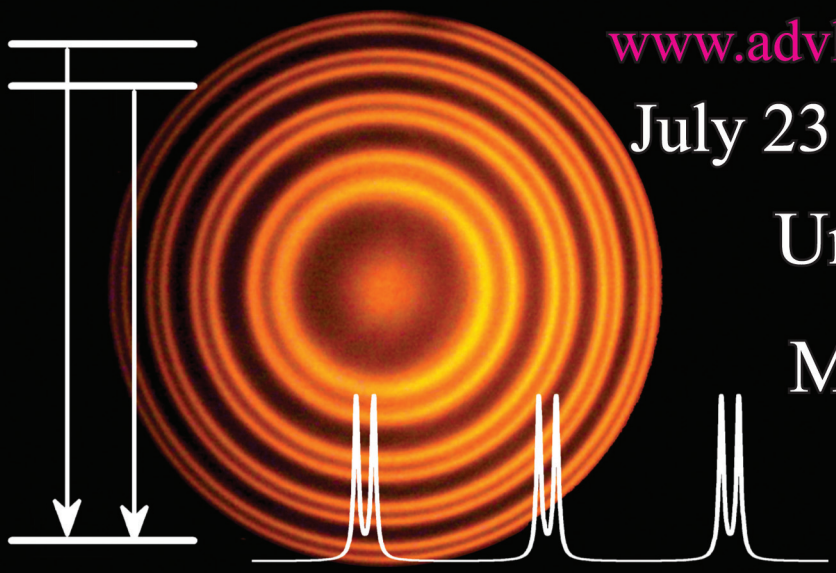
Topical Conference on

Advanced Laboratories

www.advlabs.aapt.org

July 23 - 25, 2009

University
of
Michigan

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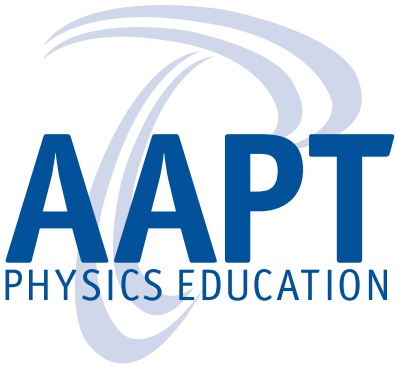
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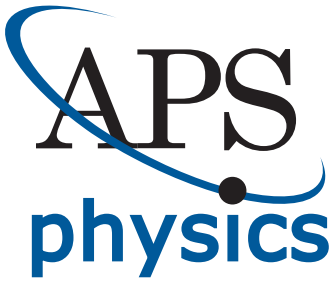
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TOPICAL CONFERENCE ON ADVANCED LABORATORIES

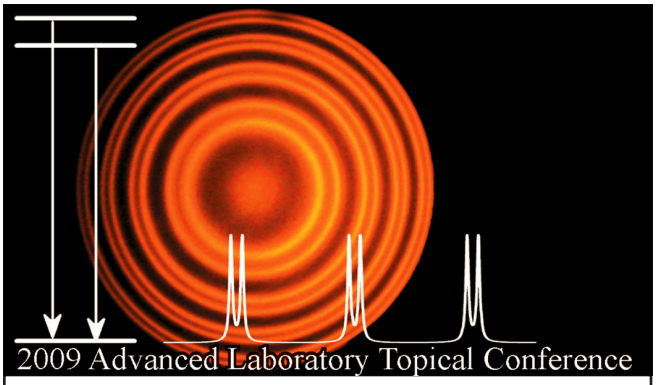
July 23–25, 2009
University of Michigan

www.advlabs.aapt.org

I welcome you to Ann Arbor and to the Topical Conference on Advanced Laboratories that is hosted by the Physics Department of the University of Michigan. It has been more than fifteen years since the last comprehensive conference on advanced labs, and hopefully the follow-up to this conference will occur in our lifetimes.

This conference grew out of the work done by the task force on the advanced lab appointed by Harvey Leff. It was 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. When Saturday arrives, the reality of this conference will be what you brought to it and what you take from it. Take time to enjoy each other's company and the laboratory experiences that are here for you.

Randy



Organizing Committee

Randy Peterson (co-chair), The University of the South

Ramon Torres-Isea (co-chair), University of Michigan – Ann Arbor

Paul Zitzewitz (co-chair), University of Michigan – Dearborn

Richard Peterson, Bethel University

Gabe Spalding, Illinois Wesleyan University

Lowell McCann, University of Wisconsin – River Falls

John Brandenberger, Lawrence University

David Van Baak, Calvin College

Eric Black, California Institute of Technology

Paul Dolan, Northeastern Illinois University

Elizabeth George, Wittenberg University

James Lockhart, San Francisco State University

Martin Mason, Mt. San Antonio College

Andra Troncalli, Austin College

Robert DeSerio, University of Florida

Van Bistrow, University of Chicago

CONTENTS

Wednesday, July 22

Registration	11:00 a.m. - 7:00 p.m. Dennison Building
Set up posters for Thursday	4:00 p.m. - 7:00 p.m. Dennison Building
Steering Committee meeting, registration desk	5:30 p.m. - 6:00 p.m. Dennison Building
Vendor meeting, registration desk	6:00 p.m. - 6:30 p.m. Dennison Building
Dinner, drop by registration to join others for dinner	

Thursday, July 23

Registration — 7:30 - 9:00 a.m., Dennison Building

Set up posters for Thursday — 7:30 - 8:00 a.m., Dennison Building

OPENING REMARKS

8:00 - 8:15 a.m., Dennison Building

Randolph Peterson (University of the South), Myron Campbell (University of Michigan), Ramon Torres-Isea (University of Michigan), and Warren Hein (AAPT)

SESSION I

"Advanced Labs: Different Visions for Different Settings" — 8:15 - 10:00 a.m., Dennison Building, John Brandenberger, presiding

- The MIT Junior Physics Laboratory Course, Isaac Chuang
- Caltech's Undergraduate Advanced Laboratory Program, Eric Black
- The Advanced Laboratory Program at California State University–East Bay, Derek Kimball
- The Advanced Laboratory at Swarthmore College, Carl Grossman

SESSION II

"Syllabi for Advanced Labs at Institutions of Participants" — 10:00 - 11:00 a.m., Dennison Building

BREAK AND POSTER SESSION

SESSION III

"Curricular Roles for Advanced Labs — What Are We Doing and What Should We Do?" — 11:00 a.m. - 12:15 p.m., Dennison Building, Elizabeth George, presiding

- Panel: Robert DeSerio, John Brandenberger, and Gabriel Spalding

Box lunches at the vendors' tables — 12:15 - 1:15 p.m., Randall Lab

Sponsored in part by Spectrum Techniques, LLC, Tel-Atomic, Inc., and National Instruments Corporation

SESSION IV

"Advanced Lab Ideas from Single-Photon Detection Quantum Mechanics" — 1:15 - 2:45 p.m., Dennison Building, Gabriel Spalding, presiding

- Optical vortices: Light in a Spin, Miles Padgett, University of Glasgow
- Experiments with correlated photons: From advanced-lab projects to dedicated laboratories, Enrique Galvez, Colgate University

SESSION V

"Short Workshops"	3:00 - 3:30 p.m. 3:40 - 4:10 p.m. 4:20 - 4:50 p.m.	Randall Lab

SESSION VI

"Workshops on Interfacing Instrumentation"	3:00 - 4:50 p.m. 5:05 - 6:40 p.m.	Randall Lab

SESSION VII

"Short Workshops"	5:05 - 5:35 p.m. 5:45 - 6:15 p.m. 6:25 - 6:50 p.m.	Randall Lab

Session II poster removal	6:45 - 8:45 p.m.
Dinner at Pizza House Sponsored by Pasco Scientific	7:15 - 8:30 p.m.
Set up posters and equipment for Session IX	8:30 - 10:00 p.m. Dennison Building

Friday, July 24

Set up posters and equipment for Session IX — 7:00 - 8:00 a.m., Dennison Building

SESSION VIII

"Applied Physics: Hot Topics in Advanced Labs" — 8:15 - 9:30 a.m., Dennison Building, Richard Peterson, presiding

- Interdisciplinary Experiments for Upper-level Physics Laboratory Courses, Suzanne Amador Kane, Haverford College
- Chaos Experiments for the Advanced Lab, Robert DeSerio, University of Florida
- The Fluid Mechanics and Computational Physics in the Advanced Undergraduate Laboratory, Keith R. Stein, Bethel University

SESSION IX:

"Especially Effective Laboratory Experiments and Open-ended Labs" — 9:30 - 11:15 a.m.
BREAK & POSTER SESSION — Dennison Building

SESSION X

"What makes a Good Advanced Lab Experiment?" — 11:15 a.m. - 12:15 p.m., Dennison Building, Paul Dolan, presiding

- Panel: Van Bistrow, Eric Ayers, Joe Kozmikski

Box lunches at the vendors' tables — 12:15 - 1:15 p.m.
Sponsored by TeachSpin, Inc. — Randall Lab

SESSION XI

"Short Workshops"	1:20 - 1:50 p.m. 2:00 - 2:30 p.m. 2:40 - 3:10 p.m.	Randall Lab

SESSION XII

"Workshops on Interfacing Instrumentation"	1:20 - 3:10 p.m. 3:30 - 5:20 p.m.	Randall Lab

SESSION XIII

"Short Workshops"	3:30 - 4:00 p.m. 4:10 - 4:40 p.m. 4:50 - 5:20 p.m.	Randall Lab

Session IX poster removal, or may remain until 2:00 p.m. Saturday — 5:30 - 9:30 p.m.

Dinner at Palmer Commons — 6:00 - 7:30 p.m.
Sponsored in part by Klinger Educational Products Corporation and Agilent Technologies, Inc.

SESSION XIV

"Advanced Lab Demonstrations" — 8:00 - 9:00 p.m., Dennison Building, David Sturm, presiding

Saturday, July 25

SESSION XV

"Funding the Advanced Lab" 8:00 - 8:30 a.m.
Dennison Building
Randy Peterson, presiding

- The Role of the NSF in Advanced Labs, Duncan McBride, NSF

SESSION XVI

"Breakout Sessions" 8:40 - 9:35 a.m. & 9:50 - 10:45 a.m.
CONTRIBUTED/INVITED TALKS Dennison Building

- Teaching the electronics course — Paul W. Zitzewitz, presiding
- Teaching the optics course — Chad Hoyt, presiding
- Communication of experimental results—graphical, written, and oral — Elizabeth George, presiding
- Machine shop and laboratory safety — Gregory Puskar, presiding
- Regional/National Advanced Lab facilities — Randy Peterson, presiding
- Advanced Computer Interfacing — Ramon Torres-Isea, presiding
- Computation and Simulation in the Advanced Lab — Keith Stein, presiding
- Advanced Labs in Biophysics —
- Teaching Condensed Matter or Materials Physics Labs — Gabe Spalding, presiding
- Teaching the Modern Physics Lab — David Alan Van Baak, presiding

SESSION XVII

"Interaction of the Advanced Lab with Undergraduate Research and REUs" 11:00 a.m. - Noon
Dennison Building
Richard Peterson, presiding

- Panel: Eric Black, Burcinn Bayram, Donald Smith, Stephen Remillard

Box lunches and concluding remarks 12:15 - 1:15 p.m.
Dennison Building

Informal Discussions 1:00 - 2:00 p.m.
Dennison Building

Posters and equipment removal Noon - 2:00 p.m.
Dennison Building

Informal Vendor workshops 1:00 - 5:00 p.m.
Dennison Building

EXPANDED SCHEDULE

Thursday, July 23

SESSION I: INVITED SESSION

"Advanced Labs: Different Visions for Different Settings"

8:15 - 10:00 a.m. · Dennison Building
John Brandenberger, presiding

The MIT Junior Physics Laboratory Course
Invited: Isaac Chuang

The MIT Junior Physics Laboratory course is a two-semester program which provides students with hands-on experience in modern physics focused both on the teaching of experimental art as well as expository writing and speaking. This course occupies a unique place in the physics curriculum, conveying much of the story of physics leading to the advent of quantum mechanics, while also building students' intuition for the experimental consequences of quantum mechanics. The twenty experiments currently offered provide experimental illustrations of key physics concepts evolving from particle-wave duality and relativity to superconductivity, principles of astrophysics, and concepts of quantum information science. Five of these experiments are typically completed each semester, each in two weeks by a team of two students who give 12-minute American Physical Society meeting-like talks and submit four-page Phys. Rev. Letter style papers on each result. This is a memorable experience that is simultaneously treasured and feared, not only by the students, but also by the faculty instructors.

Caltech's Undergraduate Advanced Laboratory Program
Invited: Eric D. Black

The California Institute of Technology is a private research university specializing in science and engineering. The undergraduate student body consists of about 900 students, and each year some 30 or 40 graduate with a degree in physics. Most of these students will go on to do research in some capacity, either as graduate students at other universities or employees in technology-based startup companies. Physics students are required either to do a senior thesis or to take two quarters of senior lab, with most taking the latter option. The senior lab course provides an introduction to several advanced experimental techniques and is divided up into sections specializing in atomic physics, modern optics, and condensed-matter physics. In this talk I will describe the mechanics and philosophy behind these sections, with a special focus on the condensed-matter track, and I will talk about how the course is intended to integrate into the broader physics community, both inside and outside the university.

The Advanced Laboratory Program at California State University–East Bay
Invited: Derek F. Jackson Kimball

California State University–East Bay is a public university focusing on undergraduate education, with approximately 13,000 students, and is one of the most diverse undergraduate institutions in the United States. The Department of Physics has a faculty of four, three of whom are assistant professors, and the number of majors has more than tripled during the past four years to about eight majors per year. Our relatively young faculty has been fortunate enough to inherit a strong advanced laboratory program built by emeritus Prof. Daryl Preston (author of The Art of Experimental Physics), which includes laboratories on electron spin resonance, saturated absorption spectroscopy, gamma ray spectroscopy, and atom trapping and cooling. The advanced laboratory is taught over two quarters, and we also teach a quarter of electronics and a quarter of computational physics (including programming in LabVIEW). In particular we will discuss our strategies to integrate advanced laboratory instruction with undergraduate research—a synthesis which has contributed to our recent success in attracting new physics majors, especially women and underrepresented minorities.

The Advanced Laboratory at Swarthmore College
Invited: Carl H. Grossman

The Department of Physics and Astronomy at Swarthmore College—a liberal arts college with 1500 students—has a faculty of nine and graduates fifteen majors per year, more than half of whom pursue graduate work in physics, astrophysics, engineering, or related disciplines. The advanced laboratory program, which spans two semesters, combines the execution of several major experiments with instruction in electronics. Students spend three weeks on each of their selected experiments followed by three weeks on basic electronics, and they write formal lab reports and receive feedback/revision (a college requirement). In all, students complete four experiments and four sessions of electronics (basic analog, basic digital, computer I/O, and specialty measurements such as lockin-amplification). The experiments are supervised by the five departmental experimentalists, each of whom is the caretaker for several experiments. The experiments include NMR, plasma physics, low temperature electrical transport, specific heats, ultrafast laser pulses, optical tweezers, nuclear lifetimes, liquid crystals, optical pumping, and Raman spectroscopy.

SESSION II: POSTER SESSION

"Syllabi for Advanced Labs at Institutions of Participants"

10:00 - 11:00 a.m. · Dennison Building

S01 **The Advanced Undergraduate Nuclear and Atomic Laboratory Course at the University of North Texas**
Duncan Weathers, University of North Texas

S02 **Optics for Scientists and Engineers Laboratory Syllabus**
Orven F. Swenson, David A. Rogers & Ivan T. Lima Jr., North Dakota State University

S03 **Syllabi and Questions for Intermediate & Advanced Labs for the College Physics Major**
Ed Deveney, Bridgewater State College

S04 **Intermediate/Advanced Laboratory: Combining Writing, Basic Instrumentation, Fundamental Electronics**
Ross Reynolds, Doug Furton, Harold Schnyders, & Richard Vallery, Grand Valley State University

S05 **The Biological Physics Labs in the JHU Department of Physics and Astronomy**
Steven K. Wonnell & Daniel H. Reich, Johns Hopkins University

S06 **The Evolving Syllabus for the Capstone Project Course at Eastern Michigan University**
Ernest Behringer & James J. Carroll, Eastern Michigan University

S07 **The Advanced Physics Laboratory Course at Pomona College**
Alma C. Zook & David M. Tanenbaum, Pomona College

S08 **Advanced Lab Sequence at San Francisco State University**
James M. Lockhart, San Francisco State University

S09 **Intermediate Lab at NEIU**
Paul J. Dolan, Jr., Northeastern Illinois University

S10 **Increasing Student Independence and Insight in the Intermediate Physics Laboratory**
Mark Masters & Timothy T. Grove, Indiana University–Purdue University Fort Wayne

S11 **Writing and Peer Review for Advanced Laboratories: A Proposal**
Mark Masters & Timothy T. Grove, Indiana University–Purdue University Fort Wayne

S12 **Intermediate and Advanced Labs at Carleton College**
Melissa Eblen-Zayas & Dwight Luhman, Carleton College

S13 **Advanced Physics Laboratory at Purdue University Calumet**
Adam Rengstorf, Purdue University Calumet

S14 **The Advanced Physics Lab at the University of Toronto**
David C. Bailey, Jason J. B. Harlow, & Natalia N. Krasnopolskaia, University of Toronto

S15 **Intermediate and Advanced Physics Laboratories: Breadth and Depth in Experimental Physics**
Matthew C. Sullivan, Ithaca College

S16 **The Contemporary Physics Laboratories of the Faculty of Science UNAM**
Beatriz Fuentes, Luis León, René Ortega, Ricardo Hernández, National Autonomous University of Mexico (UNAM)

S17 **An Advanced-lab Model for Liberal-Arts Colleges: Capstone Research Projects**
Enrique J. Galvez, Colgate University

S18 **Modern Physics Lab at Marshall University**
Maria C. Babiuc-Hamilton, Marshall University

S19 **Research Group Model for Advanced Lab**
Martin Madsen, Wabash College

S20 **Honing Experimental Physicists at UW–River Falls**
Lowell McCann & Earl D. Blodgett, University of Wisconsin–River Falls

S21 **Use of LabVIEW™ in a Senior-Level Capstone Laboratory**
Linda S. Fritz, J.K. Krebs, & N.S. Dixon, Franklin & Marshall College

S22 **A New Sequence of Advanced Laboratory Courses at the University of Wisconsin Oshkosh**
Dennis Rioux, University of Wisconsin Oshkosh

S23 **Upper-level Lab Sequence at Wittenberg University: Paths to Student Independence**
Elizabeth A. George, Wittenberg, Paul A. Voytas, & Jeremiah D. Williams University, Springfield

S24 **Advanced Physics Labs at the University of Oregon**
Dean Livelybrooks & Eric Torrence, University of Oregon

S25 **Berkeley's Two-semester Advanced Lab Sequence**
Thomas Colton, Robert Jacobsen, & Donald Orlando, University of California, Berkeley

S26 **Binghamton University Intermediate and Advanced Lab Courses**
Mark Stephens, Binghamton University

S27 **The Advanced Laboratory Program at the Colorado School of Mines**
David Schuster, Colorado School of Mines

S28 **Upper Level Labs at University of Alberta**
Isaac Isaac & Terry Singleton, University of Alberta

S29 **Contents or Discontents? Optimizing What Goes into the Undergraduate Electronics Course**
Paul Nienaber, Saint Mary's University of Minnesota

SESSION III: PANEL DISCUSSION

"Curricular Roles for Advanced Labs — What Are We Doing and What Should We Do?"

11:00 a.m. - 12:15 p.m. · Dennison Building
Elizabeth George, presiding
Panel: Robert DeSerio, John Brandenberger, & Gabriel Spalding

SESSION IV: INVITED SESSION

"Advanced Lab Ideas from Single-Photon Detection Quantum Mechanics"

1:15 - 2:45 p.m. · Dennison Building
Gabe Spalding, presiding

Optical Vortices: Light in a Spin

Invited: Miles Padgett, University of Glasgow

A feature of wave superposition is that one plus one does not necessarily equal two. The interference of two equivalent waves can result in a zero intensity—e.g. Young's double slits. However, the waves fill 3D space not just a 2D screen and the dark fringes map out planes. But two waves are a special case. In general, when three or more waves interfere, complete destructive interference occurs on lines (phase singularities) around which the phase advances or retards by 2pi. This azimuthal phase gradient means that the Poynting vector, and associated energy flow, circulates too—hence the lines are also called optical vortices. Despite their appearance in all natural light fields, it was not until the early 1990's that it was recognized that the surrounding light carried an angular momentum, completely independent of the photon spin.

This orbital angular momentum can be created using simple lens systems, or holograms—made from 35mm film or encoded onto liquid crystal displays. Both whole beams, and single photons can carry this information or transfer it to mater to create an optical spanner.

In this talk I hope to introduce the underlying physical properties and discuss a number of demonstration experiments and modeling examples, which highlight how optics still contains surprises and opportunities for both the classical and quantum worlds.

Experiments with Correlated Photons: From Advanced-lab Projects to Dedicated Laboratories

Invited: Enrique J. Galvez, Colgate University

Advances in technology have allowed the feasibility of table-top experiments with correlated photons for curricular physics laboratories. Through our own form of advanced lab, capstone research projects, we have developed a set of experiments with correlated photons into a laboratory component for an upper-level course that normally does not have one: quantum mechanics. The virtue of the experiments is that they are understood with the quantum mechanics of a single quantum, and thus lend themselves as experimental exercises of quantum mechanics algebra. The experiments also bring to the forefront of the discussion fundamental topics of quantum mechanics that are particularly difficult to understand, such as superposition, indeterminism and nonlocality. Our experiments include photon and biphoton interference, the quantum eraser and quantum entanglement. Some of the developmental student projects led to research problems that were published in research journals. This work has been funded by grants from the National Science Foundation.

