There are several ways you can reach out and join the discussion:

- Send an email to the associate zone councilor (a student) or zone councilor (a faculty member) elected to represent your zone, or to the members of the SPS Executive Committee (find contact information at www.spsnational.org/governance/council/).
- Attend an SPS zone meeting for face-to-face chats with SPS leaders from other schools. Upcoming zone meetings are listed on the SPS online calendar and announced in the biweekly SPS e-newsletter.
- Run for the SPS National Council! Nominations are due February 16, and all current SPS members are eligible to run. For details, see http://spsnational.org/governance/elections/.
- Contact the SPS National Office with your thoughts and concerns at sps@aip.org or 301-209-3007.

You can also help us incubate new ideas by attending the next Sigma Pi Sigma Quadrennial Physics Congress, slated for November 3–6, 2016, in San Francisco, California. Congresses are huge, energetic gatherings of undergraduate physics students and alumni that feature talks by world-class scientists, hands-on workshops, and tours of fascinating science locations. Workshops at these meetings have a history of giving rise to powerful discussions. Deliberations at the 2004 Congress led to the formation of a National Council Committee on Diversity that spurred the creation of the Future Faces

(continued on p. 22)

Give Counsel to the National Council *(continued)*

of Physics (FFP) program. This program has to date provided dozens of FFP kits to zone meetings and funded more than two dozen undergraduate outreach projects. The committee also initiated the 2009 statement on diversity, which articulated the society's commitment "to providing programs, resources, and opportunities that encourage greater participation in the community of physics from members of all groups."

Get involved. This is your society, your conversation to have. //

Get involved. This is your society, your conversation to have.

So You Want to Be an AZC? (continued)

BRET POLOPOLUS-MEREDITH

Graduate Student, University of Hawaii, Manoa
AZC from Zone 18, 2009–10

Being an AZC was my first experience with the dynamics of making decisions and my first experience working with a large governing body. Previously I had believed an academic career could be devoted solely to research or teaching. But now I know that how an institution operates and shares limited resources with students and faculty impacts the ability of faculty to perform quality research and teaching. My AZC experience has helped me to participate in decision-making at my institution and advocate on behalf of grad students for increased pay, security, and better work conditions.

THANH NGUYEN

Class of 2014, Cal Poly Pomona
AZC from Zone 18, 2012–13

At the 2012 Quadrennial Physics Congress, being in the same space with such minds as Freeman Dyson, Jocelyn Bell Burnell, and John Grunsfeld was a humbling, yet inspiring experience.

AMANDA PALCHAK

Physics Instructor, Mississippi Gulf Coast Community College, Hattiesburg
AZC from Zone 10, 2012–13

I was lucky enough to be an AZC during the year of the 2012 Quadrennial Physics Congress. Not only did I have the opportunity to hear and interview amazing speakers, but I also made lifelong friends. It was a once in a lifetime opportunity, and I strongly encourage all SPS members to run for the position.

KEVIN CHERIYAN

Class of 2015, University of Maryland, College Park
AZC from Zone 3, 2013–15

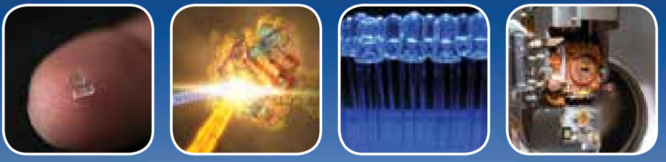
Being a member of the SPS National Council has helped me realize how large and organized the professional physics community is. But the size of the community doesn't prevent the council from being receptive to undergraduates' concerns about issues in physics education, undergraduate research, and diversity. I get a lot of pleasure out of being part of a group that affects the education of thousands of future researchers. //

ABOVE
The 2014-15 SPS National Council and the 2016 SPS Congress Planning Committee stand in front of the American Center for Physics in College Park, MD, in late September, 2014. Photo by Matt Payne.

BELOW
Attendees at the 2004 Quadrennial Physics Congress vote to approve recommendations that were drafted during the meeting. Photo by Tracy Nolis-Schwab.

Unifying Fields

SCIENCE DRIVING INNOVATION



2016 Quadrennial Physics Congress

November 3-6, 2016 • Silicon Valley

Hosted by Sigma Pi Sigma, the physics honor society

Once every four years hundreds of physics students, faculty, and Sigma Pi Sigma alumni from all walks of life gather for the Quadrennial Physics Congress. They spend a packed weekend making new connections, interacting with scientists and distinguished speakers, debating common concerns for the discipline and society, and touring iconic scientific venues.

Make plans now to attend the 2016 Congress in California's Silicon Valley!

Confirmed Speakers

Jocelyn Bell Burnell
Honorary 2016 Congress Chair
Visiting Professor at the
University of Oxford

Persis Drell
Dean of Stanford University School of Engineering
and former Director of the
SLAC National Accelerator Laboratory

Eric Cornell
Senior Scientist at JILA, NIST, and the
University of Colorado at Boulder, and the
2001 Physics Nobel Laureate

S. James Gates
Distinguished Professor and
Center for String & Particle Theory Director
at the University of Maryland

Confirmed Tour Site

SLAC National Accelerator Laboratory

Host Hotel

Hyatt Regency San Francisco Airport, Burlingame, CA

Much more to come!

