Radiations

FALL 2026

The official publication of Sigma Pi Sigma



Sigma Pi Sigma at a Turning Point: The Eighth National Convention

Three Hundred Fifty-Four Posters and One New Perspective at SPSCon

Reflections on the Past and Advice for the Future

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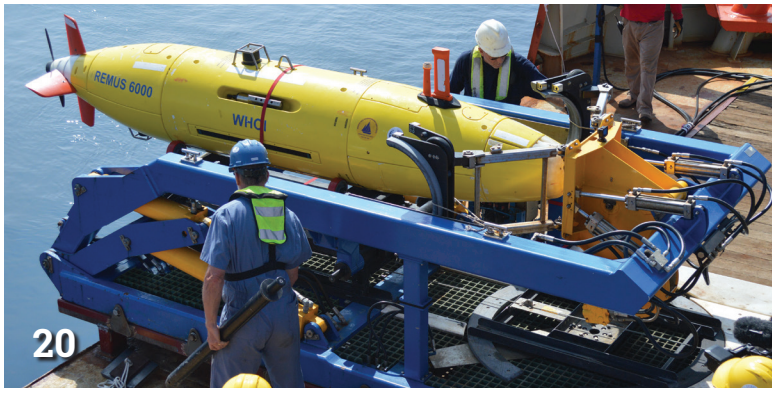
ABOUT THE COVER

The Worth Seagondollar Service Award is bestowed by SPS and Sigma Pi Sigma upon individuals who have demonstrated an exemplary level of commitment and service to the societies. The award was first presented to its namesake, L. Worth Seagondollar, a professor at North Carolina State University and past president of Sigma Pi Sigma, at the 1996 Congress. In June 2026, Brad Conrad became only the 13th person to receive the award. Photo by AIP.









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Discovering SPS and Sigma Pi Sigma:

Reflections from My Time as Director

Erin Lavik, past director of SPS and Sigma Pi Sigma.

by Erin Lavik, Past Director of SPS and Sigma Pi Sigma

Editor's note: Erin Lavik was director of SPS and Sigma Pi Sigma during the spring and summer of 2026.

I have spent my career working with students as a faculty member, an advisor, and an associate dean. Full disclosure—I am an engineer, a materials scientist who started as a physics major but pivoted when a professor suggested the women in his class would be wise to do so. I did not encounter SPS and Sigma Pi Sigma until

Get Support for Inductions and Chapter Activities

Sigma Pi Sigma Chapter Project Awards of up to $600 are awarded to chapters to support inductions or other engaging activities that include alums or promote Sigma Pi Sigma on campus or to the public. Learn more at **students.aip.org/awards**.

I was a faculty member, and I was beyond delighted at how many students talked about the welcoming community. It is truly extraordinary.

In my time in academia, I came to learn that programs in the physical sciences have justifiable pride in teaching students how to think: how to unpack problems and how to solve those problems. Yet there is much more to the work than mastering concepts or solving equations.

We need to understand which problems really matter and how to tackle them when they are deeply involved and often messy. SPS and Sigma Pi Sigma do an excellent job of providing community, support, and leadership opportunities to help students bridge the space from the defined world of the classroom to the complex challenges of the broader world.

In my short time working with SPS students and Sigma Pi Sigma members, I have been humbled at their sense of purpose, their focus, and their awareness of the complexities of the world in which they work and live. I am impressed with their sense of community, caring for each other, willingness to put others first, and passion for championing each other. I am in awe of how students weave these practices into their work and how alumni carry these practices throughout their careers, leading and collaborating and supporting each other.

Perhaps it is not surprising, then, that the Sigma Pi Sigma volunteer community is so willing to help and lead and so capable of doing it with incredible grace and kindness. SPS and Sigma Pi Sigma bridge the gap between the classroom and the world beyond and do so in a way that creates and sustains a community of brilliant, humane leaders, and these leaders, in turn, return to serve.

I am humbled and in awe of all of you. Thank you for the privilege of serving you. •



Erin Lavik (left) joins Earl Blodgett, historian and past interim director, and Brad Conrad, Sigma Pi Sigma president and past director, at the 2026 SPS Executive Committee Meeting. Photo courtesy of SPS.

Be a Resource for SPS Chapters

Join the SPS and Sigma Pi Sigma Alumni Engagement Program—a database of participants willing to be speakers, panelists, tour guides, and mentors for SPS chapters. Visit **students.aip.org/alumni/become-a-mentor**.

AIP

ABOUT AIP

As a 501(c)(3) non-profit, AIP is a federation that advances the success of our Member Societies and an institute that engages in research and analysis to empower positive change in the physical sciences. The mission of AIP (American Institute of Physics) is to advance, promote, and serve the physical sciences for the benefit of humanity.

Member Societies

Acoustical Society of America
American Association of Physicists in Medicine
American Association of Physics Teachers
American Astronomical Society
ACA: The Structural Science Society
American Meteorological Society
American Physical Society
AVS: Science and Technology of Materials, Interfaces, and Processing
Optica
The Society of Rheology

Other Member Organizations

Sigma Pi Sigma
Society of Physics Students

Connect with Sigma Pi Sigma

LinkedIn
linkedin.com/groups/142619

Instagram
instagram.com/spsnational

AIP Foundation
foundation.aip.org

News from the Sigma Pi Sigma Office

Brad Conrad Elected Sigma Pi Sigma President

Sigma Pi Sigma elected a new president this spring: Brad Conrad, former director of SPS and Sigma Pi Sigma. Conrad is the education and workforce development manager in the Office of Advanced Manufacturing at NIST, the National Institute of Standards and Technology.

"Sigma Pi Sigma exists to encourage and amplify people and the future of the field, one student at a time," he wrote in his candidate statement. "It's our responsibility to ensure that Sigma Pi Sigma responds to the needs of the community in 2026 and beyond."

As president, Conrad will focus on working with the American Institute of Physics (AIP) and its partners to:

- Increase research programs, recognition, and internship opportunities for members
- Encourage service projects and programs among Sigma Pi Sigma chapters
- Promote chapter recognition of integrity, high character, and excellence within the field
- Provide networking opportunities for SPS members within the expansive network of Sigma Pi Sigma members

Conrad says he is looking forward to helping chapters meet the needs of their members and preparing to celebrate SPS's 60th anniversary and the next Physics and Astronomy Congress in 2028.

Meet Ashley Cetnar, New SPS Executive Committee At-Large Member



Ashley Cetnar is an associate professor in the Department of Radiation Oncology at the Ohio State University. She serves as chief of medical physics at the James Cancer Hospital and is committed to advancing excellence in clinical practice and education through innovative teaching and meaningful engagement with students and colleagues.

As graduate program director for the medical physics programs, she focuses on creating supportive learning environments that foster critical thinking, professional growth, and lifelong learning.

Cetnar earned a bachelor's degree in applied physics, master's degrees in medical physics and public administration, and a PhD in education. She is active in the American Association of Physicists in Medicine (AAPM) and served as an SPS Associate Zone Councilor while an undergraduate.



The SPS and Sigma Pi Sigma staff in June 2026. Photo courtesy of AIP.



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AIP

2026 Individual Award and SCHOLARSHIP RECIPIENTS

The Society of Physics Students congratulates this year's recipients and thanks the generous SPS and Sigma Pi Sigma donors whose support makes these awards possible.

Scholarships

Scholarships of $2,500 to $10,000 are given by SPS, Sigma Pi Sigma, and their partners each year to individuals showing excellence in academics, SPS participation, and additional criteria. Learn more about the scholarships and recipients at students.aip.org/awards.

SPS Jocelyn Bell Burnell Outstanding Leadership Scholarship
Catherine Prabish
Rhodes College

SPS Leadership Scholarships
Anika Shridhar
University of South Florida

Katyanna Sciorra
Sarah Lawrence College

Krupa Pothiwala
Florida Institute of Technology

Patrick Ryan
Worcester Polytechnic Institute

Sigma Pi Sigma Leadership Scholarship
Kourtney Libenow
Pennsylvania State University

AWIS Kirsten R. Lorentzen Award
Sponsored by the Association for Women in Science
Emma Linscomb
Cornell University

Aysen Tunca Memorial Scholarship
Ella Luking
Rhodes College

Herbert Levy Memorial Scholarship
Braden Lee
University of Central Arkansas

Valentina Bonilla
University of North Florida

LLNL-AIP Leadership Scholarships
Sponsored by Lawrence Livermore National Laboratory
Ada Collins
Rhodes College

Gabriel Ambrose
University of San Diego

Grayson Garner
Colorado State University

Peggy Dixon Two-Year Scholarship
Jahzeel Martinex
Drexel University

SPS Future Teacher Scholarship
Ming Tang
Worcester Polytechnic Institute

SPS and AAPT Mary Beth Monroe Memorial Scholarship
Cher Scarlett
Coast Colleges District and Santa Barbara City College

SPS-Google Scholarships
Sponsored by Google
Abdulsalam Odofin-Kamorudo
Southern Illinois University Edwardsville

Alexander Castillo
University of Colorado Denver

Blake Schuetz
Embry-Riddle Aeronautical University - Prescott

Damien Koon
Florida Institute of Technology

Khanh Vu
Mount Holyoke College

Lindsay Taylor
University of Utah

Madison Wilson
Berea College

Walker Law
Coe College

SPS Award for Outstanding Undergraduate Research

These awards are made to individuals for outstanding research conducted as an undergraduate. Winners are awarded $2,000 to present their research at an AIP Member Society meeting and receive $500 for themselves and $500 for their SPS chapter. Learn more at students.aip.org/sps-award-for-outstanding-undergraduate-research.

