

The SPS Observer

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Fall 2010

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About the Cover: When the first performance results of the CMS (Compact Muon Solenoid) experiment at the Large Hadron Collider were posted in late 2009, the author list included 2443 names. Each person, though perhaps unknown to the wider world, had an essential role. Parts of a few of the 14 author pages are shown here. The paper, *Alignment of the CMS Silicon Tracker during Commissioning with Cosmic Rays* is available at <http://arxiv.org/abs/0910.2505>.



For the Love of the Game

It's Not About the Prize

Dwight E. Neuenschwander

“If we win or lose this weekend, it will not make a difference in our lives. But why we play and how we play will make a difference in our lives forever.”—*Beth Anders*

“A gold medal is a wonderful thing, but if you're not enough without it, you'll never be enough with it.”—*Irv Blitzer*

“Love the game because it takes all team members to give it life. Love the game because at its best, the game tradition will include your contributions. Love the game because you belong to a long line of fine athletes who have loved it. It is now your legacy. Love the game so much that you will pass on your love of the game to another athlete who has seen your dedication, your work, your challenges, your triumphs . . . and then that athlete will, because of you, love the game.”—*Anonymous [1]*

A few years ago I was asked to be one of the judges of student research papers in an annual international competition open to pre-university students. Each student would conduct a physics research project and write up the results as if for a journal. Their papers would be reviewed and prizes awarded. The competition, sponsored by the Polish Academy of Sciences, was called “First Step to a Nobel Prize in Physics.”[2] While I firmly supported the Academy's desire to encourage young people in such an experience, at first I hesitated due to the competition's name, which seemed to emphasize going after the Nobel Prize *as the motivation* for doing physics. I expressed my concerns to the program's founder, Dr. Waldemar Gorzkowski, whom I had met in the 1990s through the International Physics Olympiad (which he also founded).[3] I knew Waldemar to be a man of sterling integrity who put the interests of students first.



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Waldemar convinced me that the program's benefits for students trumped my reservations about its name, and so I have joyfully judged "First Step" entries for ten years now. My reservations about the competition's name did, however, turn my thoughts toward the spectrum of motivations for doing physics.

The title "First Step to a Nobel Prize in Physics" bothered me because I wondered if values would be implicitly attached to the program that its organizers did not intend. Could the program be interpreted as suggesting that one should learn physics *in order to* win fame and prestige? Are prizes to be ends in themselves? Are accolades to be the measure of success? Shouldn't there be reasons enough for doing physics even without designated prizes?

For several years my wife and I have held season tickets to the concerts of the Oklahoma City Philharmonic. The programs typically feature a guest artist, which in recent seasons have included violinist Itzhak Perlman, soprano Renee Fleming, pianists Yuja Wang and André Watts—over the years, individuals from the pantheon of musicians whose names instantly fill concert halls around the globe. They swoop into our city for a few hours to present a virtuoso performance that only a half-dozen people in the world are capable of delivering at a given moment. The accolades they enjoy are hard earned and well deserved.

When the guest luminary appears, a hundred members of the orchestra are on stage with them. From my place in the audience, many times with binoculars, I have closely watched the facial expressions and fingers of the guest pianist or violinist. But I also watch the members of our orchestra. At that moment, they are not in the spotlight, but there they are, giving the music everything they have. As they accompany Itzhak Perlman in Wolfgang Mozart's *Violin Concerto No. 5*, or Yuja Wang in Sergei Prokofiev's *Piano Concerto No. 3*, they are not looking at the guest artist or the audience. Each player is focused on doing his or her part to make the music excellent. Each one is immersed in something greater than themselves. I sit there and think, what a privilege it must be to help create such music, to have Mozart and Prokofiev as your intellectual companions, to be colleagues with Perlman

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(Above) Frank Goforth (left) and Nancy Halliday (third from left) play horn in the Oklahoma City Philharmonic.



(Left) Julie Dodge, one of the viola players in the Oklahoma City Philharmonic.

“Hello, I’m Yo-yo Ma, one of the cellists here.” He understood that if the player with even the smallest part were to drop out, the music would be diminished.

and Wang in making music. After all, not everybody can help the featured soloist bring a Mozart or Prokofiev concerto to life!

Two of our friends, Nancy Halliday and Frank Goforth, play horn in the Oklahoma City Philharmonic. I asked them what goes through their minds when they are playing music professionally. In conversations, both

of them expressed the fulfillment that comes from being part of the orchestra. Frank and Nancy express essentially the same thoughts in different ways. Nancy sent me this written reply to my questions:

“The opportunity to perform orchestral music on stage with 75–100 other musicians is not one that I take lightly. In fact, I consider it a privilege and my greatest gift. I’m not a soloist, so I don’t play professionally for the glory and recognition. Music is one of the most powerful languages on the planet. The goal is to convey a powerful message in a manner that will be engaging. The musicians want listeners to experience their passion and enthusiasm, comprehend the meaning of the musical message, and be transformed by the experience. For successful delivery, many hours of preparation are required on my part. But in the end, I cannot do this by depending solely on my own talents. To present a product that is much greater than the sum of its parts, each musician must surrender their individual contributions to a much larger conversation. In a professional orchestra, we perform well 99% of the time. However, there are magical performances

that happen rarely and unpredictably. What is the difference? I believe that happens when a critical mass of musicians in the orchestra get outside of their own heads and goals and surrender completely to each other and to the music. Those experiences, when they happen, are other-worldly.”

Nancy once told me that when the great cellist Yo-yo Ma came to perform, at the rehearsal he said, “Hello, I’m Yo-yo Ma, one of the cellists here.” He understood that if the player with even the smallest part were to drop out, the music would be diminished. He and the orchestra were in this together. They did not all have the same global name recognition, but they were united in a shared passion for making music together.

We are all just “one of the cellists here,” but what a privilege it is to be one of the cellists! The opportunity to study nature through physics with competent, passionate, hard-working colleagues is a transforming experience. Few of us will be superstars, and that is good. The non-superstars give depth to the enterprise and to the community. There were three astronauts in the Apollo 11 mission that first set people on the Moon, but it took the work of a third of a million people to get them there.[4] There are no unimportant roles. In the worlds of music and physics, the neighborhood piano teacher and the lab assistant have roles as essential as those of Amy Cheng and Albert Einstein. Given that so many people lead lives of “quiet desperation,”[5] we may be grateful for what we have when we can choose our intellectual companions and help make the music happen. Spending your life hanging out with Beethoven or Einstein, appreciating music or appreciating the universe, are their own rewards—and not bad ways to spend one’s life!

The world does not need more superstars. It does not even need more people to do good things if those things are not *their* tasks to do. Rather, the world needs more people who are passionate about what they do [6]. When the work and your passion come together, the work itself becomes its own reward. We say we want happiness, and too often look for it in the approval of others. But I think that what we really want is meaning. If we take care of the meaning, the happiness will take care of itself. If we take care of being competent, the respect of colleagues will take care of itself. Genuine



Photo by josephmills.com

Joel Levine, Music Director of the Oklahoma City Philharmonic.

“Why weren’t you Einstein? Why weren’t you Feynman?” But they *will* ask me, “Why weren’t you Dwight Edward?”

Prizes are nice, but they are not ends in themselves. Someone once said, “Seek not position; let it seek you.” The same can be said for prizes. If the Nobel Prize comes your way, that would be splendid! Use the accolades wisely and humbly, remembering the many people who helped you get there. Follow your passion, and give it your best. Physics, like sports or music, is best done for the love of the game.

Acknowledgment

I am grateful to Nancy Halliday and Frank Goforth for their inspiring conversations about playing music in the Philharmonic. Besides being professional musicians, Nancy is also a research biologist who teaches medical students, and Frank is also a professor of computer science.

With much appreciation I thank the Oklahoma City Philharmonic, and its director of public relations Michelle Winters for making available the photographs. Thanks also to Melissa Lewis.

Use the accolades wisely and humbly, remembering the many people who helped you get there. Follow your passion, and give it your best. Physics, like sports or music, is best done for the love of the game.

fulfillment comes from being wholly engaged in something greater than any of us. That motivation honors the integrity of the discipline, and of all its practitioners.

Few of us will be Einsteins or Feynmans, but that is not the question. I am not called to be another Richard Feynman, even if I could. We already have Feynman. Rather, I am called to be who I am. You and I each have a combination of gifts, passions, and experiences unique in the history of the universe. Therefore you and I each have something unique to contribute. If the physicist in even the smallest niche were to drop out or try to be somebody else, physics would be diminished. When my days of doing physics are over, no one will ask me,

[1] Sports quotes from < <http://smiley963.tripod.com/sports.html>>.

[2] The “First Step” website is <http://www.ifpan.edu.pl/firststep/>.

[3] See “In Memoriam: Waldemar Gorzkowski,” Radiations 13(2), Fall 2007, p. 12.

[4] In a CBS interview in 1979, Neil Armstrong thanked the “third of a million people” who “managed it.” Part of that interview was rebroadcast in 1989, in the CBS special “The Moon Above, the Earth Below,” marking the 20th anniversary of Apollo 11.

[5] This famous line is from Henry David Thoreau’s *Walden* (1854), or if you prefer, it reappears in “Time” from *Dark Side of the Moon* by Pink Floyd (EMI, 1973).

