the SPS Observer
Volume XLVII, Issue 3
Fall 2013

INTERNSHIPS:
A GOOD REASON TO DITCH THE BOOKS

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the SPS Observer

Editor
Kendra Redmond

Managing Editor
Devin Powell

Copy Editor
Cynthia Freeman

Art Director
Tracy Nolis-Schwab

SPS President
DJ Wagner,
Grove City College

SPS Director
Toni Sauncy

SOCIETY OF PHYSICS STUDENTS

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

Find SPS on:

Celebrating Interns

by Allen Scheie, Class of 2014 at Grove City College, PA, associate zone councilor on the SPS National Council and student representative on the SPS Executive Committee

Photo courtesy of Allen Scheie.

Hello and welcome to the Fall edition of *The SPS Observer*, highlighting the importance of undergraduate internships.

Internships and research experiences allow students to put their textbooks and class notes aside for a time to experience what the broader physics community is really like, sample multiple fields, and discover what really does, and sometimes does not, interest them. This means not only doing research, but also communicating research to students and the broader public, as well as bringing scientific knowledge to bear on areas such as education and public policy. An internship also makes an attractive addition to any resume!

As a former SPS Mather Public Policy Intern myself, I can attest to the incredible opportunities that an internship provides. I met multiple Nobel laureates, chatted with executives from spaceflight corporations, took tours of state-of-the-art laboratories, and helped craft national science policy. I learned much from the experience and have no doubt it will play a role in how my career advances. And public policy is only one of many areas SPS interns tackle. Others include laboratory research, outreach activities, educational resources, science history, and career resources.

As you read this issue, I encourage you to consider leaving your books behind for a time and exploring the world through the superb summer internships provided by SPS and other organizations. //

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Upcoming Awards

For details on all of the SPS awards, visit www.spsnational.org/programs/awards.

**Note that if an application deadline falls on a weekend, applications are due the following Monday.*

Kirsten R. Lorentzen Award NEW

APPLICATIONS DUE FEBRUARY 15

Awarded to an exceptionally well-rounded female student who excels in her studies as well as outdoor activities, service, sports, music, or other nonacademic pursuits, or who has overcome significant obstacles. The winner receives a $2,000 award. This is an Association for Women in Science (AWIS) Educational Foundation program administered by SPS.

SPS Scholarships

CATEGORIES: LEADERSHIP, HERBERT LEVY (NEED-BASED), FUTURE TEACHER, AND PEGGY DIXON TWO-YEAR COLLEGE

APPLICATIONS DUE FEBRUARY 15

Awarded to undergraduate students on the basis of scholarship, SPS participation, and for the respective categories: leadership, financial need, teaching career objective, or attendance at a two-year college. Winners receive $2,000–$5,000 awards.

SPS Outstanding Student Award for Undergraduate Research

APPLICATIONS DUE MARCH 15

Awarded to two or more undergraduates on the basis of their research, letters of recommendation, and SPS participation. Winners receive a free trip to attend and present their research at the International Conference of Physics Students (ICPS), usually held in Europe; are invited to give a presentation in an SPS research session at a national physics meeting; and receive a $500 honorarium for themselves and a $500 honorarium for their SPS chapter.

Outstanding SPS Chapter Advisor Award

APPLICATIONS DUE APRIL 15

Awarded to a chapter advisor whose chapter has received an Outstanding Chapter Award within the preceding two years during his or her tenure as SPS chapter advisor, on the basis of the leadership, student leadership development, support, and encouragement the advisor has provided to the chapter. The winner receives $5,000 to be divided three ways: 60% to the chapter advisor, 20% to the chapter, and 20% to the department.

The Blake Lilly Prize

APPLICATIONS DUE APRIL 15

Awarded to chapters or individuals that engage in a physics outreach activity and submit a report about the activity. Winners receive the three-volume set of *The Feynman Lectures on Physics* and a plaque. This award was established in the memory of the late Blake Lilly, by his parents.

Outstanding SPS Chapter Award

APPLICATIONS DUE JUNE 15

Awarded to chapters that demonstrate active involvement on the local, zone, and national levels in keeping with the mission of SPS in their annual chapter report. Winners receive a certificate and the pride that comes with being an outstanding chapter.

SPS AWARDS MANAGEMENT SYSTEM

SPS has a new online system for managing awards that will make it easier and faster for you to submit applications, for staff to process your application, for reviewers to input their feedback, and for winners to be notified. Check out the new system, called FluidReview, at https://aipsps.fluidreview.com.

All award applicants will need to create a FluidReview account to apply for SPS awards and programs throughout the year. All award paperwork will be handled through FluidReview, including proposals, letters of recommendation, transcripts, reports, and W9s (when applicable). For details on using the new system, visit www.spsnational.org/programs/fluid_review.htm.

ON THE COVER

Nine of the 2013 SPS summer interns pose with a statue of Einstein in Washington, DC. Meet the 2013 interns on p. 13. Photo courtesy of Alec Lindman.

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The American Institute of Physics is an organization of prestigious 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

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

AIP | American Institute of Physics

A Tribute:
Mary Beth Monroe

REMEMBERING A LIFELONG CHAMPION OF SPS

by Toni Sauncy, SPS Director

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, TX, 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 2010 she was awarded the Melba Newell Phillips Medal, AAPT's highest recognition for member leadership and lifelong service as an educator and mentor. She had been elected as the AAPT national president elect when failing health forced her to step aside. As an acknowledgment of her leadership capacity and to honor her many years of service, the membership elected her president pro-tem in July 2013.

Mary Beth served as an inspiration to many students and colleagues alike. It was Monroe, in her role as the SPS zone 13 councilor who introduced me to the Society of Physics Students. It is possible that without her advice I might have found SPS eventually, but it was her welcome and encouragement that connected me, as a student, to this group. I was one of hundreds of students over the years whose life was enriched by knowing Mary Beth Monroe. She spent her days empowering her students and furthering their ambitions. She was a true friend of physics and a shining example of what SPS strives to accomplish. She truly embodied the ideal of enriching undergraduate students in their quest to master physics and to pursue physics-based careers. I had the pleasure of interacting with her for many years after I became a faculty member myself. I welcomed several students who transferred from her institution to mine, visited her institution to do outreach and recruitment, and worked on tasks with her for the Texas Section of AAPT. I had the great honor of having a conversation with Mary Beth last summer, during which I made sure that she knew what a powerful impact her nudge into the world of SPS had on me and many of my students, and how her influence helped to set the trajectory that brought me to this office here at the American Institute of Physics.

Mary Beth was special person, an avid scientist, a mentor to so many students and someone whose life serves as a model for what is possible when equipped with a love of physics shared with a love of family and an equal love of the divine. She made a difference in many lives, in several institutions, and to the great science of physics, in a small town, and a community college, one student at a time. //

DURING AN AAPT WORKSHOP, MARY BETH MONROE gives a presentation on the importance of SPS chapters to the health of physics departments. Photographer unknown.

MARY BETH MONROE is pictured above at Trinity Site in New Mexico during the 2004 Quadrennial Congress of Sigma Pi Sigma. Photo by Tracy Nolis-Schwab.

New Memorial Scholarship

In memory of Mary Beth Monroe, friends and colleagues have expressed interest in supporting an endowed scholarship in her name.

DESCRIPTION OF SCHOLARSHIP

The Mary Beth Monroe Memorial Scholarship recognizes the outstanding academic and leadership accomplishments of physics majors who began their studies at a regionally accredited community college and who intend to pursue a career in physics education.

This scholarship is intended to memorialize and honor Mary Beth Monroe's inspiring lifelong commitment to the support and encouragement of physics students and her dedication to service at all levels in the Society of Physics Students and the American Association of Physics Teachers. Friends and colleagues are encouraged to assist in the endowment of the scholarship by donating through either SPS or AAPT, with the designation "Mary Beth Monroe SPS Student Scholarship."

Contribute via SPS and the American Institute of Physics at https://donate.aip.org.

A Tribute:
L. Worth Seagondollar

FRIEND AND SUPPORTER WAS VITAL TO THE FORMATION OF SPS

by SPS Staff

The Society of Physics Students joins the greater physics community in mourning Dr. L. Worth Seagondollar, a key figure in the histories of SPS and Sigma Pi Sigma, the physics honor society. Dr. Seagondollar passed away on September 20, 2013, at the age of 92. He 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 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, the physics honor society, 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 largely 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. //

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

For an in-depth feature detailing the contributions of Dr. Seagondollar to SPS and Sigma Pi Sigma, see the Fall 2013 issue of *Radiations* magazine, the official publication of Sigma Pi Sigma: www.sigmapisigma.org/radiations/.

In 1995 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 Sigma Pi Sigma. In a secret mail ballot, the SPS Council unanimously voted to create this award and to name it in honor of Dr. Worth Seagondollar. It also unanimously voted that he should be the award's first recipient. To learn more about the award and its recipients, visit www.sigmapisigma.org/awards/worth-seagondollar/.

WORTH SEAGONDOLLAR speaks at Trinity Site in New Mexico. Photo by Tracy Nolis-Schwab.

Witness to History

A drive of 2.5 hours from Albuquerque, NM, sits the valley known for centuries as Jornada del Muerto, the Journey of Death. There, on Monday, July 16, 1945, the predawn desert was suddenly lit with incredible brilliance as the world's first nuclear explosion took place at 5:29:45am. Since that moment the world has never been the same.

On October 14, 2004, Dr. Worth Seagondollar spoke to participants of the Trinity site visit during the 2004 Quadrennial Congress of Sigma Pi Sigma. His first-hand accounts of working at the Manhattan Project captivated the audience that day, and again that evening during a more detailed speech at the closing banquet of the Congress.

On July 24, 2007, Seagondollar attended the Society of Physics Students summer intern presentations at the American Center for Physics in College Park, MD. He again spoke about his experiences at the Manhattan Project, and this time his talk was recorded and transcribed.

This talk describes one of the greatest war-time experiences possible for a young graduate student, including an eye-witness account of the 1945 plutonium fission device explosion in the New Mexico desert.

To read the full transcript of Dr. Seagondollar's 2007 talk, visit www.sigmapisigma.org/seagondollar.pdf.

Paper Trail

HOW AN INTERNSHIP CAN SHAPE YOUR CAREER

by Bridger Anderson, 2005 SPS Intern, currently at Innovative Micro Technology

In 2005 I was an SPS summer intern at the National Institute of Standards and Technology (NIST) in Gaithersburg, MD. Working with Ganesh Ramachandran, I used an atomic force microscope to make some measurements of molecules that self-assemble on gold. The experience was often challenging. It took some time to learn how to use the $150,000 machine without breaking its fine tip. On the non-work side, the fire alarm kept going off in the building where I lived for the summer. These alarms, which caused the five-story dorm to be evacuated, were set off by individuals who executed at least two acts of poor judgment, pulling the alarm because of smoke from food burned in an oven and a microwave.

But by the end of the summer, I had finally understood the techniques for obtaining good data and getting stable measurements, and I had taped a note next to the fire alarm: "Before you pull the fire alarm, get a second opinion." My NIST supervisor wrote a paper about the research we did and gave me a copy. Though that paper was never published, it would prove to be a turning point for my career.

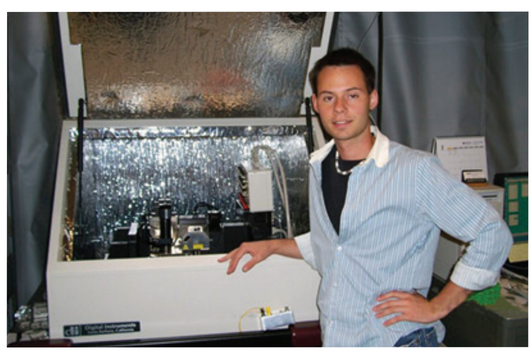
Immediately after my internship I started looking for a job. I was offered positions as a high school teacher, a construction worker, and a website designer. What I really wanted was to get a full-time position doing research before pursuing my education

After about 6 months, I scored an interview at the Center for Nanoscale Science and Engineering (CNSE) at North Dakota State University in Fargo. I showed the interview committee the paper from NIST to demonstrate my interest and experience. My soon-to-be employer's exact words were, "I'm really glad you brought this in today. This is exactly the kind of thing we are doing."

That paper helped me land my first permanent full-time position as a physicist. It changed my interviewer's feelings about hiring me from iffy to definite. At CNSE, I participated in three different projects. All of those projects involved taking measurements just like those I had done at NIST. One project required an in-depth understanding of vacuum science, knowledge that has proven invaluable for my current position. Another was presented at the American Physical Society meeting in Denver, CO, and was published before I applied to grad school.

That second paper helped me get into a few grad schools, including Arizona State University in Tempe, Ohio State University in Columbus, and Montana State University (MSU) in Bozeman. I was also diplomatically accepted to the University of Missouri, Kansas City (UMKC)—by which I mean I knew a guy from CNSE who was moving to UMKC and said he wanted me to be his student.