Angelina Zhang
Georgia Institute of Technology

Roshan Mehta
University of Rochester

2026 SPS Summer Interns

The SPS summer internship program offers 10-week positions for undergraduate physics and astronomy students in science research, education, outreach, and policy with organizations in the greater Washington, DC, area. Students are placed in organizations that use the interns' skills to engage with the community and promote the advancement of physics and astronomy.

Amelie Heying
Hamilton College
History & Library Intern, American Institute of Physics (AIP)

Bailey Wolf
Embry-Riddle Aeronautical University - Prescott
Mather Policy Intern, National Institute of Standards and Technology (NIST)

Daniel Willson
Wichita State University
Careers Toolbox Intern, SPS

Ethan Raupers
University of Rochester
Policy Intern, NIST

Faith Simmons
East Tennessee State University
Science Writing Intern, Physics Today

Jahanvi Chamria
Colgate University
AI Guide Intern, Lawrence Livermore National Laboratory

Madelyn Stochaj
Rochester Institute of Technology
Science Outreach Catalyst Kit (SOCK) Intern, American Association of Physics Teachers and SPS

Michael Bo
University of Richmond
Mather Policy Intern, National Science Board



The 2026 SPS summer interns pose for a photo at orientation. Photo by SPS.

Nicole Everage
University of California, Los Angeles
Science Policy News Intern, AIP FYI

Nora Hicks
North Carolina State University
Program Assessment Intern, Department of Defense Office of Cost Assessment and Program Evaluation (CAPE)

Paige Nolan
University of Maryland, College Park
Research Intern, Space Telescope Science Institute Research

Sierra Focazio
Appalachian State University
Public Engagement Intern, American Physical Society

Thomas Qian
University of Rochester
Research Intern, US Geological Survey

Apply for SPS Chapter Awards!

Applications are due November 16
students.aip.org/awards

Future Faces of Physics Awards of up to $600 support projects that promote physics and astronomy across cultures.

Marsh W. White Awards of up to $600 support projects that promote interest in physics and astronomy.

SPS Chapter Research Awards of up to $2,000 support imaginative chapter research activities likely to strengthen the chapter.

Sigma Pi Sigma Chapter Awards of up to $600 support local or regional chapter inductions and events that build community or promote awareness of the honor society.

FEATURE

Sigma Pi Sigma at a Turning Point:

THE EIGHTH NATIONAL CONVENTION

A firsthand account of the 1967 meeting that changed the future of Sigma Pi Sigma



Sigma Pi Sigma members pose for a group photo at the Eighth National Convention of Sigma Pi Sigma in 1967. Al Helfrick (circled in blue) and his classmate Dave Hartman (circled in green) were delegates from Upsala College. Image courtesy of the AIP Niels Bohr Library & Archives. Credit: Purdue University News Service photographs, MSP 19, Purdue University Archives and Special Collections, Purdue University Libraries.

by Faith Simmons, 2026 SPS Summer Intern and Graduate Student, The Ohio State University

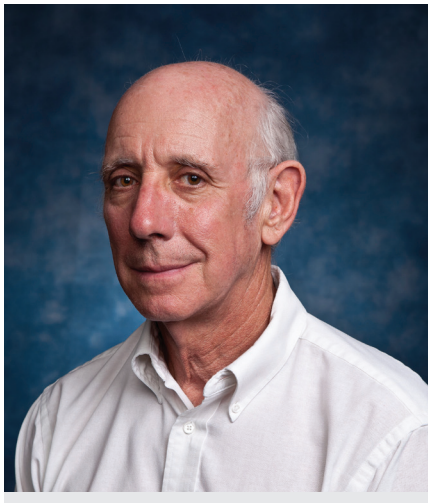
Sigma Pi Sigma's long and rich history shaped the honor society into what it is today. One of the most pivotal moments occurred on the Purdue University campus one cold December weekend in 1967. Student delegates from 140 chapters convened to consider a proposed merger between Sigma Pi Sigma and the American Institute of Physics (AIP) that would create the Society of Physics Students.

Al Helfrick, now an emeritus professor at Embry-Riddle Aeronautical University, was there as a student representing the Upsala College Sigma Pi Sigma chapter. "There were lots of discussions that had taken place in [the] few years before the 1967 convocation," he recalls, "but as students, we weren't really privy to what was going on."

When they learned of the proposed merger, many weren't too keen on the idea, Helfrick says. "Sigma Pi Sigma was an academic honor society. AIP was an organization for physicists and physics teachers, for professionals. We were afraid that we would lose the honor society."

Consideration of the proposal began with students asking questions: Must a student be a member of the Society of Physics Students to be elected to Sigma Pi Sigma? What assurance do we have that AIP won't stop supporting the Society of Physics Students? Would local chapters have the same voice in the Society of Physics Students as Sigma Pi Sigma chapters do now?

Advocates and opponents of the merger then had the floor for 10-minute presentations, which were followed by a general discussion. Many opinions were expressed. But, Helfrick says, "there was only



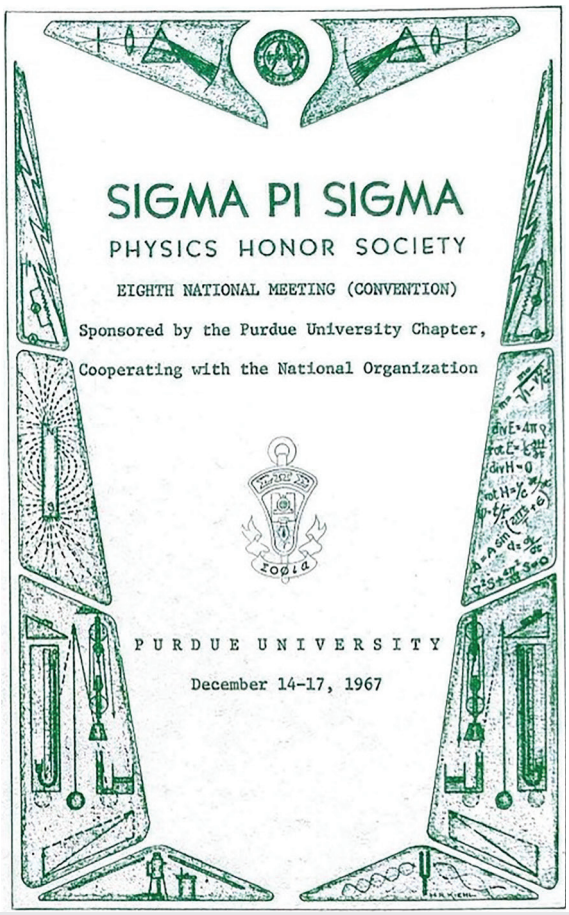
Al Helfrick was inducted into Sigma Pi Sigma at Upsala College in 1967.

one thing that was going to come out of that meeting—are we going to merge or are we not?"

Attendees ultimately voted to approve the merger by a single vote. One factor that swayed the outcome was the financial support AIP could offer Sigma Pi Sigma and SPS, Helfrick says. The agreement allowed Sigma Pi Sigma to remain an honor society under the Association of College Honor Societies and established the Society of Physics Students as a professional student organization welcoming anyone interested in physics.

The report on the Eighth National Convention of Sigma Pi Sigma, written by convention secretary Vincent E. Parker, closes with these words: "Fully aware of the significance of its most important action, the Eighth National Convention adjourned a history making session at Purdue University."

Nearly 60 years later, AIP is still home to Sigma Pi Sigma and the Society of Physics Students. This arrangement supports thousands of students and alumni each year through academic recognition, professional development, scholarships, internships, alumni programs, and other activities. "I think [the merger] was the right thing to do," Helfrick says. •



The program from the Eighth National Meeting. Image courtesy of the AIP Niels Bohr Library & Archives.