SESSION V

"Short Workshops"

3:00 - 4:50 p.m. · Randall Lab

SESSION VI

"Workshops on Interfacing Instrumentation"

3:00 - 6:40 p.m. · Randall Lab

SESSION VII

"Short Workshops"

5:05 - 6:50 p.m. · Randall Lab

Friday, July 24

SESSION VIII: INVITED SESSION

"Applied Physics: Hot Topics in Advanced Labs"

8:15 - 9:30 a.m. · Dennison Building
Richard Peterson, presiding

Interdisciplinary Experiments for Upper-level Physics Laboratory Courses

Invited: Suzanne Amador Kane, Haverford College

Our laboratory program involves three semesters of experiments at the "junior-lab" level. One semester covers analog electronics up to op-amps and LRC circuits, while others involve experiments in oscillations, waves and optics. Labs with interdisciplinary applications are a special focus, and have included experiments in ultrasound imaging, laser tweezers, microfluidics, atomic force and scanning tunneling microscopy, magnetic resonance imaging, biosensors, solid state synthesis of quantum dots and high-Tc superconductors, among others. We describe the development and implementation of this lab program and focusing on these interdisciplinary projects. These projects aim at introducing majors to new and useful research tools and interdisciplinary research topics in biophysics, medical physics and materials science. Students are exposed to LabView programming, image analysis, microfabrication techniques, chemical vapor deposition and solid state synthesis. Each modular laboratory is being developed to allow exportation to other natural science departments. Many curricular resources developed as part of this project are available on the web, including downloadable student laboratory manuals and instructor's guides.

Chaos Experiments for the Advanced Lab

Invited: Robert DeSerio, University of Florida

With frequent references in music, movies and TV, chaos theory is officially cool! The subject is also relatively new with many of the important developments occurring over the past few decades, and it is multidisciplinary with applications in the physical, biological and social sciences. Exotic terms such as "strange attractor" and "butterfly effect" as well as the visually stunning fractal structures describing chaotic dynamics further enhance the topic's allure.

Many mechanical, electronic and fluid systems have been used for advanced lab experiments on the subject, but few have demonstrated the ability to produce data suitable for creating fractals or for calculating quantitative measures of the resulting dynamics. I have used a water drop apparatus, a driven pendulum, and an electronic Duffing oscillator in an advanced lab setting. With LabVIEW software and simple data acquisition hardware, all three are easy and inexpensive to build. I will show how they produce data that can be displayed as multiple Poincaré sections or as multidimensional return maps, and I will describe the algorithms and results for calculations of the embedding dimension, fractal dimension, Lyapunov exponents, and system parameters. Student performance on one of the experiments will also be discussed.

Fluid Mechanics and Computational Physics in the Advanced Undergraduate Laboratory

Invited: Keith R. Stein, Bethel University

Fluid mechanics and structural mechanics play a small role in the vast majority of undergraduate physics programs. However, many undergraduate students use their physics major as a stepping-stone towards graduate degrees in engineering or applied physics where these areas often play a more prominent role. Professor Jerry Gollub stated in a December 2003 Physics Today article, "one of the oddities of contemporary phys-

ics education is the nearly complete absence of continuum mechanics in the typical undergraduate or graduate curriculum" and questioned how the physics academic community can justify this absence. In our program, fluid and structural mechanics experiments are integrated into an Applied Physics major option within the framework of the advanced laboratories accompanying course offerings in Fluid Mechanics and Computer Methods in Physics and Engineering.

Snapshots are presented from a variety of recent undergraduate projects in fluids and computational physics. The projects include wind tunnel and water tunnel studies employing a variety of flow visualization and fluid diagnostics techniques. Computational studies represent a complementary approach in some of the projects and serve to enrich the advanced undergraduate laboratory experience. MATLAB and COMSOL Multiphysics software applications in these areas will be highlighted. Special attention will be given to advanced lab projects that have been carried out with a Mach 3 shock tunnel. These projects have focused on shock dynamics and compressible flow in the shock tube and tunnel test section and have included piezoelectric pressure measurements, dual-beam interferometry, shadowgraph and schlieren imaging in conjunction with corresponding computational studies.

SESSION IX: POSTER SESSION

"Especially Effective Laboratory Experiments and Open-ended Labs"

9:30 - 11:15 a.m. · Dennison Building

L01 **A Michelson-Morley Experiment for the Advanced Physics Lab**
Charles Rogers & Richard Selvaggi,
Texas A&M University–Commerce

L02 **A Knots Experiment**
David C. Bailey, Jason J. B. Harlow, Natalia N. Krasnopolskaia, & Stephen W. Morris, University of Toronto

L03 **A Tabletop Measurement of the Quantization of Electrical Conductance in Gold Nanowires**
David Tam, Columbia University

L04 **Angular Momentum Outside of the Classical Mechanics Courses**
Nathan H. Frank, Augustana College
Gabriel C. Spalding, Illinois Wesleyan University

L05 **Atomic Spectroscopy in Alkali Vapor**
Marin Pichler, Goucher College

L06 **Atomic Structure from the Sodium Atom UV-VIS-NIR Spectrum**
Randolph S. Peterson, The University of the South

L07 **Can Students Design Their Own Experiments?**
Randy Knight, California Polytechnic State University

L08 **Computational and Optical Studies on the Vibrational Modes of a Tuning Fork**
Keith R. Stein, Richard W. Peterson, Jack Houlton, Justin Knapp, Brandon Peplinski, & David Swenson, Bethel University
Christopher Scheevel, University of Minnesota

L09 **Determining the Half-life of ^{40}K from the Activity of Salt Substitute**
Elizabeth A George & Paul A Voytas, Wittenberg University

L10 **Developing Research and Experimentation Skills: Demonstrated using a Black Body Radiation Experiment**
Mark J. Pearson & Jamie D. White, Juniata College

L11 **Doppler-broadening for Rubidium Absorption**
James D. White, Kenny Goodfellow, Amy Frantz, Geneva White, Brad Dinardo, Jon Green, & Mark J. Pearson
Juniata College

L12 **Driven Linear and Non-linear Resonance Experiment**
Rex Berney, University of Dayton

L13 **Example Harmonic and Anharmonic Oscillators Demonstrated and Analyzed**
Bernard Cleyet, Salinas, CA

L14 **Experimental Observation and Control of Wave Dispersion**
S.K. Remillard, Hope College

L15 **Finding Thermal Conductivity and Specific Heat via Thermal Diffusion in Rods**
Matthew C. Sullivan & B. G. Thompson, Ithaca College
A. P. Williamson, Brandeis University

L16 **Measurement of the Dispersion Relation of a Wave on a String**
Jeremiah D. Williams, Daniel Fleisch, Elizabeth George & Paul Voytas, Wittenberg University

L17 **Measuring the Molecular Polarizability of Air**
Martin Madsen, D.R. Brown, S.R. Krutz, & M.J. Milliman, Wabash College

L18 **Measuring the Speed of Light in an Optical Fiber — Integrating Experimentation and Instrumentation**
Nasser Mulaa Juma, A. D. Edwards, P. Chang, K. L. Corwin, B. R. Washburn, & N. S. Rebello, Kansas State University

L19 **Millikan's Oil Drop: Simulation and Experiment**
Sarah J Desotell, Ripon College

L20 **Noise Fundamentals, Where Noise Is the Signal**
George Herold, TeachSpin, Inc.,
David Van Baak, Calvin College

L21 **Nuclear Spin Echoes — In Live Audio**
David Van Baak, Calvin College

L22 **Resistivity Measurements and Observation of Transition to Superconducting State**
Mohammed Z. Tahar, State University of New York College at Brockport

L23 **Study of Electric and Magnetic Dipole Radiation via Scattering from Nanoparticles**
Natthi L. Sharma & Ernest Behringer,
Eastern Michigan University

L24 **Sub-picometer Resolution from a Michelson Wavelength Meter**
Chad Hoyt, Adam Banfield, & Sarah Kaiser, Bethel University
Sarah Anderson, University of Michigan

L25 **TO BE OR NOT TO BE OHMIC: A Warm-up Exercise for Advanced Labs**
Paul J. Dolan, Jr., Northeastern Illinois University

L26 **The Kenyon X-ray Facility Upgrade**
J. Terrence Klopcic, Kenyon College

L27 **Two-laser Spectroscopy in Atomic Cesium**
Andrzej (Andy) Sieradzan, Aaron Hankin, & Clark VanDam,
Central Michigan University
Mark Havey, Old Dominion University

L28 **Using Longitudinal Laser Modes to Make Accurate Speed of Light Measurements**
James D. White, Mark J. Pearson, Justin T. Schultz, Daniel Sidor, Michael Best, & Daniel D'Orazio, Juniata College

L29 **Using Pfund's Method to Find the Index of Refraction**
Helene F. Perry, Loyola College in Maryland

L30 **Vibrational Spectra of the Nitrogen Molecules in the Liquid and Gas Phase**
Burcin Bayram & David Fisher, Miami University

SESSION X: PANEL DISCUSSION

"What makes a Good Advanced Lab Experiment?"
11:15 a.m. - 12:15 p.m. · Dennison Building
Paul Dolan, presiding
Panel: Van Bistrow, Eric Ayers, & Joe Kozmikski

SESSION XI

"Short Workshops"
1:20 - 3:10 p.m. · Randall Lab

SESSION XII

"Workshops on Interfacing Instrumentation"
1:20 - 5:20 p.m. · Randall Lab

SESSION XIII

"Short Workshops"
3:30 - 5:20 p.m. · Randall Lab

SESSION XIV: DEMO SESSION

"Advanced Lab Demonstrations"
8:00 - 9:00 p.m. · Dennison Building
David Sturm, presiding

Advanced Demonstrations for the Classroom and the Laboratory
Invited: David Sturm, University of Maine and Physics Instructional Resource Association (PIRA)
Ramon Torres-Isea, University of Michigan
Dale Stille, University of Iowa
Chad Hoyt and Richard Peterson, Bethel University
David Maiullo, Rutgers University
Paul Dolan, Northeastern Illinois University

These are not the typical demonstrations used in physics demo shows, but they will be limited to those that can be completed in a few minutes and have short assembly times. The demos in this hour will include such fare as "Showdown: Toepler Holtz vs. Wimshurst", "Pohl's Mica", "Decomposition of He-Ne Laser Spectrum", "Sweeping Orthogonal Modes in a Laser", "Single Photon", "Bed of Nail" [sic], "Radioactive Ballasts", and "Half-Spin". For demonstrations that take more time to prepare, we will provide a handout sample of the PIRA Demonstration Bibliography, and a list of standard demonstrations for advanced courses with links to AJP and TPT references.

Saturday, July 25

SESSION XV: NSF SESSION

"Funding the Advanced Lab"
8:00 - 8:30 a.m. · Dennison Building
Randolph Peterson, presiding

The Advanced Laboratory and the National Science Foundation
Invited: Duncan McBride, National Science Foundation

I will describe some of the advanced physics lab projects NSF has supported. In addition, I will discuss the mechanisms of support from NSF both for development of new experiments and for the adaptation and implementation of advanced physics lab experiments in the local curriculum.

SESSION XVI: BREAKOUT SESSIONS

Contributed/Invited Talks
8:40 - 9:35 a.m. & 9:50 - 10:45 a.m. · Dennison Building
Sessions are an hour long and schedules will be posted.

Teaching the electronics course

Paul W. Zitzewitz, presiding

An Electronics Course for the Computer Age using Learning Cycle Pedagogy
Paul W. Zitzewitz, University of Michigan – Dearborn

Teaching the optics course
Chad Hoyt, presiding

Active Learning Using Tutorials in Intermediate Optics
Mark Masters & Timothy T. Grove, Indiana University – Purdue University Fort Wayne

Advanced Optics lab at SJSU
Ramen Bahuguna, San Jose State University

Laboratory Emphasis in Interdisciplinary Photonics Related Courses
Orven F. Swenson, North Dakota State University
David A. Rogers & Ivan T. Lima Jr., North Dakota State University

Undergraduate Laser Laboratory at SJSU
Ken Wharton, San Jose State University

Modifying the Optics Laboratory for Greater Conceptual Understanding
Timothy T. Grove & Mark F. Masters, Indiana University – Purdue University Fort Wayne

Communication of experimental results — graphical, written, and oral
Elizabeth George, presiding

Multi-Format Approach to Communication of Experimental Results
James M. Lockhart, San Francisco State University

Oral Assessment in an Advanced Lab Course
David C. Bailey, University of Toronto

Machine shop and laboratory safety
Gregory Puskar, presiding

Safety in the Advanced Lab - More than You Might Expect
Gregory Puskar, West Virginia University

Regional/National Advanced Lab Facilities
Randy Peterson, presiding

The Visiting Students and Faculty Program at the University of North Texas
Duncan Weathers, University of North Texas

Advanced Computer Interfacing
Ramon Torres-Isea, presiding

Computation and Simulation in the Advanced Lab
Keith Stein, presiding

Advanced Labs in Biophysics

Teaching Condensed Matter or Materials Physics Labs
Gabe Spalding, presiding

Teaching the Modern Physics Lab
David Alan Van Baak, presiding

SESSION XVII: PANEL DISCUSSION
"Interaction of the Advanced Lab with Undergraduate Research and REUs"
11:00 a.m. - Noon · Dennison Building
Richard Peterson, presiding
Panel: Eric Black, Burcin Bayram, Donald Smith, & Stephen Remillard

ABSTRACTS

Thursday, July 23

SESSION I: INVITED SESSION
"Advanced Labs: Different Visions for Different Settings"

The MIT Junior Physics Laboratory Course
Invited: Isaac Chuang, Massachusetts Institute of Technology, Cambridge, MA 02139-4307

The MIT Junior Physics Laboratory course is a two-semester program which provides students with hands-on experience in modern physics focused both on the teaching of experimental art as well as expository writing and speaking. This course occupies a unique place in the physics curriculum, conveying much of the story of physics leading to the advent of quantum mechanics, while also building students' intuition for the experimental consequences of quantum mechanics. The twenty experiments currently offered provide experimental illustrations of key physics concepts evolving from particle-wave duality and relativity to superconductivity, principles of astrophysics, and concepts of quantum information science. Five of these experiments are typically completed each semester, each in two weeks by a team of two students who give 12-minute American Physical Society meeting-like talks and submit four-page Phys. Rev. Letter style papers on each result. This is a memorable experience that is simultaneously treasured and feared, not only by the students, but also by the faculty instructors.

Caltech's Undergraduate Advanced Laboratory Program
Invited: Eric D. Black, California Institute of Technology, Pasadena, CA 91125

The California Institute of Technology is a private research university specializing in science and engineering. The undergraduate student body consists of about 900 students, and each year some 30 or 40 graduate with a degree in physics. Most of these students will go on to do research in some capacity, either as graduate students at other universities or employees in technology-based startup companies. Physics students are required either to do a senior thesis or to take two quarters of senior lab, with most taking the latter option. The senior lab course provides an introduction to several advanced experimental techniques and is divided up into sections specializing in atomic physics, modern optics, and condensed-matter physics. In this talk I will describe the mechanics and philosophy behind these sections, with a special focus on the condensed-matter track, and I will talk about how the course is intended to integrate into the broader physics community, both inside and outside the university.

The Advanced Laboratory Program at California State University–East Bay
Invited: Derek F. Jackson Kimball, California State University–East Bay, Hayward, CA 94542

California State University–East Bay is a public university focusing on undergraduate education, with approximately 13,000 students, and is one of the most diverse undergraduate institutions in the United States. The Department of Physics has a faculty of four, three of whom are assistant professors, and the number of majors has more than tripled during the past four years to about eight majors per year. Our relatively young faculty has been fortunate enough to inherit a strong advanced laboratory program built by emeritus Prof. Daryl Preston (author of The Art of Experimental Physics), which includes laboratories on electron spin resonance, saturated absorption spectroscopy, gamma ray spectroscopy, and atom trapping and cooling. The advanced laboratory is taught over two quarters, and we also teach a quarter of electronics and a quarter of computational physics (including programming in LabVIEW). In particular we will discuss our strategies to integrate advanced laboratory instruction with undergraduate research – a synthesis which has contributed to our recent success in attracting new physics majors, especially women and underrepresented minorities.

The Advanced Laboratory at Swarthmore College
Invited: Carl H. Grossman, Swarthmore College, Swarthmore, PA 19081

The Department of Physics and Astronomy at Swarthmore College—a liberal arts college with 1500 students—has a faculty of nine and graduates fifteen majors per year, more than half of whom pursue graduate work in physics, astrophysics, engineering, or related disciplines. The advanced laboratory program, which spans two semesters, combines the execution of several major experiments with instruction in electronics. Students spend three weeks on each of their selected experiments followed by three weeks on basic electronics, and they write formal lab reports and receive feedback/revision (a college requirement). In all, students complete four experiments and four sessions of electronics (basic analog, basic digital, computer I/O, and specialty measurements such as lockin-amplification). The experiments are supervised by the five departmental experimentalists, each of whom is the caretaker for several experiments. The experiments include NMR, plasma physics, low temperature electrical transport, specific heats, ultrafast laser pulses, optical tweezers, nuclear lifetimes, liquid crystals, optical pumping, and Raman spectroscopy.

SESSION II: POSTER SESSION
"Syllabi for Advanced Labs at Institutions of Participants"

S01 **The Advanced Undergraduate Nuclear and Atomic Laboratory Course at the University of North Texas**
Duncan Weathers, University of North Texas, Denton, TX 76203

The UNT Department of Physics periodically offers an upper level elective undergraduate laboratory course covering a variety of topics related to nuclear and atomic physics. Laboratory exercises explore subjects ranging from gamma, x-ray, and alpha-particle spectroscopy to Rutherford scattering, particle-induced x-ray emission, and nuclear reactions. A lecture component complements the laboratory exercises by addressing pertinent theoretical material. For the laboratory exercises, students working in small groups utilize facilities in the Ion Beam Modification and Analysis Laboratory, including a 2.5 MV Van de Graaff accelerator and an array of detectors, radioactive sources, and nuclear electronics.

S02 **Optics for Scientists and Engineers Laboratory Syllabus**
Orven F. Swenson, Department of Physics;
David A. Rogers and Ivan T. Lima Jr., Department of Electrical and Computer Engineering, North Dakota State University, Fargo, ND 58108-6050

A joint optics laboratory course is taught by the Departments of Physics and Electrical and Computer Engineering. The goal of this course is to provide students with the fundamentals necessary to enable them

to successfully apply optics in their respective disciplines. This is accomplished through hands-on use of state-of-the-art equipment in conjunction with classroom discussions in the co-requisite lecture course. All students perform ten experiments completed in weekly three-hour blocks. A major experiment related to the student's academic major (engineering, chemistry, physics, etc.) using optics is selected by groups of three to four students for the last four-week project during which they devote all of their lecture course time and laboratory course time to their project. Students write a research paper on this experiment and present their results to the class.

S03 **Syllabi and Questions for Intermediate & Advanced Labs for the College Physics Major**

Ed Deveney, Bridgewater State College, Bridgewater, MA 02325

I will present current syllabi for the three Intermediate and Advanced (I&A) labs as they appear in their present state at Bridgewater State College; electronics (recommended but not required for the major, primarily digital but with an admixture of analog), modern physics lab (a separate lab course taken in the 1st semester of second year along with the modern lecture course) and advanced experimental lab (we now recommend taking junior year to prepare for senior year thesis/research work and potential summer REUs). I would like to use this poster to initiate discussions related to the content of each lab course as well as the more global ideas and concerns associated with I&A labs:

- which labs should be required for the major/minor,
- is the content of each lab 'as is' enough
- should other labs be required
- in what order should these labs be taken
- is one semester enough for each lab
- should the advanced lab be taken in junior or senior year
- software; EXCEL, Maple, Electronics Simulation and LabView
- lab reports; if and when LaTeX

In addition, I will frame these discussions around the context of both the 4-year college student's time and other general education requirements and the professor's teaching loads, research, and of course, financial support.

S04 **Intermediate/Advanced Laboratory: Combining Writing, Basic Instrumentation, Fundamental Electronics**

Ross Reynolds, Doug Furton, Harold Schnyders, Richard Vallery Grand Valley State University, Allendale, MI 49401

With a fairly robust general education curriculum, we have had to make our Advanced Laboratory sequence serve many purposes traditionally split into separate courses. I present an overview of our attempts to satisfy a junior level writing requirement, need to create competence with laboratory instrumentation, reinforce and extend fundamental electronics, as well as try to touch on some traditional advanced laboratory experiments and have room for students to design and implement individual projects of their own choosing. The first semester of the sequence serves both our majors and minors (primarily secondary education) and typically has enrollments of 12 – 16. This is the semester we try to teach our skills, but still have time at the end for one student designed/implemented experiments. The second semester is focused more on applied measurement projects. The general flow of the class and some of the projects the students have completed are presented for discussion.