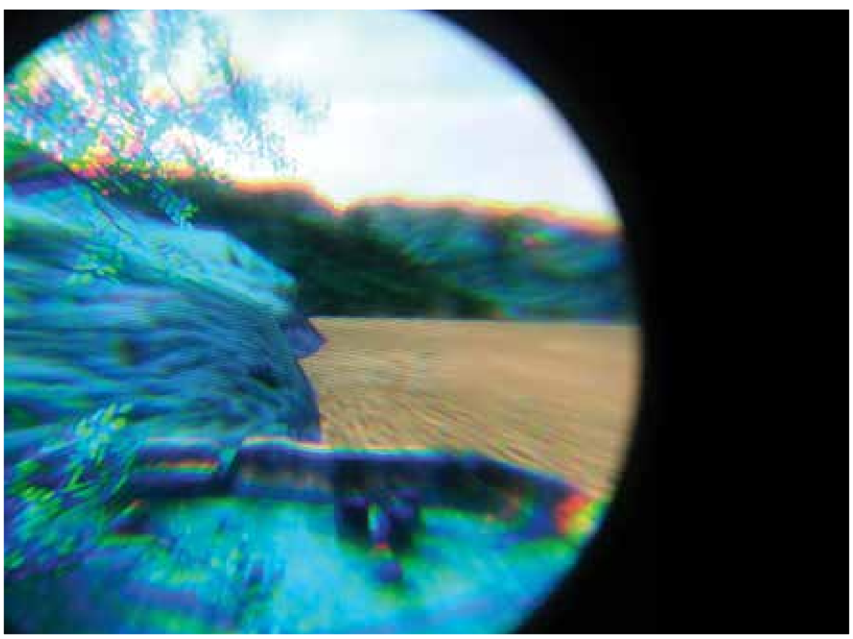
2016 Quadrennial Physics Congress
November 3-6, 2016 • Silicon Valley
Hosted by Sigma Pi Sigma, the physics honor society

Thin Lenses and Chromatic Aberrations

by Dwight E. Neuenschwander
Professor of Physics, Southern Nazarene University, Bethany, OK

As SPS gears up to participate in the 2015 UNESCO (United Nations Educational, Scientific, and Cultural Organization) Year of Light and Light-Related Technologies, we are reminded of the old proverb that says, "The eyes are the window to the soul." If through the window to your soul you look closely at a small purple dot on a white background, it appears blue in the center surrounded by red. Move farther out, and the dot appears red in the center surrounded by blue.[1] I do not know what this means for the soul, but for optics it means that the lens in the human eye exhibits *chromatic aberration*. This effect occurs when the index of refraction of the lens material varies with the wavelength of light. Such *dispersion* separates light into a rainbow when passing through a prism and causes interesting challenges for the designers of refractive optical systems.

YOUR MISSION IS TO DESIGN A compound lens.



A HEAVY CHROMATIC ABERRATION occurs in a virtual reality software demonstration. Image credit: Filip Hajek/Bill Cummings.

Imagine you, a physicist, have been hired as an optical engineer for a camera manufacturing company. You have been given the task of designing a system of lenses that will make red light and blue light come to a focus at the same spot. Of course, there are other colors in the spectrum besides red and blue. But by building a compound lens that focuses onto the same spot light from opposite ends of the visible spectrum, you will have made an important step toward removing most of the chromatic aberration.

When Isaac Newton began making his own telescopes, he started with a refractor and set to work grinding his own lenses. However, Newton was dismayed to see that red and blue light did not focus at the same place. He gave up on refractors and proceeded to invent the telescope that today bears his name, the Newtonian reflector. It remained for Chester Moore Hall, a British lawyer and inventor, to invent in 1733 the first achromatic compound lens (a two-lens system) that he used in his own telescope. In 1758 the English optician John Dolland reinvented and patented the achromatic compound lens.[2] Today you, dear reader, are invited to design an achromatic lens system using nothing but the equations developed in the theory of thin lenses, which most physics students meet in introductory physics class—well, using not quite "nothing but" thin-lens formulas. As we shall see, we also need the trick of adding a third wavelength, which opens to us some tabulated parameters for glass called Abbe numbers; but these, too, are defined by expressions that follow from thin-lens equations. The Abbe numbers provide constraints that reduce otherwise wild ambiguity in the parameter space. It's all introductory optics, but applied in a clever way.

