Physics 441/442 Advanced Laboratory – Winter 2019

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Lab: 4268 and 4288 Randall
Official class hours: Mon, Tue, Thurs - 1:00 pm – 5:00 pm
The lab is OPEN for your use during working hours: M-F 9:00 am – 5:00 pm

Course URL: http://instructor.physics.lsa.umich.edu/adv-labs/

A. Course Goals:

This course is a hands-on survey of the experimental foundations of modern physics. Some of the goals of this course are:

1) To allow you to reproduce and understand the experimental results that are the underpinnings of modern physics.
2) To provide you with an opportunity to develop critical writing skills and understand how to effectively present your scientific work to a larger audience; this course goal, for improving your scientific writing skills, is aligned with fulfilling the Upper Level Writing Requirement (ULWR), as set by the Sweetland Center for Writing.
3) To familiarize you with experimental techniques and instrumentation employed in contemporary research and industrial laboratories.
4) To give you a survey, via experiment, of many of the sub-fields of modern physics, and the pertinent experimental issues in each.
5) To expose you to the realities of the laboratory experience, where things don't always work, where the issues are not always clear, and where progress depends on perseverance, ingenuity, and judgment.
6) To learn and appreciate the ethical and social issues that are involved in scientific research. These include the handling of proprietary information, respect for colleagues and adherence to high standards of honesty in reporting scientific results.

You should be prepared for a fundamental difference in difficulty and philosophy between this course and preceding physics labs. This is going to be a "problem solving" experience, as distinct from a "cook-book" laboratory. You may have to teach yourself how to use and calibrate many different kinds of test equipment. You may have to search for weak signals in the presence of noise.

You may have to use statistical techniques to extract results from ambiguous data sets. Your success with the experiments, and with the course, will depend on the dedication and initiative that you apply to solving whatever puzzles arise. This is simply part of the reality and joy of the experimental method.

B. Requirements & Grading:

The Advanced Physics Laboratory currently offers ~20 possible experiments. You will choose and perform 4 experiments each semester. Your overall Advanced Lab experimental program is designed in consultation with the instructors. **You will need to propose a program of experiments, in writing, before the second session (see class schedule).**

1) We strongly recommend that you work in partnerships, but each person must maintain their own notebook and must submit their own oral and written reports. Some discussion of what goes into a good notebook is given in Appendix 2.

2) **We request that every student send your faculty instructor a brief E-mail report within 24 hours of the end of each lab class summarizing your progress and/or problems.** One problem that plagues most research is isolating critical issues from the complexity of the overall experimental environment. The aim of this requirement is several-fold: (a) it makes you step back for a few minutes to put your work in a larger perspective; (b) it gives you some practice in efficient communication of technical issues; and (c) it provides an opportunity for the instructor to make suggestions to overcome any serious problems you're experiencing. Even though the experimental work is generally done by pairs of people, a separate report is required from each of you. Failure to submit such reports in a timely fashion will be reflected in the class participation portion of your final course grade.

3) **You are required to write a concise, written report (6 pages max) describing each of the four experiments you complete this semester.** Each report will be submitted to the instructor for initial review. After review, it will be discussed with you with specific suggestions for improvements after which you will be asked to revise it and submit it for a final grade. This process of feedback and revision is designed to help you improve your scientific writing skills. A final course grade of C- or better satisfies the Upper Level Writing Requirement mandated for all LS&A undergraduates.

4) At the end of the semester, you will be asked to give an 8 to 10 minute oral presentation to the entire class based on one of the experiments that you found particularly interesting.

5) The course grade will be made up to scores of the four lab reports (4x20%), the oral presentation (10%), and course participation (10%). The presentation will be peer-graded based on content and style. The lab reports will be graded according to the following criteria:

    (i) Report Structure and Organization (10 pts)
    (ii) Explanation of Methods, Results, and Physics (10 pts)
    (iii) Concise Writing and Sentence Structure (5 pts)
    (iv) Professional Plots, Tables, Figures (5 pts)
    (v) Analysis of Results, including Uncertainties (20 pts)

C. The Experimental Catalog

We list here the currently available experiments, sorted into major sub-fields of physics. Some experiments show up in more than one sub-field. The more basic experiments, appropriate for Physics 441, are underlined. For e*xperiments* in italics, please consult the instructor for availability. The complete catalog is at http://instructor.physics.lsa.umich.edu/adv-labs/Experiments_main.html