I chose MSU for mainly professional reasons. I really liked the program and wanted to work for one of the authors of the magnetism book sitting on my shelf at CNSE. (It was mere coincidence that the university was in the middle of the Bridger Mountain Range, near the Bridgerbowl Ski Lodge, with great hiking and camping.) I went on to get a master's degree in physics and obtained a position as a process engineer at a micro-electro-mechanical systems (MEMS) foundry. I am currently a



BRIDGER ANDERSON is pictured at left with the 2005 SPS interns during a tour of his host site, NIST. Above, Anderson stands in front of a scanning probe microscope he frequently used during his 2005 SPS internship at NIST. Photos courtesy of Bridger Anderson.

program manager and principal engineer on three development programs for Innovative Micro Technology in Santa Barbara, CA, and lead a group which has two full-time engineers and two full-time technicians. Recently our group received a high-level award for shattering the company record for wafer level packaging, which we did by reaching a far lower vacuum level than anyone ever had before in the company. Pulling that off took all of my SPS, CNSE, and MSU knowledge. I didn't think it was that big of a deal until I got named at a board meeting two months later for the achievement.

Internships are invaluable. They give undergraduates hands-on experiences that are not attainable in school. I found internships to be more closely geared toward real-world expectations than academia. Academia provides an environment where mistakes are acceptable and allowed to perpetuate for some time. Although mistakes do happen in industry as well, they need to be fixed very quickly. Otherwise, huge expenses result. I gained that type of understanding of immediacy from my SPS internship.

In my current job I am involved in making hiring decisions. I recently interviewed three candidates. When choosing between them, I looked for experiences similar to those offered by SPS internships. A candidate may have a BS or MS degree, but without that hands-on, real-world experience, I don't really consider him or her for an engineering position. I may consider the candidate for a position as a technician, but that technician will then need to demonstrate that he or she is capable of performing as an engineer for about a year before actually advancing to an engineering position.

As an intern, I did not understand how important my two-month experience would ultimately be for my future. It not only landed me a job—and shaped how I hire others—but it also led me to my wife, whom I met in North Dakota while working at CNSE. //

Though that paper was never published, it would prove to be a turning point for my career.

Join SPS at the 2014 USA Science & Engineering Festival

Celebrate science at the 3rd USA Science & Engineering Festival, the largest STEM education event of its kind in the United States! The festival kicked off in 2013 with nationwide school programs, contests, and events. It will culminate in a two-day Grand Finale Expo on April 26–27, 2014, at the Walter E. Washington Convention Center in Washington, DC. Over 750 leading STEM organizations will present hands-on science and engineering activities for people of all ages. Learn more at www.usasciencefestival.org/2014-festival.html.

If you will be in the DC area April 26–27, consider volunteering for the Expo with SPS! Watch the SPS website, publications, and social media sites for details. If you will be at the festival with another organization, let us know by emailing sps-programs@aip.org. //

SEVERAL STAFF AND VOLUNTEERS POSE AT THE "BIG TOP PHYSICS" TENT that SPS created in conjunction with several other physics societies for the 2012 USA Science & Engineering Festival. Photo by Tracy Nolis-Schwab.

NIST: THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

From the smart electric power grid and electronic health records to atomic clocks, advanced nanomaterials, and computer chips, innumerable products and services rely in some way on technology, measurement, and standards provided by the National Institute of Standards and Technology.

Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Department of Commerce. NIST's mission is to promote US innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

The agency operates in two locations: Gaithersburg, MD, and Boulder, CO. NIST employs about 3,000 scientists, engineers, technicians, and support and administrative personnel. NIST also hosts about 2,700 associates from academia, industry, and other government agencies, who collaborate with NIST staff and access user facilities. In addition, NIST partners more than 1,300 manufacturing specialists and staff at more than 400 MEP service locations around the country.

The Society of Physics Students has partnered with NIST to place SPS research interns in the Gaithersburg, MD, location every summer since 2002. //

NIST

www.nist.gov

SOCK It to 'em

2013 SCIENCE OUTREACH CATALYST KIT (SOCK) DESIGNED BY SPS INTERNS

by Caleb Heath at the University of Arkansas in Fayetteville and Nicole Quist at Oregon State University in Corvallis, 2013 SPS interns

STUDENTS AT A SCIENCE CAMP test out SOCK activities. Photo by Kendra Redmond, used with permission from the University of Maryland, College Park, Physics Department.

Keep an eye on your SPS e-mails, and you'll soon see the term "SOCK" in your inbox—as in, "Apply now to get a SOCK for your SPS chapter." And you should do it. Or make your own SOCK. Let us tell you why.

First, let's define a *SOCK*, or Science Outreach Catalyst Kit. It's a collection of materials and activities designed to be a self-contained outreach experience. That explains the "science," "outreach," and "kit," but what about the "catalyst"? Say you're a new chapter or new to public outreach, and you want to bring physics to the masses but don't know where to begin—a SOCK can get you started! Say you're an older chapter, and your outreach is stuck in a rut—get a SOCK! The SOCK contains demos and activities, and best of all, it's free—and it comes in a giant sock. (It's not just a cute acronym.) But most importantly, each SOCK is designed around a specific theme, so you can present a focused message during your outreach.

Each summer, a pair of SPS interns chosen for their interest in outreach and physics education develops a new SOCK. The SOCK team often partners with an external organization. This year we teamed up with the National Institute of Standards and Technology (NIST) in Gaithersburg, MD. We spent 9 weeks designing and testing the lessons and demonstrations in the kit, subjecting it to the scrutiny of a broad sampling of students, from 3rd graders to high school seniors, to make sure there was something for everyone. This year's SOCK got rave reviews. The 3rd graders loved it. So did dozens of expert middle school science teachers.

Our partnership with NIST spurred the idea of exploring the theme of sensors and measurement for this kit. Detection and quantification of physical phenomena is what the working scientist does every day, and this year's SOCK aims to share that experience with students. This is different than previous SOCKs, which have focused more on a specific phenomenon (such as gravity or light).

Several activities are devoted to the details of measurement. Why is it important to put numbers to things? Why do we need standard units, and how do we define them? Length, mass, and time are all explored in the 2013 SOCK.

Each kit also includes an electrical circuit built from off-the-shelf components for hands-on investigations of different kinds of sensors. Modular parts enable you to quickly change out one type of sensor for another. Advanced activities integrate mobile technology apps to explore the mathematics behind the sensors.

If you want a SOCK, be on the lookout for announcements. You'll have to submit a plan describing how you want to use it and send in feedback detailing your event afterward. Only 25 kits are available. But since the SOCK manuals past and present (including parts lists) are available on the SPS website, you can always make your own. //

> you want to bring physics to the masses
> BUT DON'T KNOW WHERE TO BEGIN—
> a SOCK can get you started!

MORE INFORMATION

To check out every SOCK created since 2001 and learn more about the program, visit www.spsnational.org/programs/socks/.

Taking It to the **Streets**

SPS NATIONAL COUNCIL HIGHLIGHTS OUTREACH

by SPS staff

AT THE SPS BOOTH, children learn about the properties of non-Newtonian fluids by playing with Oobleck, a mixture of cornstarch and water. Photo by Matt Payne.

At the SPS National Council meeting in September, elected faculty and student representatives from each of the 18 SPS zones participated in lively discussions about the future of SPS and Sigma Pi Sigma, engaged in committee work, and, for the first time, hosted a booth at a true Washington, DC, street festival with several live music stages, multiple vendors, and a range of culinary attractions. The SPS physics outreach booth, the only science-themed booth in the 10-block H Street Festival, was situated in the kids section. There, council members spread the wonders of physics through hands-on activities with rainbow (diffraction) glasses, thin films (bubbles), and non-Newtonian fluids (aka Oobleck, a mixture of cornstarch and water).

In recent years the SPS National Council has frequently participated in a science outreach event as part of its meeting, but this year it was especially relevant. At the 2012 Quadrennial Physics Congress last November, chapter votes determined the most important area of service for SPS and Sigma Pi Sigma to be "supporting society outreach and communicating with the public." In response to this, the council adopted the following statement on outreach during a business meeting prior to the festival:

The Society of Physics Students recognizes that outreach inspires scientific literacy while promoting public understanding of the benefits of physics education and research. Community and educational partnerships also foster curiosity and passion in the next generation. These activities enrich the experience of the participating undergraduate students as ambassadors of science by promoting a deeper commitment to their discipline. We are committed to providing programs, resources, and opportunities that highlight physics and encourage community outreach partnerships. //

H Street Festival Highlights

"

DJ WAGNER
SPS PRESIDENT
GROVE CITY COLLEGE

One little girl had been playing with bubbles and Oobleck for the better part of an hour. I decided to give her a 'Future Physicist' pin. She wanted it prominently displayed on the front of her shirt. When I pinned it on her, she asked, "Does this mean I'm one of y'all now?" My heart just melted as I assured her she was indeed "one of us." That one question made the whole event worthwhile for me.

MARIA RAMOS
AZC, ZONE 18, SACRAMENTO STATE UNIVERSITY

Seeing the awe in those kids' eyes when they played with the Oobleck and seeing their smiles when they played with the diffraction glasses and soap bubbles was very inspiring for me and really made me want to encourage my school's SPS chapter (as well as the other chapters in my zone) to do more outreach events at our local elementary, middle, and high schools. All in all, it was a very inspiring and amazing experience.

STANLEY MICKLAVZINA
ZONE COUNCILOR, ZONE 17
UNIVERSITY OF OREGON

I interacted with the parents of the kids who were playing with soap bubbles, showing parents how to make your fingers 'disappear' when holding a glass of water. They appreciated the physics along with a glass of water!

STEVE FELLER
2016 SIGMA PI SIGMA CONGRESS CO-CHAIR, COE COLLEGE

A woman who came over to look at things obviously had a strong interest in science. When I asked about her interest, she told me that she teaches middle school science in the District of Columbia. She left the area laden with extra copies of all I could find for her—perhaps two dozen diffraction glasses, several posters, and many pencils. I am sure they are being put to good use.

BROOKE HAAG
ZONE COUNCILOR, ZONE 18
AMERICAN RIVER COLLEGE – LOS RIOS

I think my favorite part of the day was moderating the Oobleck. The kids were so totally fascinated, and every parent was utterly horrified. A girl with tiger face paint spent no less than 45 minutes playing with the Oobleck. Over and over she would make a hard ball with it and let it trickle through her fingers. She would then show each successive kid how to operate the Oobleck.

"

SPS Fall 2013
Photo Contest

#SPS
#ScienceBeyondBorders
#PhysicsForAll

The National Office asked, and SPS chapters delivered! More than 120 photos were entered in the SPS Fall 2013 Photo Contest. A panel of distinguished judges at the American Center for Physics, home to SPS and four professional scientific societies, narrowed the entries down to 10, which were put to a public vote on the SPS Facebook page. The top five are pictured here—congratulations to all the winners! Too see all 10 finalists, along with photos from each participating chapter, go to www.spsnational.org/programs/2013-photo-contest/.

1st Place
PHONE BOOK TUG-OF-WAR
COLORADO MESA UNIVERSITY

Two phone books were interlaced, each page on top of another, creating enough friction between pages to withstand the forces of physics and engineering students in a tug-of-war competition (see the inset for a close-up of the interlaced phone books). Photo by Joseph Howerton.

2nd Place
FAMILY WEEKEND RENSSELAER POLYTECHNIC INSTITUTE

A crowd gathers around the SPS table during Family Weekend. Josue San Emeterio, the build team leader, explains the chaotic double pendulum to a young scientist. Photo by Kelsie Larson.

3rd Place
SPS DEMO NIGHT WASHINGTON UNIVERSITY IN ST. LOUIS

Photo courtesy of Washington University in St. Louis.

4th Place
ANGULAR MOMENTUM UNIVERSITY OF MICHIGAN-ANN ARBOR

A young physicist learns about conservation of angular momentum using a giant bike wheel gyroscope. Photo courtesy of Ann Arbor Hands-On Museum.

5th Place
SPS POSTER SESSION UNIVERSITY OF LOUISVILLE

Poster presentations at an SPS zone 8 meeting. Photo by Austin Lassell.

JUMP RIGHT IN

SHAPE YOUR CAREER WITH AN INTERNSHIP, RESEARCH EXPERIENCE, OR OTHER EXTRACURRICULAR EXPERIENCE

by SPS Staff

If you want to get a handle on solving Maxwell's equations and repeating Millikan's oil drop experiment, courses are the way to go. But if you want to know what it is like to participate in cutting-edge research, work as a science writer, teach, or develop innovative science outreach programs, coursework alone is not enough. Even if you have already decided on your dream job, an extracurricular experience is a must.

Classes and homework are the foundation for learning physics content and sound laboratory practice. But even a well-taught class cannot replicate the panic/excitement/anticipation of the first day of an internship, co-op, or extracurricular research experience. Nothing can replicate the career opportunities, personal growth, and skill building that come from jumping head-first into a new environment where you can test what you have learned in a supportive, yet authentic environment.

