the SPS Observer
Volume XLVIII, Issue 1
Spring 2014

CELEBRATING PHYSICS OUTREACH

GET INSPIRED WITH SCIENCE OUTREACH ... AND INREACH

Elegant Connections

THE APPLIED PHYSICS OF GASOLINE ENGINES

- / WHAT THE QUANTUM?
- / FALL 2013 SPS AWARD WINNERS
- / SOLVING THE CLEAN WATER PROBLEM
- / DEFYING GRAVITY

the SPS Observer

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The Importance of Science Outreach

by Steve Shropshire,
SPS Chapter Advisor, Idaho State University, Pocatello
Former SPS Zone 15 Councilor

Science outreach activities are wonderful in so many ways. They can generate much-needed excitement and interest in science with students and the public. They generate appreciation in the community for your profession and institution. Delivering them brings a sense of accomplishment, camaraderie, and community. Providing science outreach activities is also a great way to gain a deeper understanding of science and its applications, and develop valuable communication skills. If you learn to successfully explain an aspect of science or technology to a third-grader, your own level of understanding is greatly enhanced. It is comparatively easy to communicate scientific ideas to another scientist. However, if we try to use the same techniques with a nonscientist, it is easy to annoy and alienate. If we want the general public to support the pursuit of science, we need to effectively convey its nature and benefits. The communication skills to be gained by engaging in science outreach will serve both you and your profession well.

Effective science outreach is fun and rewarding, but it is also greatly needed at this time in our society. Education is of great importance due to its effect on the development of future citizens. With the advancement of technology, scientific literacy is essential for adequate participation in our society. There are concerns that the United States is

> "Effective science outreach is fun and rewarding, but it is also greatly needed at this time in our society."

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falling behind other countries in science education and that innovation in this country will ebb because fewer students are interested in pursuing careers in science and engineering. An unfortunate result of the No Child Left Behind legislation is that many states have focused more on student progress in language, literacy, and mathematics than in science. Many states do not test student progress in science, or do not set goals for student performance on what science testing they do implement. This has resulted in a significant drop in the time, attention, and resources devoted to science education, especially in the elementary grades. As a result, many students enter junior high or high school with less knowledge and interest in science. Even in states that do not neglect science education, there are a variety of social pressures that have a negative impact on student interest and enthusiasm toward learning about science. Whatever the causes, there is often a common attitude among students that science is too hard, too boring, and not worth the effort. Due to limitations in school district budgets and teacher training, in many places students rarely get to do more than read about the more exciting aspects of science. Science outreach can help reverse negative attitudes, expose students to more exciting aspects of science, spark interest and enthusiasm, and encourage communities to support science education. //

This story originally appeared in the spring 2012 issue of Radiations*: www.sigmapisigma.org/radiations/2012/spring.htm.*

A YOUNG SCIENTIST looking at the world through "rainbow" diffraction glasses. Photo by Alec Lindman.

GET INSPIRED

Learn more about the impact of science outreach and how to engage with the public in "Celebrating Physics Outreach" (pages 12–19). Included are Steve Shropshire's "Top Five Tips for Doing Science Outreach" (page 19).

ON THE COVER

SPSer Parker West at Texas A&M University puts on a fiery demo during the annual Physics and Engineering Festival. Photo by Igor Kraguljac. See "Celebrating Physics Outreach," pp. 12-19.

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

AIP | American Institute of Physics

Fall 2013 Award Recipients

SPS CONGRATULATES THE FOLLOWING CHAPTERS

FUTURE FACES OF PHYSICS AWARD

Several awards of up to $300 are made each year to chapters for activities that promote physics across cultures.

Adelphi University

LAB FOR KIDS

Principal proposers: Jessica Scheff, John Dellatto, Michael Trietsch, Dennis Mars, and Brian Kaufman

Faculty advisor: Sean Bentley

Cleveland State University

PHYSICS APPARATUS CHALLENGE: MATERIALS AND NUMBERS (PAC-MAN)

Principal proposers: Janna Mino and Chris Mentrek

Faculty advisor: Kiril A. Streletzky

Colorado School of Mines

FUTURE FACES OF PHYSICS AND THE HIGHER EDUCATION SUPPORT PROGRAM

Principal proposers: Nicholas Wendrych and Leah Moldauer

Faculty advisor: Chuck Stone

Drexel University

PATCHING THE PIPELINE

Principal proposers: Robyn Smith, Jeremy Gaison, Courtney Slocum, and Rishiraj Mathur

Faculty advisor: Luis Cruz Cruz

Indiana Wesleyan University

PHYSICS OUTREACH TO A LOW-INCOME MIDDLE SCHOOL

Principal proposers: Joshua Ostrander and Robert Burchell

Faculty advisor: Roberto Ramos

Morehouse College

PHYSICS IN THE PHLESH

Principal proposer: Hakeem Jones

Faculty advisor: Aakhut Bak

Sonoma State University

SSU SPS/MESA SKILLS LAB: TEACHING ARDUINO BASED MICROCONTROLLERS TO UNDERREPRESENTED STUDENTS

Principal proposers: Ben Cunningham, Kevin Zack, and Hunter Mills

Chapter advisor: Hongtao Shi

University of Michigan, Ann Arbor

CESAR CHAVEZ PEN PAL PROGRAM

Principal proposer: Nico Wagner

Faculty advisor: Dragan Huterer

SPOTLIGHT ON:

University of Michigan, Ann Arbor

CESAR CHAVEZ PEN PAL PROGRAM

The University of Michigan's SPS chapter has started a pen pal program with Cesar Chavez Middle School, an underprivileged school in Detroit, to promote physics to 99 sixth graders. Proposed activities include weekly pen pal letters, demo shows, and a campus visit. //

University of Southern Mississippi

CONTINUATION AND IMPROVEMENT OF OUR MENTORING PROGRAM

Principal proposers: Kinsey Zarske, Abi Jacobson, and Grant Tingstrom

Faculty advisor: Michael Vera

University of Texas at San Antonio

UNDULATING INTO THE FUTURE OF PUBLIC PENDULUMS

Principal proposer: Shaylynn Clark

Faculty advisor: Kelly Nash //

SIGMA PI SIGMA UNDERGRADUATE RESEARCH AWARD

Several awards of up to $2,000 are made each year to chapters for chapter physics research projects.

Kettering University

MAGNETIC MICROBUBBLES FOR TARGETED DRUG RELEASE

Principal proposer: Nicolaas Winter

Faculty advisor: Ronald Kumon

Saint Peter's University

INFRARED SENSING OF OIL SPILLS

Principal proposers: Prajwal Niraula, Sabin Pradhan, Edwin Young, Shaikat Haque, Valentina Osorio, and Samrat Shiwakoti

Faculty advisor: Weidong Zhu

Tuskegee University

NOVEL NANOSCALE HYDROGEN STORAGE SYSTEMS

Principal proposers: Timothy T. Powell, Leah Sanks, Lamont Henderson, Jeremiah Wilson, Gad Harry, and Samuel Morenikeji

Faculty advisors: Sesha Srinivasan and P.C. Sharma

University of North Alabama

LUNAR IMPACT OBSERVING

Principal proposer: Matthew Morgan

Faculty advisor: Mel Blake

SPOTLIGHT ON:

Sonoma State University

GROUND STATION FOR SMALL SATELLITES

Students at Sonoma State University (SSU) propose to construct a ground station to receive radio telemetry from small satellites such as SSU's MagPocketQube, currently due to launch in late November. At SSU, the ground station will be used for undergraduate training, research, and outreach. It can also serve other universities. //

Sonoma State University

GROUND STATION FOR SMALL SATELLITES

Principal proposers: Kevin Zack, Aaron Owen, Hunter Mills, Cody Ray Johnson, Ben Cunningham, and Stephen Jackowski

Faculty advisor: Hongtao Shi

MARSH W. WHITE AWARD

Several awards of up to $300 are made each year to chapters for physics outreach activities to grades K–12 and the general public.

Cleveland State University

FROM COLD MILK IN THE MORNING TO READING LIGHT AT NIGHT: OUR ENCOUNTERS WITH PHYSICS THROUGH THE DAY

Principal proposers: Janna Mino, Krista Freeman, and Chris Mentrek
Faculty advisor: Kiril Streletzky

Drexel University

HOLLYWOOD PHYSICS 2.0

Principal proposers: Robyn Smith, Cameron Petersen, and Jeremy Gaison
Faculty advisor: Luis Cruz Cruz

Idaho State University

SCIENCE DAY IN THE MALL

Principal proposers: William A. Alston and Mark Wetzel
Faculty advisor: Steve Shropshire

Ithaca College

ICY SNOW FORTS: INSPIRING ENGINEERING THROUGH IMAGINATION

Principal proposer: Ivan Tso
Faculty advisor: Michael Rogers

New Mexico State University

CLOUD CHAMBER AND OUTREACH DEVELOPMENT PROJECT

Principal proposers: Khadijih Mitchell, Dennis Trujillo, Fred Smalley, Jerrett Moon, and Alistair McLean
Faculty advisor: Michaela Burkardt

Rhodes College

PHENOMENAL FIELDS OF PHYSICS

Principal proposers: Stefan McCarty, Morgan Smathers, Zain Kinnare, and Edo Draetta
Faculty advisor: Brent Hoffmeister

Goucher College

DESIGNING A CLOUD CHAMBER FOR ACADEMIC AND OUTREACH PURPOSES

Principal proposers: Alissa Murray, Phoebe Yeoh, Chloe Gooditis, Cody Nelson, Paul Meyer, and Renzo Villazon
Faculty advisor: Sasha Dukan //

Sewanee: The University of the South

PHYSICS OUTREACH WITH THERMAL IMAGING

Principal proposers: Taylor Morris, Keshonn Carter, Paul Campbell, William Jenkins, Daniel Rosales, and Caroline Roberts
Faculty advisor: Randolph Peterson

Sonoma State University

PHYSICS FAIR: A PRESENTATION OF ARCHIVAL MATERIAL

Principal proposers: Ben Cunningham, Kevin Zack, Hunter Mills, Cody Ray Johnson, Stephan Jackowski, and Aaron Owen
Faculty advisor: Hongtao Shi

Texas State University

ELEMENTARY PHYSICS VIDEOS

Principal proposers: Gregory Beuhler, Taylor Shimek, and Lee Sager
Faculty advisor: Dave Donnelly

The College at Brockport: State University of New York

FUN WITH PHYSICS

Principal proposer: Amanda Landcastle
Faculty advisor: H. T. Johnson-Steigelman

Towson University

TOWSON PHYSICS DEMO TEAM

Principal proposers: Zoey Warecki, Nathan Prins, Stephen Blama, David Lahneman, and Josh Tyler
Faculty advisor: Jeff Simpson

Tuskegee University

TU-SPS-K–12 OUTREACH DEMONSTRATION PROGRAM ON RENEWABLE ENERGY

Principal proposers: Timothy T. Powell, Alejandra Sandoval, Joanie Keel, Lamont Henderson, Kumasi Salimu, Steven Gailard, Jeremiah Wilson, and Leah Sanks
Faculty advisors: Sesha Srinivasan, P.C. Sharma, and Akshaya Kumar

United States Air Force Academy

SCOPING OUT ASTRONOMY!

Principal proposers: Thomas Dickinson, Dan Cook, and Major Matthew Spidell
Faculty advisor: Christian Wohlwend

SPOTLIGHT ON:

United States Air Force Academy

SCOPING OUT ASTRONOMY!

USAFA cadets and SPS members currently host hundreds of young students per year on our observatory tours. We plan to significantly augment these tours by adding a station where students will build, from two convex lenses and a cardboard tube, simple telescopes that they may keep at the end of the evening. //

SPOTLIGHT ON:

University of Maryland, College Park

SOUNDS AROUND

The Port Discovery Children's Museum in Baltimore is developing a permanent exhibit called the Percussion Garden for musical instruments and other objects that enhance understanding of physics principles. The SPS chapter at the University of Maryland, College Park, will help Port Discovery refine the pieces, create signs, and support demonstrations. //

University of Central Arkansas

THE GIANT BRACHISTOCHRONE OF SCIENCE

Principal proposers: John Ferrier, Shelby Burns, Rebecca Brinker, and Sarah Spellman
Faculty advisor: William Slaton

University of Maryland, College Park

SOUNDS AROUND

Principal proposer: Kevin Cheriyan
Faculty advisor: Donna Hammer

The University of Southern Mississippi

REACHING THE REGION AT HUBFEST

Principal proposer: Kinsey Zarske
Faculty advisor: Michael Vera

University of Wisconsin-Platteville

PHYSICS IS PHANTASTIC PHUNSHOP

Principal proposer: Taylor Keesler
Faculty advisor: Duane Foust //

FALL 2014–15 CHAPTER AWARD DEADLINES

Future Faces of Physics Award: October 15
Marsh W. White Award: November 15
Sigma Pi Sigma Undergraduate Research Awards: November 15

What the Quantum?

A CAREER IN OUTREACH PROVIDES CREATIVE OPPORTUNITIES CLOSE TO SCIENCE

by Jenny Hogan, Outreach and Media Relations Manager,
Centre for Quantum Technologies, National University of Singapore

With a week to go, I was worried. Almost six months earlier, we had launched a competition for short films inspired by quantum physics. It was an outreach project aimed at encouraging people to engage creatively with science. We had asked, "Does the idea of a quantum multiverse fill your head with stories? Can you picture a quantum superposition?" With little time left until the deadline, there were disappointingly few entries. I was also questioning the wisdom of our open-ended suggestion that people show us how quantum physics made them think about the world rather than try to explain the physics.

I am the outreach and media relations manager of the Centre for Quantum Technologies (CQT), a research center hosted by the National University of Singapore. The center has more than 200 staff and students, and outreach is an important part of its mission. We aim to run activities that nudge young students toward science, inform people about some of the remarkable ideas in our area of research, and show why it makes sense to spend tax dollars on curiosity-driven research as well as applied science—all while trying to make science fun.

The Quantum Shorts film competition in 2012 was one of our most fun projects, and I needn't have been anxious. We had teamed up with *New Scientist* magazine, a partnership that gave us an international reach we couldn't have achieved on our own. A heap of submissions arrived in the competition's final hours. The film that eventually won was a marvelously bizarre but scientifically rich stop-motion animation. In under three minutes, it told the story of a multiverse-hopping girl with a banana-shaped quantum computer phone. In the end we considered the competition so successful that we ran another one in 2013, this time for brief pieces of fiction ("flash fiction") inspired by quantum physics. Quantum Shorts 2013 had as media partners the magazine *Scientific American*, the sci-fi and fantasy publisher Tor Books, and Tor.com. The competition drew over 500 entries from around the world.

People working in scientific outreach come from diverse backgrounds. My route was through science writing. I studied physics in the UK as an undergraduate, and I was set on being a science journalist. I wrote for the student newspaper and did short internships before I graduated, and longer ones afterward. This led me to jobs with *New Scientist* and later with *Nature*. After family circumstances moved me to Singapore, a former colleague put me in touch with CQT. It was a lucky break for me that the center director happened to be looking for someone to manage science communication. I started work at CQT in fall 2010.