S05 **The Biological Physics Labs in the JHU Department of Physics and Astronomy**

Steven K. Wonnell and Daniel H. Reich, Johns Hopkins University, Baltimore, MD 21218

Eight experiments have been developed to date to accompany the two semester, junior-level course in Biological Physics offered in Johns Hopkins University's Department of Physics and Astronomy.Each experiment illustrates a fundamental principle of the physics underlying a biological phenomenon or of the application of a physical technique to biology, the latter of which is usually spectroscopical in nature. Topics for which we have experiments include Fourier synthesis and analysis, interference, diffraction of DNA optical transforms, magnetic resonance, diffusion and microfluidics, the microscope, and Brownian motion.

In the lecture course, importance is placed on the experimental fundamentals surrounding data acquisition and analysis, including fundamental limitations and the artifacts generated by improper data acquisition. These limitations and artifacts are explored in the lab by the students. We will discuss the choices and motivations underlying the development of these experiments; their integration and synchronization with the lecture course; funding; and important details for each experiment.

S06 **The Evolving Syllabus for the Capstone Project Course at Eastern Michigan University**

Ernest Behringer and James J. Carroll, Eastern Michigan University, Ypsilanti, MI 48197 PHY 420

Capstone Project is a one-semester course that was established to ensure that non-teaching physics majors, especially engineering physics majors, would have a collaborative advanced lab experience that would include design. This course is intended to develop and augment a variety of student skills, including searching the literature, designing and conducting experiments, developing theoretical and computational models, and communicating technical information using written, oral, and graphical means. Examples of projects include designing a vibrating bar experiment for an advanced acoustics lab, designing a shield against charged particles for a lunar base, and characterizing the fluorescence of quantum dots. PHY 420 has been offered five times beginning in Winter 2002, and the syllabus has evolved in response to changing perceptions of student skills and attitudes. Specifically, more attention has been given to student communication skills, consistent with the designation of PHY 420 as a Writing Intensive course that fulfills an Eastern Michigan University general education requirement for writing in the discipline. A detailed description of the evolution of the course and potential improvements will be given.

S07 **The Advanced Physics Laboratory Course at Pomona College**

Alma C. Zook and David M. Tanenbaum, Pomona College, Claremont, CA 91711

The advanced laboratory course, required of all Pomona physics and astronomy majors, is intended to expose physics/astronomy majors to techniques of experimental physics other than electronics that may be helpful for a student's senior thesis. (Physics majors are required, and astronomy majors are strongly encouraged, to take the department's separate laboratory course in electronics.) The core of the course consists of a "menu" of about a dozen advanced experiments of which students choose four. Several of them are suggested by faculty research interests and two are done in cooperation with the chemistry and geology departments. Over the last few years we have offered experiments on carbon nanotubes, MRI, quadrupole mass spectroscopy, X-ray diffraction, and high-temperature superconductivity, among other topics. The course also includes instruction in basic machine shop techniques, the analysis of experimental data, and a brief introduction to Labview. The culmination of

the course is an independent project of the student's choice, design, and construction. About half of these projects are entirely student-initiated, while about a third are suggested by demonstrations or experiments that faculty would like to see introduced or improved. Recent projects have included an electromagnetic quarter shrinker, the construction of a Ruben's tube, and making aerogels. The first two projects have become standard demonstrations for introductory courses, and the last became a senior thesis.

S08 **Advanced Lab Sequence at San Francisco State University**

James M. Lockhart, San Francisco State University, San Francisco, CA 94132

We will present the physics advanced lab curriculum at San Francisco State. We combine weekly lectures and homework assignments with a 3-hour/week lab period in which both common tutorial and individually-selected experiments are done. The lecture material includes data analysis, electronic instrumentation, analog and digital signal processing, computerized data acquisition, and sensor and source technologies in solid state, optical, and nuclear physics. All students carry out common tutorial experiments on the use of instrumentation, analog and digital filtering, analog-digital conversion (ADC), and computer interfacing of ADCs and instruments using LabView and MATLAB. These techniques are then applied to individual experiments chosen from a set of thirty possibilities spanning most areas of physics. We will highlight a new textbook written to support this course sequence.

S09 **Intermediate Lab at NEIU**

Paul J. Dolan, Jr., Northeastern Illinois University, Chicago, IL 60625

Intermediate Lab (Physics 330) is a 3-credit, stand-alone lab course that is required for all physics majors at NEIU. Students typically perform four experiments in some detail (in addition to a 'warm-up' experiment). Experiments fall into several broad (and overlapping) categories of 'classics', 'new classics', 'surveys', 'design your own', and a few experiments that may be unique to NEIU. Students are encouraged to pursue experiments of particular interest to them. All students also write up one of their experiments in the format of a (short) research paper, and make an oral presentation on one of the experiments they have done. Various experiments that are done, including some of the students own interests, will be presented.

S10 **Increasing Student Independence and Insight in the Intermediate Physics Laboratory**

Mark Masters and Timothy T. Grove, Indiana University–Purdue University Fort Wayne, Fort Wayne, IN 46805

Imagine you are investigating new physics with tools which you have never used previously and you have to reproduce results achieved by many others. How would you proceed to acquire the data? What would you learn in the process if you were given fairly detailed directions? This is the dilemma faced by many students in the modern physics laboratory. Students only have their introductory laboratory experience to guide them through more difficult investigations involving much more complex physics. Rather than having students perform a series of unrelated classic modern physics investigations we developed an approach to the modern physics laboratory course that involves conceptually focused investigations to help the students through these difficulties and improve their understanding of physics, experimentation and independence. The conceptually focused investigations typically start with an "introductory physics like" analog of the "modern physics" phenomenon they are to investigate. The subsequent investigations build upon these concepts. Supported by NSF DUE #0127078.

S11 **Writing and Peer Review for Advanced Laboratories: A Proposal**

Mark Masters and Timothy T. Grove, Indiana University-Purdue University Fort Wayne, Fort Wayne, IN 46805

There are a number of significant goals and issues associated with the teaching of advanced laboratories. Faculty teaching advanced laboratories often experience a feeling of isolation. For students, the laboratory should be a critical tool for synthesis of physics knowledge which can be challenging to achieve. Our proposed solution to these seemingly dissimilar issues is a new paradigm for the advanced laboratory that encourages students to write scientifically, includes calibrated peer reviews, and crosses school boundaries to create a shared mission for faculty. Writing can force synthesis but when students write a 'lab report,' they tend to write for the all-knowing professor which inhibits synthesis. By providing a journal to which students submit articles and for which students review the articles, the students are forced to face the audience of their unknown peers. Through this process faculty and students will form communities and students will engage in writing about physics.

S12 **Intermediate and Advanced Labs at Carleton College**

Melissa Eblen-Zayas and Dwight Luhman, Carleton College, Northfield, MN 55057

We will provide an overview of the Carleton College physics department's laboratory curriculum from the sophomore through the senior level. The three core courses containing experimental components are Atomic and Nuclear Physics, Electricity and Magnetism, both at the sophomore level, and an advanced lab course, Contemporary Experimental Physics. The sequence of experiments in each course will be discussed. In the Atomic and Nuclear course, students engage in classic experiments such as the Millikan oil drop experiment, atomic and gamma ray spectroscopy, and various radioactive decay experiments. Electricity and Magnetism labs include quantitative explorations of the relationship between surface charges and electric fields and currents and magnetic fields as well as a variety of activities focused on circuits. The Contemporary Experimental Physics course is taken by upper level students with the goal of introducing students to a variety of methods of experimental physics. Experiments include measurements of the speed of light, the Mossbauer Effect, particle decay and radio astronomy, in addition to a machine shop project.

Communication in both written and oral form is an important aspect of each lab course. We will highlight how oral presentations, written reports, and lab notebook evaluations are integrated into the labs, as well as discussing other writing activities that complement the experimental work.

Additional opportunities for students to obtain experimental experience in elective courses, such as electronics and optics, and the role of special projects with faculty will be discussed.

S13 **Advanced Physics Laboratory at Purdue University Calumet**

Adam Rengstorf, Purdue University Calumet, Hammond, IN 46323

I will present the syllabus for PHYS 380: Advanced Physics Lab at Purdue University Calumet. PUC is a master's comprehensive university and the Department of Chemistry and Physics offers a B.S. in physics with optional computational, engineering, and education emphases. PHYS 380 is a required course for all but the secondary teaching track. In recent history, PHYS 380 has been offered annually with a typical enrollment of 2-4 students. Students attend one hour of lecture, concentrating on error analysis, statistics and theory review, and at least 5 hours of lab per week, during which time they complete 5 'standard' experiments. Students are expected to submit a formal lab report for each experiment and give an oral presentation on a single experiment.

S14 **The Advanced Physics Lab at the University of Toronto**

David C. Bailey, Jason J. B. Harlow, Natalia N. Krasnopolskaia, University of Toronto, Toronto, M5S 1A7, Canada

The Advanced Physics Laboratory is taken by 3rd or 4th year University of Toronto undergraduates in several Physics and Engineering Science programs. The goals of the course are to give students an opportunity to work on interesting, challenging experiments, to deepen their understanding of the underlying Physics, to develop laboratory skills and analysis techniques, to improve their oral and written communication skills, and to prepare them for physics research.

On those rare occasions when everything is working, students currently have 45 experimental setups with 32 different experiments: Aperiodic Structures, Brillouin, Conductivity in <3 Dimensions, Compton, ESR, Thin Film Interference, Fourier Transform Spectroscopy, Germanium Detector Nuclear Spectroscopy, Semiconductors, HeNe Lasers, Helicons, High Energy Physics, High Tc Superconductors, Knots, Laue, Lenses, Linear Pulse Propagation, Superconductor Magnetization & Transition Temperatures, Mass Spectrometer, Mössbauer, Muon Lifetime, Neel Temperature, NMR, Powder X-rays, Raman, Optical Pumping, Low Temperature Resistivity, Sonoluminescence, SQUID, Electron Microscope, Ultrafast Fibre Laser, XRF.

We typically have about 35 students enrolled, with fluctuations up to 50; the course is typically staffed by 4 Instructors, 3 Teaching Assistants, and 1 Technologist. Each student must do 3 experiments per semester, and evaluation is based on in-lab observation, lab notebooks, interviews after each experiment, a peer reviewed formal report, and a final oral exam. Challenges in administering the course include assigning adequate instructional and technical resources, keeping antiquated equipment working, and finding money and development time for new experiments. More information can be found at www.physics.utoronto.ca/~phy326.

S15 **Intermediate and Advanced Physics Laboratories: Breadth and Depth in Experimental Physics**

Matthew C. Sullivan, Ithaca College, Ithaca, NY 14850

The Intermediate and Advanced Physics Laboratories are two standalone courses in the Ithaca College Physics curriculum. In the Intermediate Lab, students learn basic error propagation and least-squares fitting, data collection and analysis, and lab notebook use, while conducting six different experiments that span classical and modern physics. In Advanced Lab, students propose, prepare, conduct, and analyze two experiments of their own design, and write their results using the approved APS style in LaTeX. In this way, the Ithaca College Physics Department gives its students a breadth of experience in canonical measurements using a traditional advanced lab curriculum in Intermediate Lab, while also exposing the students to a more realistic, open-ended experimental physics experience in Advanced Lab.

S16 **The Contemporary Physics Laboratories of the Faculty of Science UNAM**

Beatriz Fuentes, Luis León, René Ortega, Ricardo Hernández National Autonomous University of Mexico (UNAM), México

Physics is a career that was born in Mexico in the beginning of the 1940s. Over the years it has changed from a pure theoretical career to a career that includes laboratories in its syllabus. The different laboratory programs have also been modified to include modern technology and contemporary subjects in classical and quantum physics. Nowadays, physics or engineering physics is taught in more than ten universities all over the country. In the Faculty of Science in the National Autonomous University of Mexico (UNAM), the physics syllabus includes two advanced physics laboratories: Laboratory of Contemporary Physics I and Laboratory of Contemporary Physics II. These laboratories are offered in the 8th and 9th semesters, respectively. Semesters last 16 weeks with two, three hour laboratory sessions per week. Students are offered more than ten different experiments in each course that go from the measurement of physics constants to atomic and molecular, nuclear, and solid state physics experiments. In the present work we show examples of them. The students work in groups of two. They must approve an oral theoretical exam in order to continue. Equipment manuals must be read in advance. Reports, logbooks and power point presentations to the group are requested for grading.

To graduate from physics students do a thesis. To expand their options of topics, we organize in the lab each semester, two or three conferences by experimental researchers and encourage the students to adventure in experimental physics.

S17 **An Advanced-lab Model for Liberal-Arts Colleges: Capstone Research Projects**

Enrique J. Galvez, Colgate University, Hamilton, NY 13346

In many Liberal-art colleges physics faculty are expected to do significant teaching and carry a productive research program. It is very challenging to have a successful research program when it is relegated to the summer months. In an effort to include research into the academic year, Colgate University's advanced lab curricular component consists of capstone research projects. The projects are not part of dedicated advanced-lab setups, but rather they are designed by the participating faculty members. This allows faculty to craft student projects around their own research or laboratory. It also enables faculty to engage with students in research projects, and may benefit from the student's past summer research experience. What the program loses in breadth it gains in depth. Students confront facing a challenge and a problem whose outcome is not known, and thus get a taste of scientific research. In the process they use electronics (a curricular requirement), shop work, and other experimental techniques to reach the project's objectives. Students are also expected to give talks and present a final paper in journal format. Our course format has changed over the years. Currently it consists of a mandatory component during the spring semester of the senior year and an optional for-honors component the following semester.

S18 **Modern Physics Lab at Marshall University**

Maria C. Babiuc-Hamilton, Marshall University, Huntington, WV 25755

From the muon lifetime relativistic time dilation to the nuclear magnetic resonance, the Modern Physics Lab at Marshall University gives students the chance to learn new physics while doing real scientific research. The purpose of the course is to explore modern physics models and theories in the laboratory. There are 12 exciting lab experiments to be explored: 1) Modern Physics Visualized; 2) Muon Particle Physics; 3) Blackbody Radiation; 4) Photoelectric effect; 5) Millikan Oil Drop; 6) The Electron Charge-to-Mass Ratio e/m; 7) Electron Diffraction; 8) Cosmic Radiation; 9) Frank-Hertz Experiment; 10) X-rays Analysis; 11) Infrared Camera; and 12) NMR/ESR Spectrometry. At the end of the experiments, students will have a two-week period to develop their own idea for a project in modern physics experiment, of to work on one of the following three suggested projects: 1) slowing time (muon particle physics experiment); 2) seeing in the dark (infrared camera); and 3) learning to read minds (nuclear magnetic resonance). Students will present their finding in a presentation session at the end of the semester, open to fellow students, faculty and friends.

S19 **Research Group Model for Advanced Lab**

Martin Madsen, Wabash College, Crawfordsville, IN 47933

I present our model for the course structure for our two-semester Advanced Lab. As a small liberal-arts college, we have small class sizes that enable us to approach the advanced lab in much the same way

that graduate research groups are often managed. Students work side-by-side with faculty mentors on the research experiments, providing an apprenticeship-like experience. Experimental techniques are taught in a one-on-one setting, modeling much more closely the kind of interaction found in graduate research groups. We hold a weekly "group meeting" where each research team regularly presents a status report and/or data from their experiment. The entire class then participates in a general discussion about the experiments, modeling a collaborative research environment. Group meetings are also used for oral presentations at the end of each experiment cycle, instruction on general experimental techniques, and regular evaluation of student performance in the course. Finally, we invite students to design and execute their own experiments during the course of the year. These experiments are either modifications of existing experiments in order to make new measurements, or totally new experiments based on student interests. This provides a constant in-flux of new experiments and equipment in the lab as well as allowing students to focus on a specific field of interest.

S20 **Honing Experimental Physicists at UW–River Falls**

Lowell McCann and Earl D. Blodgett,
University of Wisconsin–River Falls

We will present the course structure for the stand-alone Advanced Lab sequence at the University of Wisconsin-River Falls. The two-course sequence is required for all students majoring in Physics, Applied Physics or Physics Education. This sequence of rigorous training in the tools of experimental physics has been an integral part of our physics program for 40 years, and is regularly cited by alumni as a key part of their education. Advanced Lab meets for 6 hours each week (with students typically working another 12 hours per week outside of class) for two full semesters. The experiments evolve throughout the year to encourage student independence in the laboratory. Due to large class sizes (8 - 16) and limited budgets, the course focuses on laboratory skills and analysis, rather than specific sophisticated technologies. In the second semester, students are encouraged to pursue an extended independent project of their own design, thereby honing their research skills prior to undertaking their senior research project or other undergraduate research projects. Evaluation procedures include detailed inspections of laboratory notebooks, multiple formal lab reports with required re-writes, and oral 'group meeting' style presentations.

S21 **Use of LabVIEW™ in a Senior-Level Capstone Laboratory**

Linda S. Fritz, J.K. Krebs, and N.S. Dixon,
Franklin & Marshall College, Lancaster, PA 17604

Our Experimental Methods of Physics course is our capstone course, and one of its main goals is for the students to draw upon, integrate, and build on the physics that they have learned in the rest of the curriculum. We use LabVIEW™ as the backbone of the course. Although computers have enhanced science instruction in many ways and our students' are quite capable of using computer sources for information gathering, their practical programming skills and experience are often lacking. We will present examples of how we use LabVIEW™ at Franklin and Marshall College to provide that experience as well as enhance students' understanding of experimental design, data gathering, reduction and analysis. The exercises assist in fulfilling the course goals by exposing students to large real-time data sets, thus enabling them to obtain quantitative results in experiments to which they must apply previous course knowledge. We focus on a small number of physics "themes" for which we begin where previous courses ended and extend the students' understanding to concrete phenomena illustrated in one or two experiments per theme. In completing the experiments and the LabVIEW™ exercises students must grapple with concepts such as data sampling rates, advanced curve fitting, and error propagation that would need to be added more artificially without computer interfacing.

S22 **A New Sequence of Advanced Laboratory Courses at the University of Wisconsin Oshkosh**

Dennis Rioux, University of Wisconsin Oshkosh,
Oshkosh, WI 54901

Two credit sophomore, junior, and senior advanced laboratory courses have recently replaced a one credit Modern Physics lab and a three credit Experimental Physics course. Physics Lab I, II, and III are offered each spring and are coordinated with the two theory courses physics majors have most recently completed or are currently enrolled in. Physics Lab I for sophomores, for example, contains experiments in Modern Physics (a class they completed in the Fall semester) and Classical Mechanics (a class in which they are concurrently enrolled). Junior-Senior level theory courses are offered on an alternate year basis; therefore, Physics Labs II and III typically contain experiments from two of the following four courses – Optics, Thermodynamics & Statistical Mechanics, Electricity & Magnetism, and Quantum Mechanics.

S23 **Upper-level Lab Sequence at Wittenberg University: Paths to Student Independence**

Elizabeth A. George, Wittenberg, Paul A. Voytas, and
Jeremiah D. Williams University, Springfield, OH 45501

The intermediate and advanced lab experience at Wittenberg consists of labs associated with the Modern Physics course and the Wave Phenomena course, and a junior-level Electronics lab. Modern Physics and Wave Phenomena are designated as writing intensive, so keeping a lab notebook and writing technical papers are emphasized. The Electronics course emphasizes debugging and project design. The amount of student independence is deliberately increased throughout, leading up to a required senior capstone project evaluated via oral presentations.

The Modern Physics laboratory includes several classic experiments (photoelectric effect, electron charge/mass, electron diffraction, H/D isotope shift, superconductivity); a series of microwave analogs of light and matter wave experiments (Michelson interferometer, Bragg scattering, evanescent waves/tunneling); and nuclear physics experiments including gamma-ray spectroscopy, half-life of Ba-137m and K-40, and neutron activation analysis using our 300 kV accelerator.

The Electronics course consists of a half semester of analog electronics followed by a half semester of digital electronics, concluding with student-designed projects using the BASIC Stamp microcontroller.

The Wave Phenomena laboratory includes several experiments that involve waves in a variety of contexts (measuring the dispersion relations in stings, coaxial cable and glass) and optics (behavior of thin and thick lenses, simulations of lenses). While most of the experiments are directly connected to the course material (waves and optics), some are not as strongly connected to the course material (propagation of pulses in cables, measuring the speed of light from the resonance frequency of an RLC circuit). The course concludes with a lab that the students design.

S24 **Advanced Physics Labs at the University of Oregon**

Dean Livelybrooks and Eric Torrence, University of Oregon,
Eugene, OR 97403

Advanced physics teaching labs at the University of Oregon include Intermediate Physics Lab (IPL) for second-year students, and Analog & Digital Electronics and Modern Optics Lab for upper-division physics and other majors. These labs collectively focus on student learning goals such as: simple scientific programming; interfacing probes and sensors with computers for experiment control, data acquisition, and analysis; and gaining technical skills in electronics design and optics instrumentation and phenomenology.

Currently, the IPL is being revised away from a 1 credit per term, 3 quarter lab sequence supporting conceptual physics knowledge (as

found in the introductory lab sequence) and towards improving student understanding of measurement uncertainty, data analysis skills and FFT knowledge, all developed within the Matlab programming environment. Topics also include statistical inference, Monte Carlo techniques, linear regression, binomial and Poisson distributions. The lab comprises 4 credit hours, on par with a one term lecture course.

Participation in teaching labs also serves to prepare physics majors for substantive, undergraduate research projects, with about 50-60% participation rates among then entire population. Availability of projects is limited by inadequate student preparation but, also, by available space and resources in faculty research labs. Consequently, we are looking at a "physics projects" model, where students undertake self-directed or a la carte projects within a two term-course sequence. Students with adequate levels of preparation will be able to complete projects associated with particular research labs, and under research faculty supervision for course credit. All participants will prepare posters and research talks.