The simplest model of image formation by a lens is expressed in the well-known thin-lens equation coupled with the lens maker's equation. These working equations for imaging with lenses are derived by applying Fermat's principle to refraction at a spherical surface, then using the image formed by one spherical surface as the object for a second spherical surface.[3] The "thin-lens" approximation comes by neglecting the thickness of the lens, assumed to be small compared to other distances in the problem. In the following discussion I assume the reader to be familiar with thin-lens optics. (If you are not, see any general physics or optics textbook, or Ref. 3.) The thin-lens equation relates the distance i of the image from the lens to the object distance o and the focal length f, according to

$$1/o + 1/i = 1/f, \qquad (1)$$

where f is the focal length of the lens, which depends on the lens material's index of refraction n and the radii of curvature of the lens surfaces. These define f in the lens maker's equation, which emerges as the right-hand side in the derivation of Eq. (1) according to

$$1/f = (n - 1)(1/a - 1/b). \qquad (2)$$

In Eq. (2) a denotes the radius of curvature of the first surface encountered by the light in passing through the lens and b the radius of curvature of the second surface. Although distance and radii are normally non-negative numbers, in lens physics the image distance and radii of curvature may be positive or negative, depending on whether the image and the centers of curvature lie on the real side or on the virtual side of the lens (the real side is the side where the light energy really is after encountering the lens, and the virtual side is the opposite side). By Eqs. (1) and (2) the image location is given by

$$1/i = (n - 1)W - 1/o, \qquad (3)$$

where the lens surface curvatures have been lumped into the term

$$W \equiv 1/a - 1/b\,. \qquad (4)$$

Chromatic aberration occurs when the refractive index is a function of the wavelength λ of light, $n = n(\lambda)$. If red and blue are present together in the light ray, then the focal length for red will differ from the focal length for blue. This is the problem that you, the camera lens designer, are to address. The aberration produced by one lens for incoming light of two wavelengths can be compensated for by having the light pass through a suitably designed second lens before the final image forms. As lens physicists let us work out the simplest correction to chromatic aberration.

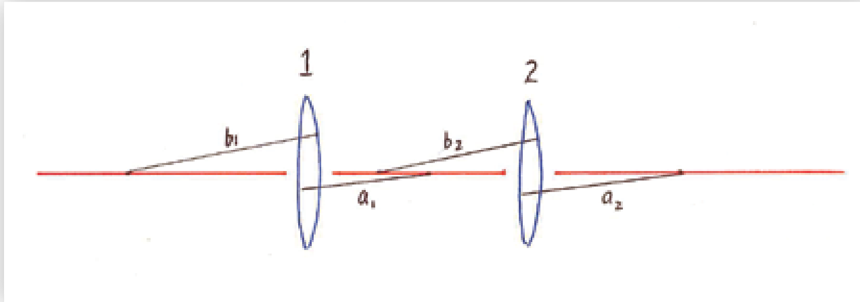


FIG. 1 The two-lens system and the radii of curvature of the first and second lenses.

Consider a beam of light that contains two wavelengths, λ and λ'. (When it's time to insert numbers, we will take for red the wavelength $\lambda = 6562.816$ Å and for blue the wavelength $\lambda' = 4861.327$ Å. But we will leave the equations in terms of symbols as long as possible so that the results derived will apply to any two wavelengths and any pair of lenses.) Now introduce a second lens coaxial with the first. For illustrative clarity (see Fig. 1), let the two thin lenses be separated by some distance D; in our compound lens application we will bring the lenses together by setting $D = 0$. To distinguish variables belonging to the two lenses, let us use subscripts 1 and 2 for them, and let parameters that depend on the two wavelengths be primed and unprimed. For instance, when the light passes through lens 1 the index of refraction for the red wavelength will be $n_1(\lambda) \equiv n_1$. When the blue wavelength passes through lens 1, the refractive index will be denoted $n_1(\lambda') \equiv n_1'$. Similar notations hold for lens 2.

Your mission is to design a compound lens, two lenses back to front ($D = 0$), such that after passing through both lenses the rays corresponding to both wavelengths form final images in the same place. A solution is worked out in an Appendix on p. 31 , but please give it your best shot before looking there. The path toward solving the problem may be separated into four steps. In doing step (1) you will cross the main conceptual threshold for solving the problem. Its result provides the essential relationship between the two lens' refractive indices and their radii of curvature that will get the job done. However, this is one equation with many unknowns. To converge on a specific set of numerical values for these parameters without having to make too many arbitrary assumptions, we will consider other constraints. The guided moves for carrying us farther are outlined in steps (2)–(4). Here we go . . .

01 Derive an equation that relates the radii of curvature and indices of refraction of the two lenses so that light of wavelengths λ and λ' form their final images at the same location (with $D = 0$). Recall that in any multiple lens system the image produced by the first lens becomes the object for the second lens. If the image produced by the first lens lands *behind* the second lens, that means the first image never actually forms; the rays are redirected by the second lens. But one solves the problem by finding where the first lens *would have* formed the image, then making that site the object location for the second lens.