One of the attractions of writing about science is getting to dip in and out of the most interesting subjects. Perhaps unwisely, I once described myself in a writer's bio as having been led to journalism by a broad interest in science and a short attention span. The broad interest in science part was fine; the short attention span part would have been better spun as "enjoying variety." Both attributes are useful for a job in outreach.

As well as coordinating big projects involving outside partners, the CQT outreach team helps to set up visits to the center, organizes public talks, and participates in exhibitions. We sometimes host writers and artists for residencies. We also produce leaflets and reports, provide news and images for the center's website, and update its social media pages. We prepare and issue press releases. We handle ad hoc requests from CQT scientists ranging from making presentation slides to proofreading grant

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POSTMORTEM

by Antonia Jade
First Prize, Student International category, Quantum Shorts 2013

Gran died on a Wednesday, but lucky for us she was back within a week.

When she knocked on the door, Olivia and I were eating dry cereal. Olivia was using her hands, which was a special thing she got to do when Mom was away. Other special things included Olivia wearing her ballet shoes to the grocery store and me getting in trouble when her arabesque knocked over 27 soup cans.

Anyway, Olivia sashayed over to the door, her fist still full of Froot Loops. I think Mom told us not to answer the door, but I forget about things like that a lot. Besides, when I heard Olivia yelling about how happy she was to see Gran, I knew it was fine.

And then, of course, I realized it wasn't exactly fine at all. //

Continue reading at
http://shorts.quantumlah.org/entry/postmortem-0

JENNY HOGAN. Image courtesy of Jenny Hogan.

applications. This is not an exhaustive list. Every week I have the opportunity to use a wide range of skills, from getting along with people and handling administration tasks, to crafting articles and coding simple web pages.

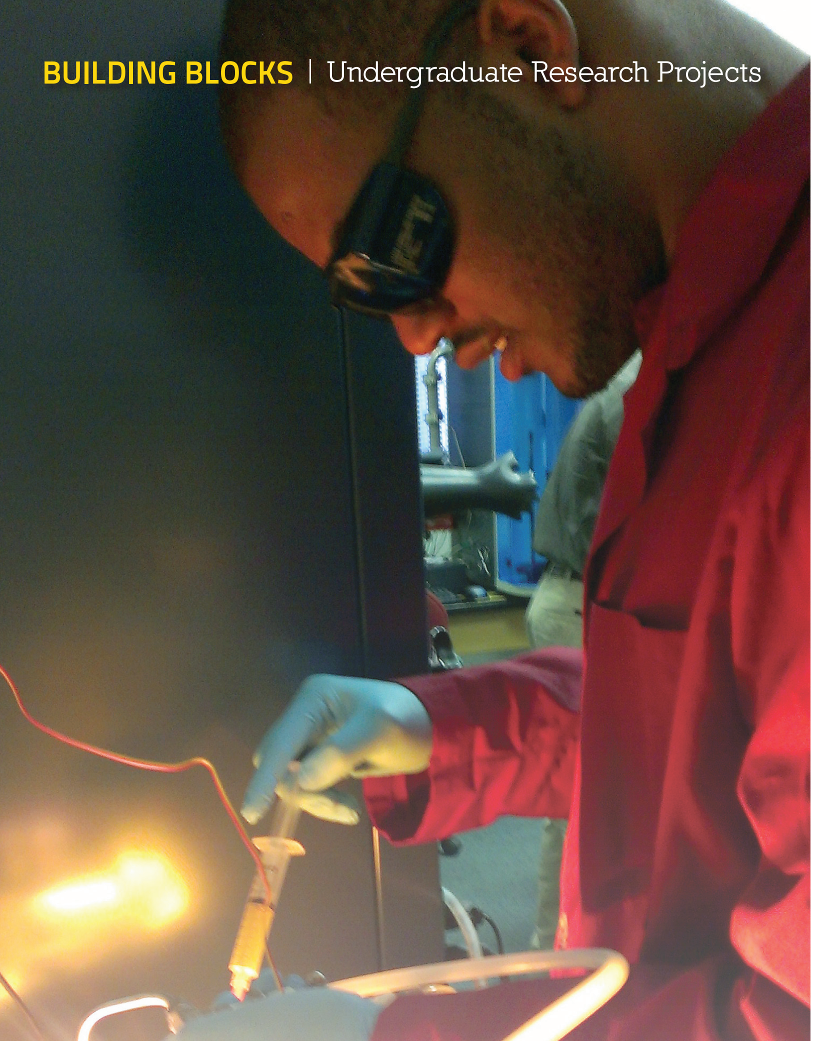
Part of this variety is a function of belonging to a small team. In a larger organization, roles may be narrower. It's something to think about when considering jobs, which kind of environment will suit you. For me, doing many different things is one of my favorite aspects of the work, second to sharing my enthusiasm for physics with others. I also like the environment of academia, and a role in outreach is a good way to stay close to science without being a scientist.

If you are considering a career in outreach, try volunteering first. For example, find out about programs your department or SPS chapter may already run, ask your city's science museums or science festivals if they take volunteers, or even approach schools to find out if they invite scientists into their classrooms. Volunteering in outreach can help you to hone your communication skills; it can also provide contacts and experience that could ultimately help you land a job. If you would like to further develop your skills in science communication, many universities offer formal courses covering this broad field.

Jobs with research organizations aren't the only way to be involved in science outreach. I am inspired by some of the people who promote science through their own platforms, such as blogging and performing. When we were planning our film competition, we had in mind some of the science-themed YouTube channels that have millions of subscribers. Readers of this magazine may be familiar with MinutePhysics, for example. If you have that kind of talent, just start using it! //

A SCREENSHOT FROM THE QUANTUM SHORTS 2012 WINNER, *QUANTUM DAUGHTER*.

Watch the film at http://shorts2012.quantumlah.org. Image courtesy of the Centre for Quantum Technologies.



Solving the Clean Water Problem

NEW NANOCOMPOSITE MATERIALS AND REACTOR SYSTEMS DEVELOPED FOR PHOTOCATALYSIS

by Jeremiah F. Wilson, Sammie Ely III, Bria M. Moore, and Lamont Henderson, Class of 2015, Tuskegee University, AL

Images courtesy of Sesha Srinivasan.

How clean is your drinking water? It's a question far from the minds of most US citizens, as we sip from the nearest water fountain. But many countries lack the water filtration technology necessary to obtain contaminant-free water. Solving this important and challenging problem will require new approaches to decontaminating water, such as photocatalysts that utilize the visible light from the sun to degrade toxins.

Photocatalysis is especially attractive for organic pollutant disposal because many toxic organics contain certain chemical structures resistant to traditional chemical attacks. Those structures are preferentially attacked by the reactive oxygen species produced during photocatalysis.[1] Besides oxidation reactions, photocatalysts can reduce chemicals as well, potentially reducing toxic heavy metals and converting CO_2 into automotive fuels.[1–3] Some researchers have also experimented with using water-splitting photocatalysis as a means of producing hydrogen, but little success has been achieved for this purpose with visible light.

Our team of SPS members investigated titanium dioxide (TiO_2), an ingredient in cosmetic products (e.g., sunscreen, toothpaste, body powder, lipstick, and soap) that is also widely used in photocatalytic and water-splitting applications because of its high stability, low cost, lack of toxicity, high oxidation potential, and chemically favorable properties. This material can only utilize the ultraviolet portion of the solar spectrum, which results in low total efficiency of catalysis for sunlight energy utilization. Improving the photocatalytic efficiency of TiO_2 or developing other photocatalysts with activity shifted toward the visible portion of the solar spectrum would have a significant impact.

Some novel approaches in improving photocatalysts have been successfully implemented and reported in the literature—including doping TiO_2 with carbon or nitrogen,[4] coupling nanoparticles to semiconductors,[5–7] and engineering the bandgaps of these materials.[8] In this project, we have developed new nanocomposite materials made of TiO_2 combined with indium vanadate ($InVO_4$) via the solid-state ball-milling

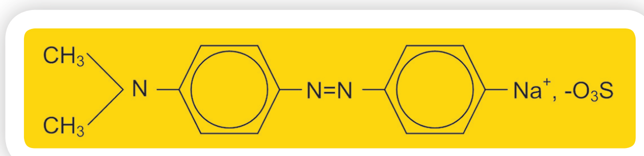
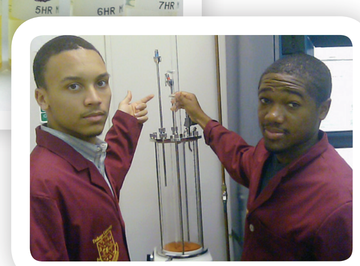


FIG. 1. The chemical structure of the dye methyl orange.

ABOVE
TEAM MEMBER SAMMIE ELY III tests MO-contaminated water samples drawn from the photocatalytic reactor constructed in-house.

RIGHT
SAMPLES OF METHYL ORANGE exposed to the team's photocatalysts for longer periods of time appeared less yellow to the naked eye as more of the toxin was broken down.



JEREMIAH F. WILSON (LEFT) AND LAMONT HENDERSON (RIGHT), constructing a photocatalytic reduction chamber for the generation of hydrocarbon from water-saturated carbon dioxide.

process, in which metal balls pulverize the materials into fine particles 100–200 nm in size. We have also fabricated a batch-type photocatalytic reactor, a device used for water treatment processes under UV-visible light irradiation.

After combining TiO_2 with different concentrations of $InVO_4$ (from 2 to 10 percent by weight), we characterized the composites' surface area, pore size distribution, chemical properties, and morphology. We then mixed each sample with methyl orange (MO), a common industrial dye that cannot be broken down by traditional biological or chemical means; our best composite degraded 50 percent of the toxin in less than 3 hours under only visible light (see Fig. 1). Plain TiO_2 degraded no MO. A plausible reason for this enhancement is that the composite nanoparticles have a higher surface area than pristine TiO_2, of benefit because the photocatalytic reaction that occurs on the surface enables electron-hole pair separation and recombination to produce reactive oxygen species that in turn degrade the organic chemicals in water.

The first and foremost challenge we overcame during this process was figuring out how to cool the light housing with a water flow; this required designing a custom water circulation system. One setback we encountered was the loss of product during the ball-milling process; it took trial and error with various proportions of TiO_2 and $InVO_4$ to obtain enough samples to complete the experiments, and we had to be very careful to make sure the experimental environment stayed consistent for each sample. We kept detailed notes and observations in log books and encouraged continual communication between ourselves and with faculty mentors.

While working on this research project, we received hands-on training on several sophisticated and state-of-the-art tools. Literature searches improved our skill at finding articles on Science Direct and other electronic sources crucial for doing background research. By the end of the project, we understood the underlying physics of semiconductor nanoparticles, band energy positions, electron-hole pair separation and recombination, chemical mineralization and intermediate species, materials characterization, and the engineering aspects of photocatalytic reactor design specific to water treatment applications.

We are continuing to optimize our material synthesis process and hope that the addition of other elements, such as nickel, will improve the degradation rate and be a next step toward discovering a solution to our world's clean drinking water problem. //

This project was funded by a $2,000 Sigma Pi Sigma Undergraduate Research Award. Faculty advisors Sesha Srinivasan and P.C. Sharma oversaw the research.

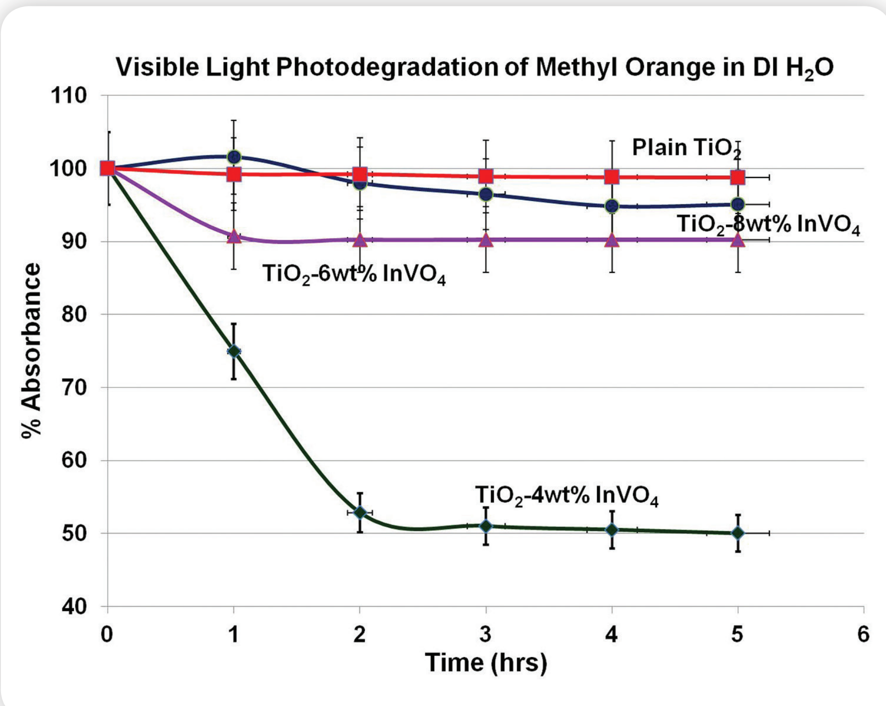


FIG. 2. Degradation of methyl orange over time by various compounds.

Drink Deeply

Learn all about the Tuskegee University team's project at www.spsnational.org/programs/awards/2013/UGR/index.htm.

Read their recent paper in the *Journal of Undergraduate Research in Physics* at www.jurp.org/2014/12030EXR.pdf.

ABOUT THE AWARD

SPS supports chapter research activities like this one through Sigma Pi Sigma Undergraduate Research Awards. Each year several awards are made to chapters for amounts up to $2,000. See page 4 for a list of the 2013–14 winners. Find out more and apply online at www.spsnational.org/programs/awards/research.htm.

ACKNOWLEDGEMENTS

Thank you SPS, AIP, and Sigma Pi Sigma for sponsoring us with an Undergraduate Research Award. We are grateful to Toni Sauncy, Kendra Redmond, Devin Powell, and Tracy Schwab for helping us shape this article.

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Defying Gravity

HOWARD UNIVERSITY TEAM TAKES A RIDE ON THE "VOMIT COMET"

by Janelle Holmes with Ajamu Abdullah and Aara'L Yarber
Class of 2016, Howard University in Washington, DC

Altitude: 34,000 feet. Speed: 469 knots. G-Force: variable.