I. Atomic, Molecular and Optical Physics

a. Atomic and Molecular Spectroscopy
b. Faraday Optical Rotation
c. Franck-Hertz Experiment
d. X-rays: Attenuation, Imaging, Bragg Reflection,
e. X-rays: Alpha-induced X-ray Emission
f. Raman Spectroscopy
g. Zeeman Effect
h. Optical Pumping
i. Nuclear Magnetic Resonance
j. Doppler-free Spectroscopy
k. Magneto-optical Trap
l. Existence of Single Photons
m. Entangled Photon States and Bell's Inequality

II. Astrophysics

a. The Solar Photosphere Temperature
b. *Radioastronomy and the Measurement of Galactic Rotation*

III. Nuclear and Particle Physics

a. Quadrupole Mass Spectrometer
b. Gamma Ray Spectroscopy
c. Positron-Electron Annihilation
d. Muon Lifetime
e. Compton Scattering
f. Electron-Positron Pair Production
g. *Beta Spcctroscopy*
h. *Neutron Detection*
i. Nuclear Magnetic Resonance

IV Solid State Physics and Materials

a. Hall Effect
b. *Quantum Hall Effect*
c. Nuclear Magnetic Resonance
d. *Atom Force Microscope and Thin-films*
e. X-rays: Attenuation, Imaging, Bragg Reflection,
f. *Optical Properties of Semiconductors*

V. Non-linear Systems

a. Chaotic Oscillator (Double Pendulum)

D. Logistics

The official class times are Monday, Tuesday or Thursday afternoons from 1 to 5 pm. However, getting the most out of this course may require more hours than class times allow, so the Advanced Physics laboratory rooms are open from 9:00 am to 5:00 pm each weekday for your use.

You will generally work with a partner, and you are encouraged to work this out in whatever permanent or impermanent arrangements that you like. However, oral reports and written reports are required separately from each person.

Descriptions of each experiment are available online via the course Web site. These materials are continuously evolving and never seem to quite keep up with the apparatus. The texts generally contain a listing of references, a historical introduction, a description of the method, an outline of the analyses and explicit questions. This should be considered the **lowest order guide** to the experiment and you will find it useful to consult other references such as textbooks, recommended journal articles, and other online resources.

There will be occasional brief introductions concerning the fundamental material; however, you are expected to be familiar enough with the basic concepts of data manipulation, measuring devices, computers, electronics, etc., that you can learn whatever else you need on the job. This is obviously a goal of the course. A number of manuals and reference books are available in the lab. Use them. However, note that you are not expected to know *a priori* how to work all the gadgets, and you should **ASK** if you have any questions about anything.

Computers: We have adopted a Windows-based system in the Lab. You can save the data to a flash drive, or E-mail it to your own computer, and analyze the data using spreadsheets and data analysis programs. Microsoft Excel, Origin, Igor, and a number of other utilities are available. Although this course does not cover programming, you are encouraged to learn how to use IDL, Mathematica, and MATLAB since these are much more powerful tools for scientific computation.

In general, you are free to employ the available equipment as desired, particularly to improve the quality of your data or make additional measurements. Be independent and have fun. However, be courteous to the other users, observe safety procedures, and also please support the integrity of the lab. Don't leave the lab unattended with equipment lying around. Clean up after you are done for the day.

NOTE: SAFETY IS EXTREMELY IMPORTANT! If in doubt, about the operation of any piece of equipment or apparatus, PLEASE ASK!

The most attractive feature of science is the joy of pursuing questions that go beyond the immediate goals. You are strongly encouraged to think about the experiments you are performing and imagine additional issues worth exploring. The instructors for this course will try their best to accommodate such ideas if the resources are available and you are willing to put in the work.

Appendix 1. Your 441/442 Sequence

In this course you can pick experiments from an extensive list covering the major areas of experimental physics. It is strongly recommended that you choose experiments from a variety of areas so that your horizons about the possibilities of this field are as broad as possible. Never turn down a chance to find out something about an area you know very little about. However, some experiments are more popular than others so we need to anticipate the choices that you would like to pursue. Thus, we request that, after discussion with the instructors, you submit a list of experiments that you wish to complete during the semester. Within whatever resources we have available, we also encourage anyone to propose an experiment not currently available.

Appendix 2: Keeping a Laboratory Notebook

Keeping a detailed laboratory notebook, or 'log book' is an essential part of experimental physics. Students taking Physics 441/442 are expected to record their laboratory procedures and observations during the course of their experiments.