02 Show that for the two-lens system, the effective focal length f_{eff} which relates the *original* object to the *final* image (again with $D = 0$) is given by

$$1/f_{eff} = 1/f_1 + 1/f_2. \qquad (5)$$

03 Write the result of exercise (1) as an expression for W_2/W_1. Set that aside temporarily and consider light of a third wavelength λ'' passing through the compound lens system. Derive another expression for W_2/W_1 in terms of f_1'', f_2'', n_1'', and

n_2''. Set the two expressions for W_2/W_1 equal to show that

$$f_1'' V_1 + f_2'' V_2 = 0, \tag{6}$$

where

$$V_1 = (n_1'' - 1)/(n_1' - n_1), \tag{7}$$

and similarly for V_2. These *V parameters* or *Abbe numbers* for various glasses are well cataloged by glass manufacturers. If a glass existed for which the refractive index was the same for all wavelengths, there would be no dispersion and the Abbe number for that hypothetical glass would be infinite. Thus low dispersion corresponds to large Abbe numbers, and highly dispersive glasses have low Abbe numbers. Glass physicists use three of a standard set of spectral lines, the so-called *Fraunhofer lines,* to measure and catalog the Abbe numbers.[4] Once the types of glass are selected from which the two lenses will be made, their Abbe numbers are known from the tabulated data. Then Eqs. (5) and (6) (both applied to light of wavelength λ'') give a pair of simultaneous equations that can be solved for the values of f_1'' and f_2''. After these individual focal lengths are known, we can choose one radius of curvature for one of the lenses and apply Eq. (2) to each lens, which tells us the remaining radii of curvature needed to grind both lenses.

2015 International Year of Light and Light-based Technologies (IYL 2015) www.light2015.org

In proclaiming an International Year focusing on the topic of light science and its applications, the United Nations has recognized the importance of raising global awareness about how light-based technologies promote sustainable development and provide solutions to global challenges in energy, education, agriculture and health. Light plays a vital role in our daily lives and is an imperative cross-cutting discipline of science in the 21st century. It has revolutionized medicine, opened up international communication via the Internet, and continues to be central to linking cultural, economic and political aspects of the global society.

04 Now we are ready to design (with numbers) a specific achromatic compound lens. The two wavelengths we require to arrive at a common image we take to be the red Fraunhofer C line $\lambda = 6562.816$ Å and the blue F line, $\lambda' = 4861.327$ Å.

Next we select an effective focal length for our compound lens. Suppose the lens you are designing will be a telephoto lens. Telephoto lenses offer a narrow field of view but bring a faraway subject in close. Their focal lengths range from 100 to about 800 mm. Let us choose our telephoto compound lens system to have an effective focal length of $f_{eff} =$ 300 mm.

Next we must choose the lens materials. Let us choose crown glass for lens 1, for which the glass catalogs say $V_1 = 59.6$. For lens 2 we choose extra dense flint (EDF), for which $V_2 = 30.9$.[5]

From these choices show from Eqs. (5) and (6) that $f_1'' = 14.45$ cm and $f_2'' = -27.86$ cm. Then from Eq. (2) the radii of curvature of each lens can be determined. Let lens 1 be an equiconvex lens (i.e., $a_1 = |b_1|$). Show that $a_1 = 14.97$ cm, and for lens 2 (which fits snug against lens 1) show that $b_2 = -66.67$ cm.

Now you have the specifications you need to grind the two lenses out of crown and EDF glass. They can then be glued together to make the achromatic compound lens. (We neglect any optical properties of the glue.) For solution details see the Appendix on p. 31. //

ACKNOWLEDGMENTS

I thank Steve Feller for his inspiration as a glass physicist and for his suggestions, Devin Powell for valuable discussions, and Sean Bentley for reviewing a draft of the manuscript.

REFERENCES

[1] Eugene Hecht, *Optics,* 4th ed. (Pearson/Addison-Wesley, San Francisco, CA, 2002), p. 269, suggests this exercise, which has been verified by the author. Hecht's book is referenced throughout this article. However, this topic is an old one, well covered in many optics books, for example, Francis A. Jenkins and Harvey E. White, *Fundamentals of Optics* (McGraw-Hill, New York, NY, 1950), pp. 145–153; Bruno Rossi, *Optics* (Addison-Wesley, Reading, MA, 1965), pp. 87–90.

[2] Hecht, Ref. 1, p. 271.

[3] "Elegant Connections in Physics, Foundations of Geometrical Optics: Phenomenology and Principles," *The SPS Observer* (Summer 2010), http://www.spsobserver.org.

[4] The *V* numbers take on the proper noun designation *Abbe numbers* when $\lambda'' =$ 5892.9 Å (the Fraunhofer D line halfway between the yellow sodium doublet); when $\lambda' = 4861.327$ Å, the Fraunhofer F line from helium; and when $\lambda = 6562.816$ Å, the Fraunhofer C line emitted by hydrogen. The Abbe number is named after its originator, the German physicist Ernst Abbe (1840–1905). See Hecht, Ref. 1, pp. 269–270.

[5] *Ibid.,* p. 270.

Beyond Academia

INDUSTRIAL-SIZED PHYSICS AT THE INDUSTRIAL PHYSICS FORUM IN SAO PAULO, BRAZIL, SEPTEMBER 28–OCTOBER 3, 2014

by Jamison Thorne
Class of 2015, Northern Illinois University, DeKalb

At college I had heard about "industrial physics." I knew it to be a lucrative career path for physicists, but it wasn't until I attended the American Institute of Physics' Industrial Physics Forum in Brazil that I really had the opportunity to explore how physics and industry can work together to improve processes and promote new business ventures. During a field trip for participants, for instance, I saw firsthand how a company can use science for the benefit of the population at large as well as itself. I visited Embrapa's satellite monitoring facility and learned how agriculture is monitored regionally across Brazil to find the best locations for crops and grazing spots for animals.

