Radiations

FALL 2013

The official publication of Sigma Pi Sigma

Sigma Pi Sigma Development & Fundraising:

Connecting donors to student programs

A Tribute to Worth Seagondollar


page 6


page 10


page 22


page 24


page 13

ON THE COVER
Society of Physics Students (SPS) and Sigma Pi Sigma chapters rely on both internal and external funding sources to bring science outreach activities to the public. Shown on the cover, a crowd gathers around the SPS table during Family Weekend at Rensselaer Polytechnic Institute. Josue San Emeterio, the student team leader, explains the chaotic double pendulum to a young scientist.

Photo by Kelsie Larson.

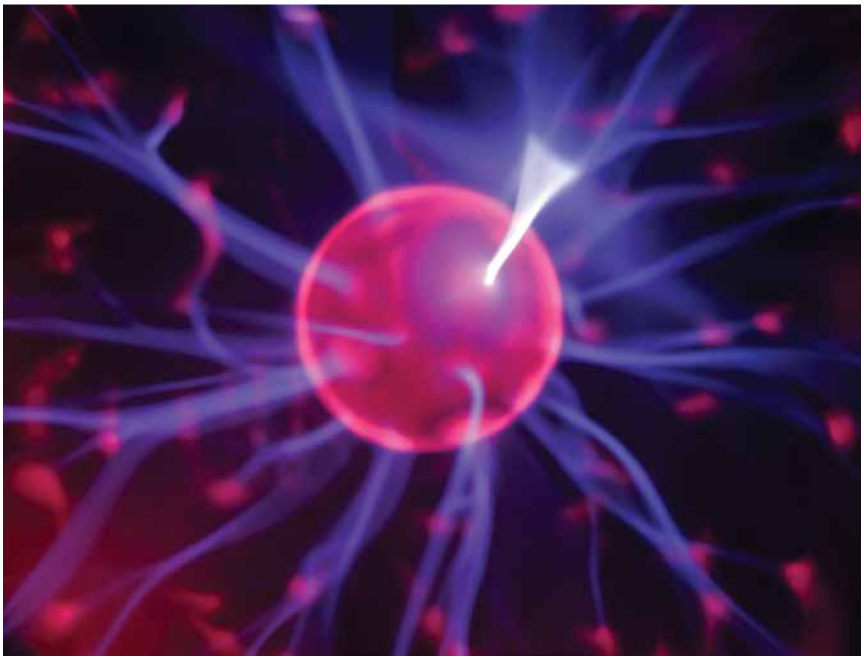
CONTENTS

Departments

Connections, Inside and Out

by Toni Sauncy

The 2012 Physics Congress hosted by Sigma Pi Sigma ("PhysCon") set the mark for achieving a lasting impact, emphasizing its importance as *the* place where the undergraduate physics community makes connections. In the year since the event in Orlando, our activities have been centered on PhysCon's "connecting worlds" theme, continuing the tradition of having the congress serve as a guide for the society. The gathering has stimulated broad efforts to reach out to the larger undergraduate physics community and impact even more students and their mentors. The new connections formed, both professional and personal, will undoubtedly influence the course of many students' decisions and interests, as well as, ultimately, their career choices.



The desire to make connections through social interaction is apparently hard wired into our brains, even for those of us who practice physics. In a recent book, *Social: Why Our Brains are Wired to Connect*, Matthew Lieberman presents compelling evidence that our need to connect with others is one of the driving motivators behind our behavior.[1] Written for an audience with no background in neuroscience, the book presents research from the relatively new interdisciplinary field of social cognitive neuroscience and includes some serious physics as it explores the analysis of fMRI scans and the physical processes in the brain associated with social interactions. The work presented in the book suggests that our brains get serious "rewards" for social interactions, and that the need for social connections with others is as fundamental as our physical needs of food and water. The neural connections formed in our brains make up the network that stores memories, allowing us to re-experience those rewards. Thus, in a very real way, it is our connections, both externally with each other and internally in our brains,

continued on page 4

Radiations

Fall 2013
Volume 19, Issue 2

Radiations (ISSN 2160-1119) is the official publication of Sigma Pi Sigma, the physics honor society. Published twice per year by the American Institute of Physics, One Physics Ellipse, College Park, MD 20740-3841. Printed in the USA. Standard postage paid at Columbus, OH. POSTMASTER: Send address changes to: Radiations Magazine, Sigma Pi Sigma, One Physics Ellipse, College Park, MD 20740-3841.

Sigma Pi Sigma is an organization of the American Institute of Physics. It was founded at Davidson College, Davidson, NC, December 11, 1921. Member, Association of College Honor Societies. Contact us at: email: sps@aip.org; telephone: (301) 209-3007; fax: (301) 209-0839.

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

Member Societies

Acoustical Society of America, American Association of Physicists in Medicine, American Association of Physics Teachers, American Astronomical Society, American Crystallographic Association, American Meteorological Society, American Physical Society, AVS Science and Technology of Materials, Interfaces, and Processing, OSA – The Optical Society, The Society of Rheology

Other Member Organizations

Sigma Pi Sigma, Society of Physics Students, Corporate Associates

Connect with Sigma Pi Sigma

LinkedIn
www.linkedin.com/groups/Sigma-Pi-Sigma-physics-honor-142619

Facebook
www.facebook.com/groups/2204770077

The Director's Space

continued from page 3

that give rise to our knowledge of the world and who we are. Leiberman's book joins other research in social neuroscience to suggest that our learning, our growth, and our development as individuals are inherently tied to our connections with others.[2] In this issue of *Radiations*, we continue to cover the connections made at the last meeting of the Sigma Pi Sigma congress, and we delve into the importance of our contributions to those connections as members of the society.

This is a profound notion, that our lives are largely determined by our relationships, and our social networks parallel the physical networks formed among our brain cells. New relationships create new professional connections, just as new thoughts and ideas form new connections within our brains. The implications of this parallelism is far reaching. For example, the research presented in Leiberman's book has begun to explore and explain the observation that the human brain reacts to physical pain or pleasure in nearly the same way that it reacts to social pain or pleasure. Evidently we experience the same pleasure when we give away money for a good cause as we do when we are rewarded with a monetary prize. This explains our need to give back, to mentor, and to support those causes that have been influential in our own development as professionals, forming new connections that define who we are individually and as a group.

Sigma Pi Sigma may be broadly considered "the physics alumni society." It connects us, no matter what our current position or interests, to a point in time when we were recognized for our academic achievements, more specifically, for our accomplishments in physics. These connections have been the foundation of Sigma Pi Sigma since 1921, when a small group of students with a common bond began to grow a network of like-minded students.

We have always known that these networks are essential to our profession and to physics, and that contributing to the group is a good thing. As scientists, it is always gratifying to discover that the experimental measurements agree with our intuitive notions.

---

1 Matthew D. Lieberman, *Social: Why Our Brains are Wired to Connect*, Crown Publishing, October 8, 2013.
2 Anthony J. Greene, Special Report: Memory, *Scientific American Mind* 21, 22 - 29, 2010.

Letters & Feedback

Don Nelson of Indianapolis recently sent in a donation and letter, shared here.

I attended the congress in Orlando in November. It was well organized with excellent speakers—a real treat to attend.

I am looking forward to the next one. The Orlando congress was my third one in a row. Each one was extremely worthwhile. You can be very proud of what you put on. It probably takes 4 years to recuperate from the last one and plan for the next.

Are some of the talks recorded and available on your website? If not, they should be—they were that good!

Also, you do an excellent job with *Radiations*! I always look forward to receiving it.

Yours truly,

Don Nelson

Editor's Note: *Audio and video files of several plenary speakers from the 2012 Quadrennial Physics Congress are available online at: www.spscongress.org/physconprogram/speakers/.*

Supporting Physics

by William DeGraffenreid, California State University, Sacramento

At Sigma Pi Sigma and the Society of Physics Students, we are working to support physics students through our scholarships, awards, and programs, which provide students with experiences they otherwise might not have. The call for supporting and encouraging students to pursue STEM (science, technology, engineering, and math)-related fields is increasing in the midst of budget and economic uncertainty on many levels.

Donations to Sigma Pi Sigma and SPS support a wide range of programs. Some of these programs directly benefit individual students. Our Leadership Scholarships give awards of $2,000 – $5,000 to truly outstanding young physicists to encourage their study of physics and pursuit of high scholarship. We also have specific scholarships for students at two-year colleges and for those interested in pursuing a career in education. Our reporter program enables students to attend professional meetings, where they have the opportunity to develop their communication skills by interviewing speakers and writing an article that is shared in our publications and on our website. These articles provide a glimpse into what happens at meetings for those who aren't able to attend themselves.

A number of our programs support larger groups of students. Our Marsh W. White Awards, Sigma Pi Sigma Chapter Project Awards, Future Faces of Physics Awards, and Blake Lilly Prize recognize chapters at campuses around the country and support their outreach efforts. Collectively, hundreds of physics students have benefited from these programs as they carried out science fairs, physics magic shows, public lectures, and even an occasional pumpkin-tossing event. In addition, thousands of community members benefit from participating in these programs each year.

While monetary donations are always welcome, there are other ways that you can help that don't require you to write a check. Local SPS and Sigma Pi Sigma chapters are always looking for people to speak at their meetings.

Bill DeGraffenreid inducts Gracie Conte into Sigma Pi Sigma. Photo by Heidi Yamazaki.

Students are interested in hearing about career possibilities. By giving an hour or two of your time, you could inspire a young physicist. If you're interested in making yourself available to students in your area, please let us know and we'll make the introduction.

As you read this issue, you'll learn more details about the programs and opportunities we provide. With the help of you and your Sigma Pi Sigma colleagues, we hope to not only continue to offer these programs, but to expand them!

Mary Beth Monroe at Trinity Site in New Mexico during the 2004 congress of Sigma Pi Sigma. Photo by Tracy Nolis-Schwab.

Mary Beth Monroe

Remembering a lifelong champion of SPS

by Toni Sauncy

The Society of Physics Students joins the American Association of Physics Teachers (AAPT) and many others in the physics community around the country in mourning the loss of Mary Beth Monroe on August 27, 2013. Mary Beth was a lifelong member of SPS and served as the SPS chapter advisor at Southwest Texas Junior College in Uvalde, Texas, where she taught for over 38 years. She was dedicated to her students and consistently devoted her work to their development. Mary Beth served in many leadership positions, including several terms as the SPS zone 13 councilor and various roles in the Texas section of the AAPT and the national AAPT. One of her many contributions was leading a study to establish the important role of physics education at two-year colleges, a study resulting in guidelines that continue to have an impact.

In memory of Mary Beth Monroe, friends and colleagues have expressed interest in supporting an endowed scholarship in her name. For an in-depth feature on Mary Beth's legacy, and information on the memorial scholarship, please see the Fall 2013 issue of ***The SPS Observer*** magazine, at www.spsobserver.org/2013/fall-singularities.pdf.

RIGHT
Worth Seagondollar poses by a sculpture at the American Center for Physics, following a 2007 talk and Q&A about his experiences working on the Manhattan Project. Photo by Tracy Nolis-Schwab.

Dr. L. Worth Seagondollar

A TRIBUTE TO A KEY FIGURE IN SIGMA PI SIGMA HISTORY

On September 20, 2013, Dr. L. Worth Seagondollar passed away at the age of 92. Sigma Pi Sigma joins the greater physics community in mourning Dr. Seagondollar, who spent much of his career championing the importance of undergraduate physics education.

A prolific teacher and scholar, his scientific roots go back to the Manhattan Project. He was one of the youngest scientists invited to work on the project and a witness to the first atomic test, at the Trinity Site. After World War II, he earned a PhD at the University of Wisconsin–Madison and then joined the faculty at the University of Kansas in Lawrence, where he helped build the first Van de Graaff accelerator. In 1965 he moved to North Carolina State University in Raleigh, where he was appointed chair of the physics department.

Dr. Seagondollar became associated with Sigma Pi Sigma in 1950 at the University of Kansas. He served as a student advisor for more than 40 years and as the president of the Sigma Pi Sigma national organization from 1962 to 1967. It was Worth Seagondollar who, in April of 1968, ironed out the details of the merger between the American Institute of Physics Student Sections and Sigma Pi Sigma that formed the Society of Physics Students (SPS). He ensured that this unique arrangement would not jeopardize the standing of Sigma Pi Sigma as a member of the Association of College Honor Societies—and helped to author the SPS National Constitution.

In 1996 the SPS National Council voted unanimously to institute the L. Worth Seagondollar Distinguished Service Award, awarded first to Dr. Seagondollar (much to his surprise!). The Seagondollar Award remains the most prestigious of all Sigma Pi Sigma or SPS service awards.

This issue of *Radiations* celebrates Dr. Seagondollar's legacy with a collection of stories, told by those who knew him and by Dr. Seagondollar himself.

A Celebration of Service

SIGMA PI SIGMA HONORED SEAGONDOLLAR FOR HIS SUPPORT OF PHYSICS EDUCATION

by Jean P. Krisch
Professor of Physics at the University of Michigan in Ann Arbor, MI
Former Sigma Pi Sigma President

This story originally appeared in the Spring 1998 issue of *Radiations.*

RIGHT
Worth Seagondollar (far right) is pictured with other past presidents of Sigma Pi Sigma at the 2004 Quadrennial Congress in Albuquerque, NM. Left to right: George Miner, Steve Feller, and Thomas Olsen. Photo by Tracy Nolis-Schwab.

One of the great pleasures in serving as an officer of Sigma Pi Sigma (ΣΠΣ) is the opportunity to represent our society in honoring outstanding members. A highlight of the 1996 ΣΠΣ Diamond Jubilee meeting was a celebratory session recognizing some of our members who have rendered exceptional service to ΣΠΣ. During the year before the Jubilee meeting, the Society of Physics Students (SPS) Executive Committee and National Council discussed a new award that would honor an extraordinary level of commitment and service to SPS and ΣΠΣ. In a secret mail ballot, the SPS Council unanimously voted to create this award and to name it in honor of Dr. Worth Seagondollar. They also unanimously voted that he should be the award's first recipient.

Worth Seagondollar has been associated with SPS/ΣΠΣ since he became a SPS chapter advisor in 1950 at the University of Kansas. He has held all of the offices in SPS and was the 13th ΣΠΣ president, serving from 1962 through 1967. This period was one of the most important in ΣΠΣ's history. In 1950 the American Institute of Physics (AIP) established Student Sections. These sections provided local physics clubs with an affiliation to a larger professional society. In 1951, ΣΠΣ became an affiliate of AIP. During the 1950s the Student Sections and ΣΠΣ coexisted, each adding chapters and growing in size. In the 1960s, a merger between the two groups was suggested and Worth Seagondollar, as a member of the National Council, helped develop a plan that would allow the Student Sections and ΣΠΣ to maintain their respective identities. It was proposed that the Student Sections would become the Society of Physics Students and ΣΠΣ would be an honor society within SPS. Worth Seagondollar was a coauthor of the constitution for the new SPS.

During the planning, one of the major concerns was that ΣΠΣ would lose its membership in the strict and prestigious Association of College Honor Societies (ACHS), since there were no other Member Societies that were subgroups of a larger organization. In the Diamond Jubilee Proceedings, Worth describes the ACHS meeting where he and Marsh White presented the merger plan to the Executive Board. After the presentation, there was silence. Then Robert Nagel, representing the engineering society ΤΒΠ, spoke strongly in favor of the new SPS/ΣΠΣ being allowed to remain a member of ACHS. As ΣΠΣ president it was now Worth Seagondollar's job to present the merger plan to the society. He called a special ΣΠΣ convocation in December 1967 at Purdue University. Two hundred delegates, representing 90 ΣΠΣ chapters, gathered to discuss the proposed merger. Initially the membership was very opposed to the plan, but Worth Seagondollar, presiding over the meeting, was able to convince the delegates of the merits of the merger, and it was approved by one vote more than was needed.

Over the years, Worth Seagondollar

has continued his work for ΣΠΣ. In addition to being a ΣΠΣ advisor for 40 years, both at the University of Kansas and at North Carolina State University, he served on the SPS Council and was a member of the Diamond Jubilee Planning Committee. During this time he maintained an active research program and served as chair of the physics department at North Carolina State University. Naming the new service award after Worth Seagondollar and making him its first recipient were very appropriate.

At the beginning of the celebratory session, the creation of the award was announced and Dr. Seagondollar was asked to come to the front of the room. He had been asked to say a few words during the session, but he knew nothing about the award or its naming. When he was standing at the front, his service to Sigma Pi Sigma was described and the naming of the award in his honor announced. Dr. Seagondollar was very surprised and pleased. When it was announced that he was also to be the first recipient of the award, he said, "How did you keep this a secret?" An engraved clock, a symbol of the award, was presented to him by Dr. Larry Cain, chairman of the physics department at Davidson College, the ΣΠΣ founding institution. The inscription read as follows:

Dr. Worth Seagondollar. In appreciation for your forty years of dedicated service to students through Sigma Pi Sigma.

Dr. Seagondollar thanked everyone. The room was full of his friends and colleagues who had come to see him honored. As he walked back to his seat, every person in the room spontaneously stood and applauded as he passed by.

Eyewitness To The Bomb

LISTENERS MESMERIZED BY SEAGONDOLLAR'S FIRSTHAND ACCOUNT OF HISTORY

by Karen Williams
Professor of Physics at East Central University in Ada, OK
2008 Seagondollar Service Award Recipient

Worth Seagondollar speaks at the closing banquet of the 2004 Sigma Pi Sigma Congress in Albuquerque, NM. Photo by Tracy Nolis-Schwab.

I first met Worth Seagondollar during the 2004 Sigma Pi Sigma Congress in Albuquerque, New Mexico. He talked to a crowd of about 200 people at the Trinity Site where the first atomic bomb was tested, recounting what it was like to watch, as he did, the detonation of the first atomic bomb on the very ground we stood upon. It was difficult to get close enough to hear him well at that time because there were so many people.

What sticks out in my mind is how utterly silent everyone was later, at a banquet where Worth described his experience working on the Manhattan Project at Los Alamos and how he had pounded plutonium back into its casing. Hemispherical shells of the material had fallen on his watch, denting one side of one of the shell's silver casings. He had to hammer it back into shape. He was alone during that shift and basically figured he had no choice but to risk serious damage to his body to put it back together.

I have been to hundreds of banquets and always hear some background noise, from chatter and whispers to the clink of ice in glasses and the rattle of silverware. But no one among the 400-plus attending the banquet made a SOUND as he talked that evening. I was seated at the back edge and, had I dropped a pin, many would have heard it that night. Everyone was amazed by his story. It was a magical night.

I was thrilled to receive the Worth Seagondollar Service Award, given in his honor for exemplary service to the Society of Physics Students and Sigma Pi Sigma, at the 2008 Congress. But I do not feel I am worthy of such an accolade. I was much more thrilled to present the award to my dear friend Steve Feller (see his story about fundraising on p. 18) at the 2012 Congress last November.

I am very saddened by Worth Seagondollar's passing. I wish more students could have heard in person his inspiring and entertaining firsthand accounts of the events surrounding the Manhattan Project.

See the full story of the dropped plutonium, as told by Dr. Seagondollar on the following page.

In His Own Words

WORTH SEAGONDOLLAR GAVE SEVERAL INVITED TALKS ABOUT HIS EXPERIENCES AT THE MANHATTAN PROJECT, WHICH HE JOINED IN THE SPRING OF 1944. PORTIONS OF A 2007 PRESENTATION ARE EXCERPTED HERE (EDITED FOR LENGTH).

On Seagondollar's role at Los Alamos National Laboratory where he was recruited while still a graduate student at the University of Wisconsin:

The thing that we wanted to calculate was the critical mass of uranium-235 and plutonium-239. Why did we want to calculate this? Richard Feynman put it very nicely. . . . He said, "What happens if we actually get the critical mass together unintentionally? What are we going to lose? We're going to lose a beaker? We're going to lose a laboratory room? We're going to lose the eastern half of New Mexico." That actually was the knowledge of the situation at that time.

The calculation of the critical mass, if you're going to really do it precisely, involves the probability of the fission process and other nuclear processes that can occur. . . . I was one of a three-man team that measured the critical mass—or very, very close to the critical mass, 98% of the critical mass—of plutonium-239 . . . I think my importance in the team is well qualified by the hours I had to work. The group leader works from 8:00 a.m. till 4:00 p.m. A more senior graduate student worked from 8:00 p.m. till midnight, and I worked from midnight till 8:00 a.m. And this kind of defines where you are in this organization. . . .

We had two of these big, long counters. . . . In between them, we had a place where we could put a neutron source . . . It was a source made up of various radioactive materials which gave off neutrons for approximately the energy that comes out from the plutonium fission reaction. We had put this source in the middle and we had these two big detectors here, and we had measured the number of neutrons coming out per second from that source. . . .

We finally ended up with two hemispherical shells which fit around this one-inch-diameter source. The first one was an eighth of an inch thick.

What we wanted to do with these neutron counters was measure the number of neutrons per second that came out with these two shells around. If you were getting a significant number of fission processes, then you would get a larger number of neutrons coming out. We were measuring what we called the multiplication ratio. The multiplication ratio with an eighth of an inch–thick shell of plutonium was 1.0, as far as we could tell. There just wasn't enough fissions occurring in that eighth of an inch to be significant. . . .

