PHYS 444W: Advanced Lab

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The purpose of this course is to broaden and refine your laboratory and analytical skills, to further your mastery of several fields of physics, and to communicate your results in journal-paper-style written reports and a conference-style talk.

LEARNING GOALS

- **Broaden and refine laboratory skills:** Students learn and practice skills such as wiring op amps, aligning lasers, calibrating a spectrometer, and using sophisticated instruments such as oscilloscopes and single-photon detectors.
- **Broaden and refine analytical skills:** Students practice skills such as solving differential equations, using Dirac notation, performing celestial-coordinate conversions, and curve-fitting.
- **Explore advanced physics:** Through experiment, students explore advanced physics topics such as hyperfine structure, Bell inequalities, and quantum cryptography.
- **Communicate to learn.** Students use communication as a form of inquiry, invention, and reflection.
- **Communicate flexibly.** Students communicate effectively for specified audiences in more than one mode, such as written, oral, and graphical modes.

You will write lab reports for **three** of your **four** modules. The lab reports will be written in the style of a journal paper. The target audience is a hypothetical editor or reviewer. For the fourth module, you will give a brief (~5 minute) presentation, similar to a talk at a physics conference.

You will choose four of thirteen available projects**,** grouped by topic:

QUANTUM MECHANICS:

Quantum entanglement: Shine violet light through a beta barium borate crystal to create pairs of entangled infrared photons, and demonstrate a violation of a Bell inequality. This apparatus was funded in part by a grant from the Reichert Foundation.
Quantum optics analogies: Investigate the quantum eraser and quantum cryptography. For simplicity, laser beams are used instead of single photons.

RESEARCH INSTRUMENTS:

Pulsed NMR: Explore the physics underlying MRI.
Optical pumping: Investigate hyperfine and Zeeman interactions in rubidium.

COMPUTER INTERFACING:

LabVIEW: Acquire basic proficiency in sophisticated interfacing software used in many research labs. Record the IV curve of a diode, and derive the ideal diode equation.
Spectrometer interfaced with Arduino: Write a Python script to control a spectrometer interfaced with an Arduino microcontroller. Wow!

OSCILLATIONS, WAVES, AND FOURIER SERIES:

Water-column oscillations: Predict and measure the frequencies of oscillating water columns.
Rotary pendulum: Observe natural frequency, damped oscillations, resonance response, period doubling, and chaotic attractors in the motion of a rotary pendulum.
Chaos in electronics: Construct circuits that exhibit the Lorenz attractor and other chaotic phenomena. *Prerequisite: Electronics tutorials at the beginning of the course.*
Wave optics: Observe standing waves between a micowave transmitter and receiver, interference in a glass slide, Fresnel reflection of a polarized light cone, and the effect of quarter-wave and half-wave plates.
Transient heat conduction: Use laser beam-bending to measure and analyze the "cold front" passing through a material dipped in ice water.

ASTRONOMY:

Galactic rotation: Determine the rotational speed of the WHOLE ENTIRE GALAXY.
Exoplanets: Join in the search for planets around other stars.

DEADLINES

- All other modules: **If** you submit a reasonable first draft by the deadline, you may rewrite each lab report as many times as you want until [the date when we would have a final exam]. Please give me a week to read rough drafts. **The sooner you submit rough drafts, the better: It typically takes 3-5 drafts to get a perfect score**. Sometimes a lot of work is required to improve the grade slightly, but sometimes only a small change is required to improve the grade significantly. Please give yourself time to submit at least three drafts by [the date when we would have a final exam]!

- [The date when we would have a final exam] **is a firm deadline for all work** because I have a firm deadline to submit grades.

Course policies:

- You may have one lab partner or work alone. To make sure you have adequate opportunity for hands-on lab experience, we avoid groups of 3 or more. (Exceptions are made for quantum entanglement.)
- You and your lab partner may share data, but you write separate lab reports.
- On the other hand, your oral presentation may be done jointly with your partner.
- [The date when we would have a final exam] is the final deadline for all lab reports!

Grades are determined as follows:

75 points Three lab reports (25 points each)

25 points Oral presentation

Please do not hesitate to contact me (jbrody@emory.edu) if you'd like help understanding any experimental principles or procedures. That's why I'm here.

INTRODUCTION

August 27: Module overview. Electronics tutorial (part 1).

Sept 3: Module selection. Electronics tutorial (part 2).

MODULE 1

September 8, 10, 15, 17, 22, 24

MODULE 2

Sept. 29; October 1, 6, 8, 15, 20

MODULE 3

October 22, 27, 29; November 3, 5, 10

MODULE 4

November 12, 17, 19, 24; Dec. 1, 3

ORAL PRESENTATIONS

December 8

Guidelines for Writing Lab Reports

Your lab report should be clearly written and correct. It will probably consist of five or six sections.