The topics covered in talks at the forum ran the gamut: trends in industrial physics, physics and diplomacy, entrepreneurial professors, physics in oil fields, and global industrial physics. I found two presentations on tools that utilize fundamental concepts in physics to be especially captivating.

Simarjeet Saini from the University of Waterloo in Canada is developing low-cost diffraction gratings that can turn smartphones into spectrometers. With this tool, food products can be analyzed to determine if toxins are present. Saini aims to provide inexpensive contaminant sensors to populations with high levels of contamination in their food sources, such as India.

Jarbas Neto from São Carlos Institute of Physics at the University of São Paulo in Brazil talked about a virus called citrus greening disease that has wiped out a large percentage of orange trees globally. He is working on a handheld spectrometer that analyzes the leaves of orange trees and makes a diagnosis by detecting a certain wavelength of light associated with infected trees. The spectrometer can detect infection up to a year and a half before a tree shows other signs of disease, and could thus save trees, resulting in more food and reduced costs.

Following a few days of presentations, there was a two-day short course on science and technology entrepreneurship that inspired me to want to found a startup in the future. It covered issues related to patents, government regulations, trading internationally, and funding. With a good idea and a working knowledge of policy and funding, starting a company definitely seems doable.

Through my interactions with other participants, I realized that even if you make decisions early about the career path you want to follow, you can change your mind later. You may even find yourself on a completely new path someday. A number of the people I met were doing really interesting things that they had never considered while they were an undergraduate or graduate student. Industry offers many viable career paths for physics majors. //

NORTHERN ILLINOIS UNIVERSITY representatives at IPF (from left to right): Ashlyn Shellito, Anna Quider, Jamison Thorne, Anusha Ravva, and Nick Thompson. Photo by Joe York.

NEXT UP

The next Industrial Physics Forum, Mesoscale Science and Technology of Materials and Metamaterials, will take place October 19–20, 2015, at the AVS 62nd International Symposium and Exhibition in San Jose, CA. For details, watch www.aip.org/industry/ipf.

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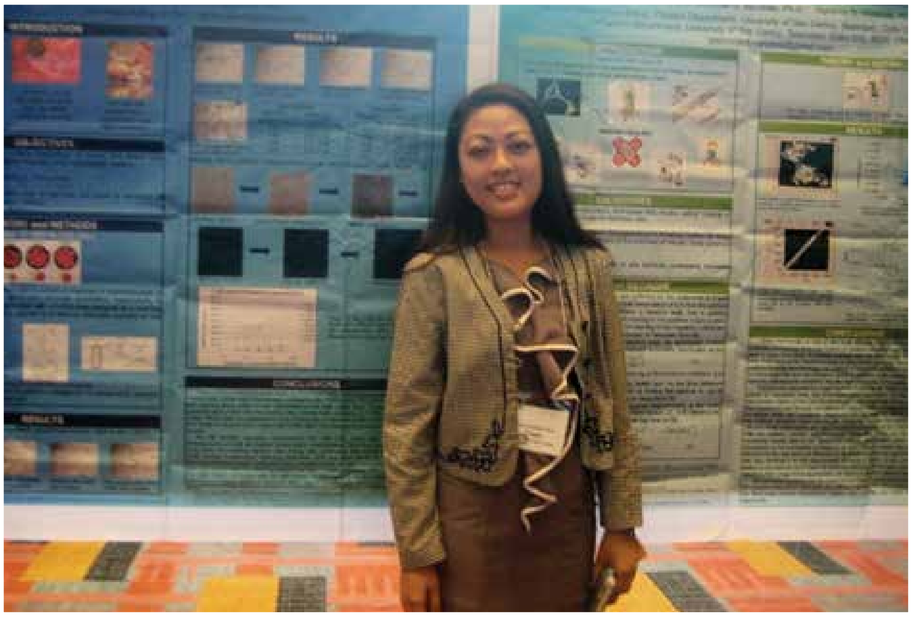
For details, visit www.spsnational.org/programs/awards/reporter.htm.

IPF ATTENDEES gather for a photo. Photo by Antonio da Costa.

My First International Science Conference

A TRIP TO THE 86TH ANNUAL MEETING OF THE SOCIETY OF RHEOLOGY, IN PHILADELPHIA, PA, OCTOBER 5–9, 2014

by Clare Maristela V. Galon
Class of 2015, University of San Carlos, Talamban, Cebu City, Philippines



THE AUTHOR presents her work on red blood cells at a poster session. Photo courtesy of Clare Galon.

Traveling from my home in the Philippines to a conference in Pennsylvania was not easy. I had to adjust to the time change, the weather, the culture, and the people. But I was happy to adapt and get away from my comfort zone. I felt proud to be given the opportunity to attend a Society of Rheology meeting and present during the poster session.

