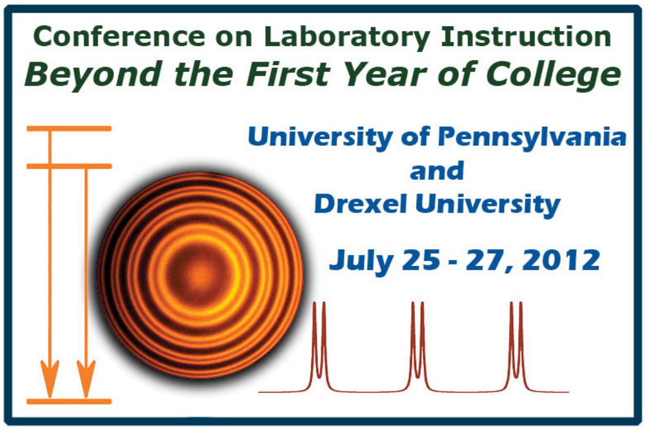
BEYOND THE FIRST YEAR OF COLLEGE

July 25–27, 2012

University of Pennsylvania and Drexel University

www.advlabs.aapt.org



This conference is an "act of community," a vision shared by many people and brought to reality by the members of this organizing committee, by many of our conference participants, and with the help of the vendors who share our vision. The idea of community is key here, underlying the degree to which this conference can impact your offerings. Take time to enjoy each other's company, and plan on sustaining the conversation even after the conference itself has ended. In addition to helping you to implement specific labs that update your curriculum, it is important to take this opportunity for broader considerations (in break-out discussion sessions and via panel discussions and also following presentations by Invited Speakers) about the curricular goals of instructional labs, tricks for introducing more lab instruction into your department's program, simple ways to produce a more cohesive, integrated curriculum, how to rate your options, etc. As a community of lab instructors, we can work together to make one another's lives simpler, better, and more productive.

Gabe

Organizing Committee

Gabe Spalding (chair), Illinois Wesleyan University

Randy Peterson, The University of the South

Joe Trout, Drexel University

Jane Horwitz, University of Pennsylvania

Charlie Johnson, University of Pennsylvania

David Van Baak, Calvin College

Paul Dolan, Northeastern Illinois University

Lowell McCann, University of Wisconsin-River Falls

Mark Masters, Indiana University - Purdue University Fort Wayne

Steve Wonnell, Johns Hopkins University

John Essick, Reed College

Elizabeth George, Wittenberg University

Eric Ayars, California State University, Chico

Robert DeSerio, University of Florida

Heather Lewandoski, University of Colorado

Ernie Behringer, Eastern Michigan University

Barbara Hoeling, Cal Poly Ponoma

Nathan Frank, Augustana College

David Jackson, Dickinson College

Randy Tagg, University of Colorado Denver

Jeremiah Williams, Wittenberg University

Ben Zwickl, University of Colorado

CONTENTS

Wednesday, July 25

OPENING REMARKS

8:00 - 8:10 a.m.
Auditorium A1, David Rittenhouse Labs

Gabe Spalding (Illinois Wesleyan University)

SESSION I

Invited speakers — 8:10 - 9:25 a.m.
Auditorium A1, David Rittenhouse Labs

- Overview of challenges and ALPhA's role, Gabe Spalding
- Amplifying practical knowledge in physics, Randy Tagg
- Lab homework in ALL courses!, Marty Johnston

SESSION II

"Curricular Models: Increasing the amount of lab instruction" — 9:30 - 10:30 a.m.
Auditorium A1, David Rittenhouse Labs
Gabe Spalding, presiding

Panel: Gary Chottiner, Bret Crawford, David Bailey

SESSION III

Invited Speakers — 10:30 a.m. - 11:45 a.m.
Auditorium A1, David Rittenhouse Labs

- Teaching optics with a focus on innovation, Doug Martin and Shannon O'Leary
- Integrating the laboratory and classroom in quantum mechanics, Mark Beck
- An alternative to the traditional Modern Physics course with its historically entrenched labs, Walter Smith

Box lunches — 12:00 - 12:45 p.m.
Field House Lobby

SESSION IV

"Case Study: Instructional Labs in Quantum (at multiple levels)" — 12:45 - 1:45 p.m.
Auditorium A1, David Rittenhouse Labs
Mark Beck, presiding

Panel: David Jackson, David Branning, Enrique 'Kiko' Galvez

SESSION V

"Short Workshops" — David Rittenhouse Labs/Disque Hall

2:15 - 2:55 p.m.
3:10 - 3:50 p.m.
4:05 - 4:45 p.m.

SESSION VI

"Short Workshops"	5:15 - 5:55 p.m. 6:10 - 6:50 p.m. 7:05 - 7:45 p.m.	David Rittenhouse Labs/Disque Hall

Dinner at City Tap House, 3925 Walnut St. 8:00 - 9:30 p.m.
Sponsored in part by PASCO Scientific

Set up posters and equipment for Thursday 9:30 - 11:00 p.m.
David Rittenhouse Labs

Thursday, July 26

SESSION VII

Invited Speakers 8:00 - 9:15 a.m.
Auditorium A1, David Rittenhouse Labs

- Assessment - E-CLASS, Heather Lewandowski
- Teaching uncertainty, Saalih Allie
- Teaching a basic experimental skill set (control, acquisition, and analysis) in a physics context, John Essick

SESSION VIII

9:30 - 10:45 a.m.
POSTER SESSION I 3rd Floor Atrium, Bossone Research Center, Drexel
Includes coffee break (sponsored in part by Klinger) and textbook giveaway

SESSION IX

"Goals of Labs / Taxonomy of Experimental Skills" 11:00 a.m. - 12:00 p.m.
Auditorium A1, David Rittenhouse Labs

Randy Tagg, presiding

Panel: Ben Zwickl, David Haase, Eric Ayars

Box lunches at Franklin Field football stadium 12:15 - 1:00 p.m.
Franklin Field, Penn

SESSION X

"Short Workshops" 1:30 - 2:10 p.m. David Rittenhouse Labs/Disque Hall
2:25 - 3:05 p.m.
3:20 - 4:00 p.m.

SESSION XI

"Short Workshops" 4:30 - 5:10 p.m. David Rittenhouse Labs/Disque Hall
5:25 - 6:05 p.m.
6:20 - 7:00 p.m.

SESSION XII

7:15 - 8:30 p.m.
POSTER SESSION II 3rd Floor Atrium, Bossone Research Center, Drexel
Includes heavy hors d'oeuvres mixer

SESSION XIII

"PIRA's Advanced Demo Show" 8:45 - 9:45 p.m.
Auditorium A1, David Rittenhouse Labs

Poster and equipment removal 9:45 - 10:50 p.m.

Friday, July 27

SESSION XIV

Invited Speaker 8:00 - 8:35 a.m.
Auditorium A1, David Rittenhouse Labs

- The ALPhA Immersion program, Lowell McCann

SESSION XV

“Breakout Discussions I” 8:45 - 9:35 a.m.
David Rittenhouse Labs, Disque Hall, and Stratton Hall

- “Methods Courses” vs. “Design Courses:” a false dichotomy? — Eric Black (CalTech) and Gary Chottiner (Case Western), presiding (Disque 919, Drexel)
- Teaching Experimental Uncertainty — Saalih Allie (Cape Town), presiding (Disque 109, Drexel)
- Instruction in Writing & Revision in the instructional lab — Mark Masters (IPFW) and Elizabeth George (Wittenberg Univ.), presiding (Stratton 101, Drexel)
- Sophomore-level physics & instructional labs — David Van Baak (Calvin College), presiding (Disque 614, Drexel)
- Updating BFY instructional labs in Electronics — Mac Stetzer (Maine) and Everett Ramer (Pittsburgh), presiding (Stratton 201, Drexel)
- Bio-related instructional labs in Physics — Jon Erickson (Washington & Lee), presiding (DRL Room 3C2, Penn)
- BFY instructional labs in Optics & Lasers — Shannon O’Leary (Lewis & Clark), presiding (DRL Room 3C4, Penn)
- Photon-based instructional labs in Quantum Mechanics — Andy Dawes (Pacific Univ.) and Mark Beck (Whitman College), presiding (DRL Room 3C6, Penn)
- Nano- and Condensed Matter/Materials Physics instructional labs — John Essick (Reed College) and Dwight Luhman (Carleton College), presiding (DRL Room 3C8, Penn)
- Statistical Physics / Soft Matter instructional labs — Michael Lerner (Earlham College) and David Bailey (Toronto), presiding (DRL Room 3W2, Penn)

SESSION XVI

“Breakout Discussions II” 9:45 - 10:35 a.m.
David Rittenhouse Labs, Disque Hall, and Stratton Hall

- “Methods Courses” vs. “Design Courses:” a false dichotomy? — Linda Barton (RIT) and Adrienne Wootters (Massachusetts College of Liberal Arts), presiding (Disque 919, Drexel)
- Teaching Experimental Uncertainty — David Haase (NC State), presiding (Disque 109, Drexel)
- Instruction in Writing & Revision in the instructional lab — Erin Flater (Luther College) and Melissa Eblen Zayas (Carleton College), presiding (Stratton 101, Drexel)
- Sophomore-level physics & instructional labs — Linda Winkler (Minnesota-Moorhead) and Walter Smith (Haverford College), presiding (Disque 614, Drexel)
- Updating BFY instructional labs in Electronics — Joss Ives (Fraser Valley) and Kurt Wick (Minnesota), presiding (Stratton 201, Drexel)
- Bio-related instructional labs in Physics — Allen Price (Emmanuel), presiding (DRL Room 3C2, Penn)
- BFY instructional labs in Optics & Lasers — Ernie Behringer (Eastern Michigan), presiding (DRL Room 3C4, Penn)
- Photon-based instructional labs in Quantum Mechanics — Sean Bentley (Adelphi Univ.) and Stephen Irons (Yale), presiding (DRL Room 3C6, Penn)
- Nano- and Condensed Matter/Materials Physics instructional labs — Eid Khalid (Miami of Ohio) and Nathan Lindquist (Bethel), presiding (DRL Room 3C8, Penn)

- Statistical Physics / Soft Matter instructional labs — Andrew Croll (North Dakota State) and Tom Solomon (Bucknell), presiding (DRL Room 3W2, Penn)

SESSION XVII

"Case Study: Evolution of tools for assessing impact of labs" 11:00 a.m. - Noon
Auditorium A1, David Rittenhouse Labs
Heather Lewandowski, presiding

Panel: Mark Masters, Mac Stetzer, Barbara Hoeling

Box lunches and concluding remarks 12:00 - 1:00 p.m.
David Rittenhouse Labs

Informal Discussions 1:00 - 2:00 p.m.
David Rittenhouse Labs

Informal Vendor workshops 1:00 - 5:00 p.m.
David Rittenhouse Labs/Disque Hall

EXPANDED SCHEDULE

Wednesday, July 25

SESSION I: PLENARY SESSION

8:10 - 9:25 a.m. · Auditorium A1, David Rittenhouse Labs

Overview of challenges and ALPhA's role
Invited: Gabe Spalding, Illinois Wesleyan University

Amplifying practical instruction in physics
Invited: Randy Tagg, University of Colorado Denver

Lab homework in ALL courses!
Invited: Marty Johnston, University of St. Thomas

SESSION II: PANEL DISCUSSION

"Curricular Models: Increasing the amount of lab instruction"
9:30 - 10:30 a.m. · Auditorium A1, David Rittenhouse Labs
Gabe Spalding, presiding
Panel: Gary Chottiner, Bret Crawford, David Bailey

SESSION III: PLENARY SESSION

10:30 a.m. - 11:45 a.m. · Auditorium A1, David Rittenhouse Labs

Teaching optics with a focus on innovation
Invited: Doug Martin, Lawrence University

Integrating the quantum mechanics classroom and laboratory and classroom
Invited: Mark Beck, Whitman College

An alternative to the traditional Modern Physics course with its historically entrenched labs
Invited: Walter Smith, Haverford College

SESSION IV: PANEL DISCUSSION

"Case Study: Instructional Labs in Quantum (at multiple levels)"
12:45 - 1:45 p.m. · Auditorium A1, David Rittenhouse Labs
Mark Beck, presiding
Panel: David Jackson, David Branning, Enrique 'Kiko' Galvez

SESSION V

"Short Workshops"
2:15 - 4:45 p.m. · David Rittenhouse Labs/Disque Hall

SESSION VI

"Short Workshops"
5:15 - 7:45 p.m. · David Rittenhouse Labs/Disque Hall

Thursday, July 26

SESSION VII: PLENARY SESSION

8:00 - 9:15 a.m. · Auditorium A1, David Rittenhouse Labs

Assessment - E-CLASS
Invited: Heather Lewandowski, University of Colorado

Teaching uncertainty
Invited: Saalih Allie, University of Cape Town

Teaching a basic experimental skill set (control, acquisition, and analysis) in a physics context
Invited: John Essick, Reed College

SESSION VIII: POSTER SESSION I

9:30 - 10:45 a.m. · 3rd Floor Atrium, Bossone Research Center, Drexel

P01 **Using the Arduino in an Analog and Digital Electronics Course for Physics Majors**
Everett Ramer and Brian D'Urso, University of Pittsburgh

P02 **Arduino Projects to Enhance STEM Education in the Undergraduate Physics Curriculum**
John R. Conrad, W. Baker, D. Wang, K. Pardo, H. Khan, A. Fant and E. Kostadinova, Furman University

P03 **Laboratory Physics and Python at the University of Toronto**
David Bailey, University of Toronto

P04 **Improving the quantification of Brownian motion**
Ashley Carter and Marco Catipovic, Amherst College

P05 **Predicting and Measuring the Resonant Frequency of a Microcantilever**
Thushara Perera and Gabe Spalding, Illinois Wesleyan University

P11 **Longitudinal Modes in a HeNe Laser**
Rick Pam, Stanford University

P12 **Neophytes Build a MOT**
Bruce Thompson, Ithaca College
Judith Olson, NIST and University of Colorado

P13 **Flexible Physics: A Multimedia Bridge from Lecture to Lab**
Duncan Carlsmith, University of Wisconsin-Madison

P14 **The Advanced Lab Sequence at Massachusetts College of Liberal Arts**
Adrienne Wootters, Massachusetts College of Liberal Arts

P15 **A framework for adopting modeling in upper-division lectures and labs**
Benjamin Zwickl, Noah Finkelstein, and H. J. Lewandowski, University of Colorado

P16 **Description on the MIT Junior Lab curriculum, with updates on recent curriculum reforms**
Charles Bosse and Sean Robinson, Massachusetts Institute of Technology

P17 **Laboratories in the Paradigms in Physics Curriculum**
David McIntyre, Janet Tate, Corrine A. Manogue, and David Roundy, Oregon State University

P18 **What's missing from the traditional explanation of NMR experiments?**
Dr. Greg Severn and Dr. Jim Bolender, University of San Diego

P19 **A Visible MOT for the Advanced lab: plans to build one and tough questions for how to fund it**
Ed Deveney, Bridgewater State University
David P. DeMille, Yale University

P20 **Labs on Quantum and Classical Optics: Old and New**
Enrique J. Galvez, Colgate University

P21 **Real-Time Thermodynamic Experiments With High Resolution**
Eric Ayars, Daniel Lund, Lawrence Lechuga, California State University, Chico

P22 **Physics project labs for advanced undergraduates at Caltech**
Eric D. Black and Kenneth G. Libbrecht, Caltech

P23 **Undergraduate Physics Major Student Development of Written, Visual, and Oral Communication Skills**
Erin Flater, Luther College

P24 **A New Combined Physics and Astrophysics Lab Course for Seniors**
Fronefield Crawford and J. K. Krebs, Franklin and Marshall College

P25 **Two Advanced-Lab Experiments for the Thrifty Physicist**
Jed Brody, Emory University

P26 **Developing Students' Scientific Communication Skills in the Advanced Lab**
Joseph Kozminski, Lewis University

P27 **Kinder, gentler oral exams**
Joss Ives, University of the Fraser Valley

P28 **What carries the current in a metal?: A modern version of the Tolman-Stewart experiment**
Kelley D. Sullivan, Ithaca College

P29 **Laboratory Assessment: Strategies that Build Useful Skills**
Linda S. Barton, Rochester Institute of Technology

P30 **The zen of learning laboratory physics through writing and the art of peer review**
Mark Masters, IPFW

P31 **Fiber Optics Module for a Physics of Medicine Program**
Mary Lowe, Loyola University Maryland, Nancy Donaldson, Rockhurst University, Alex Spiro, Loyola University Maryland, Charles Gosselin, Rockhurst University

P32 **Emphasizing oral communication skills in an upper-level electronics course**
Melissa Eblen-Zayas, Carleton College

P33 **Targeted Student Experiences in a Superconductivity Lab**
Nathan Frank, Augustana College

P34 **Study of electric dipole and higher multipole radiation via scattering from nanoparticles**
Natthi L. Sharma and Ernest R. Behringer, Eastern Michigan University

P35 **Test of Bell's inequality using entangled photons**
Stephen H. Irons and Steven K. Lamoreaux, Yale University

P36 **How to fund a large-enrollment physics advanced lab**
Thomas Colton, University of California Berkeley

P37 **An Extreme Makeover of the Advanced Labs at Morehouse College**
Willie S. Rockward and Thomas A. Searles, Morehouse College

P38 **Bridging the gap between the teaching lab and the research lab**
Yongkang Le, Fudan University

SESSION IX: PANEL DISCUSSION

"Goals of Labs / Taxonomy of Experimental Skills"

11:00 a.m. - noon · Auditorium A1, David Rittenhouse Labs
Randy Tagg, presiding
Panel: Ben Zwickl, David Haase, Eric Ayars

SESSION X

"Short Workshops"

1:30 - 4:00 p.m. · David Rittenhouse Labs/Disque Hall

SESSION XI

"Short Workshops"

4:30 - 7:00 p.m. · David Rittenhouse Labs/Disque Hall

SESSION XII: POSTER SESSION II

7:15 - 8:30 p.m. · 3rd Floor Atrium, Bossone Research Center, Drexel

P06 **Real Time Wave Study**
Ron Vogel, Dale Stille, The University of Iowa

P07 **The supersonic blowdown tunnel: a flexible apparatus for open-ended undergraduate research**
Benjamin Heppner, Pengxue Her, Keith Stein, Mark Turner, Bethel University

P08 **Two-dimensional Turbulence**
Joss Ives, Trevor Balkwill, University of the Fraser Valley

P09 **A Comprehensive Laboratory Experience**
Gary Chottiner, Case Western Reserve University

P10 **Using computer simulations to teach the Jarzynski equality**
Michael Lerner, Earlham College

P39 **Modern Physics Labs using Responsive Inquiry to Create Research Experiences**
Ben Stottrup, Augsburg College
Sarah B. McKagan

P40 **Coherent Blue Light Emission in Rubidium**
Andrew M. C. Dawes, Hunter A. Dassonville, Noah T. Holte, Marcus B. Kienlen, Pacific University

P41 **Providing a research and scientific writing experience in the student lab**
Barbara Hoeling, Nina Abramzon, California State Polytechnic University, Pomona

P42 **Laboratory Development Efforts in a Physics for Biologists Course**
Benjamin Geller, John Giannini, Kim Moore,Edward F. Redish, Wolfgang Losert, University of Maryland, College Park

P43 **The Advanced Spectroscopy Laboratory Course at Miami University**
Burcin Bayram, Mario Freamat, Miami University

P44 **Lasers and Optics open-ended projects at Bethel University**
Chad Hoyt, Sarah Venditto, Dan Mohr, Andrew Stephan, Bethel University

P45 **A Course to Prepare Physics Students for the Research Laboratory**
David G. Haase, Hans Hallen, and David P. Kendellen, North Carolina State University

P46 **The laboratory and the integral development of the students**
David Mendez Coca, Universidad Internacional de la Rioja

P47 **Will a magnet fall freely in a superconducting tube?**
Dr. Greg Severn, Mr. Tim Welsh, University of San Diego

P48 **Cat lapping: a fluid physics project for undergraduate students**
Dr. Katrina Hay, Matthew Hubbard, Pacific Lutheran University

P49 **Student Designed Experiments in Advanced Lab: A Carleton Experiment**
Dwight Luhman, Carleton College

P50 **Characterization of a Dichroic Sheet Polarizer**
Ernest R. Behringer, Eastern Michigan University

P51 **Creating Sustainable Change in Upper-Division Laboratory Courses at a Large Research University**
Heather Lewandowski, Benjamin Zwickl, University of Colorado

P52 **Initial work on Experimental Plasma Station for the undergraduate curriculum**
Jeremiah Williams, Wittenberg University, Andrew Zwicker and Stephanie Wissel (Princeton Plasma Physics Laboratory), Jerry Ross (Shawnee State University)

P53 **Electrical Circuits for Bioinspired Applications**
Jon Erickson, Washington and Lee University

P54 **Measuring the quality factor of a resonator with a lock-in**
Jonathan Newport, Gregg Harry, American University

P55 **Design and Characterization of an Optical Trap in the Advanced Lab**
Joseph Kozminski, Elizabeth DeWaard, Marek Ziebinski, Chuck Crowder, Lewis University

P56 **Developing Professionalism in a Sophomore-level Experimental Physics Class**
Linda Winkler, Juan Cabanela, Stephen Lindaas, Ananda Shastri, Minnesota State University Moorhead

P57 **The ALPhA Immersions Program - Assessment of the First Two Years**
Lowell I. McCann, University of Wisconsin - River Falls
Heather Lewandowski, University of Colorado

P58 **Assessing student understanding in upper-division analog electronics courses**
MacKenzie R. Stetzer, University of Maine
Christos P. Papanikolaou, University of Athens
David P. Smith, University of Washington

P59 **Advanced Labs in Biomedical Physics to Extend the Boundaries of the Traditional Physics Major**
Maria Babiuc-Hamilton, Marshall University

P60 **Assessment and Upgrade of Upper Level Undergraduate Laboratory Instruction**
Mark Gealy, Concordia College

P61 **An Undergraduate Research Project Incorporating LabVIEW to Measure Temperature Dependent Lifetimes in a Phosphor**
R. Seth Smith, Charles J. Nettles, Jonathan J. Heath, Francis Marion University

P62 **Fission-Neutron ToF Spectroscopy: A Simplified Advanced Teaching Laboratory**
Ramon Torres-Isea, F. D. Becchetti, M. Febbraro, M. Ojaruega and L.Baum, The University of Michigan

P63 **Berkeley's two-semester advanced lab sequence**
Thomas Colton, Robert Jacobsen, Donald Orlando, University of California Berkeley

P64 **A Simple Scanning Fabry-Perot Interferometer for High-Resolution Spectroscopy Experiments**
Thomas Moses, Knox College

P65 **A new method to investigate the side-axis spectrum of He-Ne laser**
Weifeng Su, Anxun He, Yifan Chen, Cuiqin Bai, Yongkang Le, Fudan University, China

P66 **Undergraduate Terahertz (THz) Exercises for Advanced Laboratory at Morehouse College**
Willie S. Rockward, Rudy Horne,Joshua Burrow, Ronald Celestine, Pierce Gordon, Dwight Williams, Colin Watson, and Thomas A. Searles, Morehouse College

P67 **First semester sophomore physics: The advantages of waves & oscillations with semi-coordinated lab**
Walter F. Smith, Physics Dept. Haverford College, Haverford PA

SESSION XIII: DEMO SESSION

"PIRA's Advanced Demo Show"

