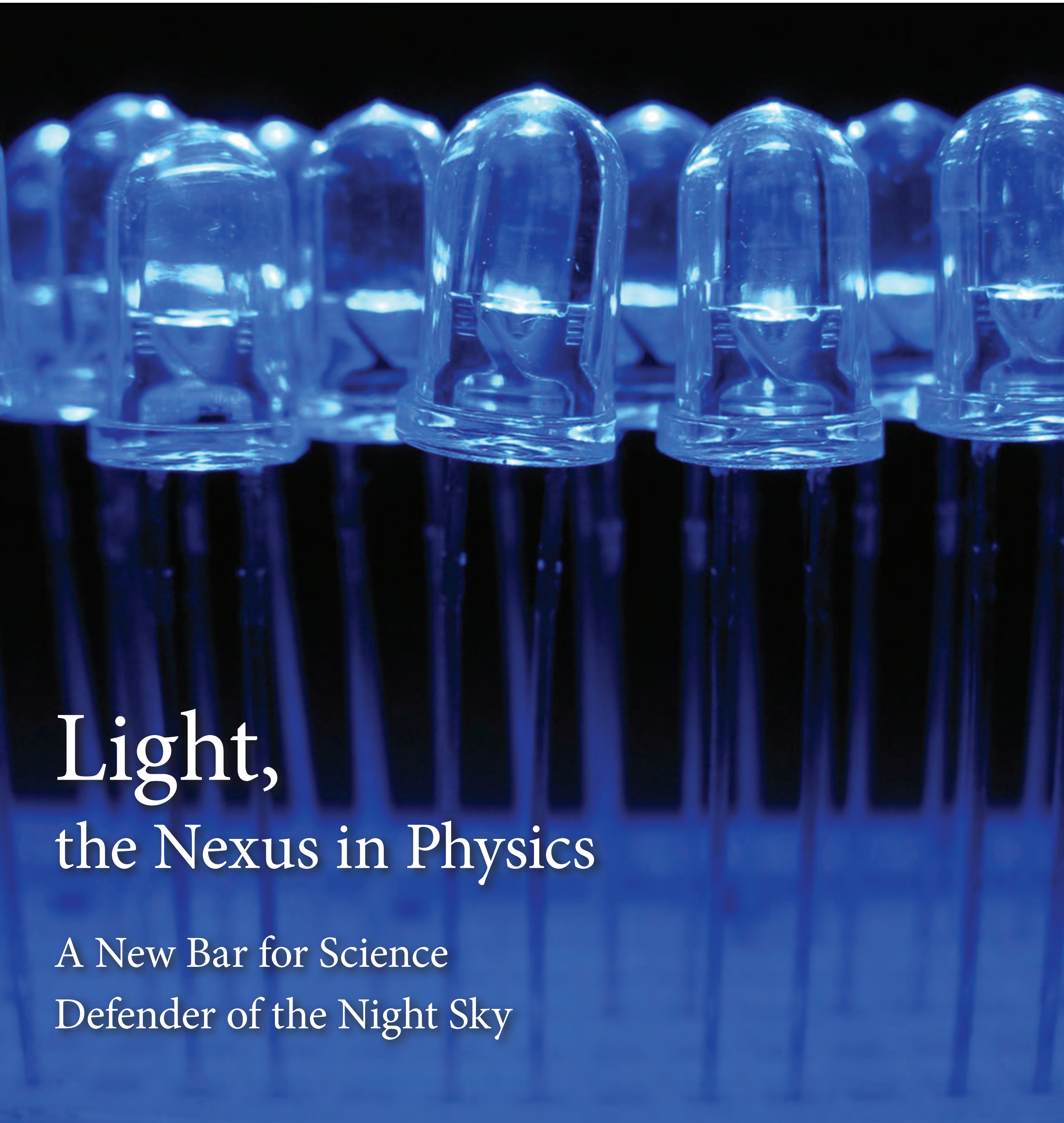
Radiations

FALL 2014

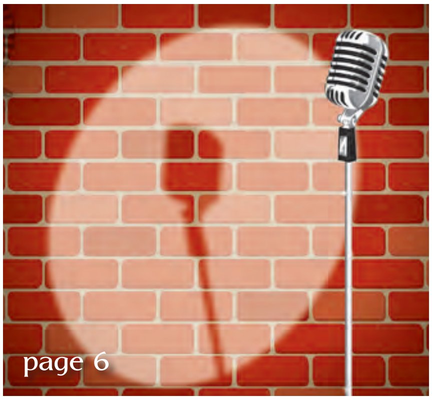
The official publication of Sigma Pi Sigma



Light, the Nexus in Physics

A New Bar for Science

Defender of the Night Sky



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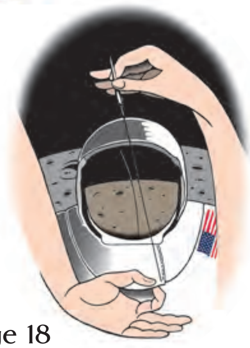

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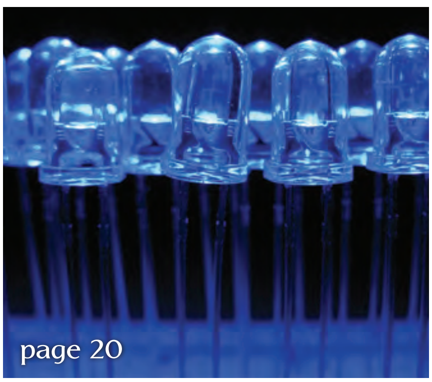

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ON THE COVER
Blue light-emitting diodes, a photo by Gussisaurio, is presented here in honor of the 2014 Nobel Prize in Physics, awarded jointly to Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura "for the invention of efficient blue light-emitting diodes, which has enabled bright and energy-saving white light sources."

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Departments

You are a Physicist

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

It is my great pleasure to introduce myself to you, the members of Sigma Pi Sigma. When I started as director of the Society of Physics Students and Sigma Pi Sigma this summer, I was very excited to bring to the societies my vision for advancing the quality of the undergraduate physics experience and promoting the value of undergraduate physics education. At the same time, I didn't want to reinvent the wheel or change what makes the societies wonderful. I greatly respect the nearly 50-year history of SPS and the over 90-year history of Sigma Pi Sigma.

With more than 95,000 members inducted into Sigma Pi Sigma to date, any decisions that we in the National Office make need to consider all of the members—where we've been, where we are now, and where we'd like to go in the future. I've enjoyed every chance I've had to meet members, speak with you on the phone, and receive your letters and emails. It is encouraging to know how deeply connected many of you still are to the society, and I hope to meet and hear from many more of you during my time here.

Prior to this position, I spent 11 years at Adelphi University in Garden City, New York, where I was a physics faculty member as well as advisor for the SPS and Sigma Pi Sigma chapters. Working with undergraduates is inspiring; I have seen them transform from high school students into adults ready to tackle graduate school, careers, and life in general. Students I have taught are now doctors, lawyers, research scientists, engineers, teachers, and much more. When I chose to dedicate my career to undergraduate education, I decided to judge my success not on papers published or grants received, but on the outcomes of my students. As most of you know but most of the rest of the population does not, students who study physics as undergraduates can go on to virtually any profession. Starting from a common undergraduate experience, SPS and Sigma Pi Sigma members spread through all areas of society and choose a multitude of professions.

However, this diversity also presents a challenge. Even though you, the members, are distributed across an array of fields, we still want you to feel connected to your roots and know that in a very real sense, regardless of your career path, *you are a physicist*. You have a way of looking at the world and its problems that very few outside of physics fully understand. As individuals and a collective group, we can do great things.

I have several goals for my time in this position. For the Sigma Pi Sigma membership specifically, I want to provide more opportunities for you to connect with each other, and more importantly, give you ways to reach out to the current undergraduates and help them develop into professionals. I want to see the undergraduate members of SPS get the most from their experience and have SPS become an integral part of their educations, not just an extra. My long-term goal is to see undergraduate physics education get the respect it deserves, and not be treated as an afterthought in an academic world that primarily focuses on graduate programs. In upcoming communications, I will speak with you about specific programs aimed at achieving each of these goals.

I look forward to the opportunity to communicate and work with each of you. As Sigma Pi Sigma approaches its 100th year and 100,000th member, the future is bright!

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Physics is for Everyone Because Everyone Uses Physics!

by Willie S. Rockward
Professor of Physics, Morehouse College
President, Sigma Pi Sigma

It gives me great pleasure and honor to write to you as President of Sigma Pi Sigma. When I was inducted nearly 27 years ago, I could not in my wildest imaginings have foreseen becoming president of the honor society, which has long been an active part of my professional and social life.

When most people think of physics, they think of complexity. They conjure images of quantum models and laws of nature. They envision rocket scientists, Sir Isaac Newton, or Albert Einstein. Most people do not imagine the connections between physics and something as simple as tossing a football. But it was football that led me to physics.

When I was a teenager, I wanted to play football at Grambling State University for the legendary Eddie Robinson, who was at the time the most winning coach in collegiate football. The only scholarship available to me from Grambling was in physics. So physics became my segue to the sport.

Soon I began to notice similarities. The quarterback throwing the football created projectile motion. The running back who carried the football built up linear momentum, and the linebacker who tackled that running back produced elastic or inelastic collisions. I was the running back. During football practice one day, an elastic collision with a linebacker helped me decide to choose the physics field over the football field.

After coursework in several areas of physics, I was inducted into the Grambling State University chapter of Sigma Pi Sigma in 1986. My affiliation with Sigma Pi Sigma and SPS has always focused on scientific citizenship, community service, and civic engagement with the physics community and the general public.

We should embrace the concept that physics is for everyone. Why? Because everyone (and every field) uses physics. It is not reserved for the few, the elite, or the geniuses. "Physics for all" leads to more interdisciplinary problems solved.