[6] Gil Bailie is reported to have said, “Don’t ask yourself what the world needs. Ask yourself what makes you come alive, and go do that, because what the world needs is people who have come alive.”

2443 Co-authors?!

The following story was originally published on www.symmetrymagazine.org on October 27, 2009 as a post titled “LHC's CMS Collaboration Submits First Detector Performance Results”. High energy physics experiments are notorious for producing papers with long author lists, and with good reason. The experiments are years in the planning, building, data collecting, and analyzing and require expertise in a vast range of areas. Individual work is highlighted within the collaborations, but the successes of the collaborations are built on thousands of individuals, each playing a particular part.

By Kathryn Grim
Reproduced with permission

The CMS (Compact Muon Spectrometer) collaboration at CERN's Large Hadron Collider (LHC) has posted its first detector performance results to arXiv.org, and the paper's author list could run as final credits for a feature film.

The collaboration acknowledges 2443 collaboration members in a list that takes up almost as many pages as the text of the paper.

“It just reflects the fact that experiments at the LHC are complicated,” said Joel Butler, US CMS program manager. “The number of people involved in an effort like this is huge.”

The CMS detector is one of the two main detectors at the Large Hadron Collider at CERN.

The paper's author list credits not only the physicists involved in the study but also the engineers and technicians who made the study possible by designing and building the detector.

Building and using the large, complex machines scientists need to conduct high-energy physics experiments requires the cooperation of thousands of collaborators. The challenge of choosing whom to give credit once the experiment yields results has been a source of discussion.

“Inside the field, this inclusive approach works very well,” Butler said. “If we need to know who did the specific work reported in the paper, we can ask. The problem is when people in the field of high-energy



The number of people involved in an effort like this is huge

physics have to be compared to people outside the field.”

It could be difficult for a high-energy physicist sharing credit with thousands of other scientists to compete for a position at a university against a solid-state physicist on a small experiment sharing the credit with fewer than five collaborators. CMS has begun highlighting individuals’

work through awards, including a thesis award for students and special service awards for students and post docs.

“The thesis award is very competitive,” Butler said. “People whose theses are even close to the top are very impressive. The winning thesis is always awesome.”

Hundreds of graduate students and post docs contribute to the CMS experiment. “Highlighting their accomplishments is important for their future and the future of our field,” Butler said.

This first paper is only the beginning of the huge number of publications to come from the CMS experiment. Collaboration members have another 22 papers in the pipeline based on cosmic ray data from 2008 alone, Butler said. They discuss alignment, calibration, background noise, and other detector issues scientists can address based on their experiences studying cosmic rays.

The CMS collaboration's first cosmic ray paper explains how scientists aligned the detector's silicon tracker using data from passing cosmic rays. The *Journal of Instrumentation Science and Technology* is considering the paper for publication. The collaboration recently completed its 2009 cosmic ray run and awaits the first particle collisions from the LHC. More publications trailing lengthy author lists behind them are sure to follow.

Note: This article was first published in October 2009. For updated progress on the CMS experiment, visit the collaboration website at <http://cms.web.cern.ch/cms>.

SPS: Supporting Chapter Outreach Activities

Who doesn't love getting people excited about science? The SPS National Office provides a number of resources to support SPS chapters engaging in physics outreach.

SOCKs

If your chapter is interested in engaging local students in a fun physics activity, but not sure what to do, just grab your SOCK! The SPS Outreach Catalyst Kit (SOCK) is a large sock (literally) filled with resources and materials designed to help SPS chapters plan an engaging physics event for students of all ages.

Which rolls faster down a ramp, a car tire or a bowling ball?

How is a laser pointer different from a LED?

The 2010 SOCK, *Rolling with LaserFest*, addresses these questions and more with detailed activity guides, lasers, rainbow glasses, rubber balls, hollow pipes, and many other surprises. SOCKs are free, but interested chapters need to send an email to sps@aip.org with the following information:

- ✓ School
- ✓ Advisor
- ✓ Student contact
- ✓ Email address
- ✓ Mailing address
- ✓ When and where you plan to use the SOCK

The supplies are limited, so reserve yours now! Previous SOCKs have addressed energy and motion, waves, temperature, and more.

Check out past activity guides for other ideas at www.spsnational.org/programs/socks/.

Galileoscopes

There is nothing like the night sky to draw people to science. SPS has a limited number of telescopes available to chapters for use during outreach events.



Photo by Phatcontroller

Moon gazing with my Galileoscope.

The Galileoscope™ is a high-quality telescope kit developed for the International Year of Astronomy 2009 by a team of leading astronomers, optical engineers, and science educators. No matter where you live, with this easy-to-assemble refracting telescope you can see the celestial wonders that Galileo Galilei first glimpsed 400 years ago. These include lunar craters and mountains, four moons circling Jupiter, the phases of Venus, Saturn's rings, and countless stars invisible to the unaided eye.

To request a set of Galileoscopes for an upcoming event, visit www.spsnational.org/partnerships/galileoscope.htm.

Money

SPS chapters can receive awards of up to \$300 annually to support projects designed to promote interest in physics among students and the general public. This award is named in honor of Marsh W. White, a charter member of the Pennsylvania State University chapter of Sigma Pi Sigma, the Physics Honor Society, in 1926. White was a leader and active participant in Sigma Pi Sigma for 70 years and a founder of the Society of Physics Students. He held every office in Sigma Pi Sigma, personally

Left: SPS Director Gary White with a class of third grade students. The class was happy to participate in testing the 2010 SOCK lessons.

installed over 200 Sigma Pi Sigma chapters, signed the documents that formed SPS, and was a coauthor of the SPS/Sigma Pi Sigma constitution.

For information on how to apply for the Marsh W. White Award, please visit www.spsnational.org/programs/awards/white.htm. Proposals are due November 15th of each year.

Marsh W. White Awards, from Hovercrafts to Space Day

In 2010, 15 chapters received Marsh White Awards to help fund their outreach efforts. Two projects are highlighted below. You can read about the other projects online at www.spsnational.org/programs/awards/2010/mw_recipients.htm.

Phalcon Physics Hovercraft University of Wisconsin—River Falls

The SPS Chapter at UW-River Falls built an electric one-person hovercraft to be used in demonstrations for various schools, prospective students, and the community. It was built using a leaf blower for the motor, a four foot diameter piece of medium-density fiberboard as the platform, and a tarp for the skirt.

Originally, our hovercraft was made with a 3' diameter circle of plywood and a skirt made out of a shower curtain. Because the platform was so small, it was a bit unstable. Also, the plywood warped. To remedy this, we increased the diameter to 4' and used medium-density fiberboard. Another problem that occurred with the prototype was a loud humming sound caused by the skirt vibrating in the air flow. In an attempt to resolve this, we used a tarp with higher density than the curtain and put duct tape on the bottom to dampen the vibrations. The basic plans for this were taken from www.amasci.com/amateur/hovercft.html.

The first opportunity for us to unveil our new hovercraft was on April 29, 2010, with a group of 28 seventh-graders in a program called "Gear Up and Get Ready," which encourages young people to go to college. This event was covered by the local news station KARE 11. We even gave



Photo by Kendra Redmond



Photos courtesy of the University of Wisconsin River Falls

Above: The top of the hovercraft. The leaf blower is directed into a hole in the platform in order to inflate the skirt. Below: The bottom of the hovercraft. The holes in the middle are where the air passes to inflate the skirt and the duct tape dampens the vibrations of the skirt.



the news reporter a ride on the hovercraft! During the demonstration, we explained how a hovercraft worked and then showed Newton's laws. To demonstrate the third law, we had the person sitting on the craft throw a bowling ball and observed the person move backward from the force exerted by the ball.

That same day we incorporated the hovercraft into a presentation for about 100 middle school students on a "get excited about college" visit. We also took the

hovercraft to a local high school physics class on May 25th. It was a big hit, even though the principal declined a ride. There are many different demonstrations we can present with the hovercraft and it will certainly become a staple in our demonstrations for years to come.

Exploration Day 2010: Science in Space Pennsylvania State University (Penn State)

The Penn State chapter of the Society of Physics Students has been working to increase its community outreach activities for the past several years. One of our largest annual events is Penn State's *Exploration Day*, sponsored by the NASA Pennsylvania Space Grant Consortium and other organizations. The event is held each year. This past April, we welcomed almost 3,000 parents, children, and community members. For the day-long event, our chapter joined with fifty-two exhibitors from university science departments, science clubs, and local schools to showcase and explain a variety of science concepts to the visitors. This is the third year that the Penn State chapter of SPS has participated in *Exploration Day* and it was once again a success. We plan to continue the tradition in the future.

Fifteen SPS members ran our exhibit, which included six demonstrations centered on space travel. By visiting each station, children were able to achieve their honorary "Space Certification." In the process, visitors first learned about the power—and potential danger—of static electricity through the use of a Van de Graff generator. Next, they explored power generation and how long they would have to pedal a bike to produce enough energy to get to the moon. The unique aspects of living in space were explored with the help of a revolving chair to explain centripetal motion and artificial gravity. Liquid nitrogen and a vacuum chamber were used to help the junior explorers understand the conditions one faces in space and how spacesuits protect humans. They even investigated gravity through a simple spandex model of general relativity.