2012 SPS INTERNS stand in front of the American Center for Physics, home to the SPS national office. Photo by Tracy Nolis-Schwab.

In the following stories, written by SPS interns, the value of their summer experience is clear. These stories, all written by undergraduate physics majors who spent a summer working in the nation's capital on projects in science outreach, education, policy, communication, and research, convey better than any brochure or flashy poster how important the experience can be long after the summer ends. The SPS internship program is broader than most, providing opportunities for physics students that more closely align with the wide variety of career paths pursued by physics degree recipients than more traditional internship or summer research experiences. If the program intrigues you, apply! If you have other aspirations, seek out other opportunities! Visit The Nucleus and SPS Jobs for a clearinghouse of research and internship opportunities for physics students, talk to nearby companies or labs, and talk to your faculty and mentors—find an opportunity that excites you and jump in head-first. It will be an experience that will help shape your career! //

MEET THE 2013 SPS SUMMER INTERNS

To learn more about their experiences, visit www.spsnational.org/programs/internships/2013.

JOSE "RO" AVILA
KING COLLEGE
AIP Career Pathways intern—Developed resources to help physics students prepare to enter the workforce.

ALEXANDRA DAY
WELLESLEY COLLEGE
National Institute of Standards and Technology (NIST) intern—Used mathematical models to explore quantum effects in MOSFETs.

JAMIE GARRETT
SOUTHERN POLYTECHNIC STATE UNIVERSITY
American Physical Society intern—Developed hands-on activities for PhysicsQuest, a national middle school program.

CALEB HEATH
UNIVERSITY OF ARKANSAS
Society of Physics Students intern—Created an SPS Science Outreach Catalyst Kit (SOCK) with fellow intern Nicole Quist that explores measurement and sensors.

ALEC LINDMAN
RHODES COLLEGE
NASA Goddard intern—Designed a blackbody source for developing and testing cosmic microwave background polarization detectors.

DARREN MCKINNON
UTAH STATE UNIVERSITY
NASA Goddard intern—Analyzed data from the Hubble Space Telescope to explore what is happening in the massive star system Eta Carinae.

FIONA MUIR
UNIVERSITY COLLEGE LONDON
AIP Center for History of Physics intern—Created lesson plans about the history of women and minorities in physics and astronomy.

CHRISTINE O'DONNELL
UNIVERSITY OF VIRGINIA
American Association of Physics Teachers intern—Developed science education policy advocacy materials for physics teachers.

NICOLE QUIST
BRIGHAM YOUNG UNIVERSITY
Society of Physics Students and NIST intern—Created the SOCK with fellow intern Caleb Heath and worked with the NIST Summer Institute for Middle School Science Teachers.

NIKKI SANFORD
HIGH POINT UNIVERSITY
US House Committee on Science, Space, and Technology intern—Worked on science policy through the AIP Mather Public Policy Intern Program.

KATHERINE STANKUS
PORTLAND STATE UNIVERSITY
US House Committee on Science, Space, and Technology intern—Worked on science policy through the AIP Mather Public Policy Intern Program.

DAYTON SYME
IDAHO STATE UNIVERSITY
US Department of Education intern—Worked on education policy related to science, technology, engineering, and mathematics.

BE A 2014 SPS INTERN!

Applications due February 1

The SPS summer internship program places undergraduate physics students with various organizations around Washington, DC, in the areas of science policy, communication, outreach, and scientific research. All internships include paid housing, a competitive stipend, commuting allowance, and transportation to/from Washington, DC. Check out the details at www.spsnational.org/programs/internships/.

INTERN 

HOW THE SPS INTERNSHIP PROGRAM WAS BORN (AND WHAT I LEARNED ABOUT COMMUNICATION ALONG THE WAY)

by Mark Lentz, 2001 SPS intern, currently a field specialist at Baker Hughes

One afternoon years ago, when I was an undergraduate working away in the physics lab, my professor Gary White called me in to his office for a chat. We had been developing educational outreach projects at Northwestern State University in Natchitoches, LA, using common household items to create optics demonstrations for inner-city elementary school children. White had taken a new job at the American Institute of Physics (AIP) just outside of Washington, DC. He asked me to join him there for a summer and explained that together we would be continuing our work and laying the foundation for an annual SPS internship program. Exactly how we would be doing this wasn't certain. I left his office feeling excited, proud, and afraid.

I WAS A **geek** WHO COULD **speak**

In addition to helping to create the first-ever SPS Science Outreach Catalyst Kit (SOCK), I spent a significant portion of the summer building up the internship program. Gary and I visited a bunch of science-related institutions around the DC area. We were salesmen marketing SPS. At each stop, we tried to learn the goals of the institution and determine how SPS members could help achieve those goals.

"INTERN ALPHA" MARK LENTZ shows off components of the inaugural SPS SOCK (Science Outreach Catalyst Kit). Photo by Tracy Nolis-Schwab.

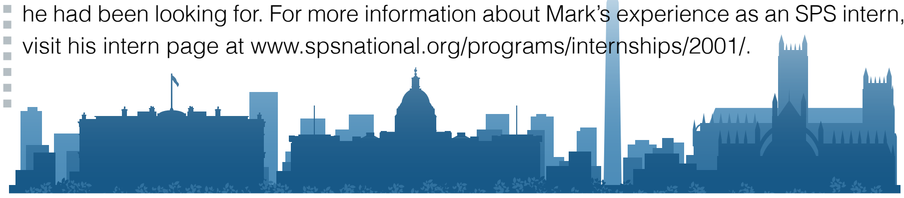
My job, as I saw it, was to demonstrate that SPS interns have skills beyond their physics and math training. In my tie-dyed t-shirt, I was a geek who could speak—able to converse both in technical and in everyday situations. "You're not what I think a mathematics and physics guy would be like," one person told me. "I mean that in a positive way!"

Every place I visited, from the National Institute of Standards and Technology to the National Science Foundation, needed excited, active, intelligent, hard-working problem solvers with the ability to adapt and communicate. In short, they needed SPS members like you. Each institution also wanted to improve science. So our sales pitch included the idea that internships could help make SPS members better scientists by exposing them to diverse experiences.

We looked into other organizations, such as the Franklin Institute, where placements for enthusiastic educators existed. We point-

MAJOR BRAIN CANDY

Mark decided to major in physics just to see what it was like. While there was not one specific thing that he wanted to learn, he had been told that physics wasn't about learning formulas and large, involved equations, but rather about how to think about situations. The intellectually stimulating conversations that he had with classmates and professors before, during, and after his classes were exactly the kind of "brain candy" he had been looking for. For more information about Mark's experience as an SPS intern, visit his intern page at www.spsnational.org/programs/internships/2001/.



ed out that outreach experiences could help to transform SPS members into teachers.

Some organizations had already set up summer research opportunities for college students. We considered how an SPS internship program could complement what they were already doing.

To be honest, there were times when I was overwhelmed. But those were learning moments, situations in which it was good to be an intern able to benefit from the experiences of mentors. I remember the awesome Jack Hehn, former director of AIP's Education Division, reminding me that whatever the outcome of a "sell," the idea was to communicate successfully and establish relationships for the future. I took that advice with me to every meeting that followed, then and today.

One of my favorite stops on this tour was the Rayburn House Office Building, where Hehn and I spent an evening promoting AIP to members of Congress and their staff. I remember one Congressman stopping to tell me that he had majored in physics as an undergraduate. He joined us for our full "have-atcha" pitch, shook my hand, and told me to keep up the good work! That interaction changed the course of the night; staff members suddenly took notice of us, and what followed was an evening of nonstop meetings and greetings as we showed off our display.

After a busy summer of wonderful experiences, surrounded by the company of many kind faces and brilliant minds, I returned to Northwestern to finish my undergraduate degree. I would go on to teach high school physics at St. Thomas More Catholic High School in Lafayette, LA, for 7 years. Now I work for Baker Hughes, where my job requires not only the physics, mathematics, and technology skills I learned in school, but also the communication skills that I acquired during that wonderful summer in DC. //

MARK LENTZ at a reception on Capitol Hill showcasing the results of National Science Foundation (NSF) funding. Photo by Jack Hehn.

UNEXPECTED CONNECTIONS

FOLLOWING UP DURING AN INTERNSHIP CAN PAY OFF

by Patricia Engel, 2006 SPS intern, currently an environmental scientist at Eastern Research Group

PATRICIA ENGEL (right) at the CNSF exhibition on Capitol Hill with, left to right, 2006 SPS interns Katherine Zaunbrecher and Kacey Meaker and Congressman Vernon Ehlers. Photo by Liz Dart Caron.

Looking up, I saw a colorful double helix hanging still, several stories tall, illuminated by filtered sunlight from the 12th-floor skylight. My first impression was of open space. I sat on a bench next to imitation palm trees, waiting for a Friday afternoon meeting at the end of my SPS summer internship. I was surprised to find such stillness in the building that is the heart of basic science research in the United States, the National Science Foundation (NSF) in Arlington, VA. Little did I know then that 4 years later I'd be working in that building, my finger on the pulse.

But I'm getting ahead of myself. It all started a few months earlier, when my SPS internship began—not at NSF, but at the National Institute for Standards and Technology (NIST) in Gaithersburg, MD.

Although at NIST I spent 8 hours a day running numerical calculations of the minimal energy structure of aqueous arsenic (a toxic groundwater pollutant), I was

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LITTLE DID I KNOW THEN THAT
4 years later
I'D BE WORKING IN THAT BUILDING

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determined to learn everything I could about how science operates at the national level. At lunch, the interns and I joined scientists swapping tales of government life. I'd attend lectures and, on special occasions, join other SPS interns for tours of NASA Headquarters, the Pentagon, and the American Center for Physics.

On one particularly eventful night, the SPS interns trekked to the House of Representatives Rayburn Building on Capitol Hill for the Coalition for National Science Funding (CNSF) exhibition and reception. A fascinating crush of people gathered to discuss federal funding for basic research. There were members of Congress, aides, lobbyists, researchers, association representatives, and members of the press. Dr. Jack Hehn, then director of education at AIP, coached us on every detail: where to stand and wait to meet dignitaries in demand, how to approach, when to give a handshake, and how to follow through after an encounter.

At the CNSF event, I bumped into geophysicist Jill Karsten, NSF's program director for geosciences diversity and education—a chance encounter that would change everything. Buoyed by Hehn's mentoring, I followed up with her after the event and arranged a meeting at NSF.

And that brings me back to the fake palm trees. During our meeting at NSF, Karsten introduced me to Lara Hutto, her science assistant, who had studied in my home state and worked at Woods Hole Oceanographic Institution, where I would begin my PhD studies in the fall. Hutto invited me to a foundation-wide gathering of science assistants where Kathie Olsen, then deputy director of NSF, spoke.

What a lucky coincidence! Olsen drew quite the crowd. She went around the table asking the science assistants about their backgrounds and what they were studying. In my weekly journal, I wrote, "The whole experience visiting NSF was phenomenal and inspirational. I might like to work there someday."

Four years later, I decided to move halfway across the country and into a cubicle down the hall from Karsten's office. A chain of events that began with a connection I made during my SPS internship and a bit of persistence eventually landed me a glorious position as a science assistant myself. //

MORE INFORMATION

For more information about Pat's experience as an SPS intern, visit her intern page at www.spsnational.org/programs/internships/2006/engel.htm.

ROACHES & FOAM

LEARNING A NEW WAY TO TEACH THROUGH AN INTERNSHIP

by Lauren Zarandona, 2002 SPS intern

the single most compelling EXPERIENCE OF MY INTERNSHIP took me by surprise

When I was a rising senior at Rhodes College in Memphis, TN, I ran a mentoring program and coached a MATHCOUNTS team at a local elementary school. My experiences at the school sparked my curiosity about how federal and state educational policies that directly impact curricula are developed. So I applied for an SPS internship in 2002 as a means of satisfying my curiosity.

In the end, I left with more questions than answers. . . and a strong desire to teach.

Memorable experiences filled my summer in DC. I traveled to Capitol Hill for a policy hearing. I learned the ins and outs of SPS. I ran on the National Mall at sunrise every morning. I survived the subway system called the Metro.

The single most compelling experience of my internship took me by surprise. Working with the other summer intern, whose name was Jason, I had finished developing several of the activities for that year's SOCK. (See p. 8 for this year's intern-developed SOCK!) We had the opportunity to test two of the activities on a small group of older elementary students. I don't remember where we taught them or even where they came from; it was the middle of summer and students were definitely on break. But I do remember what we taught them and, more importantly, how we taught them. Those were the aspects of the experience that caused me to enter the teaching profession.

For the first lesson, Jason and I carved polyhedra and other three-dimensional shapes out of foam pool noodles and construction foam using an electric carving knife. The finished products were not beautiful, but they were functional. The students at the practice lesson counted the shapes'

LAUREN ZARANDONA demonstrates activities from the 2002 SPS SOCK at the Angelus Academy. Photo by Liz Dart Caron.

edges, faces, and vertices, compiling the data into a chart. Patterns existed throughout the data. Gary White, the SPS director at the time, gave me and Jason specific instructions: let the students grapple with the patterns and then write down their observations on the board, labeling observations with student names.