8:45 - 9:45 p.m. · Auditorium A1, David Rittenhouse Labs

Friday, July 27

SESSION XIV: PLENARY SESSION

8:00 - 8:35 a.m. · Auditorium A1, David Rittenhouse Labs

The ALPhA Immersion program: Helping bring BFY ideas back home
Invited: Lowell McCann, University of Wisconsin--River Falls

SESSION XV: BREAKOUT SESSIONS I

8:45 - 9:35 a.m. · David Rittenhouse Labs, Disque Hall, and Stratton Hall

"Methods Courses" vs. "Design Courses:" a false dichotomy?
Eric Black (CalTech) and Gary Chottiner (Case Western), presiding (Disque 919)

Teaching Experimental Uncertainty
Saalih Allie (Cape Town), presiding (Disque 109)

Instruction in Writing & Revision in the instructional lab
Mark Masters (IPFW) and Elizabeth George (Wittenberg Univ.), presiding (Stratton 101)

Sophomore-level physics & instructional labs
David Van Baak (Calvin College), presiding (Disque 614)

Updating BFY instructional labs in Electronics
Mac Stetzer (Maine) and Everett Ramer (Pittsburgh), presiding (Stratton 201)

Bio-related instructional labs in Physics
Jon Erickson (Washington & Lee), presiding (DRL Room 3C2)

BFY instructional labs in Optics & Lasers
Shannon O'Leary (Lewis & Clark), presiding (DRL Room 3C4)

Photon-based instructional labs in Quantum Mechanics
Andy Dawes (Pacific Univ.) and Mark Beck (Whitman College), presiding (DRL Room 3C6)

Nano- and Condensed Matter/Materials Physics instructional labs
John Essick (Reed College) and Dwight Luhman (Carleton College), presiding (DRL Room 3C8)

Statistical Physics / Soft Matter instructional labs
Michael Lerner (Earlham College) and David Bailey (Toronto), presiding (DRL Room 3W2)

SESSION XVI: BREAKOUT SESSIONS II

9:45 - 10:35 a.m. · David Rittenhouse Labs, Disque Hall, and Stratton Hall

"Methods Courses" vs. "Design Courses:" a false dichotomy?
Linda Barton (RIT) and Adrienne Wootters (Massachusetts College of Liberal Arts), presiding (Disque 919)

Teaching Experimental Uncertainty
David Haase (NC State), presiding (Disque 109)

Instruction in Writing & Revision in the instructional lab
Erin Flater (Luther College) and Melissa Eblen Zayas (Carleton College), presiding (Stratton 101)

Sophomore-level physics & instructional labs
Linda Winkler (Minnesota-Moorhead), presiding (Disque 614)

Updating BFY instructional labs in Electronics
Joss Ives (Fraser Valley) and Kurt Wick (Minnesota), presiding (Stratton 201)

Bio-related instructional labs in Physics
Allen Price (Emmanuel), presiding (DRL Room 3C2)

BFY instructional labs in Optics & Lasers
Ernie Behringer (Eastern Michigan), presiding (DRL Room 3C4)

Photon-based instructional labs in Quantum Mechanics
Sean Bentley (Adelphi Univ.) and Stephen Irons (Yale), presiding (DRL Room 3C6)

Nano- and Condensed Matter/Materials Physics instructional labs
Eid Khalid (Miami of Ohio) and Nathan Lindquist (Bethel), presiding (DRL Room 3C8)

Statistical Physics / Soft Matter instructional labs
Andrew Croll (North Dakota State) and Tom Solomon (Bucknell), presiding (DRL Room 3W2)

SESSION XVII: PANEL DISCUSSION

"Case Study: Evolution of tools for assessing impact of labs"

11:00 a.m. - Noon · Auditorium A1, David Rittenhouse Labs
Heather Lewandowski, presiding
Panel: Mark Masters, Mac Stetzer, Barbara Hoeling

ABSTRACTS

Wednesday, July 25

SESSION I: PLENARY SESSION

Overview of challenges and ALPhA's role

Invited: Gabe Spalding, Illinois Wesleyan University

Physics is an experimental science, and so we ought to ask whether the curricula currently offered are appropriately foundational for a next generation of experimentalists. If your department were to undergo external review, how would your curriculum of laboratory instruction look to outside assessors? What case would you want to make (either to assessors or to funding agencies), regarding this core component of the discipline? More to the point, how can the ALPhA community help to facilitate the sorts of improvements you might hope for? We will chat a bit about some common issues, as well as how ALPhA, and a broader set of resources, might significantly leverage your own efforts.

Amplifying practical instruction in physics

Invited: Randy Tagg, University of Colorado Denver

Physics curriculum, including laboratory courses, emphasizes conceptual learning. This is the essential foundation for things that physicists do, but often progress towards discovery and achievement hinges on practical knowledge. This is true for individuals doing their research projects and of the discipline as a whole, with several Nobel prizes stemming from experimental advances using clever practical methods. While many physics departments teach electronics and perhaps optics, it would seem worthwhile to consider a more systematic and broader development of practical knowledge as an essential part of the curriculum. What is needed, perhaps, is a modular structure for teaching practical knowledge in parallel with the mainstream curriculum. Topics range from materials technology and machining techniques to such specialized methods as charged particle optics and low temperature probes. This talk is a call to develop a national repository of such a curriculum, available "on demand" to students who need to know a practical topic "right now" in order to move forward with their research…as well as for success in gaining employment.

Lab homework in ALL courses!

Invited: Marty Johnston, University of St. Thomas

For the past decade we have been striving for a better balance of analytical, experimental, computation and communication skills in our curriculum. By focusing on skill integration, laboratory homework, and transitional undergraduate research we have significantly enhanced the laboratory component of our program. Central to this effort is a sophomore level course that introduces students to experimental techniques while they investigate a single complex problem. The course provides a bridge between the laboratory experience found in introductory physics and the upper-level curriculum by teaching experimental skills systematically in a collaborative manner. The experience prepares them for the laboratory homework and the research problems that they will encounter in their other courses. I will talk about the structure of our curricular revision and how it continues to evolve, the sophomore laboratory course, and how we achieved departmental buy-in and support for the revision.

SESSION II: PANEL DISCUSSION

"Curricular Models: Increasing the amount of lab instruction"

SESSION III: PLENARY SESSION

Teaching optics with a focus on innovation

Invited: Doug Martin, Lawrence University

For many years, the Lawrence University physics department taught a theory-based junior/senior level course in optics. The course did not prepare students very well for work in modern optics, nor did it provide much intuition for understanding optical instrumentation, techniques, and phenomena. So in 2010, the department rebuilt the optics course around labs: in a ten-week term, the revamped course now includes ten 70 minute lectures and twenty 3+ hour lab sessions. In this talk, I will describe the rationale for the new course structure (eight "canned" labs, ranging from imaging through aberrations to Fourier optics, four "challenge" labs that focus on a telescope, a white-light Michelson interferometer, interferometric metrology, and spatial light modulator (SLM) based spatial filtering, and finally a four-session final project) as well as the labs themselves and student results from the first two offerings of the redesigned course. At their best, we find that students are learning to predict, prototype, and learn from both success and failure. Of the fourteen students who completed the course, seven have gone on to summer research work involving optics, and 4/11 graduates have gone on to PhD research that draws considerably upon optics.

Integrating the quantum mechanics classroom and laboratory and classroom

Invited: Mark Beck, Whitman College

We have developed as series of undergraduate teaching laboratories that explore some of the fundamentals of quantum mechanics. All of the experiments involve performing measurements on individual photons, or entangled-photon pairs. The experiments include: "Proving" that light consists of photons, single-photon interference, and tests of local realism. I will describe the experiments, and also describe how we have integrated the experiments with our upper-level undergraduate quantum mechanics course.

First semester sophomore physics: The advantages of waves and oscillations with semi-coordinated lab

Invited: Walter Smith, Haverford College

The coverage and format of physics courses taught in the sophomore year varies more widely between institutions than any of the other three undergraduate years. This talk presents the case for a sophomore sequence that begins with a course on waves and oscillations, with an associated lab that is loosely coordinated with the lecture. Details of how this program has been implemented at Haverford College are provided, and the results are contrasted with other approaches that have been tried here. The lab part of this approach provides all majors with a foundational set of lab and analysis skills that can be applied to the junior- or senior-level advanced laboratory course and/or to research. Waves and oscillations occur in virtually all physical systems, and mastering the needed mathematical concepts and techniques provides the perfect preparation for rigorous a sophomore-level quantum mechanics course in the second semester. This program can provide students a true insight into what it will be like to be a physics major, before they have to make their major declaration.

SESSION IV: PANEL DISCUSSION

"Case Study: Instructional Labs in Quantum (at multiple levels)"

SESSION V
"Short Workshops"

SESSION VI
"Short Workshops"

Thursday, July 26

SESSION VII: PLENARY SESSION

Assessment - E-CLASS
Invited: Heather Lewandowski, University of Colorado

Teaching uncertainty
Invited: Saalih Allie, University of Cape Town

Teaching a basic experimental skill set (control, acquisition, and analysis) in a physics context
Invited: John Essick, Reed College

SESSION VIII: POSTER SESSION I

P01 Using the Arduino in an Analog and Digital Electronics Course for Physics Majors

Everett Ramer and Brian D'Urso, University of Pittsburgh

Two years ago we began using Arduino micro controllers in the electronics course for second-year Physics majors. Arduinos feature multiple on-board digital and analog inputs and outputs, and are connected to a host computer by a USB cable, which also supplies power to the unit. A free software development environment, including editor and compiler, are used to program the micro controller using the high-level programming language C. Many easily interfaced sensors and transducers are available, making the Arduino a useful lab tool or an very entertaining toy. The large user group present on the internet is an inexhaustible source of help and ideas.

In our course the Arduinos have replaced traditional experiments involving flip-flops, counters, and seven-segment displays. These experiments involve a great deal of error-prone bread boarding that students find frustrating. The Arduino is able to easily implement these operations in software. We also use the Arduinos in end-of-semester projects that challenge students to do something interesting with the knowledge they accumulated. In previous years these projects were limited to rather simple devices like a siren, lie detector, or FM transmitter. With the Arduino students are able to build devices that incorporate a GPS receiver, send text and email messages, control servo and stepping motors, act as MIDI controllers, and have LCD and LED matrix displays. Arduino based projects are more rewarding and give the students a better appreciation of how their knowledge of electronics will be useful in their future work.

P02 Arduino Projects to Enhance STEM Education in the Undergraduate Physics Curriculum

John R. Conrad, W. Baker, D. Wang, K. Pardo, H. Khan, A. Fant and E. Kostadinova, Furman University

These activities build on, exploit, and leverage the technology-based DIY/DIWO subculture of the Maker Movement to introduce embedded system Arduino technology at every level of the undergraduate curriculum, with the goal at a local level to increase by a factor of two the number of undergraduate physics majors at Furman. We hope to attract students who might not otherwise be inclined to major in physics. We believe that the material developed will be easily transportable to other institutions and will help to allow other institutions to also increase the number of students attracted to STEM fields generally, and in particular in undergraduate physics curricula. Although the specific projects we will explore are focused on the undergraduate physics curriculum, the approach and pedagogy developed will be easily adaptable to other STEM disciplines.

The strategic goals for this program address three issues:

- Recruiting of qualified students into the undergraduate physics pipeline,
- Retention of those who enter the pipeline, and
- Enhancing the quality of the education by providing an engaged, hands-on, project-based learning experience.

In order to achieve the above strategic goals, we have identified the following seven categories of Arduino-based projects:

- Augmentation and enhancement of existing laboratory experiments,
- Research laboratory apparatus,
- Lecture/showcase demo apparatus,
- Projects that interface with Mathematica & Labview platforms,
- Standalone consumer devices,
- "Internet of Things" devices,
- Robotics competition projects.

P03 Laboratory Physics and Python at the University of Toronto

David Bailey, University of Toronto

The undergraduate teaching of experimental and computational physics is undergoing significant change at the University of Toronto, with the Advanced Physics Lab as the only remaining (almost) traditional lab course. Except in first year, lecture and laboratory courses have been traditionally separate, and computation was only formally available as optional courses in 3rd and 4th year. The Physics Department has chosen Python as the computational tool that will be supported in all our undergraduate courses in all years. Because of program constraints limiting our ability to require additional courses, and the challenge in agreeing to make drastic changes in traditional lecture courses, the primary introduction of Python has been through modification and expansion of existing lab courses into "practical physics" courses. These current and ongoing changes will be described, with particular emphasis on the implications for our Advanced Physics Lab.

References:

(1) "Putting computation on a par with experiments and theory in the undergraduate physics curriculum", Ruxandra M. Serbanescu, Paul J. Kushner, and Sabine Stanley, Am. J. Phys. 79 (2011) 919-924 (http://dx.doi.org/10.1119/1.3593296).

(2) Computers in Physics at the University of Toronto, http://compwiki.physics.utoronto.ca/.

(3) "The Advanced Physics Lab at the University of Toronto", David C. Bailey, Jason Harlow, Natalia Krasnopolskaia, 2009 Conference on Advanced Physics Labs (http://www.compadre.org/advlabs/tcal/Detail.cfm?id=2579).

(4) "Python for the Advanced Physics Lab", http://www.physics.utoronto.ca/~phy326/python/.

P04 Improving the quantification of Brownian motion

Ashley Carter and Marco Catipovic, Amherst College

A classic experiment for visualizing a random walk is to observe a small, micron-sized particle undergoing Brownian motion in a microscope. In recent years this simple experiment has been upgraded to include a cheap camera and tracking software to allow students to measure the mean squared displacement of the particle over time. Given the random walk equation and the Stokes-Einstein diffusion coefficient, the students can calculate a number of interesting parameters: the viscosity of the medium, the radius of the bead, and the temperature of the liquid, to name a few. We will describe our implementation of this experiment at Amherst College, focusing on the improvements that have increased the ease of use of the exercise.

P05 **Predicting and Measuring the Resonant Frequency of a Microcantilever**

Thushara Perera and Gabe Spalding, Illinois Wesleyan University

As a segment of our advanced lab course, students calculate the resonant frequency of a microcantilever (AFM probe) based on its dimensions (which they measure), and compare this with vibrational modes they observe (after assembling a basic system for optical transduction) when the cantilever is affixed to a piezoelectric drive. During the experiment, students become familiar with a number of instruments/components including a scanning electron microscope (SEM), a variety of optics components, a quadrant photodiode, op-amps, a digital oscilloscope, and a lock-in amplifier. This is one of our favorite labs because it exposes students to a wide range of experimental techniques while reinforcing their understanding of resonances and the continuum mechanics of solids. In addition, the data analysis component also presents realistic challenges. We present here a brief sketch of the experiment itself, the tasks assigned to students, the challenges they face, and a selection of student data/results.

P11 **Longitudinal Modes in a HeNe Laser**

Rick Pam, Stanford University

We have a long-standing experiment to study the atomic physics of a gas laser plasma, using an open-cavity HeNe laser and a grating spectrometer. A similar experiment is done at other institutions. In recent years the experiment has been extended to include an investigation of longitudinal modes using an external confocal Fabry-Perot cavity. Both the experiment and the extensive writing component that accompanies it will be described. Sourcing issues for the HeNe discharge tube will also be discussed.

P12 **Neophytes Build a MOT**

Bruce Thompson, Ithaca College
Judith Olson, NIST and University of Colorado

A Magneto-Optical Trap (MOT) is a wonderful tool for undergraduate research and teaching laboratories that highlights many topics in modern physics. Our poster describes the design decisions and process that resulted in an operational MOT using the resources and time available at an undergraduate institution. By building many components and purchasing others, we were able to complete the MOT in about two years at a cost of about $40000. Neither of us had experience with optical systems prior to starting work on the project. Recommendations are given for a phased build of a MOT.

P13 **Flexible Physics: A Multimedia Bridge from Lecture to Lab**

Duncan Carlsmith, University of Wisconsin-Madison

The Flexible Physics Project at the University of Wisconsin-Madison has created a library of short multimedia educational objects to prepare university undergraduates for physics laboratory experiences. Integrating still photographs, video, and audio using Flash, each object reviews important principles, describes the goals of the lab, and provides a brief tour of the experiment. Best practices related to the production of these materials will be described.

P14 **The Advanced Lab Sequence at Massachusetts College of Liberal Arts**

Adrienne Wootters, Massachusetts College of Liberal Arts

MCLA's Advanced Lab experience is a sequence of two courses for senior physics majors. The content of the course includes electronics and methods of data analysis, but the course's primary intent is to be a complete research experience. In the first semester, students research a topic, design an experiment, and write a proposal for funding. The second semester is devoted to the experiment itself. All students work on individual projects they have designed and built themselves. Because we are a small public liberal arts college, resources are scarce, and students are encouraged to be creative in designing experiments on a tight budget. Each week, students meet for group meeting, where they discuss their progress of the previous week and help one another with experimental challenges. At the end of the second semester, in addition to writing a paper on their research, students prepare posters for presentation at MCLA's Undergraduate Research Conference.

Assessment of such a course of study can be challenging. We have designed and present in this poster an assessment scheme that includes guidelines and rubrics for grading individual research, writing a grant proposal, keeping a laboratory notebook, designing a poster, and writing a final paper.

P15 **A framework for adopting modeling in upper-division lectures and labs**

Benjamin Zwickl, Noah Finkelstein, and H. J. Lewandowski, University of Colorado

Modeling, the practice of developing, testing, and refining models of physical systems is gaining support as a key scientific practice, and is included in the new Framework for K-12 Science Education released by the National Research Council. Modeling Instruction, RealTime Physics, Matter & Interactions, and other model-based curricula have introduced a modeling emphasis to many classrooms at the high school and introductory college level, but there has been little move to include modeling in the upper-division lecture or lab courses. In this poster we present a framework for adopting modeling into existing lab courses as part of general strategy for scientific inquiry. We also present a model of laboratory modeling that includes modeling the physical and measurement systems and their relationship. We elucidate the framework through the specific example of a polarization of light lab.

P16 **Description on the MIT Junior Lab curriculum, with updates on recent curriculum reforms**

Charles Bosse and Sean Robinson, Massachusetts Institute of Technology

The poster will detail several aspects of the 8.13 and 8.14 modern physics labs for Juniors on MIT's Physics track. An overview of the structure of class, current experimental offerings, and supporting materials and instruction will be shown, as well as recent and pending updated to the course.

P17 **Laboratories in the Paradigms in Physics Curriculum**

David McIntyre, Janet Tate, Corinne A. Manogue, and David Roundy, Oregon State University

The Paradigms in Physics project at Oregon State University has reformed the entire upper-level physics curriculum. This has involved both a rearrangement of content to better reflect the way professional physicists think about the field and also the use of a number of reform pedagogies that place responsibility for learning more firmly in the hands of the students. We have taken advantage of years of results from PER that indicate that students learn better when they are actively engaged in the learning process. We integrate laboratory experiments into the curriculum in addition to our use of white board questions, kinesthetic activities, small group problem solving, and computer activities. Our revised schedule has 2-hour class sessions twice a week that allow us to do laboratory experiments in the same time slot as the lecture; there is no separate large block of lab time, which is often the case in traditional physics courses. The labs are supervised in the same way as the lectures--by the instructor with TA support. The labs are broken up into smaller components than is usual, and class time is used for discussion of results and modeling. Labs include: a large amplitude pendulum to study anharmonic motion, an LRC circuit to study Fourier analysis, a driven waves on a string lab to study wave motion, a coaxial cable experiment to study reflection at boundaries, a stretched rubber band experiment to study entropy, and a Stern-Gerlach computer simulation to study quantum measurements.

P18 **What's missing from the traditional explanation of NMR experiments?**

Dr. Greg Severn and Dr. Jim Bolender, University of San Diego

How do NMR experiments work? This question is addressed at the undergraduate level in both chemistry and physics lectures and laboratories. In most descriptions[1], it is taken for granted that Hydrogen NMR is proton NMR, without discussion of why this is the case, and how for Hydrogen, an external magnetic field creates a two state quantum system with an energy gap simply and directly proportional to the value of the nuclear magnetic moment. No mention is made of the magnetic moment of the two electrons that make up the covalent bond connecting the Hydrogen atom to the (most often) carbon backbone of the molecule. No mention is made of the complete cancelation of the electron-induced magnetic field at the Hydrogen nucleus that is required for this technique to yield easily interpretable data. We think a brief discussion of the implications of the Pauli Exclusion Principle in connection with the physics of covalent bonds would clarify the context in which NMR experiments with the hydrogens can be simply understood, especially with regard to the necessary disappearance of the hyperfine splitting of the ground state of Hydrogen.

[1]See for example, A.C. Melissinos and J. Napolitano, "Experiments in Modern Physics", (Academic Press, San Diego, 2nd. Ed. 2003), Chap.7, and D.A. McQuarrie and J.D. Simon, "Physical Chemistry: A Molecular Approach", (University Science Books, Sausilito, CA, 1997) Chap.14. These are excellent texts which we use in our courses. We allege no errors in them about NMR experiments.

P19 **A Visible MOT for the Advanced lab: plans to build one and tough questions for how to fund it**

Ed Deveney, Bridgewater State University
David P. DeMille, Yale University

The seminal paper for the undergraduate MOT appeared in AJP in 1995 by C. Wieman and G. Flowers; 'Inexpensive laser cooling and trapping experiment for undergraduate laboratories'. Here they write: "Because of this visual appeal and the current research excitement in this area, we felt that it was highly desirable to develop an atom trapping apparatus that could be incorporated into the undergraduate laboratory classes." From our observations, it seems that while there are extraordinary examples of MOTs thriving in a few undergraduate labs, MOT experiments have yet to be widely implemented into the undergraduate curriculum —likely because they are, in fact, not trivial to make. With the luxury of having been able to consider all the progress the field has had to offer in the 17 years since this 1st undergraduate MOT design paper came out, we present a design for a Visible, Li, MOT (VMOT) that incorporates significant simplifications and straightforward techniques to make this undergraduate experiment more 'do-able'. Moreover, because the VMOT is in the visible we argue that the clarity, ease and educational impact of the experiment are significantly enhanced. Affordability is certainly the next question and while this is not the most expensive experiment, it certainly is beyond the one-time budget of most undergraduate institutions. So, what are the possible sources that one can use for this experiment and in times when assessment and student numbers are rightly being considered, how can this VMOT fare?

P20 **Labs on Quantum and Classical Optics: Old and New**

Enrique J. Galvez, Colgate University

I describe the adaptation of quantum-optics photon experiments for use in a quantum mechanics course, as a laboratory component. I also describe new laboratories on classical optics about Poincare optical beams, which serve as a way to understand states of polarization and their manipulation.

P21 **Real-Time Thermodynamic Experiments With High Resolution**

Eric Ayars, Daniel Lund, Lawrence Lechuga, California State University, Chico

The heat equation is often taught in upper-level physics and engineering courses, but laboratory equipment that allows students to test this important concept are lacking. Existing educational apparatus for this experiment is either expensive or extremely limited. Recent advances in microcontroller systems and sensor technology allow the use of large numbers of high-precision sensors to obtain temperature information with high spatial/temporal resolution in real time, at relatively low cost. We demonstrate one such apparatus here.

P22 **Physics project labs for advanced undergraduates at Caltech**

Eric D. Black and Kenneth G. Libbrecht, Caltech

For the past two years we have offered a program of "design-and-build" labs in our Senior Physics Laboratory, ph77. In it, students go through the process of quantitative design for a project, then building and testing, all in the course of a ten-week term. Topics include ion trapping, magnetic levitation, quantized conductance, thin-film deposition (with associated vacuum-system engineering), and thermoelectric temperature control. We report student progress and results of this work.