We made this measurement with a multiplication ratio of 1.0. . . . We'd repeat the measurement [with thicker shells], and we got a multiplication of 1.1 . . . This procedure was duplicated over and over and over again. The final measurement we did with a chunk of plutonium which fit around this one-inch-diameter core, which is about this big, about the size of a softball. We were making plots of the multiplication ratio as the radius of the shell. We got up to a multiplication ratio of 18. . . .

Our laboratory had been duplicated in a deep canyon nearby. The idea was that our laboratory was up on the main plateau of the town of Los Alamos. If there was a nuclear explosion, the town would go. So the 100% measurement was made down inside this deep canyon where they had duplicated our equipment.

When we finished that factor of 18 experiment, I was temporarily out of work . . . I had come back from lunch and one of my friends said, "Fermi wants you to call him." Fermi was known as the Pope at Los Alamos. I remember making the remark, "I presume God is after me too." "No, the man wants you to call him." So I called him and he asked me to come up to his office. The point was, he wanted some more detailed information about the fission experiments we had done. The other two guys were already down at a place in southern New Mexico where the first nuclear explosion was to occur. I was the best he could get a hold of. I still remember going into that office. I was absolutely terrified. I realized after about five minutes that he was asking me questions that any beginning nuclear physics student could answer. He was doing it to put me at ease. I had a high opinion of Fermi before that, and at that phase it just skyrocketed.

We were still talking when suddenly at the doorway was Louis [Slotin]. He was the man who was in charge of the 100% measurement. He didn't say a word. He went over to the blackboard and wrote a number, six-point and two other digits at the end of it. There wasn't a question what he was talking about. This was the mass of plutonium-239 in a spherical geometry; that was 100% critical mass. Unfortunately, several months later, repeating this experiment, he was killed.

On working under high security:

When you do experiments like this, you have a guard watching you. Sometimes it's a civilian, sometimes it's a man in military dress. You can tell these people always if you know what to look for. What to look for is a .38 revolver in their hand. They don't have a holster. Their job is to make sure that that plutonium stays where it's supposed to be. They don't care what happens to you, but that plutonium, they keep their eye on it.

The first one I ran into was the first day that we started doing this experiment. I walked over to the equipment. I was the first person there in the morning. There was this deep voice behind me, "Will you please stand still." I don't know what your reaction is, but I turned around to look, and there's this guy with a big, funnel-shaped .38 pointing at me. He wasn't joking one bit. That was my first introduction to one of the security guards there.

On dropping plutonium:

I had the midnight till 8 a.m. shift. Basically what you had were these two hemispheres [of plutonium] . . . with a one-inch spherical hole in the middle for the [neutron] source in there. I do not know what happened, but I bumped it and knocked it over. One piece fell about six inches onto a steel table, and the other piece I caught like this. I don't know what you do when you are really scared, and I mean really scared. I want to throw up. The piece I caught was not damaged in the slightest. The piece that fell over onto the steel table had a dent in the side, and the two pieces would not go back together. You couldn't continue the experiment. This was coated with, I think, silver. The question was, with this dent, had the silver been broken? Because if it was, I was in severe danger because the stuff would oxidize and go into the air. We had an ionization chamber there for this kind of purpose. I checked very quickly. . . .

Looking back, what I did, I'm not sure

Opposite page: Worth Seagondollar speaks at Trinity Site, NM, during the 2004 Sigma Pi Sigma Quadrennial Congress. Below: The McDonald Ranch House at Trinity Site. Photos by Tracy Nolis-Schwab.

“THE AMOUNT OF LIGHT THAT I SAW THERE WAS THE MOST INTENSE LIGHT I HAVE EVER SEEN IN MY LIFE, AND I HOPE TO GOD I NEVER SEE ANOTHER THING LIKE THAT.”

if it was the most intelligent thing in the world. But at Wisconsin when you had problems, you were told to solve them yourself. So I went and told the guard to stay there, which he obviously was going to do. And I went to the big maintenance building next door, to which we had a key for emergencies. I got a gas mask and a new ball peen hammer. I went back to the ball, put the gas mask on, put the guard out in the hall, and gently tapped this thing. I took my time with it, until it was back into a shape where it would fit back together, and went ahead with the experiment. I told Al Hanson, who was the number one man—he was the 8 a.m. to 4 p.m. guy—what had happened. I don’t remember him making any derogatory comments about it. I went home and went to bed.

The next night there I was midnight till 8 a.m., about 2:30 in walks Oppenheimer. He introduced himself, and that wasn’t necessary. . . . I had a very uncomfortable feeling he had heard my name and the reason why. After talking for a bit in a very polite manner, he said, and I can remember the words, “We are all exceedingly fortunate that you were so successful.” And he left, and that was it. That’s one of the two times at Los Alamos that I really, seriously thought about the possibility of death, though I didn’t know it.

On watching the first atomic bomb test at the Trinity Site:

[Colonel Stafford Warren] strongly recommended that you have some kind of eye protection. We thought of this, and brought back a whole case of welder’s goggles of the type that were used for acetylene torch welding.

That afternoon, I’d seen that there was a welding shop there. I went over and I traded the whole case of goggles for five pieces of blue glass that they put in an electric arc welder’s hood. We got some 18-inch square pieces of cardboard and cut a little rectangle in them and scotch taped this blue glass over it. This is what we were going to look through. I tried it out that night on a 100-Watt bare light bulb that was there, and all I could see was the blue glow where the filament was, nothing else. It was really dark.

The morning [of the test]. . . I’m looking in the opposite direction and he’s counting down—seven, six, five, four. When he gets down to zero, I’m looking in the opposite direction. The amount of light that I saw there was the most intense light I have ever seen in my life, and I hope to God I never see another thing like that. There were mountains in the distance, and they actually seemed to mechanically jump forward. Like looking into a photographer’s light bulb, except this is absolutely everywhere. I counted 1001, 1002, to 1015 and turned around and looked, and my first reaction was, “You forgot the blue glass.” But I hadn’t. I was looking through it, and what I was seeing out there was a ball of fire. When I saw it, it was about a [foot] diameter above the valley floor, and it simply went up through the clouds. I do not know how long we watched that thing. I know it was full daylight before we gave up watching it.

This is what I saw down there on this first explosion. I sincerely hope I never see anything similar to it again.

On the use of the atomic bomb during the war:

I’ve often been asked, “Do you regret your participation in this?” Well, first of all, I was a rather low man on the totem pole. But on the other hand, I was involved. It’s not pleasant to think that you . . . were involved in the killing of 100,000 people—men, women, and children. On the other hand, the United States and its Allies were ready to invade Japan . . . I have no regrets for my participation. People would come up to me and say that they strongly agree. They were on one of the ships that were ready to go into Japan. As I recall, Churchill made a statement that if the Allies had invaded Japan, there probably would have been 250,000 deaths of Allied troops, and over a million deaths of Japanese people, defenders and civilians. So from that point of view, maybe we saved some Japanese lives in cutting off the war when we did. That’s my position on it.

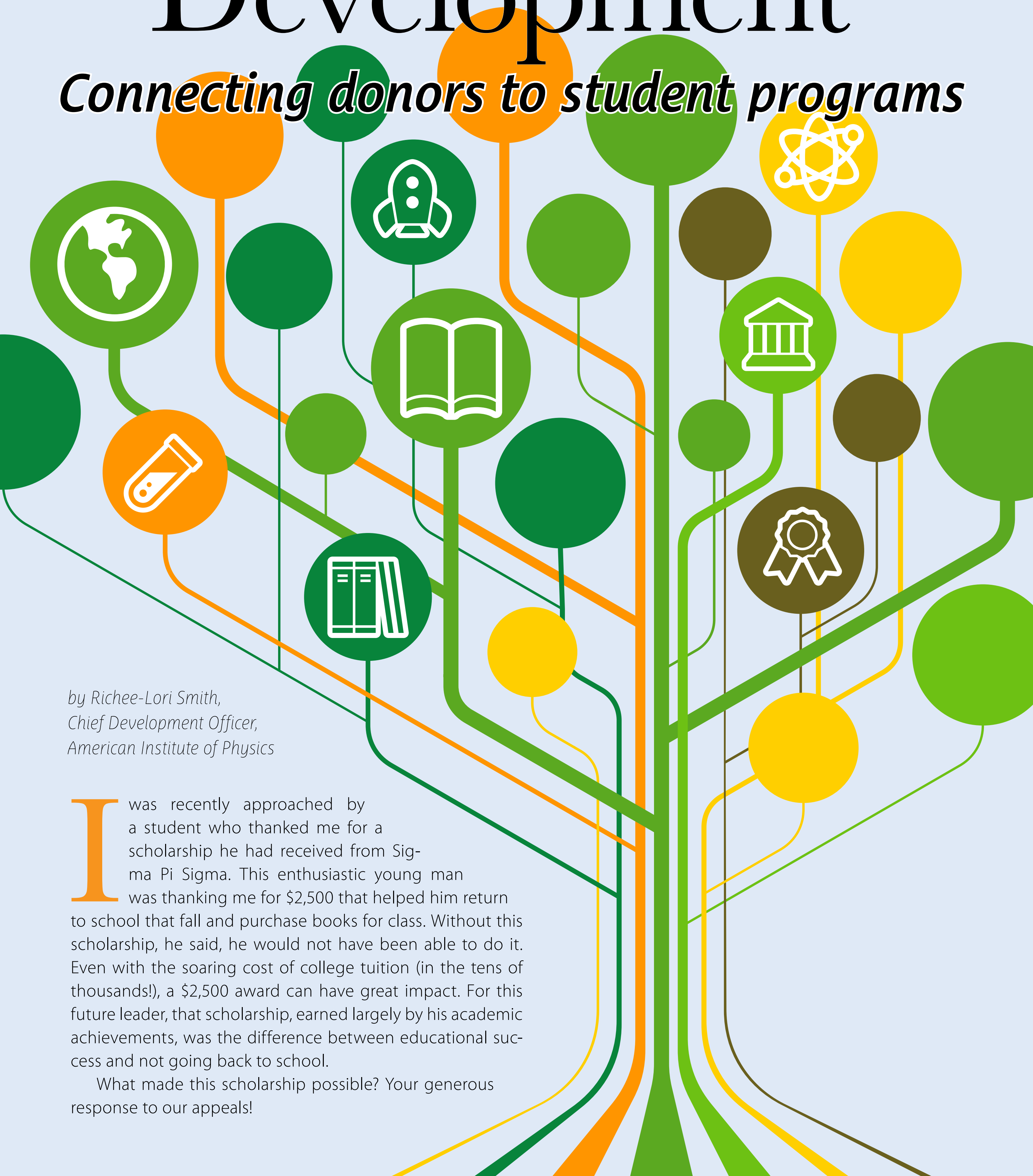
I was made particularly uncomfortable one time when I gave this talk. . . . Afterwards, I see a man that I know is a Japanese professor in the mathematics department coming up to me. I was a little uncomfortable. When he got up to me, he rapped his leg with a cane, and it was obviously a wooden leg. He said, “I got this at Hiroshima.” He said, “I agree with your feelings about you’ve probably saved more Japanese lives than you’ve taken.” It was a real feeling of relief.

MORE INFORMATION

To read the full transcript of Dr. Seagondollar’s talk, visit www.sigmapisigma.org/seagondollar.pdf.

Sigma Pi Sigma Development

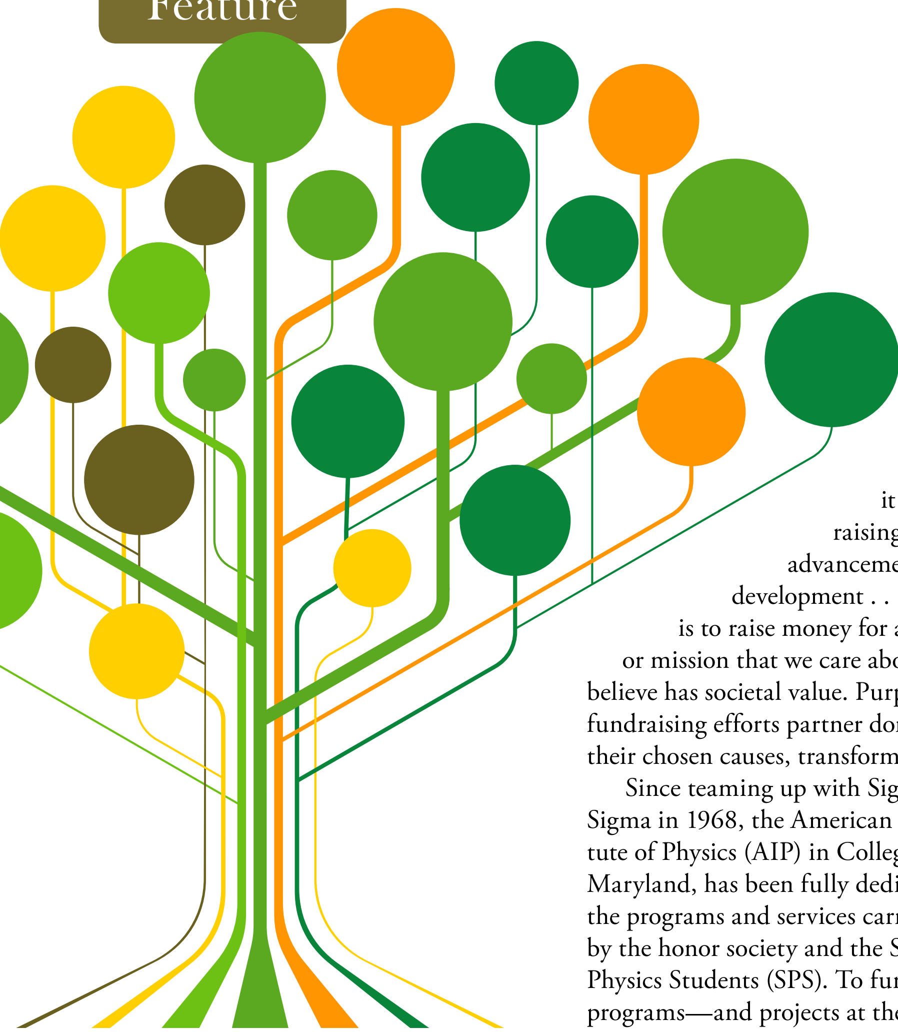
Connecting donors to student programs



by Richee-Lori Smith,
Chief Development Officer,
American Institute of Physics

I was recently approached by a student who thanked me for a scholarship he had received from Sigma Pi Sigma. This enthusiastic young man was thanking me for $2,500 that helped him return to school that fall and purchase books for class. Without this scholarship, he said, he would not have been able to do it. Even with the soaring cost of college tuition (in the tens of thousands!), a $2,500 award can have great impact. For this future leader, that scholarship, earned largely by his academic achievements, was the difference between educational success and not going back to school.

What made this scholarship possible? Your generous response to our appeals!



Call it fundraising, advancement, or development . . . the goal is to raise money for a cause or mission that we care about and believe has societal value. Purposeful fundraising efforts partner donors with their chosen causes, transforming lives.

Since teaming up with Sigma Pi Sigma in 1968, the American Institute of Physics (AIP) in College Park, Maryland, has been fully dedicated to the programs and services carried out by the honor society and the Society of Physics Students (SPS). To fund those programs—and projects at the Neils Bohr Library and Archives, as well as the Center for History of Physics—AIP recently established a dedicated Development Division. This division builds on a long history of development efforts within Sigma Pi Sigma in an attempt to increase its impact.

We target primarily individuals and private sector funding (nongovernmental funds). Our efforts provide a means for Sigma Pi Sigma members and friends to support the many programs and awards that benefit physics students, the majority of which are administered through the SPS National Office. Over the last decade, over $1.2 million in support for student programs has been gathered through different channels, including individual donations, bequests, corporate contributions, and special gifts (e.g., gifts of real estate and life insurance). Thank you!

AIP established a new Development Board in November 2011 to help expand fundraising efforts and to diversify the AIP Development funding portfolio. Under a different structure, this group is continuing and expanding the work done by members of previous Sigma Pi Sigma development committees. Aided by these enthusiastic volunteer leaders, AIP's development professionals have been working

"Purposeful fundraising efforts partner donors with their chosen causes, transforming lives."

LEFT
Many SPS and Sigma Pi Sigma chapters rely on both internal and external funding sources to bring science outreach activities to the public. Pictured here, a crowd gathers around the SPS table during Family Weekend at Rensselaer Polytechnic Institute. Josue San Emeterio, the student team leader, explains the chaotic double pendulum to a young scientist. Photo by Kelsie Larson.

diligently to explore and implement a variety of different approaches for marketing and communicating the needs of the student programs.

Counting on the value of personal interactions and relationship building, we have hosted several receptions and events at the homes of Development Board members and other friends of the organizations. At these gatherings, we provide information and highlight the impact of student programs, scholarships, and awards. SPS student members have been present at all of these events; they have proven to be an effective way to showcase the impact of Sigma Pi Sigma donations. Donors (and potential donors) come away from their interactions with these students impressed and confident about the future of our scientific community.

In preparation for the most recent Sigma Pi Sigma Quadrennial Physics Congress in November 2012, we reached out to corporations. This initial effort brought onboard several new corporate and organization partners as sponsors and exhibitors for the event.

Another part of the fundraising effort for the 2012 Congress was a silent auction held at AIP in October 2012. Employees working at the American Center for Physics (which includes not only AIP but also the American Physical Society, the American Association of Physics Teachers, and the American Association of Physicists in Medicine) contributed more than $6,000 at the event. That money helped to send several dozen students to the congress as student reporters. Those reporters documented their experiences at congress, providing a unique record of the meeting, which you can read online at www.spscongress.org.

We are excited to build upon these successes as we now turn our attention toward the next congress, planned for November 2016 in San Francisco, CA. We expect this meeting to set another record as the largest meeting in history for physics undergraduates.

To raise AIP's profile among members of the physics community, the development efforts are also focused on increasing outreach to the community. This is an effort to link donors to a cause that has inspired them and that has an invaluable impact not only on the scientific community, but the country as a whole.

In November 2012, AIP sent to all 120,000 *Physics Today* magazine subscribers a mailing that reintroduced AIP Physics Resources Center programs and highlighted student and history programs. We provided subscribers with an opportunity to show their support for these services and programs and gained many new donors!

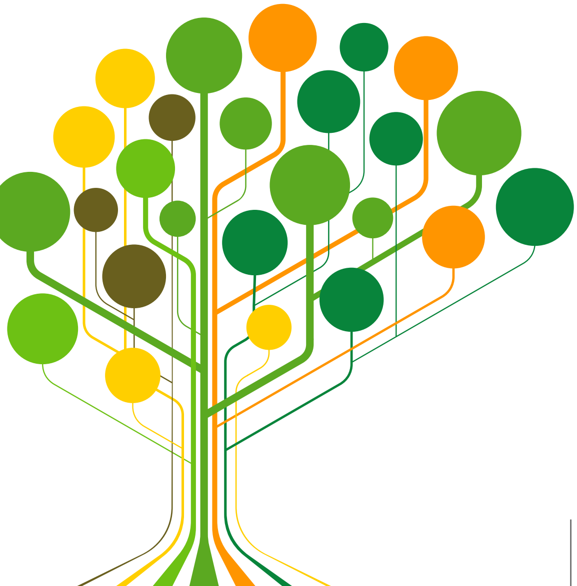
In light of the trend toward a more electronic culture, we are continuing to evaluate our web presence and visibility and have launched a new development website, accessible through the AIP main page, with a "Donate Now" button. The website also includes a video, "One Science. Many Minds.," aimed at emphasizing the unique and valuable work carried out by our student programs and history center. It features a few of our rising physics stars, as well as dedicated supporters speaking passionately about why they chose physics and the impact of physics on all of our lives. Please be sure to view it.

"Gifts of all sizes work collectively to make a huge impact in the lives of physics students!"

One of the most challenging aspects of fundraising within any community is educating potential donors about the impact of gifts of different sizes. People often wonder how a gift of $20, $50, or $100 measures up against the seven- or eight-figure gifts that we hear about in the news. Let me assure you that gifts of all sizes work collectively to make a huge impact in the lives of physics students!

One important program that benefits from these donations is the SPS Summer Intern program. Currently, SPS brings in 10–12 interns each summer for a life-changing experience. Participants in this program are selected from a national pool of highly qualified applicants and work in science outreach, education, communication, policy, and research. These opportunities are funded with support from AIP, individual donors, and the partnership organizations who host the interns. The Sigma Pi Sigma donor base can help ensure that this program continues to thrive and offer a variety of unique experiences for students.

Help preserve our past and fuel our future.
View the video at www.aip.org/donate/.