Overall, the exhibit was a huge success, attracting crowds of parents and children, hungry to learn. The Penn State news even featured our exhibit in its coverage of the event (you can find the story online at <http://live.psu.edu/stilllife/2247>). The demonstrations were envisioned and created by SPS members with the gracious assistance of our physics department.



Fifteen SPS members from Penn State University joined together to run their *Exploration Day* exhibit, which included six demonstrations centered on the theme of space travel.

What I did on my

Each summer hundreds of physics students choose to spend their break from advanced lab courses and E&M homework doing physics. To see opportunities for next summer, bookmark www.the-nucleus.org/research and check back frequently. Most applications are due in early 2011.

Linda Hunt, Kettering University Summer Research Site: Warrior Hockey

This summer I began working on my thesis with Kettering at my co-op company, Warrior Sports. I developed a new test to help correlate frequency response data to hockey players perception of feeling. To do this new test, I outfitted several sticks with accelerometers attached to where a player holds the stick, and then took slap shots to measure the frequencies felt by the players holding the sticks. I also used a high-speed camera to record the shot to make sure the impact location was consistent. The next step would be to find a way to make this into a frequency response curve so that the severity of the impact mattered less. It was pretty fun to do the testing, because it was all done in the hallway. People gave us strange looks as we fired pucks into a net with sticks that had wires running along them.

In addition to the work on my thesis, I worked on some development projects for Warrior's new lacrosse helmets. These tests included a drop test, for which I took a helmet on a head form mounted to a drop carriage and dropped it from specific heights in different orientations to make sure each passed specifications. An even more fun test was the ball cannon. For that test, we fired lacrosse balls at helmets to make sure that the mask welds did not break and poke out eyes, and also to make sure the bars did not break or bend too much, touching the face. The balls were launched from an air cannon at about 65 mph, so it was really cool to watch.



Dan Russell

The author prepares to take a shot during one of the tests.

I had a great summer working in the sporting industry as a hockey and lacrosse product development co-op student, and look forward to returning to my co-op in January.



Photo courtesy of Ashley Parker

The author (front row, third from left) with her fellow REU participants.

Ashley Parker, Marietta College Summer Research Site: National Superconducting Cyclotron Laboratory (NSCL)

I was selected as one of fourteen students to engage in Michigan State University's Research Experience for Undergraduates (REU) program which began in June 2010. Of the fourteen students, about half of us worked at NSCL while the other half worked in the biomedical and physical sciences building.

I worked at NSCL with Dr. Michael Thoennessen on a physics history project called *The Discovery of Isotopes*. This project was initiated in 2009 to catalog and report the initial observation of every isotope. The conditions characterizing the successful discovery of an isotope include a clear and unambiguous mass and element identification through decay curves, mass spectroscopy, gamma-ray spectra, and/or relationships to other isotopes, as well as the publication of such findings in an adjudicated journal.

Over the course of my ten week internship, I conducted a literature search to find the oldest article claiming discovery of a given isotope and then constructed a spreadsheet of all of the articles I collected. Once a consensus was reached on which historical document would be credited with a particular discovery, I wrote a paper for *The Discovery of Isotopes* series which will be published by Atomic Data and Nuclear Data Tables. I wrote articles about the discovery of isotopes for the elements Molybdenum, Rhodium, Rubidium, and Strontium, which have 35, 38, 31, and 35 isotopes, respectively.

Summer

Neil Johnson, University of Saskatchewan
Summer Research Site:
Mullard Space Science Laboratory
University College London

This summer, I was lucky enough to be part of a research term abroad in England. I lived and worked at Mullard Space Science Laboratory, which is in an old Guinness family mansion located about an hour southwest of London. It was easily the most unique research environment I've ever come across. Some even liken it to Dr. Charles Xavier's mansion from the X-Men comics, only with fewer mutants and more physicists.

I worked on astrophysical theory and some phenomenology; both focused on supermassive black hole (SBH) binaries in galactic nuclei. I wrote a computer program that numerically solves for orbits in the vicinity of one of these astronomical beasts and compared them to orbits around a single SBH. I also analyzed images of a suspected stellar toroid (star donut) in the center of a dwarf elliptical galaxy, determining that it could not be a disk or toroid but had to be two separate extended distributions. Hopefully this discovery will warrant publication in the near future.

This was really my first taste of the academic research environment, and I loved it. The lab was full of people from all different backgrounds with one thing in common: a passion for knowledge. Whenever a large group of motivated and genuinely interesting people are all in the same place, awesome things are bound to happen. I learned so much from my peers about theory, computational methods, general science, academia, and many, many other topics. It was truly a valuable educational experience.

Not all of the summer was about work, though. I devoted quite a



Photo courtesy of Neil Johnson

The author (second from left) with his summer research team led by Kinwah Wu (left).

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Vacation

few evenings to playing football, traveling, and hanging out with my new friends. I'm sure that the academic and personal bonds I made this summer will last a long time.

This project gave me a lot of insight into my chosen career path and deepened my interest in being a physicist. In short, it was epic.

Marc M. Doyle, Drexel University
Summer Research Site:
University of Delaware

This was my first research project as a physics major. Doing research for the first time is like a coming of age in the realm of science. I was not sheltered by the walls of the classrooms anymore. I couldn't just use an equation or a math trick to defend myself. I had to do real thinking.

The grass and brick formed a tapestry in which the University was woven. The lab sits in a row of buildings where none is differentiated from another. The lab, purring with the sound of machines, was busy. My supervisor's lab was messy. Yet, the mess didn't inhibit the work that went on in that lab.

My job was to make nanoparticles. Not just any nanoparticles, but ones that were magnetic. They were made by a violent process, a dangerous process. This method is called the autocombustion or the self-sustaining reaction process. Reactions like this are used in blast mining, but on a much larger scale. As a physics major, I wondered why I was doing chemistry. In school they taught chemistry and physics separately, so I thought they must not go together. Wrong. Interdisciplinary collaboration is crucial to science. This research has motivated me to take more classes outside of physics, because nature is expressed by all fields of science, not just one.



The author in his summer lab at the University of Delaware.

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So what did I do this summer? Oh, nothing—just learned how to think, just learned how to strive for a scientific goal, just realized that physics is more than classrooms and books and grumpy old professors. It is about finding what you want to do, what fascinates you, and how you plan to get there.

**Trevor Tomesh, University of Wisconsin - River Falls
Summer Research Site:
University of Worcester, England**

This summer I was invited by a professor at the University of Worcester, England, to work with him on utilizing video game technology to develop physics simulations for use in K-12 and undergraduate institutions. We used Unreal Script (a scripting language for game code) to design and develop demonstrations in the field of oscillations and waves for the Unreal Tournament 2004 engine. Numerical methods were used to simulate seven different physical systems that were visually represented in the immersive environment of Unreal Tournament 2004. Data from each system was written to an output file, plotted, and analyzed. This was a very exciting opportunity for me, as the project meshed together

three of my strongest interests: physics, programming, and gaming.

Aside from working vigorously on our project, I toured Eastnor Castle, visited Oxford and various abbeys and cathedrals, and had a taste of what English culture is really like. I was even invited to a graduate student's home during the FIFA World Cup to watch England play the United States.

I enjoyed my summer research experience so much that I intend to attend graduate school at the University of Worcester to attain my PhD in computer science. I am continuing to collaborate with my summer research mentor on furthering the project and hope to extend it to my PhD thesis.



Photo courtesy of Trevor Tomesh

The author (right) and mentor Dr. Colin Price outside Eastnor Castle in Herefordshire, England.

Outreach to (Nearly) the North Pole

By Dwight E. Neuenschwander

The Society of Physics Students consists of people who are passionate about physics and are invested in science education. Therefore, having friends who are working on behalf of science education in an unusual place grabs our attention.

Meet Scott and Zonda Martin. They have taught science in Oklahoma City high schools and middle schools for several years. In the spring of 2010 they were offered the opportunity to teach in the village of Kiana, Alaska.

Kiana is located 43 miles north of the Arctic Circle. To see Kiana on Google Earth, go to latitude 66.97 degrees N and longitude 160.43 degrees W. Their new teaching opportunity presents unusual challenges. But it also offers unusual adventures. Zonda and Scott accepted the offer, and they are in Kiana now. As friends of the SPS, they are allowing us to look over their shoulders, sharing their adventures with us.

About 400 people live in Kiana. Kiana was established long ago as the central village of the Kiwagmiut Inupiat Eskimos. They mastered the practical education of living in a harsh environment that would be deadly to most of us. Today “education” has a different emphasis, but geography and climate still present logistical challenges to its delivery in Kiana. But the Martin’s adventure, and the students they will teach and learn from in Kiana, offer some educational opportunities for us as well. SPS has sent the Martins some Galileoscopes and SOCK kits, along with our good wishes and the promise to keep in touch. Zonda and Scott have in return offered to tell us more about the aurora borealis, the Alaskan



Photos by Zonda and Scott Martin

The aurora borealis (northern lights) as seen from Kiana. Left: Zonda & Scott in their new surroundings

landscape and wildlife, and the culture and history of the Eskimo people. Through them we would like to learn to appreciate life in the Arctic.

If you have a question for Zonda and Scott or their students, or want to send them greetings and good wishes, please direct your comments to the editor (dneuensc@snu.edu) who will forward your messages to them. We look forward to further communication over the next several months with these our friends and colleagues of the Kiana K-12 School.

Why Physics?