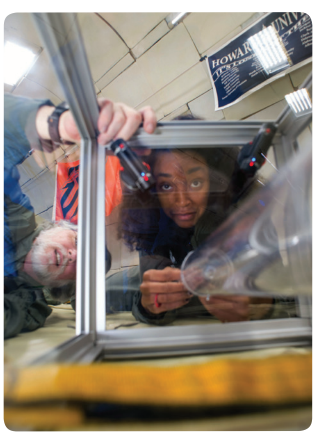
I'm floating above the Gulf of Mexico in the cabin of a Boeing 727, fighting off an exhilarating mixture of elation and nausea. My teammates and I are so focused on keeping our free-floating experiment steady that we forget to keep ourselves in check until *thud!* Ajamu and I knock heads. Luckily, the experiment itself isn't affected by our Bad News Bears-esque collision. The flight lasts for about a half hour, as the NASA plane follows parabolic paths that cause the force of gravity to vary between 0 and 2 G's. The discomfort brought on by having our weight doubled during each pullout is more than worth the subsequent elation brought on by each short period of weightlessness.

The goal of our Howard University team is to observe in microgravity the effects of Rayleigh instability, a phenomenon that explains why water from a shower head falls as droplets rather than as continuous columns. Liquids are typically subject to two forces: surface tension and gravity. On Earth the force of gravity dominates surface tension, and a liquid column develops an instability, small perturbations that cause the diameter of the column to shrink and lead to the breakup of the column into droplets. These droplets form because molecules at the surface of the liquid have a higher energy than those inside. Natural processes proceed to the lowest possible energy state, so water will minimize its surface area by taking the shape of a sphere.

Without the dominating force of gravity, our team expected to be able to form a liquid column that would not break up into droplets as quickly as it would on Earth. We got our research proposal approved by NASA in the spring of 2013 and began assembling a team. Dr. Prabhakar Misra, our SPS faculty advisor and interim chair of Howard University's department of physics and astronomy, was the organizer. Ajamu Abdullah, Ryan O'Donnell, Aara'L Yarber, and I were all undergraduate physics majors. We would be working with Raul Garcia, a graduate student, and our NASA advisor, Dr. Brian Carpenter.

The experiment was simple in principle; however, we faced quite a few logistical challenges. Flight week was to occur in early November 2013, which meant that many of our deadlines occurred over the preceding summer and early fall. Due to conflicting schedules, it was impossible for any of us to meet up until the fall semester began. When we were finally able to meet, we had to hustle to finalize our experiment design, order parts, build the apparatus, test it, and complete our test equipment data package, a detailed report designed to verify the structural design and safety of an experiment.

One of the main challenges was to design an experimental apparatus that could smoothly push water out of a syringe to form a stable column. We also had to develop a means to minimize water leakage



LEFT TO RIGHT: Janelle Holmes prepares the microgravity experiment; the microgravity team poses for a snapshot with their experimental rig; the team handles its rig in weightless conditions. Photos courtesy of Janelle Holmes.

THE HOWARD UNIVERSITY TEAM experiences zero gravity as the vomit comet plummets toward Earth. Photo courtesy of Janelle Holmes.

and construct a sturdy frame that would allow team members to observe the liquid column and hold everything steady while floating in microgravity. We solved these issues, and everything was coming together smoothly—until October.

In October the government shut down. Our project had been made possible through the partnership of two government programs: NASA's Reduced Gravity Education Flight Program (which provides opportunities for K–12 teams to fly microgravity experiments) and its Minority University Research Education Program. These nonessential programs were put on hold during the shutdown. We were not able to communicate with our NASA program coordinators during this time, and we were not sure if flight week would even occur. Fortunately, the program coordinators were able to get everything back up and running quickly after the shutdown ended. Flight week was pushed back and slightly abbreviated, but it was still going to happen.

So on November 7, 2013, Howard University's microgravity team arrived in Houston, Texas. Over the course of a few days, we finalized our experiment and answered questions regarding the safety of our apparatus. We worked in a hangar at Ellington Field, where we attended meetings and were instructed on the strict rules regarding both our experiment and our behavior on site.

NASA put us on a two-strike system. Two mistakes, and we would not fly. I'm proud to say that Howard University's team received no strikes, and we all got to fly.

In the days and moments before liftoff, we were schooled in the steps we should take to prevent motion sickness during the flight. "Don't move your head around," we were told. "Don't flip upside down or look out the window." Most importantly, we were given a drug called scopolamine that helps to prevent motion sickness. I'm proud to say that every Howard University team member kept his or her lunch—despite the nickname of the plane, the "Vomit Comet."

I had the songs "Defying Gravity" and "You Can Fly!" on repeat in the back of my mind for the entire flight, but neither song adequately describes the microgravity experience—there are few analogies that can. Imagine being on a roller coaster at that fleeting moment when the cars have crested the top of the incline and are about to plummet back toward the Earth. Now imagine that fleeting moment of weightlessness stretched out to last for 15 to 20 seconds. That's the best I can do.

In the end, we were able to capture video footage of water columns being formed and breaking up due to Rayleigh instability, which supported our hypothesis. It took a lot of time and effort to reach that point, but it was all definitely worthwhile. We rounded out the experience with tours of Ellington Field, Johnson Space Center, and the Neutral Buoyancy Laboratory. Needless to say, it was an unforgettable experience that I wish every aspiring physicist could have. //

NASA'S DEFYING GRAVITY PROGRAM FOR UNDERGRADUATES

The Reduced Gravity Education Flight Program, managed by the Johnson Space Flight Center in Houston, TX, provides a unique academic experience. Undergraduate students in the program can successfully propose, design, fabricate, fly, and evaluate a reduced-gravity experiment of their choice over the course of four to six months. The overall experience includes scientific research, hands-on experimental design, test operations, and educational/public outreach activities. The students' microgravity aircraft flies 30 parabolic maneuvers to produce periods of altered gravity ranging from weightlessness to two times the force of Earth's gravity.

—Sesha Srinivasan, Assistant Professor of Physics, Florida Polytechnic University, Lakeland, FL

Celebrating Physics Outreach

Inspiration & tips for you & your chapter

ABOVE: PARKER WEST DEMONSTRATES METHANE BUBBLES AT THE TEXAS A&M PHYSICS AND ENGINEERING FESTIVAL. IN THE SMALL PHOTOS, ATTENDEES AT THE FESTIVAL LEARN THE SCIENCE BEHIND A VARIETY OF PHYSICAL PHENOMENA. SEE "DOING OUTREACH" ON P. 17. LEARN MORE AT HTTP://PHYSICSFESTIVAL.TAMU.EDU. PHOTOS COURTESY OF TEXAS A&M UNIVERSITY.

Science Outreach... and Inreach

by Gary White
Editor, *The Physics Teacher*
Former Director, Society of Physics Students and Sigma Pi Sigma

I love those moments—and they hang in my memory like crystals from a skylight—when kids put on spectroscopic glasses for the first time and see all the rainbows everywhere. The oohs and aahs, the exclamations and fascination, the spontaneous curiosity, and, dare I say it, the science that often erupts from even the most jaded participant are positively inspirational.

Getting to bring cool science to those who wouldn't otherwise get to see it in their everyday lives is one of the privileges of being a physicist, as famed nuclear theorist Victor Weisskopf might say. Those instances when a student launches her first marble across a stretched spandex surface and when he successfully traverses the oobleck without sinking—they are not just fun, but deeply satisfying life experiences to engage in, and to observe. In fact, it's why this issue of The SPS Observer is devoted to science outreach.

Here's a kernel of truth I have distilled from the dozens of outreach events I have developed with hundreds of fellow scientists: though teaching the masses that great science is worthwhile, perhaps the most important reason why your SPS chapter should do outreach is the impact it will have on those inside your chapter. The best way to get your chapter members revved up is to get them to lead an exciting science outreach lesson.

To put it another way, science outreach is the best "inreach." I'm not able to recall which SPS chapters first introduced me to this idea, but I do remember that they had separate leadership positions for the Science Outreach Officer, who took the lead in showcasing science outside the chapter, and the Science Inreach Officer, who arranged for fun science to be brought to the chapter membership itself. This arrangement is a great way to make sure that students look after their own scientific health, as well as provide useful service to the external community. I wish I had thought of it myself!

As a former director of SPS, I have seen and been part of everything from intimate classroom efforts in which a dozen students perform experiments with weighted dice or objects rolled down ramps, to a large-scale laser haunted house at the USA Science and Engineering Festival involving dozens of presenters and thousands of participants. The impact on the students leading or participating in these projects—the additional knowledge they glean in preparing, the confidence in communication that they begin to master, the camaraderie that develops among a group of like-minded presenters—is tremendous. Many of the scientists I know have had their identity as a scientist locked in by these kinds of experiences. And while some may think that outreach is a distraction from the science, I have seen it be the catalyst that led to more-engaged science careers.

One last bit of advice about science outreach: consider using activities in which the audience gets to do the science instead of watching you do science. I'm not saying that you should abandon your favorite showy bit of science outreach—watching a 55-gallon drum implode or hearing a LN_2-laced two-liter bottle explode are great ways to get people's attention. But add some liquid nitrogen ice cream stirred by the participants to the mix, or some hands-on pressure lessons with suction cups. These experiences allow participants to own the science for themselves. //

GARY WHITE USES SPANDEX AND MARBLES to demonstrate the properties of gravity during an outreach event at the 2013 AAPT Winter Meeting. Photo by Lydia Quijada.

The Best Day at School

SPS VOLUNTEERS OPEN YOUNG MINDS TO MATH AND SCIENCE

by Theresa Coffman
Teacher, Tuckahoe Elementary School, Arlington, VA

STUDENTS IN COFFMAN'S CLASS try to measure the length of a cord using a non-standard tool. Photo courtesy of Theresa Coffman.

Eli, a student in my classroom with an extremely scientific mind, stretches a piece of spandex and thinks about space and time. The elastic material in his hands simulates the fabric of the Universe, warped by the gravity of a black hole. Intrigued, he goes home and tells his parents that he has just had the "best day of his life" in school. Any eight-year-old can tell you what a paleontologist or archaeologist does for a living, but can he or she do the same for a physicist or an engineer? Thanks to the outreach activities of SPS—including the demo that so captivated Eli—many of the third graders I teach can.

My partnership with SPS started in the spring of 2004, when then-SPS Director Gary White approached me. At the time, his son was a talented student in our third-grade community at Tuckahoe Elementary School in Arlington, Virginia, who was already grasping high-level mathematical and scientific concepts at age eight. Like all teachers, I was looking for creative ways to inspire learning and open other young minds to the real-world applications of math and science. Dr. White offered to bring his SPS interns to our school at the end of the year to stage a presentation aimed at teaching the relevance and importance of physics and math in our world. Little did I know what a success this would be; the program would continue year after year.

In our first year of exploration, the interns challenged my third graders to think about the area of a closed space. The students had to find all the options for designing an outdoor pen with an area of 24 square feet. When we then built mock fences using a peg board and string in Tuckahoe's outdoor learning space, the students were excited to see that the different options had different perimeters requiring different amounts of fencing.

This led to a more challenging problem in which students were asked to consider which shape offered the most area with the least amount of fencing. The high-level learners squealed with delight when

ANY EIGHT-YEAR-OLD CAN TELL YOU WHAT A PALEONTOLOGIST OR ARCHAEOLOGIST DOES FOR A LIVING, **but can he or she do the same for a physicist?**

SPS INTERNS HAVE TAKEN US ON MANY

exciting intellectual journeys

they discovered that a circle (not a square or rectangle) was the ideal shape. The activity laid the groundwork for another lesson later in the year that returned to this same concept and asked students to consider the optimum design for third-grade garden beds.

In the years that followed, SPS interns have taken us on many exciting intellectual journeys. We constructed a "road" test in which toy cars with clay people were sent down ramps of varying slopes to collide with a block at the end of each runway. The consequences of this impact for the clay folks moving at the highest speeds along the greatest slopes were not pleasant; let's just say that "decapitation" and "amputation" were words being used in the classroom that day.

Another year, the interns tasked the students to throw cardboard boxes through the air and record the side on which each box landed each time. Unbeknownst to the students, some of the boxes were weighted and were thus destined to land again and again on the same side. Despite the students' initial frustration over not being able to get the boxes to land on every side, they were gleeful to learn that this was actually a rudimentary test study of how the NASA scientists designed the Mars Space Rover to ensure that it would land correctly on the Red Planet. I'm sure that family dinner conversations on that evening were most impressive.

As I reach the end of my tenth year of teaching, I am already looking forward to another visit from our interns. The SPS National Office staff has taken the lead in helping to give students a higher-level understanding of the connections between math and science and our world today. Our challenge in third grade is not only to present a truckload of content (which is constantly growing), but also to inspire students to think about careers in math and the sciences. The interns help to accomplish both goals by modeling scientific or mathematical problems, as well as by talking to the students about their educational paths and career goals.

As that first class of third graders from 2004 heads off to college next year, I am not surprised that many of the students plan to pursue engineering and other science majors. I like to believe that creative learning opportunities such as the one offered by the SPS volunteers helped to influence these decisions. The administrators, teachers, parents, and students of Tuckahoe Elementary School are quite grateful to SPS members for their continued commitment to our third graders. We look forward to the upcoming SPS visit later this spring.

As always, we expect great things to transpire for learners of all ages! //

SPS INTERNS discuss the measurements made by Coffman's class and the value of having standard forms of measurement such as the meter. Photo courtesy of Theresa Coffman.

BECOME AN SPS INTERN

Pictured here are several of the 2014 SPS interns. To learn more about the SPS summer internship program and read about the experiences of these and previous interns, visit www.spsnational.org/programs/internships/.

A Passion for Teaching Physics

SPS OUTREACH INSPIRES A STUDENT TO BECOME A TEACHER

by Cristian Bahrim
Associate Professor of Physics, Lamar University, Beaumont, TX

Robert Holman discovered his love for teaching in early 2010 while standing in front of a classroom of fifth and sixth graders at Pietzsch-MacArthur Elementary School, located just a few blocks from Lamar University. Robert was then an undergraduate at Lamar, and this was his first experience presenting to children of such a young age. He was worried about delivering the information in a way they could understand and enjoy, but he got over his nervousness and was soon caught up in their enthusiasm.

"I was reminded of myself at their age, watching what I thought was magic," Robert later told me. "I hope to have lit the same flame in them that Mr. Wizard put in me." Mr. Wizard hosted a children's television program about science, filmed in the 1950s and 1960s, and watching reruns inspired Robert's interest in physics when Robert was in middle school.

Many students in our physics program have developed an interest in teaching physics while participating in outreach. Robert's story is one of the most unique. After he joined Lamar in the spring of 2003, he tried out eight different programs over the course of six years—leaning toward an English degree at one point—before deciding in 2009 to become a physics major. He was then accepted to a National Science Foundation–sponsored program at Lamar called STAIRSTEP, which supports low-income students who are minorities and the first in their families to attend college. This program helps these students graduate with a BS degree in a science, technology, engineering, and mathematics (STEM) discipline. Robert excelled in the program; he had an immense love for sharing knowledge with others, an exceptional humor, and a talent for making physics fun.

A couple of weeks after his experience at the elementary school, Robert and three other physics majors assisted me in delivering a one-hour science demo in front of about 200 high school science teachers, at a conference organized by the Science Teachers Association of Texas. The event was a big success. In Robert's words, "that day I left, as did all in attendance, in awe."