Physics Meets Policy

Sponsoring physics undergraduates to work in the heart of the nation's capital

by John Mather, NASA Goddard Space Flight Center in Greenbelt, MD, 2006 Nobel Laureate in Physics

In 2006 John Mather was a recipient of the Nobel Prize in Physics for his precise measurements of the cosmic microwave background radiation. Three years later, he used part of his prize money to promote awareness of and experience with the policy process among physics undergraduates. The John and Jane Mather Foundation for Science and the Arts and the American Institute of Physics (AIP) created the AIP Mather Policy Intern Program, which sends undergraduate physics majors to work in offices on Capitol Hill each summer through the Society of Physics Students Summer Internship Program.

I was inspired to start the Mather Interns in Public Policy program by a conversation with physicist Bill Foster, who asked for my support as a Nobel 1aureate in his congressional election campaign to represent Illinois' 11th district. Bill worked at the Fermi National Accelerator Laboratory in Batavia, Illinois. He was part of the team that discovered the top quark, so I knew he was a top scientist. I also knew that working in politics requires a very different outlook and a different skill set from mine.

So I asked him how he, with his background in physics, had become interested in politics. He said he had spent some of his youth in Washington, DC, where his parents were civil rights lawyers. My feeling for many years has been that Washington needs more technical talent on Capitol Hill. Almost every big problem we face as a nation has a major scientific or engineering component, or at the very least should face questions about what the evidence shows about what works and what doesn't.

The American Institute of Physics (AIP), American Physical Society (APS) and the American Association for the Advancement of Science (AAAS) have very successful Congressional Fellow programs for people with PhDs in the physical sciences, but I didn't have enough money to make a big difference there. I thought about Bill Foster's story, and I thought about starting younger.

Then I started looking around for organizations

"Almost every big problem we face as a nation has a major scientific or engineering component."

SPS and Sigma Pi Sigma awards and scholarships serve to encourage students around the country who are working to complete their degrees. Several award programs are designed to recognize outstanding achievements or support unique ideas for local programs in the areas of outreach, research, and service. These awards have a far-reaching effect, often deep into local communities all across the country that are impacted by the student recipients. The number of awards and scholarships that can be bestowed each year is largely determined by the level of support achieved from our donor base.

I have dedicated my professional life to making connections between generous donors and the causes that inspire them. I take great joy in seeing the results of the opportunities that our team makes possible and the satisfaction of our donors. Albert Einstein once said, "It is every man's obligation to put back into the world at least the equivalent of what he takes out of it." With that philosophy, I think Einstein might have made a decent development officer!

I urge you to help us support the invaluable and transformational programs provided by Sigma Pi Sigma and SPS—whether through a personal or corporate donation or by connecting us to corporations and organizations with a vested interest in supporting students and the sciences.

Be a part of the equation and make an impact on tomorrow's scientific leaders by giving today: https://donate.aip.org/.

John Mather, SPS interns Katherine Stankus and Nikki Sanford, and Rep. Bill Foster (left-to-right) stand on the steps of the United States Capitol. Photo courtesy of Katherine Stankus.

that could do something with my idea. I realized that I already knew one close to home, the American Institute of Physics. I got in touch and learned that they already had a summer intern program in which students lived in downtown Washington. It would be very easy to add a couple more positions and have them assigned to work on Capitol Hill. So we tried it out, and I've been very pleased with the students who came to learn the game at Capitol Hill. I think they've been very pleased too.

The Mather interns are all different, but they all say it is a very valuable experience for them. One said she was planning to run for president! And their "supervisors," if one can call them that, have been very pleased to have them. This year I had breakfast with the two interns and Congressman Bill Foster, one of the two physicists in the House of Representatives. Everyone seemed very happy to be working together. I think the interns were all a bit surprised at how things really get done on the Hill.

My Mather Internship

by Nikki Sanford, 2013 Mather Policy Intern, Class of 2013 at High Point University

After earning an undergraduate degree in physics and math, with a minor in chemistry, I've just begun my first year in law school. It's off to a great start!

My internship at the House Science Committee this summer has already proved to be extremely beneficial for my law studies. Research assignments, office memo writing, meeting updates, and outreach/interviews—all key parts of my legal writing and research classes—have been made easier by the experience I gained this summer. There is always a learning curve when applying skills learned in the classroom to real world situations. But it's immensely helpful that I've come to school with a handle on the basics and experience with utilizing them in a fast-paced work environment.

I'm sure my experience this summer will continue to have a great impact on my future plans as well. It introduced me to many career options, opportunities, and great networking contacts. I learned so much about the legislative process and congressional staff duties, as well as how each person truly can have a significant influence. My internship made me eager to be in a position where I can effect change and make a difference. I'm looking forward to these next 3 years and to seeing what the future has in store!

MORE INFORMATION

For more information about Sanford and her experiences as an intern, visit her SPS internship journal at www.spsnational.org/education/sps/programs/internships/2013/sanford.htm.

To learn more about the Mather Policy Internship program, as well as other internships managed by the Society of Physics Students, visit www.spsnational.org/programs/internships/.

On Raising and Spending Money

Tips and tricks for supporting undergraduates

by Steve Feller, Professor of Physics, Coe College in Cedar Rapids, IA
Recipient of the 2012 Sigma Pi Sigma Worth Seagondollar Award

"...fundraising is essential for building and sustaining a thriving program."

Fundraising is an important part of being a professor, as is the responsibility of spending the received funds wisely. I have found that with a reasonably strong will and a thought-out strategy, this part of a professor's life can be very successful. My stories, I should mention, are based on my experiences at a liberal arts school in Iowa. Some generalizations may be made, but the details of the funding levels will vary from school to school, depending on circumstances. Some schools may have less resources to tap and some more.

I believe, based on my experience, that colleges are more forthcoming with their resources if their commitments can be augmented by or parlayed through the acquisition of matching funds. Thus, when we knew we wanted to bring a large group of students to the Sigma Pi Sigma congress, I approached the president of Coe College to begin a chain reaction of funding. He pledged several thousand dollars toward the almost $30,000 needed to allow us to bring, ultimately, nearly 30 students to the congress.

I made it a point to talk to him a year and a half before the event. This allowed the president to commit funds from the next year, not the current fiscal year—a key consideration. After this our SPS chapter approached the Coe College Student Senate for additional funds, based in part on the commitment of the college made by the president. The senate contributed several thousand dollars, on the condition that each student make a personal commitment of $400.

We now had almost $20,000, half of which would need to come from the students. With this in hand, we approached our vice president for student affairs with a request for several hundred dollars. We also used part of our National Science Foundation (NSF) research grant

Left to Right
The Coe College group at the NASA Kennedy Space Center during the 2012 Quadrennial Physics Congress (PhysCon). Photo by Liz Dart Caron.

Nathan Barnes and Evan Troendle present their poster at PhysCon. Photo courtesy of Steve Feller.

Students Nichol Johnson, Hannah Bode, Jacob Schletztbaum, and Miles Faaborg in the new Coe College Peterson Hall Physics Lounge. Photo courtesy of Steve Feller.

to supplement students who presented research posters at the conference.

Once we realized that nearly 30 people would be able to go on the trip, I again approached the president of our college for a few thousand more to “top off” and allow more students to go. He agreed to the sum. Thus we reached the required total for the congress, and a small cadre of Coe students were ready to go to Florida.

As we worked to raise money, we also looked for ways to be economical about our expenses. We asked United Airlines for a group rate, which saved us a few thousand dollars. (Before that I had actually considered chartering a small plane!) The group rate also made it easy to secure passage for the whole group on the same flights.

Each hotel room had 4 or 5 students. Those students were responsible for cab/shuttle rides to and from the airport, as well as for food not provided by the congress. Thus each student had to pay about $500 in personal expenses but was subsidized a like amount.

The result was a fantastic, memorable trip that the students are still buzzing over. The camaraderie that resulted from the trip was priceless. We are already thinking about 2016.

We have begun the same process for our next adventure—a research conference on borate glasses in the Czech Republic that begins June 29, 2014. Already, we have a commitment from the president of Coe College for the first $5,000. As this is being written, an NSF proposal for additional funding is nearly ready to be submitted. We will approach the Student Senate in a month. I should note that this model also worked for other conferences attended by Coe students in Bulgaria (1999), Italy (2005), Japan (2008), and Canada (2011).

Let me address a few ancillary issues as well. It is important that our SPS chapter be a registered club at Coe College. We receive generous annual funds from the Student Senate, as we are one of the most active academic clubs on campus. Thus the request for funds for Orlando was based on a history of high-level activity on behalf of our students. We try to incorporate nonphysics students whenever possible. Our trip to Orlando included a gender studies student who wanted to meet Jocelyn Bell-Burnell and talk to her for a school project! It also included one other nonmajor—a math student.

Public relations is very important. I believe it is important to use funds for activities that benefit not only the students but the college as a whole. Thus photos and information need to be sent to the college’s public relations department as soon as possible after an event.

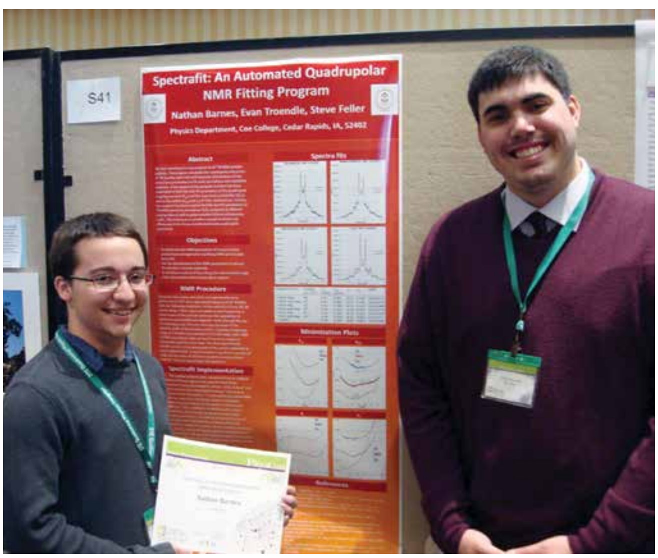
I’d like to close with another story of fundraising. A few years ago the NSF established a one-time program for building renovation, its response to the stimulus programs that were then taking place. The goal was to renovate research space. We had an older facility, built in 1968, and a very active research program (over 50 stay per summer with over half in physics). We thought we were the poster child for a small school for this grant opportunity.

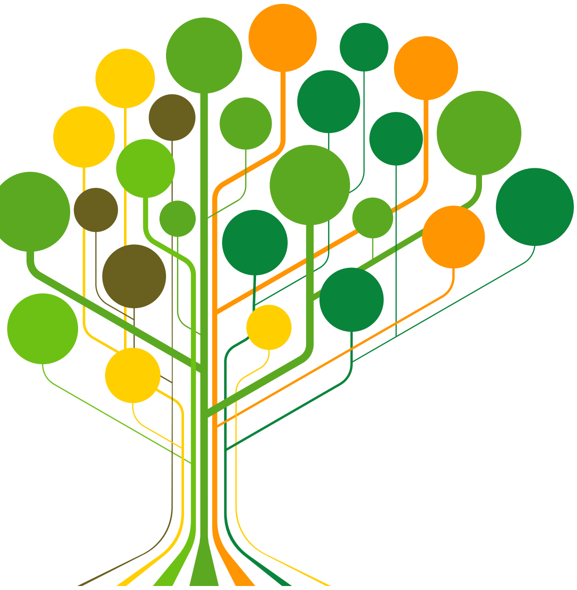
We applied for and received $4.7 million and were able to parlay that into nearly $14 million for the total renovation of our building. This project was just completed after 3 years of work.

I wrote a supplemental grant proposal to send students to collaborating labs during the one summer our building was shut. We described this as an opportunity for our students and faculty to continue their research while construction was ongoing. This, too, was funded, and we sent over a dozen students around the world. I learned a lot about construction, an area in which I was ignorant. On the other hand, I had to submit thousands of pages of data in over 60 required reports to the NSF! This was the most difficult project I ever took on as a principal investigator.

Overall, fundraising is essential for building and sustaining a thriving program. It is not easy, but it certainly makes the outcomes more rewarding. I urge you forward!

The work reported here was supported by the NSF under grants 0904615, 1262315, and 0963113.





SPS Chapters Get Creative *with* Fundraising

by SPS Staff

> "...they bring the same creativity to raising funds for their chapters as they do to conducting research in the laboratory."

SPS members are top-notch problem solvers. Perhaps it's their training in physics; perhaps it's just their natural inclination. Whatever the reason, they bring the same creativity to raising funds for their chapters as they do to conducting research in the laboratory.

Much of the money that allows chapters to function is brought in by the initiative of individual members. Small events can raise a few hundred dollars at a time, whether they involve selling ice cream frozen with a vat of liquid nitrogen at a campus SpringFest; holding a cupcake bake sale to celebrate Pi Day (March 14); or putting out a tip jar at a booth with physics demos at a local community festival.

Many chapters also reach out to their physics departments for support. Some seek corporate sponsorships. Others contact alumni networks, counting on the generosity of those who once stood in their shoes and recognize the value of nurturing undergraduates. Additional support is provided by SPS national itself—from the Future Faces of Physics and Marsh W. White awards that make outreach projects possible, to travel awards that send students to conferences.

Without fundraising, the pizza parties that bring members together to chat about physics and college life wouldn't be possible. Neither would the expensive trips to quadrennial Sigma Pi Sigma congresses, which many chapters begin to prepare for years in advance.

Below is a sampling of the experiences several chapters have had as they raised money to attend the 2012 Quadrennial Physics Congress (PhysCon), as told in their own words.

Abilene Christian University

Sixteen students (1 woman and 15 men) from the Abilene Christian University (ACU) chapter donned elaborately decorated bras and joined a parade for breast cancer awareness. Other members, more modestly dressed, sold liquid nitrogen ice cream to an enthusiastic and overjoyed crowd of spectators.

"Partnering with the Center for Contemporary Arts for their breast cancer awareness project was a great way for us to step up and be active in our community while at the same time raising funds for our chapter's trip to PhysCon," said junior physics major and ACU-SPS vice president Andrew Miller. "We had a great time doing it and made a lot of people's faces light up with our chapter's antics."

University of North Alabama

As part of our fundraising, we spent late nights baking homemade doughnuts and handmade chocolates with shapes from Star Wars.

Abilene Christian University SPS members act as human canvases for a breast cancer awareness project. Photo by Tim Head.

Eastern Michigan University

Partnering with Cold Stone Creamery, our chapter held a profit-share fundraiser at which students scooped up fun and cold treats. We also helped freshmen move into their dorms. These activities increased SPS's presence on campus and in the community. Our fundraising efforts got a boost from the university's physics department and student government.

Marquette University

This year, as we were struggling to pull together enough funding to attend the Quadrennial Physics Congress of Sigma Pi Sigma, we entered the *Radiations* magazine crossword drawing. Thanks to a stroke of luck and some hard teamwork on the tougher clues, we won a $1000 award offered by Diane Jacobs, a past president of Sigma Pi Sigma, to support chapter attendance at PhysCon. With her contribution and an SPS Chapter Reporter Award, we were able to pull together the rest of the funding required to send six students to the meeting.

Richard Stockton College of New Jersey

One of our members worked very hard to secure funding from the Student Senate of Stockton College. She kicked off what all of our members know as the first Physics Club Galactic Bake Sale. Stockton College and its SPS chapter would not have been represented at this Quadrennial Congress if its president hadn't taken the bull by the horns in the way that she did.

University of Wisconsin River Falls

In 2008 our chapter sent a group to the 2008 Congress. Our advisor is very active in SPS National, so we have heard about how exciting and important the congress is every year since! [For the 2012 PhysCon] we worked to raise funds for nearly four years and were generously funded by University of Wisconsin River Falls (UWRF) Falcon Grants and UWRF physics alumni.

Roberts Wesleyan College

After receiving a startup donation from a very generous alumnus, we continued our fundraising efforts at homecoming. We set up a variety of physics games for people to play, including a projectile-motion dunk tank stocked with SPS members and professors willing to donate their time to the cause. Though it was cold that day, three professors and a resident director were willing to take the "polar plunge." It certainly paid off. We also did some fun physics demonstrations and generated interest in our physics program and SPS, which will hopefully keep our chapter alive as some of us move on to the next phase of our education.

Grove City College

The primary fundraiser for our physics club is Rent-A-Student. Members volunteer to go to the homes of professors and people in the community to rake leaves or do odd jobs in exchange for a donation to the club. This is a surprisingly successful and dependable fundraiser for us. Each year we save a portion of this income for the congress, yielding four years of funds that help alleviate the travel expenses for students. In addition to the Rent-A-Student fundraiser, we also received a generous donation supporting the trip from KEYW Corporation, where one of our members interned last summer. Additional alumni donations, partial support from the college for the students presenting at the meeting, and an SPS Chapter Reporter Award significantly reduced the out-of-pocket costs for our club members. Three members also received funding from outside sources.

PhysCon Articles

www.sigmapisigma.org/congress/2012/reports/

In November 2012, hundreds of Sigma Pi Sigma members were fully immersed in the 2012 Quadrennial Physics Congress (PhysCon), held in Orlando, Florida. How quickly time passes! The national office continues to archive and publish content generated during the meeting, with follow-up articles, award results, and photographs appearing in Sigma Pi Sigma and Society of Physics Students (SPS) publications. Most recently, a compilation of 19 articles written by SPS chapter reporters was published and posted online. While all of the articles speak to the entire PhysCon experience, each chapter examines a particular aspect of the congress in-depth, be it a plenary speaker, workshop, or the tours of NASA's Kennedy Space Center. The articles can be accessed at www.sigmapisigma.org/congress/2012/reports/.

As we continue to propagate the PhysCon experience, we also pause to acknowledge the many friends and science organizations that generously supported the congress. Funds from the following organizations and individuals went toward the aforementioned SPS Chapter Reporter program, supporting some of the resulting articles and, more importantly, the travel of the students that wrote them. The $500 awards to participating chapters were, in many cases, the primary reason students were able to afford attending this life-changing event.

- National Institute of Standards and Technology
- American Astronomical Society
- American Center for Physics employees
- OSA, The Optical Society
- Jack Hehn

Connecting WORLDS 2012 through science & service

2016 Quadrennial Physics Congress

SAVE THE DATE: November 3 – 5, 2016
Hyatt Regency-San Francisco
San Francisco, CA

Primary scientific host will be the

SLAC NATIONAL ACCELERATOR LABORATORY

PhysCon Art Contest

Sponsored by the American Association of Physics Teachers

In the Spring 2013 issue of *Radiations* we published the winning pieces from the 2012 Quadrennial Physics Congress art contest. The pieces shown here were awarded Honorable Mention. To see images of all of the artwork, visit the congress website at www.spscongress.org/physconprogram/artwork-contest.

Honorable Mention

Plasma Plume: Towards Freedom, Prajwal Niraula, Saint Peter's University

I work with plasma as a part of my research work. When I look at the plasma plume that escapes from the end of the glass tube, it evokes a sense of freedom. I see a strong parallelism between the liberation I feel when learning the rules of the universe I live in, and the freedom argon gets in coming out of a pressurized gas cylinder as resplendent plasma, and finally dying out in the air as a minority. Thus, I believe my photograph serves as an emblem for connecting different world, as it signifies bridging the gap of the experiments with the experience of the experimenter.

Honorable Mention

Into the Heart of a Supercell Glenn A. Marsch, Grove City College

Literally showing Sturm und Drang, this photo shows the spectacular violence of a supercell thunderstorm. Over its lifetime, a supercell thunderstorm generates more energy (> 20 kilotons TNT equivalent) than that liberated by an atomic bomb. On a basic level, the lightning may demonstrate the triboelectric effect, or electrical charging by friction, as the violent convection cells in a thunderhead rub electrons off ice crystals and water droplets in the cloud. This charge builds up, and if the electric field surpasses the dielectric strength of air (~ 3x106 V/m), an explosive discharge occurs across regions of high potential difference and the molecules of air break down and ionize.

Honorable Mention

Organized Chaos, Sarah Rozman, University of Central Florida

In this painting I attempted to create a sense of chaos, and I incorporated birds because of their natural built-in sonar systems. Birds almost never collide with each other, despite their quick speeds and sudden changes in movement. There is a theory that relates to the process of synesthesia, a human condition that blurs senses so that a person can hear colors, taste a smell, or visually see music. According to this theory, birds in flight sense one another's closeness (by eyesight) and read the signals as a form of touch. Birds read their personal "sonar" and thus, avoid colliding with one another.

Spotlight on Hidden Physicists

Share your story at www.sigmapisigma.org

The Quantum Sculptor

Julian Voss-Andreae, Portland, OR
Sculptor

I have always loved reading popular science magazines. But I really got hooked on physics after reading Roger Penrose's amazing book, *The Emperor's New Mind*.

I had moved from my hometown, Hamburg, to Berlin in Germany, with the plan to study painting, but this book gave me my first real glimpse of quantum physics. Deeply fascinated, I decided to find out as much as I could about the subject by studying physics at the Freie Universität Berlin. Later, I moved to Vienna, Austria, for my graduate thesis work with Anton Zeilinger, probably best known for the first realization of quantum teleportation.

In Vienna, I participated in the setup of a new type of experiment, one that was actually first suggested by Roger Penrose. We sent carbon-60 "buckyballs" through a double-slit experiment in 1999, recording a clear diffraction pattern and demonstrating that a single buckyball (or, more accurately, the entity that is later detected as a single buckyball) goes through two openings at once—two openings a hundred times farther apart than the diameter of one buckyball. Our buckyballs were the most massive particles ever probed for wavelike behavior.

