Physics 405: Advanced Laboratory

I. Introduction

Physics is both a body of knowledge and a method of inquiry. This knowledge rests upon a firm foundation of physical observations that eventually become taken as fact, but usually only after considerable scrutiny and experimental confirmation.

Developing an understanding of how one acquires insight through physics research can only be gained with some experience in the laboratory. Too often, it is assumed that what we take to be fact is so because it is in a textbook or has been heard about in a lecture. Without direct experience, physics becomes authoritarian in nature; one would get the false impression that this field is largely an intellectual exercise in which particular conclusions are ground out of general principles.

It is the unique task of laboratory work to help develop understanding of experimental procedures. This aim can best be achieved by solving simple experimental problems. To do so, one must become familiar with a large number of common laboratory instruments. In Physics 405, you will work with real equipment rather than an ideal counterpart, and will be exposed to its performance and limitations (range, accuracy, sensitivity, etc.). These limitations invariably result in some degree of uncertainty and possibly also some error, all of which must be accounted for in drawing conclusions from experimental results. Analysis of random and systematic errors is also an essential component of all good laboratory work.

The experiments in this course have been selected because they are a) geared approximately to the level of your lecture courses and b) representative of several of the extraordinary foundational discoveries that led to the development of quantum mechanics and modern physics. As you carry out these measurements, you may discover the experimental effects of the quantization of charge. You will measure the quantization of electromagnetic energy in molecules and atoms, and in nuclei from their radioactive decay. You will directly observe cosmic particles and the emission of light quanta from a semiconductor.

You may find that laboratory work involves more effort than a lecture course with equivalent credit. You will find that good time management and a commitment to problem-solving will be very valuable. As the semester progresses, you will hopefully find that the effort involved to complete an experiment will be decreasing rather than increasing.

II. Experiments

The following experiments are available:

1. Measurement of the Velocity of Light .... (1 unit)
2. Experimental Atomic Spectroscopy .... (1-2 units)
3. The Franck-Hertz Experiment.. (1 unit)
4. Measurement of Planck's Constant…………………….................. (1 unit)
5.
6. The Charge-to-Mass (e/m) Ratio of Electrons................................... (1 unit)
7. Gamma-Ray Spectroscopy ……….. (1 unit)
8.
9. Gamma-Gamma Angular Correlation .... (2 units)
10. The Hall-Effect in Metals .... (2 units)
11. Cosmic Rays ……….. (1 unit)
12. Nuclear Magnetic Resonance in the Earth's Field …………………. (2 units)

It is expected that all students will complete the work for at least **six** units, which will typically consist of **four** to **six** experiments. You will typically have two weeks to complete an experimental unit. A recommended schedule is as follows:

- Week 1: become familiar with the theoretical aspects of the experiment, and do the prelab questions. Familiarize yourself with the apparatus and take preliminary data. A first pass through the analysis is extremely valuable to help you identify the major sources of uncertainty that you should focus on overcoming when collecting your final data.
- Week 2: Take final data, analyze it, analyze and collect the results in your lab notebook.

There is an electronic sign-up page on the computer in room 3210 in which you can designate the experiment and day on which you will perform that experiment the following 1-2 weeks. This procedure reserves the apparatus and notifies the lab technician when you expect to be in the lab. If any preliminaries are required (such as preparing a vacuum system or repairing equipment), you should be sure to coordinate with lab technician before coming in to do the experiment. For large classes, it may be necessary to place restrictions on the number of days per week you can spend on a given experiment.

III. Grading:

Course grades will be based on three factors: 1) laboratory notebook reports kept for each experiment performed, 2) a formal report on one experiment, and 3) an oral report given during the semester. Exact grading percentages will depend on the instructor and will be specified in his/her syllabus.

IV. Laboratory Notebooks:

An experimenter generally keeps a record of everything pertaining to his/her experiment in a notebook or a log book. This record usually includes descriptions and diagrams of the experimental set-up, comments about the methods used and problems encountered, data resulting from measurements, sample calculations, etc. The main reason for doing this is to be able at some future date to reassess the experiment in the light of new findings; to do so requires a clear and complete written record, including failures as well as successes.

Notebook Reports:

You should write (**in ink**) in a bound notebook. It may be necessary to have 2 such notebooks in order for one to be available while the others are being graded. The reports are broken roughly into three parts: preparation, experiment log, and analysis.

Preparation: Prior to arriving in class, you are expected to have read the laboratory manual description of the experiment to be performed. The answers to the appropriate Preparatory Questions must be answered either in the notebook or submitted electronically: these should be checked and initialed by the T.A. or instructor before the experiment is begun. The preparation section should also include a very brief description of the theory of the experiment and of the method to be used. Any preliminary diagrams may also be included.