P23 **Undergraduate Physics Major Student Development of Written, Visual, and Oral Communication Skills**

Erin Flater, Luther College

Effective communication is one of many skills that an undergraduate physics student develops during his/her college years. At Luther College, as a liberal arts institution, broader skills such as written and oral communication are especially important and are an intentional part of the college curriculum. Within science major courses at Luther, new college-wide guidelines for departmental assessment have prompted further development of courses within the major with a writing-intensive component. In a pair of sequential sophomore-level modern physics courses, students develop communication skills through use of peer-review and multiple drafts of lab reports, in addition to the development of an end-of-year poster presentation. Multiple opportunities to revise and improve on both the experimental results and the reporting of the results helped the students to hone their scientific communication skills. Progress of student work throughout the 2011-2012 year is discussed qualitatively and analyzed quantitatively using a departmental rubric for assessment of physics student work.

P24 **A New Combined Physics and Astrophysics Lab Course for Seniors**

Fronefield Crawford and J. K. Krebs, Franklin and Marshall College

We will discuss a new senior level undergraduate lab course that is under development at Franklin and Marshall College. This course combines labs in both observational astronomy and experimental physics, with the combined set of labs being performed by both astrophysics and physics majors. The course is taught by a team of one astronomer and one experimental physicist who participate in all labs. One goal of the lab is to expose each set of majors to laboratory work and research techniques that they may not have previously encountered in their respective major courses. Student response was very positive to this new lab course, and we continue to modify and improve it.

P25 Two Advanced-Lab Experiments for the Thrifty Physicist

Jed Brody, Emory University

Over the past two years, four AJP papers have resulted from innovations in Emory's Advanced Lab. I highlight the two experiments that can be done at almost no cost: a simple optical probe of transient heat conduction, and oscillations of a water column beneath trapped air. The heat-conduction experiment requires only a laser, a stopwatch, ice water, and any transparent liquid or solid; the laser beam's deflection increases and then mysteriously decreases as the transparent material is chilled from below. The water-column experiment requires only a clear tube, a bucket of water, and a digital camera; the water column's oscillations mysteriously reach their lowest frequency when the tube is about half full of water; higher frequencies are observed when a smaller or larger fraction of the tube contains water. Both experiments use simple equipment to illustrate mathematically complicated behavior--mysterious behavior that defies intuition and motivates inquiry.

P26 Developing Students' Scientific Communication Skills in the Advanced Lab

Joseph Kozminski, Lewis University

In the Advanced Lab course at Lewis University, students have various opportunities to hone their scientific communication skills. In this lab, students are required to complete a "Major Project." During the course of this project, students perform a literature search, write a project proposal, give project updates, and disseminate their findings in a journal article, an oral presentation, and a poster presentation. Students also participate in the journal submission and peer review process, this past year by participating in JAUPLI. Moreover, they are required to attend and critique several scientific talks throughout the semester and write critiques of the presentations. A description of these and other opportunities for students to develop communication skills necessary in science will be given, and ideas for developing these skills earlier in the physics curriculum will be discussed.

P27 Kinder, gentler oral exams

Joss Ives, University of the Fraser Valley

Oral exams can provide effective assessment of student understanding of theoretical, analysis and experimental details in upper-division labs. Unfortunately the most common implementation involves putting students "on-the-spot" by asking them to put together coherent explanations moments after being asked a question. This talk will discuss some modifications that I have made to address some of the aspects that I found to be the most intimidating and challenging when I was assessed using oral exams during my career as a student. The primary modification used to create my kinder, gentler oral exams was to present the student with three questions and then allow them to have some time to collect their thoughts as well as consult their resources before the formal part of the assessment was started.

P28 What carries the current in a metal?: A modern version of the Tolman-Stewart experiment

Kelley D. Sullivan, Ithaca College

The Tolman-Stewart experiment in 1916 was the first experiment to show that charge carriers inside a metal were electrons -- the same electrons discovered in J.J. Thomson's cathode rays. Their experiment is conceptually very simple: a coil of copper wire is spun at a high speed and then suddenly braked; the electrons continue to move in the coil until slowed by the resistance of the copper. From a measurement of the charge that flows in the coil, we can find the ratio of e/m. We report on a modern version of the Tolman-Stewart experiment and compare our results to results from a cathode ray tube (another undergraduate laboratory staple). This experiment can prove to students that the charge carriers in copper are electrons, and gives avenues for future expansions: finding the effective mass and sign of the charge carrier.

P29 Laboratory Assessment: Strategies that Build Useful Skills

Linda S. Barton, Rochester Institute of Technology

Traditional laboratories are assessed primarily with lab reports. However, lab report writing is not a skill that is particularly needed in working physicists! We describe an assessment system that fosters 1) excellence in laboratory notebook keeping 2) abstract writing and 3) journal-style written presentations. This assessment schema has provided ample information for the laboratory instructor, while helping students develop skills that they can really use. It has been effective in several sophomore and junior level laboratory courses.

P30 The zen of learning laboratory physics through writing and the art of peer review

Mark Masters, IPFW

Writing is a critical part of experimental physics. It helps the author synthesize the physics in the experiment through the need to articulate the work to a group of peers through peer review.

However, when students write laboratory reports, they often write for the instructor. This unfortunate choice of audience causes them to not fully synthesize their work because the instructor will fill in the blanks. As a way around this, we have created The Journal of the Advanced Undergraduate Physics Laboratory Investigation (JAUPLI). Students from different institutions submit articles to the journal and review articles submitted by other students mirroring professional practice. Our results to date on this project will be presented.

P31 Fiber Optics Module for a Physics of Medicine Program

Mary Lowe, Loyola University Maryland, Nancy Donaldson, Rockhurst University, Alex Spiro, Loyola University Maryland, Charles Gosselin, Rockhurst University

We recently received an NSF grant to develop three upper-division active learning modules that relate physics principles to medicine. The goal is to attract more students to upper division physics classes by incorporating physics concepts that are relevant to students' interests and more readily applicable than material commonly presented in traditional physics classes. We are currently developing a fiber optics module focusing on two medical applications: laser therapy and viewing with an endoscope. Our approach is to first introduce the concept of acceptance angle using a macroscopic acrylic rod (core) submerged in water (cladding). The teaching materials will contain a set of guided questions to help students with conceptual and quantitative understanding. Next, concepts of numerical aperture and coupling of the light source to the fiber will be introduced. To increase transferability to other universities, two types of teaching materials are being developed: one involves optical components used in industry (expensive) and the other involves macroscopic setups and paper-and-pencil exercises (not expensive). For both types, the students will gain knowledge of fibers, Gaussian beam optics, lens selection, and spherical aberration, but with the former approach, the students will also gain experience with experimental techniques used in research and industry. Experiments on losses in fiber due to bending and viewing objects using fiber bundles will be developed. We will explore fiber optic sensors and imaging (specifically OCT). The physics module activities will be developed around medical situations and will include slides and videos of real surgeries and endoscopic procedures.

P32 **Emphasizing oral communication skills in an upper-level electronics course**

Melissa Eblen-Zayas, Carleton College

The upper level analog and digital electronics laboratory at Carleton College has recently been modified to emphasize the development of oral communication skills. While written communication in the form of lab notebooks and formal lab write-ups has long had a significant role in advanced lab courses, oral communication often does not receive as much focus. One of the challenges of emphasizing oral communication in the advanced lab is finding time for regular student presentations. New technologies, such as screencasting and easy-to-use video recording and editing tools, offer alternative ways to incorporate oral communication opportunities into courses.

I will provide an overview of the scope and organization of the electronics course, the labs and student projects included in the course, and how I have incorporated student screencasts and videos into the course in an effort to emphasize oral communication skills. Student response to creating screencasts and videos has been mixed, and I will discuss what I see as the benefits and challenges of these new approaches.

P33 **Targeted Student Experiences in a Superconductivity Lab**

Nathan Frank, Augustana College

The transition of an undergraduate student from a guided-inquiry introductory lab to independent research requires substantial growth. This transition is about more than understanding how to use more complicated equipment and data analysis skills. It is especially important that students have the experience of debugging equipment and encountering the limits of measurement techniques, which is possible in the advanced lab curriculum. They encounter these challenges within the context of measuring the superconducting temperature of an unknown material. The experiment and the intentional problems students encounter will be presented.

P34 **Study of electric dipole and higher multipole radiation via scattering from nanoparticles**

Natthi L. Sharma and Ernest R. Behringer, Eastern Michigan University

Senior undergraduate and graduate students are hardly ever exposed to an experiment on multipole radiation even though it is taught in lecture courses on electrodynamics and nuclear physics. We have developed a simple laboratory experiment to study the angular distribution and polarization of electric and magnetic dipole radiation. This experiment arose out of studies [Phys. Rev. Lett. 98, 217402 (2007); Am. J. Phys. 71, 1294 (2003)] of the contribution of higher order multipoles to optical scattering in aqueous suspensions of 50-200 nm polystyrene spheres and colloids. These studies resulted in the first observation of the breakdown of the electric dipole approximation in the visible region. The students learn about the particle size and wavelength dependence of scattering and how the atomic-molecular scattering is modified by the presence of nanoscatterers. After performing this lab, they can explain why one does not see a (polarized) laser beam in a dark room when looking along its electric field. It is an easily implementable, low cost experiment that is rich in physics.

P35 **Test of Bell's inequality using entangled photons**

Stephen H. Irons and Steven K. Lamoreaux, Yale University

We present a description of an implementation of a Bell's Inequality experiment for our advanced lab course. The Bell inequality describes a measurable quantity that can experimentally determine the validity of a large class of hidden variable theories. The apparatus is based on that described by Dehlinger and Mitchell[1] in which two single photon counters (SPC) in conjunction with optical polarizers are used to examine the correlations between two entangled photons. The entangled state is created by downconverting a 405 nm photon into two 810 nm photons with correlated polarizations. The number of coincidences as detected by two SPCs is then measured as a function of one of the polarizer angles. The resulting curve is then fit to a theoretical equation from which we determine whether the inequality is violated or not. Students adjust the properties of the entangled quantum state by varying the phase and polarization angle of the 405 nm photons. After demonstrating that the appropriate entangled state is produced, the students take data and perform the statistical analysis to show the confidence limit with which hidden variable theories can be rejected. The students have four weeks to master operation of the apparatus, acquire their data, and perform the analysis. Time permitting, the students can do a complete realignment of the optical path with the goal of improving the experimental result.

[1] Dehlinger and Mitchell, "Entangled photon apparatus for the undergraduate laboratory," Am. J. Phys. 70 (9), 898-902 (2002).

P36 **How to fund a large-enrollment physics advanced lab**

Thomas Colton, University of California Berkeley

The equipment and operating cost per student for a physics advanced lab course dwarfs that for an introductory physics lab course because (a) the cost for equipment is much higher (10-100x), and (b) that cost is spread over a small group of physics majors rather than over a large population (10x) of students in other sciences and engineering. For very small-enrollment advanced lab courses, an instructor may be able to borrow existing research equipment, but in larger courses, this is not practical. Scavenging used equipment is another option, but can be a false economy if you count the time to recondition and maintain. It's easy to fall into the trap of applying band-aids to your band-aids until the lab course is unsustainable. We need to be realistic about projecting the true costs and to be creative in finding alternative funding sources. Resources to consider include (1) student lab fees, (2) government and private foundation grants for education, (3) education components of research grants, (4) corporate in-kind donations of equipment, (5) corporate cash donations, (6) alumni cash donations, (7) alumni volunteering time, (8) student internships to build/improve experiments. The mix of sources to tap depends a lot on the nature of your program and other local factors. We'll discuss pros and cons of each of these sources and share ideas for increasing the resources we all need to keep our lab courses strong.

P37 **An Extreme Makeover of the Advanced Labs at Morehouse College**

Willie S. Rockward and Thomas A. Searles, Morehouse College

At Morehouse College, the Advanced Lab courses are traditionally the only portion of the undergraduate curriculum for Physics, Applied Physics, and Dual Degree Engineering students to gain hands-on experimental knowledge that complement the upper level physics courses. In our department, the Advanced Lab courses consist of Advanced Lab I (required) accompanied by Advanced Lab II, an elective. Over the past decade, several alumni have emphasized the need for a stronger electronics component within our Advanced Lab I, which evolved into a hybrid of both courses. Through unexpected internal funding, we proposed an EXTREME MAKEOVER of our Advanced Lab facilities and curriculum. This EXTREME MAKEOVER was initiated by a series of site visits to gauge how our curriculum and infrastructure as compared to advanced lab facilities at 12 Physics departments across the nation. On four separate trips, we visited Massachusetts Institute of Technology, Rice University, University of Houston, Princeton University, University of Pennsylvania, Drexel University, Swarthmore College, University of California-Berkeley, Stanford University, University of California San Diego, University of California-Los Angeles, and California Institute of Technology. We will highlight the main results of the 12 schools and discuss the major layouts/designs at selected institutions. We also will discuss several commonalities and "best practices" guideline to the improvements that we propose for our state-of-art facility and curriculum. Lastly, we will present current progress in our EXTREME MAKEOVER and our assessment plans on our students' success.

P38 **Bridging the gap between the teaching lab and the research lab**

Yongkang Le, Fudan University

In a teaching lab, the apparatus is usually old and relatively simple, the contents are mostly well established and the operation guide is often provided. In a research lab, however, the apparatus is mostly new (or even home-made) and complicated, the contents are exploratory, the results will only be obtained after dozens of failure. The graduate students will often feel lost when they start a research project.

How to provide the necessary training in a teaching lab, so that the students can get better prepared for the work in a research lab? We reports on the practice in our advanced physics laboratory course from the following aspects:

1. Question based lab supervision cultivates the students' idea on how to design a lab;
2. Apparatus dissection helps the student to understand the signal processing in a lab;
3. Apparatus upgrading aims to illustrate more physics;
4. Following the new techniques in and results from frontier research, building new teaching labs with carefully modified apparatus and specially selected contents.

SESSION IX: PANEL DISCUSSION

"Goals of Labs / Taxonomy of Experimental Skills"

SESSION X

"Short Workshops"

SESSION XI

"Short Workshops"

SESSION XII: POSTER SESSION II

P06 **Real Time Wave Study**

Ron Vogel, Dale Stille, The University of Iowa

Many of the wave experiments we do in physics are not amenable to real time study. In this poster we show how a number of real time experiments can be done, and how they correlate to the continuous wave equivalents.

The three considered here are:

1. Reflections and the etalon.
2. Refraction
3. Diffraction

We will first visualize these phenomena in the time domain with ultrasonic transducers; then do a Fourier transform and compare to CW measurements.

P07 **The supersonic blowdown tunnel: a flexible apparatus for open-ended undergraduate research**

Benjamin Heppner, Pengxue Her, Keith Stein, Mark Turner, Bethel University

A fall 2010 student project in the Bethel University (BU) PHY420 Fluid Mechanics course was directed towards the design, construction, and initial testing of a small supersonic blowdown tunnel. The blowdown tunnel consists of high and low pressure reservoirs connected by a converging-diverging nozzle that can sustain a supersonic flow for about two seconds. Since its initial design, the blowdown tunnel has received a number of improvements that make it a useful platform for further open-ended student projects in BU advanced lab courses. The tunnel allows for a variety of studies involving high speed compressible flows. Preliminary studies have utilized high-speed video (HSV) shadowgraph imaging and piezoelectric pressure measurements with a LabVIEW interface to examine and compare the flow with numerical results from a MATLAB generated model of the system. The preliminary student studies, along with the flexibility of the blowdown tunnel apparatus, provide upper level students with the opportunity to design a variety of supersonic flow experiments in BU advanced lab courses.

P08 **Two-dimensional Turbulence**

Joss Ives, Trevor Balkwill, University of the Fraser Valley

In the presence of a two-dimensionally varying magnetic field, running a current through a thin layer of electrolyte will generate vortices and other turbulent behaviour. The spatially varying magnetic field is generated by a two-dimensional array of permanent magnets upon which the layer of electrolyte sits. For small currents, the flow reflects symmetries of the magnetic field. At larger currents, the flow becomes turbulent. Velocity fields are found through the use of software which compares pairs of images taken near enough in time that tracer particles (glass microspheres) in the electrolyte have moved only a small amount.

P09 **A Comprehensive Laboratory Experience**

Gary Chottiner, Case Western Reserve University

BS physics majors at CWRU take a set of four advanced laboratory courses during their sophomore and junior years. The sophomore courses cover analog and digital electronics, electronic instrumentation, computer interfacing and signal analysis. Associated lectures explain Fourier Transform and convolution principles plus filtering, phase sensitive detection and other techniques for extracting information from a signal. A popular final project in the first course is construction of a music synthesizer which is used to play a short tune, saving it in a memory chip for replay on command. By the end of their sophomore year, our majors can make valuable contributions to a research group, with practical skills that are often superior to those of new graduate students. The junior year begins with a semester of classic and modern physics experiments, with comprehensive support for each experiment plus training in professional skills such as advanced error analysis, ethics and communication (writing and speaking). In the fourth course, students work on experiments contributed by various department research groups using research quality equipment. Instructors provide information and assistance similar to the guidance one might provide a graduate student joining a research group. This experience prepares our majors for a year-long senior research project that is similar to a post-graduate research effort. These laboratory courses are time consuming and difficult for both students and instructors but our graduating seniors consistently rate them as one of the highlights of their four years at CWRU.

P10 **Using computer simulations to teach the Jarzynski equality**

Michael Lerner, Earlham College

The fluctuation theorems are some of the most exciting developments in modern statistical mechanics, yet they are rarely introduced at the undergraduate level. We found that a combination of good homework problems along with selected computer simulations not only made the Jarzynski equality accessible, but several students mentioned the section as their favorite part of an advanced statistical mechanics class. The computer simulations also provide an introduction to molecular dynamics and modern parallel computing. This poster summarizes both the choice of homework problems and the choice of computer labs. A laptop will be available for demonstration.

P39 **Modern Physics Labs using Responsive Inquiry to Create Research Experiences**

Ben Stottrup, Augsburg College
Sarah B. McKagan

Augsburg College offers a sophomore-level modern physics course with associated lab. Traditionally this lab has been used to highlight the early development of quantum theory (photo-electric effect, Franck-Hertz, etc.). We will describe our redesign of this lab to create a semester-long responsive inquiry research experience focused on nanotechnology, materials characterization tools, and biology as an inspiration for engineers. Students gain hands-on experience using scanning electron microscopes, atomic force microscopes, as well as other sample preparation tools, and develop their own research projects using the equipment. A goal of the lab is to give students an experience of what research is like and what a scientist does, in order to improve their self-identity as scientists. The focus on contemporary skill building is intended to meet the changing demographics of our student body (increased enrollment, interest in engineering, and first generation college students). Finally, we address the potential for implementation of this model at other institutions.

P40 **Coherent Blue Light Emission in Rubidium**

Andrew M. C. Dawes, Hunter A. Dassonville, Noah T. Holte, Marcus B. Kienlen, Pacific University

Using two external cavity diode lasers and a rubidium vapor cell we explore a four-wave mixing process that leads to the coherent emission of 420 nm light. The pump wavelengths, 780 nm and 776 nm, are within reach of typical diode laser systems. This project is well suited to undergraduate instruction and requires equipment that is often already available for other rubidium experiments such as saturated absorption spectroscopy or magneto-optical trapping.

P41 **Providing a research and scientific writing experience in the student lab**

Barbara Hoeling, Nina Abramzon, California State Polytechnic University, Pomona

We report on our experiences in implementing experiments using state-of-the-art quantum optics and spectroscopy research equipment into the undergraduate laboratory course. Students were exposed to a laboratory experience that very closely resembles real-life research by performing the following activities: measuring photon statistics with single photon counting modules, investigating single photon polarization in spontaneous parametric down-conversion, or analyzing the spectra of unknown sources using an optical emission spectrometer. In addition, they were required to write a report about these experiments in the format of a scientific paper, which was peer-reviewed by their classmates according to a detailed rubric. Results of student learning are presented along with an assessment of the students' ability to participate in written scientific communication.

P42 **Laboratory Development Efforts in a Physics for Biologists Course**

Benjamin Geller, John Giannini, Kim Moore, Edward F. Redish, Wolfgang Losert, University of Maryland, College Park

We have piloted the first iteration of a new physics course for biology majors at the University of Maryland aimed at developing scientific competencies. The curriculum has been developed by an interdisciplinary team of physicists, biologists, and biophysicists, and involved departures from the traditional introductory physics curriculum in making decisions about what physics topics are most relevant for biology. The development process has also been deeply connected to an ongoing conversation among physicists, chemists, and biologists about creating a common thermodynamics across the scientific disciplines. This poster describes our initial efforts to create authentic laboratory experiments for the course.

P43 **The Advanced Spectroscopy Laboratory Course at Miami University**

Burcin Bayram, Mario Freamat, Miami University

The course of Advanced Spectroscopy of Atoms and Molecules (PHY442/542) at Miami University has both lecture and laboratory components and focuses on quantum phenomenology using spectroscopy as a tool. The course goal is to create opportunity for the students to work on a wide range of stimulating experiments, designed to deepen their understanding of the underlying Physics in the various subfields of spectroscopy, to develop laboratory and analytic skills, to improve their oral and written communication abilities, and to prepare them for advanced physics research. Moreover, the physics majors get involved in substantive undergraduate research projects. An experiment particularly evocative for the spirit of our course employs laser induced fluorescence from iodine molecules to observe their vibrational and rotational bands.

P44 **Lasers and Optics open-ended projects at Bethel University**

Chad Hoyt, Sarah Venditto, Dan Mohr, Andrew Stephan, Bethel University

We describe three open-ended lab projects developed in upper-level courses by students at Bethel University. We also describe laser cooling research that integrates several open-ended projects.

In the first highlighted project, students constructed an external cavity diode laser that is tunable over several nanometers about a central wavelength of 633 nm for use in iodine spectroscopy. Using saturated absorption techniques, they observed saturation dips corresponding to the hyperfine components within a Doppler-broadened feature. The second project comprised a small, simple Michelson interferometer that was used to measure the index of refraction of air, argon, carbon dioxide, sulfur hexafluoride, and helium. Students measured n-1 of air, CO2, Ar and SF6 with a relative uncertainty of nearly 10^-3, which was limited by the uncertainty in cell length. The third highlighted project demonstrated quantum optics by using an argon ion laser to create pairs of 915.8 nm correlated photons through spontaneous parametric down-conversion. One of the photons was sent through a Mach-Zehnder interferometer to realize single-photon interference. The coherence lengths of a single photon were measured when long-pass and 10-nm bandpass filters were placed before the avalanche photo diode used to detect the photons.

Student researchers recently realized a lithium magneto-optical trap of ~10^7 atoms with a temperature of ~500 microkelvin. This research project is a collaboration of students over the past several years and has integrated multiple open-ended projects from Lasers, Optics, and Senior Research courses. These include a sub-picometer wavemeter, external cavity diode lasers, and characterization of a semiconductor tapered amplifier.