Although fully committed to physics at the time, I had never given up on the idea of making art again one day. Shortly after the Vienna experiment, I attended a confer-

1) Julian Voss-Andreae. Photo by Joni Kabana 2) Quantum Reality (Large Buckyball Around Trees), 2007. Steel and trees, diameter 30'. 3) Synergy, 2013. Stainless steel and colored glass, 20' x 6' x 6'. 4) Quantum Man, 2011. Bronze, 100" x 44" x 20". Photos courtesy of Julian Voss-Andreae. To see more of Voss-Andreae's work, see: http://julianvossandreae.com.

ence in Cortona, Italy, for scientists who wanted to explore the arts, humanities, and spirituality. One speaker, George Weissmann, especially fascinated me with his talk, “Quantum Physics and Parapsychology.” His daughter, Adriana, would exert an even stronger influence on me, compelling me soon after to move to Portland to be with her.

I felt the urge to return to art, bringing with me what I had learned and experienced in physics. I enrolled in an art school, with a focus on sculpture, and soon found myself making sculptures based on the structure of proteins, the molecular building blocks of life. Last month I installed the latest such protein sculpture, a 20-foot stainless steel and colored glass piece based on the structure of the human collagen molecule, at Rutgers University in New Jersey.

A different body of my work draws inspiration directly from quantum physics to create novel sculptures. The 2009 exhibition “Quantum Objects” at the American Center for Physics in College Park, Maryland, was devoted solely to this body of work. One of the first sculptures in this series, “Quantum Man,” envisions a walking human figure as a quantum object.

Today I am working on a large-scale commission based on a similar idea for the University of Minnesota’s new Physics and Nanotechnology Building in Minneapolis. Two monumental figures, a kneeling man and a woman each 10 feet tall, face each other on a plaza over a distance of sixty feet. They are fabricated from parallel slabs of steel arranged in such a way that the figures almost disappear from view when the viewer crosses through the line of their gaze.

I am also part of a team that recently won a $2 million National Science Foundation grant to develop cutting-edge nanomaterials built from DNA. My part is to find ways to visualize the nanostructures we are going to build in the lab as macroscopic sculptural objects. This project is my first real science-related work in over a decade, drawing on my experiences both as a scientist and as an artist.

The Singer

Renée Yoxon, Montreal, Quebec, CA
Jazz Vocalist, Teacher, and Writer

When I was 15 years old I dreamed of being a scientist by day and a jazz singer by night. I attended Carleton University from 2005 until 2010, where I studied experimental physics. In my free time I took private voice lessons with Tena Palmer in the music department and played in a community big band.

In the beginning music always seemed to be a frivolity, something one couldn’t make a career of. I diligently pursued a physics career, working every summer at the Canadian National Research Council’s Institute for Chemical Process and Environmental Technologies department. I studied optical methods of measuring polycyclic aromatic hydrocarbons in ambient conditions. Though I had a really good time working with the scientists, as each summer went by I spent less time thinking about research and more time thinking about music, performance, and song writing.

In my fourth year I met young professional musicians for the first time, which changed my whole perspective. Once I realized music could be a viable career option, I knew that I had to make some changes. I switched out of the honors experimental program and into the general physics program, which freed up a bunch of credits. For the last two semesters of my degree I didn’t take a single science or math course. I loaded up on music credits and ended up graduating with

continued on page 26

ABOVE

Renée Yoxon. Photo by Claude Brazeau.

BELOW

Yoxon sings during the "Here We Go Again" CD release in December 2012. Photo by Claude Brazeau.

continued from page 25

a BSc in physics with minors in math and music.

Although studying physics may have started me off behind my musical peers, my Carleton experience prepared me excellently for the self-employed life. To complete my degree I had to be resourceful. My time as a teaching assistant gave me the teaching bug. I now have a thriving voice teaching studio. As president of the Carleton Physics Society, I learned that I have a knack for event planning and advertising. And I don't want to leave out that I am still friends with many of my physics classmates, and they have continued to support me and my music.

Now that 10 years have passed since my teenage career aspirations, my new dream is to be a successful musician and a lifelong artist. But I still got excited when the Mars rover landed!

The Video Game Designer

Amy Nelson, Los Angeles, CA
Staff Software Engineer Architect, Disney

As an undergraduate at Michigan State University in East Lansing, I did an observational senior thesis focused on extragalactic background light. Graduating in 1994 with a degree in astrophysics, I attended the University of California, Santa Cruz, where I studied galaxy formation and evolution; in 2000 I earned a PhD for my work studying high-redshift galaxy clusters drawn from the Las Campanas Distant Cluster Survey.

Partway through my graduate studies I decided that I didn't want to pursue a traditional academic career in astronomy. The primary reason was simply that I didn't enjoy research enough to want to make a career of it. Other important factors in my decision related to quality-of-life issues. I felt that astronomers, especially postdocs and young faculty, were expected to work long hours to produce an unreasonably large amount of research for relatively low pay, usually with little to no say in where they lived.

Leaving academia, I embarked on a new career as a software engineer, creating video games. As a child, I always loved programming computers and playing video games. That lifelong affinity, coupled with my extensive knowledge of physics and mathematics, gave me the foundation to become a successful programmer. Although I didn't have many directly transferable skills (I programmed in Fortran in graduate school and had to learn C++ afterward), my graduate studies in astrophysics helped me develop my most valuable asset—being an independent learner and problem solver. Even though I had almost no direct knowledge of how to make games and faced a steep learning curve, I picked things up quite quickly and wasn't afraid to just dive right in.

After several years working on console games, I am currently a lead software engineer for Disney Interactive Worlds. My team is bringing Club Penguin, a popular kids' online virtual world, from the web to mobile devices running iOS and Android. I love working in a creative, collaborative field with smart, talented people who are passionate about games. My job is a wonderful combination of coming up with ideas to solve technical problems and executing those ideas. My company places an emphasis on work–life balance, which is really important to me. We do work extra hours sometimes during "crunch time," but that happens infrequently.

I still keep tabs on what's going on in astronomy, but predominantly through the mainstream news outlets, not through any academic or professional channels. My best friend is an astronomical lecturer at Griffith Observatory, and he keeps me in the loop as well. I'll always love learning about physics and astronomy, and am so thankful for the knowledge I have and the invaluable problem-solving skills I gained because of it. But learning about a field and conducting research in that field are two very different things. I couldn't be happier with the career choice I made to be a video game programmer.

The Spin-Statistics Theorem and Identical Particle Distribution Functions

by Dwight E. Neuenschwander

In the restaurants of some countries, the *maître d'* will seat your party at a table already occupied by strangers if the table has sufficient empty chairs. In other cultures, new diners expect to be seated at empty tables even when occupied tables are surrounded by surplus seats. Elementary particles, and composites made of them, fall analogously into two categories: bosons and fermions. Bosons readily share the same state, analogous to the first group of diners. Fermions prefer solitude, like the second group of diners. This article offers a simple argument for their respective distribution functions that describe how a system of identical particles populates the states available to them.

Since the most stable configuration of a system typically finds it in the state of lowest energy, why don't all the electrons in an atom reside in the 1*s* orbital? If they did, there would be no chemistry, and thus no biology and no life—nor would metals conduct electricity, and white dwarf stars would collapse into black holes. The universe would be very different indeed, and we would not be around to appreciate it! The Pauli exclusion principle formally articulates the hypothesis that electrons, as fermions, do not all collapse into an atom's 1*s* orbital; only two of them can live there, and then only with opposite spins, to not be in the same space-spin state.

The exclusion principle grew out of the realization that the discrete quantum states for electrons could not, by themselves, explain the periodic table of the elements. The crucial clue towards a resolution came in 1924, when Edmund Stoner published a paper noting a correlation between the number of electron states of alkali metals placed in a magnetic field and the number of closed-shell electrons in noble gases.[1,2] From this observation Pauli realized the sequence of closed-shell electron numbers 2, 8, 18,…is equivalent to the rule that no state can hold more than one electron. To implement this rule he had to invent an extra quantum number. It was soon identified with electron spin, when Samuel Goudsmit and George Uhlenbeck proposed it in the autumn of 1925.[3] Pauli's spin-statistics theorem of 1940 generalized the argument about spin and statistics.[4] Its flip side, that bosons can coalesce, finds dramatic illustration in superfluidity and superconductivity, variations of Bose-Einstein condensation.

The word "state" carries three contexts in this discussion: macroscopic thermodynamic states, and microscopic states in two varieties—single-particle and multiparticle microstates. The macroscopic state of a bottle of hydrogen gas in thermal equilibrium is characterized by observables such as pressure, temperature, and volume. Microscopically, each atom has a set of available internal states, such as the atomic orbitals with spin, $\psi_{nlm_l m_s}$ that describe the electron relative to the nucleus. For other purposes, as in the kinetic theory of gases, it may be sufficient to model a hydrogen atom as a solid point mass moving with momentum **p** and located at position **r**. Here the atom's microstate consists of six numbers, the momentum and position coordinates in phase space.

Between macrostates and single-particle microstates are states of a system of N particles. For $N = 2$, with one particle in the single-particle state ψ_a and the other in microstate ψ_b, how simple it would be mathematically if the two-particle state was merely the product of the two one-particle wave functions, $\psi = \psi_a\psi_b$. This works fine for systems of distinguishable particles, such as the deuteron—a proton and a neutron bound together.[5] But the plot thickens when the particles are indistinguishable. If $\psi = \psi_a\psi_b$ was the whole story for identical particles, the universe would be rather sterile. Simplicity is beautiful, but complexity can be essential.

Statistical mechanics aims to understand macroscopic states in terms of microstates. The next section reviews how this game is played.

Statistical Mechanics Review

Consider a system of N molecules, each in one of the many possible microstates available to it ("molecule" here is a generic term which could also denote a nucleus or a neutrino, depending on the problem). Label the various single-particle microstates as state a, state b, and so on. Let n_i denote the number of molecules in state i. If I were to reach into a box of these molecules and pick one at random, the probability P_i of selecting one in state i is n_i/N. Since every molecule must be in one microstate or another,

$$\sum_i P_i = \sum_i \frac{n_i}{N} = 1. \tag{1}$$

If E_i denotes a molecule's energy when in state i, and U the total energy carried by all the molecules (the internal energy of thermodynamics), then

$$U = \sum_i n_i E_i = N \sum_i E_i P_i = N\langle E\rangle; \tag{2}$$

$\langle E\rangle$ denotes the average molecular energy.

A primary responsibility of statistical mechanics expresses P_i in terms of E_i and the ambient thermal energy kT in which the molecules find themselves, when in thermal equilibrium with their surroundings at temperature T. Boltzmann's constant $k = 1.381\times10^{-23}$ J/K forms a conversion factor between temperature and energy. A derivation of P_i as a function of T can be approached at least two ways: through the "method of most probable distribution,"[6] or with phase space arguments based on Liouville's theorem.[7] One finds

$$P_i = \frac{1}{Z}\, e^{-E_i/kT}, \tag{3}$$

where the normalization factor Z, determined by Eq. (1), is the "partition function,"

$$Z = \sum_i e^{-E_i/kT}. \tag{4}$$

In terms of Z, the computation of U can be expressed succinctly. From Eqs. (2) and (3),

$$U = \frac{N}{Z}\sum_i E_i\, e^{-E_i\beta}, \tag{5}$$

where $\beta = 1/kT$. Thanks to a nice property of the exponential,

$a\, e^{ax} = \frac{d}{dx} e^{ax}$, Eq. (5) becomes

$$U = -N\frac{\partial}{\partial\beta}\ln Z. \tag{6}$$

The partition function offers a window from the macroscopic world of thermometers and pressure gauges into the microscopic world of atomic structures and interactions. For example, consider a system of N identical switches, each one either off (with energy $E_1 = 0$) or on (with energy $E_2 = \varepsilon$), so that $Z = 1 + e^{-\varepsilon\beta}$. To see if a real macroscopic system can be well modeled by such a set of switches, we could compare the measured heat capacity $C = dU/dT$ to the prediction of it calculated from Z.

Indistinguishable Particles in Quantum Mechanics

Now let's enlarge our perspective and speak of the states of an N-particle system. As before, each individual particle will be in a single-particle microstate of energy E_i. A possible N-particle state is specified by a list

$$\tilde{n} = (n_1, n_2, n_3, \ldots), \tag{7}$$

where $\sum_i n_i = N$. Each $\tilde{n}$ labels one possible state of the N-particle system. The energy $E_{\tilde{n}}$ of state $\tilde{n}$ is the sum

$$E_{\tilde{n}} = \sum_i n_i E_i. \tag{8}$$

In this context the partition function of Eq. (4) becomes the sum over the allowed $\tilde{n}$:

$$Z_N = \sum_{\tilde{n}} e^{-E_{\tilde{n}}\beta} = \sum_{\tilde{n}} e^{-\beta\sum_i n_i E_i}. \tag{9}$$

For example, suppose $N = 2$ and each particle can be in one of three one-particle microstates. The possible states of the two-particle system are:

$$\tilde{1} = (1,1,0) \quad \tilde{2} = (1,0,1) \quad \tilde{3} = (0,1,1)$$

$$\tilde{4} = (2,0,0) \quad \tilde{5} = (0,2,0) \quad \tilde{6} = (0,0,2)$$

with respective energies

$$E_{\tilde{1}} = E_1 + E_2 \quad E_{\tilde{2}} = E_1 + E_3 \quad E_{\tilde{3}} = E_2 + E_3$$

$$E_{\tilde{4}} = 2E_1 \quad E_{\tilde{5}} = 2E_2 \quad E_{\tilde{6}} = 2E_3.$$

From Eq. (9) the partition function reads

$$\begin{aligned} Z_2 &= e^{-\beta E_{\tilde{1}}} + e^{-\beta E_{\tilde{2}}} + \cdots + e^{-\beta E_{\tilde{6}}} \\ &= e^{-\beta E_1}e^{-\beta E_2} + e^{-\beta E_1}e^{-\beta E_3} + \cdots + e^{-\beta 2E_3} \\ &= x_1x_2 + x_1x_3 + x_2x_3 + x_1^2 + x_2^2 + x_3^2, \end{aligned} \tag{10}$$

where

$$x_i = e^{-\beta E_i}. \tag{11}$$

With N held fixed some $\tilde{n}$ do not occur, as in our illustration where $N = 2$ excludes (0,0,0) and (1,1,1). To work with fixed N means the set of all allowed $\tilde{n}$ must be known before Z_N can be evaluated. That is feasible when $N = 2$, but statistical mechanics deals with systems that contain on the order of 10^{23} particles. However, if N were *not* fixed, then each n_i in every $\tilde{n}$ could range over 0, 1, 2,…, N_{max}. To determine N_{max} for identical particles, the spin-statistics theorem steps in. Such generality makes Z summable.

"Identical" here means that no method exists *in principle* to distinguish one particle from another. This raises concern about possibly double-counting microscopic states. If particles 1 and 2 in a two-particle system exchange places in their one-particle microstates, should that swapped configuration be counted as the same, or as distinct, from the original? According to the rules of quantum mechanics,[8] one sums over both possibilities, which interfere with one another through the cross terms in $|\psi|^2 = |\psi_{original} + \psi_{exchanged}|^2$. The $N = 2$ wave function therefore has two options for including one particle in state a and an identical one in state b:

$$\psi_{ab}(1,2) = c_{orig}\,\psi_a(1)\psi_b(2) + c_{exch}\,\psi_a(2)\psi_b(1). \tag{12}$$

If these exhaust the possibilities for arranging the two particles, then $|c_{orig}|^2 + |c_{exch}|^2 = 1$. But $|c_{orig}| = |c_{exch}|$ because the particles are identical. Thus $c_{exch} = c_{orig}\,e^{i\delta}$, where $i^2 = -1$ with δ a real number. Equation (12) then becomes

$$\psi_{ab}(1,2) = \frac{1}{\sqrt{2}}[\psi_a(1)\psi_b(2) + e^{i\delta}\,\psi_a(2)\psi_b(1)]. \tag{13}$$

Now introduce the exchange operator $\mathcal{E}$ that interchanges particles 1 and 2:

$$\mathcal{E}\psi_{ab}(1,2) = \psi_{ab}(2,1). \tag{14}$$

If the interparticle potential is invariant under the exchange, then the exchange operator commutes with the Hamiltonian, and $\psi_{ab}(1,2)$ is an eigenstate of both $\mathcal{E}$ and the Hamiltonian. Besides the energy eigenvalue of the latter, there also exists an eigenvalue λ of $\mathcal{E}$, which means that under the operation of $\mathcal{E}$ the eigenstate is merely rescaled but otherwise unchanged:

$$\mathcal{E}\,\psi_{ab}(1,2) = \lambda\,\psi_{ab}(1,2). \tag{15}$$

Therefore

$$\mathcal{E}^2\,\psi_{ab}(1,2) = \lambda^2\,\psi_{ab}(1,2). \tag{16}$$

But in addition,

$$\mathcal{E}^2\,\psi_{ab}(1,2) = \mathcal{E}\,\psi_{ab}(2,1) = \psi_{ab}(1,2) \tag{17}$$

and thus $\lambda^2 = 1$, so that $\lambda = \pm 1$. Operating with $\mathcal{E}$ on the $\psi_{ab}(1,2)$ of Eq. (13) gives

$$\mathcal{E}\,\psi_{ab}(1,2) = \frac{1}{\sqrt{2}}[\psi_a(2)\psi_b(1) + e^{i\delta}\,\psi_a(1)\psi_b(2)]. \tag{18}$$

By virtue of Eq. (15), this equals

$$\mathcal{E}\,\psi_{ab}(1,2) = \pm\frac{1}{\sqrt{2}}\,[\psi_a(1)\psi_b(2) + e^{i\delta}\,\psi_a(2)\psi_b(1)]. \tag{19}$$

Comparing Eqs. (18) and (19) shows that $e^{i\delta} = \pm 1$. Therefore, Eq. (13) becomes

$$\psi_{ab}(1,2) = \frac{1}{\sqrt{2}}[\psi_a(1)\psi_b(2) \pm \psi_a(2)\psi_b(1)]. \tag{20}$$

What property of the particles determines which sign applies? One may define an elementary particle as a state of definite mass and spin. The spin **S**, the intrinsic angular momentum carried by the particle, becomes quantized in units of the reduced Planck's constant $\hbar$. In particular, to say a particle carries spin s means that its spin vector squared has magnitude $\hbar^2 s(s+1)$. One component of **S** can also be simultaneously measured, such as $S_z = m_s\hbar$, where m_s takes on the $2s+1$ possible values $s, s-1, \dots, -s$. The quantum number s can be one of the possible values $0, \frac{1}{2}, 1, \frac{3}{2}, 2, \frac{5}{2}, 3, \dots$ Particles with integer s are bosons, and particles that carry half-odd-integer s are fermions.

Pauli's 1940 proof of the spin-statistics theorem[4] makes consistent with relativistic quantum field theory the assertion that identical fermions use the minus sign in Eq. (20), and identical bosons use the plus sign. The Pauli exclusion principle emerges as a consequence: If two fermions are identical, they cannot be in the same state because, by Eq. (20), $\psi_{aa}(1,2) = 0$. But for identical bosons, the total wave function is enhanced: $|\psi_{aa}(1,2)|^2 = 2|\psi_a|^2$. Consequently, calculations of the root-mean-square distance separating identical bosons or fermions leads to the (misnomered) "exchange forces," whereby identical bosons congregate closer together than do distinguishable particles, and identical fermions are farther apart.[9]

Although the result of the spin-statistics theorem is simple to state, connecting it to deeper principles is not simple. In the *Feynman Lectures,* Richard Feynman remarked,

Why is it that particles with half-integral spin are Fermi particles whose amplitudes add with the minus sign, whereas particles with integer spin are Bose particles whose amplitudes add with the plus sign? We apologize for the fact that we cannot give you an elementary explanation. An explanation has been worked out by Pauli from complicated arguments of quantum field theory and relativity. He has shown that the two must necessarily go together, but we have not been able to find a way of reproducing his arguments on an elementary level…This probably means that we do not have a complete understanding of the fundamental principle involved…"[10]

Feynman's interpretation of what it means to "understand" a point of physics is extremely suggestive. In a 1994 contribution to a "Question and Answer" column in the *American Journal of Physics,* this Feynman quote was recalled, then followed with the question "Has anyone made any progress towards an 'elementary' argument for the spin-statistics theorem?"[11] This question generated a lively discussion over the next three years,[12] culminating in the book *Pauli and the Spin-Statistics Theorem* by George Sudarshan and Ian Duck. They wrote,

"*Everyone knows the spin-statistics theorem but no one understands it. The key word of course is 'understand.'…The question is whether physics contains this fact, and if so how does this come about; or whether physics is merely consistent with the spin-statistics theorem and that some deeper explanation exists…*[13]

Whether or not we "understand" the spin-statistics theorem, we can nevertheless apply it to systems of N identical bosons or fermions.