Later, Robert participated in an on-campus visit of students from Warren High School. His demonstrations about light—which were followed by clear, simple explanations about the physics involved in the interaction between light and matter—captivated the 26 student visitors and their teacher. Robert had a genuine interest in optics that extended beyond outreach. He performed good research in the field, and says that presenting his work at a student conference organized by the Texas Academy of Sciences was the defining moment in his life, one that tied his future to physics.

After graduating from Lamar, Robert received a job offer from the Ross Sterling High School in Baytown, near Houston, Texas, as well as four other offers for nonteaching jobs. He finally decided to become a physics teacher and continue sharing his love for physics with younger students—thanks to his experiences with outreach at Lamar. "Teaching and demonstrating physics in community outreach in the program moved me to become a high school physics teacher," says Robert, who again demonstrated his talent for inspiring students of all ages during his recent visit with students in the STAIRSTEP program. A conversation with Robert inspired current undergraduate Logan Talbert to want to be a physics teacher. //

INTERESTED IN SCIENCE TEACHING?

The American Association of Physics Teachers (AAPT) is a professional membership association of scientists dedicated to enhancing the understanding and appreciation of physics through teaching. AAPT members include physics teachers at the high school, undergraduate, and graduate level and students interested in teaching. AAPT is a Member Society of the American Institute of Physics, home to the Society of Physics Students. This means that undergraduate SPS members can receive free membership in AAPT when they join or renew their membership. For details, see www.spsnational.org/about/benefits.htm.

SPS AND AAPT HOST an outreach event at each AAPT Winter Meeting. Volunteers from both organizations engage with approximately 100 local students in grades six through eight. Shown here, students from New Orleans participate in the 2013 event. Photo by Lydia Quijada.

Get Inspired!

IDEAS FOR PHYSICS OUTREACH

by SPS Staff

MAKE EVERY HOLIDAY A PHYSICS HOLIDAY. Halloween is a great excuse to break out the lasers and transform a lecture hall into a creepy (and educational) experience for the public. But why not put on a wig and do some relativity demonstrations on Einstein's birthday (don't forget to eat pie that day, too!) and build pumpkin-tossing trebuchets on Thanksgiving, as well?

GET FESTIV(AL). Every year, Texas A&M University holds a massive physics and engineering festival that draws thousands of kids to its campus. Graduate students, undergraduates, and faculty come together to produce more than 100 demos, an experience that energizes the department and has proven to be a valuable recruitment tool. Start small by holding a booth at a campus or community fair. Consider street fairs and arts festivals in your community, as well.

TEAM UP WITH A TEACHER. Bringing hands-on outreach activities to a local school can be inspirational, not only for young students but for your SPS chapter as well (see Theresa Coffman's testimonial on p. 14). After-school science clubs can provide a nice venue for building rockets or other long-term projects. Some chapters target specific underperforming and under-resourced schools and visit the same class multiple times. Others have long-standing physics road trips with dozens of stops.

PUT A SOCK IN IT. Every year, SPS summer interns at the SPS National Office design a new Science Outreach Catalyst Kit (SOCK) full of hands-on physics activities for students of all ages. The 2013-14 kit is called "Sensors, Detectors and Meters—Oh My!" and was created in partnership with the National Institute for Standards and Technology to emphasize the importance of sensors that go beyond our touch, taste, smell, sight, and hearing capabilities. SOCKs are specifically designed to help SPS chapters kick-start or grow their outreach efforts. For information about how to get a free SPS SOCK, visit www.spsnational.org/programs/socks/.

SHOWCASE PHYSICS WITH A BANG. Get community members and students in other departments hooked on science with a regular showcase of demos on your campus that are open to the public. Juanita Community College has been doing this for more than a decade; their most popular demo involves smashing a cement block while it is perched on the chest of a math professor.

TAKE PHYSICS OFF CAMPUS. Engage community members in discussions about science by hosting a science café at a local restaurant, coffee shop, or bar. A science café is an informal event at which a scientist gives a short, informal talk (without slides!) to attendees in a casual environment. Another option—bring physics to the mall! The Idaho State University puts on physics demonstrations and hands-on science exhibits at a local mall, where SPS members also make liquid nitrogen ice cream. Consider programs at local libraries and museums; the University of Oregon chapter, for instance, partners with the Science Factory, a children's museum in Eugene.

SHOW THE STARS. Does your university have an observatory, planetarium, or even small, stand-alone telescopes? Put on a night of stargazing for the public. The US Air Force Academy SPS chapter did this for 450 scouts, students, and teachers last year. You might not be able to recruit Miss Mississippi USA to explain how a planisphere works, like they did, but you can probably recruit an astronomy student. //

SPS INTERNS KEARNS LOUIS-JEAN (LEFT) AND MARK SELLERS develop demonstrations for the 2014-15 SPS SOCK (Science Outreach Catalyst Kit). The kits may be ordered from the SPS National Office to kick-start chapter outreach efforts. Learn more and peruse recent SOCK kits at www.spsnational.org/programs/socks/. Photo by Courtney Lemon.

DOING OUTREACH, both for our annual Texas A&M Physics and Engineering Festival and throughout the year at camps and auditoriums and elementary schools, has had a direct positive impact on our current students and their educations. Guided by professors, students work together on the research, concept, design, and fabrication of science demonstration experiments. Graduate students learn how to lead a team and practice explaining their science to the public; undergraduates benefit by acquiring a deep knowledge of underlying physics concepts and learning real-life skills ranging from welding and drilling to programming and soldering." //

—Alexey Belyanin, SPS Advisor, Texas A&M chapter

Six Reasons I ~~Did~~ Do Outreach

by Jenna Smith
Graduate Student, Michigan State University, East Lansing

01 **IT REINFORCES MY OWN PHYSICS KNOWLEDGE.** Teaching science to a wide variety of audiences requires a deep understanding. I can't rely on saying, "Well, the math comes out that way." I need to have a physical understanding and communicate that to them. I also have to pick up all the details that I'd previously brushed over. This reinforcement makes me a better scientist.

02 **IT REMINDS ME THAT I LOVE MY FIELD.** On one hand, I get to interact with some people who really are enthusiastic about science, and that rubs off on me and renews my enthusiasm. On the other hand, I can't be effective at outreach without enthusiasm, so when I'm down on my research, outreach can force me into a "fake it 'till you make it" situation and bring out my original enthusiasm. Recapturing that enthusiasm can be crucial for getting me through tough days at work.

03 **IT BRINGS ME BACK TO THE "BIG PICTURE" MOTIVATION FOR MY WORK.** Sometimes I get too caught up in the details of the work and forget the bigger motivation: we don't have a good model for how protons and neutrons interact, and we still can't tell you how all the elements were made. Outreach about my research in neutron-rich nuclei requires me to provide context and motivation for my audience. There's the "motivation" section for my next research presentation or proposal.

04 **I'M A BETTER COMMUNICATOR BECAUSE OF THE OUTREACH.** The participants are different for each outreach event, which forces me to practice identifying how sophisticated their science knowledge is, reading their signals, and tailoring my message to different audiences. All of these skills are useful in giving research presentations as well.

05 **I'M BREAKING DOWN STEREOTYPES.** Stereotypes: scientists are smart people, but with minimal social and communication skills. All scientists are old, boring, white men. I can't defy the "white" stereotype, and I wouldn't dare refute the "smart" label, but my presence at outreach events shatters the rest of these stereotypes and hopefully enables others to see themselves as scientists..

06 **I'M A ROLE MODEL FOR FUTURE SCIENTISTS.** If every scientist could inspire two children to value science and be curious about it, we could change the world. //

Jenna Smith went to Rhodes College in Memphis, Tennessee, for her undergraduate degree in physics (see p. 20 for the zone meeting recently hosted by Rhodes) and recently received her PhD in nuclear physics. She is a former SPS intern and former student representative on the Executive Committee of the SPS National Council.

JENNA SMITH leads activities from the 2008-09 SPS SOCK (Science Outreach Catalyst Kit), including polarization, sound, reflection, and refraction, during her SPS internship. Photos courtesy of the American Institute of Physics.

THE OUTREACH LIFESTYLE

My outreach experience stretches back to a high school open house I spent on roller blades, demonstrating conservation of linear momentum. It continued through pumpkin drops and Oobleck sidewalks in college, and included a stint as an SPS summer intern, during which I developed a Science Outreach Catalyst Kit (SOCK) to assist other SPS chapters in setting up their outreach programs. I've taken advantage of outreach opportunities in graduate school ranging from interactive classroom lessons about nuclear science to demonstrations at a national science fair. Who knows where my outreach career will go next?

Top Five Tips for Doing Science Outreach

by Steve Shropshire
Professor of Physics, Idaho State University, Pocatello

The Society of Physics Students chapter at Idaho State University (ISU) has been very active in science outreach ever since I became the faculty advisor 20 years ago. Every year, members visit between 12 and 50 schools and provide numerous public presentations, events, and activities. The high demand for and appreciation of the ISU physics outreach programs is indicative of a very effective program. This effectiveness is due to enthusiasm, as well as trial and error. The following are a few pointers, ideas, and suggestions that I wish had been given to our chapter 18 years ago.

TOP: IDAHO STATE UNIVERSITY STUDENTS JUSTIN ANDERSON (foreground with the box speaker) and Alexis Chlarson (with the jumping ring demo) engage shoppers at a local mall during an SPS outreach event. Photo courtesy of Steve Shropshire.

BOTTOM: THE IDAHO STATE UNIVERSITY SPS HAUNTED LAB demonstration "Phun with Phluorescence." Photo by Jordan Keough.

01 MAKE IT EXCITING. To spark or reinforce interest in science, you need to acquire and keep your audience's attention. Choose activities, demos, and topics that maximize wonder, amazement, and surprise.

02 KEEP IT EDUCATIONAL. Flash and bang without science is just eye candy. Center your outreach on a few specific concepts and convey them clearly and concisely.

03 KNOW YOUR AUDIENCE. Always use age-appropriate language and explain things as simply as possible. Never talk down to folks and do not scare small children.

04 KEEP IT SAFE. Make precautions obvious and effective, so the exposure to science you provide is both positive and enlightening. One bad experience can make a lasting negative impression.

05 HAVE FUN AND MAKE SURE EVERYONE CAN TELL. Excitement about science is contagious. Pass it on! //

Zone 10 Meets in Memphis

RHODES COLLEGE HOSTS GATHERING OF PHYSICS STUDENTS FROM SOUTHERN UNIVERSITIES

by Catherine Miller, incoming SPS Chapter President, Class of 2016, Rhodes College, Memphis, TN

Rhodes College was super-excited to host this year's meeting for zone 10. We don't think there has been a zone meeting like it in quite some time!

It started with our keynote speaker, retired NASA astronaut Winston Scott. After his talk, SPS members got to ask him questions, join him for dinner, and take photos with him. Then the conference attendees were in a room full of old, unidentified objects, and they did what physicists do: they tried to figure out "What the heck is it?!" During a chill session in our physics lounge, we roasted marshmallows over a Ruben's tube, played cards, and became very invested in some impromptu Hangman games.

SPS members also came together to discuss zone business and participate in round tables on subjects ranging from fund-raising to collaborative projects such as microgravity experiments. On Saturday, Professor David Smathers of Rhodes College gave an introduction to metallurgy, and we toured the National Metal Museum in Memphis.

We hope you enjoy these stories from the event, written by Rhodes SPS members. And we hope to see you at future meetings! //

Meeting Your Heroes

The first time I met Captain Winston Scott, a retired astronaut, I threw my cell phone at him. I didn't mean to, it just kind of happened. I had just come into Rhodes' science lobby after directing guests in the parking lot, and the first person I saw was a tall man in a bright blue flight suit laughing with a group of physics students. "Hey, I want to meet an astronaut," I thought, and beelined toward him. Unfortunately, my phone also beelined, and when I stopped to shake his hand, Newton's first law held fast: the phone kept going. Crack-a-lackin', my phone hit the ground, the battery shooting off in one direction as the phone's body went in another.

Winston Scott looked down at me, and for a moment I wished the floor would just swallow me whole. He looked confused. "Good, great," I thought desperately. "I meet an astronaut and I throw my phone at him. Rad." Embarrassed, I couldn't think of anything else to do besides extend my hand to shake like nothing had happened.

With a grin, Captain Scott grabbed it and started laughing. "It's all right, you know, I'm just an astronaut!" Then, incredibly, he stopped shaking my hand and picked up my phone. I was blown away. An astronaut? Touched my phone? I'm never washing it again. I couldn't help it and started laughing as he handed me the pieces. He laughed too, then admitted, "I don't know how to fix a smartphone."

- by Catherine Miller, incoming SPS Chapter President, Class of 2016

What Being a Scientist is All About

The physics department at Rhodes College is a small one, a close group of like-minded individuals. This helps to foster an environment of friendship, fellowship, and engagement with our immediate science community. But there's a trade-off to this situation. It limits our exposure to new ideas.

Meeting other members of the zone 10 community was a great opportunity to exchange new ideas and methods of learning. As physicists, we all share the same basic goal of expanding our knowledge base and constantly growing and learning. What really surprised me, however, was how we are all such different people. Talking to a University of Memphis student, for instance, I was fascinated to discuss what got him so interested in quantum physics.

- by an Enthusiastic SPSer, Class of 2016

ATTENDEES AT THE ZONE 10 MEETING come together for a photograph. Images courtesy of Morgan Smathers.

Table Top Physics

At the zone 10 meeting, I found myself wandering over to a table labeled "camaraderie," where a small group had already gathered. The group included a chapter that had already spoken briefly about a mentoring program designed to help increase their involvement and keep younger students interested in physics, which our chapter is very concerned about. The idea interested me, and the discussion it sparked at the table was fantastic.

Students from the University of Memphis, the University of Central Arkansas, Centenary College, and Ole Miss joined the conversation. All of us had an interest in what other chapters were doing successfully and were willing to divulge our own secret formulas for success. We discussed creating a zone 10 database for physics demos, and our chapter made new connections with the SPSers from Ole Miss. Hopefully we will get the chance to team up with them for future SPS events.

I hope that everyone else left the conference as excited about the things we can achieve over the next year as I did, and I hope we will all come back next year with new accomplishments to show off!

- by Jordan Meyer, Class of 2016

We Need to Build a Segway

The purpose of the zone 10 gathering was not immediately clear to me. In essence, we met and we mingled.

After Rhodes showed off its 5' fire tornado, we were asked for designs for the chamber by another chapter that hopes to build one. Henderson State brought along its homemade Segway, which started a discussion about whether the Segway is a viable form of permanent transport for students (a subject still under much debate).

As we collectively basked in the glory of our guest astronaut, the remarkable bits of the SPS zone meeting turned out to be hidden inside the mingling. We were now part of a community, I found, one that could collaborate and improve itself solely through interaction.

As my classmate and chapter member Catherine Miller told me, SPS is "a gateway community," meaning that the valuable lessons we learn from being in SPS can be applied elsewhere. Here are some things I learned from the meeting. One: I should interact with other scientifically minded people. Two: how that chapter made its Segway. Three: Segways are cool, and I want one.

