ALPhA
Advanced Laboratories

ALPhA's Laboratory Immersions

NSF TEACHSPIN Instruments Designed For Teaching EXCELITAS TECHNOLOGIES AAPT PHYSICS EDUCATION

Five Modern Physics Experiments

The University of Michigan at Ann Arbor, June 12–16, 2017

(Five Experiments in Five Days)

In January 2015, we at the University of Michigan began the process of creating an entirely new undergraduate physics lab to complement our junior-level lecture course in modern physics, a staple of essentially all physics programs at every institution. The rationale for this new offering is described below.

In the past 100 years, the development of quantum mechanics has revolutionized our understanding of Nature on scales that range from the sub-atomic to the vastness of the Universe. Thus, the lecture course, *Introduction to Modern Physics*, is the essential course for undergraduates who have a serious interest in physics as a major and a possible future career, introducing both quantum mechanics as well as its consequences for atomic, solid state, nuclear and particle physics. The concepts of quantum mechanics are quite counterintuitive and even today some of the ideas of indeterminism that Einstein found so distasteful are still debated. Bringing a real concrete experience of this field to every student is the focus of the task I began approximately two years ago. This new course, identified as Physics 391, closely complements the parallel lecture course and includes demonstrations of the quantization of light, the wave nature of matter and the atomic spectroscopy that led Bohr to the insights that underlie the foundations of modern physics and its technological consequences. There is a strategic element of this project that complements the intellectual goals. We are in the middle of a period when the costs of an undergraduate education are becoming formidable obstacles to those students whose parents are less fortunate financially. Online courses (MOOCs) offer substantially similar educational benefits as university lecture courses for a fraction of the cost. If bricks-and-mortar institutions such as the University of Michigan are going to thrive in the decades ahead, they will have to depend on providing intellectual opportunities that cannot be transmitted down a fiber optic cable. We hope that our new lab course will serve as a model for integrating theoretical concepts with hands-on experiences that will greatly enlarge the depth of understanding of how the Universe actually functions.

Host and Mentor

Carl Akerlof obtained his B.A. in Physics at Yale University followed by a PhD in elementary particle physics at Cornell University in 1967. In 1966, he took a job as a post-doc in physics at the University of Michigan that transformed to a teaching position and tenure in 1972. His research interests originally centered on experimental high energy physics but the increasing importance of astrophysics led to experiments that discovered TeV radiation from Active Galactic Nuclei. This was followed by an intrigue with the mysterious nature of gamma-ray bursts and his development of the first cameras to record the prompt optical emission from these very distant objects. His teaching efforts for the past seven years have centered on the advanced undergraduate lab course for which he has introduced a number of new experiments to better reflect the broad scope of physics in the 21st Century. In 2015, Akerlof and Ramón Torres-Isea shared the Jonathan F. Reichert and Barbara Wolff-Reichert Award for Excellence in Advanced Laboratory Instruction.

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Ramón O. Torres-Isea received his B.S. and M.S. in Physics from Eastern Michigan University in 1980 and 1983, and quickly joined the workforce, developing a career as an industrial physicist. Since his return to academia twenty years ago, he has continuously worked to improve the teaching of physics laboratories. He manages the daily operations of the Intermediate and Advanced Physics Laboratories, teaches sections of intermediate laboratories as needed, and co-teaches every year the senior laboratories with a rotating group of faculty members. He has taught Physics at the technical and college level, as well as a graduate course in computer control of research instrumentation for ten years. Over the years Ramón has performed research in Optical Depolarization in Birefringent Crystals, Electrical Arc Physics, Shape-memory Alloys, and for the past ten years in Nuclear Physics, as part of a team led by Prof. Frederick Becchetti at the University of Michigan-University of Notre Dame TwinSol facilities. He is co-developer of the UM-DAS, a deuterated scintillator array for fast neutron detection. He is also co-inventor of three U.S. patented technologies: actuators which couple shape-memory thermal actuating elements with magnetic actuating elements; arc-suppressing current interrupters; and asynchronous magnetic-bead rotation technology for use in identifying and treating bacterial infections.