Distributions of Identical Bosons or Fermions

Returning to Z_N, we now allow every n_i to range from 0 to N_{max} in every $\tilde{n}$. According to the spin-statistics theorem, $N_{max} = 1$ for identical fermions, and $N_{max} = \infty$ for identical bosons. In our previous example of particles each having three available microstates, as identical bosons the states of the multiparticle system exhibit these options, grouped by the value of N:

$\{\tilde{n}\} = \{[\ (0,0,0)\ ]_{N=0},$

$[\ (1,0,0), (0,1,0), (0,0,1)\ ]_{N=1},$

$[\ (2,0,0), (0,2,0), (0,0,2),$
$(1,1,0), (1,0,1), (0,1,1)]_{N=2},$

$[(3,0,0), (0,3,0), (0,0,3),$
$(2,1,0), (2,0,1), (1,2,0),$
$(1,0,2), (0,1,2), (0,2,1), (1,1,1)]_{N=3}, \ldots\}$

continuing thus as $N \to \infty$; for instance, the $N = 4$ group includes (4,0,0), (1,0,3), (2,1,1), (2,2,0) and so on. The partition function for this system of identical bosons with variable N becomes

$$Z_{\text{bosons}} = [1]_{N=0} + [x_1 + x_2 + x_3]_{N=1}$$

$$+ [x_1^2 + x_2^2 + x_3^2 + x_1x_2 + x_2x_3 + x_1x_3]_{N=2}$$

$$+ [x_1^3 + x_2^3 + x_3^3 + x_1^2x_2 + x_1^2x_3 +$$

$$x_1x_2^2 + x_1x_3^2 + x_2^2x_3 + x_2x_3^2 + x_1x_2x_3\ ]_{N=3} + \ldots$$

$$= (1 + x_1 + x_1^2 + \ldots)(1 + x_2 + x_2^2 + \cdots)$$
$$(1 + x_3 + x_3^2 + \ldots). \tag{21}$$

Each factor is a geometric series,

$$1 + x + x^2 + x^3 + \ldots = \frac{1}{1-x}, \tag{22}$$

which converges for $|x| < 1$, and thus

$$Z_{\text{bosons}} = \prod_{i=1}^{3}(1 - x_i)^{-1}. \tag{23}$$

For identical fermions, in this instance where each one has three possible microstates, the list of N-particle states is much shorter:

$\{\tilde{n}\} = \{[\ (0,0,0)\ ]_{N=0},$

$[\ (1,0,0), (0,1,0), (0,0,1)\ ]_{N=1},$

$[\ (1,1,0), (1,0,1), (0,1,1)]_{N=2},$

$[(1,1,1)]_{N=3}\},$

which yields

$$Z_{\text{fermions}} = 1 + x_1 + x_2 + x_3$$

$$+ x_1x_2 + x_1x_3 + x_2x_3 + x_1x_2x_3$$

$$= \prod_{i=1}^{3}(1 + x_i). \tag{24}$$

More generally, with M one-particle microstates available to each member of an ensemble of identical particles, the partition function reads

$$Z = \prod_{i=1}^{M}(1 \pm x_i)^{\pm 1}, \tag{25}$$

where the plus sign in Z holds for fermions and the minus sign for bosons.

In allowing the possibility of an open system of variable N, the E_i are shifted. The first law of thermodynamics says that the internal energy of a closed system increases with the addition of heat and/or the performance of work; in the sign conventions typically used by physicists, we write $dU = đQ - đW$. But allowing particles to enter or leave the system can also change the internal energy. For instance, the new particles might undergo exothermic chemical reactions with the original ones. In such circumstances dU picks up an addtional term μdN,

$$= TdS - PdV + \mu dN, \tag{26}$$

where dN is the particle number increment (modeled as continuous since N is typically huge) and μ denotes the chemical potential,[14] the increase in internal energy per particle when particles are added to the system. The effect of μ can be starkly seen in processes of constant entropy and volume. In a closed system $(\Delta U)_{S,V} = 0$, so that by Eq. (2),

$$0 = \Delta(N\langle E\rangle) = N\Delta(\textstyle\sum_i E_iP_i). \tag{27}$$

In contrast, in an open system, $(\Delta U)_{S,V} = \mu\Delta N$, which with the help of Eqs. (1), (2), and (26) says

$$0 = \Delta(N\langle E\rangle - \mu N)$$

$$= N\,\Delta[\textstyle\sum_i(E_i - \mu)P_i\,]. \tag{28}$$

Thus the x_i in Eq. (11) and thereafter get replaced with

$$x_i = e^{-\beta(E_i - \mu)}. \tag{29}$$

To calculate the average number of molecules $\langle n_i\rangle$ found in state i, sum over the multiparticle states $\{\tilde{n}\}$, each with probability $P_{\tilde{n}} = \frac{1}{Z}e^{-\beta E_{\tilde{n}}}$:

$$\langle n_i\rangle = \sum_{\tilde{n}} n_i\,P_{\tilde{n}}$$

$$= \frac{1}{Z}\textstyle\sum_{\tilde{n}} n_i\,e^{-\beta\sum_j n_j(E_j - \mu)}$$

$$= -\frac{1}{\beta}\frac{\partial}{\partial E_i}\ln Z, \tag{30}$$

where $\partial E_j/\partial E_i = 1$ for $i = j$ and 0 for $i \neq j$. For indistinguishable fermions, Eq. (29) becomes

$$\langle n_i\rangle_F = \frac{g_i}{e^{\beta(E_i-\mu)} + 1}, \tag{31}$$

and for indistinguishable bosons,

$$\langle n_i\rangle_B = \frac{g_i}{e^{\beta(E_i-\mu)} - 1}. \tag{32}$$

Since the partition function is a sum over *states* and not merely a sum over *energies,* these distribution functions on the right-hand sides of Eqs. (31) and (32) also pick up a factor g_i for any polarization or spin multiplicities.

Although N was allowed to vary in order to derive these distributions, in applications they hold whether or not N is varied. Let us illustrate their use in Bose-Einstein condensation (BEC).

Its story begins in 1924 when Satyendra Bose sent to Albert Einstein a paper about counting the quantum states of photons. Bose had trouble getting his paper accepted, but Einstein was impressed, translated the paper from English into German, and submitted it on Bose's behalf to the *Zeitschrift für Physik*, where it was published under Bose's name.[15] Then Einstein extended Bose's arguments to massive particles such as atoms. He showed that if atoms with integer spin were cooled to very low temperatures, a critical temperature exists below which the atoms coalesce into their state of lowest energy, forming a macroscopic object.

Picking up this idea, in 1938 Fritz London suggested that such condensates explained the superfluidity of helium-4.[16] Helium was first liquefied by Kamerlingh Onnes in 1908, when he allowed it to reach its boiling point at 4.2 K. Below 2.17 K, a discontinuity in the heat capacity occurs, the density drops, and some of the liquid becomes a "superfluid" with zero viscocity. It will creep through microscopic holes in vessels thought to be leak proof, and climb up a vertical tube or wall (Fig. 1).

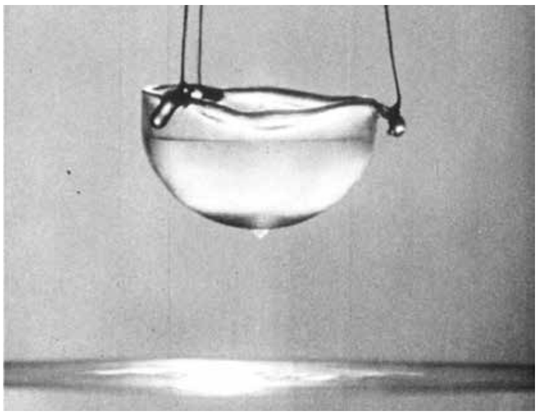


Fig. 1. Liquid helium creeping up the sides of the cup, going over the rim, and dropping outside. Photo by Alfred Leitner (1963), public domain.

The number density of atoms needs to be high, and the temperature low, so the de Broglie wavelengths are long and overlap. To make Bose-Einstein statistics relevant, the atoms must be identical, a purity difficult to achieve when starting from macroscopic samples. Under these stringent conditions, the overlapping wave functions of the individual helium-4 atoms coalesce into a coherent state with macroscopic effects.

Superconductivity, first demonstrated by Onnes in 1911 with mercury, occurs below a critical temperature (4.1 K for Hg), when the metal loses all electrical resistance. The mechanism for such type I superconductivity in pure metals (distinct from type II high-temperature superconductivity in alloys) was not understood until the mid-1950s, with the so-called BCS theory of John Bardeen, Leon Cooper, and Robert Schreiffer. The crucial insight was that electrons, which are fermions, can pair up through interactions with the metal's lattice. The negatively charged electrons repel each other but are attracted to the positive charges in the lattice. Two electrons can thereby interact acoustically through lattice vibrations, even though they are far apart compared to the lattice spacing, quenching their Coulomb repulsion. These "Cooper pairs" carry integer spin, are subject to boson statistics, and can condense into a composite state whose energy leaves a gap of some 10^{-3} eV below the excited states. When kT is less than the gap, collisions are minimized, resulting in no resistance.[17]

Because photons are bosons, we might wonder if macroscopic light waves are some sort of collective state. Coherent radiation produced by a laser, where so many photons have the same phase, polarization, and frequency, suggests a candidate occurrence, at room temperature.

We can recreate the BEC prediction by starting with Eq. (32), assuming a gas of nonrelativistic, noninteracting bosons, each of mass m and carrying kinetic energy $E = p^2/2m$. The microstate i means $(\mathbf{p},\mathbf{r})$, a state of specific momentum and location. The number of bosons within volume dV and having momentum between p and $p+dp$ is therefore

$$dn = \langle n_{(\mathbf{p},\mathbf{r})}\rangle_B \, 4\pi p^2 dp\, dV/h^3, \qquad (33)$$

where h is Planck's constant, here taking the role of a phase-space pixel to make the integration measure a dimensionless number for counting particles. I am supposing the momentum vectors point randomly in all directions, and assume spin 0 so that $g_i = 1$ (otherwise a g gets carried along). Equation (32) becomes

$$\langle n_{(\mathbf{p},\mathbf{r})}\rangle_B = \frac{w\, e^{-\beta p^2/2m}}{1-we^{-\beta p^2/2m}}, \qquad (34)$$

where $w = e^{\beta\mu}$. Our objective is to calculate, as a function of temperature, the number of bosons n_o residing in the lowest-energy microstate. That ground state has $p = 0$, which from Eq. (34) gives the constraint $n_o = w/(1-w)$, implying that $0 \le w \le 1$ since n_o can range from 0 to ∞. Thus we complete Eq. (33) by counting bosons in the zero-momentum ground state:

$$N = n_o + \frac{4\pi V}{h^3}\int_0^\infty \frac{we^{-\beta p^2/2m}}{1-we^{-\beta p^2/2m}}\, p^2 dp. \qquad (35)$$

With the change of variable $y^2 = p^2/2m$, and using the geometric series of Eq. (22) to integrate term by term, we find that

$$N = n_o + \frac{V\Gamma(w)}{\lambda^3}, \qquad (36)$$

where a temperature-dependent correlation length λ emerges,

$$\lambda = \left(\frac{h^2}{2\pi mkT}\right)^{\frac{1}{2}} \qquad (37)$$

and

$$\Gamma(w) = \sum_{j=1}^{\infty}\frac{w^j}{j^{3/2}}. \qquad (38)$$

These results turn Eq. (36) into

$$\frac{n_o}{V} = \frac{N}{V} - \frac{\Gamma(w)}{\lambda^3}, \qquad (39)$$

which will be >0 provided $N/V > \Gamma(w)/\lambda^3$. The maximum value of $\Gamma(w)$ occurs at $w = 1$, where $\Gamma(1) = \zeta(3/2) \approx 2.612$ offers an instance of the Riemann zeta function. If $N/V > \zeta(3/2)/\lambda^3$ then $n_o > 0$. The critical number density occurs when $N/V = \zeta(3/2)/\lambda^3$, giving a critical temperature

$$T_c = \frac{h^2}{2\pi mk}\left(\frac{N/V}{2.612}\right)^{2/3}, \tag{40}$$

so that, for $T < T_c$, Eq. (39) may be written

$$\frac{n_o}{N} = 1 - \left(\frac{T}{T_c}\right)^{3/2}, \tag{41}$$

with $n_o/N = 0$ for $T > T_c$ (an example of a so-called second-order phase transition).

The first demonstration of BEC with non-helium atoms occurred in 1995 when a group at the University of Colorado and NIST-JILA led by Eric Cornell and Carl Wieman made a condensate with rubidium-87 atoms cooled to 170 nK. A few weeks later, Wolfgang Ketterle's group at MIT produced a condensate with sodium-23 atoms. For this achievement, Cornell, Wieman, and Ketterle shared the 2001 Nobel Prize in Physics.[18]

What about laser light as a collective effect of massless spin-1 bosons? In November 2012 the first BEC in photons was demonstrated.[19]

In the logic of physics, what are we to make of the spin-statistics theorem itself? The *statement* of the spin-statistics theorem is analogous, in its relation to the rest of physics, to the Planck-Einstein postulate $E = h\nu$; easy to state but (so far) not derived from any deeper principle. The "proof of the spin-statistics theorem" is not analogous to the demonstration that the work-energy theorem follows from $\mathbf{F} = m\mathbf{a}$; rather, the spin-statistics proof shows consistency between the rest of known physics and the hypothesis of connecting spin to the plus/minus sign of Eq. (20). Sudarshan and Duck observed:

"The spin-statistics theorem could conceivably be an essential ingredient of a more fundamental view of the world…
With such a point of view forced upon us, we should modify the meaning of 'understand,' and at the same time reduce our expectations of any proof of the spin-statistics theorem. What is proved…is that the existing theory is consistent with the spin-statistics relation. What is not demonstrated is a reason for the spin-statistics relation…"
…It is difficult to imagine a fundamental mechanism for the Pauli exclusion principle—upon which all depends—which predicates it…Must we reduce our demands on physics to require only consistency[?] Does an understanding of the 'Why?' of the spin-statistics relation have no direct answer in physics? Or must physics be formulated to include it[?] The Pauli result does not explain the spin-statistics relation and cannot. [Those who seek an elementary explanation] must remain unsatisfied because the consistency of relativistic quantum mechanics and quantum field theory with the Pauli exclusion principle has every reason to be as complicated as these subjects are, not as simple and direct as the Pauli exclusion principle itself."[20]

For the foreseeable future we will have to leave it there!

Acknowledgments

Deep thanks to Professor George Sudarshan for his inspiration and kindness. I am grateful to Toni Sauncy for reading a draft of this manuscript and offering insightful suggestions.

References

[1] E.C.G. Sudarshan and I. Duck, *Pauli and the Spin-Statistics Theorem* (World Scientific, Singapore, 1997), undoubtedly offers the most comprehensive survey anywhere of spin, the exclusion principle, and the spin-statistics theorem. It includes all the important original papers, with discussion. See also R.F. Streater and A.S. Wightman, *PCT, Spin and Statistics, and All That* (W.A. Benjamin, New York, NY, 1964).
[2] E.C. Stoner, "The distribution of electrons among atomic levels," *Philos. Mag.* **48**, 719 (1924); Sudarshan and Duck, Ref. 1, pp. 21-22.
[3] Wolfgang Pauli, "About the Relationship of the Closing of Electron Shells in Atoms with the Complex Structure of the Spectrum," *Zeit. f. Physik* **31**, 765 (1925); Sudarshan and Duck, Ref. 1, Ch. 1. Electron spin was postulated by G.E. Uhlenbeck and S.A. Goudsmit in *Naturwissenschaften* **47**, 953 (1925), a few months after Pauli's "two-valued quantum degree of freedom."
[4] Wolfgang Pauli, "The Connection between Spin and Statistics," *Phys. Rev.* **58**, 717 (1940); Sudarshan and Duck, Ref. 1, p. 345.
[5] An important example of quantum mechanics applied to distinguishable particles may be found in the Oppenheimer-Phillips effect concerning the deuteron: J. Robert Oppenheimer and Melba N. Phillips, "Note on the Transmutation Function for Deuterons," *Phys. Rev.* **48**, 500 (1935).
[6] Erwin Schrödinger, *Statistical Mechanics* (Cambridge Univ. Press, 1946, 1967), Ch. II.
[7] Kerson Huang, *Statistical Mechanics* (Wiley, New York, NY, 1963), Chs. 7-9.
[8] R. P. Feynman, R.B. Leighton, and M. Sands, *The Feynman Lectures on Physics,* Vol. III (Addison-Wesley, Reading, MA, 1963), Ch. 3.
[9] David Griffiths, *Introduction to Quantum Mechanics,* 2nd ed. (Pearson-Prentice Hall, Upper Saddle River, NJ, 2005), pp. 207-208. One might wonder how atoms bind into molecules through covalent bonds. It is the entire spin-space state that must be antisymmetric for the shared electrons.
[10] Feynman *et al.*, Ref. 8, Ch. 4, Sec. 1.
[11] D.E. Neuenschwander, in the "Question and Answers" column, "Question # 7: The spin-statistics theorem," *Am. J. Phys.* **62**(11), 972 (1994).
[12] "Answer to Question # 7, 'The spin-statistics theorem:'" Roy Gould, *Am. J. Phys.* **63** (2), 109 (1995); Henri Bacry, *Am. J. Phys.* **63**(4), 297-298 (1995); Robert Hilborn, *Am. J. Phys.* **63**(4), 298-299 (1995); Thomas von Foerster, *Am. J. Phys.* **64**(5), 526 (1996); E.C.G. Sudarshan and I. Duck, "Toward an understanding of the spin-statistics theorem," *Am. J. Phys.* **66**(94), 284-303 (1998). See also R.T. Deck and J.D. Walker, "The Connection between Spin and Statistics," *Physica Scripta* **63**, 7-14 (2001); J.A. Morgan, "Spin and statistics in classical mechanics," *Am. J. Phys.* **72**(11), 1408-1417 (2004); Luis Boya and E.C.G. Sudarshan, "The Spin-Statistics Theorem in Arbitrary Dimensions," arXiv:0711.1111v1[hep-th] 7 Nov 2007.
[13] Sudarshan and Duck, Ref. 1, pp. 3-4.
[14] Ashley Carter, *Classical and Statistical Thermodynamics* (Prentice Hall, Upper Saddle River, NJ, 2001), Ch. 9.
[15] Ronald Clark, *Einstein: The Life and Times* (Avon Books, New York, NY, 1972), pp. 408–409.
[16] Fritz London, "The λ-Phenomenon of Liquid Helium and the Bose–Einstein Degeneracy" *Nature* **141** (3571): 643–644 (1938); *Superfluids* Vols. I and II (reprinted by Dover, New York, NY, 1964).
[17] http://hyperphsics.phy-ast.gsu.edu/hbase/solids/coop.html#c; I.J.R. Aitchison and A.G.G. Hey, *Gauge Theories in Particle Physics* (Adam Hilger, Bristol, UK, 1982), Ch. 9.
[18] Barbara G. Levi, "Cornell, Ketterly, and Wieman Share Nobel Prize for Bose-Einstein Condensates," *Physics Today* **54**, 12, 14 (2001); "New State of Matter Seen Near Absolute Zero," NIST, http://physics.nist.gov/News/Update/950742.html.
[19] Jan Klaers, Julian Schmitt, Frank Vewinger, and Martin Weitz, "Bose–Einstein condensation of photons in an optical microcavity," *Nature* **468**(7323): 545–548(2010).
[20] Sudarshan and Duck, Ref. 1, pp. 4-5.