By Thomas Olsen & Kendra Redmond, SPS
Roman Czujko & Susan White, AIP SRC

“If I had to do it over again, I would still major in physics.” According to surveys conducted by the Statistical Research Center (SRC) at the American Institute of Physics (AIP), more than 80% of the physics graduates from the classes of 2005 and 2006 agree or strongly agree with this statement. [1] This is true whether asked of students continuing to graduate school or those entering the workforce; it is true whether asked of those who had already been hired or those still seeking employment.

The SRC sends questionnaires to physics degree recipients each winter following commencement. For the classes of 2006 & 2007 ...

- 57% had begun graduate study, most (over 60% of those entering graduate school) in physics, but also in other fields
 - Graduates from a physics department that offered a PhD were more likely to choose graduate study than were graduates from departments where the highest degree is a bachelor’s degree (61% to 51%)
- 43% had entered the workforce, and over 90% of these had found a job
 - For those taking jobs, the jobs were in the private sector (59%), in high schools (13%), in colleges and universities (10%), in the government sector (6%) and military (5%), or in other areas (7%).
 - When we look at those in the private sector (59% of those taking a job), we find that 32% of the private sector jobs were in engineering, 29% were in fields outside of natural science, technology, engineering, or math (STEM fields), 16% were in computer science or information technology, 9% in other technologies, 7% in other natural sciences, 5% in physics or astronomy, 1% in math, and 1% in science education.

What can we learn from these data? Well, just over one-third of physics undergraduates

(35%) continue on to graduate school in physics. Fewer than half of these earn a PhD in physics [2]. Fewer than half of these will become a faculty member in physics. This means less than 5% of the students who earn a bachelor’s degree in physics become a physics professor!

In other words, **more than 95%** of the students who earn a bachelor’s degree in physics **do something other than become a physics professor**. What do *these* physicists do?

People with undergraduate degrees in physics do almost anything and everything. Physicists write, preach, rap, design spacecraft, teach, make electric cars, defend patents, manage wealth ...

Why do students major in physics when almost all will ultimately have titles that

won’t include the word “physics”? Here is what a few graduates had to say [3]:

- *Because I like being able to explain how the world works.*
- *The study of physics provides the tools to solve so many pesky problems. It’s also excellent training to think logically in a way that transfers to ...well...everything.*
- *I kept asking my chemistry teacher questions, and they kept sending me to the physicist for answers.*
- *I absolutely fell in love with the possibility of uncovering even a small understanding of the stars and the universe.*
- *I loved the intellectual challenge, the collaborative learning environment, and the spirit of discovery.*
- *For the love of the game.*

[1] See www.aip.org/statistics for the data used in this report.

[2] This does not imply that only half of the students who enter PhD programs succeed. Many of those entering graduate school in physics are seeking master’s degrees.

[3] These comments were selected from Facebook group “I have a bachelor’s degree in physics” at <http://www.facebook.com/home.php?#!/group.php?gid=122840883846>

A Couple of Hidden Physicists

To read these profiles in their entirety, visit www.spsnational.org/cup/profiles/hidden.html
More Hidden Physicist stories appear on page 19



Mary Anna Evans
Author, Gainesville, FL

My career began with a bachelor’s degree in physics in 1983, and then took incremental steps away from the traditional path until, in 2010, I find myself writing mystery novels. After receiving my BS, I earned a master’s degree in chemical engineering and spent a couple of years teaching. I was subsequently the assistant director of a university research center and then an environmental consultant. After the birth of my third child, I decided it was time to change course. My book *Artifacts* was published in 2003. *Relics, Effigies, Findings*, and *Floodgates* followed in quick succession, and *Strangers* will be published this year.



Paul C. Sinclair
Mechanical Engineer,
Maumee, OH

I earned my BS degree in physics from Rhodes College in 2007. I switched to mechanical engineering and earned my master’s degree in 2009. Since then I’ve found a job designing and testing radio-controlled off-road racecars. These cars involve high-strength composites, aluminum, and titanium alloys. They must endure some pretty large forces, given their extremely high power-to-weight ratios. I started racing these cars back in high school, and my foundation in physics has given me the ability to pursue my passion as a career.

Electric Permittivity and Magnetic Permeability

Dwight E. Neuenschwander

In our studies of electricity and magnetism, the ubiquitous constants ϵ_0 and μ_0 , respectively called the “electric permittivity” and “magnetic permeability” of vacuum, set the scale for electric and magnetic phenomena. The usage and meaning of these constants raises some curious questions. For instance, why would someone choose to define them in a way that spoils the otherwise beautiful symmetry between analogous formulas for electric and magnetic quantities? To illustrate, we find the energy density of the electric field \mathbf{E} to be $\frac{1}{2}\epsilon_0 E^2$, but the energy density of a magnetic field \mathbf{B} is $\frac{1}{2}B^2/\mu_0$ instead of $\frac{1}{2}\mu_0 B^2$. Furthermore, how do their values conspire to give the speed of light? And given that the “sub-0” denotes the properties of vacuum, if the vacuum is nothing but empty space, how can any number other than zero characterize its properties?[1] Why is 4π usually connected with ϵ_0 and μ_0 ? Why was the value of $1/4\pi\epsilon_0$ historically measured to several significant figures, while the value of $\mu_0/4\pi$ was said to be exact?

These constants seem to slip in through the back door. In classical field theory we meet the electrostatic field $\mathbf{E}(\mathbf{r})$ and the magnetostatic field $\mathbf{B}(\mathbf{r})$. The electric field at \mathbf{r} , due to a point source charge q' located at \mathbf{r}' , is given by Coulomb’s law,

$$\mathbf{E}(\mathbf{r}) = k_e q' \mathbf{R}/R^3, \quad (1)$$

where the vector $\mathbf{R} = \mathbf{r} - \mathbf{r}'$ goes from the source point to the field point (see Fig. 1a).

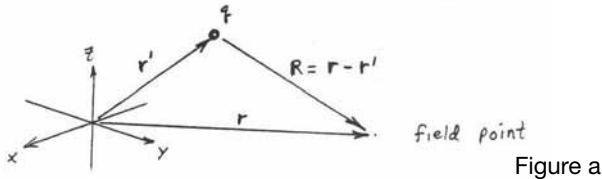


Figure a

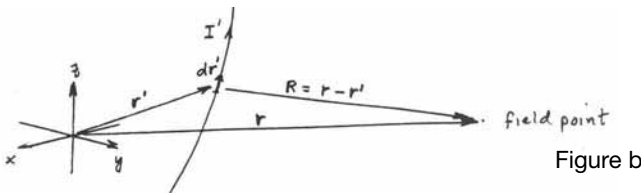


Figure b

Fig. 1. Geometry of the laws of Coulomb (a) and Biot-Savart (b).

Magnetic fields are produced by electric currents. A static magnetic field requires a steady flow of charges, a DC current I' . Let $d\mathbf{r}'$ denote the infinitesimal displacement vector of one of those charges instantaneously at a fixed location (tangent to conventional current). The infinitesimal piece of directed current $I'd\mathbf{r}'$ serves as a point source and contributes the increment of magnetic field $d\mathbf{B}(\mathbf{r})$ at the field point according to the Biot-Savart law,

$$d\mathbf{B}(\mathbf{r}) = k_m I' d\mathbf{r}' \times \mathbf{R}/R^3. \quad (2)$$

This must be integrated around the entire circuit to yield the \mathbf{B} field at \mathbf{r} .

The values of k_e and k_m set the scale for these fields and the forces they produce. In SI units their values are

$$k_e = 8.988 \times 10^9 \text{ Nm}^2/\text{C}^2 \quad (3)$$

to four significant figures, and

$$k_m = 1 \times 10^{-7} \text{ N s}^2/\text{C}^2 \quad (4)$$

exactly. As you might surmise, k_m was historically *defined* and k_e was *measured*.

When we derive Gauss’s law for \mathbf{E} from Coulomb’s law (take the scalar product of Eq. (1) with $\mathbf{n}dA$, a patch of area dA with outward-pointing unit vector \mathbf{n} , and integrate over a closed surface), we pick up a factor of 4π from a solid angle and obtain

$$\oint \mathbf{E} \cdot \mathbf{n} dA = 4\pi k_e q_{\text{enclosed}}, \quad (5)$$

where the charge q_{enclosed} resides within the closed surface. In differential form,[2] Gauss’ law says

$$\nabla \cdot \mathbf{E} = 4\pi k_e \rho, \quad (6)$$

where ρ denotes the charge density. In deriving Ampère’s law from the Biot-Savart law, another 4π appears and Ampère’s law gives

$$\oint \mathbf{B} \cdot d\mathbf{r} = 4\pi k_m I_{\text{pierce}}, \quad (7)$$

where I_{pierce} denotes the current that pierces any surface bounded by the closed contour. In differential form Ampère’s law becomes[3]

$$\nabla \times \mathbf{B} = 4\pi k_m \mathbf{j}, \quad (8)$$

where \mathbf{j} denotes the electric current density.