We strive for cooperation out of the recognition that it is easier for us to move the world if we exist within and contribute to a community. In other words, SPS members are better together than apart.

- by Edo Draetta, Incoming SPS Chapter Outreach Officer, Class of 2016

CUWiP: Engaging in Physics and Community Building

STUDENTS COME TOGETHER FOR THE CONFERENCE FOR UNDERGRADUATE WOMEN IN PHYSICS (CUWiP) AT THE PENNSYLVANIA STATE UNIVERSITY, STATE COLLEGE, PA, JANUARY 17–19, 2014

by Kathryn Hasz
Class of 2014, Oberlin College, OH

Women are underrepresented in physics and related fields. Yet for a few days in January, I was one of more than a hundred women discussing physics, with only a handful of men in sight. The occasion was this year's Conferences for Undergraduate Women in Physics (CUWiP), held simultaneously at eight universities across the country. This is my third year attending a regional CUWiP, and I have loved seeing it grow and evolve.

Our local event at Penn State gave 140 women from Pennsylvania and nearby states the opportunity to learn more about the frontiers of physics. On Saturday afternoon Debra Fischer, an astronomy professor at Yale, gave the keynote address about her work discovering exoplanets. Her talk was simulcast to all of the CUWiP locations, and the sight of over a thousand of us gathered together virtually was pretty powerful.

"Conferences such as CUWiP are extremely important in encouraging young women to continue pursuing physics as a career. Not only do they expose students to exciting research while also allowing them to present their own, but they encourage communication and questions about the possible paths to becoming a successful physicist," Kathryne Sparks Woodle, conference organizer and grad student at Penn State, told me.

During the conference I particularly appreciated the remarks on gender issues in physics by Joan Schmelz, a professor at University of Memphis in Tennessee and the current chair of the American Astronomical Society's Committee on the Status of Women in Astronomy. She warned that while explicit discrimination has become less prevalent, unconscious biases still exist, associations between traits and groups (e.g., "scientists are male") that can be easily overlooked and hard to counter. She spoke about the subconscious effect labeling someone with a negative stereotype can have on that person's performance and highlighted a concern that women sometimes feel like imposters; even women that have won awards and published in leading journals may feel like they are just faking their way along.

> WHILE EXPLICIT DISCRIMINATION HAS BECOME LESS PREVALENT, unconscious biases still exist

Many students presented original research in posters or 10-minute presentations. We also attended a variety of workshops on topics such as networking, summer research experiences, and graduate school. This year we met in smaller groups than in previous years, which allowed for more people to have their questions answered and receive personalized advice about opportunities and pitfalls in physics.

Chunks of less-structured time proved to be especially valuable. I often found myself sitting down at a random table and engaging in conversation, whether about home departments, the National Science Foundation's Research Experiences for Undergraduates, or the strange antics of squirrels on campus. We were also able to talk about some of the problems, large and small, that we have faced or expect to face as females in a field that is still dominated by males.

"Many female physicists have common concerns about their success in the field, beyond those pertaining to the science itself," Woodle explained. "I believe that a key to understanding that one can succeed is realizing that these concerns are not exclusive to a particular individual and acknowledging that we all question our path at some time." //

NEXT UP

The 2015 CUWiPs will be held January 16–8, 2015, at the following sites:

North Carolina Research Triangle
Purdue University
Rutgers, the State University of New Jersey
University of California, Santa Cruz
University of Michigan
University of Mississippi
University of Texas at Brownsville
Yale University

See www.aps.org/programs/women/workshops/cuwip.cfm.

Highlights from Other Sites

Eight sites hosted simultaneous Conferences for Undergraduate Women in 2014. Here are highlights from a few others.

On Nobel laureate William Phillips' presentation at the Mid-Atlantic CUWiP, hosted jointly by the University of Maryland in College Park and the National Institute for Standards and Technology in Gaithersburg, Maryland:
I honestly cannot remember a time that I have ever been more enthralled, entertained, and educated all at the same time. His demonstrations with liquid nitrogen were completely captivating. He explained how NIST is responsible for measurement standards and discussed his research in cold quantum matter.
– by Rebecca Bissell, Virginia Commonwealth University, Richmond

On a presentation by Luisa Bozano at the CUWiP hosted by the University of California, Berkeley, and Lawrence Livermore National Laboratory:
Bozano's first "wake-up call" to the gender gap in physics came when she tried to apply for a job in industry in Italy. Her professors told her that companies don't hire women in science, one of the main reasons being the 6–12 month paid maternity leave required by law if she decided to have a child. For this and several other reasons, she moved to the United States to do research at the University of California, Santa Cruz, where she later received her PhD. Her career at IBM started a year before she got her doctorate. At the end of the talk, Bozano showed us a picture of her baby daughter and said, "This is the one thing I know I did right." She shared that the day she went to tell her boss she was pregnant was the same day he was going to offer her a management position. Although Bozano was worried about how her pregnancy would affect his offer (based on her experiences in Italy), he said, "I don't see any problem." She is now the only female manager in the IBM Science and Technology Center.
– by Kayla Bollinger, California State University, Long Beach

On a tour of Fermi National Accelerator Laboratory (Fermilab) at the CUWiP hosted by the University of Chicago in Illinois and Fermilab:
One of my career goals is to work at a big laboratory such as CERN or Fermilab, so I was excited that the conference offered a visit to Fermilab. Our tour guide explained the history of the facility, the research taking place there, and the benefits of that research. We learned about current developments in neutrino oscillation experiments while visiting the caverns that house the Main Injector Neutrino Oscillation Search (MINOS) detector and the Main Injector Experiment for ν-A (MINERvA). After lunch, we continued our tour with visits to the historic Cockcroft-Walton accelerator and the retired Tevatron collider and its DZero detector, used to discover the top quark.
– by Caroline K. Williams, Northeastern Illinois University, Chicago

On a poster session at the CUWiP hosted by Stony Brook University in New York and Brookhaven National Laboratory in Upton, New York:
Thirty-three undergraduate research posters were presented by women to women. Jasmine Abdollahi taught me about using photodiodes to look for neutrinoless double beta decay of radioactive xenon. Kelsie Krafton explained the different types of supernovae while presenting a poster on one supernova's relevance to early dust evidence. Kelly Blumenthal showed me color printouts of the sky with the same stars appearing in multiple places, distortions caused by galaxy lensing. I presented a poster on my research at Stony Brook with a hadron-blind ring imaging Cherenkov detector. The presentations were lively, and I learned about physics topics ranging from superlattices to tadpoles.
– by Marie Blatnik, Cleveland State University, OH

Networking at the Mid-Atlantic conference at the University of Maryland. Photo courtesy of APS.

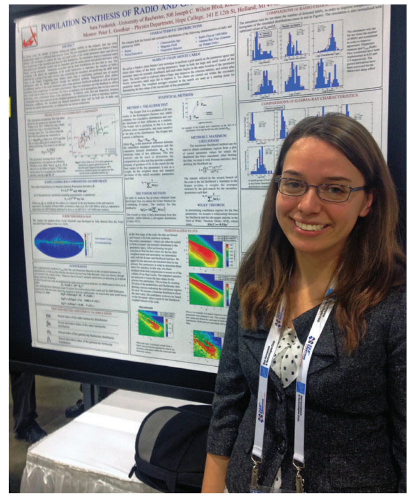
Attendees at the Midwest conference at the University of Chicago watch Debra Fischer give the keynote address, which was simulcast to all locations. Photo by Aneesa Sonawalla.

Students browse the posters of their peers at the Northeast conference at Penn State University. Photo by Melissa Quinnan.

Share Your Knowledge

CONNECTING AT THE 223RD AMERICAN ASTRONOMICAL SOCIETY (AAS) MEETING, JANUARY 5–9, IN WASHINGTON, DC

by Sara Frederick
Class of 2015, University of Rochester, NY



SARA FREDERICK presents her research at a poster session. Photo by Hind Al Noori.

The theme of the AAS winter meeting could well have been "Connecting with the Public." Broadcast during various outreach programs, astronomical education events, and talks, the message was loud and clear: Share your knowledge and data effectively.

On the first night Alyssa Goodman of Harvard University in Cambridge, Massachusetts, showcased cutting-edge multidimensional imaging techniques that allow the public to interact with data. Neil deGrasse Tyson rounded out the evening, encouraging scientists to take advantage of the public's interest in astronomy (evidenced by space tattoos, scientific memes, and his ever-expanding Twitter fandom) by sharing knowledge through "tasty" sound bites. He received hearty applause following the trailer for his new show, *Cosmos: A Spacetime Odyssey*, which premiered on FOX in March.

Another great talk was given by Nicholas Suntzeff of Texas A&M University in College Station, recipient of the US Department of State's Jefferson Science Fellowship, which engages academics from science, engineering, technology, and medicine with US foreign policy. He described his sometimes shocking experiences with how science is perceived in government.

My favorite session took place in a room that was packed, wall to wall. This astronomy education research session focused on improving attitudes toward science and finding better approaches for informing the next generation. Katherine Follette of Pima Community College in Tucson, Arizona, encouraged educators not to forgo difficult topics in astronomy just because the math may be hard for some undergraduates to handle. The session was met with overwhelmingly positive reactions from the audience.

The Society of Physics Students national organization made many appearances at the meeting. At the SPS Evening of Undergraduate Science, students showcased their posters in an informal setting. SPS also welcomed students with a booth at the AAS undergraduate orientation, and many SPS members attended AAS's first ever Open Mic Talent Night, where feats of musical, theatrical, and yo-yo prowess were enjoyed by all. My most memorable interaction at an SPS event was playing a spirited round of a card game with a dark sense of humor called Cards Against Humanity alongside a young woman who, I was later told to my surprise, was a notable blogger, researcher, and professor of astrophysics.

Getting to the meeting from my hometown in rural Nebraska during January's "polar vortex" was no small feat, but the experience was well worth it. The sensational findings unveiled at the meeting included the discovery of a triple stellar system, measurement of the scale of the Universe within 1 percent accuracy, and discovery by the Kepler Space Telescope of the first Earth-mass planet transiting its host star.

I was touched by how the senior scientists encouraged the undergraduates in attendance. Presenting my poster from a summer research project at a meeting of over 3,000 astronomers was a daunting task, but each and every onlooker was incredibly supportive. I cannot wait to attend the largest gathering of astronomers on Earth again. //

Notes from other Reporters at the AAS 223rd Meeting

CAROLINE ROBERTS, SEWANEE: THE UNIVERSITY OF THE SOUTH, TN

There was a large poster board at the meeting filled with printouts of all of the news articles generated by press coverage of the conference. It was an amazing reminder of how much the public had its eye on the meeting.

KEVIN VICTOR GIMA, PRINCE GEORGE'S COMMUNITY COLLEGE, KETTERING, MD

Talks at the meeting can be very technical and hard to understand. To alleviate this, the society has created a series of "amateur" talks to familiarize people with various topics. I attended one on exoplanets, which led me to realize that attending scientific conferences regularly is very important for keeping up to date with contemporary research.

NEXT UP

The next AAS winter meeting will take place from January 4–8 in Seattle, Washington. See http://aas.org/meetings/future-aas-meetings.

INTERESTED IN BEING AN SPS REPORTER?

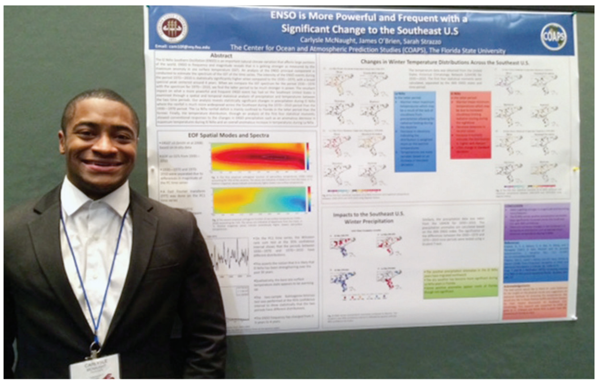
SPS offers travel support at a level of $200 for SPS chapters or individual students reporting on a national physics meeting for SPS. For details, visit www.spsnational.org/programs/awards/reporter.htm.

AMS: Opportunities in the New Job Climate and Beyond

THE 13TH ANNUAL AMERICAN METEOROLOGICAL SOCIETY (AMS) STUDENT CONFERENCE, FEBRUARY 1–2, ATLANTA, GA

by Catherine O'Riordan
Vice President, Physics Resources Center, American Institute of Physics, College Park, MD

A big storm was coming in, and decisions needed to be made. Teams of students pored over the data available to them. Should warnings be issued? If so, when? Should schools and businesses be asked to close? With the help of mentors, the students evaluated the risks associated with a severe weather event during this case study exercise at the American Meteorological Society (AMS) student conference.



CARLYSLE MCNAUGHT poses proudly with his research poster. Photo courtesy of Catherine O'Riordan.

Held just prior to the AMS meeting, the two-day conference cost just $25 to attend and drew over 800 undergraduates and graduate students from across the globe. The stimulating lineup of talks, discussions, and case studies addressed topics including extreme weather events, national climate assessment, and the overall weather enterprise.

In light of the theme, "Opportunities in the New Job Climate and Beyond," events at the conference focused on professional development and explored life in academia as well as the private and public sectors. At a two-hour evening reception, students dressed as if being interviewed, juggling small plates of appetizers while speaking with professionals. The event was partly an academic forum of graduate programs and partly a job fair.

Exhibitors included companies such as Northrup Grumman, which attends every year looking for graduates with BS, MS, or PhD degrees. Graduate programs in atmospheric sciences came from across the country. Private weather enterprises such as AccuWeather were there, as were government agencies such as NASA's space weather unit and the NOAA Center for Atmospheric Sciences at Howard University in Washington, DC. Most of the organizations and some of the universities were recruiting for summer internships as well.

Mark Benoit, a recent graduate of Texas A&M University in College Station, told me that he attended the student conference last year when he was unsure about whether to enter the workforce or apply for graduate school. His experience at the meeting convinced him to try his hand at research. He found a research project that ultimately led him to apply for graduate programs, and this year he was looking at schools at the fair.

On the morning of the second day, keynote speaker Rick Knabb, director of the National Hurricane Center in Miami, Florida, spoke about career opportunities in government. He highlighted the skills important for advancing a career in meteorology, including technical skills, communication skills, and learning skills. He also mentioned the importance of being willing and able to work with others. During subsequent breakout sessions, panelists emphasized the benefits of training in the physical sciences or engineering. They encouraged students interested in the field of meteorology to take on research experiences as undergraduates.

The conference wrapped up with a vibrant poster session that was many students' first experience presenting research. AMS really demonstrated its commitment to the next generation of scientists and managers by supporting and participating in such a great gathering of students embarking on exciting career paths. //

About AMS

The American Meteorological Society promotes the advancement of the atmospheric and related sciences for the benefit of society.