Congratulations

to the newest members of Sigma Pi Sigma

Abilene Christian University
Campbell, Chris, '13
Forrister, Erik, '13
Herndon, Case, '13
Lynn, William, '13
Simpson, Adam, '13
Tate, Aric, '13

Adelphi University
Babino, Matthew, '13
Dellatto, John, '13
Devito, Nicole, '13
Disla, Martin, '13
Fernez, Michael, '13
Jaycox, Steve, '13
Kaur, Navjot, '13
Trietsch, Michael, '13

Andrews University
Greenley, Christopher, '13
Pearson, Bryan, '13

Angelo State University
Anderson, James, '13
Blake, John, '13
Ferguson, Sarah, '13
Norrell, Jonathon, '13
Perez, Jordan, '13
Shafer, Roy, '13
Wilson, Ashley, '13

Appalachian State University
Barrios Hernandez, Jessica, '13
Bowen, Jeremy, '13
Canipe, Barry, '13
Garcia Rosales, Daniel, '13
Gerber, Jeffrey, '13
Kelley, Kyle, '13
Lambert, Ryan, '13
Lees, Eitan, '13
Norris, Gregory, '13
Pearce, Brady, '13
Volstad, Samuel, '13

Arkansas-Fayetteville, University of
Barrows, Wesley, '13
Bohlman, Doug, '13
Bothwell, Tobias, '13
Brittain, Mary, '13
Clawson, Wesley, '13
Dix, Kendall, '13
Hartley, Matthew, '13
Henderson, Casey, '13
Hiller, Brett, '13
Korb, Elliott, '13
Norman, Justin, '13
Osmon, Adam, '13
Possehl, Matthew, '13
Singh, Dilawer, '13
Stabach, Jennifer, '13
Stone, Jordan, '13

At Large
Haag, Brooke, '12
Hart, Gus, '12

Auburn University
Goforth, Matthew, '13
Hall, Taylor, '13
Hill, Andrew, '13

Auburn University (cont.)
Hilley, Zachary, '13
Mcdaniel, James, '13
Munna, Christopher, '13
Nakamura, James, '13
Schloss, James, '13
Statkewicz, Colin, '13
Stephenson, Rebekah, '13
Sutherland, Robert, '13

Augsburg College
Bier, Elianna, '13
Grant, Benjamin, '13
Hernandez, Luis, '13
Rodriguez-Sotelo, Trevor, '13
Stueck, Gary, '13

Augustana College
Pfeifle, Anne, '13

Austin College
Anderson, Amy, '13
Crannell, Graham, '13
Donor, John, '13
Hagge, Mark, '12

Austin Peay State University
Bilbrey, Hudson, '13
Fix, Mees, '13
Parvizi, Mahmoud, '13
Tanner, Travis, '13
Wainwright, Cameron, '13
Wilson, Andrew, '13
Wyatt, Samuel, '13
York-Winegar, James, '13

Ball State University
Asigbee, Priscilla, '13
Bodee, Bradley, '13
Ghaffar, Irfanullah, '13
Kan, Zhe, '13
Malakooti, Sadeq, '13
Nault, Zachary, '13
Pentecost, Luke, '13
Summitt, Zakery, '13
Wood, Shaun, '13

Benedictine College
Bax, Ryan, '13
Carson, Graham, '13
Egging, Paula, '13
Kelly, Sarah, '13
McDonough, Nathanial, '13
Niedbalski, Peter, '13
Richard, Matthew, '13
Schmitz, Erich, '13

Berea College
Boykin, Tommy, '12
Vanover, Tyler, '12

Bethel University
Abbott, Josh, '12
Clarke, Joshua, '13
Croatt, Curt, '12
Englund, Joel, '12
Fredrick, Connor, '13
Frei, Ian, '13
Gessner, Nathanael, '13
Heppner, Benjamin, '12
Heyda, Curtis, '12

Bethel University (cont.)
Hofeldt, Michelle, '12
Johnson, Karl, '12
Kilgore, Dave, '13
Logemann, Caleb, '13
Mehlhorn, Jonathan, '12
Ness, Luke, '13
Schaffer, Andrew, '13
Tetzlaff, Michael, '12
Wall, Jared, '12
Woetzel, Austin, '13

Bloomsburg University
Ashton, Michael, '13
Barko, Kelly, '13
Campbell, Mark, '13
Gionfriddo, Robert, '13

Bradley University
Anderson, Erik, '13
Nall, Duncan, '13
Roth, Emily, '13
Sorkin, Samuel, '13
Tambellini, Vincent, '13
Turner, William, '13

Bucknell University
Burgdorf, Brendan, '13
Herzog, Monica, '13
Nicolich, Kathryn, '13
Sinton, Megan, '13
Smith, Dylan, '13
Talisa, Noah, '13

Buffalo State College
Galbier, Antonio, '13
Tarasek, Steven, '13
Torsey, Brian, '13

Cal Poly-Pomona
Hankins, April, '12
Hawkin, Clint, '12
Jasso, Steven, '12
Koh, Joseph, '12
Labriola, Gina, '12
Miller, John, '12
Smith, Stephen, '12
Tran, Jonathan, '12
Ulanch, Rachel, '12
Zeeman, Joshua, '12

Cal Poly-San Luis Obispo
Baker, Robert, '13
Buckley, David, '13
Frankhauser, Josh, '13
Frawley, David, '13
Haskin, Michael, '13
Herrick, Spencer, '13
Hoff, Matthew, '13
Pilgram, Nickolas, '13
Runco, Jordan, '13
Ziegler, Joshua, '13

Calif State University-San Marcos
Jester, Blaine, '13
Millward, Christopher, '13
Simmons, Gary, '13
Wilson, Dennis, '13

California State University-Chico
Baylis, Dana, '13
Busse, Carleene, '13
Delles, James, '13
Heffern, Lena, '13

California State University-Sacramen
Bentley, Brandon, '12
Blanchard, Jamison, '12
Chan, Aaron, '12
Conte, Grace, '12
Frye, Joshua, '12
Phillips, Jessica, '12
Potts, James, '12
Voss, Ryan, '13
Weaver, Alexander, '13

California-Davis, University of
Akbarieh, Kourosh, '13
Blaine, Alex, '13
Bonilla, Gabriel, '13
Cheung, Hoi Sing, '13
Heavlin-Martinez, Jeremy, '13
Landry, Joshua, '13
Rives, Jesus, '13
Sanchez, Martin, '13

California-Irvine, University of
Lara, Ricardo, '13
Mcilwain, Lyle, '13
Persico, Elliot, '13
Sherikar, Jayaram, '13
Torres, Javier, '13

Carthage College
Vodnik, Douglas, '13

Catholic University of America
Hlavin, Nathaniel , '13
Romano, Michelangelo, '13
Yoritomo, John, '13

Central Florida, University of
Barin, Brett, '13
Kepler, Daniel, '13
Mele, Nicholas, '13
Poindexter, Carla, '13
Strunk, Evelyn, '13

Central Michigan University
Alzarough, Alshebani, '12
Batth, Avtar Singh, '12
Gill-Kaur, Kirandeep, '13
Hancock, James, '12
Harvin, James, '12
Hawks, Paul, '12
Hicks, David, '13
Kaur, Jagjit, '12
Lembryk, Ludwick, '13
Noel, Paul, '12
Perdikakis, Georgios, '13
Redshaw, Matthew, '13
Timsina, Raju, '13
Van Dyke, Adam, '12
Wager, Heather, '13
Wimmer, Kathrin, '13
Yu, Ziyang, '13

Central Washington University
Berghoff, Hans, '13
Bianco, Brian, '13
Grove, Lukas, '13
Mcknight, Mark, '13
North, William, '13
Powers, Kegan, '13

Centre College
Dulemba, Joseph, '13
Kieffer, John, '13
Lane, Sam, '13
Miller, Liz, '13
Slone, Benjamin, '13
Walters, Morgan, '13

Charleston, College of
Chaurasia, Shikha, '13
Flanagan, Sean, '13
Hayward, Timothy, '13
Hipp, Christopher, '13
Lemasters, Robert, '13
Moss, Hunter, '13
Novo, Derek, '13
Payne, Alexis, '13
Steele, Patricia, '13
Tuck, Derek, '13
Wells, Mark, '13

Chicago State University
Carmona, Rodney, '13
Komarov, Miso, '13

Christopher Newport University
Bracey, Cierra, '13
Denno, Justin, '13
Garmon, Andrew, '13
Harris, Anthony, '13
Hesse, Kyle, '13
Hillyer, Richard, '13
Losada, Anthony, '13
Mcelhenny, Caroline Marie, '13
Mcmahon, Nicholas, '13
Meadows, Victoria, '13
Miller, Charles, '13
Pierce, Walter, '13
Pietrovito, Geoffrey, '13
Ryan, Robert, '13
Talley, Megan, '13
Thomas, James, '13

Coe College
Faaborg, Miles, '13
Salzer, John, '13
Smit, Thomas, '13
Starkenburg, Daken, '13
Troendle, Evan, '13
Wang, Jianxiang, '13
Whale, Alison, '13

Colby College
Bhandari, Chiran, '13
Covert, Dan, '13
Crockett, Ethan, '13
Kesseli, Aurora, '13
Masood, Arjumand, '13
Nodder, Stephen, '13
Norton, William, '13
Prosapio, Philip, '13
Reynolds, Meredith, '13
Seyfarth, Greg, '13

Colorado Mesa University
Hudson, Isaac, '13
Langston, Michael, '13

Colorado State University
Craft, Forrest, '13
Mauser, Kelly, '13
Robinson, Zachary, '13
Smith, Matthew, '13
Weakly, Robert, '13
Whitcomb, Ryan, '13

Connecticut College
Townsend, Olha, '13

Connecticut, University of
Gee, Russell, '12
Kelly, Shane, '12
Lamotte, Sarah, '12
Nesteruk, Kurt, '12
Neubelt, Matt, '12
Violette, Daniel, '12

Creighton University
Baruth, Andrew, '13
Horst, Nathan, '13
Lefky, Christopher, '13
Mcginnis, Daniel, '13
Meyer, Christian, '13
Otto, John, '13
Rogers, Jason, '13
Wrubel, Jonathan, '13

Cumberlands, University of the
Ramsey, Joshua, '13
Spangler, Hannah, '13
Zhou, Xiaohang, '12

Davidson College
Barrick, Jessica, '13
Finger, Ashley, '13
Gauthier, Ben, '13
Keller, Steven, '13
Onken, Drew, '13
Trennepohl, Chris, '13
Wall, Phillip, '13

Dayton, University of
Esposito, Daniel, '13
Foster, David, '13
Mazur, Elliot, '13
Sun, Miao, '13

De Paul University
Asta, Christopher, '13
Bergevin, Jenna, '13
Hart, Joseph, '13
Henderson, Ian, '13
Luce, Jason, '13
Wilkin, Kyle, '13
Zobrosky, Taylor, '13

Denison University
Daswani, Raghav, '13
Daswani, Rohin, '13
Donoghue, Elizabeth, '13
Dungan, Kristina, '13
Lowe, Ian, '13
Matola, Bradley, '13
Zeng, Peiyun, '13

DePauw University
Abarr, Quincy, '13
Leeds, Courtney, '13
Tao, Wei, '13
Zheng, Xin, '13

Dickinson College
Lane, Ryan, '12
Lanes, Olivia, '12
Li, Yike, '12
Tannous, Byron, '12
Xu, Danfei, '12

Drew University
Cicchetti, Nicole, '13
Larson, Bjorg, '13

Drexel University
Ciocys, Samuel, '13
Gaison, Jeremy, '13
Giang, William, '13
Smith, Robyn, '13

Duke University
Bellis, Ben, '12
Bloedel, Alexander, '13
Chen, Yifei, '12
Dannenberg, Paul, '12
Diclemente, William, '12
Dodd, Laura, '12
Epstein, Zachary, '12
Jones, Steven, '12
Kaplan, Kirsten, '13
Lewis, Joshua, '12
Loyal, Joshua, '12
Matteucci, Jackson, '13
Mcgeehan, Ryan, '13
Qian, Zongjin, '12
Rabinovich, Eugene, '13
Rolfes, Mary, '13
Seetharam, Kushal, '13
Weir, William, '12
Xi, Likun, '13
Zhang, William, '13

Duquesne University
Au-Yeung, Courtney, '13
Carto, Andrew, '13
Finton, Drew, '13
Limongelli, Julia, '13
Matthis, Emily, '13
Neil, Andrew, '13
Saunders, Claire, '13
Warner, Cheyenne, '13
Westerlund, Christopher, '13

East Central University
Crittenden, Joshua, '13
Klingler, Jared, '13

Eastern Kentucky University
Butler, Zachary, '13
Johnson, Joseph , '13
Nolan, Nicholas, '13
Roberts, William, '13
Rogers, Patrick, '13

Eastern Michigan University
Eschelbach, Scott, '13
Laycock, Brandon, '13
Lebrun, Caliph, '13
Payne, Austin, '13
Roe, Richard, '13

Elizabethtown College
Barrow, Alexander, '13
Boretti, David, '13
Buxton, Josiah, '13
Donohue, Meghan, '13
Evangelista, Christine, '13
Fetterman, Andrew, '13
Frey, Matthew, '13
Gresh, Daniel, '13
Hartman, Andres, '13
Hess, Jack, '13
Kelly, Patrick, '13
Shaw, Timothy, '13
Signora, Justin, '13
Werner, Kaylee, '13
Yanek, Luke, '13

Elon University
Barkley, Brett, '13
Calnan, Todd , '13
Glassman, Ethan, '13

Elon University (cont.)
Grimm, Reed, '13
Need, Emily, '13
Parker, John, '13
Sherr, Benjamin, '13
Shill, Christopher, '13

Embry-Riddle Aeronautical University
Carlsvi, Finn, '13
Dinsmore, Ross, '13
Gasdia, Forrest, '13
Griffin, Eric, '13
Law, Mariah, '13
Nair, Shankar, '13
Pineyro, Benedict, '13
Rose, Christopher, '13
Symons, Teresa, '13

Fairfield University
Aung, Htet, '13
Espaillat, Ricardo, '13
Greener, Kevin, '13
Hamilton, Kerry, '13

Florida Inst of Technology
Barranger, Thomas, '13
Berg, Michelle, '13
Bird, Perry, '13
Calderon, Victor, '13
Clark, Alexander, '13
Comaskey, William, '13
Esposito, Teresa, '13
Furtado, Rachel, '13
Hastings, Danielle, '13
Havu, James, '13
Hesterly, Katie, '13
Johnson, James, '13
Kelly, Lauren, '13
Kuehler, Christopher, '13
Lange, Jacob, '13
Mcbride, Marie, '13
Prado, Pablo, '13
Salem, Mohammad, '13
Spahn, Alexander, '13

Florida, University of
Allen, Brandon, '12
Bush, Zachary, '12
Cuevas, Clemente, '12
Dorsey, Kyle, '12
Ferrante, Sergio, '12
Gilbert, Stephen, '12
Glikin, Neil, '12
Hansen, Anders, '12
Hinrichs, Martha, '12
Jones, Sean, '12
Krauth, Luke, '12
Levental, Aleksander, '12
Mancebo, Angel, '12
Mcintyre, Matthew, '12
Mcleod, Lauren, '12
Murphy, Aidan, '12
Nicks, Scott, '12
Park, Joseph, '12
Samouce, Chris, '12
Schaefer, Brian, '12
Sweeney, Andrew, '12
Weck, James, '12
Wreder, Annika, '12

Fort Hays State University
Gaughan, Zack, '13
Pauyac-Martinez, Luis, '13
Schmidt, Rachel, '13
Winblad, Aidan, '13

Fort Lewis College
Klema, Nathaniel, '13
Mckinney, Wade, '13
Tsinnijinnie, Ty, '13

Franklin & Marshall College
Bastola, Manil, '13
Kim, Minji, '13
Madden, John, '13
Myer, Rachel, '13
Xu, Jingjing, '13

Frostburg State University
Capuozzo, William, '13
Clevenger, Benjamin, '13
Ghosh, Subhasis, '13
Kane, Ryan, '13
Lee, Andrew, '13
Littlejohn, Aaron, '13
Mcdonald, Joshua, '13
Mckinney, Kyle, '13
Meneghini, Amanda, '13
Robinson, Wade, '13
Sharp, Philip, '13
Steele, Timothy, '13
Talbi, Mohammed, '13

Furman University
Guerrier, Jonathan, '13
Hanor, David, '13
Khan, Haris, '13
Kostadinova, Evdokiya, '13
Krichman, Benjamin, '13
Lowrie, Peter, '13
Pardo, Kristina, '13
Richmond, Joshua, '13
Strait, Victoria, '13

Georgia Southern College
Coggins, William, '13
Kaufman, Matthew, '12
Murray, Noel, '13
Sisk, Zachary, '13

Georgia State University
Adhikari, Bhim, '13
Del Aguila, Gustavo, '13
Gomez-Lugo, Aaron, '13
Jones, Bobby, '13
Rusert, Maria, '13
Smith, Daniel, '13
Smith, Megan, '13

Georgian Court College
Applegate, Amy, '13
Bates, Jeffery, '13

Gettysburg College
Denu, Brian, '13
Malone, Ronald, '13
Stryker, Kristen, '13

Gordon College
Harrington, Patrick, '13
Hong, Minsung, '13
Odonga, Timothy, '13

Grand Valley State University
Cooke, Brittany, '13
Mohr, Amy, '13
Pawlak, Daniel, '13
Peshl, Jeremy, '13

Grove City College
Augspurger, Michele, '13
Dallachiesa, Lauren, '13
Mcfaul, Kenton, '13
Smith, Jeremy, '13

Gustavus Adolphus College
Bisgaard, John, '13
Broscoff, Andrew, '13
Buckley, David, '13
Caruso, Anna, '13
Dahl, Laura, '13
Grundmeyer, Brian, '13
Neutkens, Nicholas, '13

Gustavus Adolphus College (cont.)
Seewald, Lucas, '13
Weiers, Samuel, '13
Wroge, Madison, '13

Hartwick College
Grzeskowiak, Steven, '13
Hotalen, Jodi, '13
Murray, Kyle, '13
Nichols, Nathan, '13
Patterson, Jaclyn, '13
Railey, Daniel, '13

Henderson State University
Bolt, Matthew, '13
Buckholz, Kristopher, '13
Greene, John, '13
Hill, Justin, '13
Martin, Ramona, '13
Pagan, Jason, '13
Springer, Johnathan, '13
Terry, Brian, '13

Hillsdale College
Harper, Devin, '13
Irmer, Mitchell, '13
Kane, Alexander, '13
Kerst, Amy, '13
Mirth, Joshua, '13
Ryskamp, Samuel, '13

Hofstra University
Giacomazza, Michael, '13
Guralnick, David, '13
Kast, Emma, '13
Mani, Endri, '13

Holy Cross, College of the
Blanchette, Kevin, '13
Eslinger, Robert, '13
Finn, Daniel, '13
Geddes, William, '13
Hartman, Allison, '13
Heffernan, Patrick, '13
Moran, Kevin, '13

Hope College
Eiles, Matthew, '13
Ploch, Caitlin, '13

Houston Baptist University
Amir, Syed, '13
Besil-Rodriguez, Gloria, '13
Bhatt, Neelam, '13
Kriel, Milandri, '13
Mandal, Tanaya, '13
Nguyen, Uyen, '13
Owens, Constance, '13
Pham, Christie, '13
Pop, Alexander, '13
Shah, Radhika , '13

Howard University
Benjamin, Gregory, '13
Carter, Stanford, '13
O'Donnell, Ryan, '13
Sneed, Nickolas, '13

Idaho State University
Chantry, Michael, '12
Chow, Claire, '12
Ivie, Eric, '12

Illinois Benedictine College
Tovalin-Schmidt, Sandra, '13

Illinois Institute of Technology
Becker, Nicholas, '13
Burns, Luke, '13
Cao, Chaoyue, '13
De Arcos Rodriguez, Jose, '13
Dooley, Melanie, '13

Illinois Institute of Technology (cont.)
Duffty, Daniel, '13
Fox, William, '13
Maus, Dylan, '13
Pelliccione, Christopher, '13
Perry, Amichay, '13
Segre, Carlo, '13
Soto, Rafael, '13
Spentzouris, Linda, '13
Varentsova, Anna, '13
White, Christopher, '13
Wisniewski, Eric, '13

Illinois State University
Baughman, Phillip, '12
Brennan, Connor, '13
Heidorn, William, '12
Legner, Christopher, '12
Nevins, John, '12
Quinn, Erik, '13
Reisinger, David, '12
Skilling, Quinton, '13
Steinacher, Andrew, '13
Vikartosky, Andrew, '12

Indiana State University
Bonacum, Jason, '13
Schulthies, Austin, '13
Borden, Nicholas, '13
Conner, Austin, '13
Nania, Thomas, '13
Workman, Daniel, '13

Ithaca College
Cele, Delani, '13
Cheng, Joshua, '13
Davis, Caitlin, '13
Engelbrecht, Joseph, '13
Garay, Martin, '13
Griffith, Michael, '13
Hallock, Rachel, '13
Lewis, Robert, '13
Mink, Zachary, '13
Porzio, Jeffrey, '13
Viola, Alexander, '13
Wan, Gary, '13
Wong, Ming, '13

James Madison University
Abeel, Jeremy, '13
Christensen, Emil, '13
Corcoran, James, '13
Didomenico, Nathan, '13
Dunnavan, Edwin, '13
Francis, Nicholas, '13
Gilman, Daniel, '13
Glassman, Brent, '13
Hagans, Nicholas, '13
Hoke, Thomas, '13
Isherwood, Bryan, '13
Jarrell, Joshua, '13
Margaret, Maruschak, '13
Mckaig, Denise, '13
Meyer, Jordan, '13

John Carroll University
Carbone, Marc, '13
Washburne, Brian, '13

Johns Hopkins University
Benarroch, Daniel, '13
Crankshaw, Daniel, '13
Firester, Daniel, '13
Hartman, Benjamin, '13
O'Neil, Paul, '13
Stafford, Evan, '13

Juniata College
Carlus, Sarah, '13
Draham, Robert, '13

Juniata College (cont.)
Ginley, Theresa, '13
Healy, Keegan, '13
McGrew, William, '13
Milligan, David, '13

Kansas State University
Bayliff, Kyle, '13
Borthwick, Grant, '13
Doebele, Brandon, '13
Heffernan, Brendan, '13
Houston, Stephen, '13
Jennings, Elizabeth, '13
Pogue, Jeremy, '13
Qin, Yukun, '13
Talley, Samantha, '13
Woodworth, Michael, '13