It is customary to hide the ubiquitous 4π ’s by dividing them out of the Coulomb and Biot-Savart constants, thereby introducing ϵ_0 and μ_0 ,

$$k_e = 1/4\pi\epsilon_0 \quad \text{and} \quad k_m = \mu_0/4\pi, \quad (9)$$

the so-called “rationalized” units of Oliver Heaviside.[4] From Eqs. (3), (4), and (9) we obtain

$$\epsilon_0 = 8.844 \times 10^{-12} \text{ C}^2/\text{Nm}^2$$

and

$$\mu_0 = 4\pi \times 10^{-7} \text{ N s}^2/\text{C}^2. \quad (10)$$

With them the laws of Gauss and Ampère look less cluttered:

$$\nabla \cdot \mathbf{E} = \rho/\epsilon_0 \quad (11)$$

and

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j}. \quad (12)$$

There is nothing fundamental about choosing ϵ_0 and μ_0 over k_e and k_m ; the choice is a matter of taste and convenience.

The constant ϵ_0 is called the “electric permittivity” and μ_0 the “magnetic permeability” of *vacuum*. The permittivity and permeability of *matter* take on values that are rescalings of ϵ_0 and μ_0 . These names suggest that the permittivity measures in some sense the transparency of a medium to an electric field, and permeability the ability of the medium to support a magnetic field. The rescaling coefficients that distinguish matter from vacuum have names such as *susceptibilities*, *dielectric constants*, and the *index of refraction*. First, let us see why μ_0 was originally defined and ϵ_0 was originally measured.

The Values of ϵ_0 and μ_0

In any system of physical measurement, some units must be defined as standards. For instance, to measure length one could choose a reference body and then express all other lengths as multiples of it. An amusing instance occurred in 1958 when some MIT students measured the length of a bridge that spans the Charles River by using their classmate Oliver Smoot as the unit. The length of the bridge was reported to be 364.4 smoots, plus or minus one ear.[5] Since the smoot as a unit of length is not reproducible in all places for all time, a less subjective standard is needed. The SI system (Système International) that you met in General Physics originally defined units for length (meter, m), mass (kilogram, kg), and time (second, s). The second is today defined in terms of the frequency of a certain spectral line of cesium-133. Before 1960 the meter was originally defined by a specific archival bar. Between 1960 and 1983 the meter was defined in terms of a wavelength of a spectral line emitted by krypton-86 (more about 1983 later). Mass was and still is (for now) defined in terms of an archived body, the carefully preserved platinum-iridium standard kilogram, “Le Grande K” stored near Paris, France.[6] All dimensioned observables in the SI or “mks” system reduce to some combination of meter, kilograms, and seconds. For example, the unit of force (the Newton, N) is $\text{kg}\cdot\text{m}/\text{s}^2$.

A close relative of the mks system is the “cgs” system, which uses centimeters (cm) for length (1 m = 100 cm), grams (g) for mass (1 kg = 1000 g), and the second for time. Here the unit of force is the dyne (1 N = 10^5 dynes). If you routinely work with small amounts of material, then cgs may be more convenient than mks.

Electric charge and current can be defined in terms of force. Historically, there were two ways to do this:[7] (1) an electrostatic definition of charge, where we choose a value for ϵ_0 and then measure the force between two standardized charge configurations; or (2) a magnetostatic definition of current, where a value for μ_0 is chosen and the force measured between two standardized currents. Let us see how this works in both instances.

Since a point charge q' produces a field \mathbf{E} given by Coulomb’s law, and another point charge q “feels” the force $\mathbf{F} = q\mathbf{E}$, the magnitude of the electrostatic force F between two identical point charges will be

$$F = (1/4\pi\epsilon_0) q^2/R^2 \quad (13)$$

so that, by dimensional analysis, $q \sim \sqrt{F\epsilon_0} \times (\text{length})$. The cgs system gives the electric charge unit the name “electrostatic unit” or esu or “statcoulomb,” and defines $1/4\pi\epsilon_0 = 1 \text{ dyne}\cdot\text{cm}^2/\text{esu}^2$. By definition, one esu of charge is carried by each of two identical point charges so that when 1 cm apart, the electric force between them equals 1 dyne. If you have done a Cavendish balance lab, then you have been through a version of this procedure. With charge defined, electric current, $I = dq/dt$, can also be defined in these units: 1 “statampere” = 1 esu/s.

The SI system historically used the second alternative (the procedure described below pertains to definitions of charge and current before 1983). For instance, at the distance r from an infinitely long straight wire, the Biot–Savart or Ampère laws gives $B = \mu_0 I/2\pi r$. If another identical wire parallel to the first also carries current I , a segment of it having length l feels the force magnitude $F = IIB$, which we rearrange as

$$F/l = \mu_0 I^2/2\pi r. \quad (14)$$

The unit of current that we call the Ampère (A) is defined to be the current such that, with these wires 1 m apart, a force per length of $2 \times 10^{-7} \text{ N/m}$ is produced. The size of the “amp” is determined by the value chosen for μ_0 . In the SI system, we *define* $\mu_0 = 4\pi \times 10^{-7} \text{ N/A}^2$. The unit of charge, the Coulomb, is defined as 1 C = 1 A·s. When 1 A of current flows by you for 1 s, then a total charge of 1 Coulomb (C) has passed by. It takes a lot of elementary particles to make a Coulomb—the charge of one electron is $1.6 \times 10^{-19} \text{ C}$.

So far we have values for μ_0 and ϵ_0 but in different units. But notice that

$$\mu_0 \epsilon_0 = 10^{-2} (1 \text{ esu/C})^2 (1 \text{ cm/s})^2. \quad (15)$$

To find the esu-to-Coulomb ratio, go back to either experiment and put into it a known amount of charge or current measured from the other system’s definition. For example, in the two-charge system used to define the esu, replace the 1 esu with a known number X of Coulombs, keep the point charges 1 cm apart, and remeasure the force in dynes. Taking the ratio of forces, the $1/4\pi\epsilon_0$ drops out, leaving

$$F_2/F_1 = (XC/1 \text{ esu})^2. \quad (16)$$

By measuring X and the force ratio (rounding the measured 2.9979250 to 3 in this discussion), one finds that 1 C = 3×10^9 esu, and Eq. (15) becomes $\mu_0 \epsilon_0 = 1/(3 \times 10^{10} \text{ cm/s})^2$. [8] It will not escape notice that

$$\mu_0 \epsilon_0 = 1/c^2 \quad (17)$$

where c denotes the pre-1983 *measured* speed of light in vacuum!

One might wonder if someone slyly worked backward from the measured value of c to engineer the value of μ_0 that ensures Eq. (17). Suppose we try it! If the value of μ_0 had been chosen to have some other value, say rescaled by a factor S from the choice mentioned above, so that our μ_0 gets replaced with $\mu_0 \rightarrow S\mu_0$, then the Ampère unit, and likewise the Coulomb, would have been rescaled by $1/\sqrt{S}$. That means there would be a compensating S on the right-hand side of Eq. (15), which would cancel the S in $\mu_0 \rightarrow S\mu_0$ on the left side of that equation. This seeming coincidence between electrostatic and electromagnetic

units and the speed of light suggests a deep insight: Light is electromagnetic! The mechanism of that linkage would have to await the rest of Maxwell's equations, with their prediction of waves in the electromagnetic field that propagate in vacuum at the speed $1/\sqrt{(\mu_0 \epsilon_0)}$.

George Gamow has reflected, "The numerical coincidences between seemingly unconnected physical quantities, such as the ratio of electrostatic and electromagnetic units on the one side, and the velocity of light on the other, often led to fundamental new discoveries and broad generalizations in physics." [9] The light-as-electrodynamics case is not unique, as Gamow reminds us. For instance, the seeming coincidence between the constant that Max Planck used in 1900 to fit the spectrum of blackbody radiation and the constant that Einstein used in 1905 to fit the energy spectrum of electrons in the photoelectric effect triggered the development of quantum mechanics. The equivalence of gravitational and inertial mass offers another instance where an apparent "coincidence" led, on deeper inspection, to profound insight into the unification of gravitation and energy with space and time.

Now we can put ϵ_0 into the same units as μ_0 , from Eq. (17) and using the measurements described above. We find (replacing 3 with the present standard value 2.99792458) [10]

$$\epsilon_0 = 8.854187817 \times 10^{-12} \text{ C}^2/\text{Nm}^2. \quad (18)$$

These considerations describe how electric charge and current were defined before 1983. With the development of high-speed electronics, it became possible by 1983 to redefine the meter in terms of the distance that light travels in a tiny fraction of a second. In particular, the speed of light is now *defined* to be 299,792,458 m/s, which was the same as defining the meter to be the distance light travels in $1/299,792,458$ s. [10] With both μ_0 and the speed of light defined, from Eq. (17) we can say that, since 1983, ϵ_0 no longer needs to be measured. However, I find it astonishing that the insight "light is electromagnetic" came from *static* electric and magnetic measurements. This was done by measuring two of the three quantities in the trio μ_0 , ϵ_0 , and c , which were then put together with the discovery of the relation $\mu_0 \epsilon_0 = 1/c^2$. That insight occurred long before high-speed electronics existed.