S25 **Berkeley's Two-Semester Advanced Lab Sequence**

Thomas Colton, Robert Jacobsen, and Donald Orlando, University of California, Berkeley, Berkeley, CA 94720-7300

The first course, Basic Semiconductor Circuits, includes one 75-minute lecture and two 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 Advanced Lab, 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 days 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, laser-induced fluorescence, 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.

S26 **Binghamton University Intermediate and Advanced Lab Courses**

Mark Stephens, Binghamton University, Binghamton, NY 13902-6000

This poster session details the syllabi of the Sophomore, Junior and Advanced Lab courses here at Binghamton University, as well as the specific experiments and exercises offered in each course.

S27 **The Advanced Laboratory Program at the Colorado School of Mines**

David Schuster, Colorado School of Mines, Golden, CO 80401

A two semester hands-on laboratory sequence is required for graduation for all physics majors at the Colorado School of Mines. Typical course enrollments are 50-60 students, primarily juniors. This presentation will focus on the second semester of the course. The syllabus, organization and experiments performed in the course will be described. The experiments include: construction and testing of a scintillation detector, measurement of the half-life of Neptunium, measurement of the muon lifetime, gamma ray attenuation through Al and Pb as well as others. A PER project assessing the outcome of the students, as well as what strategies may be used to improve that outcome, is in progress.

S28 **Upper level labs at University of Alberta**

Isaac Isaac and Terry Singleton, University of Alberta, Edmonton, Non U.S. T6G 2G7

Stand-alone lab courses at the University of Alberta are offered throughout the second and third year of program and are customized for students from different streams. We present the general layout of individual lab courses for different programs. We will discuss the advanced labs objectives, contents, and relevance to the overall curriculum. We will also share some of the challenges facing advanced labs on campuses, including delivery method, assessment, computation, space and human resources.

S29 **Contents or Discontents? Optimizing What Goes Into the Undergraduate Electronics Course**

Paul Nienaber, Saint Mary's University of Minnesota, 700 Terrace Heights #32, Department of Physics, Winona, MN 55987

The two-semester electronics sequence at Saint Mary's University of Minnesota explores mostly digital and microcontrollers electronics, but is this a suitable suite? What can students handle? What do they need today (for graduate school, for the job market)? The prerequisites are minimal (general physics II, which does basic Ohm's Law/Kirchhoff's Rules DC circuit analysis, and a tiny bit of RC); what more do they need from analog electronics (to ground future work and forestall a "black-box" mentality?) Finally, how can this sequence be better integrated into a coherent undergraduate physics program?

SESSION III: PANEL DISCUSSION

"Curricular Roles for Advanced Labs — What Are We Doing and What Should We Do?"

SESSION IV: INIVITED SESSION

"Advanced Labs Ideas from Single-Photon Detection Quantum Mechanics"

Optical vortices: Light in a Spin

Invited: Miles Padgett, Physics Department, University of Glasgow, Kelvin Building, Glasgow G12 9ES, Scotland

A feature of wave superposition is that one plus one does not necessarily equal two. The interference of two equivalent waves can result in a zero intensity—e.g. Young's double slits. However, the waves fill 3D space not just a 2D screen and the dark fringes map out planes. But two waves are a special case. In general, when three or more waves interfere, complete destructive interference occurs on lines (phase singularities) around which the phase advances or retards by 2pi. This azimuthal phase gradient means that the Poynting vector, and associated energy flow, circulates too—hence the lines are also called optical vortices. Despite their appearance in all natural light fields, it was not until the early 1990's that it was recognized that the surrounding light carried an angular momentum, completely independent of the photon spin.

This orbital angular momentum can be created using simple lens systems, or holograms—made from 35mm film or encoded onto liquid crystal displays. Both whole beams, and single photons can carry this information or transfer it to mater to create an optical spanner.

In this talk I hope to introduce the underlying physical properties and discuss a number of demonstration experiments and modeling examples, which highlight how optics still contains surprises and opportunities for both the classical and quantum worlds.

Experiments with Correlated Photons: From Advanced-lab Projects to Dedicated Laboratories

Invited: Enrique J. Galvez, Physics Department, Colgate University, 13 Oak Drive, Hamilton, NY 13346

Advances in technology have allowed the feasibility of table-top experiments with correlated photons for curricular physics laboratories. Through our own form of advanced lab, capstone research projects, we have developed a set of experiments with correlated photons into a laboratory component for an upper-level course that normally does not have one: quantum mechanics. The virtue of the experiments is that they are understood with the quantum mechanics of a single quantum, and thus lend themselves as experimental exercises of quantum mechanics algebra. The experiments also bring to the forefront of the discussion fundamental topics of quantum mechanics that are particularly difficult to understand, such as superposition, indeterminism and nonlocality. Our experiments include photon and biphoton interference, the quantum eraser and quantum entanglement. Some of the developmental student projects led to research problems that were published in research journals. This work has been funded by grants from the National Science Foundation.

SESSION V
"Short Workshops"

SESSION VI
"Workshops on Interfacing Instrumentation"

SESSION VII
"Short Workshops"

Friday, July 24

SESSION VIII: INVITED SESSION
"Applied Physics: Hot Topics in Advanced Labs"

Interdisciplinary Experiments for Upper-level Physics Laboratory Courses

Invited: Suzanne Amador Kane, Physics Department, Haverford College, Haverford, PA 19041

Our laboratory program involves three semesters of experiments at the "junior-lab" level. One semester covers analog electronics up to op-amps and LRC circuits, while others involve experiments in oscillations, waves and optics. Labs with interdisciplinary applications are a special focus, and have included experiments in ultrasound imaging, laser tweezers, microfluidics, atomic force and scanning tunneling microscopy, magnetic resonance imaging, biosensors, solid state synthesis of quantum dots and high-Tc superconductors, among others. We describe the development and implementation of this lab program and focusing on these interdisciplinary projects. These projects aim at introducing majors to new and useful research tools and interdisciplinary research topics in biophysics, medical physics and materials science. Students are exposed to LabView programming, image analysis, microfabrication techniques, chemical vapor deposition and solid state synthesis. Each modular laboratory is being developed to allow exportation to other natural science departments. Many curricular resources developed as part of this project are available on the web, including downloadable student laboratory manuals and instructor's guides.

Chaos Experiments for the Advanced Lab

Invited: Robert DeSerio, Department of Physics, University of Florida, Gainesville, FL 32611

With frequent references in music, movies and TV, chaos theory is officially cool! The subject is also relatively new with many of the important developments occurring over the past few decades, and it is multidisciplinary with applications in the physical, biological and social sciences. Exotic terms such as "strange attractor" and "butterfly effect" as well as the visually stunning fractal structures describing chaotic dynamics further enhance the topic's allure.

Many mechanical, electronic and fluid systems have been used for advanced lab experiments on the subject, but few have demonstrated the ability to produce data suitable for creating fractals or for calculating quantitative measures of the resulting dynamics. I have used a water drop apparatus, a driven pendulum, and an electronic Duffing oscillator in an advanced lab setting. With LabVIEW software and simple data acquisition hardware, all three are easy and inexpensive to build. I will show how they produce data that can be displayed as multiple Poincaré sections or as multidimensional return maps, and I will describe the algorithms and results for calculations of the embedding dimension, fractal dimension, Lyapunov exponents, and system parameters. Student performance on one of the experiments will also be discussed.

Fluid Mechanics and Computational Physics in the Advanced Undergraduate Laboratory

Invited: Keith R. Stein, Department of Physics, Bethel University, St. Paul, MN 55112

Fluid mechanics and structural mechanics play a small role in the vast majority of undergraduate physics programs. However, many undergraduate students use their physics major as a stepping-stone towards graduate degrees in engineering or applied physics where these areas often play a more prominent role. Professor Jerry Gollub stated in a December 2003 Physics Today article, "one of the oddities of contemporary physics education is the nearly complete absence of continuum mechanics in the typical undergraduate or graduate curriculum" and questioned how the physics academic community can justify this absence. In our program, fluid and structural mechanics experiments are integrated into an Applied Physics major option within the framework of the advanced laboratories accompanying course offerings in Fluid Mechanics and Computer Methods in Physics and Engineering.

Snapshots are presented from a variety of recent undergraduate projects in fluids and computational physics. The projects include wind tunnel and water tunnel studies employing a variety of flow visualization and fluid diagnostics techniques. Computational studies represent a complementary approach in some of the projects and serve to enrich the advanced undergraduate laboratory experience. MATLAB and COMSOL Multiphysics software applications in these areas will be highlighted. Special attention will be given to advanced lab projects that have been carried out with a Mach 3 shock tunnel. These projects have focused on shock dynamics and compressible flow in the shock tube and tunnel test section and have included piezoelectric pressure measurements, dual-beam interferometry, shadowgraph and schlieren imaging in conjunction with corresponding computational studies.

SESSION IX: POSTER SESSION

"Especially Effective Laboratory Experiments and Open-ended Labs"

LO1 **A Michelson-Morley Experiment for the Advanced Physics Lab**

Charles Rogers and Richard Selvaggi, Texas A&M University–Commerce, 1104 Northwood Drive, Commerce, TX 75428

The famous 1887 Michelson-Morley experiment measured the propagation of light in a rotating interferometer in the physics department at Case Western Reserve University. For more than one hundred and twenty years, the data obtained from this experiment have been examined by many professionals interested in this experiment. These investigations have raised numerous questions concerning the analysis and interpretation of the originally published data. With interest in replicating this experiment, we have designed a new rotating interferometer of the same scale as the original experiment. This apparatus is composed on a standard four foot by six foot optical breadboard supported on a cylindrical float inside a concentric cylindrical tank. The interferometer consist of sixteen adjustable front surface mirrors, an aluminized beamsplitter, and a compensation plate arranged in the same geometry as used in the original experiment. The interferometer is rotated smoothly by the equivalent of a 2-meter diameter brushless motor. The light source is a helium-neon laser and a wireless optical sensor. Our students learn to align the optics, collect realtime data using a LabVIEW vi, and analyze their data using both original and current theories of operation of this instrument. We will present the details of this experiment and preliminary data collected.

LO2 **A Knots Experiment**

David C. Bailey, Jason J. B. Harlow, Natalia N. Krasnopolskaia, and Stephen W. Morris Physics Department, University of Toronto, 60 St. George Street, Toronto M5S 1A7, Canada

Understanding how knots form and untie is crucial in understanding the biophysics of DNA or the structural properties of polymers, but it is very difficult to study these processes directly. This experiment studies the dynamics of knots in granular chains (the type used to hold drain plugs) on a plate vibrating at varying frequencies and amplitudes. These chains are interesting in their own right, and the subject of a number or recent papers in Physical Review Letters and other major research journals.

Students explore how the unknotting time of the chain depends on different parameters such as length, frequency, amplitude, linear mass density, and number and type of knots. They can also examine the statistics of the unknotting process, study the radius-of-gyration and pattern formation in unknotted chains, and investigate other aspects of the shaker and its dynamical relation with a chain (or other materials) on its surface. The phase space of possible measurements is very large, so students can explore many ideas of their own. The experiment is a bit noisy, but is simple, inexpensive, and easy to use. The challenge for the student is in the planning and analysis, and in having enough patience to take sufficient data.

The basic apparatus for the experiment will be demonstrated at the workshop. More information can be found at www.physics.utoronto.ca/~phy326/knot/.

LO3 **A Tabletop Measurement of the Quantization of Electrical Conductance in Gold Nanowires**

David Tam, Columbia University Dept. of Physics, 538 West 120 St., 704 Pupin Hall MC 5248, New York, NY 10027

We report on the design, construction, and implementation of an Advanced Laboratory on the quantization of electrical conductance in gold nanowires. The apparatus was built for the E.K.A. Advanced Lab at Columbia University in 2008. Student groups typically take 5-6 weeks to complete the laboratory, which includes some supervised work in the Columbia University Clean Room. By involving the clean room, we introduce students to the field of nanoscience research, which is in many ways just as instructive as the laboratory itself. Students also learn a variety of other useful skills, including basic computer control of devices, statistical analysis, vibration control, and the opportunity to master some hands-on techniques.

Students start by carefully preparing the contact between a thin gold wire and a gold-coated wafer, prepared in the clean room using thermal evaporation. The apparatus rests on a vibration isolation table and is covered with an acoustic shield to minimize noise. Using an existing procedure written in the software program Igor, the wafer is brought into contact with the wire's sharp tip. Each time the wafer is pulled back, a nanowire is stretched between the two gold surfaces. A precision voltage is applied, and the conductive properties are measured with a Keithley nanoammeter. Statistical analysis performed by the students reveals that the conductance is quantized in units of e^2/h, and students are asked to investigate the many sources of error, typically less than 10%.

LO4 **Angular Momentum Outside of the Classical Mechanics Courses**

Nathan H. Frank, Augustana College, 939 38th Street, Rock Island, IL 61201
Gabriel C. Spalding, Illinois Wesleyan University, Bloomington, IL 61702-2900

The angular momentum associated with "stationary" states in quantum mechanics is a source of confusion among undergraduates. A variety of experimental treatments provide opportunities for clarification, and we present three: a nuclear experiment demonstrating that a photon can have multiple h-bar of total angular momentum, along with optical and acoustic labs which demonstrate waves that carry spin and/or orbital angular momentum.

Since each photon has an intrinsic spin of one, it may surprise some that an individual photon can have multiple h-bar of angular momentum, yet this was established theoretically[1] in nuclear physics in the 1940's, and was experimentally demonstrated[2] almost as soon as detectors became available that used scintillators and photomultiplier tubes: by measuring the angular correlations between successive gamma-rays emitted, a (now standard) radioactive source of 60Co is shown to emit photons with total angular momentum greater than one h-bar. We complement this experiment with optical[3] and acoustic[4,5] labs that elucidate the nature of angular momentum in waves.

[1] Hamilton, D R, Phys. Rev. 58, 122 (1940)

[2] E. L. Brady and M. Deutsch, Phys. Rev. 78, 558 (1950)

[3] Alicia V. Carpentier, et al., Amer. Jour. Phys. 76, 10 (Oct. 2008)

[4] K. Volke-Sepulveda et al., Optical Trapping and Optical Micromanipulation IV, edited by Kishan Dholakia, Gabriel C. Spalding, Proc. of SPIE Vol. 6644, 66440Z (2007)

[5] Karen Volke-Sepulveda, et al., Phys. Rev. Let. 100, 024302 (2008)

L05 **Atomic Spectroscopy in Alkali Vapor**

Marin Pichler, Goucher College, 1021 Dulaney Valley Road, Physics and Astronomy Department, Baltimore, MD 21204

We present an advanced lab setup for atomic spectroscopy of alkali atoms in a vapor cell. External cavity diode lasers are used for excitation of the nS to nP transitions (D2 line). Laser absorption measurements of spectral line shapes and fitting are used to determine temperature and/or pressure of the atomic system, at different vapor cell set temperatures. In the second part of the experiment the optical setup is rearranged to allow two counter-propagating beams through the vapor cell in order to perform Doppler-free saturated absorption spectroscopy measurements. The goal here is to observe and measure atomic hyperfine structure of the ground or excited state. The measurements can be performed with either potassium or cesium, depending on the choice (and availability) of the diode laser and the vapor cell.

Since the optics and lasers are used in laser cooling research, we will discuss aspects of successful integration of research and advanced lab instruction. This lab is important for the curriculum and is directly related to core course in quantum mechanics and a special topics course on introduction to atomic and molecular physics. Furthermore, an interesting extension of the lab setup would be to perform the measurements on second exited D2 transitions using 405 and 455 nm diode lasers for K and Cs, respectively.

L06 **Atomic Structure from the Sodium Atom UV-VIS-NIR Spectrum**

Randolph S. Peterson, Physics Department, The University of the South, 735 University Ave, Sewanee, TN 37383

Atomic emission spectroscopy can appear to be an inert laboratory with the sole purpose of obtaining a high resolution spectrum with no real purpose. Historically these same spectra yielded basic atomic energy level diagrams and quantum numbers. I will discuss the analysis of a medium resolution spectrum from sodium and the analysis needed to unravel the energy levels and quantum numbers for neutral sodium. The analysis is not done in the historical sense but adapts to the level of chemistry and modern physics expected of a physics student performing this laboratory.

L07 **Can Students Design Their Own Experiments?**

Randy Knight, Physics Department, California Polytechnic State University, San Luis Obispo, CA 93407

Advanced labs, like introductory labs, are often fairly cookbook, instructing students step by step what to do. This is justified in part by students' lack of familiarity with the more complex equipment used in many advanced experiments. Do students, through practice with a variety of advanced experiments, learn how an experiment should be designed and run? Or does a steady diet of labs with detailed instructions preclude the critical thinking needed to design an experiment? We attempted to answer these questions by asking students in the third quarter of a junior-level lab to design and run—with no help or assistance from the instructors—an experiment requiring no knowledge of new equipment. Given a diode laser that could be pulse modulated, a pulse generator, a photodiode, several mirrors, and an oscilloscope, students were asked to devise an experiment to measure the speed of light in air and then, after an explanation that the speed of light is actually a defined quantity, to use the defined value to measure the distance between two marks on the table. How did they do? I'll report on the rather dismal outcomes.

L08 **Computational and Optical Studies on the Vibrational Modes of a Tuning Fork**

Keith R. Stein, Richard W. Peterson, Jack Houlton, Justin Knapp, Brandon Peplinski, and David Swenson, Bethel University, 3900 Bethel Drive, St. Paul, MN 55112
Christopher Scheevel, University of Minnesota

Shattering of a crystal glass with sound resonance is a favorite demonstration of the first year physics or engineering student. Unfortunately, many first year students find the demonstration entertaining and memorable, but fail to appreciate the richness of the underlying physics. It is often in the upper level lab experience that these students eventually have a "Eureka moment" and the fuller understanding of the shattering glass is obtained [1]. Experimental studies on acoustic vibrations, commonly utilizing optical diagnostics techniques, have been a frequent part of the advanced undergraduate laboratory experience at Bethel. Recently, these studies have been complemented by parallel computational studies [2].

We present results from undergraduate studies on the vibrational behavior of a tuning fork. Eigenfrequency analyses are carried out with COMSOL Multiphysics® modeling software and experimental optical studies utilize real-time stroboscopic holography. Comparative studies for the two approaches are presented on the natural vibrational modes and frequencies of the tuning fork. These studies demonstrate how the combination of computational modeling and optical diagnostics can provide a powerful blending of methods and can result in an enhanced upper level lab experience for students of applied physics, optics, and engineering.

1. R.W. Peterson, "Lighting the fire," AAPT Interactions, March/April (2007), 16-19.

2. K. Stein, R. Peterson, J. Houlton, J. Knapp, B. Peplinski, C. Scheevel, and D. Swenson, "Resonating with Students in the Undergraduate Physics Laboratory: Comprehending Acoustic Vibrations," COMSOL Conference, Boston, Massachusetts (2008).

L09 **Determining the Half-life of ^{40}K from the Activity of Salt Substitute**

Elizabeth A George and Paul A Voytas, Wittenberg University, Physics Department, PO Box 720, Springfield, OH 45501

Typical half-life experiments in student laboratories involve directly measuring rate vs. time for an isotope that decays on a time scale amenable to laboratory measurement. For example, in the Modern Physics course at Wittenberg University, students use a 1" NaI(Tl) detector and a multichannel scaler to obtain rate vs time data for isotopes such as ^{137m}Ba (obtained from a commercial mini-generator kit) or ^{56}Mn (produced by neutron activation analysis of manganese dioxide). We have recently supplemented these experiences with an experiment making use of a different method of measuring a half-life, in which students determine the half-life of ^{40}K using a container of salt substitute (mostly KI). Students use the NaTl(I) detector to obtain the photopeak rate with and without the salt substitute present, determine the background-subtracted rate, and then apply standard correction factors for the photopeak efficiency of the detector to obtain the activity of the sample. Since the mass and chemical composition of the sample and the natural abundance of ^{40}K are known, the decay constant can be obtained from the measured activity. This experiment complements the direct half-life measurements in technique and in conceptual content, and gives students experience with a standard method for measuring very long half-lives.

L10 **Developing Research and Experimentation Skills: Demonstrated using a Black Body Radiation Experiment**

Mark J. Pearson and Jamie D. White, Juniata College, Physics Department, 1700 Moore Street, Huntingdon, PA 16648

Traditionally undergraduate labs are taught by having a student carry out a number of steps to set up equipment and take specific data to achieve a certain aim. With this approach there is little opportunity to develop many of the skills important in experimentation and research. With this in mind, various labs have been developed at an intermediate and advanced lab level to offer the student an open learning opportunity, involving the student following their own ideas to research and solve a number of problems before obtaining the set goal. An example of this approach is demonstrated here, using the black body radiation approximation for a tungsten filament of a common light bulb, to obtain the ratio of Planck's to Boltzmann's constants (h/k). The propagation of error gives an expected error of about 2%, and it will be shown that only when a number of systematic errors are resolved is this level of accuracy obtained.