Kansas, University of
Elliot, Alan, '13
Ford, Alex, '13
Hofmeier, Benjamin, '13
Kunwar, Samridha, '13
Pach, Gregory, '13
Polsley, Alexander, '13
Rush, Wade, '13
Wenderott, Jill, '13

Kent State University
Buida, Thomas, '12
Leishman, Allan, '12
Rees, Aaron, '12
Sage, Tessandra, '12

Kenyon College
Campbell, Neil, '12
Rodriguez, Michael, '12
Schumacher, Benjamin, '12

Kettering University A
Ethington, Jason, '13
Fadul, Andres, '13
Keith, Amy, '13
Kostanecki, Patrick, '13
Nacy, Michael, '13
Neph, Ryan, '13
Nowicki, Tammi, '13
Payne, Macy, '13
Rowe, Logan, '13

Lafayette College
Mcquillen, Ryan, '12
Rusev, Mario, '12

Lawrence Technological University
Boryczko, Duane, '12
Daniels, Ryan, '12
Lobiado, Anthony, '13
MacLennan, Jamie, '12
Quinlan, Jeremy, '13

Lebanon Valley College
Durofchalk, Nicholas, '13
Hoover, Anthony, '13
Jacobeen, Shane, '13
Krechel, Hana, '13
Suprock, Andrew, '13
Wilson, Christy, '13

Lehman College-CUNY
Birrittella, Richard, '13
Davis, Mark, '13
Gura, Anna, '13
Lancuna, Nayra, '13

Lewis University
De Waard, Elizabeth, '13

Lincoln University
Campbell, Kasey, '13
Richardson, Carl, '13

Longwood College
Bagbey, Tyler, '13
Carr, Nicholas, '13
Hegedus, Paul, '13
Josemans, Garrett, '13
Roy, William, '13
Shiminski, Keith, '13

Louisiana St University-Baton Rouge
Antony, Andrew, '12
Brignac, Chase, '12
Broekhoven, Bethany, '12
Clesi, Laura, '12
Dagenhardt, Julie, '12
Ferriss, Mia, '12
Gardiner, Hannah, '13
Gossen, Lauren, '12
Kudla, Stephen, '12
Mendez, Joshua, '12
Morrison, Martial, '12
Morvant, Sarah, '13
Myers, Corey, '13
Myers, Donovan, '12
Sabottke, Carl, '12
Stacy, John, '13
Taylor, Joel, '12
Tobin, Gregory, '12
Watson, Christopher, '13

Loyola Marymount University
Burstein, Zily, '13
Osorno, Kevin, '13
Sblendorio, Dante, '13

Loyola University Maryland
Drexel, Matthew, '12
Kalmanovich, Yevgeniy, '12
Kara, Danielle, '12
Saad, Alexandra, '13
Seltzer, Kevin, '13
Wisniewski, Stefan, '12

Loyola University, New Orleans
Alexander, Douglas, '13
Lindberg, Dustin, '13
Mayes, Riley, '13
Mccormick, Cameron, '13
Reynolds, Emily, '13

Luther College
Grado, Logan, '13
Hemstad, Sean, '13
Novak, Joseph, '13
Rustad, Jenny, '13
Smith, Austen, '13

Lycoming College
Kenward, David, '12
Modica, Taylor, '12
Rhodes, Samuel, '12

Lynchburg College
Ramsey, Brian, '13
Stone, Samantha, '13
Yazdanpanah, Korosh, '13

Maine, University of
Beauchemin, Michelle, '13
Brackett, Shawn, '13
Brassard, Richard, '13
Carfagno, Henry, '13
Lawson, Stuart, '13
Lilieholm, Barbara, '13
Lilieholm, Jennifer, '13
Maurice, Gregory, '13
Parenteau, Alexander, '13
Stewart, David, '13

Manchester College
Taylor, Kaitlyn, '13
Wyatt, Marcus, '13

Marietta College
Carpenter, Laura, '13
Jing, Yang, '13
Su, Lin, '13
Turnewitsch, Vance, '13

Marquette University
Budelier, Melissa, '13
Meinerz, Kelsey, '13
Nugraha, Leo, '13
Rank, Gavin, '13
Selner, Alex, '13
Vogeler-Wunsch, Jesse, '13
Wu, Wei, '13

Mary Baldwin College
Beil, Randi, '13
Jin, Jennifer, '13
Lacy, Benjamin, '13
Mcaden, Grace, '13
Nguyen, Tyler, '13

Maryland-Baltimore City, University of
Pillsbury, Timothy, '13

Massachusetts College
Daniels, David, '13

Massachusetts Institute of Technology
Changala, P. Bryan, '13
Fremont, Daniel, '13
Hynes, Zachary, '13
Kuntz, Lauren, '13
Lang, Kevin, '13
Liew, Vincent, '13
Lin, Qian, '13
Long, Gabriel, '13
Nair, Nityan, '13
Ngan, Alberta Nim Ying, '13
Pasterski, Sabrina Gonzalez, '13
Pate, Monica, '13
Pearce, Michael, '13
Robert, Nathan, '13
Santorella, Elizabeth, '13
Schuch, Christopher, '13
Skirlo, Scott, '13
Tallapragada, Narendra, '13
Williams, Logan, '13
Zahedy, Fakhri, '13
Zhu, Jonathan, '13

Massachusetts-Lowell, University of
Campbell, David, '13
Catalano, Paul, '12
Choi, Aelee, '13
Fingerman, Samuel, '12
Natti, Elias, '12
Puckett, Robert, '13
Reeves, Tina, '13
Shaffery, Peter, '13
Verras, Andrew, '13
Wetherbee, Ryan, '12

McDaniel College
Blohm, Leigh, '13
Mayonado, Gina, '13
Phan, Huy, '13
Ruth, David, '13

McMurry University
Ross, Arthur, '12

Memphis, The University of
Del Conte, Devan, '13
Edwards, Kyle, '13
Goering, Kevin, '13
Greenhill, Christian, '13
Kirby, Krystal, '13

Memphis, The University of (cont.)
Lee, Stephen, '13
Levine, David, '13
Robbins, Justin, '13
Roberson, Matthew, '13
Shiver, Charissa, '13
Wilson, Ryan, '13

Miami University
Harp, Thomas Wesley, '13
Kaine, Joshua, '13
Nguemaha, Valery, '13
Rogers, Robert, '13

Michigan Technological University
Jacobson, Darcy, '13
Makoutz, Emily, '13
Nicklas, Brent, '13

Michigan-Ann Arbor, University of
Anderson, Neal, '13
Bonachera Martin, Isabel Maria, '13
Burkhardt, Andrew, '13
Carney, Sean, '13
Caruso, James, '13
Chappell, Samantha, '13
Doyle, Timothy, '13
Gordon, Kyle, '13
Hemmeter, Mary, '13
Hughes, Tyler, '13
Morningstar, Warren, '13
Murskyj, Mykola, '13
Roloff, Jennifer, '13
Rombes, Nicholas, '13
Sandler, Brett, '13
Smolkin, Daniel, '13
Swiger, Brian, '13
Tan, Shi Jie Sejay, '13
Wagner, Nico, '13

Michigan-Flint, University of
Frye, Benjamin, '13
Ghosh, Ayana, '13
Holbeck, Nathan, '13
Nguyen, Trang, '13

Middle Tennessee State University
Murphy, Robert, '13
Rigsby, Lauren, '13
Saad, Beshoi, '13
Schwartz, Peter, '13
Surles, Scott, '13

Millersville University
Geiger, Sarah, '12
Gochnauer, Daniel, '12
Heldt, Karl, '12
Long, Daniel, '13
Luckenbill, Brian, '13
Miller, Kevin, '13
Piaskowski, Kevin, '13
Waegel, Graham, '13

Minnesota State University-Moorhead
Johnson, Hollee, '13
Lane, Tyler, '13
Rydeen, Thomas, '13

Moravian College
Benson, Andrew, '12
Dragovich, Matthew, '12

Morehouse College
Alemayehu, Michael, '13
Alexander, Anton, '13
Bak, Aakhut, '12

Morehouse College (cont.)
Connor, David, '12
Gresham, Frederick, '12
Hill, Cedric, '13
Hines, Nicholas, '12
Jones, Marcus, '13
Llewellyn, Roy, '13
Mann, Joshua, '13
Mure, Jerrell, '13
Peterson, Andrew, '12
Red, Eddie, '12
Rose, Issac, '13
Welch, Cavanaugh, '12
White, Terrance, '12

Mount Holyoke College
Freese, Jessica, '13
Mcnamara, Alena, '13
Mudzi, Rudo, '13
Shrestha, Pawana, '13
Stevens, Margaret, '13
Tansey, Emily, '13
Tengdin, Phoebe, '13

Muhlenberg College
Crossette, Nathan, '13
Schweid, Benjamin, '13

Murray State University
Dankwa, Afua, '13
Garcia, Kristen, '13
Gwak, Mi Gyeong, '13
Ragsdale, Zachary, '13
Shelton, Kevin, '13
Stevenson, James, '13
Turley, Benjamin, '13
Werfel, Thomas, '13

National University of Singapore
Chin, Yue Sum, '13
Foo, Fang Fang, '13
Li, Jiang, '13
Li, Shiying, '13
Looi, Khai Chern, '13
Marcellina, Elizabeth, '13
Neo, Zhong Hao, '13
Ng, Joseph, '13
Ng, Kah Fee, '13
Ong, Zongjin, '13
Seah, Shannon, '13
Setianegara, Jufri, '13
Tan, Boon Hon, '13
Tan, Wei Hou, '13
Wang, Wei Yang, '13
Wong, Wei Juan, '13

Nebraska Wesleyan University
Haefele, Carey, '13
Hawekotte, Keenan, '13
Taute, Brock, '13

New Mexico Institute of Mining & Technology
Arrasmith, Andrew, '13
Lawrence, Zachary, '13
Mccoy, Isabel, '13
Rochelle, Samuel, '13
Rosero, Viviana, '13

New Mexico State University
Abrahamson, Sean, '13
Blanchette, Alexander, '13
Buck, Franco, '13
Hanson, James, '13
Livingston, Daniel, '13
Medina, Amber, '13
Rodriguez, Cesar, '13
Trujillo, Dennis, '13
Zhang, Yicheng, '13

New York University
Bhandari, Misha, '13
Gertler, Jeffrey, '13
Gollwitzer, Jakob, '13
Marshall, Benjamin, '13
Seara, Daniel, '13

North Carolina State University
Alvord, Megan, '13
Berry, Sara, '13
Kolb, Christopher, '13
O'Mara, Ryan, '13
Royse, Camen, '13
Stanfield, Zachary, '13
Vail, Alexandria, '13

North Carolina-Asheville, University of
Stagg, Logan, '13
Ziemba, Zachary, '13

North Carolina-Charlotte, University of
Babaie, Galareh, '12
Cappelletti, John, '13
De Los Santos, Darwin, '12
Farmer, Jennifer, '12
Franchi-Alfaro, Emmanuel, '13
Fullager, Daniel, '12
Giglio, Nicholas, '12
Godfrey, Daniel, '13
Harris, Anthony, '12
Herring, Charles, '12
Hoffman, Bryan, '13
Hurwitz, Elisa, '13
Karami, Morteza, '12
Kucukgok, Bahadir, '13
Moore, Raymond, '12
Riznyk, Raymond, '13
Savage, Luke, '12
Sheng, Tao, '13
Singer, Christopher, '12
Smith, Krista, '13
Yoder, Christopher, '13

North Carolina-Wilmington, University of
Bowman, Kyle, '13
Grimes, Derek, '13
McGee, Laura, '13
Mcneel, Tamara, '13
St. Laurent, Benjamin, '13

Northern Arizona University
Blackman, Ryan, '13
Garlant, Angel, '13
Hamm, Deborah, '13
Hayes, Rebecca, '13
Kelow, Simon, '13
Kinser, Rebeca, '13
Kutsop, Nicholas, '13
Lass, Katherine, '13
Maughan, Weston, '13
Monahan, Ryan, '13
South, Ryan, '13
Thomason, Carver, '13
Ulibarri, Zachary, '13

Northern Iowa, University of
Ahsan, Madiha, '13
Beck, Ben, '13
Cooling, Corey, '13
Danielsen, Stephen, '13
Dieken, Sarah, '12
Folken, Andrew , '13
Frost, Josh, '13
Griffith, Zach, '12
Mellenger, Corbyn, '13
Meyer, Jeremy, '12
Poellet, Shawn, '12
Skjordal, Amy, '12
Smith, Logan, '12
Zingler, Amber, '12

Northwest Nazarene University
Larson, Chad, '13
Patrick, Weston, '13

Northwestern University
Abramov, Dan, '13
Anthony, Gregory, '13
Boffi, Nicholas, '13
Charles, Noah, '13
Douglas, Daniel, '13
Godek, Benjamin, '13
Isaman, Leah, '13
Kernes, Jonathan, '13
Lassman, William, '13
Psitos, Michael, '13
Rehak, Tyler, '13
Shekhtman, Louis, '13
Spiegel, Adam, '13
Thomas, Daniel, '13

Occidental College
Coleman, Jacob, '13
Curran, Sean, '13
Osha, Quinn, '13
Price, Rachel, '13

Ohio Northern University
Bui, Albert, '13
Christman, Ryan, '13
Steinberger, Thomas, '13

Ohio State University
Alvarez, Alec, '13
Angra, Justin, '13
Bennett, Jared, '13
Can, Adam, '13
Erjavec, Tyler, '13
Hanna, Randall, '13
Ivancic, Robert, '13
Mulac, Marisa, '13
Patton, Robert, '13
Weisman, Amy, '13
Zeleznik, Natalie, '13

Ohio University
Cothrel, Helen, '13
Thrush, Samantha, '13

Ohio Wesleyan University
Chaffee, Nathan, '13
Deangelis, Cara, '13
Elder, Robert, '13
Scotten, Richard, '13
Shen, Da, '13
Telepak, Stephen, '13

Old Dominion University
Averill, Sean , '13
Berl, Seth, '13
Deslandes, Canniggia, '13
Hedges, Dawn, '13
Ingram, Eric, '13
Naginey, Timothy, '13
Newton, Joseph, '13
Schwalm, Connor, '13
Sheil, James, '13
Sukenik, Charles, '13
Wooten, Christian, '13

Pennsylvania State University, Erie
Dominick, Corey, '13
Steel, Fiona, '13

Pennsylvania State University
Abercrombie, Daniel, '13
Chesakis, Ryan, '13
Contreras, Crispin, '13
Dimenichi, Christopher, '13
Groh, John, '13
Hohman, Peter, '13
Hopper, David, '13

Pennsylvania State University (cont.)
Kim, Chansam , '13
Marino, Kristin, '13
Marshall, Jared, '13
Mathes, Gavin, '13
Mccauley, Thomas, '13
Mccullian, Brendan, '13
Noble, Joshua , '13
Potter, Kathryn, '13
Riebling, Jedidiah , '13
Snyder, Zachary, '13
Soldner, Andrew, '13
Stanisha, Nick, '13
Wahi-Anwar, Muhammad, '13

Pittsburgh, University of
Chafi, Hatim, '12
Cohen, Jesse, '13
Elharake, Maher, '12
Howard, Bruce, '12
Hua, Nelson, '12
McPartland, Connor, '13
Rosenberg, Matthew, '13
Stringer, Carsen, '12
Telford, Olivia, '13
Vannucci, Jonathan, '12
Vincent, Chelsea, '12
Weis, Andrew, '12
Yates, Daniel, '13

Portland State University
Gheen, Angelica, '13
Pak, Kai, '13

Presbyterian College
Davidson, Taylor, '13

Providence College
Burg, Allison, '13
Furney, Leah, '13
Motta, Taylor, '13
Parker, Jessica, '13
Provance, Brett, '13

Puget Sound, University of
Diener, Joseph, '13
Kim, Eudeum, '13
Sweedo, Alice, '13

Radford University
Andis, Andrew, '13
Frazier, Alec, '13
Hefta, Jon, '13
Montgomery, Sarah, '13
Uthe, Brian, '13

Ramapo College of New Jersey
Carr, Michael , '12
Ferencevych, Peter, '12
Knorr, Brian, '12
Wolfinger, Max, '12

Randolph-Macon College
Castillo, Henry, '13
Dulaney, Madison, '13
Sandford, Corin, '13
Sullivan, David, '13

Rensselaer Polytechnic Institute
Buck, Alexander, '13
Chen, Liang, '13
Cunningham, William, '13
Delarme, Emily, '13
Ebinger, Calvin, '13
Lamson, Adam, '13
Leedom, Jacob, '13
Makowski, Bryan, '13
Mcavoy, Ryan, '13
Monti, Joseph, '13
Plunkett, Evan, '13
Rice, Colin, '13
Roussel, Ryan, '13

Rensselaer Polytechnic Institute (cont.)
Spartz, Jennifer, '13
Ulin, Steven, '13
Van Bebber, James, '13
Wang, Qi, '13

Rice University
Sarkar, Tapash, '13
Sen, Onkur, '13
Swift, Michael, '13
Taylor, Jeffrey, '13
White, Christopher, '13
Zha, Gaomi, '13

Richard Stockton College of NJ
Bland, Jared, '13
Fralinger, Erin, '13
Jenkins, Kelly, '13
Malatino, Frank, '13
Mirza, Arhum, '13
Prajapati, Nikunj, '13
Pruchnicki, Steven, '13
Siteman, Dan, '13
Yarbrough, Daniel, '13

Richmond, University of
Achey, Alexis, '13
Harrison, Andrew, '13

Ripon College
Aung, Nyi Nyi, '12
Haefner, Adam, '12
Hagen, Skyler, '13
Knowles, Tyler, '13
Plantz, Cameron, '13
Schumacher, Brian, '13
Taylor, Brandon, '12
Weiss, Nicholas, '13

Roberts Wesleyan College
Anderson, Kelly, '13
Birch, Casey, '13
Cornell, Alexander, '13
Dearstyne, Matthew, '13
Dempster, Kyle, '13
Holdridge, Nathan, '13
Lawrence, Benjamin, '13
Lee, Joseph, '13
Maloney, Christopher, '13
O'Connor, Kayla, '13
Sowinski, Alexander, '13
Stefanini, Thomas, '13
Van Dyne, Aaron, '13

Rochester Inst of Technology
Beach, Matthew, '13
Butcher, Julian, '13
Canchola Fenochio, Brian, '13
Cawley, Nathan, '13
Hensley, Alexander, '13

Rochester, University of
Challener, Ryan, '13
Heuer, Peter, '13
Koch, Ingrid, '13
Lewalle, Philippe, '13
Saldan, Adriana, '13
Sharma, Saurav, '13
Sims, Robert, '13
Skeehan, Dillon, '13
Wu, Fan, '13
Zizzi, Nicole, '13

Saint Mary's College of Maryland
Baker, Seth, '12
Gilfrich, Christine, '12
Kwolek, Jonathan, '12
Raico, Pasquale, '12
Stine, Justin, '12
Warburton, Michael, '12

Saint Peter's College
Block, Sean, '13
Bodden, Alberto, '13
Niraula, Prajwal, '13

Saint Vincent College
Allman, Benjamin, '13
Cline, Samuel, '13
Sauk, Thomas, '13
Shearer, Eric, '13
Warburton, Adam, '13

Santa Clara University
Gemmell, Connor, '13
Hall, Charles, '13
Isaac, Justin, '13
Johnson, V, '13
Kittlaus, Eric, '13
Kreikebaum, John Mark, '13
Mattia, Kassandra, '13
Waight, Christopher, '13

Scranton, University of
Blanco, Joshua, '13
Checefsky, Walter, '13
Frisbie, Dustin, '13
Javitz, Joshua, '13
Pearson, Paul, '13
Salmon, Rachel, '13
Schlasta, Daniel, '13
Trischetta, Michael, '13
Wong, Ardy, '13

Seattle University
Brasseale, Elizabeth, '12
Goertz, John, '12
Graveson, Todd Justin, '12
Hankins, Andrew, '12
Rackson, Charles, '12

Seton Hall University
Manners, William, '13
Reehil, Christopher, '13
Sydlo, Ashley, '13

Shippensburg University
Barber, Kevin, '12
Kirby, Laura, '12
Miller, Ryan, '12
Salasin, John, '12
Scott, Joshua, '12
Yang, Bruce, '12

Siena College
Endres, Alyssa , '13
Gilbert, John, '13
Girard, Julian, '13
Lamountain, Gary, '13
Muenkel, Jessica, '13
Nealon, Kelly, '13
Parkhurst, Collin, '13

Simpson College
Berger, Heidi, '13
Collins, Laura, '13
Dwenger, Marc, '13
Heise, Robert, '13
Henry, Michael, '13
Kirchner, Luke, '13
Kolln, Werner, '13
Lyons, Derek, '13
Stockdale, Taylor, '13
Woods, Austin, '13

Skidmore College
Bannon, Andrew, '13
Ellis, Katrina, '13
Fowler, Terence, '13
Jo, Samuel , '13
Richards, Sophie, '13
Searles, Pauline, '13
Wolfe, Pierre-Francois, '13

South Dakota State University
Lim, Hyun, '13
Nehlich, Dan, '13
Nelson, Austin, '13