FEATURE

HOW SPS TRANSFORMED My Undergraduate Experience

by Nora Hicks, SPS Summer Intern and Recent Graduate, North Carolina State University

In a large university, where classes can have 50 to 100 students, it can be easy to get lost in a sea of faces—and hard to connect with classmates and professors. Sometimes you miss a class and no one notices. Sometimes it's a struggle to find a community. But I've learned firsthand that SPS can change the student experience.

During my first year of college, I often avoided our SPS common room. It was full of upper-level students who knew each other well, and there were never any women in the



Nora Hicks.

room. This made it difficult to feel like I belonged in the space, and I was worried it would be hard to make friends. Instead of putting myself out there, I avoided getting involved.

That changed the summer following my first year. I did research in the physics department and would have lunch in the SPS room. The room was often empty, but sometimes I would see two upper-level students. Over time, I began talking to them.

When school started again in the fall, I continued going to the SPS room for lunch. One day the two upperclassmen I had met over the summer told me that the SPS secretary had switched schools. They wanted to know if I would run for the position. I said yes, not even knowing what SPS was! I soon learned that the club hosted social and community-building events.

The first event I attended as secretary included building pasta towers and eating pizza. A couple of women students stopped by to grab something to eat. They usually left without talking to anyone, but I convinced them to join a tower-building team, telling them they could still opt for an early exit. They ended up staying for the entire event and talking with other students! They also came to the next meeting—and brought friends.

Over time, more and more first- and second-year students and women started attending the meetings. I noticed a culture shift among the SPS students and within the common room; we had created a more welcoming environment. Students began developing friendships and hanging out in the common room together.

Before long, if someone wasn't in class, we would notice. We started looking forward to seeing each other in classes, and after class we hung out or studied together. The common room became a space to gather and connect. It now remains full of students, even on weekends and breaks.

Because we were in the physics building more often, we also developed stronger relationships with our professors. SPS became a support system in our department. As a result, students now show up to class more, are less afraid to ask questions, and have the academic and emotional support they need to succeed. We've created a unique culture that doesn't exist in many other majors here, which has made me appreciate it even more! •



Nora Hicks takes a selfie with chaptermates from North Carolina State University at the 2025 Physics and Astronomy Congress.



Attendees commemorate an SPS Zone 5 Meeting hosted by North Carolina State University's SPS chapter in 2025. All photos courtesy of Nora Hicks.

Three Hundred Fifty-Four Posters

AND ONE NEW PERSPECTIVE AT SPSCON

by Tatenda Kasirori with LaDonna Kalala, Praise Gavi, and Iminabo Roberts, SPS Reporters, Grambling State University

The poster presenters had an early start, and by mid-morning everything was in place. Across the hall stretched rows of posters, each featuring a different project, a different angle on physics, and a different student ready to walk visitors through their work. As Physics and Astronomy Congress attendees drifted in, the room began to find its rhythm—slow shuffles from poster to poster, quick introductions, short bursts of explanation, warm thank-yous and good-byes.

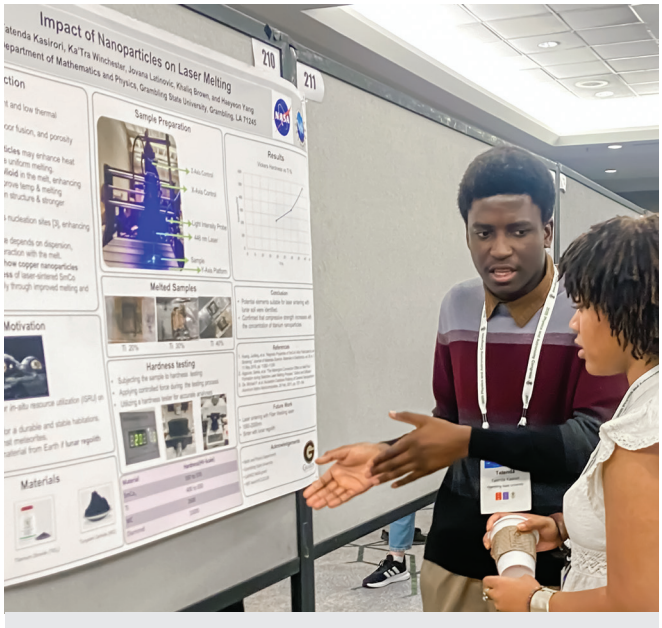
I stood in front of my poster, presenting my work on how nanoparticles affect the laser sintering of metal powders. I had been to several research conferences before, but this was the biggest one yet. I had poured months into the project, refining tests, troubleshooting results, and preparing for every question that might come my way. Even so, the session felt as if it had arrived all too soon—a sentiment I later discovered many of us shared.

Over the next few hours, we went through our motivation, methodology, results, and future work with visitors. Time and time again, minds lit up, insights emerged, and connections formed between people working on similar ideas. New faces, new questions—exhausting but deeply rewarding. As my voice began to wear thin, a lull formed around my section, and I stepped across the aisle to where Alex from California State University Sacramento was presenting his poster titled "Light Signals of Neutron Star Kilonovae." He slipped into the rhythm of the day with ease, taking me through his research. Then, once he finished explaining his work, he turned to my poster and said, "Now it's your turn." Before I knew it, the session came to an end.

The next morning, I entered the exhibition hall with a lighter step. This was the second poster session of the meeting, and today I would be listening rather than presenting. The posters were divided into several categories: Research (by far the largest), Careers and Corporate Internships, Sigma Pi Sigma Chapter Activities, and Supporting Our Phase Shifts—a category containing physics-inspired artwork. The scale of the exhibition was impossible to ignore.

While exploring, I ran into Grace from Carnegie Mellon. I had met her earlier in the week during a congress tour of the Colorado School of Mines. She had briefly told me about her project, titled "Discovering Binary Black Hole Systems," and I had been eager to hear the full story ever since. Her project touched on a region of astrophysics that is still full of unanswered questions and could help shed light on the apparent absence of intermediate-mass black holes. Her fearlessness in tackling such a large problem inspired me to resume a personal research project I had been putting off due to the daunting quantum calculations it required.

Too soon, posters were taken down and students hurried off to their next events. The hall fell into silence, and for the first time all day, I could hear my own echo. Yet in my heart, a larger echo remained—the impact the event had had on me. On all of us, I believe. It was an echo of connection, inspiration, and acknowledgement, one that will not be taken down so easily. •



Tatenda Kasirori presents "Impact of Nanoparticles on Laser Melting" at the 2025 Physics and Astronomy Congress. Photo by LaDonna Kalala.

Uncharted Waters: NAVIGATING MY FIRST POSTER SESSION

by Elizabeth Turner with Sofia Jolley, Isabelle Sealey, and Ryne Starnes, SPS Reporters, Florida State University

Arriving at the Physics and Astronomy Congress after an exhausting day of travel, I began to realize what a massive event this would be. It was a lot to take in: the world-renowned plenary speakers, the hundreds of impressive research posters, and the visiting graduate school representatives. Our cohort had traveled all the way from Tallahassee, Florida, to Denver, Colorado, for the meeting, and we made it a point to make the most of our time.

This was my first time presenting at a physics conference, but I quickly learned that poster sessions are a premier destination for reminders of how little you know. The evening before, I had gone to the presentation hall to tack up my research poster alongside all the others. Rows and rows of student posters filled every wall and corner of the hall—and only then did the scale of the conference fully set in. Titles like "Particle Tracking Velocimetry in the Field: Observations of Turbulence at 800 Hz" and "Textured PDMS Surfaces: A Promising Approach to Biofilm Prevention" daunted me; I had no idea what any of this stuff meant, and I was afraid no one would think of my research as "real physics."

Get Funding for Conference Travel

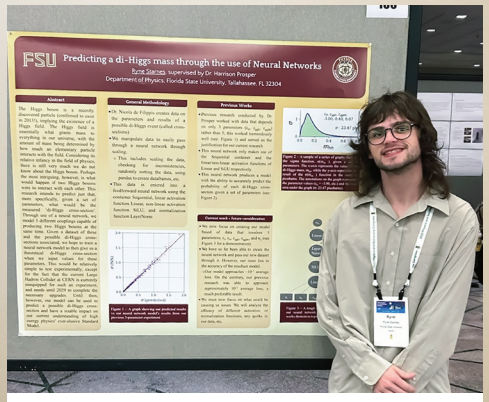
- **SPS Travel Awards offer partial travel support for SPS members to attend and present their research at national meetings of professional societies in the AIP federation and SPS zone meetings. Applications are accepted on a rolling basis. Learn more at students.aip.org/sps-travel-award.**
- **SPS Reporter Awards offer partial travel support for SPS chapters or individual members to attend and report on professional physics meetings for SPS publications. Applications are accepted on a rolling basis. Learn more at students.aip.org/sps-reporter-award.**



Author Elizabeth Turner (left) and fellow members of the Florida State University SPS chapter pose with plenary speaker Jocelyn Bell Burnell at SPSCon. Photos courtesy of the SPS reporters.