Founded in 1919, AMS has a membership of about 14,000 professionals, students, and weather enthusiasts. AMS publishes 11 atmospheric and related oceanic and hydrologic science journals in print and online, sponsors a dozen conferences annually, and offers numerous programs and services.

In late 2013 AMS became a Member Society of the American Institute of Physics, home to the Society of Physics Students. This means that undergraduate SPS members can now receive free membership in AMS when they join or renew their membership. For details, see www.spsnational.org/about/benefits.htm.

NEXT UP

The next AMS meeting and associated student conference will take place January 4–8, 2015, in Phoenix, Arizona. Watch the AMS website for more information, www.ametsoc.org/meet/meetinfo.html.

The Applied Physics of Gasoline Engines, Part 1

MECHANICS AND THERMODYNAMICS

by Dwight E. Neuenschwander, Southern Nazarene University. Images courtesy of the author.

Throughout the past two decades I have conducted, in various courses, a hands-on exercise called the "engine cadaver lab."[1] Unlike the biologists, we put our cadavers back together, because we dissect lawn mower motors (Fig. 1)! The experience has consistently been a lot of fun. In addition to new physics insights, most students report emerging from it with an enhanced appreciation for their automobiles and a deep admiration for the clever minds that envisioned how all of these systems, made of inanimate matter, could be orchestrated to give the machine a life of its own.

With occasional exceptions, most students enter this exercise with little idea of what goes on inside an automobile engine. (Those who have mechanical experience are given roles as teaching assistants.) Most students' interactions with an automobile consist of putting gas in the tank and aiming the machine down the road. This nonchalance suggests that in our society we take our machines for granted, content to not understand how they work even though we grow increasingly dependent on them. Such lack of curiosity is utterly foreign, I trust, among physics students.

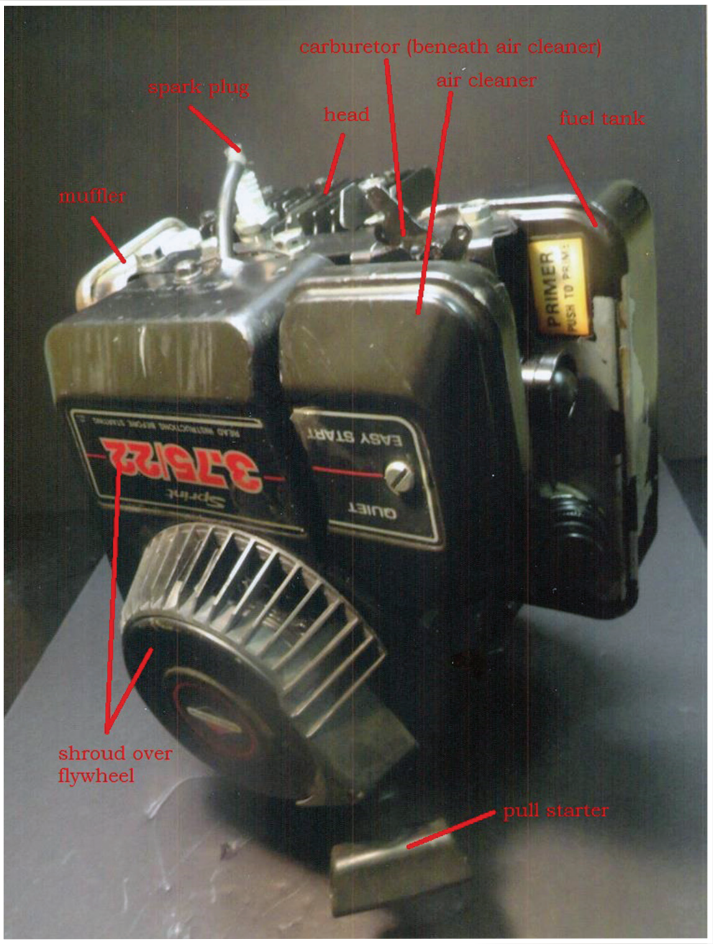
exploring internal-combustion engines

In this article we examine the inner workings of the gasoline-fueled four-stroke internal-combustion engine that powers most cars, light trucks, motorcycles, light aircraft, and lawn mowers. The basic design dates from around 1890; its longevity indicates its robustness. Since then four-stroke gasoline engines have been made far more efficient and powerful, growing increasingly complicated as we place ever more, often conflicting, demands on them. But the basic anatomy of a Ferrari V12 engine shares much in common with that of a two-cylinder 1899 Fiat. The basic ideas behind the engine can be grasped through a study of the simplest of engines, the one-cylinder, air-cooled, valves-in-block lawn mower motor that features magneto ignition, pull start, and splash lubrication. Variations on this engine have been built for decades by marques such as Briggs & Stratton, Jacobsen, and Tecumseh. By virtue of their simplicity, these no-frills machines offer into all engines a level of insight similar in depth to that offered into all atoms by the hydrogen atom.[2]

With the mower motor for illustration, in this, the first of a two-part series, we outline the basic anatomy of the four-stroke gasoline engine and its lubrication and cooling. We also work out the thermodynamic upper limit on a four-stroke gasoline engine's efficiency. Along the way we note differences between the one-cylinder mower motor and more complicated four-stroke engines.

Part 2, to be published in the next issue of the magazine, will discuss the motor's air and fuel systems, as well as the ignition system, with its magneto, RLC circuit, and spark plug. These technical notes will be followed by observations about our relationships with our vehicles. These include appreciating and respecting these marvelous machines, while simultaneously being aware of the high

FIG. 1: A 3.75 hp, one-cylinder Briggs & Stratton engine.



price paid by society and by the environment to support their sheer numbers. We will close with some glimpses into relationships between famous physicists and their motorized companions.

ENGINE ANATOMY AND THE FOUR-STROKE CYCLE

An engine receives energy by heat transfer from a source at one or more high temperatures, converts some of the heat input into work, and exhausts the remaining energy as heat to the surroundings at low temperature.[3] In a gasoline engine the heat input comes from the periodic explosive burning of a shot of vaporized gasoline. The energy of each explosion shoves a *piston* down a *cylinder* (parts and process names are italicized when first mentioned). Instead of being shot out of the cylinder and across the garage, the piston's linear motion is converted into angular momentum by a *crankshaft.* To see a crankshaft in operation, picture riding a bicycle; the up-and-down linear action of your knees gets converted into rotation by the pedals, which are offset from the sprocket's rotation axis.

The main body of the engine is an exoskeleton called the *block*, a wonderfully intricate casting that supports rotating or sliding parts on critical surfaces machined to within a thousandth of an inch (Fig. 2). The dominant feature in the block is one or more large holes, the aforementioned cylinders. The mower motor we are dissecting here has one cylinder. The piston is linked to the crankshaft by a *connecting rod* (Fig. 3; in the bicycle analogy your lower leg serves as the connecting rod). The rod's upper end fastens inside the piston by a *wrist pin,* from which the rod swings to and fro like a pendulum. The rod's lower end has a detachable cap that fits snugly around the *crankpin,* the offset part of the crankshaft. Since the piston, connecting rod, and crankpin masses lie off the crankshaft spin axis, counterweights are machined into the crankshaft to balance the entire assembly about that axis. The crankshaft is held in place by *main bearings* in the block beneath the cylinder.

In the discussion to follow, we envision the cylinder oriented vertically and the crankshaft horizontal beneath the cylinder. Many mowers mount the engine with the cylinder horizontal and the crankshaft vertical to spin a blade horizontally. Most cars have four or more cylinders with the crankshaft sitting horizontally. The cylinders may sit vertically in a straight line (e.g., a 1954 Pontiac "straight-8"), they may be inclined in two banks to form a V (e.g., a Corvette "V8"), or they may lie horizontally or "flat" to lower the center of gravity (e.g., the Porsche 911 "flat-6").

The motion of the piston from its lowest point in the cylinder (*bottom dead center*, or BDC) to its highest point (*top dead center*, or TDC), or the reverse from TDC to BDC, is one *stroke* of the engine's operation. During each stroke the crankshaft turns half a revolution. The term "stroke" also refers to the distance between TDC and BDC. The diameter of the cylinder is called the *bore.* The volume defined by stroke and bore, the volume swept out by the piston's upper surface in one stroke, is that cylinder's *displacement*. The displacement of all an engine's cylinders offers one measure of its performance capability. If you have a "427 Corvette," the displacement of its eight cylinders equals 427 cubic inches. Engine designers who use metric units describe displacement in liters or cubic centimeters.

The energy density of gasoline is about 45 megajoules per kilogram.[4] The more gasoline taken into the engine per cycle of its operation, the more power it can produce. Among engines of the same design, power output scales with displacement. The first-generation gasoline-powered cars built in the 1890s produced about the same amount of power as our mower motor, and the cars they powered performed about the same as one of today's small riding lawn mowers. The entrants in the world's first motor race in 1895, from Paris to Bordeaux and back, included 15 gasoline-fueled motor cars (specialized racing cars did not yet exist), one electric car, and six steamers. The race was won by Emile

FIG. 2: The engine's empty crankcase, showing the connecting rod protruding from the cylinder, the crankshaft (left) and camshaft (right) bearings, and the valve lifter guides (upper right).

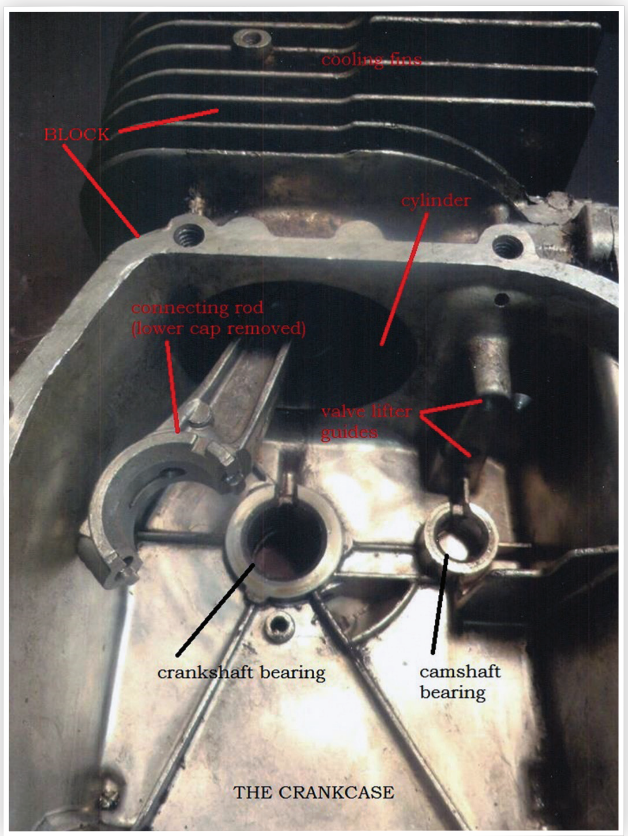
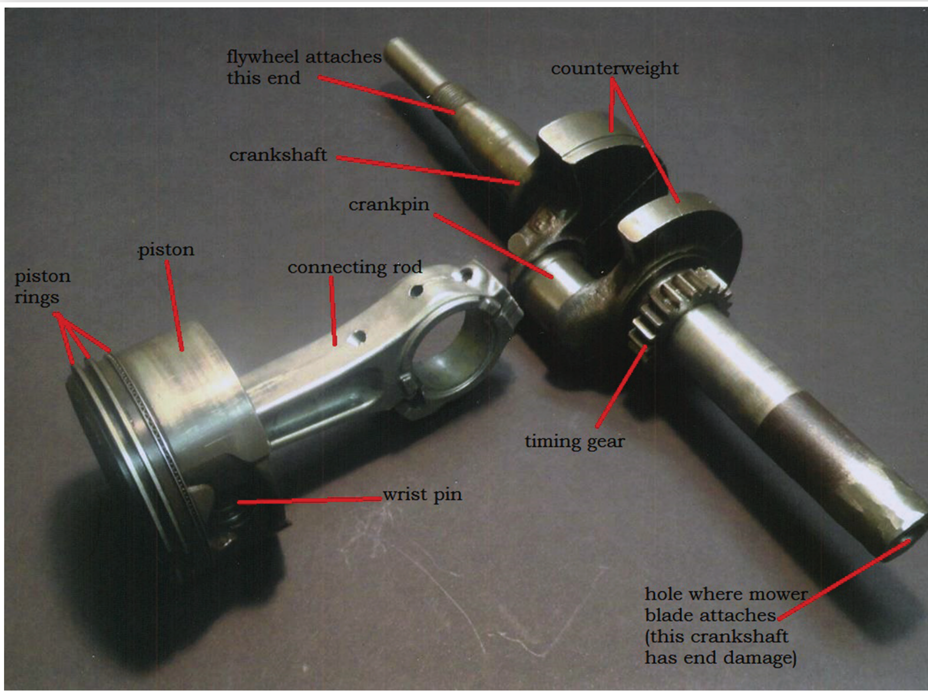


FIG. 3: The cranskshaft and the piston-connecting rod assembly. The lower end of the connecting rod fits around the crankpin.



Levassor in his Panhard-Levassor with a 1200 cc (73 cu. in.) Daimler engine producing 3.5 horsepower (1 hp = 745.7 W). Levassor drove the 723-mile course essentially nonstop at an average speed of 14.9 miles per hour.[5] A lawn mower motor designed for walk-behind mowers produces about 3.75 hp from a displacement of about 12 cu. in.[6] Its century-old design is still manufactured today because, for its intended applications, the dominant virtue is simplicity.

To increase power the displacements of first-generation designs were quickly scaled up. The first Grand Prix for specialized racing cars took place at Le Mans, France, in 1906. The engine of the Renault that won displaced 12.8 liters (781 cu. in.), developed 105 hp, and carried the car an average speed of 62.88 mph, which means it was going about 100 mph on the straights. But a revolution in efficiency was just around the corner, where power per displacement would become as critical as displacement itself. The Peugeot that won the 1912 French Grand Prix displaced only 7.6 liters, racing against the huge 14-liter Fiats and 15-liter Lorraine-Dietrichs.[7] Some of the design changes that resulted in higher power-to-displacement ratios will be described below, as we examine the simple mower motor design that echoes the first-generation automotive engines.

On top of the cylinder sits the *head* (Fig. 4), with a *head gasket* placed between the block and head to form a tight seal when the head bolts are torqued down (to about 12 ft-lbs). The space between the piston at TDC and the head's indented shape above the cylinder forms the *combustion chamber.* Putting a spark to a volatile mixture of gasoline and air in the combustion chamber shoots the piston down the cylinder to spin the crankshaft by virtue of the connecting rod. How does the air-fuel mixture get into the cylinder, how are the combustion products evacuated from it, and how is a spark delivered at the crucial moment?

Our mower motor has two valves that offer passage into the cylinder, an *intake valve* and an *exhaust valve*. Consider the motor running at speed (engine speed is measured in *rpm*, the angular velocity of the crankshaft in revolutions per minute). Let us begin at a moment when both valves are closed and the piston sits instantaneously at TDC. This state marks the beginning of the engine's four-stroke cycle of operation: the *intake, compression, power,* and *exhaust* strokes.