For the second lesson, we showed a clip from "Men in Black" featuring an alien roach. Using scissors, graph paper, and blocks, students constructed "roaches." For each roach built, they measured length, surface area, and volume. Finally, we used the data to draw conclusions about the possibility that the roach could even exist.

What we taught stood out to me because both lessons applied grade-appropriate math in engaging problem-solving contexts. The students in the room enjoyed doing the math, even in the middle of the summer, because it was interesting. How we taught the lessons changed my view of teaching. I had grown up in very teacher-centered classrooms. The lessons that we taught let the students take charge of their learning through conjecture, observations, and discussion.

I entered my senior year of college determined to become a teacher with hopes of ultimately becoming a district curriculum coordinator. Ten years into my teaching career in Mississippi, I have no plans to pursue administration. Instead, I train middle school teachers every summer. I often use both the polyhedra lesson and the roach problem. I always choose lessons in which the students are responsible for their own learning, modeling the methods I first learned as an SPS intern. //

MORE INFORMATION

For more information about Lauren's experience as an SPS intern, visit her intern page at www.spsnational.org/programs/internships/2002/glas.htm.

SUPPORTING SCIENCE

FROM SCIENCE RESEARCH TO SCIENCE JOURNALISM: HOW AN INTERNSHIP SPARKED MY CAREER TRANSITION

by Katie Peek, 2002 SPS intern, currently an information graphics editor at *Popular Science* magazine

Photo courtesy of Katie Peek.

Sometimes the most powerful realizations are the slowest to materialize. It took me years—and writing this essay—to realize what I really learned at my SPS internship in the summer of 2002. I had just graduated from Mount Holyoke College, and it was my third time with a summer gig. I would spend the summer at NASA Goddard Space Flight Center in Greenbelt, MD, researching if there was enough dust near the Sun to damage a spacecraft.

I knew what I was supposed to get out of the internship: some research expertise, some new connections, and a line on my CV. And I got those things, for sure. But I also started down a path that eventually led me away from astronomy research altogether.

Two summers earlier, I had worked at Cornell University in Ithaca, NY, through the Research Experiences for Undergraduates (REU) program. The Cassini mission was scheduled to reach Saturn in four years.

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Working with a ring-system expert, I used a simulation of Cassini's path around Saturn to flag interesting geometries, angles, and perspectives that the team might want to know about in advance of the spacecraft's arrival.

I used the foundation I built at Cornell the next summer when I worked at the Lunar and Planetary Institute in Houston, TX. There, my adviser and I put together a numerical simulation of Saturn's ring system. To test the hypothesis that the rings formed after the breakup of a moon, we simulated whether a dense, narrow ring of material could dissipate into a ring system. (The answer was an unsatisfying "maybe.")

For a student at a small liberal arts college, these two internships were windows into big research-heavy astronomy departments. The experiences made me want to become a big research-heavy astronomer. So I got a PhD at the University of California, Berkeley, to do just that.

But I'm not a working as a research astronomer today. I create the information graphics at *Popular Science* magazine. That transition was slow—it involved a lot of soul-searching and a second degree in science journalism from New York University—but the germ of it came from my third internship. At SPS.

Unlike the interns I had met during my previous summers, SPS interns took communication just as seriously as research. Two interns spent the summer designing kits for SPS chapters to use in their outreach programs. One was my roommate, Lauren Glas (now Lauren Zarandona—check out her story on p. 16). She was totally dedicated to physics teaching and science policy. I had done a bit of outreach with my SPS chapter, but I found her passion impressive.

We were particularly inspired by a trip we made to Capitol Hill to visit a science subcommittee meeting. I don't remember what the topic was, or even if the event took place in the House or the Senate, but I do remember the two of us on the bus back to our dorm, discussing just how much work it takes to make science possible. That chamber was crowded with people who, for the most part, weren't scientists. But they worked passionately to create a home for science in the United States.

I like to think that today I help create a home for science by making data beautiful and engaging. It only took me most of a decade to make that summer's realization my reality. **//**

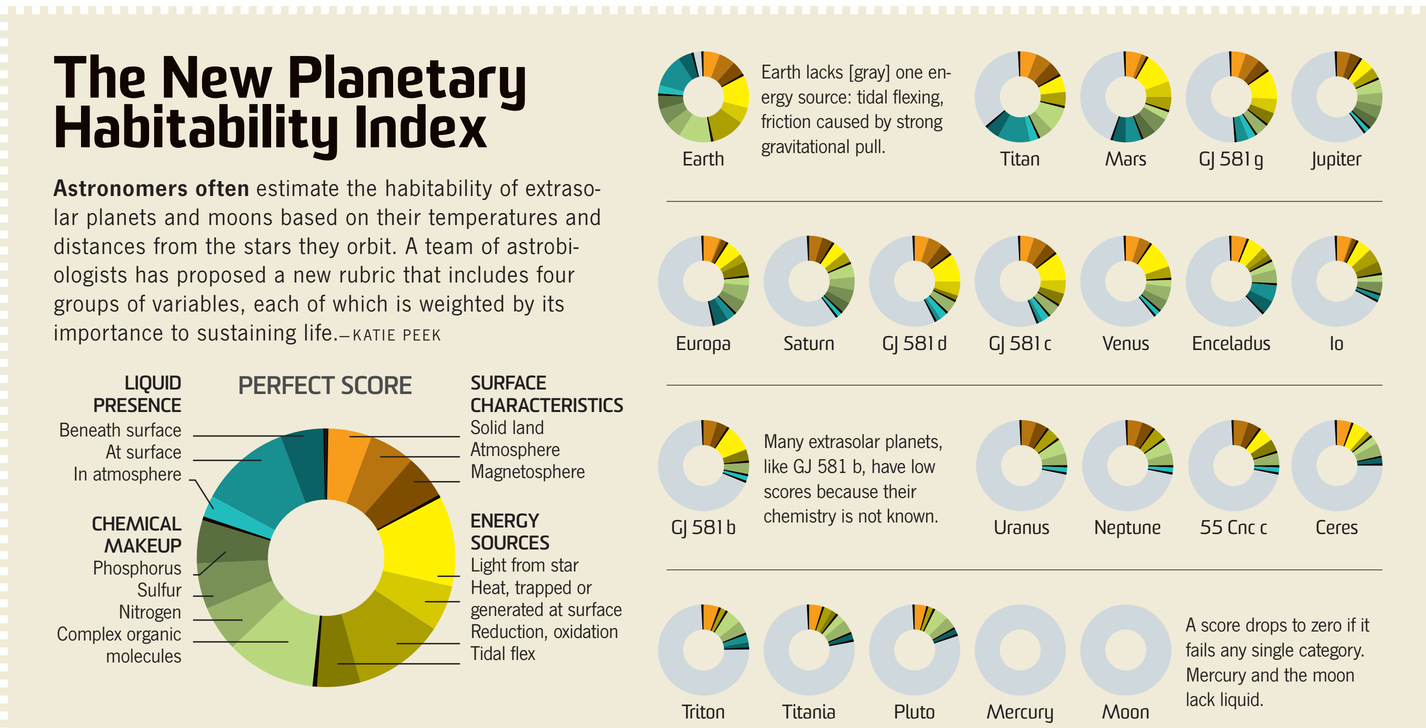
MORE INFORMATION

For more information about Katie's experience as an SPS intern, visit her intern page at www.spsnational.org/programs/internships/2002/peek.htm.

KATIE PEEK on the first day of her 2002 SPS internship at the NASA Goddard Space Flight Center. Photo by Liz Dart Caron.

GRAPHICALLY SPEAKING

Katie Peek designed the info graphic shown below for *Popular Science* magazine—view more of her work on her portfolio website: http://portfolio.katiepeek.com.



Source: Schulze-Makuch et al., "A Two-Tiered Approach to Assessing the Habitability of Exoplanets," Astrobiology, November 2011.

2013 SUMMER REFLECTIONS

BUILDING CONNECTIONS THROUGH INTERNSHIPS

BY KATHERINE STANKUS, 2013 MATHER PUBLIC POLICY INTERN, CLASS OF 2013 AT PORTLAND STATE UNIVERSITY IN OREGON

My summer internship with the Society of Physics Students was a wonderful experience. As a Mather Public Policy Intern, I not only learned how science policy is conducted at the national level but also furthered my career interests.

Working with the US House of Representatives Committee on Science, Space, and Technology allowed me to see firsthand how things are done on Capitol Hill. I conducted research for staff members, attended hearings and markups, and learned the importance of being an involved and informed citizen. In addition to my internship duties, I also had the opportunity to meet congressional representatives, go to receptions and luncheons held on the Hill, and spend time with influential people.

The diverse summer internships SPS provides help to demonstrate the different career paths a physics student can pursue besides academia and research. Participating students were also able to meet other physics students from across the country and live in Washington, DC, for the summer, which was exciting for me as a West Coaster. On the weekends, the other interns and I explored DC tourist attractions such as the Smithsonian museums and the monuments. We watched Fourth of July fireworks from the National Mall, went to a Washington Nationals baseball game, attended a classical music concert at the Kennedy Center, saw the band She and Him live, ate breakfast at the US House of Representatives dining room with Rep. Bill Foster and Physics Nobel laureate John Mather, met Bill Nye, and toured the city on Segways.

Having graduated, I now plan to work for a couple of years in my field. I have returned to the Pacific Northwest and begun to apply for jobs related to my interests in environmental issues such as atmospheric science, climate change, clean energy technologies, and science policy. My internship helped to solidify my desire to find a career that will contribute to finding solutions to global environmental problems.

I met so many wonderful people this summer and had so many great experiences. I encourage all undergraduate physics students to apply for the Society of Physics Students summer internship program. //

JOHN MATHER, STANKUS, SPS INTERN NIKKI SANFORD, AND REP. BILL FOSTER (left-to-right) stand on the steps of the United States Capitol. Photo courtesy of Katherine Stankus.

STANKUS (middle) and SPS intern Nikki Sanford pose with Bill Nye the Science Guy. Photo courtesy of Katherine Stankus.

BY JOSE AVILA, 2013 AIP CAREER PATHWAYS PROJECT INTERN, CLASS OF 2014 AT KING UNIVERSITY IN BRISTOL, TN

At the beginning of the summer I could not imagine what my internship in the capital of the United States, working with the American Institute of Physics (AIP) and SPS, was going to be like. I knew I was going to meet a lot of people. I knew I would need to catch on to a new rhythm of work and get accustomed to my boss's expectations. I knew I was going to be very busy.

But I, for sure, did not know how much fun I would have—how many great people I would be working and living with, how important and useful the project I worked on would be for physics undergraduates and other students, and what a great experience I would take away from this opportunity.

I learned how to apply my physics skills and knowledge to the AIP Career Pathways Project, which develops resources for students going into the STEM (science, technology, engineering, and mathematics) workforce. I had heard about career preparation in school but had never gone into as much detail as I did this summer. I researched related topics and talked to people about them, I analyzed ideas, I rewrote resources several times, and finally, I had them reviewed by my mentors and bosses.

I think my contribution will help students looking for a job, as well as undergraduate students undecided on their major. Career services centers in universities can use the resources as recruiting tools to draw more students to physics and STEM.

There was so much I took away from this summer internship with SPS. The friends and contacts I made will be very important for my future plans. We shared the same interests and some of the same experiences as we worked and lived together and learned about each other. And, of course, we all share one fundamental interest: PHYSICS. //

RO AVILA watches fireworks on the Fourth of July from the National Mall. Photo courtesy of Ro Avila.

PLAN YOUR SUMMER NOW!

The two best places for undergraduate physics students to find summer opportunities:
The Nucleus: www.the-nucleus.org/research
SPS Jobs: http://jobs.spsnational.org

SEVERAL OF THE 2013 SPS INTERNS gather after an outreach event. Photo courtesy of Toni Sauncy.

2013 SPS INTERNS pose for a photo during a tour of NIST (National Institute of Standards and Technology). Photo by Kendra Redmond.

ICPS: No Pressure

ATTENDING THE 2013 INTERNATIONAL CONFERENCE OF PHYSICS STUDENTS (ICPS), AUGUST 15–21, IN EDINBURGH, SCOTLAND

by John Lurie, Class of 2013 at Georgia State University in Atlanta

At ICPS, most of the talks were given by students. Many of those physicists of the future, including me, had never given a talk at a conference before—so some of us were, understandably, a little uneasy.

But there was much less pressure at ICPS than at a typical conference. As Chris Hooley of the University of St. Andrews reminded the attendees, ICPS is special because virtually everyone in the audience is a student as well. It's an excellent training ground for perfecting presentation skills in a professional environment. Guest lectures by professors even provide examples for students to follow (my favorite explored the manipulation of microscopic objects using light).