What goes into a useful laboratory log? - the answer is basically everything. Write down, in an informal 1st-person narrative style, what you did step-by-step, include sketches of the apparatus, wiring diagrams, etc., note the relevant experimental conditions and record any unusual events that might affect the experimental data, like someone accidentally turning on a light when your experiment was supposed to be done in a darkened room.

The following are some guidelines on how to write an effective log of your experiments:

- Always try to write the log <u>as you are doing the experiment</u>, not in the evening after you leave the lab. The purpose of such a log is to help you, the experimenter, to recall at a later date exactly how the experiment was performed, what the precise experimental conditions were, and to note any unusual events that might impact the analysis of the experimental data. Its value is in the <u>details</u>, which you will not remember later.

- Experimental data and observations are recorded in the log and should be accompanied by sufficiently detailed notes so that you could reproduce the data, if so required. You can never write too much in the lab book. Also note that you should never erase or delete material. Mistakes in the lab book should have a single line or "X" through them.

- If you are taking data by hand (rather than using a computer data acquisition interface), record your data in the log book, making sure to clearly label the different columns of data with the quantity that is being measured, <u>including the units of measurement.</u>

- It is a good idea to make some rough plots or charts of the data as you are recording them, or immediately after, to help you decide if the data are valid and to detect problems with the apparatus. The square grid pattern on which all good lab books are printed is useful for this purpose. These rough plots are also useful in deciding if you need to take data at finer intervals so as not to miss some important behavior. It's also a good idea to do a rough, order of magnitude, calculation of the results at this point to check if everything is going as expected. If not, at least you won't have wasted the whole afternoon because of some artifact you haven't taken care of.

Professional scientists and engineers routinely maintain detailed log books of their experiments. In industry, these records are used as legal documents to substantiate claims of original discoveries and subsequent patent rights. In the research lab, many a Nobel Prize has been won based on unexpected findings that were first recorded in a log book as an odd- ball observation and later found to be important. The results in this class probably won't get you a trip to Stockholm, but we are going to get you into the habit of keeping a good experimental log book so you will be ready when that 'eureka' moment arrives.

Appendix 3. Lab Reports

The formal lab reports are intended to present, in final and concise form, your experimental motivation, results, and conclusions, and why the reader should have faith in your results. Describe the physics and the apparatus, show your data, and describe your data analysis. Long derivations, discussions, etc. should be avoided unless relevant, and often it is adequate simply to give references. A good report will include demonstration that the nature and size of the relevant uncertainties are understood, that your apparatus is well calibrated, and that your measurement is generally robust. Final results should be clearly indicated in tabular, and where appropriate, graphical, form, and their significance should be discussed.

It is usually appropriate to compare the results obtained with "accepted" or known values. You will not be penalized for obtaining a "wrong" answer provided valid procedures were used, but in such a case you should also provide some more detailed discussion of uncertainties and at least make an attempt to understand the nature of the problem.

A model outline is provided below. You do not have to adhere to this form, as long as you cover the main points of the content.

Title, date, name, lab partner.

Brief introduction describing the purpose and physics of the experiment.

Description of the experimental technique, with emphasis on special features, problems involved, etc. Include schematic diagrams, sketches or photographs of the experimental setup.

Presentation of data, discussing any relevant details about experimental conditions during data taking and handling of data sets, etc.

Analysis of data. Here, you should present a logical and understandable description of how you reduced, analyzed, and extracted physics from the data. Outline carefully, step-by-step, including sample calculations and plots, how you obtained your final result. The final result is often given in the form:

$$A = x \pm \Delta x \; units \quad \underline{\text{or}} \quad A = x(1 \pm \varepsilon) \; units$$

where x is the numerical value of your result, Δx is the uncertainty and $\varepsilon = \Delta x / x$ is the relative uncertainty. An error analysis explaining the sources of systematic errors and statistical uncertainty of the final result should be an integral part of this analysis.

Discussion of the significance of the results. Compare your results with theoretical predictions or accepted values. Reference the source of the latter.

Answer the specific questions that are usually included in the handout.

Finally, **reference** any source material used. Any images or graphic material must be properly attributed.

Texts and References

A number of references are on reserve in the Science Library, or on the shelf in the lab. If you can't find a specific title, ask one of the instructors.

For general background on experimental physics, including many of our experiments:

G. Trigg, *Landmark Experiments in Twentieth Century Physics*.

B. Kramer, *The Art of Measurement*.

P. Cutler and A. Lucas, *Quantum Metrology and Fundamental Physical Constants*.

General textbooks relevant to most of the experiments in the Lab:

R. Eisberg and R. Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles*.

H. Haken and W. Wolf, *The Physics of Atoms and Quanta*.

There are not many good books that could serve as a single text for an experimental course. The following can be very useful. Melissinos has complete treatments of lots of the experiments. Mark is clear, but his style is quaint.