Rheology is the study of the deformation and flow of matter. It can help us understand the mechanical properties of a material. I think that rheological properties can be compared to how people respond to stress in life. We are "elastic" if we easily feel sad when we experience stress and easily feel happy again if that stress is removed. We are "viscous" if we are not easily affected by environmental changes. Lastly, we are "viscoelastic" if we easily feel sad when we experience stress, but it takes a long time for us to feel happy again after the stress is removed.

Uncertainties of what the future might bring can be a cause of stress in my life. Fortunately, a forum at the conference called "Rheology in the Real World", co-sponsored by the Society of Rheology and the American Institute of Physics, offered ideas on how to apply what I like and am learning in school to opportunities such as working for US national laboratories and world-class companies such as the Dow Chemical Company, the National Institutes of Standards and Technology–led nSoft Consortium, Mondelez International, MedImmune, and Procter & Gamble. During the forum, speakers shared their experiences and highlighted the role of rheology in their companies' products. They also discussed how this branch of physics aids in biopharmaceutical and process development. I learned a lot about not only the applications of rheology, but also how to socialize, build strong peer relationships, be productive in research, and not be afraid to travel.

> I learned a lot ABOUT NOT ONLY THE APPLICATIONS OF RHEOLOGY, BUT ALSO HOW TO SOCIALIZE, BUILD STRONG PEER RELATIONSHIPS, BE PRODUCTIVE IN RESEARCH, AND NOT BE AFRAID TO TRAVEL.

In addition to the forum, the meeting featured four plenary lectures and a series of symposia. I found a talk by Susan Muller of the University of California, Berkeley, to be the most interesting because she spoke about microfluidics. My research is on the microfluidics of human red blood cells. I was amazed by her description of how a nanoparticle can affect surrounding particles. Like Muller, I am very optimistic that there will soon be a cure for cancer; many of the researchers at the symposium were working on ways to treat the deadly illness.

The meeting did not consist of just serious talks. We had a lot of fun, as well! Michael Mackay of the University of Delaware headed a two-mile Rocky Rheology Run early one morning before the talks. At first I tried to keep up, but then I decided to walk to the last stop and take pictures of the beautiful city along the way. I took my time, and the funny thing was that I met all of the other runners as they were heading back to the start while I was still walking toward the last stop.

At the meeting, I gained a lot of knowledge and experiences (and also a little weight!). //

My Nuclear Family

RESEARCH AND RELAXATION AT THE 4TH JOINT MEETING OF THE DIVISION OF NUCLEAR PHYSICS OF THE AMERICAN PHYSICAL SOCIETY AND THE PHYSICAL SOCIETY OF JAPAN IN WAIKOLOA, HI, OCTOBER 7-11, 2014

by Marie Blatnik
Class of 2015, Cleveland State University, OH

In October I joined nuclear physicists from around the world for a physics party in Hawaii, in part thanks to an SPS Reporter Award. Our hotel overlooked an ocean-fed lagoon filled with dolphins and colorful fish. We had "bonding time" between scientific talks at the beach, where we surfed on our stomachs, and I saw a more carefree side of my coworkers from the Los Alamos Neutron Science Center in New Mexico. It was a blast.

Of course, we also learned about cutting-edge physics at this joint meeting of the American Physical Society (APS) Division of Nuclear Physics (DNP) and the Physical Society of Japan. Talks were given on everything from neutrinoless double beta decay to magic numbers.

One of my favorite talks was about the RIKEN-Brookhaven Research Center, made possible by a collaboration between Japanese and American physicists who come together to work on difficult quantum chromodynamics systems. This talk set the tone for the rest of the meeting by providing an example of how cooperation can achieve physics research goals.

International collaborations in the physics community amaze me. In large-scale experiments, pieces of equipment are often created piecemeal, thousands of miles apart. When these pieces are brought together and assembled, they must have near-perfect tolerances, interface together, and meet the sensitivity requirements of the experiment. With little margin for oversight or error, international projects are a testament to how well physicists can work together to probe the mysteries of the universe.

Collaboration in the nuclear physics community goes beyond alliances based on individual research projects; when Jolie Cizewski from Rutgers University in Camden, New Jersey, gave a talk for undergraduates about graduate school applications, she addressed us with the greeting, "Welcome to your nuclear family!" This sentiment of solidarity resonated with me. Nuclear physics is a small, intimate community. The spirit of collaboration, so alive both in my own research group and in the larger nuclear physics community, is one reason why I will be pursuing nuclear physics in graduate school.

On the fourth day of the conference, I and other undergraduates attending the meeting presented our posters to our nuclear family. The hallways of the conference venue, outside but in the shade, filled with chatter as we impressed career physicists with our efforts and discoveries.

Animated and excited about the work I had done using a magnet to control the spins of neutrons, I never had an idle moment discussing my results. My poster received a wide range of responses, from curious questions about my methods to praise for the meticulousness of my graphs. My advisor brought over his thesis advisor, whose response to my presentation was, "I believe you." It was a validating experience to have something to contribute to this meeting. I declared to the nuclear family that I am a physicist, too. How empowering! //

I DECLARED TO THE NUCLEAR FAMILY

that I am a physicist, too.

NEXT UP

The next meeting of the APS DNP section will take place October 28–31, 2015, in Santa Fe, NM.