Organized by the student-run International Association of Physics Students (IAPS), the event featured about 70 student talks covering a wide range of topics in physics and applied physics. Its more than 250 attendees came from over 30 countries. Most were from Europe, but some students were from Brazil, Egypt, Mexico, and Morocco. Five had traveled from the United States, including myself and Patrick Donnan, the other recipient of the 2013 SPS Outstanding Student Award for Undergraduate Research.

The conference also put on great social and professional networking events. I attended a céilidh, a traditional Gaelic party that featured a bagpiper and lessons in Scottish dancing. I did my best to keep up, despite my two left feet. Seeing several hundred physics students from all over the world attempt to dance like the Scots (with varying degrees of success) was really enjoyable.

When attendees prepared the cuisine of their respective countries for an international night, I was even able to share some of my own culture—helping to prepare grits, a corn porridge that is a popular breakfast food in the South. At the social events I got a chance to talk with other attendees about their research and their experiences as students. I found it was often easier to appreciate someone's research after talking one on one, when background information and details could be discussed.

We also had a significant amount of free time to explore the city. It felt special to walk the same streets as great Scottish scientists such as Thomas Henderson, the first Astronomer Royal for Scotland. He was the first to measure the distance to the Alpha Centauri star system, and I like to think of my astronomy research, which focuses on measuring distances to nearby stars and looking for planets around them, as part of the continuation of Henderson's work.

Throughout the conference, I was struck by the similarities between the students I met. Physics provides us with a way of approaching problems that transcends political and cultural boundaries. Meeting so many friendly and enthusiastic physicists has inspired me to look for research and work opportunities abroad. If you want to travel, learn about physics, and have a lot of fun all at the same time, then you should make your way to the next ICPS! //

Meeting so many friendly and enthusiastic physicists

HAS INSPIRED ME TO LOOK FOR RESEARCH AND WORK OPPORTUNITIES ABROAD

JOHN LURIE pauses for a snapshot on top of Edinburgh Castle. Photo courtesy of John Lurie.

MORE INFORMATION

John Lurie and Patrick Donnan of Auburn University in Alabama received all-expenses paid trips to ICPS as winners of the 2013 SPS Outstanding Student Award for Undergraduate Research, the most prestigious award SPS has for students. You can read both of their research abstracts and full meeting reports online at www.spsnational.org/programs/awards/2013/OSA/index.htm. Interested in applying for the 2014 Outstanding Student Award? Visit www.spsnational.org/programs/awards/

NEXT UP

The next ICPS will take place in Heidelberg, Germany, August 10-17, 2014. For details, visit http://icps2014.com.

SACNAS: Changing the Face of Science

PHYSICS AT THE 2013 SOCIETY FOR ADVANCEMENT OF CHICANOS AND NATIVE AMERICANS IN SCIENCE NATIONAL CONFERENCE IN SAN ANTONIO, TX, OCTOBER 3–6, 2013

by Daniel Golombek, SPS staff

Photo courtesy of Juan Burciaga.

Celebrating its 40th anniversary, the Society for Advancement of Chicanos and Native Americans in Science (SACNAS) held its annual meeting in October, drawing more than 3,000 students, faculty, and industry members from groups currently underrepresented in science, technology, and engineering. Amidst the sea of biologists and health scientists that attended, there were about 100 physics students (undergraduate and graduate). SPS staff Daniel Golombek and Toni Sauncy joined them and participated in a special event just for physics majors, sponsored by the National Society of Hispanic Physicists (NSHP).

"Physics Day" was held the day before the start of the SACNAS conference and hosted by the Department of Physics and Astronomy at the University of Texas at San Antonio (UTSA). The program included several talks and laboratory tours. Chris Packham, a faculty member in the department, gave a science talk on looking back in time with astronomy. Sauncy, who is the director of SPS and Sigma Pi Sigma, spoke about the AIP Career Pathways project, aimed at helping undergraduates enter the STEM workforce after completing their bachelor's degree. Ramón López of the University of Texas at Arlington discussed options for students aiming for graduate school.

One group of students then toured the Southwest Research Institute (SwRI), visiting a clean room where space-bound equipment is developed and tested. The visitors interacted with two SwRI staff scientists who shared their academic and research experiences. Another group visited the UTSA laboratory facilities, where their tour started with a lesson in the UTSA Kleberg Advanced Microscopy Center. The center's director, Arturo Ponce-Pedraza, provided a short introduction and demonstrated the capabilities of the equipment. The students reunited on the bus ride back to the conference center, exchanging stories with great enthusiasm.

THE CORE OF THE MEETING WAS THE **scientific symposia**

After this exciting prelude, the full SACNAS meeting began, featuring oral talks, poster presentations, career workshops, and professional development sessions. The core of the meeting was the scientific symposia, a dozen or so concurrent sessions in the mornings and afternoons. Other sessions were tailored to different audiences, offering, for example, academic career path sessions for undergraduates, networking advice for graduate students, mentoring workshops for postdocs, as well as workshops to explore career paths in industry, government, and nonprofits for professionals. SACNAS staff and volunteer leadership conducted a session on creating and invigorating chapters within the organization.

"Conversations with Scientists," 20 informal roundtable discussions between students and professionals in discipline-specific gatherings, took place after dinner on the first day of the conference. These discussions were well attended and allowed students to learn more about their chosen majors. Many of the conversations centered on issues related to career paths, such as how to pursue a graduate degree and how to choose a school. More than 60 students and 10 faculty or postdocs attended a physics and astronomy/astrophysics roundtable. Their conversations lasted almost three hours, well into the night. //

ABOUT SACNAS

SACNAS is a society of scientists dedicated to fostering the success of Hispanic/Chicano and Native American scientists, from college students to professionals, to attain advanced degrees, careers, and positions of leadership.

SACNAS' goals are to increase the number of Hispanics/Chicanos and Native Americans with advanced degrees in science and their motivation to be leaders; to increase the number of Hispanics/Chicanos and Native Americans in science research, leadership, and teaching careers at all levels; and to increase governmental commitment to advancing Hispanics/Chicanos and Native Americans in science, resulting in increased resources, elimination of barriers, and greater equity.

Learn more at http://sacnas.org.

NEXT UP

The next SACNAS National Conference will take place in Los Angeles, CA, October 15-19, 2014. For details, visit http://sacnas.org/events/national-conf.

AAPT: A Journey into the National Physics Community

ATTENDING THE AMERICAN ASSOCIATION OF PHYSICS TEACHERS (AAPT) SUMMER MEETING 2013, JULY 13–17, IN PORTLAND, OR

by Scott Gimbal, Class of 2014 at California State University, Chico

At the California State University, Chico, our SPS chapter has a new initiative: to send all of our members to present at a national conference at least once during their undergraduate career. This summer, nine of our members fulfilled this goal at the AAPT meeting in Portland, OR. We hoped to soak up knowledge and experience from the other undergraduates, physics teachers, graduate students, and vendors attending the conference. And we certainly did!

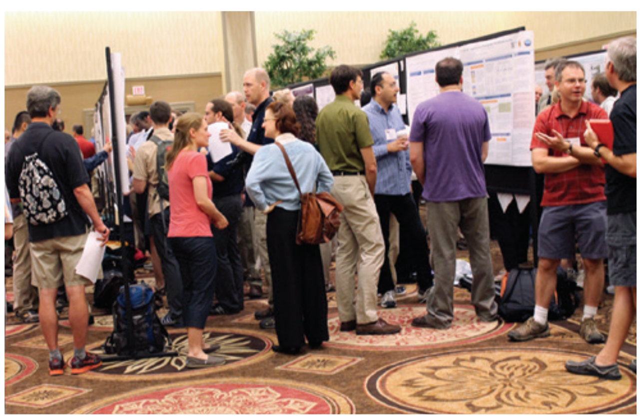
To meet other attendees, we stopped by the "first timers" gathering and the speed networking sessions. We also attended workshops covering a variety of physics topics that complemented the various topics each of us had been working on. These events provided casual forums in which we could talk to new people we had not run into during presentations and poster sessions. One of our members met a professor from Mexico who was trying to get his department on the map. Another member talked about condensed matter theory with a graduate student.

One of our research groups had designed a new way to measure Earth's magnetic field for the lower division electricity and magnetism laboratory. They entered their device in an apparatus competition in which each entry was judged on many aspects, including the concept, the design, and the price point. We thoroughly enjoyed investigating all of the submitted apparatuses and conversing with groups from other schools. The winner of the competition had built his own data acquisition device for less than $100!

Some of us presented our work on physics education in the general poster sessions. I presented a poster about an upper division undergraduate laboratory experiment that involves the complex indices of refraction. Another member of our chapter showed that a student's understanding of a laboratory experiment improves if that student is shown a video of the lab before beginning the experiment. Presenting our studies provided us with valuable experience in conveying our ideas and work to passersby. We found exploring the AAPT poster sessions to be inspiring and motivational because we were able to see what other people had been doing in the field.

A few of us who had participated in summer Research Experiences for Undergraduates (REU) programs entered the SPS poster session competition. This was a competition for undergraduate physics students only. The posters were judged on criteria such as content and presentation. At this competition we met some of the people from the national office of SPS. Later, at an SPS reception, we met SPS members and physics students from across the country and learned how to get involved in SPS on the national scale.

Given how successful this conference was for us, our chapter plans to send members to give presentations at the next AAPT meeting. We also are very excited to get involved in SPS at the regional level by sending representatives to the next zone 18 meeting. We encourage you to do the same and hope to see you at future meetings! //



MEMBERS OF THE CALIFORNIA STATE UNIVERSITY, CHICO, SPS CHAPTER look at light sources through diffraction glasses (left). Photo courtesy of Scott Gimbal. AAPT meeting attendees mingle during a poster session (right). Photo courtesy of AAPT.

NEXT UP

The next AAPT Summer Meeting will take place in Minneapolis, MN, July 26–30, 2014. There will also be an AAPT Winter Meeting in Orlando, FL, January 4–7, 2014. For details, visit www.aapt.org/Conferences.

Diffraction, Part 3

CURVED WAVEFRONTS AND FRESNEL DIFFRACTION

by Dwight E. Neuenschwander, Southern Nazarene University

When Thomas Young presented his wave theory of diffraction before Great Britain's Royal Society on January 16, 1800, it was coolly received. One historian of physics writes[1]

> *"...the wave theory might have suffered sterility and oblivion had not sounder critics revived it in France. In 1815 Augustin Fresnel, a brilliant young military engineer and mathematician, submitted to the Academy a paper on diffraction, which, as was the custom of that learned body, was reported upon by two members—François Arago and Louis Poinsot. The former took up the matter with great enthusiasm and drew Fresnel's attention to the almost identical views of Young published fifteen years previously. Although this was the year of the battle of Waterloo, Fresnel paid a generous tribute to Young and they corresponded frequently until the year 1827 when the death of the former put an end to a career full of great promise."*

Parts 1 and 2 of this series[2,3] considered diffraction produced by plane wave fronts—Fraunhofer diffraction. Its signature phenomena include Young's famous double-slit experiment, which demonstrated the wave nature of light. But of course there is more to the story. An unobstructed wave front radiating from a point source forms an expanding spherical surface. Fresnel diffraction takes into account this spherical shape, and I would be remiss to not discuss it, and show how to derive it, in this summary of the basic elements of diffraction theory.

As in the plane wave paradigm, Huygens' principle forms the working tool for understanding Fresnel diffraction. The principle holds that each infinitesimal patch of surface on a primary wave front may be considered the source of a secondary wave. The signal subsequently detected at a point P beyond the surface is the superposition of those secondary waves that reach P.

Consider a point source S that radiates a monochromatic wave of angular frequency ω, so that the signal leaving S is proportional to $\cos(\omega t)$. It is sufficient to consider a monochromatic harmonic wave because, so long as the wave equation is linear, any wave can

AS IN THE PLANE WAVE PARADIGM, HUYGENS' PRINCIPLE FORMS

the working tool in Fresnel diffraction

be written as a superposition of harmonics. Picture the spherical wave front when it has expanded to radius ρ, and formed a spherical surface σ. Because of energy conservation, the amplitude of a spherical wave drops off as the inverse of the distance from the source. The spherical wave front at σ carries time-dependence $\cos[\omega(t-\rho/c)]$ with amplitude $\sim 1/\rho$, as described by the wave function

$$\psi(\rho,t) = \frac{\mathcal{E}_o}{\rho}\cos(k\rho - \omega t) \qquad (1)$$

where $k = 2\pi/\lambda$ denotes the wavenumber, and λ the wavelength. The coefficient $\mathcal{E}_o$, determined by the source's luminosity L, will be considered known; in particular, for a light wave, $\mathcal{E}_o = \sqrt{(L/2\pi\epsilon_o c)}$.[4]

On another spherical surface σ' centered on S but having radius $\rho + r_o$ (see Fig. 1), i.e. a surface that includes point P, Eq. (1) says that for the wave front passing over P,

$$\psi(\rho + r_o, t) = \frac{\mathcal{E}_o}{\rho + r_o}\cos[k(\rho + r_o) - \omega t]. \qquad (2)$$

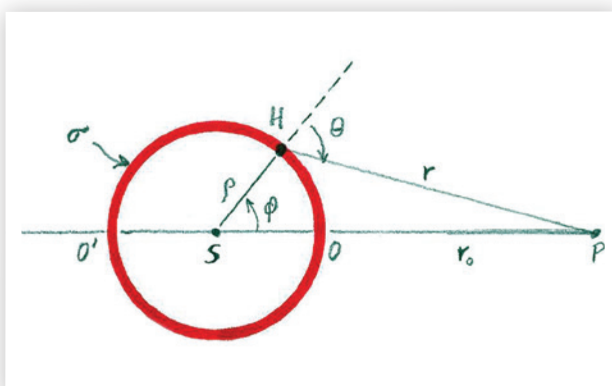


FIG. 1: The geometry of the Fresnel diffraction analysis. Please note the distances $\rho = \overline{SH}$, $r = \overline{HP}$, $r_o = \overline{OP}$, the angles φ and θ, and the annular ring of area $da = (2\pi\rho\sin\varphi)(\rho\, d\varphi)$.