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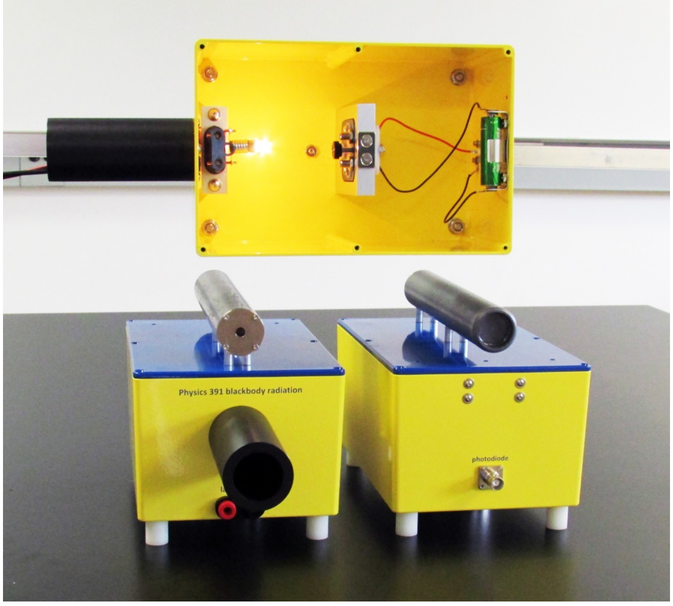
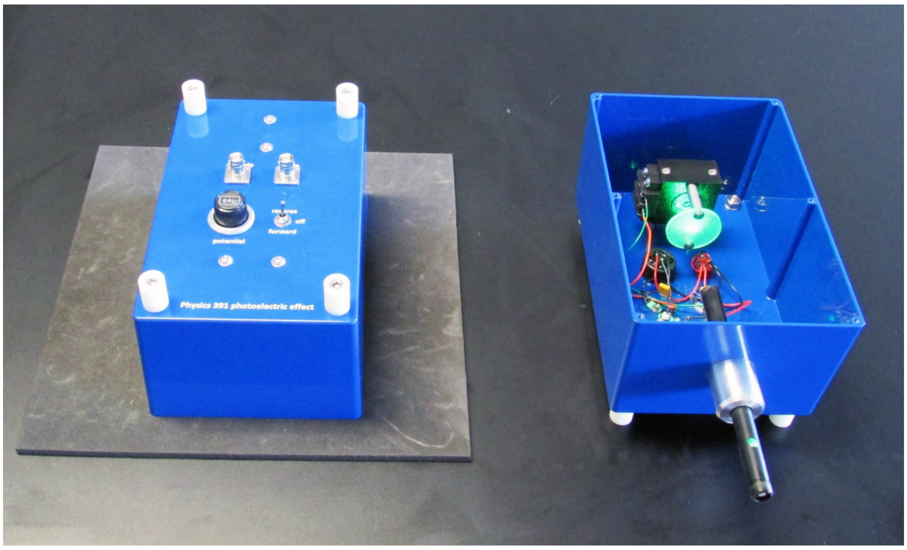
To provide as broad an introduction to modern physics as possible, a different lab experiment is executed each week throughout the course of the semester. This amounts to a total of 12 distinct exercises plus one class period set aside for students to give 10-minute talks on physics topics that they find particularly compelling. For this ALPhA Immersion, we would like to offer each participant an opportunity to become closely involved in a selected set of five of these twelve assignments so that they could begin to construct a similar course at their home institution. The experiments we have chosen to showcase are:

1. Blackbody Radiation: The Stefan-Boltzmann Law and the Planck spectral distribution are studied by measuring the power dissipated by an incandescent lamp and the illumination through several narrow band filters.