LEFT: The author discusses her research on neutrons at a poster session.
ABOVE: Hawaii is a beautiful place to visit for a meeting.
Photos courtesy of Marie Blatnik.

"We Exist as a Section!"

INAUGURAL MEETING OF THE MID-ATLANTIC SECTION OF THE AMERICAN PHYSICAL SOCIETY IN UNIVERSITY PARK, PA, OCTOBER 3–5, 2014

by Matthew Parsons
Class of 2015, Drexel University, Philadelphia, PA

"We exist as a section!" These were the words spoken to the crowd at the opening talk of the inaugural meeting of the Mid-Atlantic Section (M-AS) of the American Physical Society (APS). The newly formed section was gathering together for the very first time!

> We physicists can do anything.
> THAT'S THE GREAT PART ABOUT OUR EDUCATION.

The meeting's agenda was packed with a variety of exciting activities, from tours of the university's research facilities to a plenary presentation given by a Nobel laureate from the region.

Upon arriving on Penn State's campus, where the meeting was held, my first stop was a tour of the university's nuclear reactor. This was an awesome experience because you can actually look at the fissioning core in the water of the pool-type reactor and see the blue glow of Cherenkov radiation coming from it. Although the reactor operates at a low power (about 1 MW, compared to 1,500 MW for a typical commercial-power-generating reactor), it creates a high neutron flux used for various materials characterization techniques.

The meeting also included many sessions of contributed talks. I gave a presentation on work that I am doing at the Princeton Plasma Physics Laboratory in Plainsboro Township, New Jersey. My computational research involves simulating the movement of plasma inside of the lab's experimental fusion device. As I compare the results to actual measurements, I look for differences between theory and experiment.

It was a meeting full of affirmation. At a panel discussion on industrial careers for physicists, retired IBM researcher Paul Grant told the audience, "We physicists can do anything. That's the great part about our education."

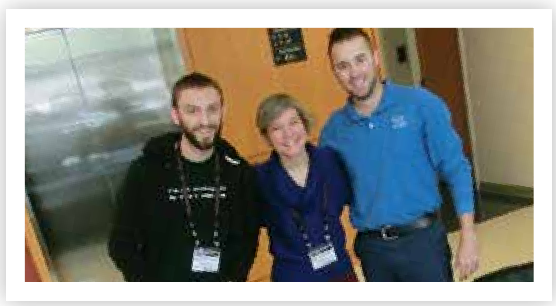
That evening, some other students and I sat down to dinner with Dr. Grant and talked about everything from quantum computing to the etymology of the English language. When you're surrounded by physicists, there is never a dull moment!

Dan Vergano, reporter for *National Geographic*, spoke at the meeting about communicating science to the public. "People don't just want facts about what's happening in science," he told us. "They want to hear a story about what's going on." His personal tips included the advice to share science news on Facebook.

On the final day of the meeting, I spent the morning at a session on physics education. I believe that an understanding of teaching pedagogy makes one not only a better teacher and communicator, but a better student as well. The audience was reminded that unless you build up concepts from a foundation that a student already has, in the end he or she won't really have learned anything. Whether you are leading a recitation, conducting public outreach, or trying to digest the lecture that you just sat through, this is an important point to keep in mind. //

MORE INFORMATION

The newly formed Mid-Atlantic Section of the American Physical Society includes the District of Columbia, Delaware, Maryland, New Jersey, Pennsylvania, and West Virginia. APS currently has ten regional sections. To find out what is happening in your part of the country, visit www.aps.org/membership/units/sectionmap.cfm.



LEFT: Pennsylvania State University's big, open campus was quite different from the author's campus in Philadelphia. **ABOVE:** Parsons (left) with APS staff members Crystal Bailey and Jonathon Burkin. Photos courtesy of Matthew Parsons.

Solution to the Achromatic Compound Lens Problem

Here is a solution to parts (1)–(4) of the achromatic compound lens design problem from p. 24–26.

01 According to the thin-lens equation, monochromatic light impinging on lens 1 forms an image at i_1 given by

$$1/i_1 = 1/f_1 - 1/o_1. \qquad \text{(S1)}$$

The image of lens 1 becomes the object for lens 2. Therefore $o_2 = D - i_1$ so that $o_2 = -i_1$ when we set $D = 0$. (Recall that the second object is located where the first image *would have* formed.) The final image lands at i_2 given by

$$1/i_2 = 1/f_2 + 1/i_1$$

$$= 1/f_2 + 1/f_1 - 1/o_1$$

$$= (n_2 - 1)W_2 + (n_1 - 1)W_1 - 1/o_1. \qquad \text{(S2)}$$

Now let two wavelengths, λ and λ′, be present in the light beam. Write Eq. (S2) twice, once for λ and once for λ′. To remove their chromatic aberration we require $i_2 = i_2'$, which gives

$$(n_2' - n_2)W_2 = (n_1 - n_1')W_1. \qquad \text{(S3)}$$

When writing out explicitly the radii of curvature of the lens surfaces, Eq. (S3) becomes [1]