1. The abstract is a single short paragraph that summarizes the report. It gives the main objectives and conclusions of the experiment. **Specific, quantitative results** must be included. Many readers of scientific papers read only the abstracts and the figure captions before deciding whether the whole paper is worth reading. The abstract is sometimes in the present tense, never the future tense. I've often written my abstract by copying the **conclusion** section, rephrasing it a little, and adding an introductory sentence in front.
2. Introduction. This section introduces all the theory that the reader will need to understand the subsequent sections. Any equations that you'll use are given here with qualitative descriptions. Define all variables! If you like, you may **briefly** discuss the historical background and importance of the experiment.
3. Procedure. This section contains a description of the experimental process. In principle, someone should be able to reproduce your experiment after reading this section. The procedure, unlike the lab manual, is **always in first or third person**, never second person. (**Incorrect**: Turn on the laser. **Correct**: We turned on the laser. **Correct** but less clear: The laser was turned on.)
4. Results. This section is for your experimental data tables and all other unprocessed data collected during the experiment. (The text **must** refer to every table and figure. Example: "Figure 1 shows….") I tend to combine this section with the subsequent section and call it "Results and discussion."
5. Analysis and discussion. In this section, the theory from the introduction is applied to your own data. Manipulation of the data from the results section is presented here. Graphs showing functional relationships among experimental parameters are usually the best way to present your findings. It is frequently desirable to show theoretical curves and experimental data values on the same plot.
6. Conclusion. What do you want the reader to remember about your report? What results or insights are you proud of? How can you clearly and concisely summarize what you've learned? If appropriate, comment on the limitations of your findings, or suggest future work.

<u>Your lab report will be graded with the following in mind:</u>

Understanding: Do you correctly explain the physics underlying the experiment?

Completeness: Have you left out anything?

Clarity: Is your report clear and to the point? Define variables as you introduce them. **Remember that units are very important.** Include units in the axis labels of graphs and the headings of tables.

Ambiguity: **This is very important!** Think about ambiguity, and avoid it. Examples:

- "Inadequately focused, we could not see anything with the microscope." In this sentence, what (or who?) was inadequately focused?
- "In free space, he came up with a value of c = 2.99796 * 10^8 m/s." In this sentence (from an actual lab report!), who (or what) is in free space?

Both examples above illustrate the common error of a **misplaced modifier**.

Poets want every word to mean as many things as possible; science writers want exactly the opposite. Every single sentence in your report should have only one possible interpretation.

Significant digits: Be reasonable. Do not show ten significant digits in your results unless there are ten significant digits in your raw data.

Uncertainties and error propagation: This is a sophisticated subject. A good introduction is http://user.physics.unc.edu/~deardorf/uncertainty/UNCguide.html, which also explains how the uncertainty determines the number of significant digits to use in the measured result. A more advanced treatment is http://www.physics.umd.edu/courses/Phys261/F06/ErrorPropagation.pdf.

Captions: Figure captions go **below** the figure. Table captions go **above** the table. (This is an arbitrary but universal rule; check any journal.) Only the first letter of each sentence is capitalized. The first sentence in a caption is typically a fragment, as in "Figure 1. The apparatus." Subsequent sentences, if there are any, are complete sentences.

Equations: Even sentences containing equations should be punctuated normally. Avoid sentence fragments. The format for equations is as follows:

We now will study the beloved Pythagorean Theorem,

$$a^2 + b^2 = c^2. \qquad (1)$$

Equation (1) shows.... *(Notice the period in the previous line!)*

Spelling and grammar: Proofread.

Most common grammatical error: Run-on sentences (specifically, comma splices, which are common in informal writing but inappropriate in scientific papers).

INCORRECT: I love writing lab reports, I weep at the beauty of my work.

CORRECT: I love writing lab reports; I weep at the beauty of my work.

CORRECT: I love writing lab reports, and I weep at the beauty of my work.

CORRECT: I love writing lab reports. I weep at the beauty of my work.

Another common grammatical error: Not knowing the difference between "its" and "it's."

Accommodate your reader: Good scientific papers accommodate both the "lazy reader" and the "thorough reader":

- The "lazy reader" reads only the abstract and the figure captions. All the evidence that you've accomplished something interesting should appear in the abstract, figures, and figure captions. The abstract should stand on its own and make sense to someone who hasn't read the rest of the paper. Each figure with its caption should similarly make sense to someone who hasn't read the rest of the paper.
- The "thorough reader" (possibly a "lazy reader" impressed by your abstract and figures) wants to read a **continuous narrative** from start to finish. This reader will ignore your figures and tables until the text refers to them; you should guide your reader to each figure and table whenever you want your reader to look there.

Plagiarism: Plagiarism is a violation of the Emory Honor Code. You are expected to write your laboratory reports on your own. Any unique phrases lifted directly from any source, including the internet, must be enclosed in quotation marks with the source clearly identified. All sources that you studied to gain understanding while preparing to write your laboratory report, including links to the internet, should be listed at the end of your report under References. If you are ever in doubt, identify the source of your material. In particular, **be sure to cite the source of any graphics you download into your report.** I don't like to be bossy, but I'd like to help you avoid the mistakes made by former students. Therefore, just to be helpful, I'm providing a list of things that you may not do:

- You may not copy entire paragraphs from any source. In physics papers, we almost never quote exact text.
- You may not do a sentence-by-sentence paraphrase of any document. I know it's hard to come up with a unique explanation of a technical topic, but the idea is to understand it well enough to pull the sentences "out of your head" (or your notes).
- You may not use anyone else's data in lieu of data you're supposed to record yourself. You may, however, cite anyone else's data for purposes of discussion.
- If you don't show up in lab, you may not use your lab partner's data. Equivalently, you may not share your data with a so-called lab partner who doesn't show up in lab. If you can't come to lab due to quarantine, we'll find remote experiments for you to do.