Now return to Huygens' principle. Each little patch of area on the spherical surface σ, such as the one at a typical point H as shown in Fig. 1, serves as a source of a secondary wave. The signal increment $d\psi$ that leaves H at time zero arrives at P at time $t > 0$ with an amplitude modified from that of Eq. (1), is

$$d\psi(H \rightarrow P) = \frac{\mathcal{E}_H\, K(\theta)\, da}{r} \cos\left[k(\rho + r) - \omega t\right] \quad (3)$$

where $\mathcal{E}_H$ depends on $\mathcal{E}_o$; relating them forms one of our tasks. The factor $K(\theta)$ (see θ in Fig. 1), called the "obliquity factor," was originally included *ad hoc* by Fresnel because of his intuition that the amplitude of the signal that makes it from H to P depends on θ. To see the need for this, look at the extremes on the surface σ. The *da* at O will assuredly send signal towards P, but signal radiated from the *da* located at O' never arrives at P. Evidently, $K(0) = 1$ and $K(\pi) = 0$. A function that exhibits this behavior is

$$K(\theta) = \frac{1}{2}(1 + \cos\theta). \quad (4)$$

But until demonstrated rigorously, this expression merely offers a plausible candidate for describing Fresnel diffraction. We may assume, however, that $K(\theta)$ will change very slowly especially for small θ because $\cos\theta \approx 1 - \frac{1}{2}\theta^2$. Although Fresnel's intuition was sound, an obliquity factor derived with rigor had to await some 60 years, until Gustav Kirchhoff published in 1883 a diffraction theory based on the differential equations of waves.

The conceptual distinction between Eqs. (2) and (3) raises basic questions: Why bother with the Huygens surface σ in the first place? Why not merely go with Eq. (2) and be done with it? After all, integrating Eq. (3) over σ must reproduce Eq. (2).

That's a good question. If spherical waves always traveled unobstructed from S to P then Huygens' principle would indeed be a redundant complication. But neither would there be much interest in diffraction, where the interesting results arise in the interactions of waves and apertures. The superposition of Huygens secondary waves *that get through an aperture* makes possible the calculation of diffraction patterns. The aperture problem is what we intend to solve, taking into account the curvature of the wave front. Thus the spherical wave front of interest will be the one with a radius ρ that places its surface at the aperture.

FRESNEL ZONES

At first glance, our task may appear rather simple. To predict the diffraction pattern produced by an aperture, we could merely integrate Eq. (3) over limits defined by the aperture boundary, it would seem. However, the finite speed of the wave (e.g., *c* for light) offers a subtle complication. Let's approach it this way: If the source S emits a flash of light of infinitesimal duration, in the reference frame of S that flash arrives at all points on σ at a time we may set to zero. What does the observer at P (assumed to be at rest with respect to S) detect? Nothing at all for $0 < t < r_o/c$. Then at the time r_o/c the first light arrives at P, the light from point O. After the signal from O sweeps by, subsequent signals arrive later at P from other locations on σ. A secondary signal leaving a point on σ at the distance *r* from P (see Fig. 1) arrives at $t = r/c$. The last light to arrive at P from σ occurs as $t \rightarrow (r_o + 2\rho)/c$, when some fraction of the signal from the "back side" of the sphere makes it to P (signal from O′ at θ = π never reaches P). How do we account for this time delay when S emits a sinusoidal wave continuously? Here the *Fresnel zones* fall readily to hand.

The Huygens analysis of spherical wave fronts with strengths that oscillate harmonically proceeds by partitioning σ into a set of Fresnel zones centered on the "north pole" at O. By definition, the vibrations from the inner and outer boundaries of a zone are half a cycle out of phase when they arrive at P. To map them in terms of the *r* of Fig. 1 and the wavelength λ, let $r_1 = r_o + \lambda/2$, $r_2 = r_o + \lambda$, $r_3 = r_o + 3\lambda/2$, etc. All points on σ for which *r* lies between r_o and r_1 are within the first Fresnel zone, those for which $r_1 \le r \le r_2$ lie in the second Fresnel zone, and so on.

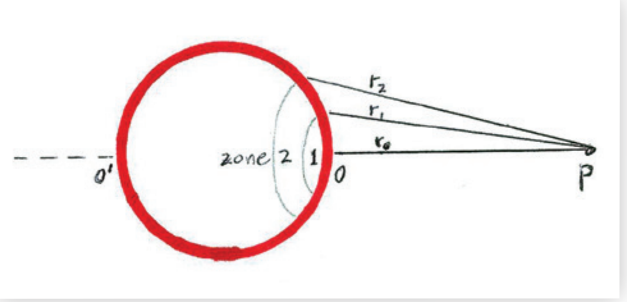


FIG. 2: Fresnel zones.

Consider the situation when S continuously emits a sinusoidal wave. Suppose that at time $t = r_o/c$ a wave crest from O sweeps over P. At the same instant, a wave trough from r_1 will be passing through P, and another wave crest from r_2 will be at P, and so on. At any time, the signals arriving at P from boundaries of adjacent Fresnel zones will be half a cycle out of phase. Their amplitudes at P diminish with larger r_n, thanks to the varying *r* and the obliquity factor.

Let us prepare to integrate Eq. (3). For an infinitesimal area *da* consider an annular ring on Fig. 1 for which $da = (2\pi\rho \sin\varphi)(\rho\, d\varphi)$. For fixed ρ, *da* may be written terms of *r* with the help of the law of cosines applied to triangle SHP,

$$r^2 = \rho^2 + (\rho + r_o)^2 - 2\rho(\rho + r_o)\cos\varphi, \text{ for} \quad (5)$$

from which

$$da = \frac{2\pi\rho r\, dr}{\rho + r_o}. \quad (6)$$

Now consider an aperture of area Γ, located at O and oriented with the aperture plane perpendicular to the SP axis. The number of Fresnel zones *N* (assumed for simplicity to be an integer) that pass through the aperture follows from

$$A_1 + A_2 + \cdots A_N = \Gamma \quad (7)$$

where A_n denotes the area of the *n*th Fresnel zone. Its value follows by integrating Eq. (6) from r_{n-1} to r_n, so that

$$A_n = \frac{\pi\rho\lambda r_o}{\rho + r_o}\left[1 + \frac{\lambda}{4r_o}(2n + 1)\right]. \quad (8)$$

Whenever $\lambda \ll r_o$ (typical for visible light and macroscopic apertures), then A_n becomes approximately independent of *n*:

$$A_n \approx \frac{\pi\rho\lambda r_o}{\rho + r_o}. \quad (9)$$

For instance, with a circular aperture of radius a, Eq. (7) gives

$$N = \frac{\pi a^2}{A_1} = \frac{a^2}{\lambda}\left(\frac{1}{\rho} + \frac{1}{r_o}\right). \quad (10)$$

Numerically, if $\rho = r_o = 1$ m, $\lambda = 600$ nm, and $a = 1$ mm then $N \approx 3$; but if $a = 1$ cm then $N = 333$. Seen another way, if $\rho = r_o$ then the distance r_o that allows only the first Fresnel zone to pass is $r_o = \frac{2a^2}{\lambda}$, which, for $a \sim 1$ mm and $\lambda \sim 500$ nm gives $r_o \sim 4$ m! At larger values for r_o and ρ, only a fraction of the first Fresnel zone, approximately flat, passes through the aperture. The situation reduces to the Fraunhofer diffraction of plane waves for which $\rho \to \infty$.

Before continuing discussion with this or that aperture, let us investigate the contribution at P of just one Fresnel zone. The signal ψ_n arriving at P from the nth Fresnel zone follows by integrating Eq. (3) over that zone only:

$$\psi_n = \frac{2\pi\rho\mathcal{E}_H}{\rho + r_o}\int_{r_{n-1}}^{r_n} K_n(\theta)\cos[k(\rho + r) - \omega t]\,dr \quad (11)$$

where in general θ is a function of r. But $K(\theta)$ varies slowly with θ, so it may be safe to assume that, *within* any single Fresnel zone, its obliquity factor K_n is approximately constant. Then Eq. (11) can be integrated at once:

$$\psi_n = \frac{2\pi\rho\mathcal{E}_H K_n}{k(\rho + r_o)}\left[\sin(\alpha + n\pi) - \sin[\alpha + (n-1)\pi]\right]$$

$$= K_n\,(-1)^{n+1}\,\psi_1 \quad (12)$$

where $k = 2\pi/\lambda$, $\alpha = k(\rho + r_o) - \omega t$, and

$$\psi_1 = \frac{2\rho\lambda\mathcal{E}_H}{\rho + r_o}\sin[k(\rho + r_o) - \omega t]. \quad (13)$$

As we anticipated, the signal $\psi_{(N)}$ that passes through P at time t, coming from Fresnel zones 1 through N, forms an alternating series:

$$\psi_{(N)} = \psi_1 \sum_{n=1}^{N} (-1)^{n+1} K_n(\theta)$$

$$= \psi_1\,[K_1 - K_2 + K_3 - \ldots + (-1)^{N+1}K_N]$$

$$\equiv \psi_1 Z_N. \quad (14)$$

Because K_n varies slowly with θ, we may assume that $K_{n+1} \approx K_n$. In that case, should N be an even number, then $\psi_{(N)} \approx 0$. But for odd N one obliquity factor survives. The K_n are not all *exactly* equal, because $K(\theta)$ *does* diminish with increasing θ. This ambiguity presents us with a technical problem. Consider, for example, the case $N = 5$, for which

$$Z_5 = K_1 - K_2 + K_3 - K_4 + K_5\,. \quad (15)$$

To make use of the near-cancellation of adjacent obliquity factors, should Z_5 be grouped as

$$Z_5 = (K_1 - K_2) + (K_3 - K_4) + K_5 \approx K_5, \quad (16)$$

or as

$$Z_5 = K_1 - (K_2 - K_3) - (K_4 - K_5) \approx K_1, \quad (17)$$

or in some other way? In the absence of an explicit obliquity factor the sum is ambiguous. Pending a justification of a result like Eq. (4), we have to make use of the decreasing nature of $K(\theta)$ and consider averages under various alternative grouping scenarios. Requiring consistency offers as an estimate the median value between the first and last obliquity factors[5]

$$Z_N \approx \frac{1}{2}(K_1 + K_N). \quad (18)$$

The intensity (or "irradiance") at P is proportional to $|\psi|^2$. Slide the detector (move point P) along the SP axis, and a series of intensity maxima and minima appear as $\psi_{(N)}$ passes through successively odd and even values of N.

Since adjacent Fresnel zones tend to cancel one another, Fresnel zone plates can be constructed, typically by photographic reduction. These are masks consisting of concentric opaque rings that block out either the even Fresnel zones or the odd ones. For example, should all the even zones be blocked and an aperture allow no more than 10 zones to pass, then the total signal arriving at P would be that of the odd-numbered zones 1 through 9. Assuming all their obliquity factors to be near unity,

$$\psi \approx \psi_1 + \psi_3 + \psi_5 + \psi_7 + \psi_9. \quad (19)$$

Since each $\psi_n \approx \psi_1$ for small n, in this example $\psi \approx 5\psi_1$, giving an intensity 25 times that of the first Fresnel zone by itself![6]

A special case of an aperture would be no aperture at all! Then N becomes very large. The number of Fresnel zones across the entire sphere is $N_{all} = 4\rho/\lambda$, which follows by counting the Fresnel zones between O ($r = r_o$) and O' ($r = r_o + 2\rho$). For instance, $N \sim 10^5$ for a sphere of 1 cm radius with $\lambda = 400$ nm. At least for waves in the optical portion of the spectrum, including all the Fresnel zones across the entire sphere suggests taking the limit as $N \to \infty$. Because $K_\infty \approx K(\pi) = 0$, it follows from Eq. (18) that $Z_\infty \approx \frac{1}{2}K_1$.