P45 **A Course to Prepare Physics Students for the Research Laboratory**

David G. Haase, Hans Hallen, and David P. Kendellen, North Carolina State University

At NC State more and more undergraduates participate in physics research, even beginning as sophomores. However, the Advanced Laboratory course, which is meant to prepare students for the research laboratory experience, is a senior-level course. Several of our faculty have urged that the students be prepared earlier and become acquainted with laboratory procedures, data acquisition and analysis and other research issues. In response we created and piloted a new sophomore-level course entitled "Instrumentation and Data Analysis for Physicists." The two-credit laboratory course meets in two 2-hour sessions per week. In the class the students work on basic electronic circuits used in the laboratory, and data acquisition using LabVIEW. There are also exercises or projects on laboratory safety, data analysis, finding research literature, reporting research results and preparing machine shop drawings. The topics were selected by surveying the research faculty. There is no text for the course and students are meant to use the web to find data on devices and applications. The students are graded by two exams, including a lab practical, their homework reports and by the quality of their laboratory notebooks. The new laboratory course is now a graduation requirement for physics majors at NC State.

P46 **The laboratory and the integral development of the students**

David Mendez Coca, Universidad Internacional de la Rioja

The laboratory has been studied much, especially the design and the effects in the comprehension of the science concepts. Moreover, it is said that the laboratory stimulates the students' motivation. However, what other dimensions of the human being can these works favor by the help of these activities? The study has been realized with students of the first year of college in Spain by a test at the end of two academic courses. The students had two practices every week, before they had several subjects with a few practices during secondary school. It is possible to conclude with the results of the test that the laboratory practices can develop characteristics in the students as the reflection towards the nature and in general before the life, the search of explanation before the phenomena that they observe in their ordinary life, an improvement in the planning and organization in the life.

P47 **Will a magnet fall freely in a superconducting tube?**

Dr. Greg Severn, Mr. Tim Welsh, University of San Diego

A common demonstration of Lenz's law and of Faraday's law of Magnetic Induction is to drop a strong rare earth magnet through a tube of conducting material, typically copper. The result is that the magnet falls far slower than free-fall speeds due to the resistive damping that arises from induced electron currents in the metallic tube wall. The standard follow up question to this demonstration is to ask of students what would happen in the case of a superconducting tube. There are various (conflicting) answers given in the popular press. We have performed the experiment, for the first time we believe, and we show that the magnet remains suspended indefinitely, so long as superconductivity is maintained in the tube. Comparison with theory will be discussed.

P48 **Cat lapping: a fluid physics project for undergraduate students**

Dr. Katrina Hay, Matthew Hubbard, Pacific Lutheran University

In addition to having broad applicability in science, the study of fluids offers an opportunity for curiosity-driven research training, appropriate for senior thesis-type projects. In my fluid physics phenomenological approach, the student asks a "driving question" and designs (hands-on) observational experiments. This leads to a better understanding of theory. During the second phase, the student participates in quantitative experiments to investigate the validity of equations, concepts or to investigate new phenomena. This type of research uses inexpensive common laboratory materials that make it accessible at many levels. I will present an experimental investigation of cat lapping completed by a student researcher under my mentorship.

P49 **Student Designed Experiments in Advanced Lab: A Carleton Experiment**

Dwight Luhman, Carleton College

Carleton College's advanced lab course is taught over a ten-week academic term. The course is divided into three lecture meetings and one four hour lab meeting per week. This compressed schedule creates a challenging environment to teach the multifaceted nuances of experimental physics. In an effort to expose students to the full range of experimental physics from experimental design through data analysis and to provide an authentic experience in experimental physics, student-designed experiments were implemented in the latter portion of the course this year. Seventeen students were divided into six lab groups. Each group was required to develop an idea for an experiment (usually from existing literature or discussions with the instructor), draft an experimental proposal, revise the proposal based on instructor and peer feedback, and then carry out the experiment. The experiments had not been done previously at Carleton College, but relied on available (or buildable) equipment and instrumentation. The experiments ranged from studying the physics of liquid drop pinch-off to measuring the mass of the muon. In this presentation I will briefly provide the scope of experiments undertaken by the students and present the benefits and shortcomings of using the pedagogical technique of student-designed experiments in an advanced lab course.

P50 **Characterization of a Dichroic Sheet Polarizer**

Ernest R. Behringer, Eastern Michigan University

Students are typically exposed to polarization phenomena, including the action of ideal linear polarizers, during the introductory course in electromagnetism. Students begin to learn about the behavior of real polarization optics during the intermediate course in optics. At Eastern Michigan University, our intermediate optics course includes a laboratory that meets weekly for three hours. One of these laboratory meetings is devoted to characterizing a dichroic sheet polarizer through the use of a visible diode laser beam and measurements of the orientation dependence of the beam intensity transmitted by a single polarizer and by two polarizers. Students combine these measurements with a simple computational model of the transmitted intensity to characterize the dichroic sheet polarizer and gain an appreciation of the observable behavior of real polarization optics.

P51 **Creating Sustainable Change in Upper-Division Laboratory Courses at a Large Research University**

Heather Lewandowski, Benjamin Zwickl, University of Colorado

Courses at a large research university are often taught by a large number of faculty members. This can present a challenge when transforming courses because a large number of faculty have to buy in to the transformed course structure. We highlight the steps we took to create widespread faculty support for significant transformations of the senior-level advanced lab course at the University of Colorado-Boulder. The process began with observations of the original course, followed by the development of consensus learning goals, renovation of the space, purchasing new equipment, redesigning curriculum, and finally assessing student learning. We demonstrate how physics education researchers can form a constructive relationship with the faculty to combine the expertise of traditional faculty with a research-based approach to create sustainable positive change to an upper-division laboratory course.

P52 **Initial work on Experimental Plasma Station for the undergraduate curriculum**

Jeremiah Williams, Wittenberg University, Andrew Zwicker and Stephanie Wissel (Princeton Plasma Physics Laboratory), Jerry Ross (Shawnee State University)

Plasmas are a type of an ionized gas that constitutes the fourth and most common state of matter in the visible universe. In addition to providing a wealth of applications from all areas of classical physics, this phase of matter plays an important role in many industrial applications and will likely play a key role in future energy sources. Despite this, plasma physics does not often appear in the undergraduate curriculum. This is particularly true in the advanced lab setting, where most experiments involving plasmas require the use of fairly complicated and complex experimental setups. In this poster, we present preliminary work on the design of a simple experimental setup will allow for range of experiments using plasmas as the experimental medium that covers many areas of classical physics and can be used throughout the undergraduate physics curriculum. The apparatus is designed to be easy to implement that can be replicated at institutions, regardless of the presence of local expertise, and to support a number of possible experiments in order to bring the cost per experiment to a reasonable level.

P53 **Electrical Circuits for Bioinspired Applications**

Jon Erickson, Washington and Lee University

A new course emphasizing topics at the intersection of biology and physics, titled "Bioengineering and Bioinspired Design," was recently launched at Washington and Lee University (Lexington, VA). The course features a 6-week long, open-ended research project, chosen by the student group, in consultation with the instructor.

One such project seeks to develop means of controlling insect locomotion via extracellular neural stimulation--i.e., making cyborg insects. The electrophysiological response can also be measured. This project serves as a natural conduit for learning about various types of standard electronic elements (logic gates, D/A converters, FET switches, op-amp-based summer, buffer, active filters); practical construction techniques (component selection, PCB layout and fabrication, soldering); as well as testing and debugging. Students also learn to apply RC circuit concepts (transient and step response) to model the electrical properties of neurons in response to extracellular voltage- and/or current-controlled stimuli. They must also consider how microelectrode geometry and implantation site selection can be critical for the efficacy of the stimulus.

Another project sought to develop a discrete-component-based circuit which mimics the shark's exquisitely sensitive electrosensory system. Concepts and construction techniques similar to those described above are utilized.

An underlying theme for these bioinspired projects is that electronic instrumentation is a powerful, widely applicable skill. Instructor assessment and course evaluations indicate that these interdisciplinary projects facilitate a meaningful learning experience and that students are inherently enthusiastic about them (it's their brainchild after all!).

P54 **Measuring the quality factor of a resonator with a lock-in**

Jonathan Newport, Gregg Harry, American University

Dual-phase lock-in amplifiers are capable of measuring the in-phase and quadrature components of an AC-signal with respect to a given reference signal. Students already familiar with producing Bode-plots for high-pass, low-pass and resonant circuits via calculations and time-consuming oscilloscope measurements are introduced to the lock-in amplifier through the reproduction of these plots with phase-sensitive detection. Coupled with a dual-channel function generator under computer control, the lock-in amplifier is capable of measuring the quality factor of a resonator, such as a crystal oscillator, in both the frequency and time domains. This tool was initially developed to find and measure resonant modes of both high- and low- quality factor resonators to determine the mechanical loss in mirror coatings for the LIGO collaboration. It has since found use in the advanced undergraduate laboratory as an instructional tool and training exercise for those wishing to pursue LIGO research.

P55 **Design and Characterization of an Optical Trap in the Advanced Lab**

Joseph Kozminski, Elizabeth DeWaard, Marek Ziebinski, Chuck Crowder, Lewis University

Single beam gradient-force optical traps, or laser tweezers, are useful for manipulating small particles, molecules, and biological specimens like cells or bacteria. In this Advanced Lab project, students designed and constructed an optical trap using a 532 nm laser with a measured power output of 34 mW, a 40x microscope objective, and various optical components. They also designed a method to control the sample using a linear motorized stage and implemented a system for imaging the trapped particle using a digital microscope camera. An optical trapping strength on the order of 0.1 pN was measured using 3 micron polystyrene spheres in a distilled water solution. In making the trap strength measurements, two unexpected anomalies were encountered and subsequently studied — asymmetric trapping strengths on opposite sides of the trap and the presence of multiple traps. This project demonstrates the design, experimentation, and analysis process expected of students conducting a capstone laboratory project (i.e. the Advanced Lab "major project"); and it allows the students to reinforce and apply material learned in other courses, Optics in this case, in their Advanced Lab experience.

P56 **Developing Professionalism in a Sophomore-level Experimental Physics Class**

Linda Winkler, Juan Cabanela, Stephen Lindaas, Ananda Shastri, Minnesota State University Moorhead

Our experience with sophomore-level physics majors is that they still perceive themselves as students in classrooms, rather than budding professional scientists. The sophomore year is a critical one for personal growth and commitment to the field, and we have found that a year-long experimental physics class can be crucial to developing the budding physicist. Our sequence develops professionalism through having students work in groups, and communicate both orally and in writing with peers as well as the faculty. The communication goes beyond the walls of the classroom, as students develop and review articles for JAUPLI (peer-reviewed online Journal of the Advanced Undergraduate Physics Laboratory Investigations), and develop a poster to be presented during our campus-wide Student Academic Conference. The professionalism is developed in a supportive environment that includes: intensive faculty/TA interactions (the course is team-taught), conceptual development of the investigations modeled on our introductory "ABC" labs, and intensive tutorials on data/error analysis. Structure and components of the course will be presented, along with samples of student work.

P57 **The ALPhA Immersions Program — Assessment of the First Two Years**

Lowell I. McCann, University of Wisconsin - River Falls
Heather Lewandowski, University of Colorado

Starting in 2010, ALPhA (the Advanced Laboratory Physics Association) began offering a unique set of workshops for faculty who teach non-introductory physics laboratory courses. This program, the ALPhA Laboratory Immersions, offers intensive, hands-on instruction over the course of 2-3 days so that the participants can learn an experiment well enough to teach it to their own students. In this poster, we will present the preliminary assessment of the first two years of the Immersion program. This work has been supported by NSF grant DUE-1106928.

P58 **Assessing student understanding in upper-division analog electronics courses***

MacKenzie R. Stetzer, University of Maine
Christos P. Papanikolaou, University of Athens
David P. Smith, University of Washington

While there are many important goals of laboratory instruction, particularly in upper-division courses, relatively little work has been done to assess the impact of such courses on students. As part of an ongoing, in-depth investigation of student learning in upper-division laboratory courses on analog electronics, we have been examining the extent to which students enrolled in these courses develop a robust conceptual understanding of analog electronics (one of many course goals). We will highlight the development and use of written questions on diode and op-amp circuits that have been instrumental in probing student understanding in sufficient depth to identify specific conceptual and reasoning difficulties. We will also illustrate the role such questions may play in revealing weaknesses in the traditional treatment of certain electronics topics and in informing modifications to instruction.

*This work has been supported in part by the National Science Foundation under Grant No. DUE-0618185.

P59 **Advanced Labs in Biomedical Physics to Extend the Boundaries of the Traditional Physics Major**

Maria Babiuc-Hamilton, Marshall University

Statistics show that about 75% of all physics departments offer a bachelor's as their highest degree, but produce only 45% of all the physics bachelor's degree. There is also a clear trend for physics students to take additional course work for a double major, or to change major. Thus, although the number of students enrolled in physics graduate programs has been steadily increasing, small to medium departments struggle with low enrollment and are commonly forced to reduce their degree offerings to just the bachelor's. In order to be competitive and to accommodate the current tendency, we proposed to offer a number of flexible tracks towards a Bachelor of Science (BS) degree in Physics with a number of different Areas of Emphasis (AoE), in addition to a traditional standard BS in Physics. Among those, starting the Fall of 2012, the physics department at Marshall University will offer two new areas of emphasis: in Bio and Medical physics - designed for those who are interested in future study in biophysics, medical physics, biotechnology, or medicine. The backbone of the AoEs is the Biomedical Physics course PHY 350, an ambitious core III, 4 credits course, which combines lecture and advanced labs providing a description of physics methods important to modern biology and medicine. During the labs, students study thermal imaging with the use of infrared camera, computed tomography by the X-ray apparatus, and nuclear magnetic resonance spectroscopy with the NMR spectrometer. A Major Research Instrumentation (MRI) program was recently approved and made possible for the acquisition of an Atomic Force Microscope. Another MRI program for a state-of-the-art Electron Paramagnetic Resonance (EPR) spectrometer is under consideration by NSF. If funded, new labs will be added, to explore the radiation damage in biological systems by detecting, identifying, and characterizing radicals in the sample. Therefore, initially centered on exploring physics applications for medicine, the course will be extended to include new physics and modern experiments in cellular biology.

P60 **Assessment and Upgrade of Upper Level Undergraduate Laboratory Instruction**

Mark Gealy, Concordia College

The physics department at Concordia College has just completed its first of three years in the implementation of an integrated studio instruction model for all algebra- and calculus-based introductory classes. Our intermediate and upper level physics laboratories are in need of considerable upgrade, having been put 'on hold' as significant resources are devoted to modifying entry-level courses.

For our majors in their second year, we offer a two-semester introductory modern physics sequence with associated laboratories. Historically, activities in these labs have mirrored the topics covered in the lectures, including relativity, atomic, statistical, condensed-matter, nuclear physics and electronics. Current consensus of our staff is that these students would benefit more from activities targeting broader experimental competencies, such as computer interfacing of instruments, computational modeling, error analysis and technical writing. If necessary, we will abandon the assumption that each experiment must pertain to the specific subject of that week's lecture.

Majors in their junior or senior year take a one-semester dedicated advanced physics laboratory course that requires them to carry out a half dozen or so experiments of significant complexity, and prepare formal papers. This course is also in need of modernization, and we are seeking ways to effectively team teach it in order to draw upon the diverse experimental expertise from among our faculty.

The poster outlines our proposed trajectory of laboratory reform and solicits ideas and suggestions from workshop colleagues.

P61 **An Undergraduate Research Project Incorporating LabVIEW to Measure Temperature Dependent Lifetimes in a Phosphor**

R. Seth Smith, Charles J. Nettles, Jonathan J. Heath, Francis Marion University

In the Spring of 2012, a group of undergraduates varied the temperature of a LaSO4:Eu phosphor and performed performed fluorescence lifetime measurements on one of its transitions. The phosphor's temperature was varied by using a thermoelectric (TE) cooler that was driven by a temperature control circuit. The temperature was monitored with a thermistor. The students learned LabVIEW by using John Essick's excellent text, entitled Hands-On Introduction to LabVIEW for Scientist and Engineers. The students wrote a LabVIEW program that allowed the user to enter a set point temperature for the TE device and used feedback from the thermistor to adjust the temperature of the phosphor until it reached the set point. The phosphor was excited with the 337 nm output of a Nitrogen laser. An Oriel monochromator was used to disperse the fluorescence. The lifetime for a particular transition was determined by photomuliplier measurements of the fluorescence.

P62 **Fission-Neutron ToF Spectroscopy: A Simplified Advanced Teaching Laboratory**

Ramon Torres-Isea, F. D. Becchetti, M. Febbraro, M. Ojaruega and L.Baum, The University of Michigan

We have developed a simplified 252Cf fission-neutron ToF advanced laboratory experiment to provide undergraduate and graduate students with an introduction to fission and neutron ToF techniques. The experiment utilizes low-cost sealed, depleted 252Cf well-logging neutron sources together with plastic scintillators and simple NIM-based electronics. The technique is adapted from methods in use at the University of Michigan for evaluating neutron detectors using digital pulse analysis. The teaching apparatus described also is suitable for other neutron-related experiments such as neutron activation, including nuclear forensics.

P63 **Berkeley's two-semester advanced lab sequence**

Thomas Colton, Robert Jacobsen, Donald Orlando, University of California Berkeley

The first course, Instrumentation, includes one 75-minute lecture and two or more 4-hour lab meetings per week introducing students to electronics and data acquisition. The first nine weeks focus on designing and building circuits, including JFET circuits and op amps. In the next three weeks, students write programs in LabVIEW to acquire, process, and analyze data as well as control an experiment. The course ends with a three-week final project for which students propose, design, and build an experimental device that involves circuits and usually software. Recent examples include an amplitude-retaining bat detector, rf and optical theramins, pulse oximeter, AM laser communicator, color detector and analyzer, and ultrasonic termite detector. The second course, called the Experimentation section, is organized around 20 experiments that are permanently set up in lab. Each pair of students selects four of these to perform over the semester and signs up for 6-10 afternoons on the station for that experiment. Many of the experiments replicate Nobel Prize-winning studies of the last century, covering a wide range of physics topics and lab techniques. Examples include atom trapping, beta ray spectroscopy, Brownian motion and intracellular transport, CO2 laser, Compton scattering, Hall effect in a plasma, holography, Josephson junction, muon lifetime, nonlinear spectroscopy and magneto-optics, NMR, optical trapping, optical pumping, and Rutherford scattering. Each student gives an oral report and three formal written reports on their experiments. Student interns each summer work with faculty and staff to build new experiments and upgrade old ones.

P64 **A Simple Scanning Fabry-Perot Interferometer for High-Resolution Spectroscopy Experiments**

Thomas Moses, Knox College

The Fabry-Perot interferometer is a useful tool for high-resolution spectroscopy experiments and can be investigated as an interesting system in its own right and for understanding the physics of lasers. We describe an easy-to-build scanning Fabry-Perot interferometer using inexpensive, commercially available parts. By using low-cost, off-the-shelf beamsplitter mirrors in the interferometer, we greatly reduce the inconvenience or expense of a custom mirror fabrication. We find that the instrumental finesse is limited less by low mirror reflectivity than by flatness considerations, which can be mitigated by restricting the instrument's aperture. We find a typical finesse around 8-9, which is sufficient for many experiments. As examples, results are presented showing measurement of the instrumental profile and the wavelength of helium-neon laser light, and measurement of the Zeeman splitting in mercury, a standard high-resolution spectroscopy experiment.

P65 **A new method to investigate the side-axis spectrum of He-Ne laser**

Weifeng Su, Anxun He, Yifan Chen, Cuiqin Bai, Yongkang Le, Fudan University, China

The experiment of side-axis spectrum of He-Ne laser is to investigate the change of the population distribution of the corresponding energy levels with or without laser output by measuring the intensity of spontaneous spectrum. The side-axis spectrum can not only show which lines are created by the stimulated radiation, but also reveal the phenomenon of population inversion in the complex of He-Ne plasma emission spectrum. Side-axis spectrum is generally detected by movable mirror grating spectrometer with a photo-multiplier tube as the detector. This kind of spectrometer scans wavelength through grating rotation and record the intensity of each wavelength at a time. The entire spectral measurements usually take a few minutes or even longer. In order to reduce the intensity fluctuation, a beam chopper and a lock-in amplifier are necessary to get a reliable result. It increases both the cost and the complexity of the equipment. We adopted a micro grating spectrometer for the record of the side-axis spectrum from a He-Ne laser tube. With a CCD as a detector, the entire spectrum can be recorded within tenth of a second. Thus, the lock-in amplifier is no more necessary for the setup. During the laboratory, the students can spend more time on studying laser physics instead of the operation of a lock-in amplifier.

P66 **Undergraduate Terahertz (THz) Exercises for Advanced Laboratory at Morehouse College**

Willie S. Rockward, Rudy Horne,Joshua Burrow, Ronald Celestine, Pierce Gordon, Dwight Williams, Colin Watson, and Thomas A. Searles, Morehouse College

The undergraduate terahertz (THz) imaging and research laboratory exercises are designed to expose undergraduate students to THz technology. Instructional laboratory experiments using THz optics, detectors, and sources will be useful for STEM majors to learn imaging and spectroscopy principles associated with concealed weapons and explosive objects. We are designing and prototyping an instructional lab manual for undergraduates that will capture a wide range of THz experiments and modeling simulations with increasing complexity. We will present selected experiments, simulations, and ongoing developments.

SESSION XIII: DEMO SESSION

"PIRA's Advanced Demo Show"

Friday, July 27

SESSION XIV: PLENARY SESSION

The ALPhA Immersion program: Helping bring BFY ideas back home

Invited: Lowell McCann, University of Wisconsin--River Falls

The ALPhA Laboratory Immersion Program grew out of the 2009 Advanced Lab Topical Conference, where ALPhA members recognized that short workshops describing and demonstrating experiments were mostly valuable in giving faculty a taste of what *could* be done by students. In order for most undergraduate instructors to be able to implement a new experiment (usually outside their field of expertise), they would need a longer, hands-on opportunity - under the guidance of an experienced mentor - to learn the new experiment well enough to teach it themselves.

This talk will provide an overview of the Immersion program: what has happened in the past three summers, what we've learned about creating a successful Immersion, how the Immersions can facilitate the dissemination of experiments developed through NSF grants, and how the Physics community can help shape future Immersion offerings. Conference participants will be asked for their feedback on the Immersions program and their suggestions for future Immersion sites and experiments via an online survey distributed at the end of the BFY conference.

SESSIONS XV AND XVI: BREAKOUT SESSIONS

"Methods Courses" vs. "Design Courses:" a false dichotomy?

Teaching Experimental Uncertainty

Instruction in Writing & Revision in the lab

Sophomore-level physics & instructional labs

Updating BFY instructional labs in Electronics

Bio-related instructional labs in Physics

BFY instructional labs in Optics & Lasers

Photon-based labs in Quantum Mechanics

Nano- and Condensed Matter/Materials Physics instructional labs

Statistical Physics/Soft Matter labs

SESSION XVII: PANEL DISCUSSION

"Case Study: Evolution of tools for assessing impact of labs"

WORKSHOPS

W00 **Using a Chaotic Pendulum to turn Sophomores into Experimentalists**

Marty Johnston, Univ. of St. Thomas

Quantifying the behavior of a nonlinear pendulum provides the setting for a semester long introduction to experimental methods. Students learn electronics, LabVIEW, data acquisition, and numerical analysis as they build stepper motor controllers, hardware timed data acquisition systems, and analysis software used to study the rich behavior of a chaotic pendulum.

The course is designed to build both the skills and confidence that students need to take on the ill-defined and difficult problems that they will see in the future. The first two thirds of the course is devoted to building the apparatus and controls, the data collection system, and writing the basic analysis software displaying Poincare' sections and bifurcation diagrams. The physics, technical topics and mathematical tools are presented as the topics become relevant. Homework problems and written work is assigned and tested on throughout the semester. Students work at their own stations but discuss problems with their peers in a collaborative environment. During the last third of the course students conduct individual explorations of different aspects of the chaotic pendulum. These investigations vary from measurements of Lyapunov exponents and correlation dimensions, to building FPGA stepper motor controllers, to studying chaotic magnetic dipole-dipole interaction. The semester concludes with a poster session where students present what they have been working on.