The finite value of the speed of light suggests that the vacuum of empty space offers impedance to the flow of electromagnetic energy. As the names of ϵ_0 and μ_0 suggest, such impedance even for vacuum will be related to these constants. The impedance Z that any medium presents to a current I sent through it is related to the voltage V driving that current in a generalization of Ohm's law:

$$Z = V/I. \quad (19)$$

By definition, voltage is the line integral of \mathbf{E} . By Ampère's law (generalized to include Maxwell's displacement current, see Eq. (22) below), the current is $1/\mu_0$ times the line integral of the magnetic field. The geometrical factors in the line integrals cancel, giving us $Z = \mu_0 E/B$. Looking ahead to other parts of electrodynamics, we note that the amplitudes of harmonic *radiation* fields (light waves) are related in SI units by $E = cB$, so that, for space filled with light waves but no matter, we find that vacuum offers to the propagation of light waves the impedance

$$Z = \mu_0 c = \sqrt{\mu_0 / \epsilon_0} \approx 377 \text{ ohms}. \quad (20)$$

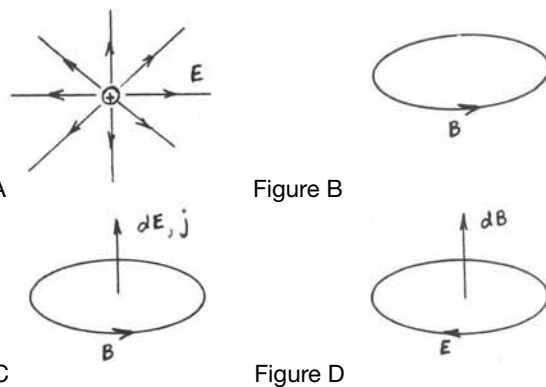


Figure 2. Cartoon illustrations of Maxwell's equations: (A) Gauss's law for \mathbf{E} ; (B) Gauss's law for \mathbf{B} ; (C) the Ampere–Maxwell law; and (D) Faraday's law.

Let us go beyond vacuum and look at the permittivity and permeability in matter. These quantities depart from their vacuum values because externally applied electric and magnetic fields impinging on matter can distort the molecules, producing or enhancing electric and magnetic dipole moments. These dipoles then produce electric and magnetic fields of their own, which combine with the original external field.

Before going there, let us write the time-dependent Maxwell equations that hold in vacuum *or* in matter (see Fig. 2). [4] One is Gauss's law for \mathbf{E} , Eq. (11), which says \mathbf{E} field streamlines diverge from (or converge toward) their source charges. Gauss's law for \mathbf{B} conveys a similar relationship, although physics has yet to find evidence for isolated magnetic poles—the density of magnetic monopoles evidently vanishes:

$$\nabla \cdot \mathbf{B} = 0. \quad (21)$$

Streamlines of \mathbf{B} do not diverge from or converge to a point, but can only close back on themselves.

Moving charges and changing electric fields produce \mathbf{B} fields with whirlpools (a "curl"), described by the Ampère–Maxwell law, generalizing Eq. (12) to

$$\nabla \times \mathbf{B} = \mu_0 (\mathbf{j} + \epsilon_0 \partial \mathbf{E} / \partial t) \quad (22)$$

where t denotes time.

When the magnetic field is time-dependent, it generates an electric field with whirlpools, and Faraday's law says

$$\nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t. \quad (23)$$

In all these expressions, the charge density ρ and the current density \mathbf{j} are totals due to *all* charged particles in the system. It is crucial in what follows to distinguish total charges and currents from the so-called "free charges" and "mobile currents." Free charges are those *in excess* of those that make up neutral matter. A prototypical example would be the excess positives in one plate (and the same number of excess negatives on the other plate) of a charged capacitor. They set up an electric field between the plates, which points from the free positives to the free negatives. When we insert our sample material between the plates, the molecules are "hit" by this original electric field.

Mobile currents are merely charged particles in motion, such as the loosely bound outer-shell electrons in the atoms of a good conductor. To visualize a venue for mobile currents, imagine the current flowing in the wire of a solenoid. When our sample of matter is placed inside the solenoid, its atoms are hit with its original magnetic field.

These externally applied electric and magnetic fields may induce electric and magnetic dipole moments among the material's molecules. Consider the electric case. When the capacitor's electric field is switched on, in the material between the plates a molecule's electrons are pulled away from the negative plate of the capacitor and toward the positive plate, while the positive charges are oppositely pulled. The molecules are still electrically neutral, but they get "stretched" with the centers of positive and negative charge separated. The molecules have become little dipoles, and each one produces its own electric field. That field's direction opposes the original one that was set up between the capacitor plates by the free charges.

An idealized electric dipole consists of equal and opposite charges, $+q$ and $-q$, separated by some small distance. Recall that a point charge q sets up an electric potential given by

$$V(\mathbf{r}) = (1/4\pi\epsilon_0) q/R \quad (24)$$

where $R \equiv |\mathbf{r} - \mathbf{r}'|$ denotes the distance from the source point to the field point. The potential of a dipole will be the superposition of such terms for both charges. Being a pair of charges, the electric potential produced by an electric dipole is (to lowest order in R),

$$V(\mathbf{r}) = (1/4\pi\epsilon_0) \mathbf{p} \cdot \mathbf{R}/R^3 \quad (25)$$

where the electric dipole moment \mathbf{p} is defined as $\mathbf{p} = q\mathbf{a}$, with \mathbf{a} the displacement vector from $-q$ to $+q$.

Consider now a sample of matter that consists of polar molecules, and let $\mathbf{P} = \mathbf{P}(\mathbf{r}')$ denote the density of electric dipole moments. The potential due to a distribution of such dipoles follows by superposition of Eq. (25) over the volume of the matter:

$$\begin{aligned} V(\mathbf{r}) &= (1/4\pi\epsilon_0) \int (\mathbf{P} \cdot \mathbf{R})/R^3 dx'dy'dz' \\ &= (1/4\pi\epsilon_0) \int \mathbf{P} \cdot \nabla'(1/R) dx'dy'dz' \end{aligned} \quad (26)$$

where the gradient operator ∇' takes derivatives with respect to the \mathbf{r}' coordinates. By integrating by parts and using Gauss's divergence theorem on one of the terms,[2] we obtain one contribution to V from the surface of the material and another from the bulk volume:[11]

$$\begin{aligned} V(\mathbf{r}) &= (1/4\pi\epsilon_0) [\oint (\mathbf{P} \cdot \mathbf{n})/R dA' \\ &\quad - \int (\nabla' \cdot \mathbf{P})/R dx'dy'dz']. \end{aligned} \quad (27)$$

By comparing these results to the generic superposition based on Eq. (24), in particular[12]

$$V(\mathbf{r}) = (1/4\pi\epsilon_0) \int \frac{\rho(\mathbf{r}')}{R} dx'dy'dz', \quad (28)$$

we identify $\mathbf{P} \cdot \mathbf{n}$ as a charge per unit area due to polarization on the surface of the material, and $-\nabla' \cdot \mathbf{P}(\mathbf{r})$ as the volume density of polarization charges (now dropping the prime because we are henceforth looking at the \mathbf{P} field itself, not having to distinguish

source points from field points).

Returning to Gauss's law for \mathbf{E} , Eq. (11), we now see that the total charge density can be split into a contribution of free charges and another one from the electric dipoles:

$$\nabla \cdot \mathbf{E} = (\rho_{\text{free}} - \nabla \cdot \mathbf{P}) / \epsilon_0. \quad (29)$$

This can be transposed to appear as

$$\nabla \cdot \mathbf{D} = \rho_{\text{free}} \quad (30)$$

where

$$\mathbf{D} \equiv \epsilon_0 \mathbf{E} + \mathbf{P}. \quad (31)$$

When no matter exists other than the free charges, then $\mathbf{P} = \mathbf{0}$; \mathbf{D} and \mathbf{E} are two names for the same field, except for the factor of ϵ_0 . But with polarization "turned on," \mathbf{D} and \mathbf{E} have different roles: \mathbf{D} is the electric field due to free charges and \mathbf{E} the total electric field. Polarization charges orient themselves so their field partially cancels the \mathbf{D} field of the free charges; thus, \mathbf{E} is proportional to $\mathbf{D} - \mathbf{P}$.

Before we turn to magnetic dipoles, we should notice that the polarization charge density, when time dependent, forms an electric current that must be included among magnetic field sources. A surface layer of polarized material has charge per area $\mathbf{P} \cdot \mathbf{n}$ which, if changing (imagine time-dependent molecular stretching), means a current through the layer exists, given by

$$I_{\text{pol}} = \int (\partial \mathbf{P} / \partial t) \cdot \mathbf{n} dA \quad (32)$$

and thus

$$\mathbf{j}_{\text{pol}} = \partial \mathbf{P} / \partial t. \quad (33)$$

Turning to magnetism, because the divergence of a curl identically vanishes, Gauss's law for \mathbf{B} says that \mathbf{B} may be written as the curl of a vector potential \mathbf{A} . For a generic current density \mathbf{j} , \mathbf{A} is given by [12]

$$\mathbf{A}(\mathbf{r}) = (\mu_0/4\pi) \int \frac{\mathbf{j}(\mathbf{r}')}{R} dx'dy'dz'. \quad (34)$$

From this one can show that the \mathbf{A} of a magnetic dipole of moment \mathbf{m} is[13]

$$\mathbf{A} = (\mu_0/4\pi) \mathbf{m} \times \mathbf{R}/R^3. \quad (35)$$

In the presence of an external magnetic field the molecules in matter may acquire a magnetic dipole moment \mathbf{m} or have an existing one enhanced. Consider a chunk of matter that carries magnetic dipole moment per unit volume \mathbf{M} . By superposition, and with the same tricks (integration by parts) that we used in the electric dipole case, you can show that $\nabla \times \mathbf{M}$ forms a current density due to the magnetic dipoles.