So far this result has been shown to hold only for odd N. The case of even N must also be worked out. For large N one finds the same result[5], which might be expected because the difference between one more or one fewer Fresnel zone makes no difference as $N \to \infty$. Therefore all Fresnel zones contributing to the signal at P (no aperture) yields the elegant result

$$\psi_{all} \approx \frac{1}{2}\psi_1 \quad (20)$$

where $K_1 \approx 1$ has been used. About one-quarter of the intensity of the unobstructed wave comes from the first Fresnel zone.

It is interesting to note from Eq. (14), that by separating the first Fresnel zone's contribution from all others,

$$\psi_{(N)} = \psi_1 + \psi_{(N>1)} \quad (21)$$

then for large N and from Eq. (20) it follows that $\psi_{(N>1)} \approx -\frac{1}{2}\psi_1$. Blocking out the first zone of an otherwise unobstructed wave produces a wave function inverted relative to ψ_1 and carrying half its amplitude. This is the Fresnel diffraction version of the famous Poisson spot, mentioned earlier[3] in the context of its Fraunhofer analog that applied Babinet's principle.

Now we can relate the $\mathcal{E}_H$ of Eq. (3) to the $\mathcal{E}_o$ of Eq. (2). Using Eqs. (13) and (20) and $K_1 \approx 1$, the unobstructed wave function arriving at P, due to all the Huygens secondary sources on σ, is

$$\psi_{all} = \frac{\mathcal{E}_H \rho\lambda}{\rho + r_o}\sin[k(\rho + r_o) - \omega t]. \quad (22)$$

Comparing this amplitude to that of Eq. (2) requires

$$\mathcal{E}_H = \frac{\mathcal{E}_o}{\rho\lambda} \quad (23)$$

so that, for the unobstructed wave,

$$\psi_{all} \approx \frac{\mathcal{E}_o}{\rho + r_o}\sin[k(\rho + r_o) - \omega t]. \quad (24)$$

There remains the difficulty of the $\pi/2$ phase shift between the cosine in Eq. (2) and the sine in Eq. (24). We leave its resolution as a question for the Kirchhoff theory (see Appendix) and turn to diffraction with specific apertures.

FRESNEL DIFFRACTION WITH AN APERTURE

Interference between the Huygens sources emanating from the spherical surface σ produces the wave function that arrives at P. Apply Eqs. (3) and (23), switch to complex notation for the harmonic dependence, and we obtain

$$d\psi = \frac{\mathcal{E}_o K(\theta) da}{\rho\lambda r}\, e^{i[k(\rho + r) - \omega t]} \quad (25)$$

which will be integrated to find the contribution to the signal at P that comes from the Fresnel zones allowed pass through the aperture. In Eq. (25) the area *da* is a patch of area on the sphere σ, but the aperture is presumably a plane. However, where the sphere σ intersects the aperture in the plane of the aperture, the aperture boundary forms the limits of integration. Towards this end we construct an *xy* coordinate system in the aperture plane, with the origin lying at the intersection of that plane and the SP axis. Note in Fig. 3 the distinction between ρ and ρ_o, the latter being the distance from S to the origin of the aperture plane.

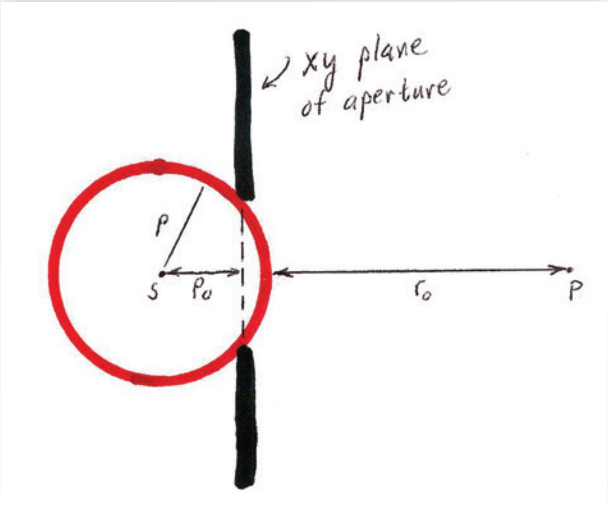


FIG. 3: A spherical wave front passing through the aperture of area Γ, and the area da.

In Eq. (25) we may approximate $\rho \approx \rho_o$ and $r \approx r_o$ in the *amplitude*. However, the *phase* is far more sensitive to small differences in distances. From Fig. 3, the Pythagorean theorem followed by the binomial expansion gives

$$\rho = (\rho_o^2 + x^2 + y^2)^{\frac{1}{2}} \approx \rho_o + \frac{x^2 + y^2}{2\rho_o} \quad (26)$$

and

$$r = (r_o^2 + x^2 + y^2)^{\frac{1}{2}} \approx r_o + \frac{x^2 + y^2}{2r_o}. \quad (27)$$

If only a small number of Fresnel zones are allowed to pass through the aperture, the approximation $K(\theta) \approx 1$ may be used for each contributing zone.

Now we are ready to integrate Eq. (25) over the aperture. In terms using rectangular coordinates,

$$\psi \approx \frac{\mathcal{E}_o}{\rho_o \lambda r_o}\, e^{i[k(\rho_o + r_o) - \omega t]} \int_\Gamma e^{i\pi\beta(x^2 + y^2)/2}\, da \quad (28)$$

where

$$\beta \equiv \frac{2(\rho_o + r_o)}{\lambda \rho_o r_o}. \quad (29)$$

From Eq. (1), the wave that *would* have arrived as a spherical wave front at P in the absence of an aperture would have been described by

$$\psi_o \approx \frac{\mathcal{E}_o}{\rho_o + r_o} e^{i[k(\rho_o + r_o) - \omega t]}. \quad (30)$$

Writing $\mathcal{E}_o = \psi_o(\rho_o + r_o)e^{-i[k(\rho_o + r_o) - \omega t]}$ and using Eq. (29) turns Eq. (28) into

$$\psi = \psi_o \frac{\beta}{2} \int_\Gamma e^{i(x^2 + y^2)\pi\beta/2}\, da. \quad (31)$$

The integral modifies the amplitude and phase of ψ_o thanks to the superposition of the portion of σ not blocked by the aperture.

Consider a rectangular aperture. The limits on Eq. (31) become

$$\psi = \psi_o \frac{\beta}{2} \int_{x_1}^{x_2} e^{ix^2\pi\beta/2} dx \int_{y_1}^{y_2} e^{iy^2\pi\beta/2}\, dy. \quad (32)$$

Let $u = x\sqrt{\beta}$ and $v = y\sqrt{\beta}$. Then

$$\psi = \frac{1}{2}\psi_o \int_{v_1}^{v_2} e^{i\pi v^2/2}\, dv \int_{u_1}^{u_2} e^{i\pi u^2/2}\, du. \quad (33)$$

Introduce the *Fresnel integral*[7]

$$\mathcal{Z}(W) \equiv \int_0^w e^{\frac{i\pi s^2}{2}} ds$$

$$\equiv \mathcal{C}(w) + i\mathcal{S}(w) \quad (34)$$

where

$$\mathcal{C}(w) \equiv \int_0^w \cos\left(\frac{\pi s^2}{2}\right) ds \quad (35)$$

and

$$\mathcal{S}(w) \equiv \int_0^w \sin\left(\frac{\pi s^2}{2}\right) ds. \quad (36)$$

Now Eq. (33) may be written

$$\psi = \frac{1}{2}\psi_o[\mathcal{Z}(v_2) - \mathcal{Z}(v_1)][\mathcal{Z}(u_2) - \mathcal{Z}(u_1)]. \quad (37)$$

$\mathcal{Z} = \mathcal{C} + i\mathcal{S}$ is a complex number. Starting at $w = 0$, compute successive values of $\mathcal{C}(w)$ and $\mathcal{S}(w)$, then plot them on the complex plane. This procedure generates the *Cornu spiral*, a phasor diagram (Fig. 4) named after the French physicist Alfred Cornu (1841-1902).

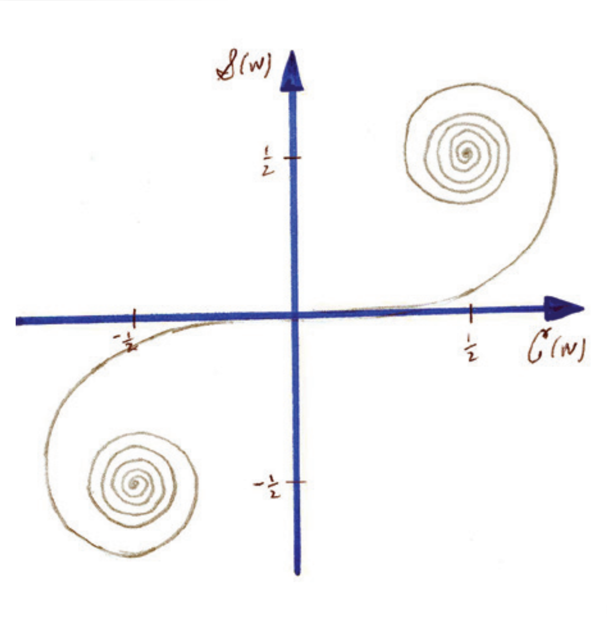


FIG. 4: The Cornu spiral (schematic).

To graphically determine $\mathcal{Z}(b) - \mathcal{Z}(a) \equiv Re^{i\delta}$ draw a straight line connecting $\mathcal{Z}(b)$ and $\mathcal{Z}(a)$. The length of this line is the magnitude $|\mathcal{Z}(b) - \mathcal{Z}(a)| = R$, and δ is the angle the line makes with the real axis.

From the definitions of $\mathcal{C}(w)$ and $\mathcal{S}(w)$, one may easily show that $\mathcal{C}(-w) = -\mathcal{C}(w)$ and $\mathcal{S}(-w) = -\mathcal{S}(w)$, and that $\mathcal{C}(\infty) = \mathcal{S}(\infty) = \frac{1}{2}$.[8] For a consistency check consider no aperture at all: The limits on both x and y go from $-\infty$ to $+\infty$, and Eq. (35) gives the expected intensity, $|\psi|^2/|\psi_o|^2 = 1$.

To map the wave function and intensity pattern off the SP axis—a main objective of diffraction theory— make an $x'y'$ plane parallel to the aperture plane and passing through P, and locate the origin at P. To examine the wave function at $(x',y') = (a',b')$, instead of moving P move the aperture in the reverse direction: Merely translate the origin of the aperture coordinates by the amount $\Delta x = -a'$ and $\Delta y = -b'$. Adjust the limits on the Fresnel integrals, use Eq. (37), and $\psi(a',b')$ results.

A circular aperture of radius a suggests mapping the plane of the aperture in polar coordinates, so that $da = 2\pi r dr$. Now Eq. (31) becomes

$$\psi = \pi\beta\psi_o \int_0^a e^{i\pi\beta r^2/2}\, r\, dr. \qquad (38)$$

Let $z = \pi\beta r^2/2$, so that

$$\psi = \psi_o \int_0^{\beta\pi a^2/2} e^{iz}\, dz$$

$$= 2\psi_o e^{i\pi\beta a^2/4} \sin\left(\frac{\pi a^2\beta}{4}\right). \qquad (39)$$

Minima (maxima) occur when $\pi a^2\beta/4 = m\pi$ where m denotes a positive integer (half an odd integer), which produces a result analogous to the thin lens equation of geometrical optics,

$$\frac{1}{\rho_o} + \frac{1}{r_o} = \frac{1}{f_m} \qquad (40)$$

where $f_m = a^2/2m\lambda$. This exhibits serious chromatic aberration!

There remains the task to confirm with a derivation the behavior of the obliquity factor, $K(\theta)$, and put the whole Huygens-Fresnel approach on a less cobbled-together and more rigorous basis. The main ideas are described in the Appendix, highlighting the principal elements of Kirchhoff's diffraction theory.