The apparatus consists of a pendulum operating in a variable magnetic potential. Driving torque is controlled by eddy forces, monitored by hall sensors and modulated by a stepper motor. Optical sensors provide information about position and driving phase. The system is relatively inexpensive which allows an entire course to be equipped at a reasonable cost. In this workshop I will introduce the hardware and software used in the course and discuss how they are used achieve our educational goals for the course.

W01 **Statistical/Nonlinear Physics with Subwoofers**

David Bailey, Univ. of Toronto

The least expensive experiment in the University of Toronto Advanced Physics Lab has one of the largest phase spaces for student exploration. We originally set out to just develop an experiment to study the unknotting and entropy of chains, but soon realized even more fun is possible with a subwoofer, an amplifier, and a frequency generator. In addition to the physics of chains, which are models for polymers, DNA, and other interesting biomolecules, versions of the system can be used to observe nonlinear waves in liquids and particulates, to study chaotic bouncing balls, and to try to create experimental models of fluids and crystallization.

Workshop participants will play with two different systems: one has a basic subwoofer that is capable of knotting and bouncing ball experiments, and one with a modified subwoofer that can be used for more varied explorations. A picture of the latter system can be found at http://www.physics.utoronto.ca/~phy326/knot/index.htm, along with more information on our basic chain experiment. Information on a Faraday waves experiment using a more powerful and linear shaker can found at http://www.physics.utoronto.ca/~phy326/far/index.htm.

The basic experiment only requires a stopwatch and notebook for data acquisition, and basic fitting software for analysis, but the workshop may also demonstrate Python/ vPython video, analysis, and simulation tools that are under development.

W02 **Synchronization and Encryption with a Pair of Simple Chaotic Circuits**

Ken Kiers, Taylor University

In recent years, students in Taylor University's Physics Capstone Course have built pairs of nearly identical chaotic circuits that they have used to encrypt, and subsequently decrypt, a signal. These circuits can be constructed using inexpensive parts and can also be modeled very accurately using relatively simple differential equations. Students have found the construction and analysis of these systems to be technically challenging, yet, ultimately, very rewarding. Two methods of encryption have been studied to date; both methods will be demonstrated in this workshop. In the first approach, a digital potentiometer in one of the chaotic circuits is switched back and forth between two settings (corresponding to "ones" and "zeros") in such a way that a binary data stream is encrypted within the chaotic output of the circuit. The other circuit is used to decrypt this data stream. In the second approach, a small analog signal is added to the chaotic output of the first circuit, and is then extracted by the second circuit. In both approaches, the decryption of the signal relies on the fact that the second circuit is able to synchronize its output to the output of the first circuit if the two circuits are identical to each other. Changing the value of one of the resistors in the first circuit (as in the first approach), or adding a spurious signal to its output (as in the second approach), causes the second circuit to be unable to synchronize with the first. In both cases, comparison of the output of the second circuit to that of the first allows for the recovery of the original signal.

Reference:

Ken Kiers, Dory Schmidt and J.C. Sprott, "Precision Measurements of a Simple Chaotic Circuit," Am. J. Phys. 72, pp. 503-509, 2004.

W03 **Fundamentals of low-noise electrical measurements: Ground loops, interference, shielding, etc.**

Walter Smith, Haverford College

In this workshop, participants will run through the highlights of a series of labs that teach students about amplifier noise, Johnson/Nyquist noise, capacitively- and inductively-coupled interference, and ground loops. Students learn both about the origins of these usually undesired signals, and how to minimize them. The labs require a low-noise amplifier such as a Stanford Research Systems SR560. Optionally, the students can instead design and build their own amplifiers, if time permits, based either on op amps or on instrumentation amplifier integrated circuits. In a culminating exercise, students measure the Johnson/Nyquist noise of a resistor at liquid nitrogen temperature. Workshop participants will be furnished with complete lab write-ups including conceptual questions for the students, complete lecture notes, supporting problem sets and solutions, and sample exam questions and solutions.

W04 **Real-world projects for digital & analog electronics courses**

Sean Bentley, Adelphi University

Participants in this workshop must bring along their own laptops.

With the limited exposure most physics undergraduates get to circuitry, the pieces can often seem disconnected with little tie to real-world applications. To overcome this problem, it is important to expose these students to projects that bring together many of the concepts from the semester. In this workshop, we will explore two examples of application-based semester projects I use in my courses. These include a real-time clock programmed in VHDL on an FPGA educational board for digital circuits, and an AM radio built from discrete components for analog circuits.

Rather than giving the students explicit instructions on the designs, each is asked to build their designs from pieces they have learned throughout the semester. To avoid students just taking a design from the web that they don't understand, when they demonstrate their working designs, they must be able to explain what each section does. Upon completing such projects, the students not only feel a sense of accomplishment, but truly appreciate the importance and connection of many topics learned.

W05 **Arduino: PID-controlled thermostat**

Sean Robinson, MIT

Participants in this workshop are requested to bring their own laptops along, but the laptops are not required.

This workshop will show a simple application of Arduino microcontrollers to solving a common Advanced Lab apparatus problem: regulating the temperature of an oven via modulating the current supply to its resistive heating elements using a PID-controlled feedback algorithm. Consistent with the experience of the presenter, this workshop will be given from the perspective of starting with zero knowledge of Arduino design or programming, and proceeding to a working device without ever becoming and expert.

W06 **Teaching with Arduino**

Andy Dawes, Pacific University

Participants in this workshop must bring along their own laptops.

A hands-on introduction to the Arduino programmable circuit board. The Arduino is a small self-contained micro controller platform that can be easily integrated into analog and digital electronics projects. Programmed in C++ and connected to a computer via USB, the Arduino eliminates many of the traditional hurdles that prevented practical micro controller use in the classroom setting.

You will learn how the Arduino works and how to integrate it with your curriculum on many levels. Arduino can fit in anywhere, from a first-year unit on electronics to an upper-division electronics course and senior research projects. If you are new to Arduino or new to teaching with Arduino, this is the place to start. There are several other Arudino workshops at BFY where you will be able to extend what you learn here.

W07 **Arduino as a "gateway drug"**

Eric Ayars, CSU-Chico

Participants in this workshop are requested to bring their own laptops along, but the laptops are not required.

The Arduino can do a lot, but sometimes you don't need to do that much. In many cases, it's simpler (and more economical) to use a smaller microcontroller such as the ATtiny series rather than the full Arduino platform. Fortunately, the same user-friendly Arduino IDE can be used to program these smaller microcontrollers: in fact, you can use the Arduino as the programmer. In this short workshop I'll demonstrate how to do this, and show some of the uses we've found for ATtiny microcontrollers in our upper-division labs.

W08 **Using Cypress Programmable System on a Chip as part of a electronic instrumentation course**

Mark Masters, Indiana Univ-Purdue Univ. Fort Wayne

Participants in this workshop must bring along their own laptops.

The Cypress Programmable System on a Chip (PSoC) is different from a traditional microcontroller because it incorporates analog circuitry such as op-amps on chip. These analog elements are defined through software. The inclusion of these analog components makes building instrumentation somewhat simpler because of the greatly reduced chip count. We use PSoC's exclusively in our electronics instrumentation course in which students are expected to design, test, and build an electronic instrument and use that instrument to perform an investigation.

In this workshop we will go through the basics of creating a program for the PSoC. Workshop attendees will use a PSoC to build a simple electronic instrument (there will be several different options) and hopefully test it.

A participant in this workshop will need to bring a computer with Windows XP or better installed (or on a mac at least running vmware fusion, virtual box does not work properly). Software available at http://www.cypress.com/?id=2492&source=header - Psoc Designer and PsoC Creator should be installed prior to the workshop. Each participant will receive their own PsoC CY8KIT-001 from Cypress Electronics - development and prototyping kit.

W09 **Introduction to FPGA's**

Matthew Vonk, Univ. of Wisconsin - River Falls

Participants in this workshop must bring along their own laptops.

Field Programmable Gate Arrays (FPGA's) are user configurable integrated circuits that can be designed to perform specific tasks with true parallelism, unlike microprocessors which operate sequentially. Their flexibility, ease of use, and relatively low cost has made them increasingly popular in a wide variety of applications.

This workshop would show attendees how to use the Xilinx ISE development software (a combined smart-editor, simulator, and synthesizer which is available for free on the Xilinx website) to interface with Digilent FPGA-boards. The boards are extremely user friendly, with lots of built-in inputs and outputs, and are also very reasonably priced.

The workshop will show users the basics of writing, compiling, and instantiating code and will step attendees through several practical applications.

W10 **FPGA Coincidence Module**

David Branning, Trinity College

Many quantum optics experiments are making their way into the undergraduate laboratory, motivated by their effectiveness at demonstrating fundamental features of quantum mechanics. These experiments usually involve the detection of two or more photons simultaneously at different detectors, called "coincidence counting." We have developed a small, inexpensive, flexible, and intuitive coincidence-counting module to be used in conjunction with single-photon detectors, that anyone can build. In this workshop, we will discuss how to assemble and operate the module, and outline some of its uses when paired with a parametric downconversion light source.

W11 **Single Photon Labs**

Barbara Hoeling, CSU-Pomona

Quantum optics experiments are becoming more and more popular in the advanced student laboratory. With a blue diode laser beam impinging on an optically nonlinear crystal (beta barium borate BBO), pairs of entangled photons are created. With this heralded single photon source, quantum optics experiments such as anti-coincidence, single photon interference, and tests of local realism can be performed. Essential pieces of equipment for these experiments are single photon detectors, avalanche photodiodes (APDs) operated in Geiger mode that are capable of detecting individual photons. In most advanced student labs, the commercially available, fiber-coupled single photon counting modules by Perkin-Elmer/Excelitas are used. We are presenting single photon detectors developed at the University of Erlangen, Germany, which use either the APDs by Perkin-Elmer/Excelitas or by LaserComponents together with "home-made" electronics. We discuss their performance in comparison to the Excelitas product and their potential advantages in a free-space set-up.

W12 **Temperature Dependent Lifetime Measurements of Fluorescence from a Phosphor**

Jim Parks, University of Tennessee

This laboratory activity exploits the very efficient fluorescence of atoms that are constituents of solid state phosphor materials. Learning and working with fluorescence the student learns concepts and experimental techniques not just applicable to atomic physics but to a wide range of disciplines including chemistry and the life sciences. The objectives of this experiment are: (1) to study and investigate the principles of atomic lifetimes, (2) to learn experimental techniques for measuring lifetimes, (3) to study and investigate the energy pathways in a solid that fluoresces when excited, (4) to measure and analyze the temperature dependence of fluorescent light lifetimes (of a particular wavelength) emitted from a phosphor material excited with a nitrogen laser, LED, or other energy source, (5) to learn computer-based data acquisition and analysis procedures for measuring temperature dependent lifetimes, and (6) to learn a practical application for this technique. The basic apparatus can easily be adapted to incorporate other more advanced subjects such as signal processing, signal-to-noise investigations, and optics-based sensing.

1. Department of Physics and Astronomy, 401 Nielsen Physics Building, The University of Tennessee, Knoxville, Tennessee 37996-1200.

2. Sensors and Controls Research Group, Measurement Science and Systems Engineering Division, Oak Ridge National Laboratory, Oak Ridge, TN. 37831-6056.

3. Emerging Measurements Company, 9910 Kay Meg Way, Knoxville, TN. 37922.

W13 **Optical Spectroscopy/Zeeman Effect**

Greg Elliott, University of Puget Sound

The Zeeman effect offers a striking visual demonstration of a quantum system and provides a detailed, multi-faceted corroboration with the theoretical treatment. How can one see the effect and observe the various experimental dependences and not end up believing in quantum mechanics? At the University of Puget Sound the effect is first introduced at the sophomore level in Modern Physics, and then treated in full mathematical detail in senior level Quantum Mechanics. The seniors spend some time observing and quantifying the effect, as one of a few experiments that complement their theoretical studies. Students have also explored the effect in the advanced lab course, and as independent study and summer research projects.

Following an NSF sponsored workshop on advanced lab curricula in the 1990's, we built an Ebert spectrometer to observe and study the Zeeman effect and the fine structure of hydrogen.1 Our instrument has evolved over the years, and now consists of four elements: (1) a discharge source in the field of a permanent magnet, that illuminates an adjustable width slit, (2) an objective mirror (12" diameter f/8), (3) an Echelle grating on a rotary stage, and (4) a ccd camera detector. Working at high order (~20), the Echelle grating gives a resolving power in excess of 500,000 and a resolution of about .01.

A mercury discharge produces several transitions of interest for observing the Zeeman effect.2 The normal effect is observed for the yellow 1D2 1P1 transition at 5790.65 , yielding three lines. The anomalous effect is observed for the blue 3S1 3P1 at 4358.35 (six lines) for the yellow 3D2 1P1 transition at 5769.59 (nine lines) and the green 3S1 3P2 transition at 5460.74 (nine lines). The splittings and the line polarizations yield a quantitative test of the agreement with the predictions given by the Lande g-factor.

For the workshop I will give a brief tour of the instrument, discuss some of the experimental difficulties in its construction and operation, and demonstrate the effect for the mercury (and other) systems.

1. D. Preston and E. Dietz, The Art of Experimental Physics, Wiley 1991.
2. G. Herzberg, Atomic Spectra and Atomic Structure, Dover, 1944.

W14 **External cavity diode lasers and iodine spectroscopy**

Chad Hoyt, Bethel University

External cavity diode lasers (ECDLs) are common tools in undergraduate and graduate laboratories. One can tune and stabilize inexpensive laser diodes (as will be done here) to be used in contexts such as high precision optical metrology and spectroscopy experiments. Their relative ease-of-use, potential for customization, low price, and large choice of wavelengths make them accessible and interesting parts of undergraduate advanced laboratories.

The apparatus in this workshop will comprise components of a home-built external cavity diode laser system: machined mounts, temperature controller, precision current source, pzt driver for fine tuning, etc. Participants will have the opportunity to align and tune an ECDL at 633 nm. They will also scan the laser frequency for simple absorption spectroscopy in iodine vapor. Versions of this workshop have been offered at the AAPT summer meeting in Portland in 2010 and at an ALPhA Immersion at Bethel University in 2011. Participants will be offered schematics and a parts list for a home-built ECDL system based on a NIST design.

W15 **From Jones Matrices to Ellipsometry: Modeling and Measuring the Polarization of Light**

Ben Zwickl and Heather Lewandowski, Univ. of Colorado-Boulder

Every physics lab has a special moment where students, after hours of toil, compare their laboriously collected data with theoretical predictions. At this moment, neat and tidy theoretical predictions are viewed side-by-side with messy and complicated real-world results. How can we make the most of this educational opportunity?

At the University of Colorado Boulder we have partially answered this question by redesigning our senior-level Optics and Modern Physics Lab to emphasize creating, testing, and refining of models, whereby "model" we mean a simplified representation of a more complex system that has predictive power and specified limitations to its validity. By emphasizing modeling, students use the full suite of mathematical and computational tools from their lecture courses to make predictions about the behavior of real-world systems. In the lab, a model-based approach allows for an improved discussion of topics we previously neglected, such as systematic error and understanding various "black box" measurement tools.

A model-based approach can be applied to any experimental setup, but in this workshop we will demonstrate the transformation process from our older polarization lab to a model-based experiment. Students build up models of polarized light, starting with linear polarization and ending with arbitrary states of elliptically polarized light. They model optical components such as polarizing filters and quarter wave plates, and refine idealized models to account for systematic error effects in their actual equipment. In the end, mathematical models are developed that can be used to predict the outgoing light field from a sequence of optical components. Measurements of arbitrary polarization states can also be done using the computational model to fit results of the measured power transmitted through a rotating polarizer. The final challenge implemented during a student project was to use the same measurement techniques and computational modeling to infer the thickness and index of refraction of a thin film, a technique known as ellipsometry.

Mathematica is employed for computational modeling. LabVIEW is used in combination with low-cost USB data acquisition devices for quicker data taking. The experimental setup consists of a commercial HeNe laser, amplified photodetector, rotation stages, linear polarizers, and mounted lenses and mirrors. The equipment can be reused in a variety of optics labs.

At the end of this workshop you will be able to deliver a model-based polarization lab appropriate for the upper-division level. We will also spend a portion of the workshop discussing how your favorite labs at your institution can be adapted to incorporate aspects of modeling, including systematic error, and a deeper understanding of the experimental apparatuse

W16 Using Spatial Light Modulators to Teach Students Experimental Fourier Optics

Doug Martin, Lawrence University
Shannon O'Leary, Lewis and Clark College

A spatial light modulator (SLM) changes the phase and/or amplitude of light incident on the SLM. The SLMs we use alter the phase of the incident light via an array of 1024x768 9x9 μm pixels. What can these computer-controlled devices be used to do?

We use SLMs to teach students Fourier optics and Fourier transforms, experimentally. As an amplitude modulator (with the addition of polarizers), we use SLMs to create objects within a collimated laser beam. These objects can be imaged with a lens, or, by moving the lens, the Fourier transform of the object can be seen. A particularly simple use of SLMs is in a multiple-slit experiment, where the width of single slits, the spacing between slits, and the total number of slits are dynamically controllable. The single-slit diffraction pattern is a particularly simple Fourier transform; a multi-slit diffraction pattern is a nice application of the Array Theorem.

More interestingly, by placing the SLM in the transform plane of a single lens, the Fourier transform of an arbitrary object can be manipulated; a second lens is used to take the inverse transform and display the modified image. Regularly repeating features of an image can be removed — for example, in one lab, students are given the picture of this kitty in a cage (printed onto a transparency), and asked to remove the cage.

In the workshop, we will use SLMs to:

- perform a multi-slit diffraction experiment, with slit width and spacing changeable onthe fly
- perform 2-D crystal diffraction demonstrations, including quasicrystals
- remove the kitty from the cage using spatial filtering
- create computer generated holograms (along the lines of Thad Walker's Holography Without Photography).

W17 Optical Trapping in Biophysics

Tom Colton, UC-Berkeley

An optical trap, or laser tweezers, is a device used to manipulate objects between about 20 nm and several microns in diameter and to measure piconewton-sized forces on these objects. This scale of operation makes them a useful tool in biophysics to study mechanical properties of cells, organelles within cells, and single molecules involved in movement and force production. An optical trap is a good learning tool in the physics instructional lab because of the insight it gives into mechanical properties of biological structures, but also because of the physical principles of operation and particularly of the techniques used for calibrating position and force. In Berkeley's physics advanced lab course, students spend about 8 afternoons performing several types of calibrations and performing two biophysics experiments. Building and alignment of a trap could be a challenging semester-long project for a small class, though alignment of the Class 3b IR laser requires safety training and close supervision.

An optical trap is essentially a microscope incorporating a trapping laser and position-detection system. Traps can be made either by adding a laser beam path to a conventional microscope or by building the microscope and beam path from standard optical components. We took the latter approach, which makes the optics easier for students to see (though we shield the collimated IR laser beam with lens tubes for safety), and makes it easy to modify. For instance, last summer our students added a second laser to support fluorescence microscopy needed for a single-molecule experiment. Our trap is patterned after one developed for teaching and research at MIT. A somewhat more expensive version is available in kit form from Thorlabs. Our student write-up and information on experiment development is available on our course wiki at http://advancedlab.org. I also recommend the excellent write-up by Sean Robinson on his MIT Physics Junior Lab web site.

In this workshop, we will do the following activities:

- Practice trapping 1 micron Silica beads.
- Observe the effect of laser power on the motion of the bead.
- Record the position of the bead through the quadrant photodiode (QPD).
- Use the power spectrum of the QPD data and our understanding of Brownian motion to calibrate sensitivity and stiffness of the trap.
- Examine student-collected data on (1) E. coli flagellar swimming, (2) internal transport of vesicles in live onion cells, and (3) in vitro stall forces measured from single kinesin motor molecules.

W18 Simple Dynamic Light Scattering Apparatus

Bob DeSerio, University of Florida

A HeNe laser beam, incident on a sample of micron-sized spheres suspended in water, scatters into a random pattern of spots of varying size, shape, and intensity. The pattern results from the coherent superposition of the outgoing waves scattered from the spheres and because the spheres are in constant Brownian motion, the pattern changes in time. An avalanche photodiode detector is placed in the pattern to measure the random fluctuations in the light intensity. The autocorrelation function and the power spectrum of the photodiode signal are computed, averaged over time, and fit to predictions based on Brownian motion. The fitting model parameters are then used to determine the diameter of the spheres.

The apparatus will be available for use and complete construction and analysis details will be provided. The geometry of the source, scattering cell and detector will be discussed in relation to the scattering angle dependence of the intensity fluctuations. The circuit for the avalanche photodiode will be provided and the computer hardware and software for collecting and analyzing the signal will be demonstrated. The results for two sphere sizes as a function of scattering angle will be presented.

W19 Simple Experimental setup for demonstrating Surface Plasmon Resonance

Erik Sanchez, Portland State University

Plasmonics has become a very important focus of scientific research. Oftentimes the topic can be difficult to describe to students. The lab demonstrates an optical method for visibly showing the resonance condition. This setup can be easily replicated without the need for typically expensive components. The coating methodology allows for flexibility in coating precision and expense.

W20 Frontiers in Contemporary Physics Education: Gold Nanoparticle Photoabsorption & Quantization of Conductance Experiments

Jan Yarrison-Rice and Khalid Eid, Miami University

This BFY workshop highlights the new pedagogical format of our sophomore Experimental Contemporary Physics course. We strive to provide a strong underlying core of experimental skills in modern topics and, at the same time, encourage students to join faculty research groups. We follow a physics research model using experiments that explore contemporary physical concepts from ongoing faculty research projects. The experimental format shows students "how physics research is actually conducted!" The two experiments we will highlight, 1) Optical characterization of Au nanoparticles, and 2) Quantization of Conductance, were developed as a direct result of the nanoscience and technology research the co-leaders conduct in their own laboratories. Using this basic curricular plan, the course maintains a truly contemporary nature, while providing an introduction to the concepts and instrumentation skills necessary for our students to begin physics research.

1) We explore how surface area, volume and shape change material behavior via optical spectroscopy of Au nanospheres and nanorods

(NPs). White light induces a plasmon resonance in the metallic NPs which is measured spectrally. The transmission and scattering spectra of the Au NPs provide a measure how the spectral plasmon resonances reflect the particle morphology. The basic optical setup requires a fiberoptic light source and a reasonably inexpensive spectrometer, as plasmon resonances are quite broad. The excitation of charge carriers in a semiconducting nanowire is introduced next. Finally, both concepts are brought together by describing their application in a plasmon-enhanced nanowire-based biosensor. Students enjoy the visual nature of this experiment and the opportunity to align an optical system.

2) We demonstrate an extremely simple and inexpensive experiment to introduce atomic-scale confinement effects and particle-wave duality. A manual break junction in a gold wire is utilized to explore the quantization of the electrical conductance when the wire width is stretched to the atomic limit. A simple circuit reads the voltage across the break junction via LabView. Just before the wire breaks, the lateral confinement of the conduction electrons causes a step- wise increase in resistance with steps that depend on two fundamental constants of nature divided by an integer. This is due to the wave nature of the electrons that traverse the junction. This experiment is exciting for students because they can measure a complex idea like wave- particle duality with objects that they can "see."