Physicists come from all walks of life and venture into a variety of professions. The physics connection is obvious in the sciences and technology, but physics is also important in the humanities, in law, and in medicine as well. Intellectual property attorneys, physicians, nurses, technicians, radiologists, and political scientists all use physics. Natural laws apply in all fields, in all professions.

As Sigma Pi Sigma president, I will utilize my position to help strengthen, shape, and sustain the future of this society. My Sigma Pi Sigma vision is to encourage undergraduates, graduate students, professors, professionals, faculty, and the public to appreciate their physical surroundings through the concepts and applications of physics. We are because physics is.

To: Dr. Toni Sauncy (2012–14 SPS and ΣΠΣ director) from an Old Tech Red Raider (TT '49)

I just finished reading your "Director's Space" in the Spring 2014 issue of *Radiations,* "Finding Historical Ties." Below are my historical ties with you.

In 1953–54, I was a graduate teaching fellow at Texas Tech under long-term physics department chairman Dr. C. C. Schmidt. In 1954, he asked me to contact Dr. Marsh White, professor of physics at Penn State and then-national director of Sigma Pi Sigma, about establishing a chapter at Texas Tech. What began was some 10 letters via snail mail with Dr. White, completing numerous forms, and Dr. White traveling to Lubbock in the early spring of 1955 to install the Tech chapter. The first nine chapter keys were awarded to the Tech physics faculty (several declined to join). I was awarded key 10 as Tech's first chapter president. I was able to arrange to have the director of the Sandia Los Alamos National Labs in New Mexico serve as our dinner speaker during our chapter installation week.

Tech at that time did not offer a doctorate in physics, so when I received my MS in physics later that spring, I turned down Dr. Schmidt's faculty offer. I needed to go somewhere to pursue my doctorate. Besides, after serving in the Air Force during WWII and in the Korean War as a fighter pilot, I now had married a Tech gal and had a small child. Thus I needed to find a job that paid some income and work on my doctorate part time. I also needed access to a technical computer. Tech had only a business computer in the administration at that time.

I left Lubbock in 1955 to work for North American Aviation in L.A. They offered a starting salary of $10,000 a year, access to their IBM 6090 Scientific Computer, and to underwrite all my doctorate expenses. My Tech research professor was shocked at this offer, as he was an associate professor making only $4,500 a year at that time.

I have a long story of working on the developments of the F-100, the F-107, and the B-70 aircraft, the X-15 space plane, and as development director for the Apollo Moon Landing Program, etc. Now I am sliding down toward 90, and I am in reasonably good health. I have had two spinal surgeries these past four months, which has affected my mobility at the present.

Needless to say, I am elated to discover a Tech physics person guiding Sigma Pi Sigma at the national level and doing a great job.

Best personal regards,
Joseph (Joe) H. Robinson III, PhD,
MBA (Retired)

Corrections: *"Finding Historical Ties" in the Spring 2014 issue of Radiations incorrectly stated that Purdue University is in Illinois. The university is located in West Lafayette, Indiana.*

In the spring issue, the alma maters of Sigma Pi Sigma alums Richard Montgomery and Rodney Smith were erroneously listed. These generous donors were inducted in 1962 and 1963, respectively, at the University of Texas at El Paso. We apologize for the errors.

A New Bar for

Casual science talks are catching on

by Devin Powell
Managing Editor, Radiations

Louis Schwartz, a lawyer from Brooklyn, has a different concept of celebrity than most people. While standing in line at a coffee shop, he once chatted up Hugh Jackman, failing to recognize one of the biggest stars in Hollywood (and the winner of *People* magazine's 2008 "sexiest man alive" award).

Who does Louis recognize? Theoretical physicist and author Brian Greene, whom he spotted walking through a subway station with his wife one day. Thrilled, Louis ran up to the scientist and began questioning him about string theory.

When Louis wants answers to the many questions he has about science, his favorite place to go isn't a university or a museum. It's a dark, cavernous bar called the Bell House on 7th Street in Brooklyn. Once a month, science enthusiasts like Louis pack the place to hear a talk by a scientist and participate in a Q&A session. The event, started eight years ago and run by a jazz musician and a pair of writers, is called the Secret Science Club (SSC), though that's a bit of a misnomer these days—the club has been publicized in everything from *Scientific American* to *The New York Times*, so the secret is definitely out.

Janna Levin, a cosmologist at Barnard College in New York who studies black holes and the size of the universe, gave one of Louis' favorite SSC talks. "She said that photons have no mass," Louis told me. "So I asked, 'How does using light sails to provide propulsion for long-duration interplanetary space flight work, if photons don't have mass?'" An enlightening discussion about momentum ensued, said Louis.

SSC's lineup has included such scientific all-stars as Neil deGrasse Tyson and Steven Pinker. Sigma Pi Sigma's own David Hogg, a cosmologist at New York University, kicked off the 2012 season with a talk about the history of the universe. Becky Ferreira, a reporter for *New Scientist*, recorded Hogg's opening remarks as he looked out at the big crowd that had gathered: "Holy [expletive]! I didn't know science was this cool!"

Science is so cool, in fact, that it is leaking out of academia across the nation and finding its way into bars, clubs, coffee shops, and other places where lay people congregate to be social and have a good time. The Secret Science Club is part of a community of new "science cafés" popping up, projects that connect the public to science in casual settings that often involve snacking on appetizers and sipping mixed drinks.

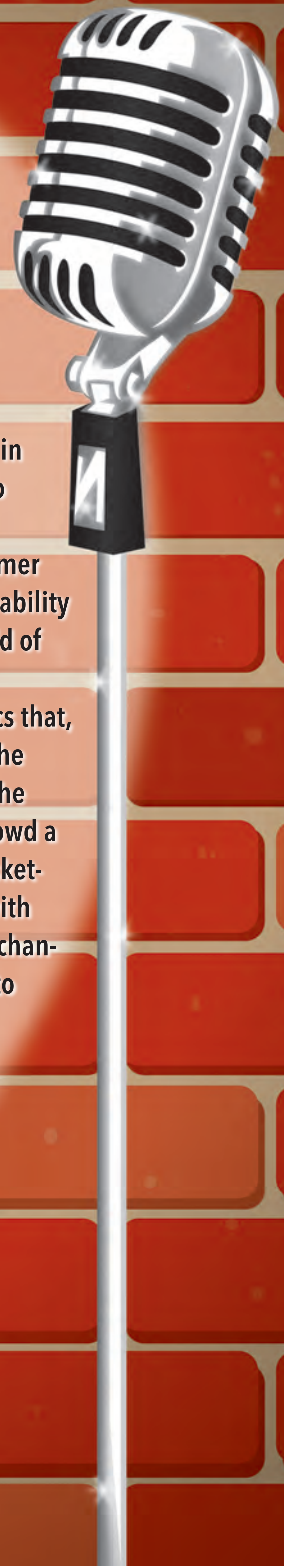
One of my favorites is PechaKucha. The brainchild of two architects, this event challenges presenters to explain something they are passionate about in 20 slides, with 20 seconds for each slide. The nerve-wracking format forces one to be concise and clear. The first PechaKucha I attended was hosted by a warehouse-turned-art space in New York, where the audience sat on the floor cross-legged; others took place in a chic art gallery in Washington, D.C., and a park next to a coffee shop in Thailand.

To learn more about how Sigma Pi Sigma members are getting caught up in this trend of informal science presentations, I tracked down two alums who have participated in events similar in spirit to the Secret Science Club. They graciously offered to share their stories with the Sigma Pi Sigma community. Perhaps they will inspire you to get out and share your own expertise at a bar near you!

Science

Nerd Nite

*by Julie Krugler Hollek
Fellow, Hackbright Academy, San Francisco, CA, and Sigma Pi Sigma Member, Michigan State University, Class of 2008*



Nerd Nite is a monthly event that takes place in cities across the United States. Experts, hobbyists, and enthusiasts gather to give short, informal talks covering a wide array of topics. These events take place at casual venues such as bars and coffee shops, and presenters are usually Nerd Nite patrons who have attended a few times and volunteered to share their knowledge.

When I heard that Nerd Nite Austin was putting together its first astronomy Nite, appropriately entitled "Space Jam," I jumped at the opportunity to give a talk. At the time I was an astronomer at the University of Texas, Austin, where I studied the chemical composition of the oldest stars in the galaxy. With a friend of mine who worked in a related field, I gave a joint talk telling the story of the early universe, from the big bang to the stars that are observable today.

"If you wish to make an apple pie from scratch, you must first invent the universe," astronomer and science popularizer Carl Sagan famously wrote. Borrowing from Carl (and the general agreeability of baked goods), we framed the talk in terms of a pie. The metaphor helped to tie my esoteric field of study to something that was understandable and relevant to the audience.

One of the most appealing aspects of participating in Nerd Nite was being able to discuss topics that, though important to my research, never make appearances in my professional talks. As I laid out the ingredients required for pie baking, I needed to talk about supernovae, which are responsible for the creation and distribution of many of the elements that make up the periodic table. I showed the crowd a supernova demonstration that I find particularly enlightening; I placed a tennis ball on top of a basketball and dropped the pair. The energy transfer that happened between the two balls upon impact with the floor was obvious, causing the tennis ball to shoot upward! This is a good illustration of the mechanics of a supernova, in which the expansion of an inner layer (the basketball) transfers momentum to an outer layer (the tennis ball), causing material to shoot outward into space. It also never fails to entertain a crowd!

Demos like these don't often find their way into colloquia or plenary talks at conferences, but they are engaging ways to present information.

At Nerd Nite I shared knowledge with a general audience that was actually interested in science. Giving a public talk was a mutually beneficial experience; it helped me to better understand my subject matter. I had to simplify the explanations I gave of my studies by omitting the jargon and hand-waving. In fact, the slides I developed for my Nerd Nite talk were so thoughtfully put together that I was able to use a few of them in my doctoral defense.