Now the Ampère–Maxwell law, Eq. (22), may be written with mobile currents distinguished from electric and magnetic polarization currents. Explicitly, with $\mathbf{j}_{\text{total}} = \mathbf{j}_{\text{mobile}} + \mathbf{j}_{\text{pol}} + \mathbf{j}_{\text{mag}}$, Eq. (22) becomes

$$\nabla \times \mathbf{B} = \mu_0 (\mathbf{j}_{\text{mobile}} + \partial \mathbf{P} / \partial t + \nabla \times \mathbf{M} + \epsilon_0 \partial \mathbf{E} / \partial t). \quad (36)$$

Now use Eq. (31) and transpose the result to write Eq. (36) as

$$\nabla \times \mathbf{H} = \mathbf{j}_{\text{mobile}} \quad (37)$$

where

$$\mathbf{H} \equiv \mathbf{B}/\mu_0 - \mathbf{M}. \quad (38)$$

Notice that the total magnetic field \mathbf{B} is proportional to $\mathbf{H} + \mathbf{M}$; the magnetism induced in the sample typically enhances the externally applied field.

We have rewritten the Maxwell equations with source terms to distinguish “free and mobile” sources from polarization sources. The remaining two Maxwell equations have no source terms, so they can remain expressed in terms of \mathbf{E} and \mathbf{B} . When a charge q finds itself in the presence of electric and magnetic fields, the electromagnetic force on it is still $q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$: the *total* fields exert force on a test charge.

Constitutive Relations

Now we need constitutive relations that relate \mathbf{P} and \mathbf{M} to the other fields. For an isotropic medium we define its dimensionless “electric susceptibility” χ according to

$$\mathbf{P} = \epsilon_0 \chi \mathbf{E}. \quad (39)$$

If χ is not itself a function of \mathbf{E} then the material is said to be linear (when χ *does* depend on \mathbf{E} , then we are in the regime of nonlinear optics). From Eq. (31) we obtain the constitutive relation between \mathbf{D} and \mathbf{E} ,

$$\mathbf{D} = \epsilon_0 (1 + \chi) \mathbf{E} \equiv \epsilon \mathbf{E}. \quad (40)$$

The factor $\kappa \equiv 1 + \chi$ is called the “dielectric constant” and $\epsilon_0 \kappa \equiv \epsilon$ the “permittivity” of the material.

Some materials, when hit with an electric field \mathbf{E} in, say, the x -direction, may show a polarization in, say, the y -direction. To allow for such cases we define the *susceptibility tensor* (or matrix), a quantity with nine components $\{\chi_{ij}\}$, according to $P_i = \epsilon_0 \chi_{ij} E_j$. The subscripts denote the various components, and repeated indices are summed over all three of them. From here one can go on to define dielectric and permittivity tensors.

In a similar way the magnetic susceptibility ψ is defined for an isotropic medium as $\mathbf{M} = \psi \mathbf{H}$, which, by Eq. (38), also gives the constitutive relation between \mathbf{B} and \mathbf{H} ,

$$\mathbf{B} = \mu_0 (1 + \psi) \mathbf{H} \equiv \mu \mathbf{H} \quad (41)$$

where $\mu \equiv \mu_0 (1 + \psi)$ denotes the “permeability” of the medium. Generalizing to tensor relations for nonisotropic materials is straightforward.

The speed of light v in a medium is related to its permittivity and permeability according to $\mu\epsilon = 1/v^2$. The index of refraction n of a piece of material is determined by the polarizability of its molecules, according to [14]

$$n = c/v = [\mu\epsilon/\mu_0\epsilon_0]^{1/2} = [(1+\psi)(1+\chi)]^{1/2}. \quad (42)$$

Such macro/micro connections generalize, of course. The electric and magnetic susceptibilities, and other such coefficients, can be predicted by using statistical mechanics applied to models of the molecules that make up the material. These constants offer a window from the macroscopic world of voltmeters and ammeters into the microscopic world of atoms and molecules.

Finally, you might wonder why the definitions put $k_m \sim \mu_0$ but $k_e \sim 1/\epsilon_0$ instead of the more symmetrical $k_e \sim \epsilon_0$. I suppose this is due to the lack of symmetry in the definitions of capacitance and inductance. In terms of self-inductance L and capacitance C , the voltage across an inductor is Ld^2q/dt^2 but is q/C for the capacitor. Notice the inverse relation between voltage and charge (or its derivative) in comparing C to L . That inversion explains, I think, why the permittivity and permeability are defined according $k_m \sim \mu_0$ but $k_e \sim 1/\epsilon_0$. This way, whenever you derive a formula for an object’s capacitance you get $C \sim \epsilon_0 \times (\text{length})$, and for inductance you get $L \sim \mu_0 \times (\text{length})$. The SI units of ϵ_0 may be written as Farad/meter (F/m) and for μ_0 they are Henry/meter (H/m). “Farads” and “Henrys” are the SI names for the units of capacitance (1 F = 1 volt/Coulomb) and inductance (1 H = 1 volt/(C/s²)).

From vacuum to superconductors, from water to iron, a body’s permittivity and its permeability tell us complex stories about the medium’s interactions with electric and magnetic fields.

Acknowledgment

I thank Thomas Olsen for carefully reading a draft of the manuscript and making many helpful suggestions.

References

- [1] The vacuum, itself, is a curious object of study—think of dark energy, for example, in cosmology.
- [2] We make much use of Gauss’s divergence theorem, which says that the volume integral of the divergence of a vector field \mathbf{V} equals the flux of \mathbf{V} through the surface enclosing the volume:

$$\iiint \nabla \cdot \mathbf{V} \, dx \, dy \, dz = \iint \mathbf{V} \cdot \mathbf{n} \, dA$$

where dA is a patch of area on the surface and \mathbf{n} an outward-pointing normal unit vector.

- [3] We also need Stokes’ theorem, which says that the flux through a surface of the curl of a vector field \mathbf{V} equals the line integral of \mathbf{V} around the perimeter of the surface:

$$\iint (\nabla \times \mathbf{V}) \cdot \mathbf{n} \, dA = \oint \mathbf{V} \cdot d\mathbf{r}$$

- [4] Maxwell’s equations and constitutive relations as Maxwell wrote them spelled out, component by component, some 20 equations. Oliver Heaviside developed vector calculus and put Maxwell’s equations into the concise form that we use today.
- [5] <http://en.wikipedia.org/wiki/Smoot>. This source notes that, fittingly, Oliver Smoot later became the chairman of the American National Standards Institute and president of the International Organization for Standardization.
- [6] Quantum effects, notably the Josephson junction and the quantum Hall effect, may make the reliance on Le Grande K unnecessary, analogous to how special relativity with its invariance of the speed of light made unnecessary an archival body as the standard of length. See Neil M. Zimmerman, “Quantum electrical standards,” *Physics Today*, Aug 2010, p. 68.
- [7] Well described in E.U. Condon and H. Odishaw, Eds., *Handbook of Physics* (McGraw-Hill, 1958), p. 9 of the “Units and Conversion Factors” section.
- [8] E.g., see J.D. Jackson, *Classical Electrodynamics* (Wiley, 1975), p. 812; and D. Griffiths, *Introduction to Electrodynamics*, 3rd ed. (Prentice-Hall, 1999), p. 559.
- [9] G. Gamow, *The Great Physicists from Galileo to Einstein* (Dover, 1988), pp. 156–157.
- [10] E.g., see R. Resnick, D. Halliday, and K. Krane, *Physics*, Vol. 1, 4th ed. (Wiley, 1992), Ch. 1. The NIST value may be found at <http://physics.nist.gov/cuu/Constants/index.html>.
- [11] For the details of these manipulations, see, e.g., D. Griffiths, ref. 8, Ch. 4 for electric polarization, and Ch. 6 for magnetic polarization.
- [12] For brevity, the formulas for the potentials V and \mathbf{A} are written as though for static sources. However, these expressions are correct in time dependent situations if we choose the Lorentz gauge, and if the time delay R/c between the doings of the source point and the resulting change in the field at the field point are taken into account.
- [13] E.g., Griffiths, ref. 8, Ch. 5.
- [14] For a simplified model of the “Origin of the Refractive Index” in terms of light scattering by oscillating electrons (and thus electric dipoles), see R.P. Feynman, R.B. Leighton, and M. Sands, *The Feynman Lectures on Physics* (Addison-Wesley, 1963), Ch. 31 of Vol. 1.

The XXV International Conference of Physics Students (ICPS) Graz, Austria, August 17-23, 2010

by Anya Burkart, Creighton University

2010 SPS Outstanding Students Award recipients Anya Burkart (Creighton University) and Daniel Glass (Elon University) represented the United States and presented their research at the 2010 ICPS. They were joined by 2009 award recipient and returning ICPS attendee Joshua Fuchs (Rhodes College). An abbreviated account of Anya's trip appears below.

To read the complete report and a report from cowinner Dan Glass, visit the SPS website, www.spsnational.org/programs/awards/2010/osa.htm.