L11 **Doppler-broadening for Rubidium Absorption**

James D. White, Kenny Goodfellow, Amy Frantz, Geneva White, Brad Dinardo, Jon Green, and Mark J. Pearson, Physics Department, Juniata College, 1700 Moore St. BAC, Huntingdon, PA 16652

A diode laser at 780 nm was used to excite the $5S_{1/2}$ to $5P_{3/2}$ transition of Rubidium-85. Doppler-broadening of this transition occurs as a function of temperature of the cell. Students in Advanced Lab have verified that this broadening goes as square root of Temperature. Saturated absorption was used to verify the wavelength of the laser. The rubidium cell, in which the temperature dependence of Doppler-broadening was observed, consisted of a Pyrex cylinder with a long arm that extended perpendicularly to the length of the cell. The cylindrical component of the cell was encased within an oven (made of Electrotemp Cement). The temperature of the cell was increased by wrapping a Thermolyne BriskHeat flexible electric heating tape around the outside of the oven while the arm of the cell was extended out of the oven into a beaker of cool water. By keeping the temperature of the stem a constant, the pressure of the cell was held constant to the vapor pressure of rubidium at stem temperature. Both ice water and liquid nitrogen baths have been used.

L12 **Driven Linear and Non-linear Resonance Experiment**

Rex Berney, Physics Department, University of Dayton, 300 College Park, Dayton, OH 45469-2314

Resonance is an import concept for physics majors to understand. In this experiment a computer controlled driven oscillator with magnetic damping gives excellent data in either a linear or non-linear mode. For this experiment to work well, precise control of the driver frequency and phase are very important and easily achieved with computer control. All of the programming for the experiment is done using LabVIEW.

L13 **Example Harmonic and Anharmonic Oscillators Demonstrated and Analyzed**

Bernard Cleyet, 134 Hawthorn St., Salinas, CA 93901-3116

A commercially available teaching apparatus was easily modified to show the behavior of a spring oscillator and a magnetic hardening oscillator. That apparatus will be demonstrated with position (time) data collected and graphed. Simple approximate fits reveal the character of their dissipations in addition to the anharmonic oscillator's expected period variation and transition to harmonicity. The latter is especially obvious when phase plotted. The oscillators are then numerically modeled using a simple leapfrog algorithm. The appropriate force laws are found using a force sensor.

L14 **Experimental Observation and Control of Wave Dispersion**

S.K. Remillard, Physics Department, Hope College, 27 Graves Place, Holland, MI 49423

To refer to the relationship between wavelength and frequency, f=c/lambda, as "inverse" implies that the phase velocity, c, is a constant for all wavelengths. Deviations from the simple model of constant phase velocity, called dispersion, are common, with well known examples including electron propagation through a crystal lattice, electromagnetic wave propagation near the plasma frequency, and sound wave propagation through elastic media. The motivation of this work was to find a hands-on way to investigate the dispersion of, in particular, electron waves in a crystal lattice. In this experiment, crystals are simulated using transmission lines with periodic variations which can be hand carved from copper tape on an alumina substrate or fabricated using photolithography. Propagating microwaves along the periodic transmission line resemble nearly free electrons in the crystal lattice. After measuring a hand-made periodic transmission line with a vector network analyzer, the student then writes a computer program to transform the measured transmission and reflection coefficients into a complex propagation constant, which when plotted as a dispersion curve (wave number versus frequency) reveals a band structure which agrees with the textbook transcendental formulation of dispersive wave propagation. The student is then able to modify the location of the Brillouin zone edge in the reciprocal lattice space and to introduce defects in the crystal which result in states in the band gap. This approach provides an experimental way to discover, to study and to understand the band theory of solids.

L15 **Finding Thermal Conductivity and Specific Heat via Thermal Diffusion in Rods**

Matthew C. Sullivan and B. G. Thompson, Department of Physics , Ithaca College, 953 Danby Rd, NY 14850
A. P. Williamson, Martin Fisher School of Physics, Brandeis University

We present an experiment to measure thermal diffusion in cylindrical rods. From one measurement, using analytical solutions to simple heat flow equations, we can determine both the thermal conductivity and the heat capacity of the material to within 5% of the accepted values. A simple circuit controls the energy flowing into the rod via a heater and amplifies the voltages from up to three thermistors to measurable values. This circuit is controlled by one output and three inputs of a computerized data acquisition system. This experiment is versatile, and can be expanded in several ways, allowing students to customize their experience in the lab. Students can modify the lab though advanced electronic circuitry to enhance control of the experiment, through work in the machine shop to produce rods of different sizes, shapes, and materials, through advanced data analysis by incorporating heat losses and finite heater models via numerical solutions of partial differential equations, and through further experimentation in a vacuum.

L16 **Measurement of the Dispersion Relation of a Wave on a String**

Jeremiah D. Williams, Daniel Fleisch, Elizabeth George and Paul Voytas, Physics Department, Wittenberg University, 225 North Fountain Avenue, Springfield, OH 45504

At Wittenberg University, the final advanced laboratory experience is associated with a junior-level course, Wave Phenomena. A major goal in this

lab experience is to move the students from the well-defined laboratory experiences that they have seen in previous courses toward the more open ended activities that they will we be involved in as part of their senior research project. This poster will present the first lab that these students encounter in this laboratory experience. Using equipment that is quite common in an introductory lab, students measure the dispersion relation of a wave on a string. While the experiment is similar to what might be done at the introductory level, it is much more open-ended and requires a deeper level of analysis. In this way, this laboratory experience provides an excellent start in the transition to the more open-ended experiences that the student will be involved in during their senior year. In addition to presenting the lab as it is currently offered and typical results, we will also present simple extensions to this lab that we intend to make in future offering.

L17 **Measuring the Molecular Polarizability of Air**

Martin Madsen, D.R. Brown, S.R. Krutz, and M.J. Milliman, Wabash College, Crawfordsville, IN 47933

We present an update of the "refractive index of air" experiment commonly used in optics and undergraduate advanced labs. The refractive index of air is based on the average molecular polarizability, which we measured from the period of the phase shift in a Michelson interferometer as a function of pressure. Our value of the average molecular polarizability of air is $2.133\pm0.032\times10^{-29}$ m^3 (95% CI) and from this we find the refractive index of air at atmospheric pressure to be n = 1.0002651(66), which is in agreement with the accepted value of n = 1.000271375(6).

L18 **Measuring the Speed of Light in an Optical Fiber — Integrating Experimentation and Instrumentation**

Nasser Mulaa Juma, A. D. Edwards, P. Chang, K. L. Corwin, B. R. Washburn, and N. S. Rebello, Physics Dept, Kansas State University, 116 Cardwell Hall, Manhattan, KS 66506

Successful experimental physicists must understand the conceptual basis of experiments and the techniques of modern instrumentation, data collection and analysis. Through new capstone projects at Kansas State University, students in an electronics course, Physical Measurements and Instrumentation (PMI), apply their knowledge of electronics, instrumentation and LabVIEW to experiments from previous courses. This allows students to revisit the physics of earlier experiments and to solve real-world problems associated with experimental control and data acquisition. As an example, in the undergraduate Modern Physics Lab (MPL), students measure the speed of light in air with a time-of-flight measurement where pulses of ultraviolet light are reflected across the room in ~ 30 ns. Thus, measurement requires use of a fast photodiode and oscilloscope. This experiment is too fast for standard data acquisition software and hardware such as LabVIEW and NI ELVIS to be used for the measurement. As a solution, students proposed and implemented a much slower and inexpensive experiment using optical fiber. A fiber-coupled laser diode ~1300 nm (Part No. BA5979, Mitsubishi) is directly driven by circuitry on the NI ELVIS board and LabVIEW. The light is then sent through 1 km optical fiber (Corning SMF-28e) and detected by a 200 Hz Infrared Photoreceiver (New Focus, Model 2033). The time between the driving and the detected electronic pulse is determined via NI ELVIS using Virtual Instruments (LabVIEW VIs) which allows the calculation of the speed of light. This work is supported by the U.S. National Science Foundation under grant DUE-0736897.

L19 **Millikan's Oil Drop: Simulation and Experiment**

Sarah J Desotell, Ripon College, 300 Seward Street, PO Box 248, Ripon, WI 54971

In our Advanced Laboratory and Computational Physics course, students combined numerical and experimental methods to study the historic Millikan oil drop experiment which revealed the charge of a single electron. Both the experiment and numerical model were relatively simple, however students benefited from the variety of skills and analysis techniques used to study the same system with two different methods. In the experiment, an oil drop apparatus (purchased from PASCO) allowed the motion of charged oil drops to be observed as they moved in the presence and absence of an external electric field. Gravitational and drag forces also acted on the moving drops, and terminal velocities of each drop were determined by observing motion over long times. Through the application of Stokes Law, the elementary charge of a single electron was deduced. In the numeric approach to the oil drop system, the forces on a single drop were calculated using prescribed values for mass, charge, and electric field. The motion of a single oil drop was simulated using FORTRAN by calculating the resulting acceleration, velocity, and position of the droplet in time. Modeling the drag force introduced complexity to the model, as drag force depends on velocity, thus acceleration varies until terminal velocity is reached. The model allowed microsecond-scale transient times to be studied before terminal velocity was reached, and provided results to compliment the data collected experimentally. Visualization software was also used to illustrate the data produced by the mathematical model.

L20 **Noise Fundamentals, Where Noise Is the Signal**

George Herold, TeachSpin, Inc., 2495 Main Street - Suite 409, Buffalo, NY 14214
David Van Baak, Department of Physics and Astronomy, Calvin College, Grand Rapids, MI 49546

The measurement and theoretical examination of noise is an important and underrepresented topic in the advanced laboratory. Noise is inherent in all measurements and sets the lower limit of any physical measurement. Noise can be used to determine fundamental constants. The Johnson voltage noise from a resistor ($v_n^2 = 4RkT$) gives a measure of the Boltzmann constant (k) if the resistance (R) and temperature (T) are known. The charge of the electron (e) can be determined from a DC current (I) with full shot noise ($i_n^2 = 2eI$).

The apparatus that will be demonstrated can be used to measure the Johnson noise from resistors in the range from 10 ohm to 10 M ohm, over a calibrated frequency range of 3 to 100 kHz and temperatures from 77 to 373 K. Shot noise is measured in currents ranging from 10 nA to 1 mA. The currents can be derived from a variety of sources: a photodiode illuminated by an incandescent light bulb or an LED; a forward biased PN junction; a diode connected bipolar junction transistor; or from a zener diode. Some of the experimental subtleties of noise measurement will be presented, especially the effect of capacitance.

L21 **Nuclear Spin Echoes — In Live Audio**

David Van Baak, Department of Physics and Astronomy, Calvin College, Grand Rapids, MI 49546

Earth's-Field NMR offers perhaps the most transparent way in which to demonstrate the phenomena of NMR, in part because the signals observed are really 'free-precession signals' or 'free-induction-decays', without external signal generator, and no actual 'resonance' required. Modest modifications of an existing apparatus make it possible also to demonstrate the phenomenon of 'nuclear spin echoes', in which the signals' disappearance (due to magnetic-field inhomogeneities) can be reversed by a brief pulse of suitably oscillating magnetic fields. Since the precession signals involved have frequencies near 2 kHz, and durations

on the order of seconds, the experiment also lends itself to direct and real-time audio presentation.

L22 **Resistivity Measurements and Observation of Transition to Superconducting State**

Mohammed Z Tahar, State University of New York College at Brockport, 350 New Campus Drive, Brockport, NY 14420

Superconductivity is a hot topic at all levels and seeing the drop of resistance to zero on a student prepared sample(s) is a special experience. Here, we present the use of four point contacts onto small cross-section samples (wire or other) of elements (In, Pb, Sn ...) and NbTi and varying lengths (several cm) to measure the resistivity (resistance) and its temperature dependence. The samples are obtained from off-the-shelf wire or sheet stock and then prepared to obtain sample resistance of 0.1 – 10 Ohms which is easily and accurately measured with either DC or AC techniques. Using lock-in-detection, the AC method has nano-Volt resolution which, with milli-Ampere floating excitation current source, leads to the detection of micro-Ohm resistance change at any temperature. This laboratory experiment lends itself to practicing many aspects, techniques and skills of experimental physics from the four-point probe, cryogen handling, thermometry, data acquisition, error analysis and curve fitting (data manipulation) to obtaining the materials transport parameters, to safety procedures in sample preparation. The resistivity (resistance) temperature dependence and the residual resistivity ratio (RRR) do shed light on materials process issues such as alloying and cold working. Solid state physics concepts and ideas like Matheson's rule, phonons and their effect on resistivity temperature dependence are demonstrated and studied, as well as the transition from normal conductor to superconductor state.

L23 **Study of Electric and Magnetic Dipole Radiation via Scattering from Nanoparticles**

Natthi L. Sharma and Ernest Behringer, Eastern Michigan University, 303 Strong Hall, Ypsilanti, MI 48197

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

L24 **Sub-picometer Resolution from a Michelson Wavelength Meter**

Chad Hoyt, Adam Banfield, and Sarah Kaiser, Physics Department, Bethel University, 3900 Bethel Dr. #2336, St. Paul, MN 55112
Sarah Anderson, University of Michigan, Department of Physics

We describe high-resolution wavelength measurements of light from a commercial frequency stabilized helium neon laser. Using a home-built Michelson wavemeter we resolved adjacent longitudinal cavity modes. With good repeatability we measured the vacuum wavelengths of adjacent modes to be 632.9910 nm and 632.9902 nm. This result is consistent with the expected separation of 0.85 pm as measured from the mode beat frequency (640 MHz). With picometer-level accuracy—verified by measuring light from an external cavity diode laser stabilized to an iodine molecular transition—this wavemeter is suitable for use in high precision atomic spectroscopy.

The wavemeter uses a commercial frequency stabilized helium neon laser at a nominal wavelength of 632.8 nm as its reference. The moving arm of the interferometer comprises a common physics laboratory air track (1.4 m), glider and solid corner cube for retro-reflection. In order to maximize the number of interferometric fringe counts we use photogates near the glider's turning points and a simple digital circuit to trigger the fringe counter (Fluke PM6681). A LabView software application and a general purpose interface bus connection enables control of the counter and data manipulation.

L25 **TO BE OR NOT TO BE OHMIC: A Warm-up Exercise for Advanced Labs**

Paul J. Dolan, Jr., Dept. of Physics, Northeastern Illinois University, 5500 N. St. Louis Ave., Chicago, IL 60625

Frequently we (and thus our students) assume that something on which we make a resistance measurement is 'Ohmic', in a quite general sense: the current and voltage have a linear relationship, and this relationship does not depend on any external parameters, including such things as frequency and temperature; this misconception can persist beyond the introductory level. In the exercise that is used as the 'warm-up' for NEIU's required Junior/Senior level course "Intermediate Lab", students measure the 'resistance' of various general circuit elements, with the thought that these may or may not be 'Ohmic', where 'Ohmic' is taken in the most general sense. The lab exercise and materials used will be presented and discussed.

L26 **The Kenyon X-ray Facility Upgrade**

J. Terrence Klopcic, Department of Physics, Kenyon College, Hayes Hall, Gambier, OH 43022

The Senior Lab course at Kenyon has developed into a series of varied and challenging experiments, done by advanced students with minimal guidance from the faculty. This collection of experiments includes use of x-ray machines for experiments in crystallography and fluorescence. The x-ray machines used at Kenyon are two Diano 1970s vintage industrial grade machines. While the machines provide exceptionally robust and accessible physical parts - particularly the goniometers, the electronics and software parts of the machines had become prohibitive to maintain. We therefore completed a project to upgrade these machines, replacing all but the physical goniometers with off-the-shelf components. New operating software was written in National Instruments' LabVIEW to operate the machinery, and capture and analyze data. The result is a pair of self-maintainable, modern x-ray machines. A cursory check has shown that many mothballed Diano x-ray machines are extant. Thus, our project has revealed a cost-effective method for educational institutions to acquire robust x-ray facilities.

This poster will present brief before-and-after views of the project and include rationale for choices made, specs, sources, and approximate costs of the various components. We will also present examples of data taken with these facilities. Incidentally, these machines are also used in introductory and non-science-major courses at Kenyon. As a result, (at our small, liberal arts college) 60 to 100 student-experiments are run on these machines each year.

L27 **Two-laser Spectroscopy in Atomic Cesium**

Andrzej (Andy) Sieradzan, Aaron Hankin, and Clark VanDam, Physics Department, Central Michigan University, Mount Pleasant, MI 48859
Mark Havey, Physics Department, Old Dominion University, Norfolk, VA 23529

Inexpensive, narrowly tuned diode lasers have been often used to introduce students to modern spectroscopy, with saturation spectroscopy of alkali D lines becoming a standard undergrad research project. For labs which could afford more than one such diode laser, we propose a two-quantum two-color spectroscopy experiment in which relative strengths of atomic transitions can be determined. The relevant ratios of transition probabilities can be also modeled using simple quantum mechanics, so the theoretical and experimental results can be compared and discussed. Using the same set-up, a step-wise excitation with narrow-line lasers can be conducted, and provide clear evidence for velocity-selective atomic excitation and Doppler shift proportionality to the atomic transition frequency.

L28 **Using Longitudinal Laser Modes to Make Accurate Speed of Light Measurements**

James D. White, Mark J. Pearson, Justin T. Schultz, Daniel Sidor, Michael Best, and Daniel D'Orazio, Physics Department, Juniata College, 1700 Moore St. BAC, Huntingdon, PA 16652

An adjustable-cavity helium-neon laser is an excellent setup for providing undergraduates practical experimental and research experience. In this study, a laser was constructed from a helium-neon plasma tube and a movable output coupler (99% mirror), thereby allowing the cavity length to be varied. The laser beam from the cavity was directed onto a fast photodetector, the output of which went to a spectrum analyzer. The longitudinal mode beat frequencies were measured on a spectrum analyzer, along with their corresponding change in cavity lengths. With this data, and the refractive index of air derived from temperature and atmospheric pressure, the speed of light was calculated to an accuracy of better than 0.03% as predicted from the propagation of error. This experiment demonstrates by optimizing measurement precision, very accurate results can be obtained.

L29 **Using Pfund's Method to Find the Index of Refraction**

Helene F. Perry, Loyola College in Maryland, 4501 North Charles Street, Baltimore, MD 21210

When our department introduced conceptually-oriented experiments in the freshman general physics laboratory, we soon found we also needed to revise the sophomore-level lab to give majors some simple lab exercises that would require reasonably sophisticated error analysis. Using Pfund's method to find the index of refraction of both a glass plate and a liquid provided an engaging exercise that gave students an excellent opportunity to practice these skills.

In our adaptation of Pfund's method, we use a flat and relatively thick glass plate that is sprayed on one side with white paint. A laser beam incident at 0°on the upper surface is diffusely reflected from a spot on the bottom painted surface. Rays from this spot travel back to the upper surface and pass through it as long as the incident angles are less than the critical angle. When the critical angle for the glass-air interface is reached the rays are reflected back and form a sharp ring of light on the bottom painted surface. Measurements of the diameter of this ring, together with the thickness of the glass allow the index of refraction of the glass to be calculated to within 1%. When a liquid layer is placed on the surface of the glass, the index of refraction of the liquid can be calculated also.

L30 **Vibrational Spectra of the Nitrogen Molecules in the Liquid and Gas Phase**

Burcin Bayram and David Fisher, Department of Physics, Miami University, 133 Culler Hall, Oxford, OH 45056

We will describe (1) a highly visual experiment designed to demonstrate Raman scattering spectroscopy by measuring the vibrational energy spacing of nitrogen molecules in the liquid phase, and demonstrate (2) vibrational spectrum of the nitrogen molecules in the gas-phase using a gas-filled discharge tube and a hand-held spectrometer. For the experiment (1); a high intensity Raman spectra and a multitude of nonlinear phenomena in liquid nitrogen via pulsed laser Raman scattering at 532nm will be presented. The presence of strong stimulated Raman scattering in the liquid nitrogen generated multiple Raman-shifted orders and greatly enhanced the normal Raman-shifted signal, allowing for a more engaging laboratory experience in comparison to traditional Raman scattering experiments. This enhancement allows for an easier determination of intrinsic properties of the nitrogen molecules such as the vibrational frequency and the force constant. For the experiment (2); the electron-impact excitation will be the primary excitation mechanism in the discharge. Although the electron-impact excitation of nitrogen molecules occurs, the great majority of the "targets" for electron-impact excitation collisions at the cathode-anode are argon atoms. Large populations of the argon metastables will result at 11.55 and 11.72eV. Since argon metastables have resonant energies with the C-state in neutral nitrogen, C-band to B-band transitions will occur. Students determine the upper and lower vibrational level quantum numbers associated with each observed band, construct energy level diagram of the resulting upper and lower electronic level's vibrational structures, determine the energy spacings between those levels, and discuss any deviations from the SHO model predictions.

SESSION X: PANEL DISCUSSION

"What makes a Good Advanced Lab Experiment?"

SESSION XI

"Short Workshops"

SESSION XII

"Workshops on Interfacing Instrumentation"

SESSION XIII

"Short Workshops"

SESSION XIV: DEMO SESSION
"Advanced Lab Demonstrations"

Advanced Demonstrations for the Classroom and the Laboratory

Invited: David Sturm, University of Maine and Physics Instructional Resource Association (PIRA)
Ramon Torres-Isea, University of Michigan
Dale Stille, University of Iowa
Chad Hoyt and Richard Peterson, Bethel University
David Maiullo, Rutgers University
Paul Dolan, Northeastern Illinois University

These are not the typical demonstrations used in physics demo shows, but they will be limited to those that can be completed in a few minutes and have short assembly times. The demos in this hour will include such fare as "Showdown: Toepler Holtz vs. Wimshurst", "Pohl's Mica", "Decomposition of He-Ne Laser Spectrum", "Sweeping Orthogonal Modes in a Laser", "Single Photon", "Bed of Nail" [sic], "Radioactive Ballasts", and "Half-Spin". For demonstrations that take more time to prepare, we will provide a handout sample of the PIRA Demonstration Bibliography, and a list of standard demonstrations for advanced courses with links to AJP and TPT references.