Science on Tap

by Alice Bean
Professor, University of Kansas, Lawrence, and Sigma Pi Sigma Member, University of California, Irvine, Class of 1983

A few years ago, I decided to put solar panels on my house in Lawrence, Kansas, and dump the excess power I generated back onto the grid. Evidently, I was the first person in Lawrence, Kansas, to enter into such a grid tie-in agreement with the regional electric company.

Staff members at the University of Kansas (KU) Natural History Museum found out about this arrangement. They invited me to give a presentation at Science on Tap, a monthly event that takes place in the evening at a popular local brewery called the Free State Brewery. In a room that holds about 60 people, I was to give a 30-minute talk about do-it-yourself solar power. Other talks at the event have covered topics ranging from the extinction of trilobites to the evolution of galaxies. Anyone can stop by, join in, and participate in the discussion.

As an experimental particle physicist at KU, I've had many great opportunities to get physics out to the public over the years. These experiences have helped me to understand physics at a deeper level by forcing me to figure out how to boil down the information to something that's engaging. I've spoken to high school classes, and I've created materials for elementary-aged students, who are incredibly challenging because they are, I believe, the brightest among us. With a team of collaborators, I developed the outreach program *Quarked! Adventures in the Subatomic Universe* (www.quarked.org). Speaking to adult groups is the most interesting form of outreach, in my experience.

After eating dinner at Science on Tap, I was handed the microphone and had to remember how to talk without using PowerPoint slides! I explained the physical principles behind solar power and actually did some math for the audience. Then I answered questions for as long as the participants cared to ask them, about 45 minutes.

What you find at these events is that the public wants to engage with faculty members and discuss intellectually interesting ideas. The questions were insightful, and I learned something as well.

The best part about participating in this form of community engagement was getting to see, firsthand, that science actually matters to our society!

DIY Physics

Sigma Pi Sigma alum shares do-it-yourself expertise online

by Glenn Roberts, Jr.
SLAC National Accelerator Laboratory, Menlo Park, CA

Background illustration courtesy of SLAC National Accelerator Laboratory

Michael Kelsey (Sigma Pi Sigma Member, University of California, Los Angeles, Class of 1986) has a knack for tinkering. A physicist at the Stanford Linear Accelerator Center (SLAC) in Menlo Park, California (and Sigma Pi Sigma alum), his do-it-yourself (DIY) projects include modifying a crib, hacking a children's toy, and testing the fundamental properties of light using garbage bags, Silly Putty, a laser pointer, and some thick foil.

Kelsey has worked on the detector for the Stanford Linear Collider experiment at SLAC, the Beijing Spectrometer, and BaBar experiments, and is now involved in simulating particle interactions and searching for dark matter. While the practical and fun projects he takes on in his spare time may seem a far cry from his work in particle physics, Kelsey sees them as a natural crossover for the ingenuity and problem-solving skills that scientists routinely enlist.

Particle physics experiments are like massive DIY projects, Kelsey says, as they often require custom-built components and plenty of resourcefulness and inventiveness. "What we build—what we do experiments with—is often a one-off," he says. "It's a really huge do-it-yourself project." And the physics community is as open and collaborative as the community of do-it-yourselfers, he says.

For many years Kelsey has engaged in online science forums, freely sharing his expertise and working to demystify science for all comers. In 2008 a web search led him to Instructables.com, an online DIY community launched in 2005 that features user-shared tutorials for projects ranging from electricity-generating shoes to wine-bottle electron accelerators to garage-built fusion reactors.

Kelsey's first foray to the Instructables.com community was in 2008, when he shared a furniture-modification project that accommodated his wife's disability by allowing her to get their daughter in and out of a crib without needing to reach over its top. "I bought a wonderfully cheap IKEA crib, modified one side of it to be a French door so you could slide the door open sideways, and then cut the legs off," he says. The project was featured in *Make* magazine, a publication for the DIY community.

His most popular contribution to Instructables.com, which has so far drawn about 128,000 views, explains how to convert a children's toy from battery-powered to plug-in. Other instructions, which borrow from physics projects he carried out in college, explain how to demonstrate that light behaves like a wave. Kelsey gives advice and insight on other projects as well; he has logged thousands of comments on the site.

He's not the only physicist using DIY projects to share his love of science.

Todd Johnson of Fermi National Accelerator Laboratory in Batavia, Illinois, has posted numerous science how-to videos on YouTube, including instructions for building a Ping-Pong-ball accelerator. He says he hopes to make science more approachable for the masses.

"The real key is engaging those people who otherwise may be a little shy about it," he says. "If you can make them aware of what's going on at a level they can appreciate, then maybe they will go and read some more about it."

Tim Koeth, a professor of electronics and applied physics at the University of Maryland in College Park, has shared numerous DIY science projects via Facebook and on his blog. He has built sophisticated gamma-ray spectrometers with an assortment of eBay purchases and spare and donated parts. He has built particle-accelerating cyclotrons (also featured in *Make*) and offered up detailed online instructions on DIY cyclotrons. He sometimes enlists the help of students in his DIY projects. "I'm able to turn some of these things into a teaching lab," he says. His DIY gamma-ray tools, for example, demonstrate to students how to detect and measure radiation.

There's a tremendous amount of information out there for DIY science enthusiasts, including online forums and textbooks, he says. Kelsey and others like him continue to contribute to the stockpile.

This story originally appeared in Symmetry *magazine (www.symmetrymagazine.org). It has been reprinted here in an edited form with permission.*

A 3-D-printed model of the Homunculus Nebula is compared to a Hubble image of the object.
Photo courtesy of NASA's Goddard Space Flight Center/Ed Campion

Astronomy for a Better World

Office of Astronomy for Development promotes societal benefits of science

by Kevin Govender
Director, International Astronomical Union Office of Astronomy for Development, Cape Town, South Africa

To many people the words "astronomy" and "development" simply don't belong together. The former conjures up images of celestial beauty and the grandeur of our evidence-based imaginations, while the latter brings us down to Earth, to the poverty-ridden, disease-ridden, conflict-ridden society of which we are very much a part. That one should impact the other is sometimes a contentious issue. Why invest in astronomy when people are starving? Why invest in any "blue-skies" science for that matter?

In 2009 the International Astronomical Union (IAU) took the bold and visionary step of ratifying a strategic plan that aimed to use astronomy to stimulate global development. IAU, the largest body of professional astronomers in the world, is a global voice in astronomy with a mission "to promote and safeguard the science of astronomy in all its aspects through international cooperation." At the core of the IAU's new plan was the establishment of an Office of Astronomy for Development (OAD), inaugurated in 2011 in Cape Town, South Africa, and hosted at the South African Astronomical Observatory. Since then, new regional offices have been established in China, Thailand, and Zambia.

"Astronomy can inspire thought and stimulate problem-solving skills at all levels from cradle to grave."

Our vision is simple and broad: "Astronomy for a better world!" Astronomy has close ties to three key areas that contribute to development. The first is technology, from the construction of telescopes to projects that push the limits of our data handling abilities. The second is science, since exploring the universe requires interdisciplinary approaches that stimulate diverse fields from physics to chemistry to biology. The third is culture; across the world, societies have profound cultural connections to the cosmos that include deep questions such as whether there is life "out there." We aim to use these characteristics of astronomy for the benefit of society at large.

Because of its cross-cutting nature, astronomy can inspire thought and stimulate problem-solving skills at all levels from cradle to grave. OAD activities are therefore shaped around three target groups: universities and research; children and schools; and the general public. Through an annual open call for proposals, the OAD seeks innovative ideas that reach out to these groups and use astronomy to stimulate education and development.

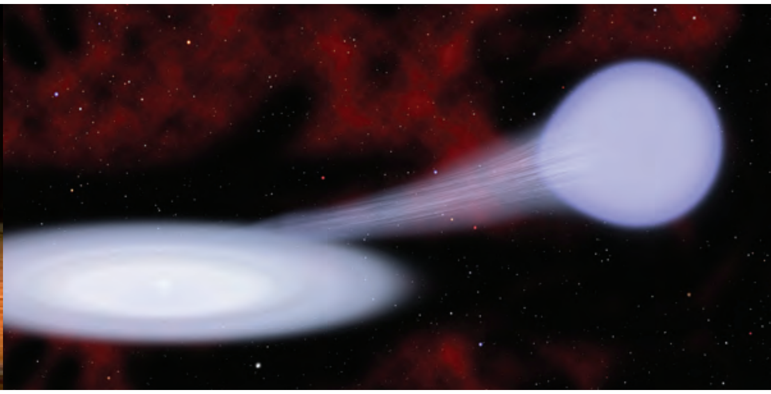
One project we recently funded, "Astronomy for the Visually Impaired," distributed innovative tactile models that brought astronomy to the visually impaired in about 30 countries. We hosted Wanda Diaz-Merced, a blind Puerto Rican astronomer, at the OAD for two months. She taught us about astronomy tools that are useful for visually impaired learners, including 3D-printed models and NASA's Radio JOVE, a radio astronomy kit. We visited schools where blind learners were given tactile models of the Sun, Moon, and Earth to literally get a feel for astronomy. The reactions were incredible. As Diaz-Merced put it, "Good questions arose from every corner of the room after our presentations. The children asked, asked, asked!" While at the OAD she also gave an inspiring TEDx talk, available online at at http://tedxtalks.ted.com/video/Listen-to-the-Stars-Wanda-L-Dia.

In total we have funded 41 projects over the years, reaching out to over 40 countries. "Astrolab" (a three-year project) seeks to develop a virtual telescope control room that accesses robotic telescopes remotely from university physics departments. "Astronomy for the Extremely Ill or Traumatically Injured Children and Their Families" uses the inspirational power of astronomy to lift the spirits of children and their families at Ronald McDonald Houses in the United States. Regular updates on all these projects are posted on the OAD website.

The door remains open for innovative ideas that can be funded with seed money and subsequently incubated at the OAD. We currently face overwhelming demand for a limited pool of funding. (Only 10 percent of potential projects were funded in 2013.) OAD has been trying out new forms of fundraising, from crowdfunding to forming in-kind partnerships with organizations involved in similar activities.