Each year the International Association of Physics Students (IAPS) hosts the International Conference for Physics Students (ICPS) in a different city. The purpose is to foster the exchange of ideas and experiences between physics students throughout the world. In 2010, 400 students from 47 nations gathered in Graz, Austria, for student lectures, lab tours, distinguished speakers, excursions, and social events.

The day before my departure, I was presenting a poster at a regional conference and I heard an alarming talk about air toxicity in airplanes. To know about the radiation exposure incurred through flying was already enough; I did not need to hear this before boarding nine airplanes in the course of two weeks. Thankfully, I survived the journey in good health. I could deal with flight delays resulting in missed planes and lost luggage.

The conference included student lectures and posters, lab tours, guest speakers, and an outstanding experimental show. Dr. Peter Zoller from the University of Innsbruck began the week with a crash course in quantum mechanics for us, followed by a discussion of his work in quantum information and optics. Other guest lecturers included Dr. Sabine Schindler, Head of the Institute for Astro- and Particle Physics at the University of Innsbruck, who talked about new developments in astrophysics; and Dr. John Ellis from King's College London, who gave an entertaining presentation on the Large Hadron Collider and the universe. Near the end of his talk, Ellis shared an amusing story about meeting with then-Prime Minister of the United Kingdom Margaret Thatcher in 1982. She asked him what he did, and he replied, "I think of things for experiments to look for and hope they find something different." Puzzled, Thatcher asked, "Wouldn't it be better if they found

what you predicted?" Ellis answered, "Then we would not learn anything!"

Dr. Gernot Pottlacher from the Institute of Experimental Physics at the University of Technology in Graz presented a suspenseful two hour experimental show with explosions, accelerated objects, sparks, fire, and destruction. Of course, he also took time to devour the sausage he cooked in a 400 W circuit. I am looking forward to using my notes and further research to repeat some of the less dangerous demonstrations with students in SPS at Creighton University this year.

At ICPS, students give the majority of the presentations. I heard talks on black holes, time, lasers, radiation, and astrophysics. Not all talks were about traditional physics research. One talk presented the future of electric car design, and another informed students about the politics involved in the advancement of solar energy in Turkey. Discussions that sprang from the presentations carried on to the dinner table at the conference. I had the time of my life sharing creative ideas and perspectives with physics students from all around the world at ICPS.

After days packed with lectures and activities, we spent the evenings partying together. At the All Nations Party, I traveled the world in one evening, trying treats from Arabian dates to Swiss chocolate. The Finns even hosted a traditional Finnish dinner



The University of Graz, where most of the ICPS scientific program was held.

Photos by Josh Fuchs



The Austrian table at the All Nationals Party.

party (called Sitsit) that involved singing physics songs. Each country put on performances, too. I really enjoyed the Romanian students' traditional dance performance. Dan Glass and I represented American physics students by singing "Take Me Out to the Ballgame" and sharing buttered popcorn and root beer.

One evening we had a costume party where

SPS at Meetings

I dressed up as a typical American Crayola crayon. Apparently crayons are not as universal as I had thought, and people assumed I was a wizard of some sort. Throughout the night I met robots, hula dancers, clowns, and even Steve Jobs. The Austrian students put on a special Ghost Busters performance, too.

Rather than taking a normal city tour, the Austrian students creatively planned a city scavenger hunt. In groups we scouted out the city, stopping at checkpoints to solve riddles involving the city's history. The ornate pastel buildings decorated with



Photos by Josh Fudhis

Physicists calculating the depth of a well.

blooming flower boxes added great charm to the narrow, twisting streets. Of course, as physics students, indulging in our nerdy impulses enhanced our Graz experience. For instance, some of the students who

found a deep well on top of the Schlossberg hill dropped fruit down it and calculated the depth within 6 m of the reported value. During a coffee break, my friend Norbert from Malta and I took another adventure and went geocaching in Graz.

The International Conference for Physics Students in Graz was a splendid opportunity to meet fellow physics people, present research, share ideas, and have fun traveling abroad. I am grateful for the Society of Physics Students award that made it possible for me to go.



Want to go to ICPS 2011?

Apply for the SPS Outstanding Student Award for Undergraduate Research!

Winners will receive a \$500 honorarium and a \$500 award for their SPS chapter, as well as expenses for transportation, room, board, and registration for the 2011 ICPS in Budapest, Hungary. In addition, winners are invited to give their research presentation at an SPS research session at a national meeting in 2011-12. For details, visit www.spsnational.org/programs/awards. Applications are due March 15, 2011.

For information about the International Association of Physics Students, see www.iaps.info/about.

For more information about the International Conference of Physics Students, see <http://icps2011.mafihe.hu>.

Lasers and Social Media are Hot in Portland

2010 AAPT Summer Meeting
Portland, OR, July 17–21
by Tracy Schwab, SPS
Communications Coordinator

The cool weather in Portland, OR, was a welcome relief from soaring summer temperatures on the East Coast for SPS national office staff and several SPS interns (Shane Allison, Linda Henneberg, Jasdeep Maggo, and Foha Rafiq) who attended the American Association of Physics Teachers (AAPT) Summer Meeting, July 17–21. So what was *hot* in Portland?

The above-mentioned interns joined a dozen other undergraduate SPS members from across the country to present their research at an SPS poster session and reception on July 18th. This was SPS intern Jasdeep Maggo's first poster session, and she enjoyed presenting her poster about developing the 2010 SPS SOCK (Science Outreach Catalyst Kit).

Since SPS/American Physical Society intern Linda Henneberg uses Facebook and Twitter every day, she thought the most interesting session was "Social Networking: What's the Next Big Thing?" SPS Communications Coordinator Tracy Schwab was one of four invited speakers in this session, where he gave an overview of SPS's social

Hidden Physicists



Photo by Tracy Schwab

SPS intern Jasdeep Maggo explains to SPS Assistant Director Thomas Olsen how physics demonstrations are crafted for inclusion in the SPS SOCKs (Science Outreach Catalyst Kit).

media strategies, success stories, and best practices, and spoke about the challenges of presenting a consistent identity and brand across multiple social media channels.

The “Young Physicist Meet and Greet” was likely the most interactive session. Says Maggo, “I like these kinds of sessions where one can have random topics of discussions and meet a variety of people with different approaches towards physics. I am always curious to know what other people are trying to do with their degree.”

SPS/AAPT intern Shane Allison thought that the demo show “The Physics of Vaudeville” on the closing evening was spectacular, stating “I’m a big fan of physics one-liners, and the show had quite a few of them.” The other interns agreed: the demonstrations were simply amazing, and they thought it was nice seeing people using physics concepts in fun ways. That event ended with an extensive laser show, which in Maggo’s opinion was “awesome!” She sums up the entire meeting as follows: “The AAPT meeting was very educational and at times very exciting. I’m proud to be a physicist.”

Going to a meeting?

The Society of Physics Students (SPS) offers travel support at a level of \$200 for SPS chapters or individual students who report on a national physics meeting for SPS. Interested? See the details at www.spsnational.org/programs/awards/reporter.htm.

Kate M. McAlpine

Writer, Rapper, and Video Producer, Lowell, MI

I’m a freelance writer and sometimes rapper, specializing in physics. As a science communicator, my job is to explain research. Sometimes it’s documenting the progress of a long-term project, like my work with the ATLAS e-News, for the ATLAS experiment on CERN’s Large Hadron Collider. Sometimes it’s reporting about a recent advance, as in articles for *New Scientist* magazine. Sometimes it’s just goofing off and trying to get the word out to whoever cares to listen, as with the Large Hadron Rap (view at www.spsnational.org/wormhole/).

Brian L. Tichenor

Materials Engineer, League City, TX

I enjoy meeting physicists seemingly everywhere! During my undergrad years I was interested in magnetic properties of materials. In grad school I explored the ultramicrostructure of dental enamel. When I joined the materials engineering group at Boeing, my lead and his manager were also physicists! I worked in failure analysis, then process development, then later in the implementation of materials engineering in systems design. For the last 3 years I’ve been leading a young group of engineers in the development of Orion, the NASA manned spacecraft, and yes one of those is a young physicist! After a 25-year career with Lockheed, I now consult on materials engineering across the corporation.

Barrett Ware

Real Estate Portfolio Manager, Washington, DC

After graduating I assumed I would work in a research lab for a few years and then go back and get my PhD. However, the Cold War was ending and with it, the era of unlimited jobs for physicists. As an undergraduate, I was day-trading stocks with great success. Eventually, I became a portfolio manager for real estate-secured municipal debt.

Robert L. Greeson

Patent Attorney, Dallas, TX

I am a patent attorney at the international law firm of Fulbright & Jaworski, LLP, in Dallas, TX. My practice largely involves the prosecution of patents before the United States Patent & Trademark Office (USPTO). My practice further focuses on patents in the areas of fluid analysis, wireless communications, audio recognition, semiconductors, networks, and energy. Also, I am involved in various patent litigation matters.

Note: Many of these profiles have been significantly abbreviated here. Read complete profiles at <http://www.spsnational.org/cup/profiles/hidden.html>.

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Photo by Jason Bardi

Meet the 2010-2011 Council!

SPS and Sigma Pi Sigma (the physics honor society) are governed by the SPS National Council. The National Council is composed of one elected student representative and one elected faculty representative from each of 18 regional zones within SPS. Meet your 2010-2011 representatives and share your thoughts with them at www.spsnational.org/governance/council!