Three copies of the blackbody radiation apparatus show the device from different directions. The box on top shows the interior while power is applied to the #1446 incandescent lamp on the left. The two boxes on the table include the solar imaging tube lids that aid in pointing these devices towards the Sun to determine the photosphere temperature. (Click on photo for a higher resolution view.)

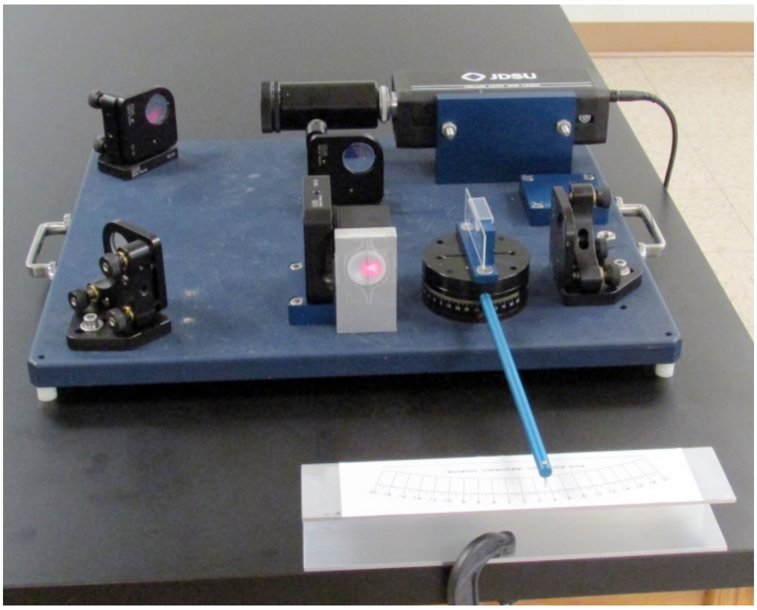
2. Photoelectric Effect: The maximum energies of electrons ejected from the photocathode of a photocell are determined for illumination by three different laser pointers and the Planck Constant is estimated from the hypothesis of a linear relation between photon frequency and energy.



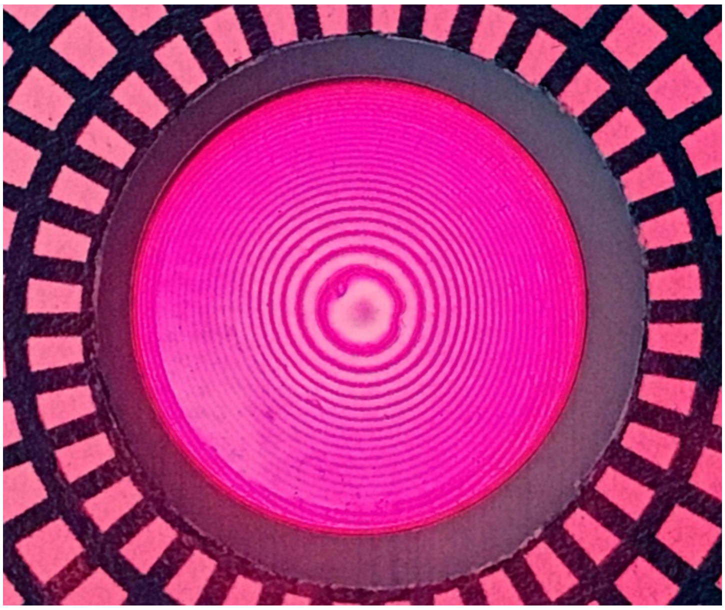
The photoelectric effect apparatus from top and bottom. Lasers with three different wavelengths are used to illuminate a vacuum photodiode. A potentiometer provides the ability to control the reverse bias voltage to determine the point when photocurrent ceases.