Opportunities to engage with the OAD range from volunteering to internships to visiting fellowships. We also have an open "to-do list" online, with ideas that we think would be great to implement but for which we don't have the staffing—such as developing a platform to crowdsource English proofreading for scientific papers that are written by authors who did not learn English as their first language.

More information on the OAD and various opportunities to get involved can be found on www.astro4dev.org.



Left: Diaz-Merced presents "Listen to the Stars" at TEDx Westerford High School in Cape Town. Photo courtesy of TEDx.

Right: Diaz-Merced worked with data from NASA's Chandra X-ray Observatory. This artist's conception, "Music of the Spheres: Star Songs," shows the binary star system EX Hydrae, which consists of a normal star and a white dwarf. Photo courtesy of Christine Pulliam (CfA).

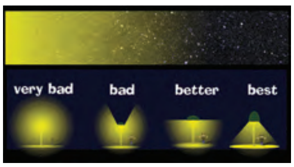
Defender of the Night Sky

A Q&A with Sigma Pi Sigma Member Rachel Nydegger, Utah State University, Class of 2013

Can you tell us about the award winning research you've done as an undergraduate at Utah State University (USU) in Logan?

For the past two years, my research has focused on light pollution. I have been measuring the brightness of the night sky to determine how efficient street lamps are. Many streetlights emit light radially rather than focusing the light on the ground, which can be an issue for ground-based astronomy. The light that goes into the sky is wasted energy and wasted money, a loss of 2.2 billion dollars annually in the United States. It also poses a huge threat to nocturnal creatures. Tens of thousands of sea turtle hatchlings die heading toward the light of cities instead of the ocean; disoriented birds crash into buildings; the circadian rhythm of frogs is disastrously disrupted; and so on. Light pollution can even disrupt the lives of humans, potentially contributing to depression, insomnia, and obesity.

Using a portable device that allowed me to move around while I collected data, I made a light pollution map of USU's campus. By measuring the light output at different angles from various street lamps, I determined which fixtures were most efficient (i.e., delivering more light toward the ground than to the sky). I also deployed stationary sky quality meters that collected data for months at a time and revealed temporal trends in the pollution.



Example of degrees of streetlight pollution. Photo courtesy of NASA.

How did your research open doors for you in the physics and astronomy community?

This research allowed me to work at the National Optical Astronomy Observatory in Tucson, Arizona, last summer. Astronomy is a big part of the economy in Tucson, and I helped to create an automated way to interpret light pollution levels measured at the observatories and in the city. This method of analyzing data will also help the citizen-science project Globe at Night, in which people around the world measure light pollution in their areas.

I have been to several conferences to present my work, from an SPS Zone Meeting and the Utah Conference for Undergraduate Research to an American Physical Society meeting. I also had the opportunity to travel to the International Conference on Artificial Light at Night in Berlin, Germany; following this event, I received the Dark-Sky Defender Award from the International Dark-Sky Association.


Photo courtesy of Rachel Nydegger.

How have science and the Society of Physics Students connected you to the lay public?

As an SPS member I have volunteered at USU's Science Unwrapped seminars, where kids learn about science through hands-on activities. I also volunteer with SPS as an amateur astronomer at USU's Public Observatory Nights, in which we teach visitors about celestial objects.

Once I started uploading my research to the Internet, local media agencies began contacting me. There has been much public interest. I was interviewed by local newspapers, magazines, and blogs. At one point FOX 13 News in Salt Lake City interviewed me for TV; I'm considered to be an expert on Utah's light pollution. I still periodically get e-mails asking for advice on what individuals can do to combat light pollution.

As you prepare to finish up your bachelor's degree, what are your plans for the future?

Light pollution has many ecological aspects to it, so I've become interested in ecology. My plan is to use my physics degree to go to graduate school in ecology and apply my scientific background to that field.

Effects of Light Pollution

"One of the beauties of modern civilization is seeing the city lighting at night. It provides a feeling of security and is indicative of the power and endeavors of humanity, but overlighting is a form of pollution. Many outdoor light fixtures spread light in all directions, sending a majority of the light into the sky, away from where we want the light to be on the ground. This light spreading upward is not only wasted light, but it is wasted energy and money, destroys our ability to view the night sky, and has profound effects on nocturnal creatures. The direct harm to certain species then affects the ecosystem it interfaces with, causing damage on a much larger scale than expected. Small changes in lighting practices would positively affect energy use and economies, ecosystems, and the efficiency of astronomical endeavors."

—from "Mapping Light Pollution at Utah State University" by Rachel Nydegger and Shane Larson. See: http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1000&context=poth_slc.


NASA Earth Observatory/NOAA NGDC

The Game Designer

Ed Beach
Lead Game Designer, Firaxis Games

I remember clearly what first spurred me to be a physics major in college. It was watching Carl Sagan's television series *Cosmos: A Personal Voyage*. Never before had I realized the size and beauty of the universe and the fragility of our position within it. I spent a lot of time writing college application essays during my senior year of high school, and many of them discussed themes from *Cosmos*.

One year later I was in the advanced freshman physics track at Dartmouth College in Hanover, New Hampshire. In one of our lab assignments we were asked to create software that could compute orbital trajectories around stars and planets. I soon realized that my true calling was creating computer models, often of physical systems, but not exclusively. My major evolved into "computer science modified with physics," with a few astronomy courses thrown in for good measure.

"It's no coincidence that launching the Hubble Space Telescope is one of the best ways to win a scientific victory in Civilization V."

With this background I was fortunate enough to start my career by developing software that supported the mission of the Hubble Space Telescope, managed out of NASA's Goddard Space Flight Center. After 10 years supporting Goddard's scientific missions, I moved on to the telecommunications industry and wrote software that modeled the propagation of cellular signals and microwaves for companies setting up new wireless networks. Once again, a strong background in physics combined with knowledge of how to model physical systems on the computer proved invaluable.

Photo courtesy of Ed Beach.

However, I had one more interest that had not surfaced in my professional career: a love of history. My passion has always been playing detailed historical strategy games, so in 1999 I made a move into the computer game industry. That path led me to Firaxis Games, where I have led the design of the game Civilization V for the past three years. The game starts 6,000 years ago, when humankind was founding its first cities. Step by step, a player's people advance through history, replicating many of the key scientific discoveries highlighted by Sagan in *Cosmos*.

In developing the gameplay and artificial intelligence systems for complex strategy games I am constantly creating small computer models that capture the behaviors needed to depict population growth, food consumption, or rates of scientific progress. I have also been able to acknowledge some of my favorite accomplishments in world history; it's no coincidence that launching the Hubble Space Telescope is one of the best ways to win a scientific victory in Civilization V.

This year, I watched with interest as Neil deGrasse Tyson launched his *Cosmos* sequel, *A Spacetime Odyssey*. As the television series tracked the course of scientific discovery and showed images from the Hubble Space Telescope, I reflected on my career path and how it all started with physics.

HUBBLE IN CIVILIZATION V
Beach features the Hubble Space Telescope in Civilization V by game development studio Firaxis. Firaxis has released dozens of hit games on multiple platforms and is recognized as an industry leader in game development.

My Piece of the Pi(e)

STUDENTS AND PHYSICISTS CELEBRATE PI DAY BY GIVING BACK

by Tara Davis,
Development Manager, American Institute of Physics, College Park, MD

March 14 is always a great occasion to pay homage to the mathematical constant approximated as 3.14. But this year students and professional physicists celebrated Pi Day in an entirely new way. They used it as an opportunity to support Sigma Pi Sigma and the Society of Physics Students (SPS), organizations that have helped many physicists throughout their educations and well into their careers.

To raise awareness of and support for their programs, SPS and Sigma Pi Sigma, in collaboration with the American Institute of Physics Development Office, collaborated on a website that encouraged visitors to donate in increments of pi. The site also featured short videos and photos of students, faculty, and Sigma Pi Sigma alumni talking about the "piece of the pi(e)" they received from SPS or Sigma Pi Sigma. Homemade pies and pie servers were given away to provide extra incentive to donate. In total to date, Pi Day efforts have raised $28,104.

"I would like to give ☑ $3.141592653589793238462643383279502
88419716939937510582097494459230781640628620899862803482534
21170679821480865132823066470938446095505822317253594081284
81117450284102701938521105559644622948954930381964428810975
66593344612847564823378678316527120190914564856692346034861
0454326648213393607260249141273724587006606315588174881…"

"I just thought it was really important to give back, and I thought it was important for me to encourage others to give," said donor Beth Cunningham, who is the executive officer of the American Association of Physics Teachers. "I thought it was a really clever idea."

Cunningham earned her bachelor's, master's, and PhD degrees in physics from Kansas State University in Manhattan. As she worked her way through tenure and prestigious positions teaching physics at universities, she realized she wanted to help others on a broader scale. "I knew I wanted to do something to help people on the national level, something to help faculty and physics educators."

Cunningham isn't the only physics-student-turned-physics-professional who had this realization. Philip "Bo" Hammer currently serves as the associate vice president of physics resources for the American Institute of Physics. Hammer was the director of Sigma Pi Sigma and the Society of Physics Students from 1996 until 2000, and believes the groups are important because they "honor scholarship, service, and commitment to the field and have the potential to build long-lasting affinity to physics."

Sigma Pi Sigma president Willie Rockward created a video for the Pi Day site in which he describes how he received his first "piece of pi(e)" in 1987 when he was inducted into Sigma Pi Sigma at Grambling State University in Louisiana. Rockward, who is also chair and associate professor of physics at the department of physics at Morehouse College in Atlanta, Georgia, said he found even bigger pieces of the pi(e) by serving on the SPS National Council and by becoming an SPS advisor at Morehouse, where he has had the pleasure of inducting into the honor society his own students.