Right before the session began, I read over my poster before tensely taking my place beside it, hands clasped and eyes darting, anxious to present to anyone who might come over. My first visitor recognized the Florida State seal attached to my poster and initiated conversation. He had earned his PhD in physics at FSU! Even though I'd never met him before, I felt an immediate connection and was more at ease as I calmly presented my work. My confidence built with every question I answered, and I felt well prepared for the rest of the session.

Another of my more memorable visitors was a panelist from the career panel on national labs. It turned out he did research in the same field, so he asked a lot of questions. Some of them went way over my head, but thanks to my FSU PhD guardian angel, I kept my cool and successfully presented my research. That was the moment I knew I belonged at SPSCon. My research wasn't any less important or impressive than anyone else's. I looked around, and everyone seemed just as anxious as I did. Truly, none of us were impostors; we were all just students who cared deeply about our work. •



SPS reporter Ryne Starnes presents a poster at SPSCon.

Save the Date for the 2028 Physics and Astronomy Congress!

Diamond Jubilee: 60 Years of Brilliance
Saint Paul, Minnesota
October 26–28, 2028

2025 PHYSICS AND ASTRONOMY CONGRESS FEATURE

Reflections on the Past AND ADVICE FOR THE FUTURE

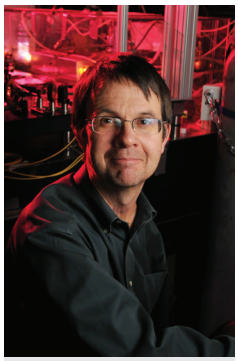
A Q&A with Eric Cornell, Plenary Speaker at the 2025 Physics and Astronomy Congress and Physics Nobel Laureate

Interview by Rupert Lim and Owen Gill, SPS Reporters, Haverford College

Eric Cornell is an adjoint professor at the University of Colorado Boulder and a fellow at JILA. In 2001, he received the Nobel Prize in Physics with Carl E. Wieman and Wolfgang Ketterle for achieving the first Bose-Einstein condensate. Today, he works on precision measurements in atomic, molecular, and optical (AMO) physics.

Looking back at your career over the past 40 years, what were some defining moments in your journey?

A lot of them involved meeting people. I went to MIT to do traditional solid-state physics. Then I ran into Professor Dave Pritchard, an atomic physicist. He was charismatic and fun and had this idea he sold really well. It turned out to be not very realistic, but that didn't really matter. I learned a lot.



Eric Cornell.

Another pivotal moment was meeting Carl Wieman, who was very influential in my life as a postdoctoral advisor. We just kind of hit it off. I saw a kindred spirit there.

Aside from your Nobel Prize work, what are some career highlights?

Recently, my lab made the best-ever measurement of the electron's electric dipole moment. I'm extremely proud of that. That was fun, and we're going to do an even better one in three or four years.

I'm very proud of the people I've taught and mentored. I see all the different things they're doing, and it fills me with a great sense of pride, contentment, and purpose. Many of them are doing things not particularly related to physics, but I like to think that somehow I impacted their lives. One is a major league baseball coach who applies very rigorous statistical methods. Another went into stand-up comedy. I caught her act once, and I was a character in it. I was mildly buffoonish but not a villain. I can live with that.

Given the state of research funding and competition in PhD programs, what advice would you give people who aren't sure what they want to do after college?

This is such a difficult question. No one knows what's going to happen. You could soldier on and get into a PhD program or take a gap year and try and figure out where things are going. Or treat a year of graduate school like a gap year—after the first year, if you don't like the picture, go do something else. I just don't know; we live in a weird time.

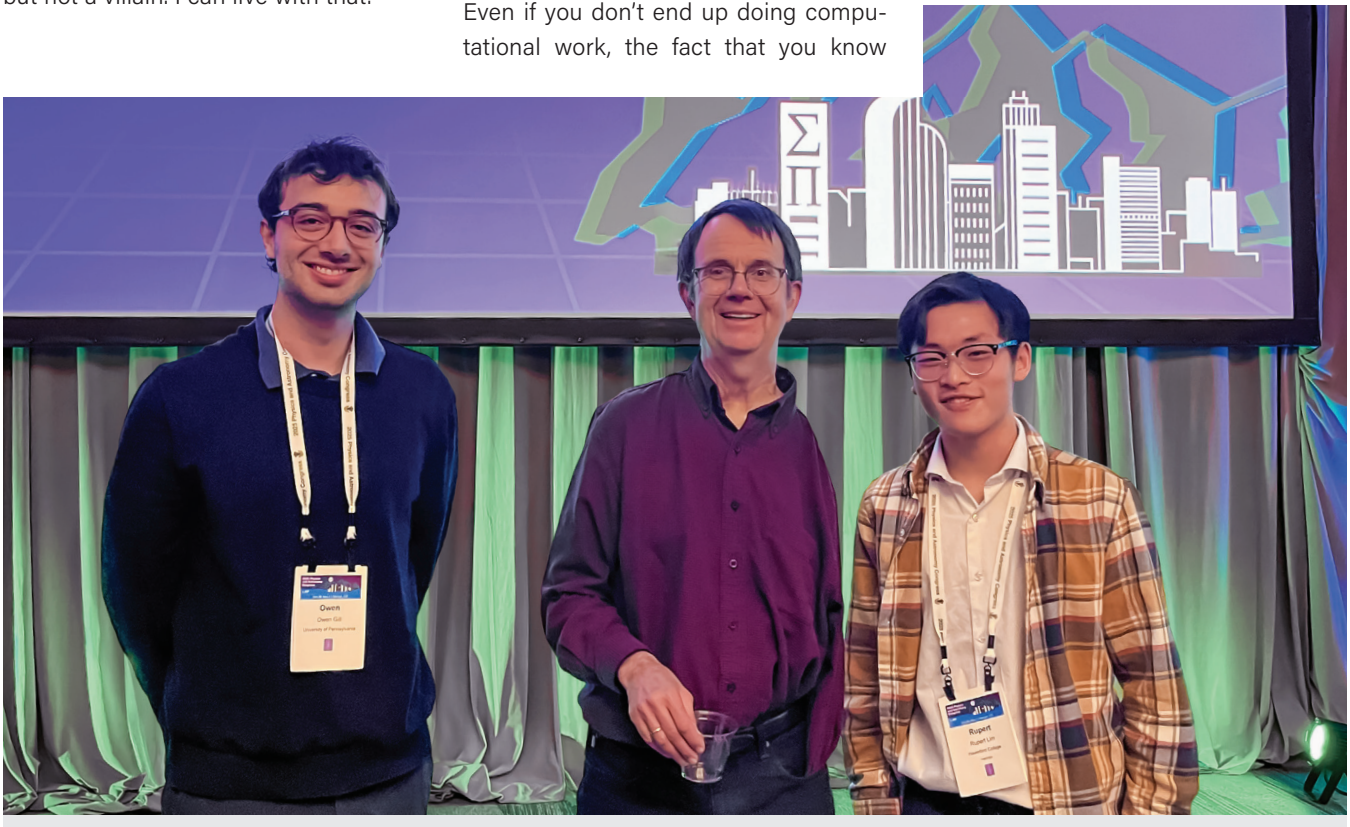
For students exploring experimental, computational, and theoretical research, would you recommend focusing on what they enjoy and excel at or trying different things?

None of those things are a waste of time. Even if you don't end up doing computational work, the fact that you know what one can do and what's out there—that's important. When I was in college, I took a machine shop class. I don't do a lot of machining, but I can design a piece of equipment that's cheaper, easier, more reliable to make because I took that class.

What mindset should a student have when going into an unpredictable field, like quantum information science?

It's a good idea to get deep into something, but at the same time—say you're in a physics graduate program—go to the department colloquium. Especially the ones with titles that don't sound interesting. Read the newspaper. When you're in the lab, you might need to be focused, but poke your head up occasionally and look around. That's important. •

This interview has been edited for length and clarity.



SPS reporters Owen Gill (left) and Rupert Lim (right) with plenary speaker Eric Cornell at the 2025 Physics and Astronomy Congress. Photo courtesy of the SPS reporters.

What Can Physicists Do?

Interviews by Toni Feder, Editor, Physics Today

"What can physicists do?" is an interview series that profiles physicists who opted for careers outside of academia. Read more at physicstoday.aip.org/news/what-can-physicists-do.