3. Interference & Diffraction: Since interference and diffraction are critical to understanding many quantum mechanical phenomena, these effects are demonstrated with laser pointers of different wavelengths and a variety of targets ranging from single slits and wires through multiline diffraction gratings. Newton’s Rings provide a window to use interference to determine the curvature of long focal length lens and a Michelson Interferometer is used to measure the thickness of a microscope cover glass.

Apparatus for observing diffraction & interference patterns. For this image, the target is a 10 micron slit simultaneously illuminated by red, green and violet laser pointers.

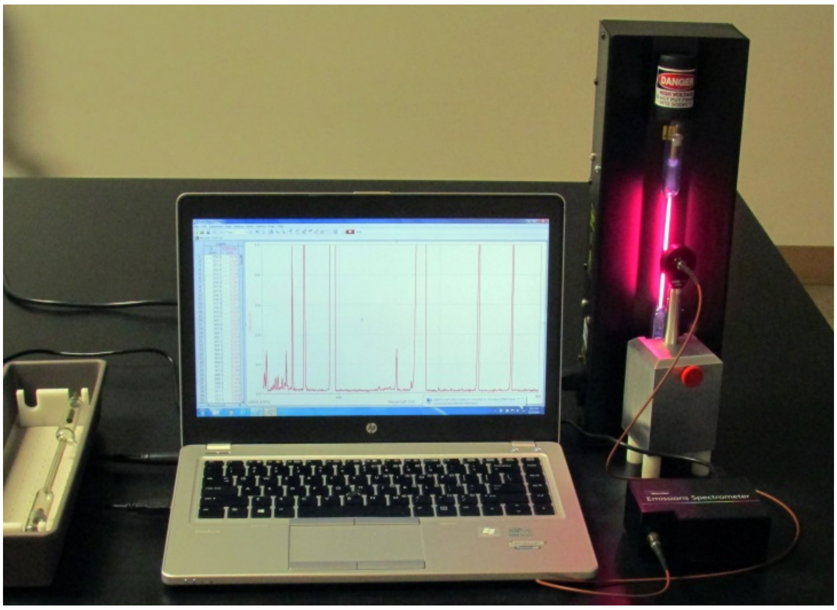


Michelson interferometer with rotating sample stage. A thin rod extends forward for tracing the correlation between optical path length and the interference pattern location.

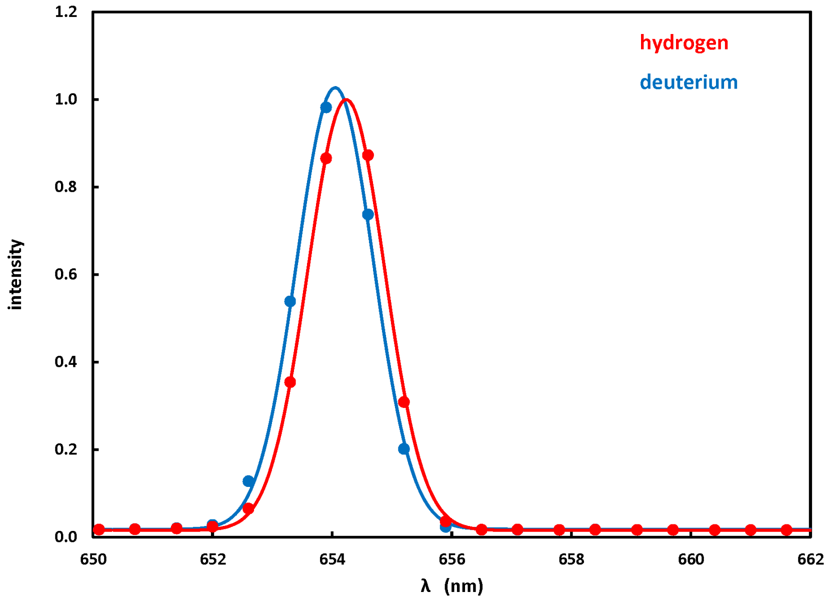


Photograph of the Newton's rings optical target. The image has been somewhat Photoshopped to enhance the contrast. Photo obtained by Jennifer Ogilvie with an iPhone 6s.