Like Rockward, undergraduate Robyn Smith also said she has received several pieces of pi(e) thanks to her active membership in SPS. "My local chapter [at Drexel University in Philadelphia, Pennsylvania] receives a piece of the pi(e) every time we succeed and our proposal is awarded a grant that allows us to bring our excitement for physics to local middle and high school classrooms," she said. "I personally received my own piece of the pi(e) when I was nominated and elected as zone 3's associate councilor. As an AZC, I've been able to directly participate in the governance of SPS National, as well as meet other inspirational student SPS leaders from across the country."

Help us put the pi in Sigma Pi Sigma! Donate today at www.sigmapisigma.org/the-pi-is-coming.html.

Your Dollars at Work

Sigma Pi Sigma and the Society of Physics Students thank you for your continuing contributions. Alumni gifts impact and enrich the undergraduate physics student experience across the country and provide the funds for innovative projects that excite and motivate students, teachers, and the public at large. THANK YOU!

The 2014 SPS Interns. Photo by Courtney Lemon.

2014 SPS INTERNS

www.spsnational.org/programs/internships/

SPS internships are awarded on the basis of scholastic record and potential for future success, SPS participation, and relevant experience. Interns are placed in a variety of organizations and work on research, policy, or education projects.

NICK DUROFCHALK
Lebanon Valley College
Project: Following Eta Carinae Across Periastron
Host: NASA's Goddard Space Flight Center

ASHLEY FINGER
Davidson College
Position: AIP Mather Policy Intern
Host: US House Committee on Science, Space, and Technology

CALEB HEATH
University of Arkansas
Project: Developing and Revising Materials for the Physics Teaching Resource Agents Program
Host: American Association of Physics Teachers

KEARNS LOUIS-JEAN
Xavier University of Louisiana
Project: Developing the 2014 SPS Science Outreach Catalyst Kit
Hosts: Society of Physics Students and National Institute of Standards and Technology

SIMON PATANE
Vassar College
Project: Developing a Teacher's Guide to the History of African-Americans in Physics and Astronomy
Host: American Institute of Physics Center for History of Physics

BENJAMIN PEREZ
Coe College
Project: Identifying Biomolecules in Solution
Host: National Institute for Standards and Technology

KELBY PETERSON
Utah State University
Project: Identifying Biomolecules in Solution
Host: National Institute for Standards and Technology

BENJAMIN PREIS
Tufts University
Position: AIP Mather Policy Intern
Host: Representative Bill Foster's office (D-IL 11)

KIRSTEN RANDLE
University of Massachusetts Amherst
Project: Detecting Cosmic Microwave Background Polarimetry
Host: NASA's Goddard Space Flight Center

MARK SELLERS
Rhodes College
Project: Developing the 2014 SPS Science Outreach Catalyst Kit
Host: Society of Physics Students

STEPHEN SKOLNICK
Indiana University
Project: Bringing Physics to the Public
Host: American Physical Society

JACOB ZALKIND
Shippensburg University
Project: Developing a Teacher's Guide to the History of African-Americans in Physics and Related Fields
Host: American Institute of Physics Center for History of Physics

2014 SPS SCHOLARSHIPS

www.spsnational.org/programs/scholarships/

Several awards of up to $3,000 are made each year to individuals showing excellence in academics, SPS participation, and additional criteria as noted.

SPS Outstanding Leadership Scholarship

CHRISTIAN BAYENS
University of North Alabama

KATRINA HANSON
University of Wisconsin-River Falls

ASHLEY LINDOW
Grove City College

SPS Leadership Scholarship

MEREDITH GOLD
Brigham Young University

NICOLE JOHNSON
Coe College

CHRISTINA KREISCH
Washington University in St. Louis

SEAN MCLAUGHLIN
University of Illinois at Urbana-Champaign

KHADIJIH MITCHELL
New Mexico State University

PRAJWAL NIRAULA
Saint Peter's University

KELBY PETERSON
Utah State University

BEN POUND
Utah State University

RICHARD PRINCE
University of Tennessee, Knoxville

Future Teacher Scholarship

JERIKA NEWITT
Brigham Young University

Peggy Dixon Two-Year Scholarship

AARON BLASBAND
Collin College

Herbert Levy Scholarship

LAUREN DALLACHIESA
Grove City College

Kirsten R. Lorentzen Award

(Awarded by the Association for Women in Science)

ANGELA LUDVIGSEN
University of Wisconsin-River Falls

OUTSTANDING STUDENT AWARD FOR UNDERGRADUATE RESEARCH

www.spsnational.org/programs/awards/student.htm

Awards are made to individuals for outstanding research done as an undergraduate. Recipients represent the United States and SPS at the International Conference of Physics Students and receive $500 for themselves and $500 for their SPS chapter.

HELEN MESKHIDZE
Elon University
Modeling the Composition and Emissions of Gamma-Ray Burst Jet Cocoons

ZOEY WARECKI
Towson University
Structural and Electrical Properties of Electron-Doped $CaMnO_3$ Thin Films

Honorable Mention

ALEXANDRA DAY
Wellesley College

REBECCA JOLITZ
University of California, Berkeley

BLAKE LILLY PRIZE

www.spsnational.org/programs/awards/lilly.htm

Several awards of the three-volume set *The Feynman Lectures on Physics* are given each year to chapters or individuals that engage in physics outreach activities and share feedback from participants.

THE COLLEGE OF WOOSTER
Project leader: Elliot Wainwright
Faculty advisor: John F. Lindner

RHODES COLLEGE
Project leader: Edoardo Draetta
Faculty advisor: Brent Hoffmeister

UNIVERSITY OF CENTRAL ARKANSAS
Project leader: John Ferrier
Faculty advisor: William V. Slaton

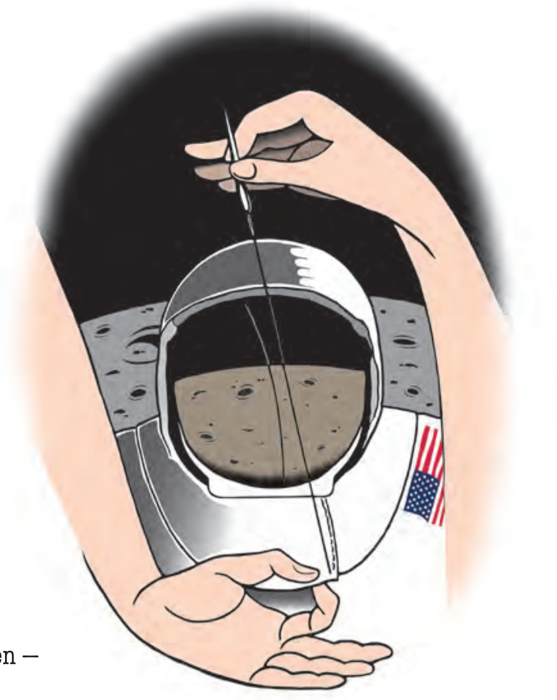
LEARN MORE

For more information on SPS awards, winners, and future deadlines, visit **www.spsnational.org/programs/awards/.**

The Poetry of Physics

Seamstress

by Michele Bannister



I have the measurements of your very skin.
This is my integument against uncertainty: twenty-one layers to fit your form,
spandex, nylon, mylar, and hope —
the last stitched down with ragged edges.

I must be as precise as the width of the eye of my needle,
as precise as your launch window;
you can measure the movements of the planets to millimetres,
but oh, unforgiving gravity, and you in less than half a centimetre of my care.

This piecing for the curve of your hips; this for the arch of your back.
Now the fiddly seams around the bust; a crease is eighteen hours of torment.

There is such grace in every arc from pad to orbit, you tell me
and for the delight in your eyes, I will see it too —
and check the tolerances three more times. And again after lunch.

I quilt beside the cooling pipes. This stitch will lie next to your heart;
in silken metal I add the dogwood-petal circuits your grandmother loved.
But for the gloves, grass-green and gold, I embroider all the flowers of our garden —

It is the aluminised gleam that catches in my eye. So bright
as acrid as the glare
when you see that first sunrise from orbit; they say the glory
of that thin layer of lightning-quilted atmosphere, excruciating blue,
is heartbreaking.

Michele Bannister is a member of the Outer Solar Systems Origins Survey and a postdoctoral fellow at the University of Victoria in British Columbia, Canada. "Seamstress" was first published in issue no. 7 of *Stone Telling* (http://stonetelling.com/issue7-mar2012/bannister-seamstress.html).

The Real Story

Writer and poet Julia Rios interviewed Bannister about "Seamstress." This excerpt is reprinted with permission. For the full interview, see http://stonetelling.com/issue7-mar2012/rios-st7-roundtable.html.

"I wrote this poem after reading of the women who outcompeted large companies to obtain NASA's contract for the Apollo spacesuits. They individually crafted each spacesuit, and a lot of details in the poem reflect the requirements of their technical precision. In a future where such skill in craft remains valued, what better gift for an astronaut than a personalized spacesuit? The details the seamstress-protagonist adds touch on history: the Apollo 12 moonwalkers found pinup pictures added among the pages of their wrist checklists, and modern suits retain splashes of color to help visually distinguish spacewalking astronauts.

I also wanted to subvert the narratives that surround the Apollo program, with its heroic exploration-era emphasis on individual masculinity. This future values the traditionally female pursuit of fabric-work, the gentleness of gardening, and the love of the astronaut and her wife. But this story also sits firmly within the heroic tradition of romantic poems. In that context, these people are both extraordinary not in who they are, but in what they do. Theirs is a future in which their love and strength are celebrated, as surely as any astronaut and partner's resolution in the face of uncertainty has ever been."

Illustrations by Matt Payne.