Experimental Log: In keeping with the above paragraph on laboratory notebooks, you should keep a log for the experiment. This should include a **complete** (but concise) description of the steps taken in performing the experiment. The description should be clear enough and legible enough for a colleague to be able to determine how the experiment was done. Each page or entry should be dated. Mistakes should be **lightly** crossed out; they may become relevant later. The log should also include apparatus sketches and electrical circuit diagrams as appropriate. Note that the diagrams in the laboratory manual may not accurately reflect the way in which you have set up the experiment. You should be sure to reflect the true configuration for your data. Finally, the log should contain the results of all measurements taken as well as the method used for the measurements; in all cases accuracy limitations and the reasons for the limitations must be included.

Analysis: Upon completion of the experiment the data must be analyzed to yield final results and estimates of the uncertainties. It is wise to make preliminary calculations before disassembling the apparatus to make sure the experiment is going as expected. The laboratory report must include the method of analysis, sample calculations, and a statement of results and uncertainties. Typically the most difficult part is in the assignment of systematic errors to the final results. The final error estimates must include systematic errors as well as statistical uncertainties and uncertainties propagated from individual measurements. Systematic errors are difficult to estimate since they sometimes involve quantities not directly measured; their assignment therefore is somewhat of an art and requires some delicate judgement. The final error estimates should be as small as possible while still bounding the correct (but unknown) results. It is most important to make honest estimates using a reasonable method; there is no rigorous prescription for doing so. Grades are based more on the reasoning involved than on the final numbers arrived at, however some evaluation will be based on the expectation that you will be able to achieve results typical of that expected from the apparatus you have available. The actual results of the experiments in this course are well established. The laboratory report should conclude with a comparison of your results with the established results; and any discrepancies should be discussed.

Due Dates: Due dates for laboratory reports, the formal report, and oral presentations will be specified in the instructor's syllabus.

A. Ten-Minute Talks:

You will be expected to give a ten-minute talk on an experiment of your choice or some other topic selected by the instructor. You should give a clear presentation of your experimental results and analysis. The theory should be kept to the minimum necessary for understanding by those students who did not perform the experiment. The talk will be followed by questions from the instructors and other students.

B. Formal Report:

The weekly write-ups are not intended to be polished reports of the type submitted for publication. One such report is required on one of the experiments performed during the semester. The level of sophistication should be approximately that of the review articles in the American Journal of Physics. The report should be self-contained and should be intelligible to anyone with a Bachelor's Degree knowledge of physics. The report should contain introductory remarks, theoretical principles and descriptions of the apparatus used. This is to be followed by your data, analysis of the data to give the desired result, and a critical assessment of the whole experiment. The text of the report should not exceed 15 pages; shorter reports are acceptable if all relevant points are covered. The format to be used and the relative grading weight of the various sections are detailed below. Deviations from this format will usually result in loss of credit.

Format for the long report:

Title: Include date of writing, title of experiment, experiment number, and your name.

The Abstract (10%): A one-paragraph abstract giving a very brief summary of the report. The abstract should state the purpose of the experiment, how this purpose was achieved, the conclusions drawn and the numerical value obtained with its uncertainty for any specific parameters measured, e.g., the velocity of light in Experiment I.

Introduction (20%): Discuss the significance of the experiment: the importance of the physical quantities and the principles involved. Either in the introduction or in a separate section ("Principles"), give the theory of the experiment in sufficient detail so that someone unfamiliar with this particular experiment could follow it. The theory section should include the following:

1. A clear specification of the quantity or entity to be measured.

2. Since the quantities you are interested in must generally be measured indirectly, it is necessary to justify the use of this indirect method. The equations that you use in the calculation of the desired quantity should be derived in a clear and logical fashion.

3. Describe briefly how the determination of the desired quantity is to be made, but do not include details of the manipulation of the equipment in this section.

Procedure (15%):

1. Include a neat diagram of the experimental set-up and/or appropriate circuits. These must be the ones you actually used, rather than those in the write-ups which are often simplified for ease of understanding. With the diagrams, list the major pieces of equipment used stating the sensitivity of the various meters, focal lengths of lenses, etc. (Approximate figures are sufficient here.)

2. Describe the basic procedure used in the experiment.

Data (10%): It is not necessary to include all the data you collected, but you should include all data relevant to the presented result. The data should be labeled as Table I, II, III, etc. as appropriate, or as figures if presented in graphical form. If you import tables from, for example, Excel, be sure to give them reasonable formatting: use an appropriate number of significant figures, make sure everything has units, names, etc. If you present your data in graphical form, be sure to use reasonable fonts, label the axes, etc. Good figures are particularly valuable for summarizing your findings.

Results (20%):

1. Give a sample calculation to illustrate how you obtained your results from the data.

2. List the values determined for the desired quantity, including both its and uncertainty.

3. Graphs of data should include uncertainties on the data. Display the data as points, and fits to the data as lines.

4. Describe the sources of systematic error and show how these have led you to the uncertainty quoted in (2).

Conclusions (20%): This section should be a critical assessment of the experiment as a whole. Include any possible errors caused by approximations in the theory on which the experiment is based, weaknesses of this particular experiment or of the particular apparatus used. Suggestions on how to improve the experiment are encouraged! State how well the purpose of the experiment has been achieved.

References (5%): You should be sure to reference any information that is not directly in the lab manual.