Hannah Pell ensures regulatory compliance at Three Mile Island

Nuclear regulatory specialist, Crane Clean Energy Center

BS, physics; BA, music theory and oboe performance; Lebanon Valley College, 2016

MA, music theory, University of Oregon, 2019

2015 SPS Summer Intern



Hannah Pell.

What were you looking for in a job?

I never sought out a specific role for myself. I've navigated toward questions that interest me. I was an intern with the Society of Physics Students, working in science outreach. Later, I was a research assistant at the Center for History of Physics at AIP. Then I was an editorial coordinator at the American Association for the Advancement of Science.

How did you get into nuclear power?

My father worked at Three Mile Island in radiation protection and maintenance, and after the plant closed in 2019, I started writing about it.* That led to my being hired as a licensing engineer onto a project to complete the decommissioning of Three Mile Island Unit 2, the site of the 1979 accident. It was a unique opportunity to enter the industry. That was in 2021.

How do you spend your time?

I'm now a nuclear regulatory specialist at Crane Clean Energy Center [formerly known as Three Mile Island Unit 1; it's scheduled to restart operations next year]. My job is to understand the rules and regulations and ensure that we stay in compliance. It includes doing historical research to understand the context of the regulations. I interact with NRC [Nuclear Regulatory Commission] inspectors, with other stakeholders, and with the public when people come to tour the plant.

I've been focused on understanding Executive Order 14300 , which was issued in May 2025 and directs the NRC to take steps to accelerate deployment of nuclear energy in the country.

What do you like about your job?

My favorite part is working with groups that specialize in different aspects of plant operations. I'm always learning new things.

How does your physics background come into play?

First and foremost, in understanding how the plant works. I interface with the engineering department to research requirements in support of planned modifications. My physics background helps me quickly process technical information and approach complex problem-solving with confidence.

What new skills have you needed to learn?

Soft skills, like writing and communicating. I've also had to develop strong project management skills to work in areas such as decommissioning, license renewal, and restart. •

**See Pell's 2022 Physics Today article, "Why did the Three Mile Island Unit 1 reactor close?," written with Ryan Hearty and David Allard, at physicstoday.aip.org/features/why-did-the-three-mile-island-unit-1-reactor-close.*

Jenna Tempkin organizes activities for kids at a science museum

STEM educator, Liberty Science Center, Jersey City, New Jersey

BA, physics, Lafayette College, 2024

2023 SPS Summer Intern

What were you looking for in a job?

As an undergraduate, I did an REU [NSF Research Experience for Undergraduates] at Rutgers in physics education research. The next summer, I was the public engagement intern at the American Physical Society through the Society of Physics Students. Those experiences showed me the wider realm of what you can do with physics. I decided to not go to graduate school right away. I started looking at museums. I wanted to be in science education and to interact with people.

How do you spend your time?

As part of the STEM education team, which includes the planetarium staff and other educators, I present 45-minute science workshops at schools around New Jersey and sometimes New York. We bring resources that teachers may not have access to. I mostly work with 3rd to 5th graders, but it can be through 12th grade. The workshops are mostly in the physical sciences, Earth science, and engineering.

I also help out with things in the museum. We do seasonal programming, such as a Halloween-themed potions lab. And I develop new programs and plan future events for the museum.

What do you find most challenging?

Learning the content that we teach. In addition to physics, there is biology and chemistry content that I am less familiar with. And the schedule can be a challenge. Sometimes, I have to come in early and stay late. And I'd never had to manage a classroom of 25 eight-year-olds.



Jenna Tempkin. Photo by Sabrina Hale.

How do you use your physics training?

There is the content side: How do I take what I know and make it appropriate for the kids' level? And there are critical thinking and organizational skills that I learned as a college student.

What do you like about your job?

I get to keep up in physics and grow my teaching skills. One of the best parts is being able to share my knowledge and love of physics with the kids. It's rewarding. The other day, for example, we got a note from a school where the kids wrote, "This was so exciting. We hope you come back." •

David Gagnon analyzes baseball to give his team a competitive edge

Team lead, baseball sciences, Washington Nationals Baseball Club

BS, mechanical engineering, Brown University, 2010

PhD, mechanical engineering and applied mechanics, University of Pennsylvania, 2017

What was your research focus?

I started off in physics but switched to mechanical engineering to work in a particular fluid dynamics lab. As a graduate student, I studied how biological organisms swim through non-Newtonian fluids. For practical applications, like fertility studies, you want to know how organisms move through biologically relevant fluids like mucus.



David Gagnon. Photo by Amanda Bowen/Washington Nationals.

How did you end up with the Washington Nationals?

As a postdoc in physics at Georgetown University, I was ready to go on the faculty market. I wanted to keep doing experimental fluid dynamics, but I saw a posting for a full-time analyst role at the Washington Nationals and thought it would be a fun and interesting application of my skill set. The quote "Pitching is not mysterious, it's just physics" [said by Brian Bannister in the 2019 book *The MVP Machine: How Baseball's New Nonconformists Are Using Data to Build Better Players*] was a nudge to look into it. I started with the Nationals in January 2020.

How did you make the transition?

My postdoc and PhD advisors encouraged me to explore, and they made it clear that it didn't have to be a permanent career change.

How do you spend your time?

I work with vast troves of information about how players, the ball, and the bat move and interact. I build models to evaluate our players' pitching, hitting, and defensive skills. I provide tools to help the rest of our organization make decisions about players and their development and how to interpret the game to get competitive advantages.

How do you use physics in your job?

Thinking about throwing a ball that spins and translates through the air, or swinging a bat that has inertia and mass, or the collision dynamics between a ball and a bat, or the kinematics of a fielder moving toward a ball involves physics. Fluid dynamics is helpful. I often apply physics concepts for models and data analysis.

What new skills did you need to pick up?

I had to learn how to write deployable code. I have also developed stronger skills in machine-learning modeling.

What do you like about your job?

I am immersed in a dynamic, collaborative, and competitive environment.

Is there anything you'd like to add?

Every major sports team, not just in baseball, has analysts and scientists. There are plenty of opportunities to get involved. •

Originally published by *Physics Today*.

Congratulations

TO THE NEWEST MEMBERS OF SIGMA PI SIGMA

2025-2026 Inductees

Each year, *Radiations* is proud to recognize those inducted into Sigma Pi Sigma during the previous year. Due to system-related challenges, we were unable to compile a complete list of individuals inducted between July 16, 2025, and July 15, 2026, in time for this issue.

We extend our warmest congratulations to all who were inducted into Sigma Pi Sigma during this period and celebrate this important achievement. We look forward to recognizing and highlighting these inductees in an upcoming issue of *Radiations*. •

Deep-Sea Explorer David Jourdan on Saying Yes to Luck

by Korena Di Roma Howley, Contributing Editor

As a child, David Jourdan spent hours on his rooftop gazing at the stars above Maracay, Venezuela, where he moved with his family at the age of eight. It was the 1960s, and the growing city's clear night skies sparked Jourdan's early interest in astronomy. "We would make our own star maps … and even when I started reading, I was reading about space," he says.

Jourdan's interests eventually grew to include another vast unknown—the ocean depths. Today, he's the founder and president of Nauticos, a deep-sea exploration company that counts the wreckages of the Japanese aircraft carrier *Kaga* and the Israeli submarine *Dakar* among its discoveries. Jourdan has led three high-profile searches for Amelia Earhart's famed Lockheed Electra, presumed to have gone down in the Pacific Ocean during her 1937 attempt to circumnavigate the globe. He's authored books on many of his expeditions and has appeared on the National Geographic Channel, the Discovery Channel, and NBC's *Today*.