APPENDIX: KIRCHHOFF'S DIFFRACTION THEORY

The German physicist Gustav Kirchhoff (1824-1887) derived a theory of diffraction based on the linear wave equation.[9] It uses a standard tool of field theory, Gauss's divergence theorem, which says the integral of the divergence of a vector field **A** over a volume V equals the flux of **A** through the closed surface Σ that forms the boundary of V:

$$\int_V \nabla\cdot\boldsymbol{A}\, d^3r = \oint_\Sigma \boldsymbol{A}\cdot\hat{\boldsymbol{n}}\, da \qquad (A1)$$

where $\hat{\boldsymbol{n}}$ denotes the outward-pointing unit vector normal to Σ on the patch of area da. Consider the case $\boldsymbol{A} = \zeta\,\nabla\eta$ for some scalar fields ζ and η. The divergence theorem gives

$$\int_V [\zeta\nabla^2\eta + (\nabla\zeta)\cdot(\nabla\eta)]\, d^3r = \oint_\Sigma \zeta\frac{\partial\eta}{\partial n}\, da \qquad (A2)$$

where $\frac{\partial\zeta}{\partial n} \equiv (\nabla\zeta)\cdot\hat{\boldsymbol{n}}$ denotes the directional derivative. Interchange ζ and η and subtract the two versions to obtain "Green's identity,"[10]

$$\int_V [\zeta\nabla^2\eta - \eta\nabla^2\zeta]\, d^3r = \oint_\Sigma \left[\zeta\frac{\partial\eta}{\partial n} - \eta\frac{\partial\zeta}{\partial n}\right] da. \qquad (A3)$$

Now connect this fancy mathematics to some physics. For wave propagation let η be a solution to the inhomogeneous wave equation,

$$\nabla^2\eta(\boldsymbol{r},t) - \frac{1}{c^2}\frac{\partial^2\eta(\boldsymbol{r},t)}{\partial t^2} = -4\pi J(\boldsymbol{r},t) \qquad (A4)$$

where J denotes a source density. Maxwell's equations lead to such a wave equation. The total signal is a superposition of harmonics, where each harmonic carries some angular frequency ω. Writing $\eta(\boldsymbol{r},t) = \eta(\boldsymbol{r})e^{-i\omega t}$ and similarly for J, the wave equation becomes the inhomogeneous Helmholtz equation for $\eta(\boldsymbol{r})$,

$$\nabla^2\eta(\boldsymbol{r}) + k^2\eta(\boldsymbol{r}) = -4\pi J(\boldsymbol{r}) \qquad (A5)$$

where $k = \omega/c$. The Helmholtz equation can be solved by the method of Green's functions, for which a function $G(\mathbf{r} - \mathbf{r}')$ is found that solves the Helmholtz equation when J gets replaced by a point source,

$$\nabla^2 G + k^2 G = -4\pi\delta^3(\boldsymbol{r} - \boldsymbol{r}'). \qquad (A6)$$

The Dirac delta function $\delta^3(\boldsymbol{r} - \boldsymbol{r}')$ is the density of a point source (think of a point mass): It vanishes everywhere except at the source itself, where it blows up. Yet its integral is finite (e.g., the integral over all the particle's density equals its mass, whatever its distribution). Thus the Dirac delta may be operationally defined as

$$\int_V f(\boldsymbol{r})\delta^3(\boldsymbol{r}-\boldsymbol{a})d^3r = f(\boldsymbol{a}) \qquad \text{(A7)}$$

provided $\boldsymbol{a}$ lies within V; otherwise the integral vanishes. Once G is found, then η follows from the original source density J, by Green's theorem,[11]

$$\eta(\boldsymbol{r}) = \int J(\boldsymbol{r}')G(\boldsymbol{r}-\boldsymbol{r}')d^3r' \qquad \text{(A8)}$$

where the integral is over all space. As shown in electrodynamics textbooks, the Green's function for the Helmholtz equation, with outward-traveling spherical waves, is a damped oscillation:[12]

$$G(\boldsymbol{r}-\boldsymbol{r}') = \frac{e^{ikR}}{R} \qquad \text{(A9)}$$

where $R = |\boldsymbol{r}-\boldsymbol{r}'|$. In Eq. (A3) let η = G, and let ζ be the "optical disturbance," e.g., the electric potential ψ of the electromagnetic field. With the help of Eq. (A5) in source-free regions, and Eqs. (A6) and (A7), Eq. (A3) becomes

$$\psi(\boldsymbol{r}) = \frac{1}{4\pi}\oint_\Sigma \left[G\frac{\partial\psi}{\partial n} - \psi\frac{\partial G}{\partial n}\right]da. \qquad \text{(A10)}$$

For the surface Σ consider the arrangement of Fig. 5. Σ does not enclose the original wave source S, but it does enclose the point P, and the point H lies on the surface of Σ.

From Eq. (2), on Σ at H,

$$\psi = \frac{\mathcal{E}_o}{\rho}e^{i(k\rho-\omega t)} \qquad \text{(A11)}$$

so that

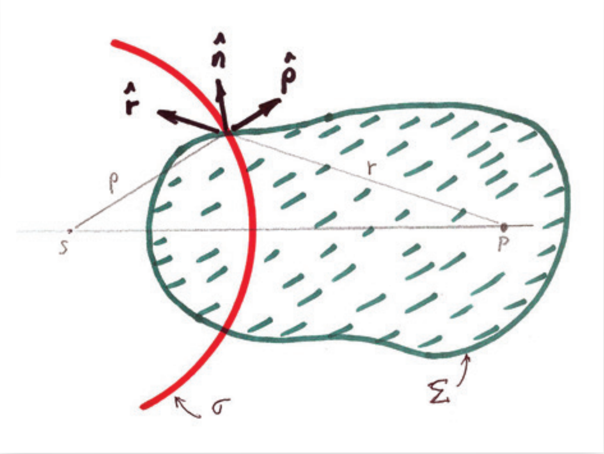


FIG. 5: The closed surface Σ used in Eq. (A10).

$$\left.\frac{\partial\psi}{\partial n}\right|_\Sigma = (\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{\rho}})\left[\frac{ik}{\rho} - \frac{1}{\rho^2}\right]\mathcal{E}_o e^{i(k\rho-\omega t)}. \qquad \text{(A12)}$$

Similarly, by Eq. (A9),

$$\left.\frac{\partial G}{\partial n}\right|_\Sigma = (\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{r}})\left[\frac{ik}{r} - \frac{1}{r^2}\right]e^{ikr}. \qquad \text{(A13)}$$

Now Eq. (A10) becomes

$$\psi(\boldsymbol{r}) = \frac{\mathcal{E}_o}{4\pi}\oint_\Sigma \left[\frac{e^{ik(\rho+r)}}{r}\left(\frac{ik}{\rho}-\frac{1}{\rho^2}\right)(\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{\rho}}) - \frac{e^{ik(\rho+r)}}{\rho}\left(\frac{ik}{r}-\frac{1}{r^2}\right)(\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{r}})\right]da. \qquad \text{(A14)}$$

If λ << r and ρ, then we may neglect the $1/r^2$ and $1/\rho^2$ terms. Eq. (A14) becomes

$$\psi(\boldsymbol{r}) \approx \frac{-i\mathcal{E}_o e^{-i\omega t}}{4\pi}\oint_\Sigma \frac{e^{ik(\rho+r)}}{r\rho}\left(\frac{(\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{r}})-(\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{\rho}})}{2}\right)da. \qquad \text{(A15)}$$

The differential form of Eq. (A15) says that

$$d\psi(\boldsymbol{r}) \approx \frac{\mathcal{E}_o}{\lambda}\frac{e^{i[k(\rho+r)-\omega t-\frac{\pi}{2}]}}{r\rho}\left(\frac{(\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{r}})-(\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{\rho}})}{2}\right) \qquad \text{(A16)}$$

where $-i = e^{-i\pi/2}$ has been used. Eq. (3), when rewritten as a complex harmonic, appears as

$$d\psi = \frac{\mathcal{E}_o}{\rho r\lambda}K(\theta)\, e^{i[k(\rho+r)-\omega t]}da \qquad \text{(A17)}$$

where Eq. (23) has also been used. Comparing Eqs. (A16) and (A17), the former has the correct phase, and comparing the coefficients shows the obliquity factor to be

$$K(\theta) = \frac{1}{2}[(\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{r}}) - (\hat{\boldsymbol{n}}\cdot\hat{\boldsymbol{\rho}})]. \qquad \text{(A18)}$$

It remains to evaluate the dot products between the unit vectors, expressing them in terms of observables. Consider for this application the doubly-connected surface Σ (Fig. 6), whose outer surface Σ_2 encloses point P, and whose inner surface Σ_1 excludes the source point S. A study of Fig. 6 shows that Eq. (A18) reduces to Eq. (4). //

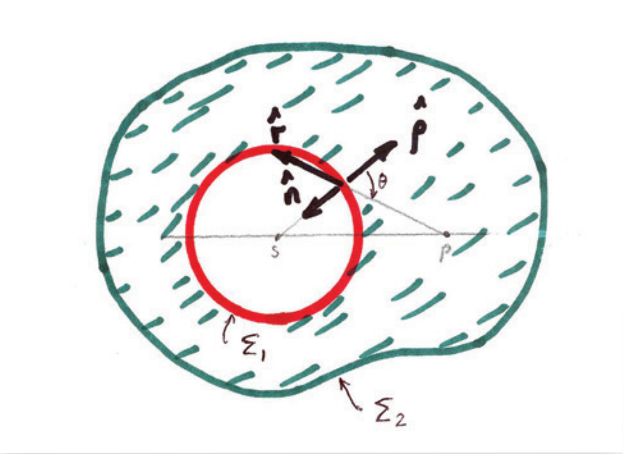


FIG. 6: The doubly-connected closed surface Σ made by inner surface Σ_1 and outer surface Σ_2.

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REFERENCES AND NOTES

[1] W.P.D. Wightman, *The Growth of Scientific Ideas* (Yale Univ. Press, New Haven, CT, 1953), pp. 146–150.
[2] “Elegant Connections in Physics, Diffraction Part 1: Huygens’ Principle and Young’s Interference,” *SPS Observer*, Winter 2012–13, pp. 20–23.
[3] “Elegant Connections in Physics, Diffraction, Part 2: Multiple Point Sources, Apertures, and Diffraction Limits,” *SPS Observer*, Spring 2013, pp. 18–23.
[4] At a distance r from a point source of luminosity (power output) L, the intensity I (power per unit area received) relates to L according to $I = L/4\pi r^2$. For light waves, the intensity is also given by the time-average of the Poynting’s vector $\mathbf{S} = (\mathbf{E}\times\mathbf{B})/\mu_o$. Since $\mathbf{E}$ and $\mathbf{B}$ are perpendicular, $|\mathbf{E}| = c|\mathbf{B}|$ and $1/c^2 = \mu_o\,\varepsilon_o$, the result follows.
[5] Eugene Hecht, *Optics,* 4th ed. (Addison–Wesley, San Francisco, CA, 2002), pp. 485–489; Francis A. Jenkins and Harvey E. White, *Fundamentals of Optics* (McGraw–Hill, New York, 1950), p. 352. The arguments go like this: For odd N the series may be grouped as

$$Z_N = \frac{K_1}{2} + \left(\frac{K_1}{2} - K_2 + \frac{K_3}{2}\right) + \left(\frac{K_3}{2} - K_4 + \frac{K_5}{2}\right) + \ldots$$

$$+ \left(\frac{K_{N-2}}{2} - K_{N-1} + \frac{K_N}{2}\right) + \frac{K_N}{2}$$

$$= \frac{K_1}{2} + \left(\frac{K_1 + K_3}{2} - K_2\right) + \left(\frac{K_3 + K_5}{2} - K_4\right) + \ldots + \frac{K_N}{2}$$

$$\equiv \frac{K_1 + K_N}{2} + R \qquad \text{(a)}$$

where R denotes a “remainder.” If the nth obliquity factor is greater than the average of its two neighboring ones, then $R < 0$ and $Z_N < ½(K_1 + K_N)$. A different grouping gives

$$Z_N = K_1 + K_N - \frac{K_2 + K_{N-1}}{2} - T \qquad \text{(b)}$$

with remainder T. Again, if the nth obliquity factor is larger than the mean of its neighbors, then $T < 0$. Because $K_{n+1} - K_n$ is small, for N not very large inequality Eq. (b) gives $Z_N > ½(K_1 + K_N)$. Consistency between the two inequalities requires $Z_N \approx ½(K_1 + K_N)$. The same conclusion holds when the nth obliquity factor is less than the mean of its neighbors.
[6] Another way to describe the effect of the obliquity factor is through the “vibration curve,” a phasor diagram. See Hecht (Ref. 5), p 489; Jenkins and White (Ref. 5), p. 286; Bruno Rossi, *Optics* (Addison-Wesley, Reading, MA, 1965), p. 162.
[7] Fresnel integrals and the Cornu spiral are well tabulated numerically and graphically, e.g., see Hecht (Ref. 5), pp. 497–509; Jenkins and White (Ref. 5), pp. 358–366; Rossi (Ref. 6), pp. 189–198.
[8] This result requires the Gaussian integral,

$$\int_{-\infty}^{+\infty} e^{-ax^2}\,dx = \sqrt{\frac{\pi}{a}}.$$

[9] Gustav Kirchhoff, “Zür Theorie der Lichtstrahlen” (“On the Theory of Light Rays”), *Annalen der Physik-Berlin* **254** (4), 663–695 (1883). See also Hecht (Ref. 5), p. 510.
[10] George Green (1793–1841) was an amazing fellow, brilliant and self-taught in mathematics. Despite being stuck in the family’s bakery and grain milling business, Green laid down some fundamental results in vector calculus and differential equations that would be used later by James Maxwell in his theory of the electromagnetic field.
[11] “Discrete Sources and the Continuum, and the Functions of Dirac and Green,” *SPS Newsletter* (October 1996), pp.10–12.
[12] E.g., see J.D. Jackson, *Classical Electrodynamics* (Wiley, New York, 1975), p. 224.

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