Saturday, July 25

SESSION XV: NSF SESSION
"Funding the Advanced Lab"

The Advanced Laboratory and the National Science Foundation

Invited: Duncan McBride, National Science Foundation

I will describe some of the advanced physics lab projects NSF has supported. In addition, I will discuss the mechanisms of support from NSF both for development of new experiments and for the adaptation and implementation of advanced physics lab experiments in the local curriculum.

SESSION XVI: BREAKOUT SESSIONS
Sessions are 1 hour long and schedule will be posted.

Teaching the electronics course

An Electronics Course for the Computer Age using Learning Cycle Pedagogy

Paul W. Zitzewitz, University of Michigan-Dearborn, 4901 Evergreen Rd, Dearborn, MI 48128

Low-cost data acquisition units (DAQs) coupled with LabVIEW have dramatically changed the way data is collected and experiments are controlled in both academic and industrial laboratories. My course focuses on a few sensors and limits the electronics to that necessary to interface these sensors to a DAQ (NI 6809) and to use the DAQ to control an experiment.

The Learning Cycle closely matches the way scientists learn. A topic starts with a reason why the material is useful. Experiments that explore the topic are followed by the explanation (theory). Additional experiments and explanations expand on the topic. Evaluation is done during the exploration and explanations and at the conclusion. The laboratory and classroom are integrated so that exploration and explanations can be linked closely in time. Three 50-minute lectures and a four-hour lab are replaced by two 3½ hour lecture/lab sessions per week.

The course emphasizes temperature, light, magnetic field, and force sensors that are prepared for the DAQ using linear ICs and instrumentation amplifiers. Digital inputs are conditioned by ICs to debounce switches and to count up to three for a start/stop/reset sequence. Analog and digital outputs are conditioned using discrete transistor amplifiers and a push-pull power amplifier. Analog-digital conversion uses a Schmitt trigger and an 8-bit DAC. The DAQ is introduced and an introduction LabVIEW taught. The analog and digital inputs and outputs are explored and students do a three-week long project of their choice.

A combination laboratory manual/textbook was written that is available to anyone who is interested in using or adapting the course.

Teaching the optics course

Active Learning Using Tutorials in Intermediate Optics

Mark Masters and Timothy T. Grove, Department of Physics, Indiana University-Purdue University Fort Wayne, 2101 Coliseum Blvd E, Fort Wayne, IN 46805

Active learning is the process through which students in a class are actively engaged in the material under investigation. The success of this method of instruction has been well documented for introductory classes. In intermediate/advanced undergraduate physics classes there are fewer published results of experience or materials for use in active learning. This may be due to the mathematical rigor required in these classes and the traditional use of derivations to gain insight into physical problem solving. In this presentation we present our work in developing tutorials to help the students learn and use the mathematics and techniques of derivations as well as develop a stronger conceptual foundation for intermediate optics. These tutorials form a basis for the development of an active learning process in an advanced physics class setting. Supported by NSF Grant #0410760.

Advanced Optics Lab at SJSU

Ramen Bahuguna, Department of Physics, San Jose State University, One Washington Square, San Jose, CA 95192-0106

We have a three-hour lab and a one hour lecture associated with the optics lab per week. The students do 6-7 experiments and a project towards the end of the semester. These projects give them a reason for learning, understanding and analyzing the fundamentals and experiencing them in action. In their project they build an optical instrument or develop a method to measure an optical parameter. The experiments will be briefly discussed and the projects discussed in some detail.

Laboratory Emphasis in Interdisciplinary Photonics Related Courses

Orven F. Swenson, Department of Physics, North Dakota State University, Dept # 2755, PO Box 6050, Fargo, ND 58108-6050
David A. Rogers and Ivan T. Lima Jr., Department of Electrical and Computer Engineering, North Dakota State University

The facilities of an undergraduate optics teaching laboratory that were developed with National Science Foundation support have been incorporated in a sequence of courses in optics, lasers, photonics and optical signal transmission. Students with majors in physics and engineering

have learned professional optics techniques and obtained hands-on experience in a well-equipped optics teaching laboratory. We will share lessons learned over the past eight years of developing and teaching these laboratory intensive courses.

Undergraduate Laser Laboratory at SJSU

Ken Wharton, Department of Physics and Astronomy, San Jose State University, One Washington Square, San Jose, CA 95192-0106

The department of physics and astronomy at San Jose State University houses the Institute for Modern Optics, and our upper-division laboratory offerings reflect this departmental research focus. This presentation will focus on our undergraduate laser laboratory course (the optics laboratory course will be covered in a companion talk by Dr. Ramen Bahuguna). The laser laboratory utilizes both off-the-shelf and homemade lasers, both department-purchased and donated lab equipment. A summary of the experiments and central learning concepts will be presented. Of particular note will be the balance between developing useful laser laboratory skills and reinforcing the theoretical analysis from the associated lasers course (much of which turns out to be overly simplistic, when applied to actual experiments).

Modifying the Optics Laboratory for Greater Conceptual Understanding

Timothy T. Grove and Mark F. Masters, Department of Physics, Indiana University—Purdue University Fort Wayne, 2101 Coliseum Blvd E, Fort Wayne, IN 46805

We developed a sequence of optics laboratories which assist the student in understanding critical concepts in optics. Our approach relies upon discussion, direct confrontation of misconceptions, and leading questions as opposed to a series of detailed, cookbook-like instructions. Through the labs we build conceptual understanding in subjects like image formation by lenses and mirrors, ray optics, and ultimately elliptical polarization while fostering laboratory independence. Initial support structure in the laboratory is progressively removed. In the final three weeks, students are complete an independent research project. We present details of our laboratory sequence and our impressions of the modifications. Supported by NSF Grant #0410760.

Communication of experimental results—graphical, written, and oral

Multi-Format Approach to Communication of Experimental Results

James M. Lockhart, Physics and Astronomy Dept., San Francisco State University, 1600 Holloway Ave., San Francisco, CA 94132

We will describe the multi-format approach to lab reports used in the physics advanced lab sequence at San Francisco State University. We use a combination of reports written into laboratory notebooks, brief "Measurement Reports" consistent with industrial lab practice, publication-quality papers, and oral reports. We will mention the use and advantages of MATLAB for plotting and analysis of data, and the incorporation of MATLAB plots into MS Word, LaTeX, and LyX reports and papers. We will also discuss implementation of modern standards for the reporting of measurement uncertainty as recommended by the International Organization for Standardization publication "Guide to the Expression of Uncertainty in Measurement."

Oral Assessment in an Advanced Lab Course

David C. Bailey, Physics Department, University of Toronto, 60 St. George Street, Toronto M5S 1A7, Canada

Interviews and Oral Examinations are powerful tools for assessing student competence and achievement. In the Advanced Physics Lab, oral assessments can complement Lab notebooks, formal reports, or formal presentations, with challenges and benefits for both student and instructor. Benefits of oral assessments are that they are relatively efficient and flexible; drawbacks are that they are stressful for students (and sometimes professors) and they are perceived to be more subjective and inconsistent.

At the University of Toronto, almost 40% of a student's Advanced Lab grade is associated with interviews and a final oral examination. After each experiment is complete, the instructor and student sit down together to discuss the experiment and any issues that may have arisen from reading the notebook. This allows both assessment of student understanding and the immediate pedagogical feedback and help. At the very end of the course, an oral examination is carried out by a panel of 3 instructors and TAs after all other work has been completed. We see "what has stuck" and what is understood, and allows us to grade students relative to each other in a fairly consistent way.

Our methods of oral assessments will be described, data will be presented, and issues associated with the use of oral assessment will be discussed.

Machine shop and laboratory safety

Safety in the Advanced Lab — More than You Might Expect

Gregory Puskar, West Virginia University Physics Department, PO Box 6315, Morgantown, WV 26506

Advanced Lab practioners are generally safe people where experiments are concerned. However, there can be a tendency, especially among long time teachers, to have a narrow safety focus. A holistic view of safety is vital to the Advanced Laboratory program. The goal of this presentation is to recall broader issues that everyone should have in mind and perhaps present a few that you may not have considered.

Regional/National Advanced Lab Facilities

The Visiting Students and Faculty Program at the University of North Texas

Duncan Weathers, Physics Department, University of North Texas, 1155 Union Circle #311427, Denton, TX 76203

For the past two decades, the Ion Beam Modification and Analysis Laboratory (IBMAL) in the UNT Department of Physics has regularly hosted groups of undergraduate students and their instructors for campus visits, for the purpose of having the students conduct advanced laboratory exercises related to nuclear and atomic physics. Topics range from gamma, x-ray, and alpha-particle spectroscopy to Rutherford scattering, particle-induced x-ray emission and nuclear reactions. For the laboratory exercises, which typically fill two intense days and are assisted by IBMAL personnel, students utilize a 2.5 MV Van de Graaff accelerator and an array of detectors, radioactive sources, and nuclear electronics. The program is principally designed for upper-level students from institutions lacking their own advanced experimental facilities, and has been patronized by schools from throughout Texas, adjoining states, and beyond.

Advanced Computer Interfacing

Computation and Simulation in the Advanced Lab

Advanced Labs in Biophysics

Teaching Condensed Matter or Materials Physics Labs

Teaching the Modern Physics Lab

SESSION XVII: PANEL DISCUSSION

"Interaction of the Advanced Lab with Undergraduate Research and REUs"

WORKSHOPS

W01 **Compton Scattering**

Daniel Phalen, Physics Department, University of Michigan

The scattering of X-rays by electrons was discovered by A. H. Compton in 1923. From careful measurements of the spectrum of scattered X-rays he showed that they suffered a shift to longer wavelengths. The size of the shift depended on the angle of scatter, and could be calculated by considering the process as a collision between a single photon and a single electron in which energy and momentum were conserved. The effect provides a striking demonstration of an electromagnetic wave behaving like a beam of "particles". The main purpose of this experiment is to observe the effect of gamma rays being scattered by material, and to measure their energy shifts as a function of their scattering angles.

W02 **Faraday Effect**

Fang Yuan, Physics Department, University of Michigan

This experiment allows the measurement of the effects of a magnetic field on the polarization of light (laser beam) propagating through a solid medium. A new experimental setup that uses modern rare earth magnets will be presented. The use of lasers of various frequencies enhances the pedagogical value of the setup. The experimental setup was developed by Professor Carl Akerlof at The University of Michigan.

W03 **Mass Spectrometry: Quadrupole Mass Filter**

Roy Clarke, Physics Department, University of Michigan

The mass spectrometer is essentially an instrument that can be used to measure the mass, or more correctly the mass/charge ratio, of ionized atoms or other electrically charged particles. Mass spectrometers are now used in physics, geology, chemistry, biology and medicine to determine compositions, to measure isotopic ratios, for detecting leaks in vacuum systems, and in homeland security. The first mass spectrographs were invented almost 100 years ago by A.J. Dempster, F.W. Aston, and others, and have been in continuous development ever since. However, the principle of using electric and magnetic fields to accelerate and establish the trajectories of ions inside the spectrometer according to their mass/charge ratio is common to all the different designs. Dempster's original mass spectrograph is a simple illustration of these physical principles.

In practice, it is difficult to achieve very stable and spatially uniform magnetic fields, especially with permanent magnets. These difficulties can lead to degradation of the mass resolution and drifts in the calibration of the instrument. In addition, the presence of stray magnetic fields can affect other instruments that may be used in conjunction with a mass spectrometer, for example, electron energy analyzers. In the early 1950's it was realized, by W. Paul (shared Nobel Prize in Physics, 1989) that use of magnetic fields could be eliminated altogether by a clever design which uses alternating quadrupolar electric fields rather than magnetic fields, hence the name Quadrupole Mass Spectrometer. This is the design that is currently in widespread use for residual gas analysis. It is highly stable and has excellent mass resolution. With high sensitivity electron multipliers, it can measure partial pressures down to 10^{-14} Torr! The operation of the Quadrupole Mass Spectrometer (QMS) is not quite so simple to understand as the magnetic sector design, but it is extremely elegant and involves some beautiful mathematics, and therefore the details are worth appreciating.

W04 **Magneto-Optical Trap**

Georg Raithel, Physics Department, University of Michigan

Rubidium atoms, students learn the principles of MOT operation. In the first phase of this lab, students develop the following skills: (1) Locking of the trap laser to a suitable frequency within the Rb saturation spectrum, (2) Alignment of the six trap laser beams through the MOT chamber, and (3) development of strategies to determine correct combinations of magnetic-field polarity and laser polarizations. In the second phase, students observe and record the MOT loading curve, that is, the MOT population as a function of time elapse after turning on the trap. From the loading curves, three important parameters associated with the MOT are determined: (1) the loading rate associated with the MOT growth, (2) the characteristic time constant of the MOT, and (3) the total number of atoms trapped. The characteristic time constant equals the average dwell time of a trapped atom in the MOT before it is lost due to collisions.

W05 **Blackbody Radiation and the Solar Surface Temperature**

Daniel Celestino, Physics Department, University of Michigan
Aparatus designed by Carl Akerlof

The basic goal of this experiment is the determination of the solar surface temperature from the relative intensities of the spectrum sampled at a number of wavelengths from 450 to 880 nm. The sampling is determined by a set of broadband interference filters that modulate the light intensity measured by the photocurrent in a reverse biased silicon diode. If the detailed characteristics of the filters and photodiode were all initially well known, a single set of measurements of sunlight through the filter set would suffice. In the absence of such information, the light from a tungsten lamp at different temperatures will be used to establish the appropriate calibrations. In addition, sunlight is also reddened by the atmosphere, which differentially absorbs the blue end of the spectrum. This effect can be corrected by measuring the spectral intensities as a function of zenith angle. Finally, least squares techniques determine the solar temperature by modeling the data with the Planck spectral distribution function. The experimental setup was developed by Professor Carl Akerlof at The University of Michigan.

W06 **Positron-Electron Annihilation**

Carl Akerlof, Physics Department, University of Michigan

This experiment attempts to explore several features of positron-electron annihilation. One of the attractive aspects of e+-e- annihilation is the relative simplicity of the interaction. To first order, the two-body system decays into two back-to-back photons, each carrying an energy of mec2. This feature has provided the basis for a medical imaging technique called Positron Emission Tomography (PET). PET is often used in conjunction with other tomographic techniques, such as MRI, to image potentially cancerous tumors in which exploratory surgery is particularly hazardous. In condensed matter, the interactions between positronium and the substrate can provide information about the details of the substrate structure via the effects on the momentum distribution at the instant of annihilation. The angular distributions measured in this experiment will be used to estimate the typical momenta associated with these systems. This is not quite trivial because the angles are typically of the order of a few milliradians(fractions of a degree).

The source for positrons in this experiment is a radioactive source, Na-22, with an activity of about 5 μCi. Na-22 has a half-life of 2.6019 years and decays with the release of 2,842.3 keV of energy. In 90.3% of the decays a ß+ is emitted with a 545.7 keV maximum kinetic energy followed by a 1,274.5 keV gamma-ray transition to the Ne-22 ground state. Approximately 0.06% of the time, the ß+ emission bypasses the excited state and directly transitions to the Ne-22 ground state. About 10% of all decays proceed by electron capture instead. The total energy budget is satisfied by including the 511.0 keV rest mass energy carried off by the sodium valence electron that is now unbound.

W07 **Raman Spectroscopy**

Divine Kumah, Physics Department, University of Michigan

When light is scattered from a molecule or crystal, most photons are elastically scattered. The scattered photons have the same energy (frequency) and, therefore, wavelength, as the incident photons. However, a small fraction of light (approximately 1 in 107 photons) is scattered at optical frequencies different from, and usually lower than, the frequency of the incident photons. The process leading to this inelastic scatter is termed the Raman effect. Raman scattering can occur with a change in vibrational, rotational or electronic energy of a molecule. If the scattering is elastic, the process is called Rayleigh scattering. If it's not elastic, the process is called Raman scattering. Raman scattering (or the Raman effect) was discovered in 1928 by V. C. Raman who won the Nobel Prize for his work. If the substance being studied is illuminated by monochromatic light, for example from a laser, the spectrum of the scattered light consists of a strong line (the exciting line) of the same frequency as the incident illumination together with weaker lines on either side shifted from the strong line by frequencies ranging from a few to about 3500 cm-1. The lines of frequency less than the exciting lines are called Stokes lines, the others anti-Stokes lines. Raman spectroscopy is very important practical tool for quickly identifying molecules and minerals. A Raman spectrometer was deployed on the Viking landers in 1972 and in other missions. Raman spectroscopy also has important scientific applications in studying molecular structure. In this experiment we will study both kinds of applications. A set of real, man-made, and optically equivalent diamonds will be provided as a final project.

W08 **Microscopy in Advanced Labs: TEM and AFM**

Codrin Cionca, Physics Department, University of Michigan

In this experiment we will explore the use of transmission electron microscopy (TEM) to take us into the world of ultra-small structures. This is the regime between 1000 Å and atomic dimensions in which the continuing miniaturization of integrated electronics is being pursued. It is also a very important region for structural biology. These length scales are far below the limit where the resolution of conventional optical microscopy becomes dominated by the wavelength of visible light (~5000 Å). The transmission electron microscope (or TEM), first invented in the late 1930's, has now developed into the technique of choice for microstructural studies in a wide range of fields: materials research, biophysics, polymer science, mineralogy, and health sciences, to name a few.

In the first part of the experiment, you will get a feel for the capabilities and immense resolving power of TEM by imaging some samples of DNA. We will measure the diameter and pitch of DNA's famous double-helix structure. In the second part of the experiment, we will use TEM to study some "quantum well" structures made from ultra-thin layers of Silicon and alloyed Silicon-germanium. We will determine the point spread function of the Philips 420 electron microscope and measure, at the highest magnification, the width of a quantum well and the abruptness of its boundaries. These are key quantities that determine the spectrum of electronic energy levels of the quantum well. The Si/Si-Ge samples will also demonstrate the capability of TEM to obtain selected-area diffraction patterns, from which detailed structural information can be obtained at atomic dimensions.

W09 **Alpha-induced X-ray Spectroscopy**

Timothy Chupp, University of Michigan

The discovery of x-rays by Roentgen in 1895 in many ways marks the dawn of modern physics. The short wavelength end of the electromagnetic spectrum represented by x rays and g rays is of great practical importance as a probe of the internal structure of matter, as a diagnostic tool in medicine, and as a window into cosmic processes such as supernovae and black hole accretion. In this experiment you will use a precision solid-state detector to study x-ray energy spectra of x-ray from a number of sources. Nuclear x-ray sources are used to calibrate the device to high precision. Then, bombardment from an alpha source is used to stimulate atomic x-ray transitions in a number of materials. The x-ray energies reveal the atomic level spacings with great clarity, and can be used to show the existence the atomic number. The characteristic x-ray lines of the elements are then used to determine the composition of unknown samples. There will be a surprise source of x-rays that will delight you and your students!

W10 **Nonlinear Motion**

Robert DeSerio, Physics Department, University of Florida

A chaotic pendulum apparatus, Am. J. Phys. 71, 250-257 (2003), and an electronic chaos apparatus, Am. J. Phys. 72, 253-258 (2004), will be demonstrated with interfaces for a stepper motor, rotary encoder, and electronic chaos circuit plainly visible on a standard breadboard. Software for simulating the apparatus, for acquiring and displaying data, and for calculating fractal dimensions, Lyapunov exponents, and system parameters from the data will be presented.

W11 **Interfacing**

Robert DeSerio, Physics Department, University of Florida

Simple data acquisition programs and electronic circuits will be available to demonstrate the low-level interfacing to a stepper motor, Pasco rotary encoder, Pasco motion sensor, and electronic chaos apparatus.

W12 **Mössbauer Effect**

Van Bistrow, Physics Department, University of Chicago

Participants will be shown the Mössbauer Effect experiment done at the University of Chicago. Students typically measure

- the natural line width of a nuclear transition
- nuclear Zeeman splitting
- magnetic quadrupole splitting of nuclear energy levels
- chemical shift of nuclear energy levels

The Austin Scientific apparatus consists of a magnetically driven rod, which moves a Co-57 source with a constant acceleration. The resulting Doppler-shifted Co-57 photons have a range of energies which span the resonant absorption energy of nuclei in a stationary absorber. Photons not absorbed by the stationary nuclei are detected in a proportional counter. Students use a laser and Michelson interferometer to determine the velocity of the source at each point in the spectrum.

A multi-channel analyzer/multi-channel scaler is used to obtain and display the Mössbauer spectra. Various absorbers are provided, placing the Co-57 nuclei in a variety of lattice environments. We hope to show the participants one technique for obtaining Mössbauer spectra and a start on their interpretation.

W13 **Ultrasound Imaging: a laboratory in sound, medical physics & imaging**

Suzanne Amador Kane, Haverford College

Participants will be able to experiment with an apparatus designed to train physicians and medical physicists about the principles behind ultrasound imaging, as well as to use an actual medical imaging device to image a kidney "phantom" model. Laboratory manuals, purchasing information and other curricular information will be provided via a website to facilitate adopting this lab.