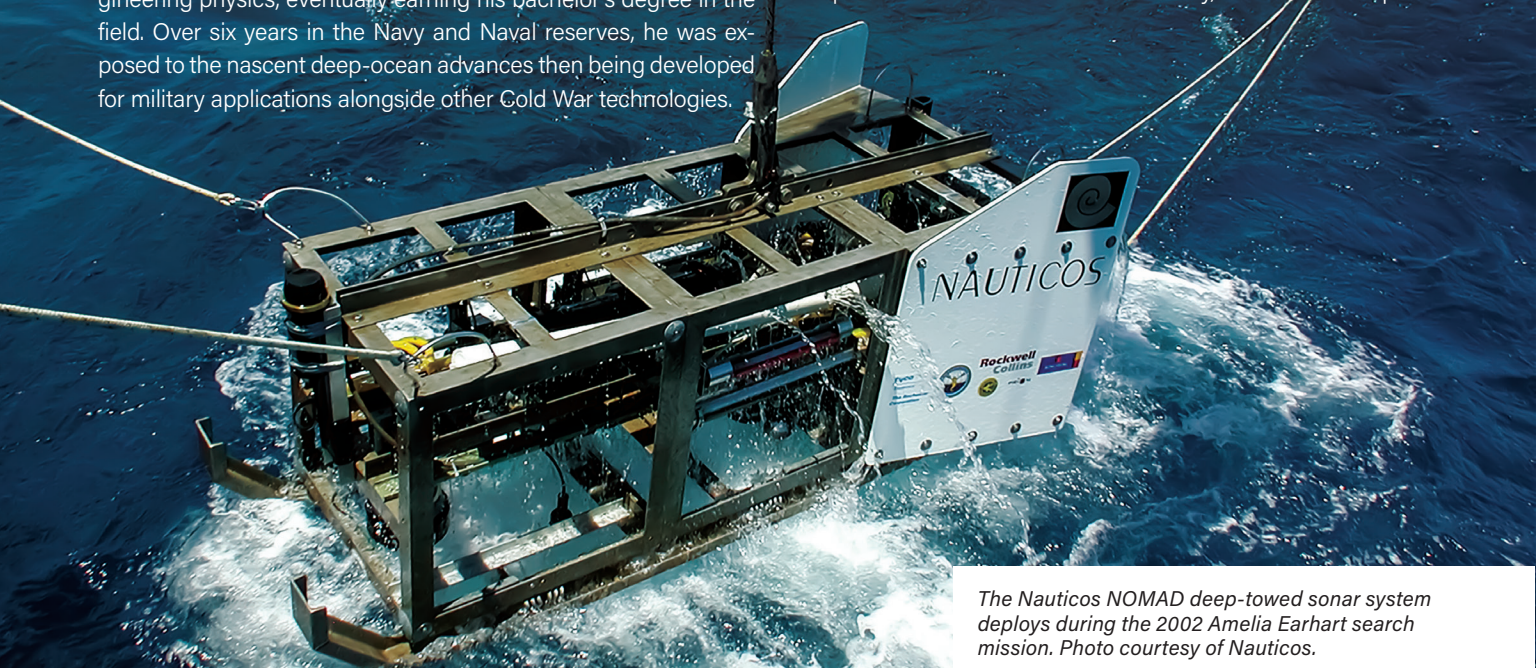
Jourdan says that, on a career path that could have gone in many different directions, his choices have often been opportunistic. He was in high school when his family returned to the United States. By then, an interest in engineering steered him toward the U.S. Naval Academy, where he discovered the broader field of engineering physics, eventually earning his bachelor's degree in the field. Over six years in the Navy and Naval reserves, he was exposed to the nascent deep-ocean advances then being developed for military applications alongside other Cold War technologies.



David Jourdan. Photo courtesy of Nauticos.

"They were just learning how to use computers to digitize sonar," he says. In a time of technological breakthroughs, Jourdan says he found himself in lucky circumstances, including his recruitment—on leaving the Navy—into an ocean engineering graduate program at the Johns Hopkins Applied Physics Lab. The work was high security. "They said, 'Dave, we can't tell you anything about this except that you'll love it,'" he says. "So that's what I picked."

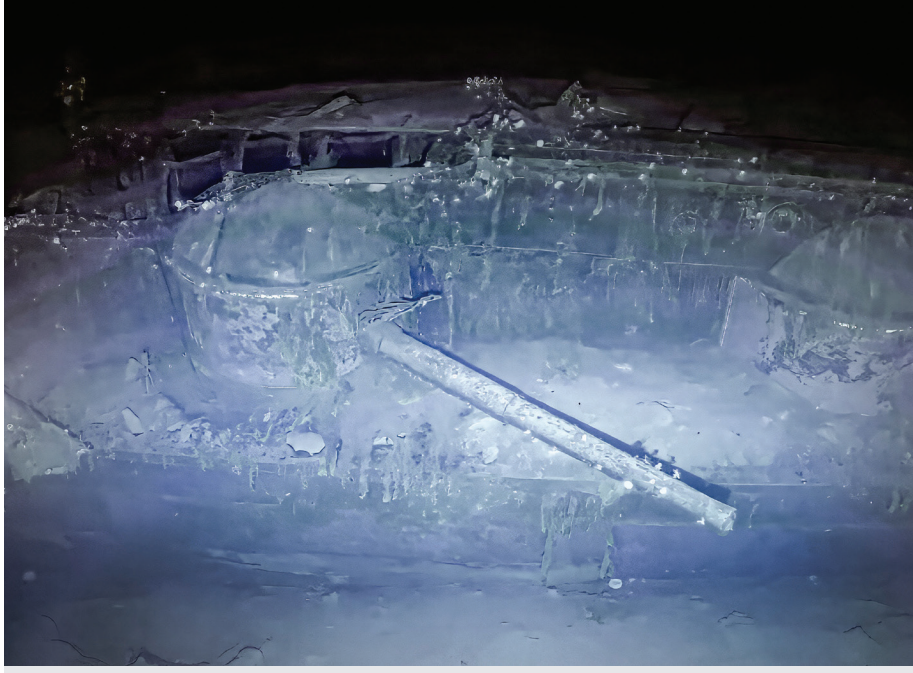
After spending months obtaining a special security clearance, he joined a lab developing software to study ocean data. His task: Install a software program used to navigate submarines onto a mini-computer that, despite its name, filled a floor-to-ceiling rack. Soon he became an expert in a tool others knew little about, which launched him into a career of deep-sea mapping, underwater navigation, and, ultimately, deep-sea exploration. Jourdan says this particular trajectory came down to how he approached the question of what to do next. Ultimately, he followed the paths



The Nauticos NOMAD deep-towed sonar system deploys during the 2002 Amelia Earhart search mission. Photo courtesy of Nauticos.



David Jourdan on the water he's passionate about exploring. Photo by Sue Morris.

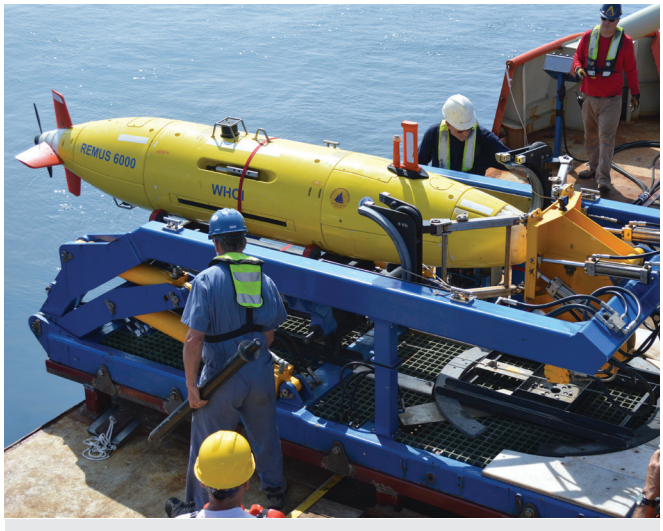


The Japanese aircraft carrier Kaga *within Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands, where it sank during the Battle of Midway in 1942. Image courtesy of NOAA Ocean Exploration/Ocean Exploration Trust, Ala 'Aumoana Kai Uli.*

that he thought were most interesting and provided the most opportunity. "That's led to some wonderful prospects," he says.

Jourdan then left Johns Hopkins to contract with a Naval lab built to process the ocean data they were collecting and to use the navigation software in which he had developed an expertise—a move that began his journey into entrepreneurship.

Over the course of his unique career, Jourdan has remained an enthusiastic student of physics and astronomy. At the Naval Academy, he took courses in astronomy and astrophysics and led the institution's SPS chapter. In recent years he's fed his interests through video courses and personal reading.



The REMUS-6000 autonomous underwater vehicle is readied during the 2017 Amelia Earhart search expedition. Photo courtesy of Nauticos.

"Even though I've not been in a lab practicing as a physicist, [physics] does help inform your way of thinking and gives you insights," he says. He looks to the ocean by way of example. "Most of our limitations in ocean operations are based on the physics of seawater … so I can't help but think that my background [in physics] has really helped me to understand and work with that."

Jourdan is now writing his first novel and is eager to begin a final search for Amelia Earhart's plane, for which he's in the process of securing funding. "I have a team of very ardently dedicated volunteers that are working on this project and will go to sea with me when we can," he says.

Reflecting on his career as a whole, Jourdan comes back to luck.

"You have to prepare yourself to be lucky," he says. "Maybe it'll happen without any preparation, but if you don't learn, if you don't study, if you don't put in the time, you might not have that [lucky] opportunity."

Jourdan also emphasizes the importance of recognizing luck. Pay attention, he says, and notice interesting opportunities when they arise.