In addition, we discuss how small adjustments make the experiments appropriate for more advanced students.

W21 **Granular Materials: A Low-Tech Advanced Lab Exercise**

Paul Dolan, Northeastern Illinois Univ.

Can an Advanced Lab be low-tech, but still be productive & fun? Consider some of the following questions:

- How many crates will fit in your truck?
- How much does your box of (cereal, candy, grain, marbles, push-pins, ...) settle during shipment?
- Can you use only half of the package of dry soup mix, and still have both peas and spice in your soup?
- How many jelly beans does that giant jar in the drug store REALLY contain? Why are the Brazil Nuts all at one end of the can?

These are the types of questions that studies of Granular Materials address. Experiments on Granular Materials can help answer these and other questions.

A granular material can be defined as any loosely interacting collection of (usually) solid particles. Depending on the conditions, a granular material can be best described as a solid, or as a fluid, or as a gas, or in some case not adequately as any of these, which makes this both an interesting and difficult field of study. Granular Materials is an area of study in physics that, while it has many important applications, is poorly understood on a fundamental level, and has become a recent area of much interest.

This is one area in which the experiment is not only more fun, but MUCH simpler than the associated calculation/modeling — even if you stay with monodisperse (all the same), spherical particles, the calculations can be daunting (especially in 3 dimensions). However, many of the measurements are simple (in concept), but still have a number of interesting experimental and measurement challenges.

Experiments can range from the basic (Angle of Repose of a pile of granules - think piles of sand), to the complex and not yet fully understood (Longitudinal and Axial Segregation in the 'Rotating Drum'). Depending on the granules used, ANY experiment your students do may be completely new, as there is such as great range of sizes, shapes and types of 'granules', including such things as bubbles and foams.

We will do some basic measurements (Angle of Repose, Flow Rate, Packing Fraction), and touch on the more complex situations, in particular a version of the Rotating Drum. Most likely, we will be using various shapes of foodstuffs (cereal), so in principle we can even eat our results when we are done (though that is not really recommended)!

W22 **Fluid Diagnostics: Compressible Flow and Shock Waves in a Benchtop Blowdown Tunnel**

Keith Stein, Bethel University

At Bethel University, fluid mechanics is integrated into the physics curriculum as a required component in the Applied Physics major option. Although the fluid mechanics course is not required for students pursuing other physics major options, most of these students take the course as an elective. Open-ended advanced lab projects are key components of the fluid mechanics course, as is the case in the upper level Optics, Contemporary Optics (i.e. lasers), Electronics and Computer Methods in Physics courses.

In this workshop, we demonstrate the operation of a small supersonic blowdown tunnel (please see figure) that was initially constructed as part of a fall 2010 project in our fluid mechanics course. Following the initial construction and testing of the apparatus, subsequent student research projects have included high-speed video (HSV) shadowgraph imaging and the development of a MATLAB GUI for side-by-side comparisons between simulation and ongoing experiments with the tunnel [1-2]. HSV imaging of the flow in the tunnel was highlighted as a 2011 ALPhA laboratory immersion workshop at Bethel University [3]. Ongoing student project work is supported to further characterize the flow in the tunnel and to assess the 1D isentropic flow assumption for our numerical simulations. Details will be presented on the design, construction, operation and ongoing project objectives with the blowdown tunnel.

1. K. Stein, J. Schommer, and B. Heppner, "Undergraduate Studies on Compressible Flows and Shock Waves," American Physical Society March Meeting 2012, Boston.
2. J. Schommer, K. Stein, and B. Heppner, "Graphical User Interface for Supersonic Flow and Shock Waves in a Converging-Diverging Nozzle," submitted for American Physical Society March Meeting 2012, Boston.
3. "Imaging of Shock Waves in Compressible Flows," Advanced Lab Physics Association (ALPhA) Laboratory Immersion, Bethel University, July 20-22, 2011.

W23 **New configurations for a hanging chain covered by soap film: Measurement of surface tension from the triangular configuration**

Fred Behroozi, Univ. of Northern Iowa

A chain assumes the familiar shape known as a catenary when it hangs loosely from two points in a gravitational field. The derivation of the catenary equation was one of the early triumphs of the newly invented calculus of variations at the end of the 17th century.

We will show that three new and distinct configurations are possible if a soap film covers the area bounded by the catenary as it hangs from a horizontal support rod. We will demonstrate how the chain can assume a concave, triangular, or convex configuration. Furthermore, we will show how the chain can be transformed smoothly from one configuration to another and shall discuss the conditions necessary for each configuration. Not surprisingly, the deciding factor is the strength of the surface tension relative to the gravitational force per unit length normal to the chain.

The conditions under which the chain assumes a perfect triangular configuration is particularly simple and provides an elegant method for measuring the surface tension of the soap film. Naturally the triangular configuration is visually striking but students are more intrigued when they learn that by measuring just one angle of the triangle they can obtain the surface tension of the soap solution.

The convex and concave configurations require more sophisticated analysis and can form the basis of a lab experiment for more advanced students.

F. Behroozi and P.S. Behroozi, "The effect of soap film on a catenary: measurement of surface tension from the triangular configuration", Eur. J. Phys. 32, pp. 1237-1244 (2011).

W24 **Video Analysis with Tracker for Advanced Physics Labs**

Aaron Titus, High Point University

Participants in this workshop must bring along their own laptops.

Video analysis is an inexpensive, easy-to-use technique for measuring the motion of objects with fairly good precision--and it's not just for introductory physics! It allows students to do advanced experiments in classical dynamics such as systems with changing mass, systems studied with Lagrangian dynamics, and systems without analytic solutions such as projectile motion with quadratic drag and spin. It's an excellent technique for labs as well as student projects. In this workshop, participants will learn how to use Tracker which is free, open source video analysis software developed by Doug Brown. Tracker's features include: (1) calibration point pairs that allow you to compensate for panning and zooming of the camera; (2) autotracking of objects; (3) the ability to specify a moving reference frame; (4) automatic calculation and marking of the center of mass of a system; and (5) the ability to solve a differential equation numerically and display the solution on the video. Example experiments include: motion of an American football in a placekick(*), a two-body orbit with a Hooke's law central force(**), and a swinging Atwood's machine(***).

(*) Kevin Sanders at High Point University
(**) Jeff Regester, Greensboro Day School
(***) Leah Ruckle, Davidson Colleges

W25 **FPGA Lab Exercise: Using Pulse Width Modulation to Study Analog-to-Digital Converter Properties While Building a Simply Music Player**

Kurt Wick, Univ. of Minnesota

Participants in this workshop must bring along their own laptops (running the Windows OS).

During the electronic component of the advanced lab course, students spend one week building a simple music player by programing an FPGA on a Digilent BASYS board. First, they use the FPGA as a digital-to-analog converter (DAC) using a simple Pulse Width Modulation (PWM) technique. This reconfigurable DAC is implemented with a just a few lines of Verilog code and is then used to explore DAC concepts such as resolution and conversion time. Second, an improved PWM technique using a Sigma-Delta algorithm is explored and its application as a voltage-to-frequency converter is discussed. Finally, 8-bit and 16-bit musical data is read from a flash memory and played through a speaker using the Sigma-Delta PWM technique. The workshop will cover the hardware and software used and PWM concepts.

W26 **A simple, inexpensive single molecule DNA microscope**

Allen Price, Emmanuel College

Techniques for trapping, manipulating and measuring single macromolecules include optical trapping, magnetic tweezers, and flow stretching. These techniques have been used to study DNA replication, RNA folding, protein folding, and gene translation.1,2 These single molecule methods are out of reach for most undergraduates, mainly because of the difficulty of isolating single molecules. Participants in this workshop will learn about how we are making single molecule techniques both simpler and less expensive. Participants will get hands on experience with a microscope that has been used in several senior thesis projects by our students.

Our single molecule DNA microscope uses an upright microscope coupled to a webcam for imaging single DNAs. The DNA molecules are tethered on one end to a glass surface within a microfluidic cell. The DNAs are visualized by tethering paramagnetic microbeads to their free ends. The beads, which can be seen under visual light microscopy, also serve as "handles" for applying forces to the DNA using fluid drag and/or magnets.

We will cover basic webcam video microscopy and microfluidic flow cell construction. We will cover how these two elements can be used to study Brownian motion. Next, we will cover the basics of DNA tethering, including surface functionalization and DNA labeling. These techniques may be new to physicists, and we will discuss the challenges and requirements for successful tethering---the key to a successful single molecule experiment! Our DNA tethering technique takes several hours to complete, so we will not have time to demonstrate the complete method in each workshop. However, we will cover the important steps. We will end with discussion of ideas for different experiments that can be done with the microscope, including measuring the DNA-force extension curve, DNA replication, and DNA cleavage.

1. For an excellent review of the field, see the single molecule theme issue of Annual Reviews of Biochemistry 77 (2008).

2. W. J. Greenleaf, M. T. Woodside, and S. M. Block, "High-resolution single-molecule measurements of biomolecular motion," Annu. Rev. Biophys. Biomol. Struct. 36, 171-190 (2007).

W27 **Chaotic fluid mixing and Hamiltonian phase space**

Tom Solomon, Bucknell University

Participants in this workshop are requested to bring their own laptops along, but the laptops are not required.

Very simple, two-dimensional (2D) fluids flows can exhibit mixing which is chaotic, in the sense that nearby tracers in the flow separate exponentially in time. Furthermore, the equations that describe tracer motion in a 2D flow are equivalent to Hamilton's equations of classical physics; consequently, the real space motion of a tracer in a 2D flow is equivalent to a phase space trajectory of a Hamiltonian system. For these reasons, simple experiments with 2D mixing are ideal for illustrating both the concepts of chaotic dynamics and also for developing an intuition for the value of using a phase space description of dynamical and kinematic processes.

In this workshop, we will discuss junior-level experiments that can be used to explore these topics, using two fluid flows: (a) a "blinking vortex flow" which can be set up in a simple petrie dish with some minimal electronics; and (b) an oscillating vortex chain flow which has become a paradigm in the scientific literature for chaotic mixing. The experiments are imaged from above with a CCD camera and analyzed on a Windows-PC. Individual tracers moving in the flow can be tracked in time; the resulting trajectories can be analyzed to show sensitive dependence on initial conditions and to assemble Poincaré sections that reveal the ordered/chaotic structure of the phase space. The mixing of dye in these systems illustrates the importance of chaotic stretching on larger-scale mixing processes. All of the experimental results can be compared with simple numerical simulations that students can perform. These flow systems are also ideal for independent research projects involving undergraduate students. In fact, in the past 15 years, we have published 17 papers – 16 with undergrads – on results from these systems, 4 of which are in Physical Review Letters and one in Nature.

W28 **Nanoparticle Scattering of Polarized Light**

Ernest Behringer and Natthi Sharma, Eastern Michigan University

This experiment allows students to explore electric dipole radiation in the optical frequency domain. Here, electric dipoles are induced in polystyrene nanospheres suspended in water by the electric field of a linearly polarized HeNe laser beam and the resulting angular distribution of optical radiation in the plane normal to the incident beam is compared to the expected sin2q distribution.

This experiment is highly flexible, with implementations that span a range of simplicity and cost. Details of the construction of the experiment and analysis of the data will be provided. The polarization, particle size and concentration dependence of the angular distribution, and the radial dependence of the irradiance will be discussed. The apparatus will be available for use and typical results will be presented.

For graduate students, the experiment can be extended easily to the study of magnetic dipole (and/or electric quadrupole) radiation by mounting a polarizer in front of the detector. The experiment serves as a handy teaching tool to elucidate the polarization and angular distribution of low order multipole radiation when teaching multipole fields. Many details are contained in Am. J. Phys. [71,1294 (2003)] and Phys. Rev. Lett. [98, 217402 (2007)].

After doing the experiment, students understand how electric dipole radiation explains polarization by reflection (Brewster's angle), polarization by scattering, and the polarization of radiation emitted by circulating charges (as in pulsars).

W29 Brownian Motion: Measuring Avogadro's Constant for $70

Beth Parks, Colgate University

Participants in this workshop must bring along their own laptops.

Brownian motion played a pivotal role in the development of modern physics. One of the four papers in Einstein's 1905 annus mirabilis explained Brownian Motion using atomic theory. Up until this publication, there were still prominent physicists who believed that atoms were a convenient fiction, but not real objects; Einstein's paper provided the convincing evidence for their existence.

Through measurements of Brownian motion, students can measure a fundamental constant, Avogadro's number, from which they can determine the size of atoms.1 Additionally, they are introduced to a currently active research area-in the past 12 months, there have been 80 manuscripts submitted to cond-mat on Brownian motion.

These inexpensive measurements are made possible by using microscopes from the consumer market, solutions of polystyrene spheres of uniform size, and the image processing software ImageJ available free from the NIH. During this session, participants will learn how to set up the experiments and analyze the data to yield accurate measurements (within a few percent) of Avogadro's number and Boltzmann's constant.

1. "Einstein, Perrin, and the reality of atoms: 1905 revisited," Ronald Newburgh, Joseph Peidle, Wolfgang Rueckner, American Journal of Physics 74 6, June 2006.

W30 Microfluidics Fabrication Workshop

Kevin Seale, Vanderbilt University

Organizers: Kevin Seale and Ron Reiserer from Vanderbilt University Searle Systems Biology and Bioengineering Undergraduate Research Experience (Searle SyBBURE)

This workshop will introduce participants to the fundamentals of UV lithography and PDMS microfabrication of devices. These methods have been developed and used successfully by SyBBURE undergraduates at Vanderbilt to build and implement novel devices for studies of physical, chemical and biological phenomena including nanopumps, valves, mixers, chemical gradient generators and microformulators.

The hands-on portion of the workshop will include:

- Ratiometric mixing of polydimethylsiloxane polymer epoxy
- Casting of prefabbed microchannel mixer masters
- Curing, punching and plasma bonding procedures for device assembly
- Priming and controlled perfusion of the fabricated device with miscible colored liquids

Hands-on work will be accompanied by a concurrent informational powerpoint presentation with handouts and plenty of opportunity for question and answers. Our objective is to provide a tool kit and resources for professors who may wish to incorporate microfluidic methods into their laboratory courses.

W31 Simple Laser-Induced Fluorescence Setup to Explore Molecular Spectroscopy

Burçin Bayram and Mario Freamat, Miami University

We will demonstrate a relatively simple, affordable and highly visual experiment to explore molecular spectroscopy by measuring the laser-induced fluorescence (LIF) spectrum of the iodine molecules at room temperature. Iodine is a uniquely suited seed molecule for LIF measurements since it conveniently absorbs about 20,000 lines in the 490- to 650-nm visible region of the spectrum and serves excellent example of displaying discrete vibrational bands at moderate resolution and rotational structure at high resolution.

The apparatus consists of a diode laser 532 nm (or a laser pointer), an iodine cell, and a handheld spectrometer. We will scrutinize the LIF spectrum about the potentials associated with the vibrational states of the diatomic molecules and assign spectral lines based on the transition probability between vibrational levels, build vibrational energy level diagram and tabulate Deslandres table, evaluate the harmonic and anharmonic characteristics of two states and thereof the merits of the harmonic approximation for the molecular oscillator, and finally extract the molecular constants such as dissociation energies of the molecular potentials.

In this workshop, the rotational structure is not seen at a resolution of about 0.2 nm, a common limit for commercial ultraviolet-visible spectrometers, but the vibrational features can be easily discerned in the measurement. At the end of the workshop, we will discuss how to determine rotational inertia and rotational temperature if a higher resolution spectrometer is available.

Experimental explorations in instructional laboratories of molecular spectroscopy are instrumental not only in educating students about the quantum mechanical phenomenology ingrained into the microscopic structure of matter, but also familiarize them with the germinal scientific puzzles and revolutionary answers that historically led to the discovery of quantum mechanics. Thus, a great deal of effort was directed in our department toward maintaining an advanced laboratory course focused on spectroscopy of atoms and molecules, for a diverse and solid education of our upper-level physics majors.

W32 Diffusion in Microfluidic Structures

Steve Wonnell, Johns Hopkins University

This is a hands-on workshop in which participants perform one of the eight experiments developed to accompany a junior level biophysics course at the Johns Hopkins University. The year-long course can also be used as an alternative sequence to the sophomore level waves and statistical mechanics courses. The experiments are short and designed to be performed in place of one or at most two discussion sections; this particular experiment has participants using a "lab on a chip" to measure molecular diffusion in water, from which a value for Boltzmann's constant can be found. The concepts of Reynolds number and laminar flow, diffusion, viscous drag, and Einstein's relation underlie this experiment. Video capture with a microscope, analysis of the image data, least-squares fitting, and using microfludic structures to manipulate molecules are some of the techniques utilized. The experiment can be assembled from commercially available apparatus and parts.

W33 Advanced Laboratories in Acoustics and Ultrasonics

Dale Stille/Ron Vogel, University of Iowa

This workshop will consist of three experiments with the following descriptive titles. 1. Acoustic Velocity, Impedance, Reflection, Transmission, Attenuation, and Acoustic Etalons. 2. Experiments in Acoustical Refraction and Diffraction. 3. An introduction to Acousto-Optics. The experiments use acoustical transducers that operate in the frequency range 8 to 18 MHz and are excited by either signal pulses or bursts, depending on the experiment. Acoustical properties of water and a variety of solids are measured, elastic properties of the solids are calculated from these, and several types of devices are analyzed. Single slit and grating diffractors, refractors, thin plates, acoustic etalons, and an acousto-optic modulator are some of the devices. Students doing these labs will become more familiar with the following areas of physics: ultrasonic wave propagation, elastic properties of solids, acoustical and optical etalons, phonon-photon interaction, and acousto-optics.

W34 **Doppler-Free Spectroscopy**

Dean Hudek, Brown University

In this experiment a tuneable diode laser is used to explore a very narrow wavelength range of rubidium (Rb) near 780 nm. First the students tune the laser to the resonant frequency of Rb. Once resonance has been established a detector is placed in the beam exiting the Rb cell. With a little adjusting the fine structure of rubidium is observed on the scope. Next a technique known as saturation-absorption spectroscopy is employed. The students rearrange the optical setup such that three beams pass through the Rb cell; two in on direction and one in the other. Two opposing beams are adjusted to intersect inside the Rb cell without disturbing the third beam. Detectors collect the light from the two beams going the same direction. The signal from the undisturbed beam is subtracted from the intersected beam. The difference in signals is the hyperfine structure of Rb. Lastly the students set up a Michelson interferometer and use it to calibrate their data. For the full version of our manual go to: https://wiki.brown.edu/confluence/download/attachments/5890/doppler.pdf?version=5&modificationDate=1320259684000

Information on how to acquire the required equipment will be provided at the workshop.

W35 **Laser Cooling and Trapping for Advanced Teaching Laboratories**

Heather Lewandowski, University of Colorado-Boulder
Evan Salim, ColdQuanta Inc.

A considerable number of modern atomic physics experiments rely on laser cooling and trapping of neutral atomic samples. Cutting edge work with Bose-Einstein Condensates, degenerate Fermi gases, dipolar gases, optical lattices, atomic clocks and quantum computation all start with the production of a magneto-optical trap, (or MOT). In an educational environment, the MOT offers a fertile landscape for teaching a host of theoretical concepts, such as atomic structure including fine and hyperfine structure, the Zeeman effect, scattering, laser cooling, and polarization states of light; as well as relevant experimental techniques, such as spectroscopy, optics, feedback control systems and measurement techniques. Commercially available equipment has recently become available to bring this exciting and important class of techniques into the teaching laboratory environment, making laser cooling experiments possible even at institutions without substantial atomic physics infrastructure or expertise.

In this workshop we will present a system that enables the production of cold atoms in a MOT in an advanced undergraduate teaching environment. Participants in the workshop will:

- Receive a brief introduction into laser cooling and trapping of atoms
- Align optics into the correct configuration for producing a MOT
- Tune and lock diode lasers to the correct frequencies for laser cooling
- Produce a MOT
- Measure atom number in the cloud.

W36 **A simple experiment to measure the electron temperature and plasma density using a Langmuir Probe**

Jeremiah Williams, Wittenberg University

Plasmas, an ionized gas, are the fourth and most common state of matter in the visible universe. In addition to providing a wealth of applications from all areas of classical physics, this state of matter plays an important role in many industrial applications and will likely play a key role in future energy sources. Despite this, plasma physics does not often appear in the undergraduate curriculum. This is particularly true in the advanced lab setting, where most experiments involving plasmas require the use of fairly complicated and complex experimental setups. In this workshop, we present a relatively simple and low cost experiment involving the use of a Langmuir probe, a basic plasma diagnostic that makes use of ideas from the kinetic theory of gases, to introduce the basics of idea of what a plasma is and to measure the electron temperature and density of a plasma.

W37 **The Angular Dependence of Cosmic Ray Muons**

Brett Fadem, Muhlenberg College

Many undergraduate level experiments are possible with a cosmic ray muon telescope. Two of the more common examples are the muon lifetime, and the angular distribution of muons produced in the upper atmosphere. In the process of making these measurements, students learn about scintillating detectors, signal processing electronics, coincidence counting, data acquisition software, and the treatment of experimental data.

In addition to assembling the detector and the components of the data acquisition system, students at Muhlenberg designed and built a mount that rotates in polar and azimuthal angles. For the workshop, this equipment will be used to determine the dependence of the cosmic ray flux on polar angle. Conference participants will connect the detector to signal processing and logic modules, and take data using the system.

The detector consists of two plastic scintillating slabs connected to photomultiplier tubes. They are mounted as described above. The experiment also utilizes a NIM crate containing a power supply, discriminators, a coincidence logic module, and a NIMBox (Nuclear Electronics Miniature Box) programmable Logic/DAQ module. The remainder of the data acquisition is performed with a PC running LabView and a digital interface box.

For a thorough understanding of the rates, students must grapple with the geometric acceptance of the detector, counting statistics, sources of systematic error, and the efficiency of the detectors. We look forward to giving conference attendees some hands on experience with the detector, discussing different ways to use the apparatus, and sharing insights on interesting pedagogical approaches.

W38 **Scanning Tunneling Microscopy for Advanced Undergraduate Physics Labs**

NanoScience Instruments

The Scanning Tunneling Microscope illustrates principles of modern physics in a way that that is not achievable by any other instrument. The primary reason for this is the fact that the STM operates on the principle of “electron tunneling” and allows the user to probe the real space atomic structures of conductors and examine the local density of states (LDOS) of surfaces.

This demonstration will involve the use of simple, readily available starting materials with minimal sample preparation and will obtain real space atomic resolution of the metal-like substance, highly ordered pyrolytic graphite (HOPG). The lab will be divided into two segments, the first involving the imaging of graphite to see the individual atoms using the easyScan STM. Image analysis will be performed by identifying the hexagonal “honeycomb” pattern of carbon atoms and calculating the atom-to-atom distance. The second segment will involve obtaining current-voltage (I-V) curves on HOPG and its subsequent interpretation. The demonstration will also show how to construct and the differential conductance (dI/dV) of the I-V curve. Lastly, we will obtain I-V curves for a semiconductor and contrast the features with those obtained for the conductor, HOPG.