Astrophysics

by Bronwyn Lovell

Beside the telescope, I ask Dad if he ever tires of the same
old objects night after night, year after year. He says each
viewing has its own quality, just as the particles in any
breath of air are unique. He's checking in on constant
friends as they rise and waltz across a ballroom sky
(ladies' diamantes glittering, men's dress shoes shining)
and that dazzle, for him, could never grow dim.
Hands snug in snow-jacket pockets, I ask if he believes
that the pull of planets affects humans, as astrologers
would claim. He says, Bullshit. It's all too far away.
But what about the moon? I say. And the way blood
gushes from women in tides? Yes, he concedes, that is
amazing. I ask about UFOs. He says, if so, our aliens are likely
just humans from the future who found a way to fold
time—disciples of Einstein. Ah, so you believe in time travel
then? I smile. Look up, he says. You're doing it now.

Bronwyn Lovell lives in Melbourne, Australia. Her poetry has appeared in numerous publications, including *Award Winning Australian Writing*, *Australian Poetry Journal*, *Australian Love Poems*, *Antipodes*, *Cordite Poetry Review*, and the *Global Poetry Anthology*. Bronwyn has won the Adrien Abbott Poetry Prize and been shortlisted for the Newcastle, Bridport, and Montreal prizes. She works for *Australian Poetry* and is writing her first verse novel (www.bronwynlovell.com).

LIGHT, THE NEXUS IN PHYSICS

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

In December 2013, the United Nations 68th General Assembly declared 2015 to be "The International Year of Light and Light-Based Technologies."[1] The following essay explores the importance of light to all branches of physics. Optics is the study of light, but here we imagine physics as the study of optics.

In a concept map of physics the study of light stands at all the major intersections. Insights into light illuminate the whole of physics, just as scattered light rays illuminate a whole house. This article is not a scholarly history but an illustrative overview, written with hindsight, of the central role of light in making connections.

In 1267 Roger Bacon, with whom the post-medieval "awakening began,"[2] published *Opus Majus*. In Book V, the *Optics* section of that encyclopedic work, Bacon wrote:[3]

> *"It is possible that some other science may be more useful, but no other science has so much sweetness and beauty of utility. Therefore it is the flower of the whole of philosophy and through it, and not without it, can other sciences be known."*

Seven hundred years later this motif was made explicit by Jacob Bronowski:[4]

> *"We see matter by light; we are aware of the presence of light by the interruption of matter. And that thought makes up the world of every great physicist, who finds that he cannot deepen his understanding of one without the other."*

Let us begin at the beginning.

Geometrical Optics

> *"About 10 months ago a rumor came to our ears that a spyglass had been made . . . This finally caused me to apply myself totally to investigating the principles and figuring out the means by which I might arrive at the invention of a similar instrument, which I achieved shortly afterward on the basis of the science of refraction."* –Galileo Galilei [5]

Navigation and surveying have long depended on the straightness of light rays. Through the practical experience provided by these activities, the optical laws of rectilinear propagation and reflection became known in antiquity. The first unified theory in physics came from Hero of Alexandria (c. 10–70 CE), who set forth the principle that light rays follow the path of minimum distance; rectilinear propagation and the law of reflection follow as consequences.[6]

Refraction has been known qualitatively from time immemorial. A partially immersed stick appearing to be sharply bent at the water's surface was mentioned in Plato's *Republic* (c. 360 BCE). "Burning glasses," lenses for starting fires by focusing sunlight, were part of ancient technology, as documented by artifacts such as a magnifier found in the ruins of the palace of Assyrian King Sennacherib (708–681 BCE). Refraction was made a quantitative science in the Middle Ages by Muslim scholars such as Ibn al-Haytham (c. 965–1040), known to us as Alhazen, who introduced the practice of measuring angles from the normal for reflected and refracted rays. Alhazen's contemporary Abu Sàd al-Alá ibn Sahl (c. 940–1000) expressed the law of refraction in terms of the hypotenuses of right triangles.[7] Willebrord Snellius (or Snell) rediscovered in 1621 the law of refraction, which René Descartes rediscovered again and published in its well-known sine form in 1637.

Refraction made possible the lens, which made the cell and the stars accessible to human senses. Galileo's *Starry Messenger* of 1610 and Robert Hooke's *Micrographia* of 1665 opened new worlds to investigation. They deepened the questions, and not only for scholars:

> *. . . He burned his house down for the fire insurance*
> *And spent the proceeds on a telescope*
> *To satisfy a lifelong curiosity*
> *About our place among the infinities.*
> –Robert Frost, "The Star-Splitter"

Hero's principle of minimum distance does not explain refraction. That gap was remedied by Pierre de Fermat in 1657 through a broader unifying principle: Of all possible paths connecting two fixed points, the path followed by a light ray minimizes the time for light to go between the points. Fermat's principle requires light to travel at finite speed. Astronomy offered the first meaningful estimate of this speed in 1676 when Ole Rømer used as a clock the periodic emergence of Io from behind Jupiter's shadow. (The moon has an orbital period of 42.5 hours.) During the time of year when Earth recedes from the Jupiter–Io system, after each orbit of Io around Jupiter the clock is seen from Earth to run slow. Rømer interpreted the delay as the time light took to travel the additional distance between Earth and Io. Astronomy, which possesses information carried from the heavens to us by light, now gave back from the heavens information about light itself.

Lenses and Spectra

> *"I procured me a triangular glass-prisme, to try therewith the celebrated Phenomena of Colours . . ."* –Isaac Newton

The edge of every lens forms a prism. The rainbow of colors that emerges from prisms was familiar in Aristotle's time. Received doctrine held that a prism somehow modifies the color of light. Isaac Newton had to investigate. He made a hole in his window shutter to let in a fine beam of sunlight. The prism produced the expected colors of the rainbow, but Newton noticed the significance of something else: the circular beam that entered the prism emerged as an elongated ellipse. Each color refracted at a different angle.[8]

With a second aperture Newton could select from this rainbow one color to enter a second prism. This prism did not change the color. Allowing *all* the colors to enter the second prism produced white light on its far side. A prism did not *modify* light but *separated* it. Newton wrote, "A naturalist would scarce expect to see ye science of those colours become mathematical, and yet I dare affirm that there is as much certainty in it as in any other part of Optiks."[9] This image of a prism separating white light into a spectrum and the inverse operation of synthesizing distinct colors into white light, illustrates visually the mathematics of synthesis and analysis, such as the harmonic series of Fourier's theorem.

William Herschel and his sister Caroline made some of the first catalogs of stars, discovering many binary systems and the planet Uranus. While testing a red filter for observing sunspots, William happened to place his hand at the focal point of his reflecting telescope and noticed the region to be unexpectedly warm. To study the temperature of light, in 1800 William inserted thermometers into the separate colors of the sun's spectrum. He noticed that in going from violet to red, the temperature increased. Intrigued, he placed a thermometer beyond the red, and there found the highest temperature. Herschel called this warm invisible light beyond the red "caloric rays," which we know as infrared. Herschel's results were anticipated by 63 years by Emilie du Châtelet. This remarkable woman essentially discovered the work-energy theorem, translated Newton's *Principia* into the French translation used to this day, and collaborated with Voltaire across many years. Her opus was *Eléments de la Philosophie de Newton* (1738), which went deep into the philosophical foundations of mechanics and was influential in shifting French scientists from the mechanics of Descartes to that of Newton. In 1737 du Châtelet entered an essay competition on the nature of fire. In her essay "Dissertation on the Nature and Propagation of Fire," she argued that fire is not a material substance, and different colors of light transport different quantities of heat. The way to demonstrate this, she suggested, was to line up an array of thermometers, one inserted into each of the separated colors of the spectrum, which was precisely what William Herschel did in 1800. du Châtelet was not able to perform the experiment herself for lack of thermometers.[10]

Joseph von Fraunhofer supervised glass melting and grinding processes in his Munich optical institute. He needed to measure the refractive indices for different colors in various kinds of glass. In one of his experiments, light from an oil lamp flame passed through a prism to be viewed through a telescope. Fraunhofer noted dark lines in the spectrum. Intrigued, he looked for generalizations. Repeating Newton's experiment on sunlight with his telescope-equipped prism, in 1814–15 dark lines were revealed in the solar spectrum.

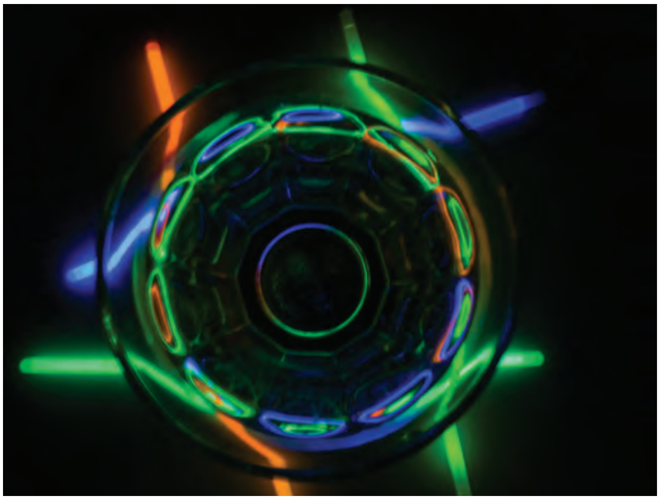
In 1857 the "daring and resourceful experimenter" Robert Bunsen invented a burner that produced a colorless flame.[11] With Bunsen's burner the spectra of chemicals placed in the flame could be cleanly separated. His collaborator Gustav Kirchhoff added a prism to complete the basic tool of modern spectroscopy, the spectroscope. Payoffs came quickly. In 1860 Bunsen and Kirchhoff discovered rubidium and cesium in a sample of Dükheim mineral water. In 1868 two astronomers, Pierre Janssen from France and Norman Lockyer from England, independently reported a yellow line in the solar spectrum that fit no known element. Interpreting it as an unknown element, Lockyer named it after *helios*, Greek for "the Sun."[12] Terrestrial helium was not confirmed until 1895 when William Ramsey isolated it as a byproduct of uranium ore. In 1907 Ernest Rutherford and Thomas Royds collected alpha particles emitted by radioactive decay, examined their spectra, and showed that the particles were helium.