South, University of the
Brudvig, Abigail , '13
Murphree, Victoria, '13
Odom, Frank, '13
Shirimpaka, Jean, '13

Southeast Missouri State University
Kelly, Dean, '13
Meyer, James, '13
Rhodes, Michael, '13
Seyer, Richard, '13
Westbrook, Jonathan, '13

Southern Mississippi, University of
Bloor, Erica, '13
Gautrau, Sidney, '13
Jones, Brenton, '13
Kirkup, Steven, '13
Willoughby, Alyece, '13

Southern Nazarene University
Adams, Nathan, '13
West, Johnnie, '13

Southwestern Oklahoma St University
Fields, Amy, '13
Frizzell, Dylan, '13
Kraft, Luke, '13

St Bonaventure University
Harner, Mary, '12
Winger, Daniel, '13

St. John's University-NY
Ahmed, Awais, '13
Kunkel, George, '13
Rahman, Taraqur, '13
Ramlall, Tariq, '13
Singh, Kimberly, '13
Thomas, Robert, '13

St. Lawrence University
Buxton, Katherine, '13
Gay, Christina, '13
Kane, Brian, '13
Keller, Matthew, '13
Reed, Luke, '13
Ullah, Quazi, '13

St. Mary's College of Minnesota
Baertlein, Luke, '12

St. Olaf College
Brown, Jared, '13
Christian, John, '13
Cox, Nathanael, '13
Dalla Santa, Kevin, '13
Gobel, Rebecca, '13
Hall, Christian, '13
Hemingway, Emily, '13
Massey, William, '13
Mellem, Stefen, '13
Moravec, Emily, '13
Nygren, Katherine, '13
Roth, Leah, '13
Trettel, Keven, '13
Weiss, Lora, '13
Yanckello, Michael, '13
Yuan, Ye, '13

Stephen F Austin State University
Anderson, Lucas, '13
Drake, Kyle, '13
Parker, Timothy, '13

Stevens Institute of Technology
Capone, Aaron, '13
Corrado, Matthew, '13
Noga, Nicholas, '13
Parker, Kimberly, '13

SUNY at Albany
Richards, Ryan, '13
Shapiro, Seth, '13
Spaulding, Jared, '13

SUNY at Binghamton
Clark, Daniel, '13
Harrison, Connor, '13
Jin, Xi, '13
Quackenbush, Nicholas, '13
Song, Fangfang, '13

SUNY at Brockport
Conine, Kyle, '13

SUNY at Fredonia
Pagano, Joseph, '13

SUNY at Geneseo
Barber, Kirstin, '12
Ceriello, Joseph, '12
Clark, Michael, '12
Coon, Matthew, '12
Dodge, Kenneth, '12
Eisinger, Michael, '12
Ellison, Drew, '12
Ford, Ryan, '12
Gearhart, Sara, '12
Giordano, Michael, '12
Gullo, Katherine, '12
Hall, Matthew, '12
Kinney, John, '12
O'Shea, Martin, '12
Palermo, Gregory, '12
Paolucci, Angela, '12
Reisch, Justin, '12
Russ, Megan, '12
Ryan, Megan, '12
Schultz, Isaac, '12
Steidle, Jeffrey, '12
Wing, Anthony, '12
Wirth, Jacob, '12

SUNY at Plattsburgh
Betthauser, Tobey, '12
Bushey, Cody, '13
Danforth, Jordyn, '13
DeCosta, Richard, '12
Marshall, George, '12
Schultz, Ben, '12
Stowe, Dan, '13

SUNY at Stony Brook
Carvalho, Wilka , '13
Chiraz, Timothy , '12
Chonigman, Benjamin, '12
Crowe, Sean, '13
Dotsenko, Andriy, '12
Dragan, James, '13
Etkin, Michael, '13
Evans, Stefan, '13
Garger, Alexander, '13
Gavarian, Gregory, '13
Hassinger, Julian , '12
Hicks, Shannon, '12
Kaushik, Rohit, '13
Kim, Jae Hong, '12
Kim, Junho, '12
Kubo, Takashi, '12
Kulinich, Yakov, '12
Li, Keren, '12
Lu, Hong Wen, '12
Lunden, William, '12
Macker, Wesley , '13
Martorano, Anthony, '13

SUNY at Stony Brook (cont.)
Meltzer, David , '12
Miah, Forid, '13
Mittiga, Thomas, '12
Mujeeb, Umer, '13
Nafis, Daniel, '13
Nevola, Daniel , '13
O'Neill, Sean, '13
Orvedahl, Ryan, '12
Puri, Akshat, '13
Ross, Austin , '12
Rusch, Christopher, '12
Sackel, Kevin , '12
Sage, Alexander, '13
Salerno, Michael , '13
Schweitzer, Deran, '13
Segal, Carrie, '13
Shelton, Siddhartha, '12
Tan, Lizhen, '12
Wysk, Joseph , '13
Yakimenko, Evgeny, '12
Zvezdzin, Anton, '12

Tennessee Technological University
Eller, Micah, '13
Johnson, Travis, '13

Tennessee-Knoxville, University of
Hoskin, Logan, '13
Luttrell, Nickolas, '13
Prince, Richard, '13
Weitering, Hanneke, '13

Texas A&M University-Commerce
Dahir, Andrew, '13
Mendoza, Carlos, '13
Newton, William, '13
Stahl, Jacob, '13
Williams, Kurtis, '13
Zimmerman, Jessica, '13

Texas Lutheran University
Kanas, Derek, '13
Mittelstadt, Matthew, '13

Texas State University
Beuhler, Gregory, '13
Blair, James, '13
Chalupa, Adam, '13
Charles, Thomas, '12
Mcalmon, Robert, '13
Miracle, John, '13
Schiber, Catherine, '13
Welch, Eric, '13

Texas Tech University
Baykal, Eda, '13
Bebek, Bahadir, '13
Caglar, Umut, '13
Clark, Jonathan, '13
Contos-Heidrich, Jake, '13
Fielder, Catherine, '13
Halverson, Tom, '13
Hart, Jonathan, '13
Hassan-Zadeh, Ebrahim, '13
Karaoglan, Gulten, '13
Libeiro, Terence, '13
Nazari, Mohammad, '13
O'Loughlin, Trevor , '13
Pattillo, David, '13
Qiu, Liming, '13
Silva, Carlos, '13
Sohal, Sandeep, '13
Stam, Henry, '13
Streseman, Matthew, '13

Texas-Arlington, University of
Castillo, Erica, '13
Deng, Yue, '13
Hoffman, Timothy, '13
Nguyen, Phu, '13
Sterrett, Jaime, '13
Tejeda, Hector, '13

Texas-Austin, University of
Baker, Robert, '13
Berdanier, William, '13
Brittain, Randy, '13
Chan, Megan, '13
Crowley, Joseph, '13
Davis, Douglas, '13
Hathaway, Arjuna, '13
Koeller, Jason, '13
Loftin, Johnathon, '13
Morrison, Tharon, '13
North, Caleb, '13
Ott, Evan, '13
Reinhart, Alexander, '13
Stein, Miquela, '13
Wilhelm, Alex, '13

Texas-San Antonio, University of
Catala, Alexis, '13
Hall, Zacharie, '13
Kim, Howard, '13
Packham, Christopher, '13
Rhoads, Lawrence, '13
Salinas, Reginald, '13

The College of New Jersey
Billmers, Harrison, '13
Calafut, Victoria, '13
Chiusano, Jeffrey, '13
Dilorenzo, Paolo, '13
Erickson, Nicholas, '13
Fuller, Margaret, '13
Mcloughlin, Michael, '13
McSweeney, Robert, '13
Nowak, Dawid, '13
Oliff, Zachary, '13
Revalski, Mitchell, '13
Rhodes, Will, '13
Ryan, Kerry, '13
Santisi, Anthony, '13
Spector, Kayla, '13

Thomas More College
Broering, Mark, '12
Muse, Brian, '12

Toledo, University of
Galang, Abril, '13
Kinder, David, '13
Mulia, Alexander, '13
Safron, Emily, '13
Togi, Aditya, '13

Towson University
Adams, Todd, '13
Bates, Evan, '13
Ermer, Henry, '13
Hughes, David, '13
Keshavarz, Camron, '13
Lahneman, David, '13
Rainey, Lisa, '13
Thompson, Zachary, '13
Tyler, Joshua, '13
Warecki, Zoey, '13
Yost, Bradley, '13

Trinity College
Quinonez, Erik, '13
Morales Urrutia, Juan, '13

Truman State University
Liegey, Lauren, '13
Maxwell, Katherine, '13
Wetzel, Casey, '13

Union College
Aprelev, Pavel, '13
Collison, Sean, '13
Linthicum, Will, '13
Margulies, Adam, '13
Miceli, Michael, '13
Parkash, Vaishali, '13
Smith, Jeremy, '13
Turley, Colin, '13
Viani, Lucas, '13
Wong, Christine, '13
Zhao, Xuanhan, '13

United States Military Academy
Adams, Grant, '13
Arnold, Frank, '13
Burton, Levon, '13
Eid, Mazen, '13
Eliasen, Nathaniel, '13
Martin, Austin, '13
Moores, Geoffrey, '13
Rauenzahn, Tyler, '13
Rollings, Nathaniel, '13
Scales, Austine, '13
West, Derek, '13

United States Naval Academy
Gorinski, Laura, '13
Kelly, James, '12

University of Missouri Columbia
Blessing, Christopher, '12
Hosmer, Laura, '12
Johnson, Colby, '12
Mills, Bradley, '12
Moghe, Dhanashree, '12
Rezaei Matin, Tina, '12
St John, Alexander, '12
Van Hoesen, Daniel, '12

University of Notre Dame
Hughes, Shannon, '13
Kelly, Kevin, '13
Lannon, Kevin, '13
Mcdermott, Kevin, '13
Mcintyre, Patrick, '13
Moser, Bailey, '13
Nguyen, Vu, '13
O'Brien, Timothy, '13
Sevova, Stanislava, '13
Summa, Branden, '13
Tang, Xiao-Dong, '13
Williams, Amanda, '13
Zeng, Jianchun, '13

Utah State University
Andersen, Allen, '13
Bunn, Catharine, '13
Christensen, Justin, '13
Ellis, John, '13
Griffin, David, '13
Lewis, Maggie, '13
Nydegger, Rachel, '13
Peterson, Kelby, '13
Pound, Benjamin, '13
Rawlins, Wesley, '13
Ryan, Carlsen, '13
Sainz, James, '13
Shreeve, Samuel, '13
Work, Carston, '13

Valdosta State University
Fuzia, Brittany, '13

Valparaiso University
Beckmeyer, Erin, '12
Cheek, Wesley, '12
Kutz, Kayla, '12
Miller, Kevin, '12

Vanderbilt University
Eads, Patrick, '13
Kulpins, Ryan, '13
Musher, David, '13
Pelaschier, Isabelle, '13
Rolen, Emily, '13
Scher, Eliot, '13
Stewart, Cameron, '13
Thomas, Colin, '13
Turok, Rebecca, '13
Twedell, Christopher, '13

Vermont, University of
Allman, Daniel, '13
Dimario, Matthew, '13
Feeley, Matthew, '13
Heath, Joshuah, '13
Van Seters, Cole, '13

Villanova University
Abdul-Masih, Michael, '13
Bachmakov, Eduard, '13
Chiciak, Adam, '13
Evans, Michael, '13
Ferguson, Joseph, '13
Fry, Mandi, '13
Fuller, Robert, '13
Georghiou, Phillip, '13
Hawkins, Ken, '13
Horgan, Colin, '13
Johnston, Cole, '13
Leahy, Ian, '13
Marion, Anna, '13
Michener, Scott, '13
More, Joseph, '13
Nelson, Kristopher, '13
Pollichemi, Joseph, '13
Smolinski, Katharine, '13
Vogel, William, '13
Watson, William, '13
Wong, Tsz-Him, '13
Xhori, Paul, '13
Yun, Samuel, '13

Virginia Commonwealth University
Abreu, Marissa, '13
Alrashid, Ebtihaj, '13
Angevine, Christopher, '13
Ashley, Zack, '13
Brady, Kyle, '13
Brown, William, '13
Carlson, Thomas, '13
Chavis, Amy, '13
Child, Brandon, '13
Diallo, Ibrahima, '13
Earles, Bryan, '13
Hafiz, Shopan, '13
Howe, Garrett, '13
Joseph, Augustin, '13
Khammang, Alex, '13
King, Nicholas, '13
Kradi, Ahmed, '13
Lazea, Alexandru, '13
Marsh, Jonathan, '13
Oliver, William, '13
Pedicini, Anthony, '13
Phillips, Jason, '13
Phumisithikul, Karen, '13
Rich, Bobby, '13
Roberts, David, '13
Selden, Tyler, '13
Shaw, James, '13
Smither, Paul, '13
Sundberg, Sean, '13
Taylor, Duane, '13
Tippie, Jonathan, '13
White, Lauren, '13
Wray, John, '13

Virginia Military Institute
Lawrence, William, '13
Liu, Minghanbo, '13
Pineiro, Aurelio, '13
Tseng, Ching-Hung, '13

Virginia Tech
Brown, Mark, '13
Eltahir, Amnah, '13
Fenstermaker, Daniel, '13
Forster, Adrion, '13
Harter, David, '13
Kim, Daniel, '13
Lange, Garrett, '13
Mills, Adam, '13
Rahmani, Arash, '13
Tauscher, Keith, '13
Walters, Jackson, '13
Warnock, Michael, '13

Virginia, University of
Brody, Alan Vincent, '13
Henderson, Alyssa May, '13
Ho, Chung Yau Elton, '13
Levin, Zachary Ryan, '13
Lin, Siqi, '13
Mclaughlin, Chatham David, '13
Panichpibool, Poon, '13
Rodgers, Amy Helen, '13
Sharma Rijal, Ashutosh, '13
Trung, Huy-Duc, '13
Wang, Qichen, '13
Yanchenko, Anna, '13

Wake Forest University
Backerman, Grant, '13
Carlson, Rowland, '13
Diemer, Peter, '13
Einhorn, John, '13
Fogel, Derek, '13
Guy, Emily, '13
Mccarthy, Michael, '13
Obaid, Abdulmalik, '13
Payne, Margaret, '13
Shoemaker, Brian, '13
Soliman, Karim, '13
Story, William, '13
Thompson, William, '13
Zinchuk, Cameron, '13

Wartburg College
Sprain, Kyle, '13

Washington and Jefferson College
Gallegos, Armando, '12
Hansen, Casey, '12
Kern, Riley, '12
Leavor, Sean, '13
Pochiba, Zachary, '13
Rodriguez, Kate, '12
Tyra, Eric, '13

Washington University Saint Louis
Goldfinger, David, '13
Lynch, Brian, '13
Miller, Derek, '13
Ong, Wei Jia, '13
Stavig, Alissa, '13
Tenzer, Ari, '13
Witte, Samuel, '13

Washington, University of
Coy, Jim, '13
Dijulio, Ross, '13
Fryett, Taylor, '13
Harvey, Sarah, '13
Kim, Yujung, '13
Lynch, Connor, '13
Nguyen, Paul, '13

Washington, University of (cont.)
Picard, Julian, '13
Quan, Wei, '13
Ransom, Eliot, '13
Schmitz, Denise, '13
Sivitilli, Alexander, '13

West Chester University
Frost, Desmond, '13
Frost, Gavin, '13
Heintz, Jonathan, '13
Kandalam, Anil, '13
Kneebone, Curran, '13
Knight, Ryan, '13
Lawton, Jacob, '13
Lechner, Eric, '13
Legall, Nicolas, '13
Massaro, Christopher , '13
Petrucci, Anna, '13
Pfeil, Shawn, '13
Sawyer, William, '13
Sheriff, Brett, '13
Van Mol, Kurt, '13

Western Illinois University
Halbe, Daniel, '13
Kim, Hyung Kwan, '13
Olorunsola, Oluwatobi , '13
Olumoroti, Akinloluwa, '13
Onaghise, Andrew , '13
Patel, Kinnary , '13
Patel, Yogeshabi, '13
Quadri, Adetola, '13
Saeedi, Ahmad, '13
Woodworth, Timothy , '13

Western Kentucky University
Gaulle, Owen, '13
Hall, Jessica, '13
Morrow, Courtney, '13
Yadon, Jamey, '13

Westminster College
Mauri, Sarah, '13
Mellon, Samuel, '13
Rogers, Jonathan, '13
Waszyn, Sarah, '13

Wheaton College
Cartolano, Melinda, '13
Poelarends, Arend Jan, '13
Whitney, Heather, '13

Whittier College
Barna, Patrick, '13
Cook, Jon-Paul, '13
Duan, Lingxiao, '13
Kleponis, Nathan, '13
Luna, Alberto, '13
Nicassio, Austin, '13
Romberger, Wesley, '13
Silva, Aaron, '13

Widener University
Kindt, John, '13
Kosteski, Alysa, '13
Nodolski, Nathan, '13
Pagano, Glenn, '13
Weber, Alexander, '13

William Jewell College
Conner, Joshua, '13
Dice, Bradley, '13
Giannetti, Shane, '12
Hazelrigg, Conner, '13
Heflin, Patrick, '13
Lampe, Samantha, '12
Pollpeter, Brandon, '12
Taylor, Zachary, '13
Wright, Richard, '13

Wisconsin-Eau Claire, University of
Bowe, Matthew, '13
Gewiss, Adam, '13
Neumann, Mandy, '13
O'Connell, Sean, '13
Pederson, Jacob, '13
Smith, Blake, '13
Truchinski, James, '13
Yeager, Travis, '13
Yohn, Michael, '13

Wisconsin-La Crosse, University of
Camenga, Elizabeth, '13
Ikeyama, Ran, '13
Ji, Qiuzhi, '13
Kubicek, Allison, '13
Mueller, Scott, '13
Nickel, Tyler, '13
Prudhom, Andrew, '13
Vo, Hieu, '13

Wisconsin-Platteville, University of
Dahl, Jacob, '13
Heal, Adam, '13
Martinson, Dena, '13
Morton, Caleb, '13
Rosas, Jose, '13
Sigwarth, Jerry, '13
Smiles, Maria, '13

Wisconsin-River Falls, University of
Chen, Hao, '13
Dirks, Tim, '13
Dvorak, Emily, '13
Hanson, Katrina, '13
Jones, Rory, '13
Mcdonough, Theodore, '13
Miller, Cameron, '13
Puyleart, Andrew, '13
Schweppe, Lauren, '13
Zaske, David, '13

Wittenberg University
Massengale, Jeremy, '13
Simpson, Lisa, '13

Wright State University
Anders, Jason, '13
Branco, Daniela, '13
Camden, Alyxis, '13
Fosnight, Alyssa , '13
Guo, Tianle, '13
Kistler, Michael, '13
Lukawska, Anna, '13

Xavier University
Farwick, Annie , '13
Heath, Jake, '13
Herbert, Donovan , '13
Patton, Daniella, '13

If you were inducted between September 2012 and October 2013 and do not appear in the initiates list, or if your chapter does not appear, please contact the National Office so we can update our records.

Sigma Pi Sigma
E-mail: sps@aip.org
Tel: 301-209-3007

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

Get Involved

A pencil and paper. A rock and a feather. These are some of the simplest tools of the physicist. You probably used them when you were a student: You dropped objects off a tall building, registered the results, repeated the experiment until the data were sufficient, and shared your results—as you learned about the state of physics back then.

ABOVE

Poster presentations at an SPS zone 8 meeting. Photo by Austin Lassell, University of Louisville.

Today, the physics community knows far more about the matter, energy, and forces that make up the universe. And the physicist has an incredibly sophisticated toolbox to work with. Ever since physics went Big Science, larger and larger tools have allowed larger and larger teams to ask new questions and think of new ways to seek answers. Computers now play a central role in physics, and new textbooks contain concepts that were still unverified when you were a student and, in some cases, a completely new view of how the universe works. But students are still going up on top of tall buildings and letting objects fall, doing the hard work of learning for themselves how nature works. The developments in physics that they are learning about reflect the contributions of you and your colleagues, and there is much they can learn from you about participating in the community of scientists.

Sigma Pi Sigma and the Society of Physics Students have more than 500 active chapters across the United States and beyond. Chapter and zone meetings, outreach events, and research experiences are taking place around the clock. All of these activities benefit from the participation and input of alumni. This season, consider reaching out and supporting some students near you:

- **Volunteer to share your story at a local chapter meeting**
- **Host a tour of your workplace for chapters in your area**
- **Help a chapter write and submit an award-winning SPS grant proposal**
- **Donate to the SPS scholarship fund**

The opportunity to connect with students is at your fingertips, literally! Just type www.facebook.com/SPSNational into your browser, or visit twitter.com/SPS_physicsnews or linkedin.com/groups/sigmapisigma to find out what is going on. If social media is not your thing, contact the National Office and we will connect you to your local chapters. We still read mail in paper form (Sigma Pi Sigma – 1 Physics Ellipse – College Park, MD 20740). We also respond to electronic mail (sps@aip.org), we answer the phone (301-209-3007), and we would love to talk with you in person at a meeting. We would be delighted to connect you to current students—and promise that you will be delighted, too!