And finally—take the risk. "I can think of many times in my life where I said, 'OK, this is a possibility. I'm going to say yes. I'm going to do that. I don't really know how hard it's going to be or if I'm going to like it, but I'm going to try.'

"And I have never regretted it." •

Do you know a Sigma Pi Sigma member we should spotlight in *Radiations*? Send us a note at sps@aip.org.

Champion a Professor:
Celebrating Excellence Through a Night of Fun

by Wanrou Sun, Sigma Pi Sigma Chapter President, Case Western Reserve University

It's 5 p.m. on a Tuesday evening, and the physics lounge is teeming with life as we prepare for our third-annual Champion a Professor event. This is how the Case Western Reserve University's SPS and Sigma Pi Sigma chapters choose one professor to induct into Sigma Pi Sigma alongside each induction class. The tradition is almost as old as our chapter, which was founded in 2023.

During the event, students spend time with their physics and astronomy peers, enjoy some free food, and most importantly, give short, funny, PowerPoint-style presentations explaining why their nominee should be inducted into the honor society. The night concludes with voting to decide who will ultimately be inducted.

In the past, students have showcased immense creativity, delivering the presentation in the same format as their chosen professor's lectures, compiling a professor's most iconic sayings, or flipping through the highlights from a professor's Bluesky. No matter who secures the nomination, it's always a night packed with laughter, making it my favorite event of the year.

Champion a Professor gives students a fun outlet to de-stress, build community, and recognize the hard work of our faculty. Through events like this, we hope to foster a lively and welcoming environment while expanding access to the resources that a Sigma Pi Sigma membership provides. We have our founding executive board to thank for this idea, and we hope it's a tradition that will last far into the future. •



Jacob Hannan nominates Professor Johanna Nagy, the most recent Champion a Professor winner. Photo by Wanrou Sun.



The Sigma Pi Sigma chapter at Case Western Reserve University poses for a group picture at its 2025 induction. Photo courtesy of the chapter.

Get Featured in Radiations!

Is your Sigma Pi Sigma chapter doing something awesome? We want to know about it! Send us an email at sps@aip.org and you may be featured in an upcoming issue of *Radiations*.

Get Money for Chapter Activities

Sigma Pi Sigma Chapter Project Awards of up to $600 are awarded to Sigma Pi Sigma chapters to support inductions or other engaging activities that include alums or promote Sigma Pi Sigma on campus or to the public. Applications are due November 15 each year. Learn more at students.aip.org/chapter-project-award.

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The Degenerate Fermi Gas, Pauli Blocking, and Compact Objects

Part I: The Degenerate Fermi Gas

by Dwight E. Neuenschwander, Professor Emeritus, Southern Nazarene University

Bosons and Fermions

Since the most stable equilibrium configuration of a system is the state of lowest energy, why don't all the electrons in an atom reside in the 1s orbital? Of course, if they did, there would be no chemistry, no biology, and no life. There would be no metals to conduct electricity. All white dwarf and neutron stars would collapse into black holes. The universe would be very different indeed, and we would not be here to appreciate it! The Pauli exclusion principle asserts that electrons do not all collapse into an atom's 1s orbital because only two electrons can live there, and then only when they have opposite spins, to not occupy the same space-spin state.

Elementary particles, and composites made of them, fall into two categories: bosons and fermions. Identical bosons (named after Satyendra Nath Bose, 1894–1974) readily share the same state. In contrast, identical fermions (named after Enrico Fermi, 1901–1954) occupy states in solitude. Here's an analogy: In the restaurants of some countries, the *maître d'* will seat your party at a table already occupied by strangers if the table has a sufficient number of empty chairs. But in other cultures, new diners expect to be seated at empty tables even when occupied tables contain surplus seats. Bosons are analogous to the first group of diners; fermions to the second group.

The exclusion principle that applies generally to identical fermions grew out of the realization that the discrete quantum states for electrons in atoms could not, by themselves, explain the periodic table of the elements. The crucial clue toward a resolution came in 1924 when Edmund Stoner (1899–1968) published a paper giving the first correct extension to multielectron atoms of Niels Bohr's model of the hydrogen atom.[1] From Stoner's paper, Wolfgang Pauli (1900–1958) realized that the sequence of closed-shell electron numbers 2, 8, 18,... is equivalent to a rule asserting that no quantum state can hold more than one electron.[2] But to implement this rule he had to postulate the existence of an extra quantum number to account for a pair of electrons in the same *spatial* state, so each electron in that spatial state could have a unique set of quantum numbers. The extra quantum number was forthcoming from Samuel Goudsmit (1902–1978) and George Uhlenbeck (1900–1988) in the autumn of 1925. Passing a beam of free electrons through a magnetic field, the beam split into two.[3] This splitting—two energy possibilities revealed for electrons interacting with a magnetic field—is evidently a property of the electrons themselves. Therefore, for electrons bound in an atom—where an ambient magnetic field exists because of the relative motion between the nucleus and an electron—each spatial state should be split into a pair of states, one for each electron in the pair. Thanks to this response of the electron's magnetic dipole moment when placed in a magnetic field, this new quantum number was identified with the electron's intrinsic angular momentum, or spin, because the spin angular momentum is proportional to its magnetic dipole moment.

One may define an elementary particle as a state of definite mass and spin. The intrinsic angular momentum, the spin $\mathbf{S}$ carried by a particle, like any angular momentum, is quantized in units of Planck's quantum $\hbar$. This occurs because a generic angular momentum $\mathbf{L}$ is defined by $\mathbf{L} \equiv \mathbf{r} \times \mathbf{p}$, where $\mathbf{r}$ denotes the particle's position and $\mathbf{p}$ its linear momentum. But in quantum mechanics the position and momentum variables do not commute, as in $p_x x - x p_x = \hbar/i$, which shows up in angular momentum components as the cyclic commutation relation such as $L_x L_y - L_y L_x = i\hbar L_z$. From these relations it follows that a spin vector $\mathbf{S}$ is described by a quantum number s, where $|\mathbf{S}|^2 = \hbar^2 s(s+1)$, where the options for s are $s = 0, \frac{1}{2}, 1, \frac{3}{2}, 2, \ldots$.[4]

Thanks to the commutation relations, only $|\mathbf{S}|^2$ and just one component of $\mathbf{S}$ can be simultaneously measured (the component parallel to an ambient magnetic field is a typical choice). That distinguished component will have values $\hbar m_s$ where $m_s = s,\ s-1,\ s-2, \ldots, -(s-1),\ -s$, making $2s+1$ possible values of m_s, the multiplicity. The electron beams that were split into two by Goudsmit and Uhlenbeck tell us that $2 = 2s + 1$, so that $s = \frac{1}{2}$ for the electron.

All particles that carry odd-half-integer spin, $1/2, 3/2, 5/2, \ldots$, are fermions, and particles that carry integer spin $0, 1, 2, 3, \ldots$ are bosons. Identical fermions will not be found in the same quantum space-spin state, whereas identical bosons "like" to be in the same quantum state. Illustrations of boson collective behavior are found in Bose-Einstein condensation, superfluidity, and superconductivity. A classic electromagnetic wave is, in a quantum mental picture, a swarm of spin-0 photons all in the same energy, momentum, and polarization state. Illustrations of the aloof behavior of fermions range from the

electronic configuration of atoms and conduction electrons in metals to white dwarf and neutron stars, where fermion aloofness exhibits a pressure that prevents these compact objects from undergoing gravitational collapse—provided the star's mass does not exceed certain limits.

The assertion that no two identical fermions will be in the same quantum state, and any number of identical bosons can be in the same quantum state, finds formal expression in Pauli's spin-statistics theorem of 1940.[5] The *theorem* shows that this *postulate* about how the spin of identical particles determines how they populate quantum states is *consistent* with relativistic quantum field theory.[6, 7]

Because electrons have spin-1/2, they are fermions, and therefore only two electrons can be in the same spatial state if their spin orientations are opposite relative to, say, an ambient magnetic field. If a system consists of N electrons, at absolute zero the N-electron system's ground state will be the configuration of Fig. 1(a). The electrons "stack up," and the electrons at the top of the "stack" have the *Fermi energy* E_F. The fact that electrons cannot coalesce into the same state suggests that some kind of pressure keeps them apart.

When the system is excited by thermal or other energy input, some electrons are kicked above the Fermi energy, leaving electron vacancies, or "holes," beneath it.