Classical Mechanics

> *"Following in the footsteps of Hero and Fermat, he [Maupertuis] then proclaimed that this simplicity causes nature to act in such a way as to render a certain quantity, which he named the 'action,' a minimum."* –Wolfgang Yourgrau and Stanley Mandelstam [13]

After Newton revolutionized optics he turned to mechanics. Generalizing inductively from specific problems solved in quantitative detail [14]—Archimedes on the lever, Galileo on projectiles, Huygens on the pendulum, and Newton himself on gravitation—he postulated in 1687 three laws of motion that turned mechanics into an axiomatic system. As the laws of geometrical optics could be derived from Fermat's least time principle, could the same be done for mechanics? Several proposals were forthcoming. These included Johann Bernoulli's 1717 principle of virtual work for statics, extended to dynamics by Jean le Rond d'Alembert in 1743.

Around 1740 Pierre Louis Moreau de Maupertuis (who tutored young Emilie du Châtelet in calculus) suggested that a particle acted on by specific forces moves in a way that minimizes the "action." This approach was successfully demonstrated for central forces by Leonhard Euler in 1744. In his *Mécanique Analytique* of 1788, Joseph Lagrange generalized Maupertuis' principle to all conservative forces and clarified "action" as the line integral of momentum. The generalization of this principle to all of mechanics (later extended to most of physics) was published in two papers by William R. Hamilton in 1834–35.[15] Hamilton's principle postulates that of all the conceivable trajectories whereby a particle might travel between two fixed points, the trajectory actually followed minimizes the time-averaged difference between the particle's kinetic and potential energies. The principles of Hamilton and Fermat arose from similar motivations, but a logical connection between them would have to await general relativity.



Used by permission from AAPT, 2014 High School Physics Photo Contest, "Glowing Refraction," by Claire Inna Isabelle Saloff-Coste, Ithaca High School.

Ontology

"From the multitude of experiences it [science] selects a few simple forms, and constructs from them, by thought, an objective world of things." –Max Born [16]

"You know something and then the quality stimulus hits . . . , but to define it all you've got to work with what you know. So your definition is made up of what you know. It's an analogue to what you already know." –Robert Pirsig [17]

A debate about the ultimate reality of light began in the time of Plato and the Sophists. By the time of Newton and Huygens, those arguing the question "What is light?" faced a binary choice: What is light—wave *or* particle? Robert Hooke's *Micrographia* describes how colors of thin films depended on a film's thickness, suggesting a standing wave condition. Christaan Huygens argued that the tremendous speed of light would be feasible only if light was a disturbance *through* a medium, not the bulk motion *of* a medium. He gave the wave hypothesis predictive power by postulating that each point on a wave front behaves as the source of another wave. If that were so, then light should radiate into regions that would otherwise remain in geometric shadow. Hooke and Francesco Grimaldi had noticed diffraction in the fine structure of shadows cast by a needle.

Initially ambivalent ("I make no hypotheses"), Newton eventually argued that light was a beam of particles. While acknowledging that *something* periodic occurs with waves (and discovering an interference pattern called "Newton's rings"), he interpreted the periodicity as something that matter does *to* light. To Newton, the diffraction reports did not require light to be a wave. Gravity acts between separated massive bodies, so matter could bestow its periodic influence on light from a distance.

Refraction offered one way to decide the question. When light passes from air into water the ray bends toward the normal. If light consists of waves, the speed of light in water would be less than its speed in air. If light consists of particles the reverse would happen.

In 1800 Thomas Young demonstrated that the interference of light passed through a double aperture. Such a pattern could be interpreted only as the superposition of waves. Augustin Fresnel worked out a comprehensive theory of diffraction based on the assumption that light consists of waves, and his predictions were vindicated, famously so with the notorious "Poisson's spot," a bright spot, due to wave diffraction, in the shadow behind an illuminated disk. In 1850 Léon Foucault measured the speed of light in water and found it to be less than the speed of light in air. The riddle "What is light?" seemed answered.[18]

Lingering questions remained, as they always do with important questions that have multiple layers. First, supposing light to be a wave, what is waving? Second, acoustical waves require a medium; what serves as the medium for light, the "aether"? Third, light had been found to be polarized by bifringent crystals. Reconciling polarization and the rapid speed of light with our ability to breeze freely through the aether offered a perplexing situation.

Electromagnetism

"Maxwell shewed light to be an electromagnetic phenomenon, so that the whole science of Optics became a branch of Electromagnetism. . . ." –James Jeans [19]

Hints at a connection between electricity and magnetism came when Hans Christian Ørsted showed that moving electric charge makes magnetism and when Michael Faraday showed that changing magnetism makes electricity. A unified theory of electromagnetism was written by James Maxwell in 1862. Action at a distance, which served well for static interactions, was replaced with the dynamic concept of the field, a function of space and time.

The interactions of matter proceed through fields. On one hand, local fields tell a particle of matter how to move. Newton's second law with the Lorentz force, for instance, predicts the motion of a charged particle in response to electromagnetic fields. On the other hand, matter determines the fields around it. Maxwell's equations relate the electric and magnetic fields to their charged particle sources and relate the fields to each other. When a charged particle accelerates, Maxwell's equations say the fields it produces must change. A changing electric field produces a magnetic field that also changes, and the changing magnetic field produces a changing electric field. Together the changing fields make a self-propagating wave moving at the speed of light.

In response to the "What is waving?" question, light must thus be a wave in the electromagnetic field! The equations describing this wave have no restriction on the frequency, suggesting the existence of a continuous electromagnetic spectrum of harmonics whose frequencies range from zero to infinity. The equations also say that the propagating fields are transverse to the direction of wave travel, implying polarization and explaining the effects of bifringent crystals.

In 1886–89 Heinrich Hertz affirmed Maxwell by broadcasting and detecting radio waves in the laboratory. While doing so the alert Hertz noticed a spurious glitch in his apparatus. Radiation of low intensity but sufficiently high frequency immediately stimulates an electric current in certain materials; at low frequencies the incoming light produces no current even at high intensity. Dubbed the photoelectric effect, this anomaly in the interaction of light with matter did not fit Maxwell's theory. For two decades it remained a mystery.

Maxwell had answered important questions about light, but others remained. The equations say that electromagnetic waves need no medium, that they travel in empty space at the speed of light, c, but the equations are silent on the frame of reference. In 1895 16-year-old Albert Einstein wondered what he would observe if he rode on a beam of light. Intuition said that Einstein's light-wave surfer should observe a stationary crest of the electromagnetic wave. But Maxwell's equations insist that electromagnetic waves travel at speed c even from the surfer's perspective! This paradox, like all paradoxes, suggested that the question should be restated.

Einstein held the question in his mind for 10 years. Then the 26-year-old Einstein wrote "On the Electrodynamics of Moving Bodies," noting that "Maxwell's electrodynamics—as usually understood at the present—when applied to moving bodies, leads to asymmetries that do not seem to be inherent in the phenomena."[20]

The relative motion between a magnet and a coil of conducting wire illustrates the issue. Whatever the reference frame, the relative motion results in a force on the charge carriers, driving an electric current in the coil. An observer aboard the coil sees a changing magnetic flux as the magnet sweeps by. Faraday's law says an electric field $\mathbf{E}$ gets induced in the coil, producing the force $q\mathbf{E}$ on the charges. An observer aboard the magnet sees a different picture. The coil sweeps by with velocity $\mathbf{v}$, carrying the charged particles through the magnetic field $\mathbf{B}$. Each charge q feels the force $q\mathbf{v}\times\mathbf{B}$. Thus do distinct mechanisms describe the same result, an asymmetry in the *explanation* not inherent in the *phenomena*. Einstein wondered what principle would unify the two explanations.

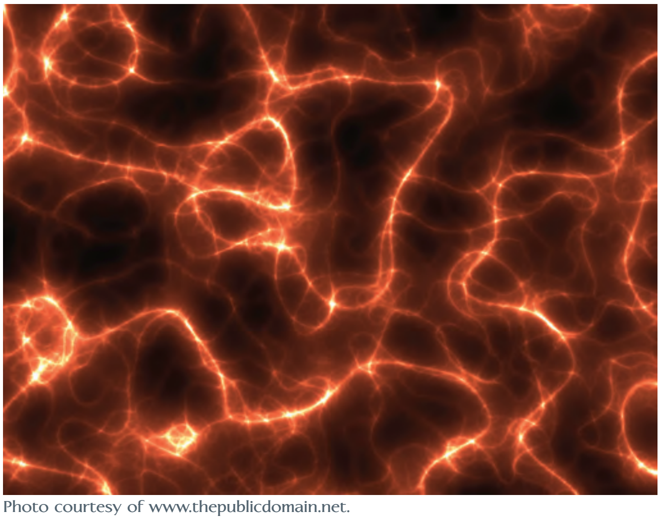
The thought experiment about light surfing suggested a clue in light itself. If you ride on the beam of light that bounces off a clock at 10:00 am, then you stay with the information that says the time is 10 o'clock.[21] For the light-wave surfer, time stands still. Newtonian relativity of inertial frames postulates the separate invariance of length and time intervals; as a consequence, the speed of light must be relative. Einstein replaced those assumptions with the postulate of the invariance of the speed of light between inertial frames, which requires space and time intervals to be relative. Mechanics had to adapt to light, instead of the light adapting to mechanics.

Special relativity, which linked light to space and time, also linked light to mass and energy. Energy and momentum became the time and space components of a vector in four-dimensional space-time. Its geometry was not Euclidean but hyperbolic. The square of the energy–momentum four-vector was given by a difference, not a sum, with the particle's mass as the vector's magnitude. For a free particle, $E^2 - (pc)^2 = (mc^2)^2$.