W14 **Optical Pumping A**
TeachSpin

To facilitate real comfort with both the physics and the apparatus, we have limited the sessions to groups of 3, and created double sessions. We strongly recommend that you sign up for both A and B sessions. Optical pumping is a non-laser way to use light, interacting with atoms in the vapor phase, to 'pump' the atoms into states that permit the observation of radio-frequency quantum transitions between energy levels of the atoms' ground states. This experiment is a fine illustration of the polarization properties of light, the energy-level structure of atoms' ground states, and the Zeeman effect of external magnetic fields on these atomic energy levels. Participants will see, at level A, Introduction to Optical Pumping

- a hands-on familiarization with the parts of the apparatus, and instruction on how to align it for operation
- magnetic-field sweeps through zero (total) field, in the presence of the earth's ambient field, and detection of the 'zero-field resonances'
- optimization of the zero-field resonance, and detection of its width; also application of the resonance to the detection of magnetic-field fluctuations

W15 **Optical Pumping B**
TeachSpin

Available only to those who have taken session A. For abstract, see above in 'Optical Pumping A'. Participants will see, at level B, More on Optical Pumping

- radio-frequency resonances, induced by the addition of a radio-frequency magnetic field (of frequency 10 – 100 kHz), and the dependence of the resonances' location and size on the frequency and amplitude of the r.f. fields
- the Zeeman effect, in the dependence of the resonance's location on the strength of the steady magnetic field

W16 **Pulsed NMR (nuclear magnetic resonance) A**
TeachSpin

To facilitate real comfort with both the physics and the apparatus, we have limited the sessions to groups of 3, and created double sessions. We strongly recommend that you sign up for both A and B sessions. Nuclear magnetic resonance is a tool that allows the interaction of external radio-frequency magnetic fields with the magnetic moments of the nuclei found in ordinary liquids. In this workshop offering, participants will work on TeachSpi's new PS2-a, a tabletop, permanent-magnet, pulsed-NMR system that will display all the basic features used in modern pulsed-NMR technology.

Participants will see, at level A, Introduction to pulsed NMR

- a working PS2-a unit, configured for pulsed (rather than cw) operation on proton (rather than ^{19}F) nuclei
- familiarization with the permanent magnet and its temperature stabilization, and the sample-holder and its 'tuning' for optimal operation
- installation of a sample, and detection of the pulsed-NMR signal, and its optimization by electronic gradient cancellation
- measurement of the nuclear resonant frequency, and the inference of the magnetic-field strength, to 6-digit precision
- variation of the signal with pulsed-rf amplitude and duration, and an interpretation in terms of rotation of a spin vector on the Bloch sphere

W17 **Pulsed NMR (nuclear magnetic resonance) B**
TeachSpin

Available only to those who have taken session A. For abstract, see above in 'Pulsed NMR A'. Participants will see, at level B, Advanced topics in pulsed NMR

- methods for measuring T1, the 'spin-lattice relaxation time'
- the simplest spin echo, and its near-immunity to magnetic-field imperfections
- multiple-pulse spin-echo sequences
- methods for measuring T2, the 'spin-spin relaxation time', in the presence of gradients
- (as time permits) Fourier methods, and the detection of chemical shifts

W18 **Modern Interferometry A**
TeachSpin

To facilitate real comfort with both the physics and the apparatus, we have limited the sessions to groups of 3, and created double sessions. We strongly recommend that you sign up for both A and B sessions.

The 'Modern Interferometry' set-up available from TeachSpin offers a tabletop-sized optical breadboard, and all the components required for students to lay out, build, and apply a variety of interferometer topologies. In the Workshop, participants will be guided through the actual assembly, alignment, and use of one such topology — the Michelson interferometer.

Participants will see, at level A, Introduction to Interferometry

- an optical table with laser and alignment system installed
- how to lay out, assemble, and align a Michelson interferometer
- how to detect 'fringe formation' visually, and how to optimize alignment
- how to understand 'interferometric sensitivity', and its implications for vibrational effects
- how to add a photodetector, for the high-speed detection of signal variation

W19 **Modern Interferometry B**
TeachSpin

Available only to those who have taken session A. For abstract, see above in 'Modern Interferometry A'. Participants will see, at level B, Applications of Interferometry

- how to make controlled and measureable sub-micron displacements of one mirror in the interferometer
- how to process fringe signals electronically, and how to 'count fringes', in order to measure the wavelength of light directly with a micrometer
- how to derive an experimentally-measured value of the wavelength of light

W19 **Diode-laser Spectroscopy A**
TeachSpin

To facilitate real comfort with both the physics and the apparatus, we have limited the sessions to groups of 3, and created double sessions. We strongly recommend that you sign up for both A and B sessions.

Modern diode-laser technology makes it possible to realize on a tabletop the ideal of a monochromatic, yet tuneable, source of collimated light waves, in the form of a laser beam of many mW of power, and well under 10 MHz of optical linewidth, near a frequency of 384 *million* MHz (near wavelength 780 nm in the near-infrared). This laser radiation can resonate with an optical transition in atoms of rubidium, conveniently available in the vapor phase in glass cells near room temperature. The

result is a system in which the fundamentals of the resonant interaction of light and atoms can be studied in exquisite detail.

Participants will see, at level A, Introduction to Diode-laser spectroscopy

- how to activate a (temperature-stabilized) diode-laser system; how to detect the (invisible) beam, and how to reach threshold and operating points of the laser
- how to make the laser beam interact with an atomic vapor, and how to image the fluorescence that occurs when the laser is properly tuned
- how to use a piezo-electric drive to tune the diode-laser source, and how to display the effect of 'scanning' the laser frequency over the atomic resonance(s)
- how to use a non-imaging photodetector to display the absorption (as well as the fluorescence) by the atomic sample
- how to use a slow scan to show the absorption and fluorescence are correlated properties
- how to use the spectroscopy system to infer the 'Doppler width' of the atomic transitions observed

W20 **Diode-laser Spectroscopy B**
TeachSpin

Available only to those who have taken session A. For abstract, see above in 'Diode-laser Spectroscopy A.Participants will see, at level B, Advanced diode-laser spectroscopy,

- how to set up a 'pump-probe' experiment in rubidium vapor
- how to use differential probe absorption to isolate the effects of pump light
- why Doppler-free signals result, and what Doppler-free signals reveal
- why there are more peaks observed than expected, and what 'crossover transitions' are

W21 **Two-slit interference, one photon at a time A**
TeachSpin

To facilitate real comfort with both the physics and the apparatus, we have limited the sessions to groups of 3, and created double sessions. We strongly recommend that you sign up for both A and B sessions. Young's experiment of two-slit interference is a very convincing demonstration of the wave properties of light, and it makes possible a direct measurement of the wavelength of light. In this version of the experiment, a special apparatus makes it possible to perform Young's experiment at a level of light intensity so low that light can be thought of as passing through the apparatus 'one photon at a time'. Yet despite the detection of light at the single-photon level, displaying the particulate nature of light, the interference of the light persists, and the wavelength of the light can still be measured.

Participants will see, at level A, Quantitative Two-slit Interference

- how to 'open the cover' of the apparatus, and identify all of its parts
- how to use a laser light source to trace the transport of the light from entrance slit, to double slit, to exit slit; how to use the 'slit-blocker', and how to move the exit slit
- how to see the regime of single-slit diffraction, and how to see the emergence of the two-slit interference
- how to use a photodiode system to map the two-slit interference signal quantitatively; and how this permits wavelength measurement
- how to replace the laser source by a bulb, and the photodiode detector by a photomultiplier tube, to get into the single-photon mode of operation
- how to hear, and to see, the count rate of single-photon events
- how to map out the interference signal that remains visible in the single-photon mode of operation

W20 **Two-slit interference, one photon at a time B**
TeachSpin

Available only to those who have taken session A. For abstract, see above in 'Two-slit interference, one photon at a time A'. Participants will see, at level B, Single-Photon Two-slit Interference

- how to replace the laser source by a bulb, and the photodiode detector by a photomultiplier tube, to get into the single-photon mode of operation
- how to hear, and to see, the count rate of single-photon events
- how to map out the interference signal that remains visible in the single-photon mode of operation
- how to estimate the 'number of photons in the box' in the 'single-photon' mode

W21 **Quantum Analogs A**
TeachSpin

To facilitate real comfort with both the physics and the apparatus, we have limited the sessions to groups of 3, and created double sessions. We strongly recommend that you sign up for both A and B sessions.

The wave equation for the propagation of sound in air inside structures, and the Schrödinger Equation for electron waves in space, share many mathematical features. This apparatus is aimed at building intuition about solutions of the fundamental equation of wave mechanics via hands-on encounter with analogous features in the properties of sound waves in air. The experiments are conducted using sound waves of ordinary (1 - 10 kHz) frequencies, produced and detected by ordinary speakers and microphones, inside metal-walled resonant systems. In particular, participants may choose the general area of either resonant modes inside an spherical cavity, or resonant modes in a periodic 1-dimensional system. The analogous features in quantum mechanics are the spherical harmonics that emerge in any spherically-symmetric system, and the 'bands and gaps' that appear in the mode structure for a 1-d spatially-periodic system.

Participants will see at level A, Introduction to Quantum Analogs

- how sound waves are generated, detected, and quantified in the quantum-analogs system
- how to set up 3-d spherical, OR 1-d spatially-periodic, acoustic 'testbad' systems
- how to sweep in frequency, and how to identify normal modes of the acoustic system with eigenstates of the analogous quantum system
- how to detect the angular structure of modes in 3-d space, OR how to see band and gap structure in the 1-d system

W24 **Quantum Analogs B**
TeachSpin

Available only to those who have taken session A. For abstract, see above in 'Quantum Analogs A'. Participants will see at level B, More on Quantum Analogs

- how to explore the angular structure of mode patterns in 3-d space, and how they are connected with spherical harmonics
- how to identify and change parameters in 1-d spatially-periodic systems, and how they are correlated with changes in the band structure that results

W25 **The Torsional Oscillator A**

TeachSpin

To facilitate real comfort with both the physics and the apparatus, we have limited the sessions to groups of 3, and created double sessions. We strongly recommend that you sign up for both A and B sessions.

The simple harmonic oscillator is perhaps the most central 'model system' in all of physics, and TeachSpin's 'Torsional Oscillator' is a fully-instrumented example of the harmonic oscillator. It permits an extremely wide variety of experiments, appropriate to instruction from introductory to graduate-level lab courses. The torsional oscillator can be calibrated and modelled in detail, it can be damped by three independent mechanisms, and it can be driven by arbitrary torque waveforms.

Participants will see, at level A, Intermediate torsional oscillations,

- where the 'spring' and the 'mass' are located in a torsional oscillator
- how static, and oscillatory, properties of the oscillator can be deduced directly from experiment
- how the separate angular-position and angular-velocity transducers work, and how they can be calibrated
- how the 'torque drive' works, and how to calibrate and use it
- how the linear-in-velocity damping works, and how to acquire, and to model, the damped- oscillatory decaying waveforms

W26 **The Torsional Oscillator B**

TeachSpin

Available only to those who have taken session A. For abstract, see above in 'The Torsional Oscillator A'. Participants will see, at level B, Advanced torsional oscillations

Participants will see, at level B, Advanced torsional oscillations

- the simplest 'driven damped oscillations', and how to get, and to model, amplitude resonance
- how to get, and how to model, the behavior of phase shift near resonance
- how to understand the response to non-sinusoidal drive
- how things change for other damping laws
- coupled oscillators, energy interchange, and normal modes

W27 **Muon Physics**

TeachSpin

Cosmic-ray protons impinging on the upper atmosphere create showers of secondary particles, and the (relatively) long-lived muons resulting from pion decay reach the earth's surface to offer a free and reliable steady flux of fundamental particles for study. TeachSpin's 'Muon Physics' apparatus uses a single large scintillator, a photo-multiplier tube, and its associated electronics to make possible the study of muons' arrival. Happily, some muons come to rest in the scintillator, and decay within microseconds to produce a second detectable event.

Participants will see

- how the configured apparatus produces a series of 'muon arrival events'
- what a 'Poisson process' looks like, and what can be inferred from it
- what a 'muon arrival followed by decay' event looks like, and how to measure muon survival time
- how to histogram the measured muon survival times, and how to interpret this histogram
- understanding mean life and half-life, and the lifetime for muons in matter

W28 **Atomic resolution imaging with the Scanning Tunneling Microscope**

Mark R. Flowers, Nanoscience Instruments, Inc.

Participants will use the scanning tunneling microscope to image carbon atoms in highly ordered pyrolytic graphite (HOPG). Experiment will demonstrate the setup of the easyScan STM, cutting an STM tip, and scanning HOPG to reveal the atomic lattice structure. The atomic spacing will be measured. Additionally, given more time, I/V curves will be demonstrated to show the quantum mechanical tunneling current dependence on voltage, and I/Z curves showing the tunneling current dependence on distance.

W29 **Measure surface forces with the Atomic Force Microscope**

Mark R. Flowers, Nanoscience Instruments, Inc.

Participants will use the atomic force microscope to measure the adhesion forces between a silicon AFM probe and different materials. The AFM can be operated in "Force-Distance" curve mode that allows very precise measurements of a microfabricated probe coming into contact with a surface and its subsequent retraction. Hooke's law is used to determine actual force. Materials with different surface properties will be investigated.

W30 **Introduction to nanoscale imaging with the Atomic Force Microscope**

Mark R Flowers, Nanoscience Instruments, Inc.

Participants will learn the basics of operating an Atomic Force Microscope by imaging nanoscale particles in both contact mode and dynamic force mode. This will include an introduction to how the AFM scans the surface and interprets interactions into 3D images. Software to measure cross-sections of nanoparticles will be demonstrated as well as additional off-line analysis of data.

W31 **Driven Damped Harmonic Motion**

Ann Hanks, PASCO Physics

The amplitude vs. frequency curve is measured for a magnetically damped, sinusoidally driven, spring and mass system. The sweep of the driving frequencies is achieved using a computer and the signal output of the ScienceWorkshop 750 interface. The amount of damping can be varied to see how this affects the shape of the curve and the resonant frequency. Also, the phase relationship between the motion of the driver and the motion of the mass can be studied for the frequencies above, below, and at resonance. The simple addition of a point mass makes the system nonlinear, allowing studies of chaos.

W32 **Brewster's Angle**

Ann Hanks, PASCO Physics

The index of refraction of nonconducting reflective materials can be determined by finding Brewster's Angle. In this experiment the percentage of polarized light reflected off the surface of the material sample is plotted as a function of the angle of incidence. The angle which gives the minimum reflection is Brewster's Angle. Curve-fitting is used to determine this angle precisely. But the question is: Can you see a difference in the index of refraction for different frequencies of light?

W33 **Gamma Spectroscopy**

Roger Stevens, Spectrum Techniques

Nuclear half lives will be measured using the multichannel scaling feature of an MCA. Several sources will be used including a Cs-137 cow, filtered air, and a simple deposition from natural Thorium. The gamma

spectrum from the Thorium deposition includes peaks from only a few of the isotopes of the decay chain.

W34 **Adiabatic compression of gases**

Physics Enterprises

This workshop will demonstrate the use of the adiabatic gas law apparatus to verify various gas law relationships. Pressure-volume plots illustrating the ideal gas law, Boyle's law and the adiabatic gas law will be examined and the ratio of specific heat at constant pressure to constant volume (gamma) will be extracted. Pressure-volume plots of a complete cycle will be analyzed as well.

W35 **PS-15 Pulsed NMR**

Joe Dohm, Tel-Atomic

Investigate nuclear magnetic resonance of protons with the PS-15 Pulsed NMR Spectrometer. Both spectroscopy and relaxometry experiments can be performed. By acquiring a signal of a free induction decay (FID) and performing a fast Fourier transform, spectra can be obtained capable of resolving chemical shifts of approximately 5 ppm. T1 (spin lattice) and T2 (spin spin) relaxation times can be measured. The presentation will focus on using TEL-Atomic's proprietary software to acquire and analyze a FID, and also on acquiring a spin echo sequence to measure T2. The PS-15 is a 15 MHz NMR Spectrometer with a .350 Tesla electromagnet. A block diagram is provided summarizing all connections between various components which are inside the unit (with the exception of the probehead and magnet).

W36 **CWS 12-50 Continuous Wave NMR/ESR Spectrometer**

Joe Dohm, Tel-Atomic

Investigate nuclear magnetic resonance of protons, as well as electron spin resonance with the CWS 12-50 Continuous Wave NMR/ESR Spectrometer. Continuous wave NMR is the simplest method of investigating magnetic resonance. The magnetogyric ratio of protons will be calculated, and the qualitative difference between the spectra of solids and liquids will be discussed. The g-factor of electrons will be calculated.

W37 **TEL-X-Ometer**

Joe Dohm, Tel-Atomic

The TEL-X-Ometer is a useful platform that can be used to perform a wide variety of x-ray experiments. Bragg's law will be demonstrated using single crystals of several ionic compounds, such as NaCl and LiF (all face centered cubic). In addition, investigation can be made into Mosley's theory that every element is characterized by its atomic number. The TEL-X-Ometer is a compact and portable x-ray machine. X-rays can be produced at either 20 or 30 KV by an x-ray tube with a copper cathode. Operation of the TEL-X-Ometer can be automated with the TEL-X-Driver. Data is recorded onto a computer using TEL-Atomic's software.

W38 **Cavendish Balance**

Joe Dohm, Tel-Atomic

The computerized Cavendish balance from TEL-Atomic will be demonstrated. The basic operation of the unit will be demonstrated, as well as sample data provided. The unit uses an innovative capacitive sensor to eliminate much of the noise associated with the traditional setup. Data is collected and analyzed via computer. In addition, a derivation is provided that allows the calculation of G from dynamic data, allowing the experiment to be completed in a single lab period.

W39 **Electrical Characterization of Photovoltaic Materials and Solar Cells with the Keithley Model 4200-SCS Semiconductor Characterization System**

John Hayes Keithley Instruments

The Keithley Model 4200-SCS provides a total system solution for DC I-V, C-V, and pulse characterization and stress-measure/reliability testing of a large variety of nanotech and semiconductor devices. This advanced parameter analyzer provides intuitive and sophisticated capabilities for semiconductor device characterization. The 4200-SCS combines unprecedented measurement speed and accuracy with an embedded Windows®-based PC and the Keithley Interactive Test Environment (KITE) to provide a powerful single-box solution.

In this workshop we demonstrate the broad capability of the 4200-SCS using a solar cell as an example device. Because of the increasing demand for energy and the limited supply of fossil fuels, much research is being done on solar or photovoltaic (PV) cells which convert light energy into useful electrical power. When the cell is illuminated, optically generated carriers produce an electric current when the cell is connected to a load.

Some of the electrical tests commonly performed on solar cells involve measuring current and capacitance as a function of an applied DC voltage. Capacitance measurements are sometimes made as a function of frequency or AC voltage. These measurements are usually performed at different light intensities and under different temperature conditions. A variety of important device parameters can be extracted from the current-voltage

(I-V) and capacitance-voltage (C-V) measurements, including output current, conversion efficiency, maximum power output, doping density, resistivity, etc. Electrical characterization is important in determining how to make the cells as efficient as possible with minimal losses."

W40 **Computed Tomography**

Irwin Malleck, Klinger Educ. Prod. Corp. and Werner Bietsch, LD Systeme

The table top X-ray apparatus allows demonstrations of all major topics concerning basic and advanced applications of X-rays. The new computed tomography module, used with a Tungsten X-ray tube allows the user to perform introductory real time experiments with intensity and transparency control.

In this workshop the participants will perform a selection of experiments concerning the following topics:

- Computed tomography of a frog and a LEGO house
- Moseley's law and elemental analysis of coins with x-ray fluorescence
- Compton effect on x-rays: Measuring of the energy of the scattered photons

W41 **NMR of a Flower**

Irwin Malleck, Klinger Educ. Prod. Corp. and Werner Bietsch, LD Systeme

To demonstrate the advantages of various spectroscopic methods, e.g. in life sciences, the students can additionally perform introductory experiments of nuclear magnetic resonance. Experiments like NMR of a flower and hand crème (e.g. NIVEA) will enable the participants to understand the kind of opposite elemental sensitivity of x-ray spectroscopy and nuclear magnetic resonance spectroscopy on an introductory level.

W42 **How to optimize quantization of detector data by minimizing noise and improving signal fidelity when using a real time oscilloscope.**

Marty Gubow, Agilent Technologies, Inc.

A real-time oscilloscope is a critical tool in the quantization of detector data. Modern tools can digitize at rates of 40GSa/s and achieve bandwidths that exceed 10 GHz. Unfortunately data can be distorted by poor signal fidelity and digitizer design. Scientists should understand the effects of inherent noise and digitizer error on their test data.

In this workshop we will explore:

- Measuring oscilloscope noise floor and its effect on your measurements
- Quantifying digitizer linearization
- Limiting bandwidth to reduce noise
- Advanced analysis techniques using MATLAB®
- With transient or pulsed events how to maximize sample rate and record length by segmenting memory

W43 **Studies in using an Optical Trap**

Ludwig Eichner, Thor Labs

An optical trap or an optical tweezers is a scientific instrument that uses a focused laser beam to provide an attractive or repulsive force, depending on the refractive index mismatch to physically hold and move microscopic dielectric objects. Optical tweezers have been particularly successful in studying a variety of biological systems in recent years. Studies in Brownian motion, the random movement of particles suspended in a fluid. Studies in Mie Scattering of particles relative in size as the wavelengths being scattered. Studies in Rayleigh scattering from molecules, describing the electrical charges on the molecule will move in an electric field. Calculating in trap forces, stokes oscillation and spectral density analysis may be calculated and analyzed.

W44 **Fundamental Studies in Polarization**

Ludwig Eichner, Thor Labs

Polarization is a property of waves that describes the orientation of their oscillations. When light travels in free space it typically propagates as a transverse wave. Polarization occurs perpendicular to the wave's direction of travel. The phenomena of polarization may be demonstrated in a series of experiments. Specific polarization effects in optical systems can be demonstrated with simple experiments. Polarization effects in reflection, refraction, scattering, circular polarization, and birefringence may be demonstrated.