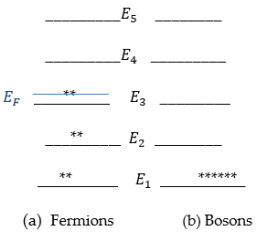


Figure 1: The zero-temperature ground states for a system of six identical particles: fermions [(a), left] and bosons [(b), right]. The energy labels in the center are eigenvalues of the single-particle spatial states, with E_1 the single-particle ground state. The fermions must have opposite spin to not be in the same space-spin state. Each E_i can therefore accept two fermions (although there is a slight energy difference—an energy level splitting—for the oppositely oriented spins, e.g., the spin-orbit interaction). The energy of the most energetic electrons in the multifermion system's ground state defines the Fermi energy E_F.

The Fermi Surface

Consider a system of N freely mobile spin-½ fermions, such as the loosely bound valence electrons in a good conductor that collectively form an electron gas. Examples are found in the conduction electrons in a metal and the gas of electrons permeating completely ionized carbon atoms in a white dwarf star. These electrons, each of mass m, are enclosed within a finite volume and may therefore be modeled as otherwise free particles in a three-dimensional box having rigid walls enclosing the volume $V = L^3$. The time-independent Schrödinger equation yields, for one electron, the standing-wave "eigenstates," the normalized quantum spatial states:[8]

$$\psi_{n_x n_y n_z}(x,y,z) = \sqrt{\frac{8}{V}} \sin\left(\frac{n_x \pi x}{L}\right) \sin\left(\frac{n_y \pi y}{L}\right) \sin\left(\frac{n_z \pi z}{L}\right), \qquad (1)$$

where $n_i = 1,2,3,\ldots$ (a general electron state is a superposition of eigenstates, just as the music emitted by a violin is a superposition of a harmonic series of standing waves). This state, when squared, gives its contribution to the probability density for locating the electron within the box. The energy eigenvalues corresponding to the spatial-only states of Eq. (1) are

$$E_{n_x n_y n_z} = \frac{\pi^2 \hbar^2}{2mL^2}\left(n_x^2 + n_y^2 + n_z^2\right), \qquad (2)$$

where $k_i = n_i \pi / L$ denotes the wave number of a de Broglie wave, and $k_i = 2\pi/\lambda_i$, where λ_i denotes the de Broglie wavelength of one of the standing waves.

Including the electron's spin state $\chi_\pm$ (plus for spin-up, minus for spin-down) creates the space-spin eigenstate $\psi_{n_x n_y n_z}(x,y,z)\chi_\pm$. The spin-orbit interaction, where the electron's magnetic dipole moment $\boldsymbol{\mu}$ contributes the potential energy $-\boldsymbol{\mu} \cdot \mathbf{B}$ because of its interaction with magnetic field $\mathbf{B}$ produced by the relative motion between the electron and the nucleus, gives a slight energy splitting for electrons having opposite spins but residing in the same spatial state $\psi_{n_x n_y n_z}(x,y,z)$.

Note that the energy eigenvalues of Eq. (2) are highly degenerate, e.g., $E_{112} = E_{121} = E_{211}$, even though the corresponding eigenstates are different. The state (111) is the ground state of a single particle, but the question that needs answering for the multiparticle system is this: What is the ground state for the entire system of N identical electrons? The ground state, of course, would occur at absolute zero, $T = 0$. If the free particles were distinguishable particles or identical bosons, then, at absolute zero when they have negligible thermal energy $k_B T$ to bounce them along (where k_B denotes Boltzmann's constant), they would all coalesce into their (111) states and the state of the system would be as in Fig. 1(b).

But with a system of identical fermions, we need to find the number of single-particle states from E_{111} to E_F. Since the states are identified by sets of integers, this means counting the number of possibilities for (n_x, n_y, n_z) that can fit within the energy range $0 < E \leq E_F$. To proceed, since $E = \mathbf{p}^2/2m$ for a single free particle, make an orthogonal coordinate system (p_x, p_y, p_z) in momentum space, or, equivalently, since $p_i = \hbar k_i$, make an orthogonal coordinate system in k-space, where $(k_x, k_y, k_z) = (\pi/L)(n_x, n_y, n_z)$. Thus, any ordered triplet (n_x, n_y, n_z) designates a lattice point in k-space (Fig. 2) that corresponds to one of the single-particle spatial states of Eqs. (1) and (2). The volume of one lattice cell in k-space (also called reciprocal space) is π^3/V because adjacent n_i differ by π/L.

Suppose L is sufficiently large that the k-space lattice spacing becomes infinitesimal. Since each n_i in Eq. (2) is positive, the N free-electron states occupy the (+++) octant of a sphere of radius k_F, where $E_F = \hbar^2 k_F^2/2m$. Invoking the fact that electrons carry spin-½, two opposite-spin electrons may live at each lattice site. Therefore, within the octant bounded by the Fermi surface, the number of lattice sites is

$$(2)\left(\frac{1}{8}\right)\left(\frac{4\pi}{3}k_F^3\right) = N\left(\frac{\pi^3}{V}\right), \tag{3}$$

where the term on the right arises because the volume within the octant equals the number N of fermions times the reciprocal volume π^3/V of one lattice cell. Therefore, for the wave number of the Fermi momentum we find

$$k_F = \left(3\pi^2\,\frac{N}{V}\right)^{1/3}. \tag{4}$$

The quantity $\hbar k_F = p_F$ is called the Fermi momentum and the surface $k = k_F$ in k-space is called the Fermi surface. It forms the boundary between occupied and unoccupied states when the system of N identical fermions is in its lowest energy state, the ground state at $T = 0$. The energy of an electron at the Fermi surface, the Fermi energy E_F, is

$$E_F = \frac{\hbar^2 k_F^2}{2m} = \frac{\hbar^2}{2m}\left(3\pi^2\frac{N}{V}\right)^{2/3}. \tag{5}$$

The total energy of all the electrons within the Fermi surface—energy here called E_{Pauli} because it's due to the Pauli exclusion principle—is given by

$$E_{Pauli} = \int_0^{k_F} E(k)\,d\kappa = \int_0^{k_F}\left(\frac{\hbar^2 k^2}{2m}\right)d\kappa, \tag{6}$$

where $d\kappa$ denotes the number of states from k to $k + dk$.

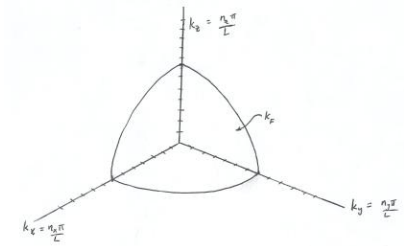


Figure 2: The k-space, showing the Fermi surface $k = \sqrt{k_x^2 + k_y^2 + k_z^2} = k_F$ for free, nonrelativistic identical fermions. The lattice sites are labeled with integers (n_x, n_y, n_z). Author image.

To evaluate $d\kappa$ is to count the number of lattice points in a shell of thickness dk in k-space. As noted above, since L is large compared to an atom's size, $k_i = n_i\,\pi/L$ approaches a continuum as the difference between two adjacent lattice points becomes very small. Then, the number of states between k and $k + dk$ equals the volume of the spherical shell of radius k and thickness dk. The number of lattice points with their corresponding states equals this volume divided by the volume of a unit cell, π^3/V. In addition, since each lattice point corresponds to a state $\psi_{n_x n_y n_z}(x, y, z)$ of Eq. (1) and an electron has spin-½, each lattice site can accommodate two electrons. Thus, we can say

$$d\kappa = (2)\,\frac{\frac{1}{8}(4\pi k^2\,dk)}{\pi^3/V} = \frac{Vk^2 dk}{\pi^2}. \tag{7}$$

Insert Eq. (7) into Eq. (6) to complete the integration,

$$E_{Pauli} = \int_0^{k_F}\left(\frac{\hbar^2 k^2}{2m}\right)\frac{Vk^2 dk}{\pi^2} = \frac{\hbar^2 V}{10m\pi^2}\,k_F^5. \tag{8}$$

Using Eq. (4), Eq. (8) may also be written

$$E_{Pauli} = \frac{\hbar^2(3\pi^2 N)^{5/3}}{10\pi^2 m\,V^{2/3}}. \tag{9}$$

We must keep in mind that as the *ground-state* energy of the N-identical spin-½ particle system, Eq. (9) describes its energy at absolute zero. However, it will turn out that Eq. (9) approximately holds even in the thermodynamic environments of white dwarf stars! While their temperatures are many orders of magnitude above absolute zero (e.g., white dwarf stars are typically built of carbon, and to fuse helium to carbon in a star before it becomes a white dwarf requires a temperature of about 100 MK), we shall see how a comparison of the Pauli energy of Eq. (9) to core thermal energy $\frac{3}{2}k_B T$ allows Eq. (9) to be a useful approximation even in those extreme environments.

In Part 2 we will examine how the degeneracy in a gas of fermions leads to a pressure that keeps the fermions from collapsing into a common ground state and see the role of this pressure in compact objects—white dwarfs and neutron stars.

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