W39 **NSF Mock Panel: Reviewing Advanced Lab TUES Proposals**

Richard Peterson and Duncan McBride, Program Officers - NSF Division of Undergraduate Education (DUE)

After a broad orientation to the TUES program and its priorities - and the proposal reviewing process, workshop participants will split-up into mock review panels and go through a pseudo-review process using two “beyond-first-year” lab impacting proposals that have recently been funded in the TUES program. In a final large group session, participants will discuss their proposal’s ratings, weaknesses and strengths. Individual panels will work with just one of the two distributed proposals. The workshop format is primarily intended for those who have not previously been TUES review panelists. Up to 36 pre-registered participants may split-up between 6 mock panels.

W40 **Surface plasmons, atomically-smooth patterned gold, and bio-sensing**

Nathan Lindquist, Bethel University

The rapidly emerging field of plasmonics offers many exciting research opportunities. In particular, the large field intensities and short probing range of surface plasmon waves makes them an ideal candidate for sensing. A surface plasmon is a collective wave-like oscillation of the free electrons right at the surface of a metal film. Beyond prism-coupling techniques, the illumination of properly nano-structured metallic surfaces, gratings, and particles will also demonstrate significant plasmon resonances, with rich physics and many interesting applications. Using a novel, low-cost nano-fabrication technique for creating ultra-smooth patterned metallic surfaces, this workshop will cover the fabrication, characterization, and analysis of nano-structured metallic films and their use as bio-sensors.

W41 **Torsional Oscillator**

TeachSpin
Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

The simple harmonic oscillator is perhaps the most generally useful model system in all of physics, and TeachSpin’s Torsional Oscillator is a great way to learn and teach all of its properties. This system is of a human scale in space and time, and offers complete control of the restoring force, the inertia, and the damping. It can also be driven by an arbitrary electrical waveform, and it generates an electrical position signal as output. All the standard properties of a damped, driven, simple-harmonic-oscillator can be studied in detail. The apparatus makes possible dozens of investigations, and dozens more optional projects.

Participants will:

- See the parts, and chart the outputs, of the Oscillator
- Hand-excite the oscillator, to see the damped waveform
- See that same waveform in the ‘phase plane’, of position vs. velocity
- Excite the oscillator with a waveform of chosen shape, amplitude, and frequency, and explore the effect of varying the damping

W42 **Fourier Methods**

TeachSpin
Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

Although oscilloscopes are most often used to observe electrical signals as a function of time, seeing the same signals as a function of the frequencies of which they are composed, the frequency domain, provides powerful, and often unexpected, insights. TeachSpin’s Fourier Methods is a complete experimental ‘arena’, built around the SRS-770 Waveform Analyzer, specifically designed to teach physics students how much can be learned about physical systems by understanding the frequency content of the signals emerging from them. No matter what your acquaintance with the Fourier spectrum, you’ll find something new to do with our electrical/ mechanical/acoustical package of experiments.

Participants will:

- See how the Analyzer responds to simple waveforms
- See the operation of summing, and of multiplying, in time and frequency domains
- Choose parameters of AM or FM waveforms, and see their frequency spectra
- See the spectra of chaotic waveforms
- Tune a mechanical 2-mode resonator, seeing its spectrum reveal its normal modes

W43 **Modern Interferometry**

TeachSpin
Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

See interferometry in a new way with TeachSpin’s Modern Interferometry set-up. Learn how to set up interferometers from scratch, using carefully-designed optical components on a standard optical table. Learn how to use Michelson, Sagnac, and Mach-Zehnder topologies. See how electrical detection of fringe signals allows digital counting of fringes and how a ‘quadrature Michelson’ will also permit successful reversible counting of fringes, up and down. Enjoy investigations in piezoelectric deformation, magnetostriction, electro-optic modulation, or other physical effects which show off the power of interferometric techniques.

Participants will:

- Learn to align a Michelson interferometer, and see its operation
- Add the optics and detectors needed for reversible fringe counting
- Set up and align another interferometer geometry (Sagnac or Mach-Zehnder)
- Learn how interferometry can measure some physical variables

W44 **Noise Fundamentals**

TeachSpin
Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

Many instructors, and some students, have heard of Johnson-noise and shot noise in electric circuits, TeachSpin’s apparatus provides a way to study both in detail in a trouble-free experimental arena. Students can see electrical noise, and measure spectral noise density, right from its definition. They can investigate, quantitatively, the dependence of Johnson noise on source resistance and bandwidth, as well as on temperature in the 77 - 350 K range using the dewar and proprietary probe provided. A measurement of Boltzmann’s constant, to a precision of a few percent, is a by-product. Furthermore, quantitative measurements of the shot noise present in a photocurrent allow the measurement of the fundamental charge ‘e’ to similar precision.

Participants will:

- Follow a noise signal from birth to quantitative measurement
- Learn how noise density is defined and measured
- See the dependence of Johnson noise on source resistance
- Deduce a value for Boltzmann’s constant from Johnson-noise data
- Learn how shot noise is generated and measured

W45 **Pulsed/CW NMR**

TeachSpin

Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

The technique of nuclear magnetic resonance has revolutionized physics, chemistry, and even medicine since its discovery over 60 years ago. Now students can learn all the features of NMR in an instrument optimized for teaching. TeachSpin's PS2-A is a tabletop system allowing pulsed or continuous-wave investigations of proton (or 19F) NMR within a temperature-stabilized permanent magnet. Students have full control of all the pulse-sequence parameters, and the electrical shimming and scanning of the magnetic field.

Participants will:

- Learn how pulsed NMR of protons is conducted, and learn pulse nomenclature
- Optimize a 90-degree pulse, and see free induction decay
- Optimize field homogeneity by gradient adjustments
- Learn the pulse sequence needed for nuclear spin echoes
- Measure either the T1 or the T2 relaxation time in their sample

W46 **UltraSonics**

TeachSpin

Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

TeachSpin now offers a full line of apparatus from GAMPT mbH for displaying a host of features of ultrasonic waves in liquids and solids. Lying behind the glamorous medical applications is a wealth of fundamental physics of compression (and shear) waves. The GAMPT apparatus includes well-engineered piezoelectric transmitter/receiver heads, and the pulsed and continuous-wave generators/receivers which support them. Also included are the apparatus and samples on which students can learn the phenomena, and the wave science, of invisible waves of MHz frequency and sub-mm wavelength.

Participants will:

- Generate and launch a pulsed ultrasonic wave
- Detect ultrasonic echoes and use them to measure time of flight
- Measure speeds of sound for longitudinal and shear waves
- Be introduced to the use of ultrasonic techniques for non-destructive testing

W47 **Diode-Laser Spectroscopy**

TeachSpin

Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

The tunable diode laser has revolutionized optics and atomic physics, by providing a reliable source of narrowband light which is easily tunable across an adequate range of the spectrum. TeachSpin's Diode Laser Spectroscopy system shows off the capabilities of such a system on a tabletop, using everyone's favorite atomic resonance, the 780-nm D2 transition in rubidium vapor. Because of the intensity available from a laser source, it is simple to display non-linear phenomena such as (Doppler-free) saturated absorption spectroscopy, coherent population trapping, and nonlinear Faraday rotation, in set-ups easily replicated by students.

Participants will:

- Aim and align the invisible beams of 780-nm monochromatic radiation
- See the fluorescence from Rb vapor when the laser is properly tuned
- Relate the structure of resonances observed in terms of isotope and hyperfine structure of the atomic transition
- Follow the beams which permit pump-probe Doppler-free spectroscopy
- See the sub-Doppler upper-state hyperfine splittings of a transition

W48 **Two-Slit Interference**

TeachSpin

Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

Every modern-physics textbook introduces the thought experiment of operating a Young's two-slit interference demonstration with the light intensity set so low that there is only one photon in the apparatus at a time. TeachSpin's tabletop experimental realization of this textbook system delights both instructors and students. Using the diode laser source (included) students first see, and measure quantitatively, two-slit interference fringes in the high-intensity regime. Then, switching over to a dim-bulb source and photomultiplier-tube detector, they see that interference phenomena persist even in the limit of 'one photon at a time'. These workshops will also use TeachSpin's new Counter/Timer unit, especially designed for use with the Two-Slit apparatus.

Participants will:

- Open the box and see the full optical layout, operating the device in the laser-light mode
- Get the data which will determine the wavelength of red diode-laser light
- Choose the low-light source, and photomultiplier detector, and close the box
- Get the photon-counting data which will determine the wavelength of green light
- Agonize over how photons which can be counted one at a time can have their wavelength measured

W49 **Quantum Analogs**

TeachSpin

Jonathan Reichert, Barbara Wolff-Reichert, George Herold, David Van Baak

Students have trouble forming intuition about quantum mechanics, especially if partial differential equations are not their natural language. To help in conceptualization, TeachSpin offers a collection of apparatus and experiences in classical acoustics of air in confined volumes to teach analogies to quantum phenomena. By using acoustic experiments to display the solutions of a differential equation analogous to the Schrödinger Equation, students can see classical normal modes as the analogs of quantum eigenstates. Using a spherical resonator, they can see directly the spherical harmonics that are common to classical and quantum-mechanical problems in spherical systems. A one-dimensional array of acoustic modules provides hands-on analogs from particle-in-a-box to the behavior of semiconductors

Participants will:

- See the 'mode spectrum' of acoustic resonances in a spherical resonator by scanning over frequency
- Choose one mode, and explore its spherical-harmonic character
- Perturb that mode out of a sphere, and see frequency splittings
- Graduate to a periodic 1-d acoustic structure, and see acoustic bands and gaps
- Learn how 3 independent variables control 3 dependent variables in the band-gap pattern
- Manage to leave the room after only 40 minutes of using this highly addictive apparatus.

W52 **Open Frame Helium Neon Laser**

Klinger

Dr. Walter Luhs, Irwin Malleck, and Jaclyn Kay

The humble HeNe Laser is still important for education in Photonics. We demonstrate an open cavity training system with components like the HeNe tube with Brewster windows on sides, the two cavity mirrors and line tuning elements are placed onto the optical rail. The basic alignment is demonstrated and the beam diameter inside the cavity is measured to verify the nature of Gaussian beams. By means of a Littrow prism the line tuning is demonstrated. The power of the laser is determined by measuring the current of the provided photodiode. Cleaning of optical components is trained as well as the proper use of sensitive optical components.

W53 **Diode Pumped Solid State Laser**

Klinger

Dr. Walter Luhs, Irwin Malleck, and Jaclyn Kay

Step by step the modules needed for a DPSSL using a Nd:YAG crystal will be explained and arranged on an optical rail. Spectroscopic measurements of the Nd:YAG are performed. The operation of a the Nd:YAG laser with demonstration of the so called "spiking" is shown by means of an oscilloscope. Frequency doubling to visible green radiation and the stability criteria of the optical cavity is verified. Higher transverse modes are demonstrated and the reduction to the TEM00 mode is performed by using an intra-cavity iris.

W54 **Glass Fibre Optics**

Klinger

Dr. Walter Luhs, Irwin Malleck, and Jaclyn Kay

Within this hands on training the stripping and cutting of a telecom optical fiber will be learned. The light of a modulated diode laser is collimated and launched into the prepared fiber. The alignment process is monitored by a photodiode at the end of the 5000 m long fiber by means of an oscilloscope. Once the optimum alignment is achieved the time of flight inside the fiber is measured and the speed of light determined. Finally the angular distribution of the light at the end of the fiber is measured and the numerical aperture of the fiber determined.

W55 **Imaging Innovation In Your Classroom: Exploring the principles of medical imaging with the DeskCAT optical CT scanner**

Modus Medical

Andrea Battista, Jennifer Dietrich

The DeskCAT multi-slice CT scanner uses state-of-the-art technology to safely demonstrate the principles of medical imaging. Teach more effectively and allow students to learn interactively by bringing the CT scanner into your classroom! Participants will run through the capabilities of the DeskCAT system by imaging a phantom silicone mouse with internal organs. Each participant will have the opportunity to navigate the DeskCAT software and witness real-time acquisition, reconstruction and 3D display of the phantom mouse.

W56 **LabVIEW-Based Instruction for Instructional Labs**

John Essick, Reed College

This hands-on workshop will be of interest to those seeking to include LabVIEW-based instruction in their instructional lab curricula.

As an example of a computer-based instrument that students can build in an instructional lab setting, during the workshop you will construct a digital thermometer using a National Instruments myDAQ data acquisition device, LabVIEW software, and a thermistor excited by a constant current circuit. If time permits, a digital oscilloscope with software analog triggering and/or a spectrum analyzer can also be constructed. These projects are all drawn from the book "Hands-On Introduction to LabVIEW for Scientists and Engineers, Second Edition" (Oxford University Press).

A station with all of the required hardware will be provided for your use during the workshop, including a Windows laptop loaded with the current version of LabVIEW, a myDAQ device, and the electric circuit components. Courtesy of Oxford University Press, you will receive a free copy of the Hands-On Introduction to LabVIEW text to keep. You will work in self-paced fashion at your station with a partner (or possibly solo, depending on workshop enrollment).

As you will be writing LabVIEW programs that control the myDAQ device during the workshop, a basic skill-level in LabVIEW programming will be assumed. The required familiarity with LabVIEW should be acquired in advance of the workshop, for example, by reading the first three chapters of Hands-On Introduction to LabVIEW (if available) or completing an online tutorial such as http://www.ni.com/gettingstarted/labviewbasics/. A free trial version of LabVIEW software can be downloaded from the www.ni.com web site.

W57 **Advanced Cavendish Balance**

TelAtomic

Joe Dohm, presenting

The Cavendish Balance allows students to replicate a historic lab and to perform an interesting analysis. Come see how easy it can be to follow in the footsteps of many talented and careful physicists who have sought to measure the weakest fundamental force. A capacitive sensor and integrated electronics makes the Cavendish Balance from TEL-Atomic a compact and powerful tool for teaching your students. Come learn how you can use the Cavendish Balance from TEL-Atomic in your lab.

W58 **TEL-X-Ometer X-ray Apparatus**

TelAtomic

Joe Dohm, presenting

The TEL-X-Ometer from TEL-Atomic is a general purpose x-ray apparatus designed for use as an x-ray diffractometer, as a source for x-ray fluorescence, or for making radiographs. It is easy to investigate the basic properties of x-rays and x-ray detection, investigate the crystal structure of elements and ionic compounds, and investigate the elemental makeup of unknown samples. Participants will be able to choose one of several experiments to perform.

W59 **E&M experiments**

NADA

NADA Scientific will be demonstrating the e/m Apparatus with an e/m tube containing an integrated phosphor ruler. Also, the Crookes Tube with our NEW power supply will be on display and users can view and experiment with the electron beam. In terms of electrostatics, we will be presenting the "Raijin" Van de Graaff, the Static Genecon, and the Electrostatic Field Apparatus. We will show instructors how to effectively use each instrument in a physics science lab, the variety of experiments that can be derived from using our instruments, and the simple steps to maintain and prolonging the life of each item.

W60 **Basic Gamma Spectroscopy with a NaI(Tl) Detector**

Randy Peterson, The University of the South and Spectrum Techniques

Simple gamma spectroscopy is easily demonstrated for science students and they find such demonstrations intriguing. When given the opportunity to perform some spectroscopy on their own, we find there are many issues with instrumentation and data interpretation that have escaped them in their previous laboratory work. The meaning of calibration, the effects of small nonlinearities, the operation of high-voltage electronics, pulse amplification and analog to digital conversion are all important issues to be explored. Even reading and commenting on a gamma energy spectrum fools some good students.

We will calibrate a NaI(Tl) detector plus multichannel analyzer system to observe the spectrum from common radioisotopes. The spectrum of the Compton edges will be used to determine the mass of the electron. This experiment is an excellent test of the idea of relativistic mass-energy. If time allows, the multi-channel scaling feature of the MCA will be used to measure the half-life of the first excited state of Ba-137 and to measure the statistical nature of the decay process.

W61 **Thorlabs' Teaching Spectroscopy Kit (SKDAV)**

Thorlabs

Thorlabs SKDAV spectroscopy kit is an ideal tool for undergraduate teaching labs. The kit provides a set of proven components to set up dichroic atomic vapor spectroscopy (DAVS) of alkali metals. DAVS allows students to study atomic transitions and to observe the Zeeman effect. Together with a tunable laser and feedback electronics, the SKDAV can serve as a worry-free building block for more complex experiments, such as Zeeman Slowers or Magneto-Optical Traps. In contrast to Saturated Absorption Spectroscopy, the DAVS signal provides a zero-crossing with tunable frequency offset to the transition, saving the additional cost of acousto-optic modulators to create frequency detuning.

How does it work? Dichroic Atomic Vapor Spectroscopy utilizes the Zeeman effect to create signal suitable for frequency locking a laser. A vapor cell is placed in a weak longitudinal magnetic field, and linear polarized light passes through the cell. Due to the presence of the weak magnetic field, the absorbtion profiles of the two circularly polarized components (left and right) that comprise the linearly polarized input beam are shifted to higher and lower frequencies, respectively. After passing through the vapor cell, the beam propagates through a quarter-wave plate and a polarizing beamsplitter. A dispersion-like curve is generated, which provides an error signal for the frequency lock.

W62 **Using Igor Pro for data analysis in advanced and research laboratories**

Carl Grossman, Swarthmore College

Participants in this workshop are requested to bring their own laptops along (see below), but laptops are not required.

Igor Pro is a versatile data display and analysis program that also provides a rich environment for programming, scripting, interactive application building, and as a front-end for National Instruments data acquisition hardware. While it has far more capabilities than are needed in most teaching labs, the overhead needed to do basic plotting and analysis is minimal and the interface is as user-friendly as other popular software packages commonly found in teaching labs. Students at more advanced levels may find the command-line, history, and programming features of Igor to be more powerful and useful than simpler programs when they encounter sophisticated data analysis in the advanced labs and in research labs.

This workshop will go over basic data entry/analysis (display, curve-fitting, layout), data input from oddly formatted files, C-like programming, and macro scripting (for example, programming series of procedures into a single command that can be applied repeatedly to different data sets). There will be hands-on exercises for the workshop participants to become familiar with the software package. A demo version of Igor Pro can be installed on laptops that participants bring to the workshop.

W63 **Exploring atomic physics using X-ray fluorescence**

Jose Vithayathil, University of Pennsylvania

The aim of the workshop is to use x-ray flourescence to demonstrate concepts in atomic physics. The lab quantitatively studies :- the shell structure of multi-electron atoms and the extent of validity for Moseley's law, fine structure splitting and the variation with atomic number, and the background noise illustrates Compton scattering. The students also use their data to identify an unknown element.

We use, a Co57 gamma source for the excitation of elements and for calibration, a high purity Germanium detector with a built-in cooled preamplifier, and a multichannel analyzer. The elements studied vary from Z=29 to 92. Other gamma or beta sources can be used for excitation and less expensive silicon based detectors can be used for lower Z elements. With the Ge detector, the resolution of energy is about 0.1%.

W64 **Fourier and Wavelet Analysis**

Joe Trout, Drexel University/Richard Stockton College of NJ

In this laboratory experiment, techniques in data analysis using Fourier and wavelet analysis are introduced. First the students review Fourier series. Sound recordings of tuning forks are then made using Matlab and the students use a simple code to find the amplitudes of the frequencies present in the recording. The students then repeat the analysis using Matlab's Fast Fourier Transform utility and compare the results. Wavelets are then introduced and the recording are then analyzed using wavelet techniques to understand the similarities and differences between Fourier analysis and wavelet analysis. Finally, topics of "noise" and "filtering" are introduced and voice recordings or recordings or music are made and analyzed.

W65 **The Millikan Oil Drop Experiment**

Som Tyagi, Drexel University

The Millikan oil-drop experiment is one of the most elegant and important experiments in the history of physics. The essence of the experiment is to observe the motion of an oil drop under the combined influence of an adjustable electric and gravitational field. The observation of the trajectory of the drop then permits a calculation of the net force on the sphere, and therefore, the net charge it carries. The oil droplet is traditionally tracked by watching it through a microscope. The students find this step the most tedious part of the experiment that also detracts them from the elegance and importance of the experiment. We have replaced the 'manual' tracking by employing video capture using a microscope coupled to a CCD camera. After the frame capture, the droplets can be selected and their trajectories analyzed.

W66 **Modeling the faster cooling of Mars as compared to Earth by measuring relative cooling rates of metal spheres**

Leonard Finegold, Drexel University

Why did Mars cool faster than Earth? And more generally, how do things cool?

It is believed that Mars and Earth were formed of similar geology at about the same time. (Nowadays, we use astrological symbols for planets).

(Assuming that life began at around the same time on both planets, we don't expect any life on Mars now. The last life that may have existed on Mars might have been like some existing life in the Antarctic. A faculty member here has done research on such Antarctic life, and can show you Antarctic rocks which contained such life.)

The diameter of Mars is about 53% that of Earth.

Students measure cooling rates of 3 metal spheres, plot rates vs. 1/diameter.