W46 **NI-ELVIS Basic Workshop (1.5 hours)**

Arjun Khullar & John Wilson, National Instruments
Paul Dixon, California State University at San Bernadino

Using the RLC resonance circuit and some other interesting circuits, we will explore the use of NI-ELVIS (National Instruments Educational Laboratory Virtual Instrumentation Suite). ELVIS features an integrated suite of 12 instruments (oscilloscope, digital multimeter (DMM), function generator, variable power supply, dynamic signal analyzer (DSA), bode analyzer, 2- and 3-wire current-voltage analyzer, arbitrary waveform generator, digital reader/writer, and impedance analyzer) with a USB interface. Some familiarity with LabVIEW, such as the on-line tutorial, is necessary.

<http://zone.ni.com/devzone/cda/tut/p/id/5247>http://zone.ni.com/devzone/cda/tut/p/id/5247

W47 **NI-ELVIS advanced workshop — The bug: A temperature-controlled experiment on a protoboard (1.5 hours)**

Paul Dixon, California State University at San Bernadino

We will develop and explore a fully-automated temperature-controlled experiment using inexpensive electronic components, LabVIEW and the NI-ELVIS platform. The core of the experimental system, which we call "the bug," is a simple three-component system made up of a thermistor, a resistor, and a ceramic (doped ferroelectric) capacitor bonded together. The thermistor and resistor combine to form the temperature measurement and control system. The ceramic capacitor is the component under study. The overall objective of the experiment is to measure its capacitance, and thus its underling ferroelectric behavior, as a function of temperature. This simple and inexpensive system allows for the exploration of a significant range of computer-based data acquisition and control topics. When fully integrated, this system mimics many of the common interfacing, acquisition, and control issues encountered in table-top condensed-matter physics experiments.

Participants will:

- develop software to measure resistance, and to control and measure slowly-varying voltage signals
- implement, tune, and test a software-based proportional-integral-derivative (PID) temperature controller capable of mK stability
- develop software to generate and acquire buffered voltage waveforms in response to a variety of triggering conditions
- implement and explore noise rejection techniques using signal averaging and synchronous triggering
- implement a fully-automated and multi-threaded experimental control system based upon the previous exercises, using it to measure the underlying ferroelectric response of the capacitor versus temperature

W48 **Projects, from *Hands On Introduction to LabVIEW*, (Oxford Press, 2009) (1.5 hours)**

John Essick, Reed College

Minimum preparation is completion of on-line LabVIEW tutorial (free). Introductory and advanced using NI USB-6009. Participants will complete one or two of the following projects, depending upon each person's level of experience with LabVIEW.

A. Digital Oscilloscope (Analog Input)

- (optional) Use MAX to set-up DAQ device (Section 4.6, p132-136)
- Build DC Voltmeter to acquire single voltage sample (Section 4.7, p136-144)
- Construct Digital Oscilloscope with digital triggering (Section 4.8, p. 144-152). For help in making the Digitizing Parameters control cluster, see p104-105. The Unbudle By Name icon is explained on p. 107.
- (optional) Use your digital oscilloscope to measure the time constant of an RC circuit as described in problem 5 on page 414.

B. Thermistor-Based Digital Thermometer (Analog Input)

- Thermistor's temperature-dependent resistance obeys the Steinhart-Hart Equation (Section 9.1, p. 304-306). For our thermistor, $A =$, $B =$, and $D =$.
- (optional) To gain experience configuring the DAQ Assistant Express VI, build DC Voltmeter (Section 4.7, p. 136-144)
- Construct the Digital Thermometer described on p. 330-331.

C. Toggle Lighting of Two LED (Digital Output Lines)

- Carry out Alternating LED project descibed on p. 168-169

D. Spectrum Analyzer (Analog Input)

- Build Frequency Calculator VI (Section 10.5, p. 343-345). For help in making the Digitizing Parameters control cluster, see p104-105. The Unbudle By Name icon is explained on p. 107.
- Construct the Spectrum Analyzer described on p. 374-375. The required front panel and block diagram are shown on the back of this sheet.
- (optional) Add Estimated Frequency and Amplitude (Section 10.14, p. 370-373) to your Spectrum Analyzer program.
- (optional) Explore windowing (Section 10.13, p. 365-370) and/or aliasing(Section 10.15, p. 373-374) using your Spectrum Analyzer.

W49 **MATLAB for Data Acquisition and Analysis (1.5 hours)**

James Lockhart, San Francisco State University

Minimum preparation is completion of a MatLab tutorial (free).

This workshop will allow attendees to explore the use of MATLAB to acquire data from digital instruments and to perform several types of data analysis commonly used in advanced physics labs. We will run through basic statistical analysis, plotting, curve fitting, spectral analysis, and digital filtering. The use of graphical interface tools such as cftool (curve-fitting tool) and sptool (spectrum analysis tool) will be featured. You may bring your own PC/Mac to this workshop.

W51 **Lock-in amplifier Experiment**

National Instruments

Thursday 20 minute sessions with focus on using the Lock-in to perform a couple of experiments (Harvard group?). One might be a demo experiment where you send an AC signal through a dark room, AC-modulated LED to photo-transistor receiver. Room lights are turned on and the lock-in does its job.

W53 **Single Photon Interference**

Enrique Galvez, Colgate University

Late Abstracts

A New Experiment on Radioactivity

Celia Cunningham, University of Michigan

Scattering of Polarized Light

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

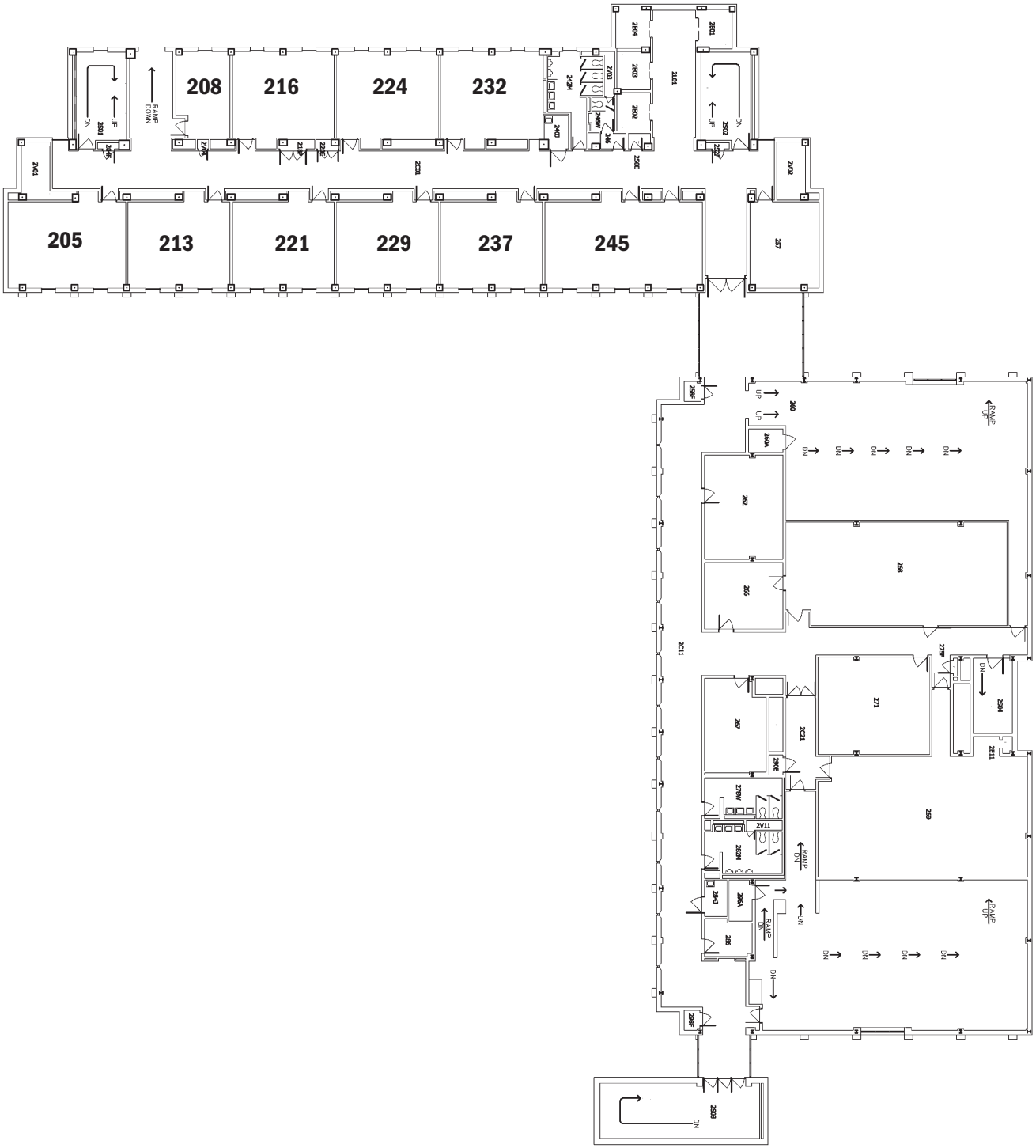
This experiment allows students to explore electric dipole radiation in the optical frequency domain. Here, electric dipoles are induced by a linearly polarized laser beam and the resulting angular distribution of optical radiation is compared to the expected $\sin 2\prod$ distribution. Further explorations of the radial dependence and polarization behavior will be discussed.

Axial and Transverse Laser Modes

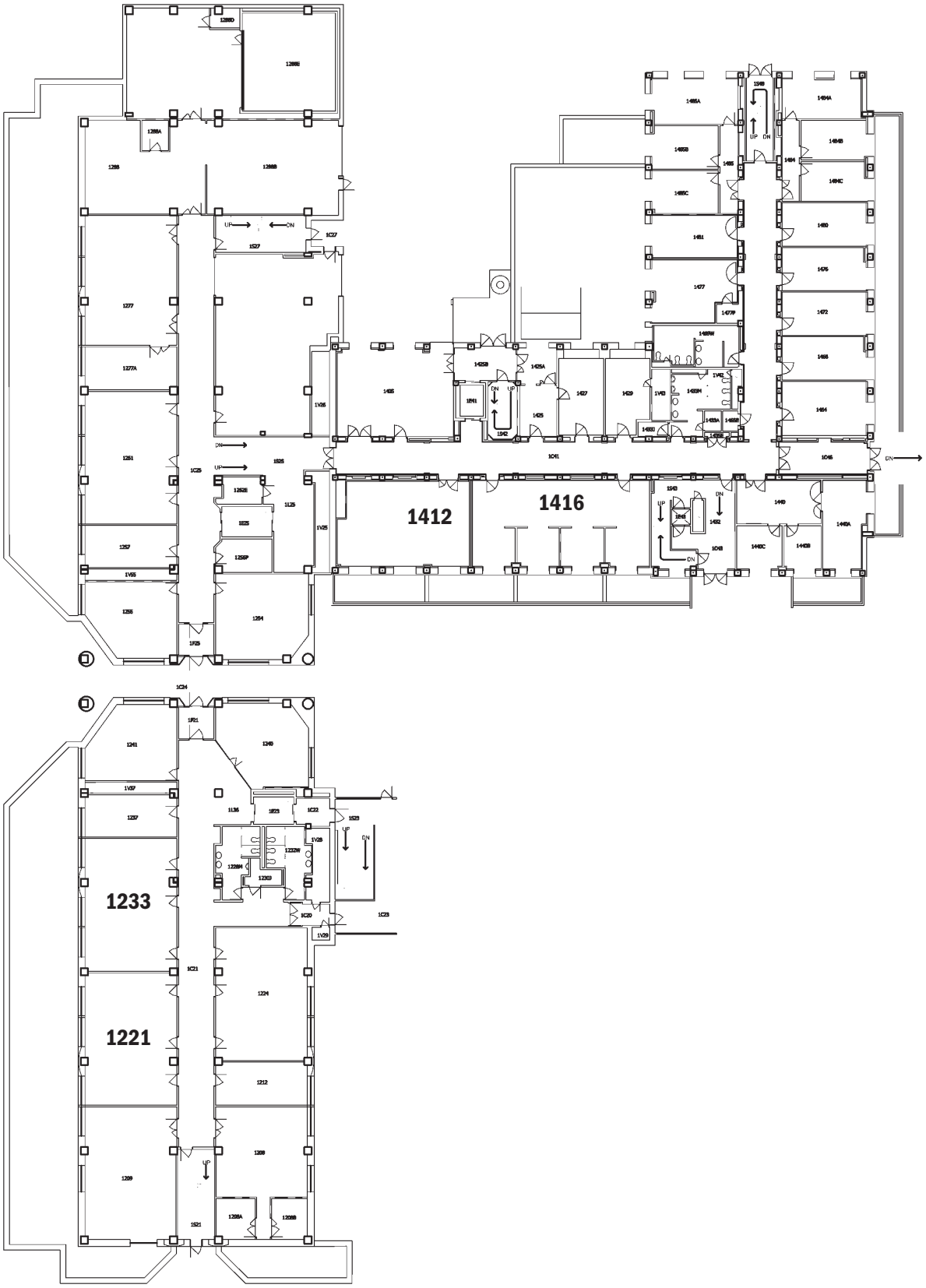
Natthi L. Sharma and Ernest R. Behringer, Eastern Michigan University

The axial modes of a HeNe laser are investigated using a commercial spectrum analyzer. The observed transverse modes of a laser assembled from a wide-bore HeNe plasma tube and an adjustable output coupler mirror are compared with theoretically predicted Hermite-Gauss and Laguerre-Gauss modes.

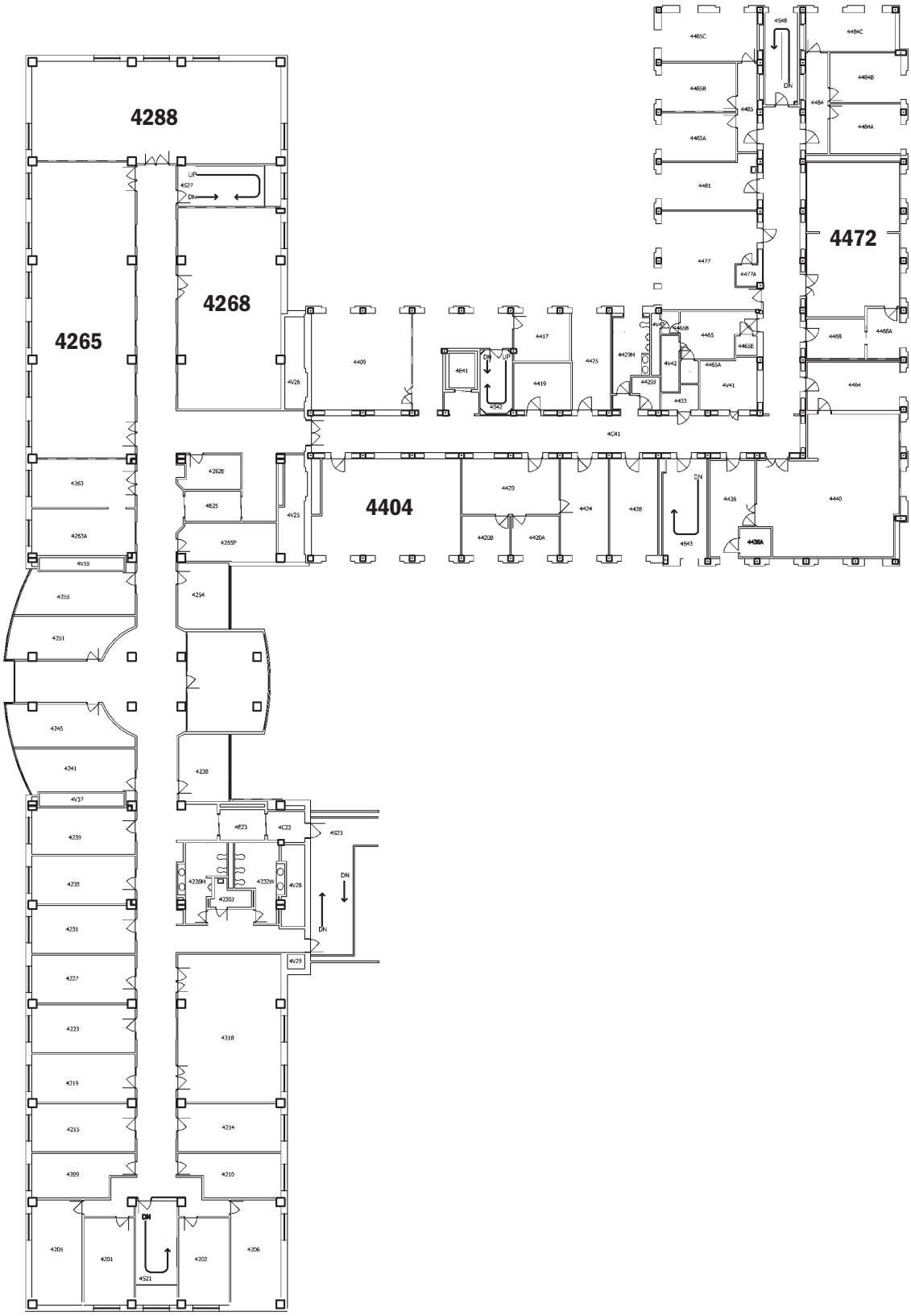
DENNISON BUILDING FLOOR PLANS



RANDALL LAB 1ST FLOOR



RANDALL LAB 4TH FLOOR



NOTES

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Thanks to the following organizations for their donations of time, money, and equipment to help support this conference

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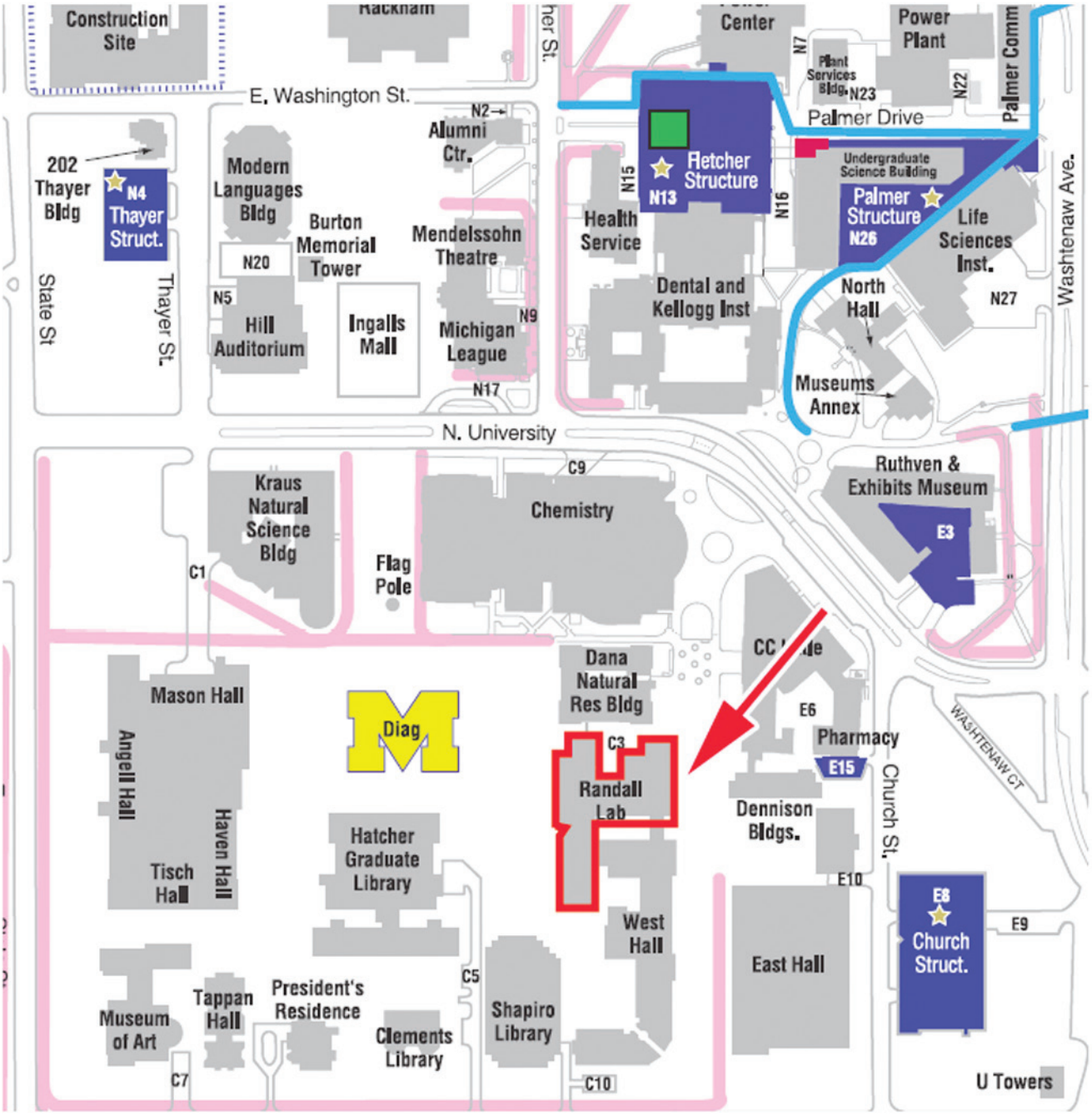
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