Thermodynamics and Quantum Physics

> *"By 1906 or 1908 Planck had come to see that his compromise over cavity radiation had loosed something brand new and menacing into the world of physics."* –J.L. Heilbron [22]

The thermodynamics of light motivated the extension of Newtonian mechanics to quantum mechanics. Macroscopic thermodynamics serves as a boundary condition on microscopic statistical mechanics. After many triumphs with engines and phase changes and the kinetic theory of gases, statistical thermodynamics confronted the question of finding the energy density of light as a function of frequency. Light and matter in thermal equilibrium was produced in the laboratory by a metal box held at temperature T. The atoms in the box walls are made of oscillating charged particles and radiate light. According to Newtonian mechanics, the energy



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of a harmonic oscillator is proportional to the frequency squared. The sum over all microscopic states, a procedure required by statistical mechanics, thus predicts an energy density that diverges as frequency cubed, the "ultraviolet catastrophe." Although the experimental spectrum of light in thermal equilibrium with matter goes as the frequency cubed at low frequencies, as the frequency increases the distribution mapped by data reaches a peak and then slides toward zero at the highest frequencies.

Max Planck realized that the predicted distribution function could be made to peak and trail off at high frequencies if the energy of an oscillator of frequency f was linear in f and exhibited only a harmonic series of discrete overtones, so that $E_n = nhf$, where $n = 0,1,2,3, \ldots$ with h a constant to be fit to data. The distribution function that resulted had the right shape, whatever the value of Planck's constant h. It fit the data precisely if h had the astonishingly small value 6.6×10^{-34} J-s. Planck had solved this important problem, but at the price of making an *ad hoc* hypothesis about energy quantization, a drastic move which at the time pointed to nothing else.

Five years after Planck's hypothesis Einstein revisited the thermodynamics of light. He calculated the entropy of radiation and compared the result to the entropy of a box filled with ideal gas molecules. Then came the heretical punch line. The entropy of the radiation matches the entropy of the molecules, said Einstein, if a light wave of frequency f corresponds to a swarm of particles, each carrying energy $E = hf$. According to Einstein, light itself is quantized. He showed how this corpuscle interpretation of light solved outstanding mysteries in the interaction of matter and radiation. Most famously, the photoelectric effect made sense as a collision between a light corpuscle and an electron if Einstein's h has the same value as Planck's h. Planck's constant h pointed to something deep.[23] The name of the light corpuscle, the photon, came years later, in 1926.[24]

With the concept of the photon in mind, one can look again to special relativity, which requires any particle moving at the speed of light to carry zero mass. With zero mass, the energy–momentum relation for a photon simplifies to $E = pc$. Together with $E = hf$ and $c = \lambda f$, it follows that a light wave of wavelength λ corresponds to a swarm of photons, each carrying momentum $p = h/\lambda$. This idea, rigorous for massless particles, was boldly postulated by Louis de Broglie in 1924 to hold for massive particles too. Thus did the thermodynamics of light—along with spectroscopy's stained-glass window into the atom—lead the way into quantum mechanics.

General Relativity

> *"Another important consequence of the theory, which can be tested experimentally, has to do with the path of rays of light . . . We can therefore draw the conclusion from this, that a ray of light passing near a large mass is deflected . . . The existence of this deflection, which amounts to 1.7 . . . was confirmed, with remarkable accuracy, by the English Solar Eclipse Expedition in 1919. . . ."* –Albert Einstein [25]

Between 1905 and 1915 Einstein extended special relativity to arbitrarily accelerated frames. Thanks to the principle of the equivalence of gravitational and inertial mass, general relativity serves as a theory of gravitation. Early tests of general relativity checked its predictions for the behavior of light, including the deflection of a light ray grazing the sun, gravitational redshift, and radar echo delay.

David Hilbert realized that Einstein's gravitational field equations could be derived in analogy to Fermat's principle: Of all the possible trajectories that a particle might follow between two events in space-time, the trajectory actually followed maximizes the particle's proper time for the trip. In the limiting case of a particle moving slowly in a weak gravitational field, this "Fermat's principle for gravity" reduces to Hamilton's principle of classical mechanics.

Newtonian cosmology had originally envisioned a static, everlasting, infinite universe. However, the Newtonian universe was unstable and paradoxical—how could a universe filled to infinity with stars show a dark sky at night (Olbers' paradox)? In 1917, with his new tool expressing gravitation as the curvature of space-time, Einstein solved the cosmological problem at infinity by abolishing infinity. He postulated the three-dimensional universe to be the surface of a static sphere embedded in four-dimensional Euclidean space. Alexander Friedmann and Georges Lemaître asked why the universe must be static. Their equations predicted a universe in which space could contract or stretch to show a velocity–distance relation. At the cosmic scale the relative speed of two points would be proportional to their separation.

Measuring astronomical distances requires the light of standard candles. Henrietta Swan Leavitt provided crucial candles in 1912 when she discovered a relationship between the periods and luminosities of Cepheid variable stars. Edwin Hubble used Cepheids in 1924 to probe distances to spiral nebulae, which turned out to be millions of light-years away. The universe suddenly became very big. By applying the Cepheid distance indicators and Doppler shifts to the spectra of galaxies, in 1929 he offered the first evidence for the cosmic velocity–distance relation. The journey toward big-bang cosmology was underway.

In a universe that begins in the big-bang scenario, after the primordial gas of relativistic particles cools sufficiently for atoms to form, an afterglow of photons must remain. The wavelengths of those photons are continuously stretched by the cosmic expansion. In 1948 the existence in our universe of this background radiation was predicted by Ralph Alpher and Robert Hermann. Their first estimate placed its temperature today near 5 K. Alpher and Hermann tried throughout the 1950s to convince radio astronomers to look for the afterglow.[26] In 1964 it was accidently found by Arno Penzias and Robert Wilson. Their measurements gave a temperature of 2.7 K.[27] Ever since, it has offered a window into the genesis of the universe.

Today light has become the most incisive of tools in cosmology. Precision measurements of the cosmic afterglow of the big bang heralded the era of precision cosmology; the harmonics in the afterglow's power spectrum offer a kind of electrocardiogram for the early universe. The irony of our present state of fertile ignorance is that the greatest mysteries at present are not about the existence of light, but its absence: dark matter and dark energy. Could dark energy be our aether?

Quantum Electrodynamics and Beyond

> *"The diagrams we make of quarks exchanging gluons are very similar to the pictures we draw for electrons exchanging photons. So similar, in fact, that you might say that the physicists have no imagination—that they just copied the theory of quantum electrodynamics for the strong interactions! And you're right: that's what we did, but with a little twist."*
> –Richard Feynman [28]

In the mid-1920s, quantum mechanics developed into the form now taught to physics majors. But it took two more decades to reconcile quantum mechanics with electrodynamics. An electron is not an ideal point charge. The "total" electron includes its ideal "bare" charge plus the interactions of the electron with its own electromagnetic field. An electron emits and reabsorbs photons, and some of those photons briefly turn into electron–positron pairs that combine back into a photon before returning to the original electron. The energy budget for producing these virtual particles comes from the energy fuzziness inherent in the Heisenberg uncertainty principle. Thus what we see as "the electron" in the laboratory includes a cloud of virtual photons and electron–positron pairs. This is a serious problem because these intermediate processes contribute infinity to the quantum state!

The remedy is "renormalization." A theory is said to be renormalizable when all divergent pieces cancel out each other in perturbation theory, leaving as a residue the observed charge and mass. According to our present understanding, renormalizability presents a necessary condition for any sensible theory of fundamental interactions.

Quantum electrodynamics—the interaction of light with electrically charged matter—was the first renormalizable theory of elementary particle interactions. It serves as the template for the other theories of elementary particle physics.[29] At its foundation stands a principle of least action, adapted to quantum field theory, that traces its inspiration back through the analogous principles of Hamilton and Fermat.[30]

***

From quarks to cosmology, light has been a tool, a model, and an inspiration to all of physics. Light has also been a metaphorical symbol of hope and wisdom in all cultures. The Hindu four-day festival of lights, Diwali, celebrates the triumph of knowledge over ignorance, hope over darkness. In the Book of Genesis, the "poem of the dawn" in the Judeo-Christian mythos, God speaks the universe into existence by uttering "Let there be light." In Buddhism one seeks enlightenment, the lights of wisdom and compassion. Let 2015, the Year of Light, be a celebration of knowledge and wisdom overcoming poverty and ignorance.[31] Physics and its technological applications have essential roles in achieving these ends. May we use them wisely and in the service of all that lives. May the secular world of physics help us find "our place among the infinities" in a festival of light.

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Lindow, Ashley Elaine
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Guilford College
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Gustavus Adolphus College
Adams, Wyatt
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Euerle, Kellan Gerald
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Legatt, Jenna
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Hampton University
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Henderson State University
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Goodin, Will
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Paschke, Arthur M., III
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Hillsdale College
Karney, John McLean
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Hope College
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Howard University
Islam, Mecca Bentta Abour Rahim

Illinois State University
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Turley, James Francis
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Mann, Emily E.
Schmitt, Leighton
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Indiana University – Purdue University Fort Wayne
Adams, Gregory
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Magner, Aaron
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Siri, Mattison Scott
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Ithaca College
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Jacksonville University
Deen, Shameer
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James Madison University
Creange, Nicole
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Loving, David Alexander
Szwejkowski, Chester
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John Carroll University
Carbone, Marc A.
Marek, Gage
Sauer, T .J.
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The Johns Hopkins University
Allard, Victor Paul
Fonda, Helen
Jiang, George Xiang Yu
Lampayan, Kelly
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Rule, Evan Johnson
Skerritt, Elizabeth Anne
Sloan, Joseph Thomas
Wagner, Emily Gail
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Juniata College
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Kansas State University
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Robben, Kevin
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Kent State University
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Kenyon College
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Kettering University
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Kutztown University
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Mikel, David James
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Lebanon Valley College
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Gopal, Vineet
Lynch, Evan
Pappas, Michael
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Tucker, John Gordon

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Weerawarne, Darshana Lakmal

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Simpson College
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Skidmore College
Chen, Quanhang
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Slippery Rock University
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Brown, Andrew
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Towson University
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