4. Spectroscopy of Hydrogen and Deuterium: The emission spectra of hydrogen and deuterium are used to explore the basic elements of atomic structure. The first six lines of the Balmer series are measured for hydrogen and used to determine the value of the Rydberg Constant. By carefully analyzing the spectral waveforms, a small shift for the Hα line between hydrogen and deuterium is used to see the effect due to finite nuclear mass and thus obtain an estimate for the electron/proton mass ratio.

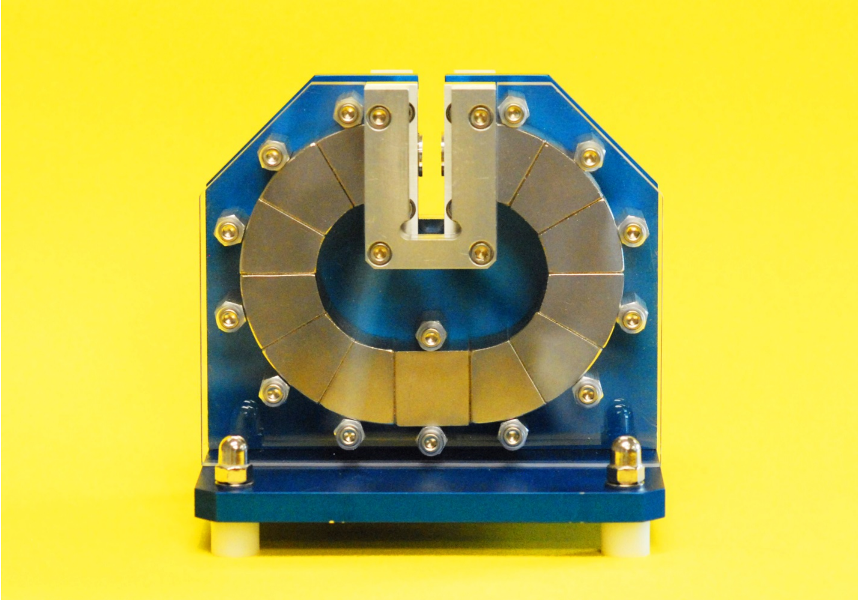


Atomic spectroscopy apparatus with a hydrogen light source. The display shows the first six lines of the Balmer series. Click on photo for a higher resolution view.



H_α lines for hydrogen and deuterium. The small spectral shift is due to the difference of nuclear masses between H and D and permits an estimate of the electron-proton mass ratio. Click on photo for a higher resolution view.

5. Hall Effect: The Hall Effect gives students an opportunity to become better acquainted with the electrical conduction properties of semiconductors, the basic principles of which govern the technologies upon which our modern world depends. The Hall Effect of p-doped germanium sample is measured in a magnetic field of 1 Tesla (10 Kilogauss) as a function of current and temperature to determine the nature of the majority carrier and the band gap potential.



The permanent magnet ring for providing test fields for the Hall effect. The magnetic field in the ¼″ gap at the top is 1 Tesla (10 kGauss). Click on photo for a higher resolution view.

For the Immersion program, one day will be allocated for each experiment. Typically each experiment takes about 2 ½ hours to execute followed by 2 hours or so for data analysis. Participants are urged to work in pairs. Although we have enough setups to accommodate 16 people, we would like to limit this workshop to a maximum of 8. For anyone who is interested in this program, we will be glad to send you copies of the lab manuals that we provide for our students.

Please note that the Jonathan F. Reichert Foundation has established a grant program (ALPhA webpage; Foundation website) to help purchase apparatus used in Laboratory Immersions. Limitations and exlusions apply, but generally speaking the foundation may support up to 40% of the cost of the required equipment.