$$(n_2' - n_2)(1/a_2 - 1/b_2)$$

$$= (n_1 - n_1')(1/a_1 - 1/b_1). \qquad \text{(S4)}$$

Since the two lenses are glued together back to front, $b_1 = a_2$. Suppose lens 1 to be given (i.e., its refractive indices for both wavelengths and its radii of curvature are known). Then the right-hand side of Eq. (S4) is a known constant. On the left-hand side of Eq. (S4) we can play around with various values of b_2 and the type of glass for lens 2, giving many scenarios that would satisfy Eq. (S4). For a simple illustration of using Eq. (S4) as it stands, suppose lens 1 is plano-convex, so that $b_1 = \infty$. Because the lenses are back to front, we must also write $a_2 = \infty$. Equation (S4) then reduces to

$$(n_2' - n_2)/b_2 = (n_1' - n_1)/a_1. \qquad \text{(S5)}$$

Steps (3) and (4) will show how the multiplicity of possible lens parameters can be systematically reduced by introducing a third wavelength.

02 Whether or not two coaxial thin lenses are designed to be achromatic, together they are equivalent to a single lens of focal length f_{eff}. To find this effective focal length, return to the derivation of Eq. (S2) and note the intermediate step

$$1/o_1 + 1/i_2 = 1/f_2 + 1/f_1. \qquad \text{(S6)}$$

This can be written as a thin-lens equation for light from object 1, winding up as image 2 if we identify

$$1/f_2 + 1/f_1 = 1/f_{\text{eff}}. \qquad \text{(S7)}$$

03 Now let us turn to the role of the auxiliary wavelength λ″. With this color the two lenses have focal lengths given by Eq. (2), so that $1/f_1'' = (n_1'' - 1)W_1$ and similarly for lens 2. Taking the ratio W_2/W_1 in this instance and setting this ratio equal to that obtained from Eq. (S4) gives, after some algebra, Eq. (6), with the V numbers, or Abbe coefficients, defined by Eq. (7).

04 Equations (5) and (6) can be solved simultaneously for f_1'' and f_2''. In terms of symbols we obtain

$$f_1'' = f_{\text{eff}}''(V_1 - V_2)/V_1 \qquad \text{(S8)}$$

and

$$f_2'' = -f_{\text{eff}}''(V_1 - V_2)/V_2. \qquad \text{(S9)}$$

The value of $V_1 - V_2$ is typically chosen to be large to avoid a tight radii of curvature for the lenses. For crown glass the tabulated data says $V_1 = 59.6$ and $V_2 = 30.9$ for EDF (see footnote 5, p. 26). Upon choosing $f_{\text{eff}} = 30$ cm, Eqs. (S8) and (S9) give $f_1'' = 14.45$ cm and $f_2'' = -27.86$ cm. Choosing lens 1 to be an equiconvex lens means that $b_1 = -a_1$, and Eq. (2) gives $a_1 = 14.97$ cm. Since the two lenses are glued together, the first surface of lens 2 has the same radius of curvature as the second surface of lens 1 so that $b_1 = a_2$. Equation (2) then tells us that $b_2 = -66.67$ cm. Now you have all the specifications you need to grind your lenses!

Let us reflect on the strategy here: We require the red and blue wavelengths to form their images at the same spot. But there are too many free parameters. A pair of lenses placed back to front presents us with two indices of refraction and three radii of curvature. After choosing the glass materials, the radii of curvature remain unspecified. To help us select specific shapes for lenses 1 and 2, we bring in a third color whose wavelength "splits the difference" between red and blue. After we're finished, the red and blue wavelengths selected for achromatic treatment will be brought to a common focus, but other wavelengths will not. The residual chromatic aberration is called the *secondary spectrum.* Upon looking at a distant white object through a set of binoculars, the secondary spectrum can be faintly seen as a border in green and magenta around the image edges.
[2] Compound systems of three or more lenses have been built for specialized tasks that require the secondary spectrum to be further minimized. (Real lenses in high-dollar cameras are not perfectly spherical either, but thanks to computer ray tracing that finesses the details for different wavelengths, their surfaces can be described by eighth-order polynomials!)

To celebrate your successful design of an achromatic lens system, I suggest brewing yourself a cup of fine coffee and going outside to watch the sunset. Take your camera, too. It probably has an achromatic compound lens. As you sip your coffee and watch the sky, Alexander Pope offers for your meditations a poetic background for the challenges in bringing diverse colors to a common focus:[3]

Dipt in the richest tincture of the skies,
Where light disports in ever-mingling dyes,
While ev'ry beam new transient colors flings,
Colors that change whene'er they wave their wings. //

REFERENCES

[1] For another derivation see Hecht, Ref. 1, p. 269. Our Eq. (S3) is his Eq. (6.47).
[2] Hecht, Ref. 1, p. 273.
[3] Lines from Canto II of "The Rape of the Lock" (1712, expanded 1714), by Alexander Pope (1688–1744). Pope was a contemporary of Newton. This poem is a social satire, told with the pomposity of a Greek epic, about a trivial incident of a lock of hair being snipped off without permission.

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American Institute of Physics College Park
One Physics Ellipse
College Park, MD 20740

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