(1) *Intake stroke:* As the crankshaft turns, the piston moves down and the intake valve opens. The pressure difference between the cylinder's interior and the outside air pushes the air-fuel mixture into the cylinder as the piston descends. As the piston reaches BDC the intake valve closes.

(2) *Compression stroke:* The piston moves back up with both valves closed, compressing the air-fuel mixture. Let V_2 be the volume of the gas inside the cylinder when the piston is located at BDC, and let V_1 denote the volume with the piston at TDC. The *compression ratio* V_2/V_1 offers another measure of an engine's performance. Engines designed to operate for a long time, such as mower motors, need to run at low stress and typically have a compression ratio of around 4 or 5; competition engines may have compression ratios of 10 or higher. Since the compression stroke happens quickly, during the stroke negligible heat is conducted to the outside world (an "adiabatic" process), and the temperature of the air-fuel mixture rises.

(3) *Power stroke*: When the piston reaches TDC at the end of the compression stroke, the *spark plug* fires, igniting the air-fuel mixture. The flame sweeps explosively through the combustion chamber, raising the temperature and doing work as it pushes the piston emphatically down in the power stroke. Although the ignition of the fuel releases enormous internal energy into the cylinder, negligible energy escapes as heat conduction during the rapid power stroke, so this stroke is also adiabatic.

(4) *Exhaust stroke*: As the piston moves up from BDC, the exhaust valve opens, and the piston shoves the exhaust gases out of

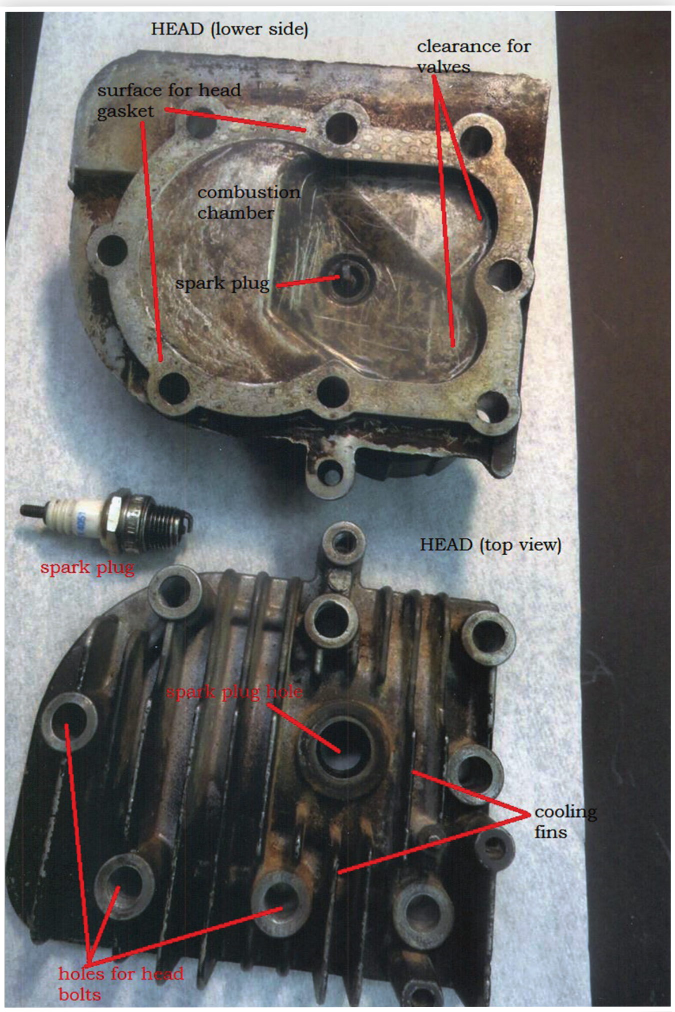
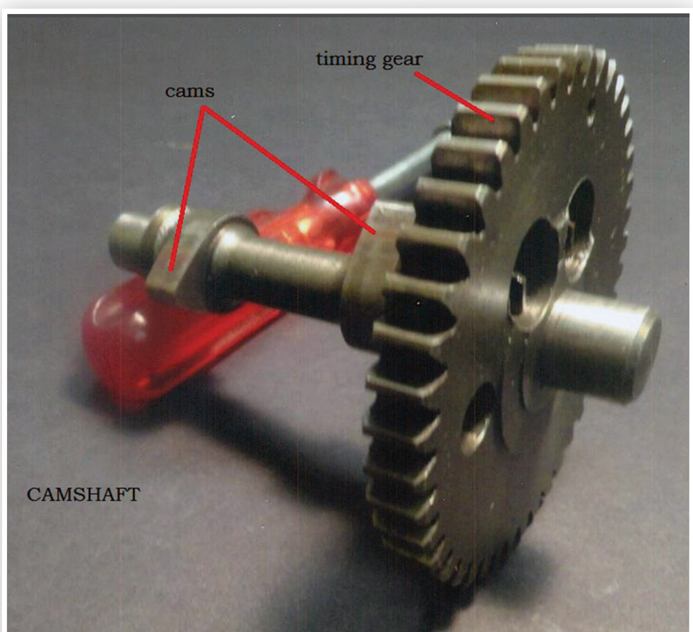


FIG. 4 (LEFT): The cylinder head's lower surface (upper image, showing the combustion chamber and the electrode end of the spark plug), and the cylinder head's exterior surface (lower image) with cooling fins.

FIG. 5 (BELOW): The camshaft.



the cylinder. They flow out through *muffler* (with baffles to dampen noise) into the atmosphere. The engine exchanges heat with its surroundings during the exhaust and intake strokes, expelling the hot exhaust gases and drawing in the relatively cool intake gases. At the end of the exhaust stroke the piston has returned to TDC with both valves closed and the cylinder is ready to repeat the four-stroke cycle.

What opens and closes the valves and provides spark at the right moment? Parallel to the crankshaft rides the *camshaft,* which features lobes, or cams (Fig. 5). Through a pair of meshed *timing gears*, one on the end of each shaft, the spinning crankshaft turns the camshaft. In our mower motor the crankshaft gear has 20 teeth and the gear on the camshaft carries 40 teeth, spinning the camshaft at half the angular velocity of the crankshaft. Perpendicular to the camshaft and riding on the cams are *valve lifters*, and the valves themselves stand on top of the lifters. As the camshaft spins the cam raises a lifter and a valve, opening a passage into the combustion chamber. When the cam rolls out from underneath the lifter, *valve springs* snap the valve closed again (Fig. 6). On the camshaft of our one-cylinder motor with two valves, the cams are oriented 90 degrees apart because the intake and exhaust valves open on adjacent strokes. One stroke is half a revolution of the crankshaft, and thus a quarter revolution of the camshaft. Both timing gears have marks on them that must be aligned so the valves will open at the correct times during the cycle (Fig. 7).

In the four-stroke cycle a one-cylinder engine delivers one power stroke for every two crankshaft revolutions.[8] With two cylinders, a power stroke occurs every revolution. Four cylinders produce a power stroke every half revolution. Eight cylinders provide one power stroke every quarter revolution, and so on. Increasing the number of cylinders makes the machine more complicated, but the payoff is the power being applied more uniformly. Most cars have either four, six, or eight cylinders; some have 10 (e.g., the Dodge Viper), a few have 12 (e.g., most Ferraris and Lamborghinis, and Lincolns and Auburns from the 1930s), and a few have 16 (e.g., the 1932 Cadillac, the 1933 Marmon, and the contemporary Bugatti Veyron).

Attached to the external end of the crankshaft on the end opposite the timing gear we find the *flywheel* (Fig. 8). The most important job for the flywheel in any engine is to provide a large moment of inertia to carry the rotation of the crankshaft, with its rod and piston assembly, as smoothly as possible between power strokes. In mower motors the flywheel also has a role in the cooling and ignition systems, as will be described.

Volumetric efficiency, the ratio of the volume of air-fuel vapor brought into the engine during the intake stroke to the cylinder's displacement, offers another descriptor of engine performance. In casual jargon it measures how well the engine "breathes." Moving air has inertia, and with turbulence the force of air resistance goes as air velocity squared. Valve size and placement, as well as the smoothness of internal surfaces through which gases flow, significantly influence engine performance. Our mower motor engine is a "flathead" or "L-head" design, so called because the valves come up through the block parallel to the cylinder, and thus the combustion chamber must lie above not only the piston, but also over a region in the head to one side of the cylinder, where the valves pop up (Fig. 8). Through the 1940s most automobile engines were of the flathead design. Around 1950 manufacturers began

FIG. 6: The valve springs, with the stems of the valves visible inside the coils. The exhaust valve lies on the left, with the exhaust port above it, and the intake valve lies on the right.

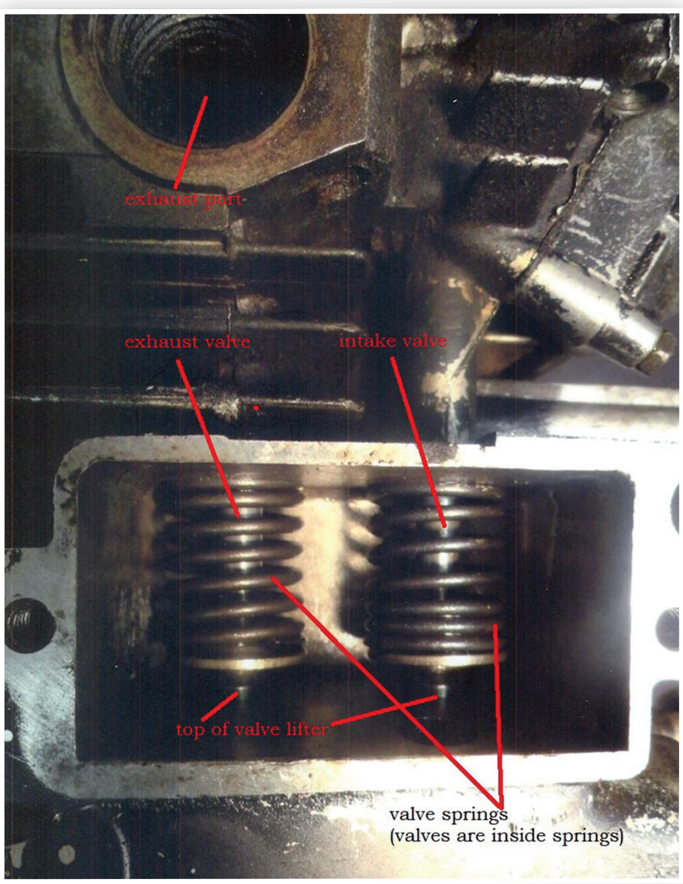
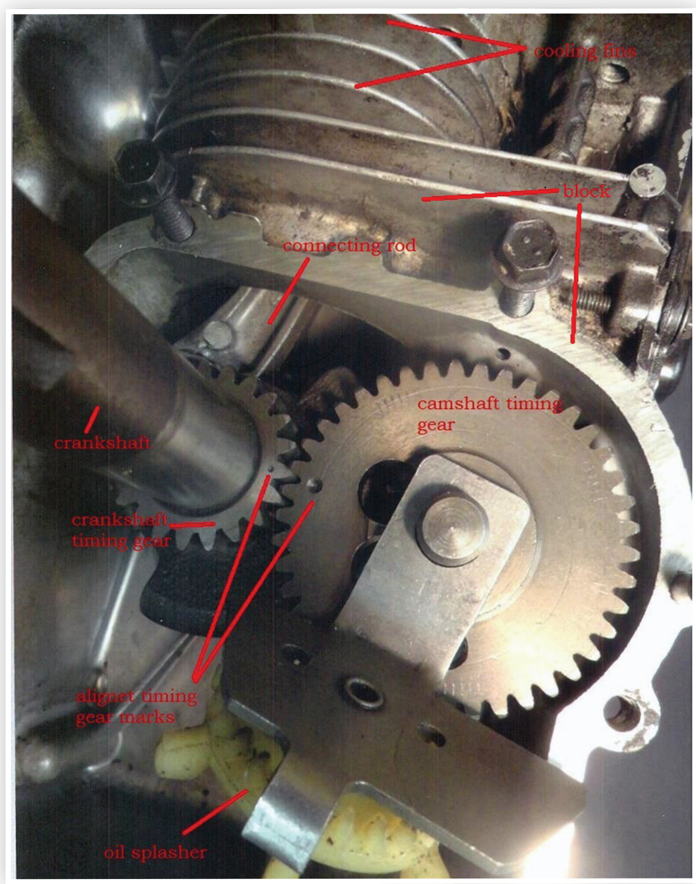


FIG. 7: The alignment of the timing marks on the crankshaft timing gear (left) and the camshaft timing gear (right). Note the oil slinger, the plastic paddle wheel driven by the camshaft timing gear.



producing *overhead valve* (ohv) designs. Relocating the valves above the piston increases flow and volumetric efficiencies because the air-fuel mixture enters the combustion chamber directly above the piston instead of off to the side. With valves now having to be pushed down from above and the crankshaft and timing gears still coupled by their timing gears, long *pushrods* are placed above the valve lifters, and *rocker arms,* which rock back and forth on a horizontal shaft like a teeter-totter, now sit on top of the head. The cam lifts the pushrod, which raises one side of the rocker arm, and the other side of the rocker arm pushes down on the valve to open it. Springs beneath the rocker arms close the valve when the cam rolls out from under the lifter and pushrod.

If the pushrods and rocker arms could be eliminated, and the camshaft positioned on the upper side of the head, the mechanical energy consumed by the engine moving its internal parts would be greatly reduced. This is accomplished in *overhead camshaft* (ohc) engines. (The "DOHC" logo seen on some car badges denotes double overhead cams, one for the bank of intake valves and another for the exhaust valves.) With the crankshaft and camshaft too far apart to be coupled by timing gears, the crankshaft turns the camshaft by a *timing belt* or *timing chain*. Timing belts are made of wire-reinforced synthetic rubber and must be changed at regular intervals, typically around 90,000 miles. If the timing belt breaks, the opening of the valves will no longer be correlated to piston location. A valve colliding with a piston results in an expensive noise!

To further increase volumetric efficiency some engines have four valves per cylinder, two intake and two exhaust. Adding a *supercharger* (or "blower") dramatically enhances volumetric efficiency. A supercharger is a compressor, driven by a belt operated from a crankshaft pulley, that forces more air into the engine per cycle than would be possible by atmospheric aspiration alone. Superchargers were in use on Grand Prix racing cars by the early 1920s. A *turbocharger* uses the flow of exhaust gases to drive a small compressor for the same purpose.

LUBRICATION AND COOLING

The inside of our humble mower motor operating at a modest 800 rpm is a lively environment. The piston travels between TDC and BDC 1,600 times a minute; the crankshaft and camshaft spin in their bearings at 800 and 400 rpm, respectively, while engaging each other through whirring meshed gears; cam lobes open valves which are snapped closed by springs; and gasoline vapor explodes 200 times a minute. Some sport motorcycles run up to 14,000 rpm or more! To survive for more than a few seconds, this show must have adequate lubrication that keeps the metal surfaces from fusing together as they spin or slide past one another. Excess heat must be removed to maintain constant temperature.