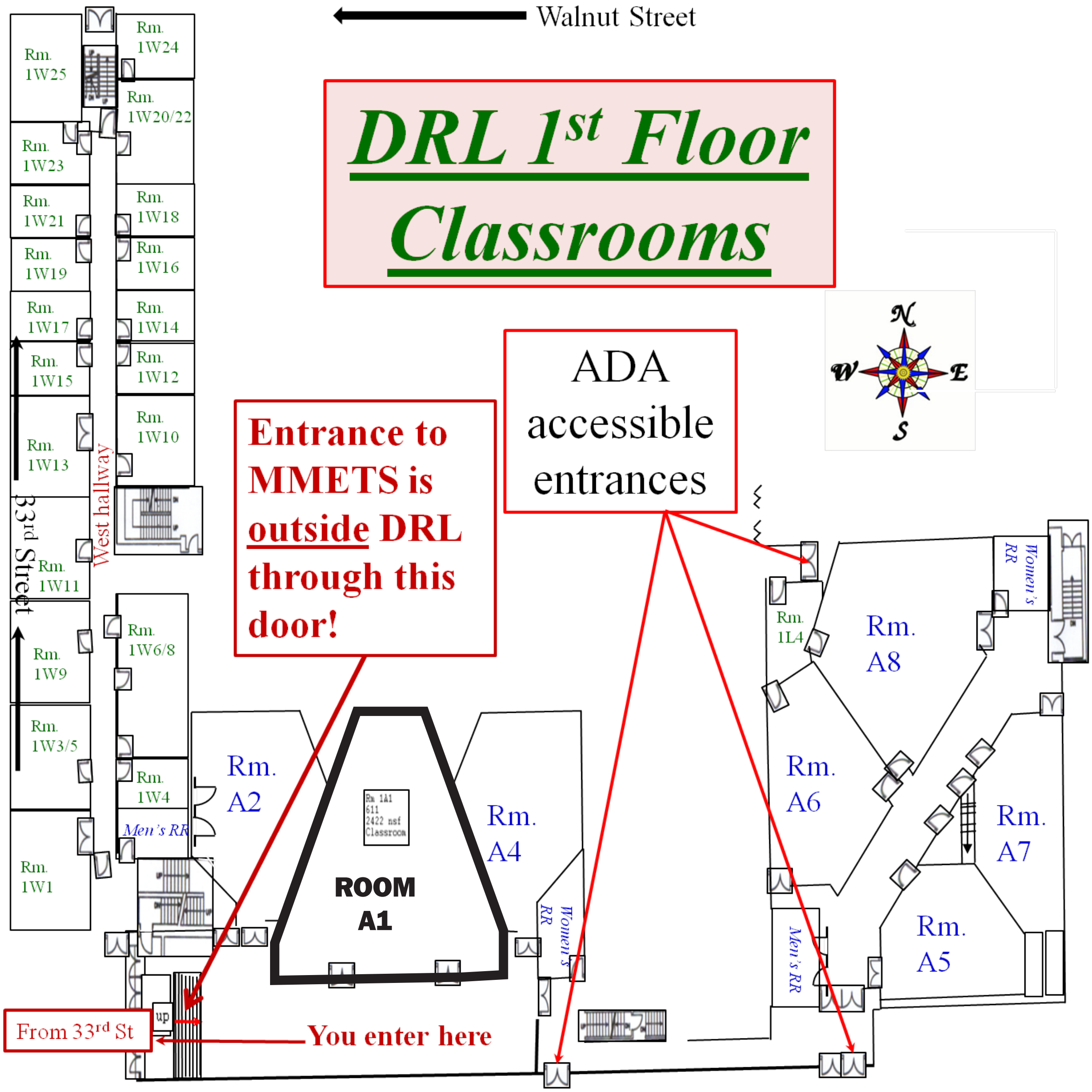
PARTICIPANTS

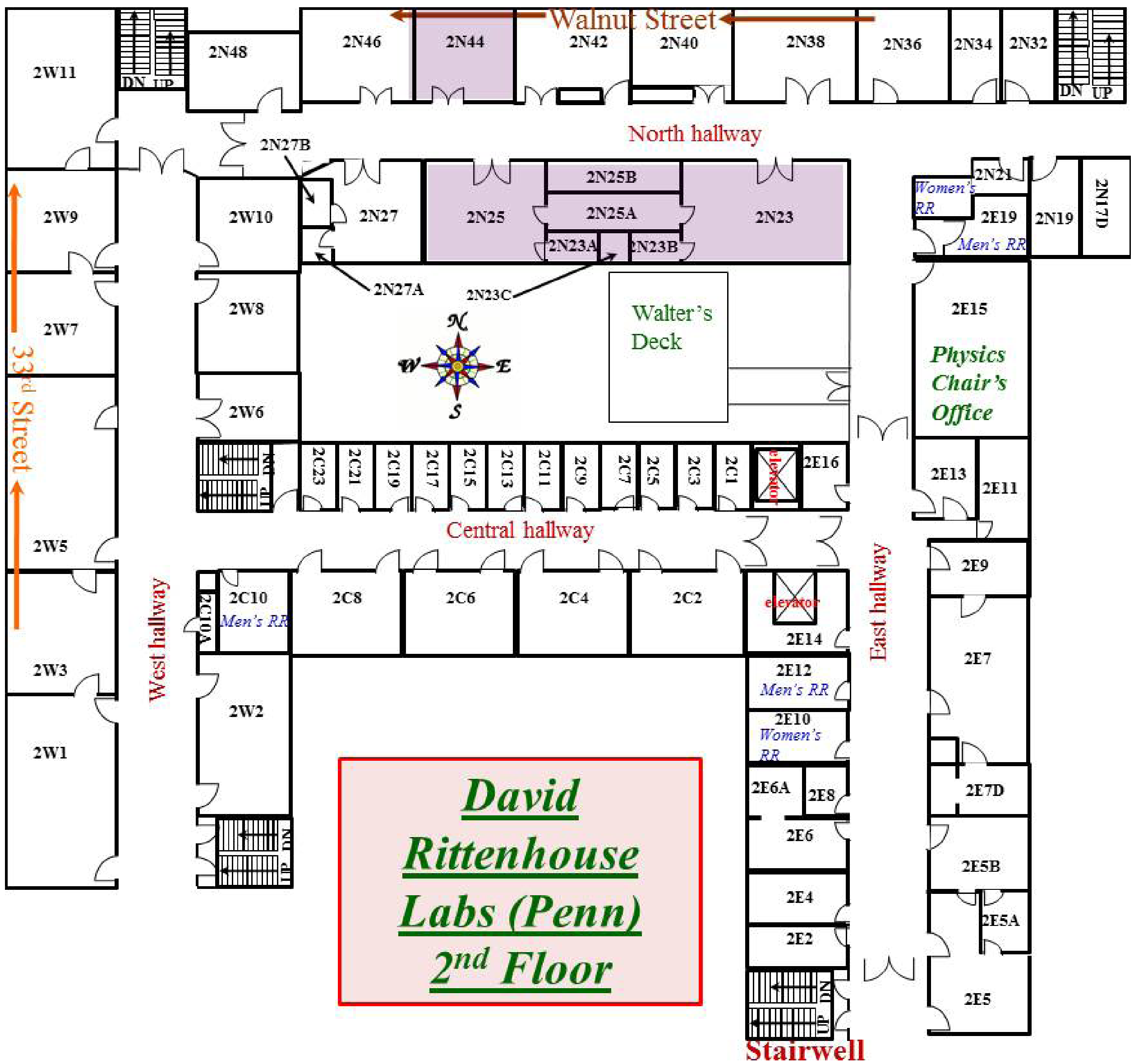
Steven Adams	Widener University	spadams@widener.edu
Saalih Allie	University of Cape Town	saalih.allie@uct.ac.za
Deepthi Amarasuriya	Northwest College	deepthi.amarasuriya@gmail.com
Eric Ayars	California State University – Chico	ayars@mailaps.org
Maria Babiuc-Hamilton	Marshall University	babiuc@marshall.edu
David C. Bailey	University of Toronto	dbailey@physics.utoronto.ca
Linda Barton	Rochester Institute of Technology	lsbsps@rit.edu
Andrea Battista	Modus Medical	abattista@modusmed.com
Burcin S. Bayram	Miami University	bayramsb@muohio.edu
Mark Beck	Whitman College	beckmk@whitman.edu
Dan Beeker	Indiana University - Bloomington	debeeker@indiana.edu
Ernest R. Behringer	Eastern Michigan University	ebehringe@emich.edu
Feredoon Behroozi	University of Northern Iowa	behroozi@uni.edu
Sean Bentley	Adelphi University	bentley@adelphi.edu
Shreya Battacharyya-McCamy	NanoScience	shreya@nanoscience.com
Van D. Bistrow	University of Chicago	vanb@uchicago.edu
Eric Black	California Institute of Technology	blacke@its.caltech.edu
Yuriy Bomze	Duke University	Bomze456@phi.duke.edu
Charles Bosse	Massachusetts Institute of Technology	bossec@mit.edu
David Branning	Trinity College	david.branning@trincoll.edu
Lawrence P. Brehm	SUNY Potsdam	brehmlp@potsdam.edu
Jed Brody	Emory University	jbrody@emory.edu
Jeremy Carlo	Villanova University	jeremy.carlo@villanova.edu
Duncan Carlsmith	University of Wisconsin – Madison	duncan@hep.wisc.edu
Ashley Carter	Amherst College	acarter@amherst.edu
Michael Chin		mr.mpchin@gmail.com
Gary Chottiner	Case Western Reserve University	gary.chottiner@cwru.edu
Thomas F. Colton	University of California – Berkeley	tcolton@berkeley.edu
Brad Conrad	Appalachian State University	conradbr@appstate.edu
John Conrad	Furman University	john.conrad@furman.edu
Froney Crawford	Franklin and Marshall College	fcrawfor@fandm.edu
Bret Crawford	Gettysburg College	bcrawfor@gettysburg.edu
Andrew Croll	North Dakota State University	abcroll@gmail.com
John D. Cunningham	Loyola University - Chicago	yonniesj@juno.com
Nouri Dassi	NADA Scientific	nouridassi1@gmail.com
Andy Dawes	Pacific University	dawes@pacificu.edu
Thomas Dershem	W.M. Keck Science Department	tdershem@kecksci.claremont.edu
Robert DeSerio	University of Florida	deserio@phys.ufl.edu
Edward F. Deveney	Bridgewater State College	edeveney@bridgew.edu
Jennifer Dietrich	Modus Medical	
Joe Dohm	TelAtomic	JDohm@telatomic.com
Paul Dolan	Northeastern Illinois University	p-dolan@neiu.edu
Johan Du Plessis	Royal Melbourne Institute of Technology	johan.duplesis@rmit.edu.au
Jeff Dyck	John Carroll University	jdyck@jcu.edu
Melissa A. Eblen Zayas	Carleton College	meblenza@carleton.edu
Khalid Eid	Miami University	eidkf@muohio.edu

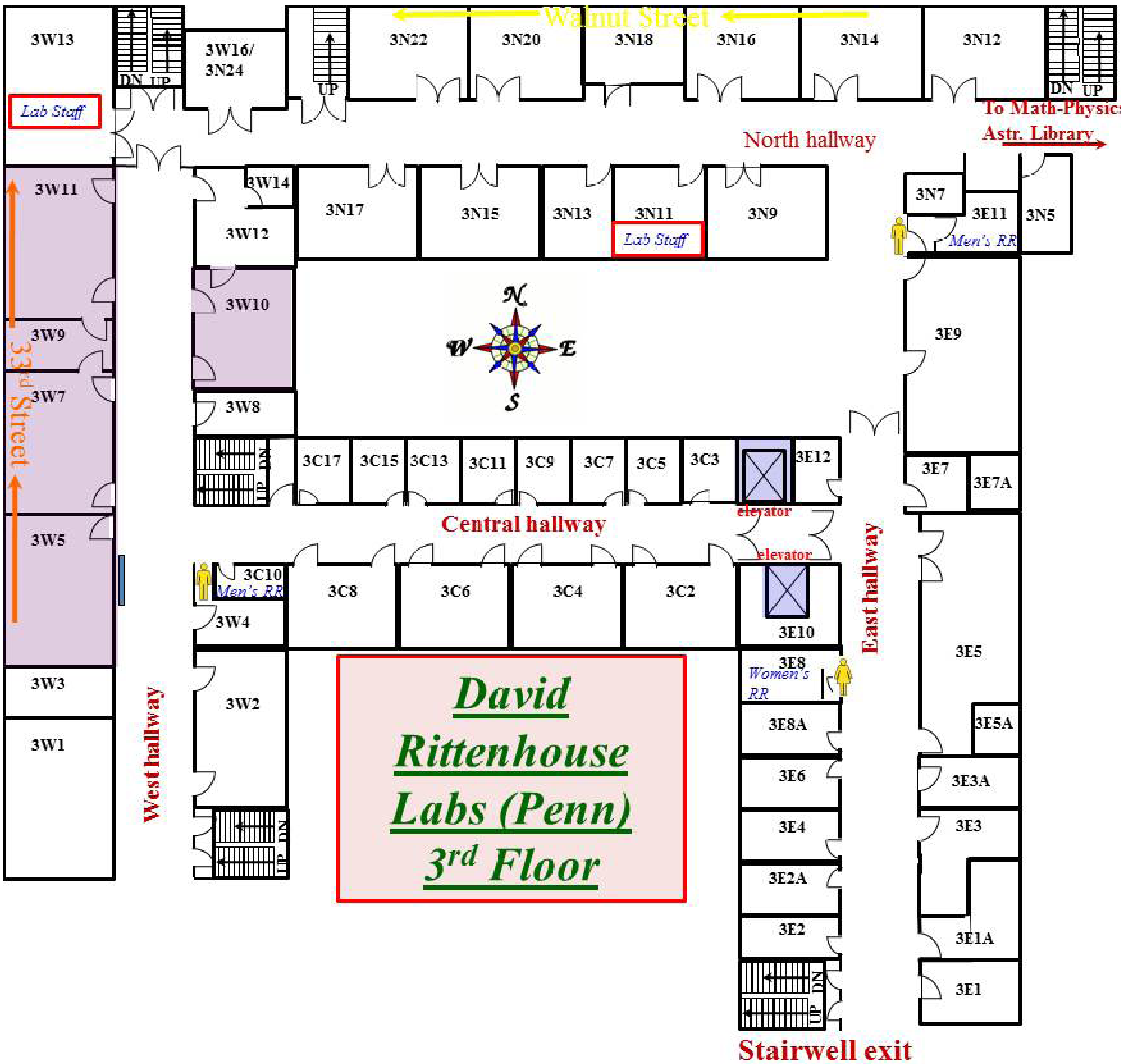
Gregg Elliott	University of Puget Sound	gelliott@ups.edu
Jon Erickson	Washington & Lee University	ericksonj@wlu.edu
John M. Essick	Reed College	jessick@reed.edu
Brett Fadem	Muhlenberg College	fadem@muhlenberg.edu
Len Feingold	Drexel University	L@drexel.edu
Erin Flater	Luther College	flater01@luther.edu
Lorcan Folan	Polytechnic University	folan@poly.edu
Vincente Fonesca	Universidade do Minho	vicente@fisica.uminho.pt
Duncan Forbes	Thomas Jefferson High School	DForbes@fcps.edu
Nathan Frank	Augustana College	nathanfrank@augustana.edu
Mario Freamat	Miami University	freamamv@muohio.edu
Greg Gabrielsen	Carroll College	ggabriel@carrollu.edu
Enrique J. Galvez	Colgate University	egalvez@mail.colgate.edu
Mark Gealy	Concordia University	gealy@cord.edu
Ben Geller	University of Maryland - College Park	geller@umd.edu
Elizabeth George	Wittenberg University	egeorge@wittenberg.edu
Mike Goggin	Truman State University	mgoggin@truman.edu
Carl H. Grossman	Swarthmore College	cgrossm1@swarthmore.edu
David Haase	North Carolina State University	david_haase@ncsu.edu
Gregg Harry	American University	harry@american.edu
Quyen Hart	Regis University	qhart@regis.edu
Jim Haskins	Thorlabs Inc.	jhaskins@thorlabs.com
Katrina Hay	Pacific Lutheran University	haykm@plu.edu
George Herold	TeachSpin Inc.	gherold@teachspin.com
Barbara Hoeling	California State Polytechnic University - Pomona	bmhoeling@csupomona.edu
Chad Hoyt	Bethel University	hoycha@bethel.edu
Dean Hudek	Brown University	dean_hudek@brwn.edu
Stephen Irons	Yale University	stephen.irons@yale.edu
Isaac Yakoub Isaac	University of Alberta	iisaac@ualberta.ca
Joss Ives	University of the Fraser Valley	joss.ives@ufv.ca
David Jackson	Dickinson College	jacksond@dickinson.edu
Floyd James	North Carolina A&T State University	fjames@ncat.edu
Marty Johnston	University of St Thomas	mejohnston@stthomas.edu
Jaclyn Kay	Klinger	
Mary Keeffe	Carroll College	mkeeffe@carroll.edu
Ken Kiers	Taylor University	knkiers@taylor.edu
Joseph F. Kozminski	Lewis University	kozminjo@lewisu.edu
Shawn T. Langan	University of Nebraska – Lincoln	slagan3@unl.edu
Urs Lauterberg	University of Bern	urs.lauterberg@space.unibe.ch
Yongkang Le	Fudan University	yongkangle@gmail.com
Michael Lerner	Earlham College	mglerner@gmail.com
Heather Lewandowski	University of Colorado - Boulder	lewandoh@colorado.edu
Nathan Lindquist	Bethel University	n-lindquist@bethel.edu
Mary L. Lowe	Loyola College - Baltimore	mlowe@loyola.edu
Dwight Luhman	Carleton College	dluhman@carleton.edu
Walter Luhs	Klinger	luhs@luhs.de
Helen Major	Lincoln University	hmajor@lincoln.edu
Irwin Malleck	Klinger	IMalleck@KlingerEducational.com

Dan Marlow	Princeton University	marlow@princeton.edu
Douglas Martin	Lawrence University	douglas.s.martin@lawrence.edu
Viktor Martisovits	Central College	martisovitsv@central.edu
Mark F. Masters	IPFW	masters@ipfw.edu
Donald R. Matthys	Marquette University	don.matthys@marquette.edu
Duncan E. McBride	National Science Foundation	dmcbride@nsf.gov
Lowell McCann	University of Wisconsin – River Falls	lowell.mccann@uwrf.edu
David McIntyre	Oregon State University	mcintyre@ucs.orst.edu
David Mendez Coca	Univeridad Internacional de la Rioja	davidmendezcoca@gmail.com
Jim Michels	SUNY Oneonta	James.Michels@oneonta.edu
Tom Moses	Knox College	tmoses@knox.edu
Declan Mulhall	University of Scranton	mulhalld2@scranton.edu
Jason Neiser	Centre College	jason.neiser@centre.edu
Jonathan Newport	American University	newport@american.edu
Paul Nienaber	St Marys University of Minnesota	pnienabe@smumn.edu
Shannon O'Leary	Lewis and Clark College	soleary@lclark.edu
Rick Pam	Stanford University	rickypam@stanford.edu
Beth Parks	Colgate University	meparks@colgate.edu
James E. Parks	University of Tennessee – Knoxville	jeparks@utk.edu
Christopher Pearson	University of Michigan – Flint	pear@umflint.edu
Tara Peppard	Cleveland State University	t.peppard@csuohio.edu
Thushara Perera	Illinois Wesleyan University	tperera@iwu.edu
Randolph S. Peterson	University of the South	rpeterso@sewanee.edu
Richard W. Peterson	Bethel University	petric@bethel.edu
Joseph Powlette	Moravian College	Powlette@moravian.edu
Allen Price	Emmanuel College	priceal@emmanuel.edu
Kirstin Purdy Drew	Pennsylvania State University - University Park	krp15@psu.edu
Gregory Putman	Kent State University	gputman1@kent.edu
Everett Ramer	University of Pittsburgh	evr13@pitt.edu
Jonathan Reichert	TeachSpin Inc.	jreichert@teachspin.com
Sean Robinson	Massachusetts Institute of Technology	spatrick@mit.edu
Julie Roche	Ohio University	rochej@ohio.edu
Willie Rockward	Morehouse College	rockwar@morehouse.edu
Evan Salim	Cold Quanta	evan.salim@coldquanta.com
Erik Sanchez	Portland State University	esanchez@pdx.edu
Tak Sato	Kwantlen Polytechnic University	takashi.sato@kwantlen.ca
Robert Schmedicke	The Science Source	bob@thesciencesource.com
Mizuho Schwalm	University of North Dakota	mizuho.schwalm@und.edu
Bill Schwalm	University of North Dakota	william.schwalm@und.edu
Kevin Seale	Vanderbilt University	sealekt@gmail.com
Greg Severn	University of San Diego	severn@sandiego.edu
Natthi Sharma	Eastern Michigan University	nsharma@emich.edu
Nathan Shepherd	Iowa Doppler Products	
Satinder Sidhu	Washington College	ssidhu2@washcoll.edu
R. Seth Smith	Francis Marion University	rsmith@fmarion.edu
Walter Smith	Haverford College	wsmith@haverford.edu
Tom Solomon	Bucknell University	tsolomon@bucknell.edu
Gabe Spalding	Illinois Wesleyan University	gspalding@iwu.edu

Keith R. Stein	Bethel University	k-stein@bethel.edu
Mac Stetzer	University of Maine	mackenzie.stetzer@maine.edu
Roger Stevens	Spectrum Techniques LLC	
Kory Stiffler	Iowa Doppler Products	kstiffle@umd.edu
Dale Stille	Iowa Doppler Products	dale-stille@uiowa.edu
Benjamin Stottrup	Augsburg College	stottrup@augsburg.edu
Weifeng Su	Fudan University	suwf@fudan.edu.cn
Kelley Sullivan	Ithaca College	kdsullivan@ithaca.edu
Orven Swenson	North Dakota State University	orven.swenson@ndsu.edu
Randy Tagg	University of Colorado - Denver	randall.tagg@ucdenver.edu
Aaron Titus	High Point University	atitus@highpoint.edu
Ramon O. Torres-Isea	University of Michigan	rtorres@umich.edu
Joe Trout	Richard Stockton College of New Jersey	troutj2@stockton.edu
David Alan Van Baak	Calvin College	dvanbaak@calvin.edu
Jose Vithayathil	University of Pennsylvania	vithayat@physics.upenn.edu
Ron Vogel	Iowa Doppler Products	ronald.vogel@uiowa.edu
Matt Vonk	University of Wisconsin - River Falls	matthew.vonk@uwrf.edu
Kurt Wick	University of Minnesota	wick@umn.edu
Joe Wiest	West Virginia Wesleyan College	wiest@wvwc.edu
Jeffrey Wike	Pennsylvania State University - Berks	jww12@psu.edu
Jeremiah D. Williams	Wittenberg University	jwilliams@wittenberg.edu
Linda Winkler	Minnesota State University - Moorhead	winklerl@mnstate.edu
Barbara Wolff-Reichert	TeachSpin Inc.	bwolffrichert@teachspin.com
Steven K. Wonnell	Johns Hopkins University	wonnell@pha.jhu.edu
Adrienne Wootters	Massachusetts College of Liberal Arts	adrienne.wootters@mcla.edu
Jan Yarrison-Rice	Miami University	yarrisjm@muohio.edu
Liang Zeng	University of Texas – Pan American	zengl@utpa.edu
T. Waldek Zerda	Texas Christian University	t.zerda@tcu.edu
Benjamin Zwickl	University of Colorado - Boulder	benjamin.zwickl@colorado.edu


Walnut Street
DRL 1st Floor Classrooms
ADA accessible entrances
Entrance to MMETS is outside DRL through this door!
From 33rd St
You enter here
33rd Street
West hallway
Rm. 1W25
Rm. 1W24
Rm. 1W20/22
Rm. 1W23
Rm. 1W21
Rm. 1W18
Rm. 1W19
Rm. 1W16
Rm. 1W17
Rm. 1W14
Rm. 1W15
Rm. 1W12
Rm. 1W13
Rm. 1W10
Rm. 1W11
Rm. 1W6/8
Rm. 1W9
Rm. 1W3/5
Rm. 1W4
Men's RR
Rm. 1W1
up
Rm. A2
ROOM A1
Rm. A4
Women's RR
Rm. 1L4
Rm. A8
Women's RR
Rm. A6
Rm. A7
Rm. A5
Men's RR
N
W
E
S


Walnut Street
2W11
2N48
2N46
2N44
2N42
2N40
2N38
2N36
2N34
2N32
North hallway
2N27B
2W9
2W10
2N27
2N25
2N25B
2N25A
2N23A
2N23B
2N23
2N21
Women's RR
2E19
2N19
2N17D
Men's RR
2W7
2N27A
2N23C
2W8
Walter's Deck
2E15
Physics Chair's Office
33rd Street
2W6
2C23
2C21
2C19
2C17
2C15
2C13
2C11
2C9
2C7
2C5
2C3
2C1
elevator
2E16
2E13
2E11
Central hallway
2W5
2C10
Men's RR
2C8
2C6
2C4
2C2
2E9
2E14
East hallway
West hallway
2W3
2E7
2E12
Men's RR
2W2
2W1
2E10
Women's RR
David Rittenhouse Labs (Penn) 2nd Floor
2E6A
2E8
2E7D
2E6
2E5B
2E4
2E5A
2E2
2E5
Stairwell


Walnut Street
3W13
3W16/
3N24
3N22
3N20
3N18
3N16
3N14
3N12
Lab Staff
To Math-Physics
Astr. Library
North hallway
3W11
3W14
3W12
3N17
3N15
3N13
3N11
Lab Staff
3N9
3N7
3E11
3N5
Men's RR
3W10
3W9
33rd Street
3W7
3W8
3E9
3C17
3C15
3C13
3C11
3C9
3C7
3C5
3C3
3E12
3E7
3E7A
elevator
Central hallway
3W5
3C10
Men's RR
3W4
3C8
3C6
3C4
3C2
3E10
East hallway
3E5
3W3
3W2
3E8
Women's RR
3E8A
3E5A
3W1
West hallway
3E6
3E3A
3E4
3E3
3E2A
3E1A
3E2
3E1
Stairwell exit
David Rittenhouse Labs (Penn) 3rd Floor