H. Mark and N. Olson, *Experiments in Modern Physics*.

A. Melissinos & J. Napolitano, *Experiments in Modern Physics*.

Some good books on specifics:

J. Hollas, *Modern Spectroscopy*.

S. Svanberg, *Atomic and Molecular Spectroscopy*.

O. Svelto, *Principles of Lasers*.

S. Sze, *Semiconductor Devices, Physics, and Technology*.

H. P. Myers, *Introductory Solid State Physics*.

In teaching and research, we have found many of the following books useful.

Statistics:

The Drunkard's Walk – How Randomness Rules Our Lives, Leonard Mlodinow

Probability and Statistics in Experimental Physics, Byron P. Roe

Kendall's Advanced Theory of Statistics: 3-Volume Set, Alan Stuart, Keith Ord, Steven Arnold, Anthony O'Hagan, Jonathan Forster

Statistical methods in experimental physics, W. T. Eadie, D. Drijard, F. E. James, M. Roos, B. Sadoulet

Statistical Methods in Experimental Physics: 2nd Edition, Frederick James

Statistics for Nuclear and Particle Physicists, Louis Lyons

Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences, R. J. Barlow

How to Lie With Statistics, Darrell Huff, Irving Geis

Electronic Techniques:

The Art of Electronics, Paul Horowitz, Winfield Hill

Computational Techniques:

The Art of Computer Programming, Volumes 1-3 Boxed Set (2nd Edition), Donald E. Knuth

Numerical Recipes 3rd Edition: The Art of Scientific Computing, William H. Press, Saul A. Teukolsky, William T. Vetterling, Brian P. Flannery

Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables, Milton Abramowitz, Irene A. Stegun, P. M. Morse (foreword)

Graphics:

The Visual Display of Quantitative Information, 2nd edition, Edward R. Tufte

The Cognitive Style of PowerPoint: Pitching Out Corrupts Within, Second Edition, Edward R. Tufte

Computational Environments:

EXCEL, Microsoft Corporation, *IDL*, ITT Corporation

Mathematica, Wolfram Research, Inc.

MATLAB, The MathWorks, Inc.

And finally, the Web, used responsibly and with some caution, is a wonderful resource for many of the topics in this lab. For the values of fundamental constants, the following is particularly recommended: http://physics.nist.gov/cuu/Constants/index.html

Books about scientific research as a career

Broad, William, *Star Warriors*
Djerassi, Carl, *Cantor's Dilemma*
Dürrenmatt, Fredrich, *The Physicists*

Dyson, Freeman, *The Scientist as Rebel*

Feynman, Richard P., *The Pleasure of Finding Things Out*

Frayn, Michael, *Copenhagen*

Firestein, Stuart, *Ignorance: How It Drives Science*

Frisch, Otto, *What little I remember*

Gertner, Jon, The Idea Factory: Bell Labs and the Great Age of American Innovation

Goodman, Allegra, *Intuition*

Goodstein, David, *On Fact and Fraud: Cautionary tales from the front lines of science*

Kevles, Daniel J., *The Baltimore Case: A Trial of Politics, Science, and Character*

Kirshner, Robert P., *The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Cosmos*

Laughlin, Robert B., *A Different Universe: Reinventing physics from the bottom down* Levin, Janna, *How the Universe Got Its Spots: Diary of a Finite Time in a Finite Space* Mlodinow, Leonard, *The Drunkard's Walk – How Randomness Rules our Lives*

Reich, Eugenie Samuel, *Plastic Fantastic – How the Biggest Fraud in Physics Shook the Scientific World*

Sobel, Dava, *Galileo's Daughter*

Turkle, Sherry, *Alone Together: Why We Expect More from Technology and Less from Each Other*

Watson, James D., *The Double Helix, A Personal Account of the Discovery of the Structure of DNA*

Poetry for geeks

Hein, Piet, *Grooks 1*, *Grooks 2*, *Grooks 3*, *Grooks 4*

Guidebooks about scientific careers and conduct

Feibelman, Peter J., *A PhD Is Not Enough! – Guide to Survival in Science*

Grinnell, Fredrick, *The Scientific Attitude (Second Edition)*

Committee on Science, Engineering and Public Policy, NAS, *On Being A Scientist – A Guide to Responsible Conduct in Research (3rd Edition)*