In our mower motor the oil (1 quart of 30W) is splashed over the moving parts within the *crankcase* by a *slinger* (Fig. 7), a gear meshed with the camshaft timing gear and sporting little paddle wheels on its perimeter. Though primitive, it provides adequate lubrication even in go-kart racing, in which engines experience far more stress than they do when mowing lawns. In larger engines an oil pump driven by the camshaft delivers oil directly to bearings through passages in the block and head. The oil not only provides lubrication to prevent the moving pieces of metal from welding themselves together, but it also helps carry heat away. Oil is blocked from creeping past the piston into the combustion chamber (where it could foul the plug and produce blue smoke), and the air-fuel mixture is prevented from squeezing past the piston to dilute the oil in the crankcase by a set of *piston rings*, springy alloy circles (with a small gap for installation and thermal expansion) that ride in grooves near the top of the piston (Fig. 2).

The lawn mower motor is an *air-cooled* engine (Figs. 2, 4). The head and block, made of aluminum that efficiently conducts heat, have cast into them *cooling fins* that provide a large surface area for exchanging heat with the ambient air. The flywheel on the mower motor doubles as a

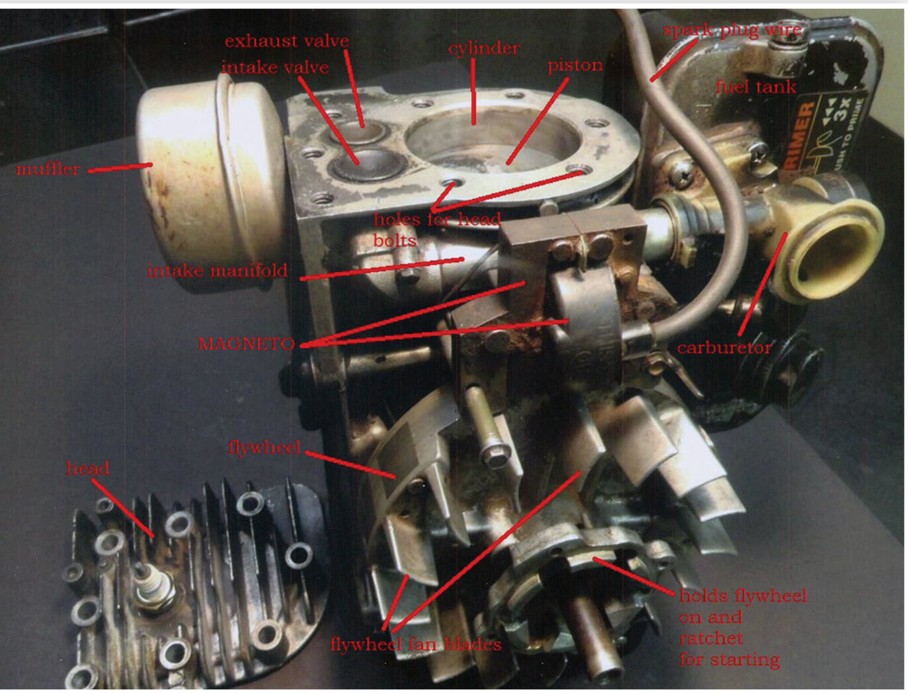


FIG. 8 (ABOVE): The flywheel, the valves, and piston with the head removed. The carburetor sits on the fuel tank to the right. (The air cleaner has been removed.) Note the intake manifold that carries air-fuel mixture from the carburetor to the intake valve. The intake valve is the larger of the two valves.

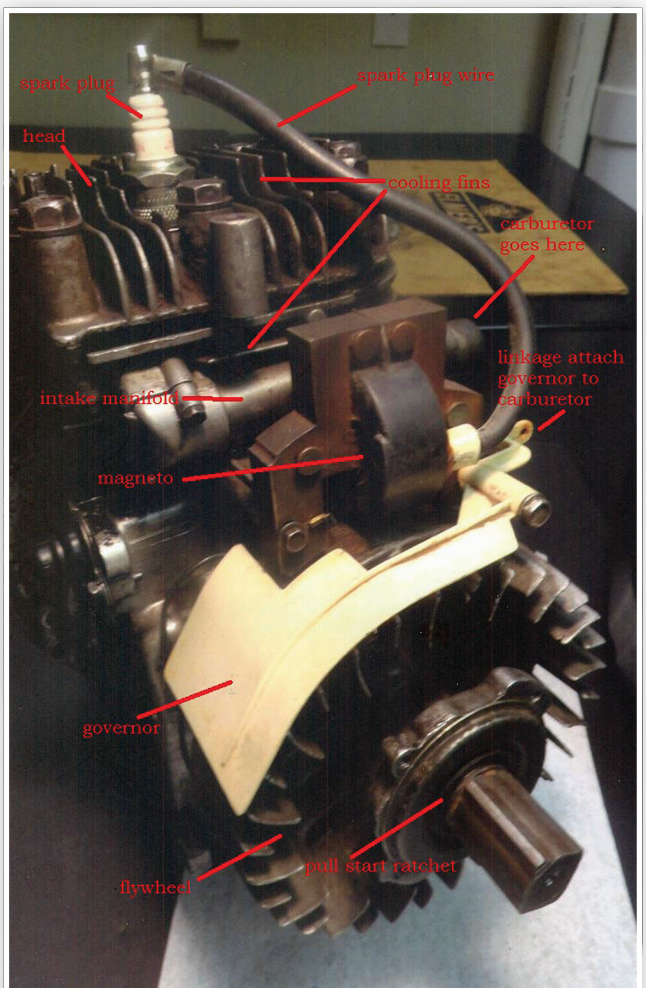


FIG. 9 (RIGHT): The governor.

cooling fan. Surrounded by a sheet metal *shroud* (Fig. 1) with a wire mesh that allows air to be pulled inside, the flywheel has vanes cast into it that, when spinning, circulate air over the cooling fins on the block (Fig. 9). A plastic blade called a *governor* (Fig. 9), connected by a spring to the throttle, lives between the flywheel perimeter and shroud, where it pivots in response to changes in air pressure coming from changes in engine speed due to variable engine load. The simple governor helps maintain a constant engine speed for a given throttle setting, and prevents the operator from accidentally over-revving the engine.

Most automotive engines are *water-cooled*; the block and head have passages called *water jackets* cast into them through which coolant circulates. From the engine the coolant enters the *radiator,* where it flows through long tubes surrounded by cooling fins before returning to the engine. In addition to the car's forward motion, a *fan*, driven either by a *fan belt* or a *serpentine belt* or an electric motor, helps pull air through the radiator. The coolant passes between engine and radiator through upper and lower *radiator hoses*, and is pushed along by a *water pump* typically driven by the fan belt or timing belt. The coolant is typically 50 percent distilled water and 50 percent ethylene glycol; the lower freezing point of this mixture, compared to that of pure water, prevents cracked blocks in cold weather (since water expands upon freezing), and the mixture provides corrosion resistance, as well.

THERMODYNAMIC EFFICIENCY

In the context of engines, "efficiency" means the ratio of work performed (what you want) to the heat energy input (what it costs). The second law of thermodynamics says the efficiency can never reach unity, raising the question of how large it *can* be, limited only by the second law. Steam engines receive their energy input from superheated steam injected at temperature T_H into the cylinder. They perform work and exhaust spent steam to the ambient air at temperature T_C. The Carnot cycle was invented by Sadi Carnot (1796-1832) in 1824 to conceptualize an idealized version of the steam engine. With it one finds the maximum efficiency attainable in principle by a two-temperature engine. In each cycle the Carnot engine isothermally receives energy as heat from a hot reservoir at absolute temperature T_H, performs work, and dumps heat isothermally to a cold reservoir at temperature T_C. The two isothermal heat exchanges are connected by adiabatic processes. A common general physics exercise asks one to show the Carnot engine efficiency to be $1 - T_C/T_H$.

A conceptual cycle called the *Otto cycle* (ca. 1880) performs the same theoretical service for the four-stroke gasoline engine. This idealized cycle is named in honor of Nikolaus Otto (1832-1891), who built the first commercially successful four-stroke engines. Like the Carnot cycle, the Otto cycle is thermodynamically reversible (i.e., departures from equilibrium are negligible), and ideal gas serves as the working fluid. But the steps in the cycle differ from those of Carnot. Let us think them through and map their changes of state on a pressure-volume diagram (Fig. 10), starting with the power stroke, which we break into two parts. Let us start with an event, the firing of the spark plug at point *a* on the *PV* diagram, which occurs at volume V_1 with the piston at TDC. This event raises the temperature and pressure from that of point *a* to that of point *b* on the *PV* diagram, while the volume remains at V_1. The rest of the power stroke is modeled by the piston being forced down adiabatically to BDC (*b* to *c*) as the volume of the gases increases from V_1 to V_2. The exhaust stroke then expels the hot exhaust gases as the piston goes from BDC to TDC, and the intake stroke brings in the cooler air-fuel mixture as the piston returns to BDC. In *PV* space the net effect of the exhaust and intake strokes is to drop the temperature and pressure while at constant volume V_2, taking the cycle from *c* to *d*. The compression stroke adiabatically decreases the volume from V_2 to V_1, raising the temperature and pressure and returning the cycle's representation on the *PV* diagram from *d* back to point *a*.

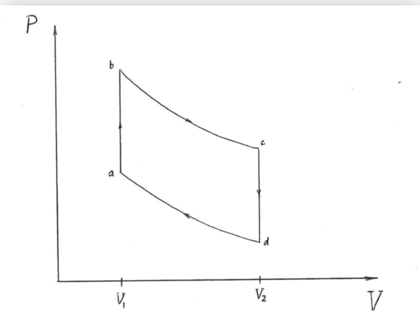


FIG. 10: The PV diagram for the Otto cycle.

The efficiency of this cycle, as you may have demonstrated in introductory thermodynamics, is $1 - (V_2/V_1)^{1-\gamma}$. V_2/V_1 is the compression ratio and γ denotes the ratio of the specific heat at constant pressure to that at constant volume. For air, $\gamma \approx 1.4$. Mower engines have a compression ratio of about 5, corresponding to a theoretical upper limit efficiency of 0.47. In contrast, a competition engine with a compression ratio of 15 has an upper limit efficiency of 0.66. A real engine is less efficient than its ideal upper limit because it has not only dissipative influences such as friction, but also heat exchanges beyond the requirements of the second law, work losses in moving its internal masses, and so on, not to mention rolling and air resistance working against the machine's motion. Typically, a car does well if a quarter of the power output measured at the flywheel is converted into kinetic energy of the entire car's center of mass.[9]

Now that we are entering mowing season, show your mower motor respect by treating it to an oil change and a washed or new air filter, scrub the crud off the cooling fins, and interact with your machine with engaged appreciation!

In Part 2 we will discuss how the fuel is mixed with air before combustion and how a spark is supplied to that mixture at the crucial moment between the compression and power strokes. That article will also include a few notes on maintenance, and we will glimpse some famous historical physicists interacting with their cars and motorcycles. //

ACKNOWLEDGMENT

Many thanks to Devin Powell for his considerate editing of this article.

REFERENCES AND NOTES

[1] The engine cadaver lab, with photos of students working on the motors, is described in "Motorcycle Maintenance and Physics Appreciation," *Radiations* (Fall 2007), pp. 5-11. A website that has interactive simulations of all kinds of motors may be found at http://www.animatedengines.com/index.html.
[2] The point that we can understand atoms at all thanks to the existence of the simplest one, hydrogen, is made elegantly by John Rigden in *Hydrogen, The Essential Element* (Harvard University Press, Cambridge, MA, 2002).
[3] The work output necessarily being less than the heat input is a statement of the second law of thermodynamics. See "The Second Law of Thermodynamics and the Non-Conservation of Entropy," *SPS Newsletter* (June 1998), pp. 9-13.
[4] Glenn Elert, ed., *The Physics Factbook*, http://hypertextbook.com/facts/2003/ArthurGolnik.shtml.
[5] Brad King, *All Color Book of Racing Cars* (Crescent Books, New York, NY, 1972), pp. 5-7.
[6] The displacements of single-cylinder Brigg & Stratton motors range from 5 to 32 cubic inches; this and other mower motor specifications from Paul Dempsey, *How to Repair Briggs & Stratton Engines* (Tab Books, Blue Summit, PA, 1978), p. 9.
[7] To go faster the displacement of early racing cars grew ever larger. The 1910 Fiat S79 carried what may be the largest 4-cylinder engine ever, at 28.3 liters from a dirigible, and achieved 132.37 mph in 1913. The famous "Blitzen Benz" with a 21.5 liter engine achieved more than 140 mph in 1911; King, ref. 5, pp. 5-7, 22.
[8] Two-stroke engines use the piston as a valve, with openings, or ports, machined into the sides of the cylinder, the intake and exhaust on opposite sides. To lubricate the piston-as-valve, oil must be pre-mixed with the gasoline. These engines are smoky and noisy but crank out a lot of power for their size, with one power stroke per revolution. Diesel engines operate on four strokes without a spark plug. The compression ratio is sufficiently high that the temperature reaches the less volatile diesel fuel's flash temperature at the end of the compression stroke.
[9] Colin Campbell, *The Sports Car Engine: Its Tuning and Modification* (Robert Bentley Inc., Cambridge, MA, 1965, an oldie but goodie, loaded with applied physics and written with humor), pp. 4-7.

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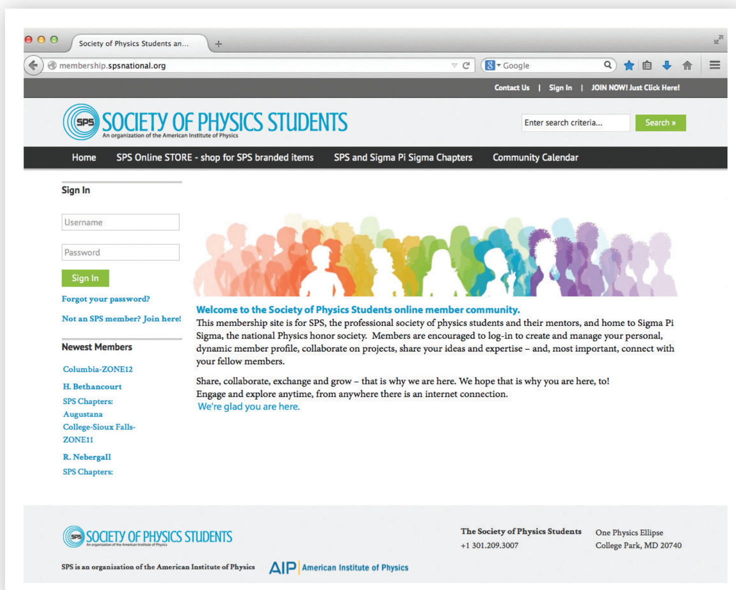

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