Caltech

Physics 6

Experimental Physics Laboratory

COURSE INFORMATION AND REQUIREMENTS

Contents

Course background and goals

Physics 6 is intended to introduce majors in the physical sciences to the rigors of research as an activity engaged in by professional experimental scientists. The construction of scientific theories (mathematical models describing the various things found in the world and their interactions and evolution), the development of quantitative experimental or observational tests of the predictions of these theories, and the resulting continual refinement in the accuracy and comprehensiveness of the theories and the tests applied to them — these elements comprise the activity that is scientific research. In this course you will begin to develop the skills required for you to successfully participate in this enterprise.

Experimental research in physics is motivated by theory, which is expressed mathematically. Experimental tests of hypotheses derived from theory thus involve control of quantitative parameters and measurement of observable quantities. All such efforts are subject to noise, calibration errors, and other sources of measurement uncertainties, errors, and lack of precise repeatability. Providing examples of and experience with the quantitative evaluation and refinement of theoretical models in the face of such challenges is the primary goal of the course.

The course is actually quite advanced for the early undergraduate level. You will be required to make precise measurements and to provide detailed, rigorous analyses of error sources and uncertainties along with your results. You will work alone and perform the experiments using research-grade apparatus with minimal supervision from the laboratory instructors and your section's graduate student and undergraduate student teaching assistants. The menu of weekly experiments covers several subtle phenomena and concepts of classical, quantum, and statistical physics, and each experiment requires a significant amount of student preparation prior to coming to lab. To understand what is going on during an experiment and how the data relate to theory will require you to call on things you should have learned in all

of the physics and math courses you have taken; many times you may find that you will need to go back and review some particular topic to prepare for an experiment.

> **You must maintain professional-quality notes** of your experimental procedures, data, and analyses, and you will attend weekly, individual recitations during which you defend your latest results and demonstrate your preparedness for your next experiment.

Because this is a beginning course in experimental science, each experiment will have a preassembled, well-designed suite of equipment for you to use. Most of the experiments, however, will require you to perform some configuration and calibration of the apparatus before you can collect accurate, relevant data. An important part of your learning during the term will be to become somewhat familiar with the various equipment and techniques we use, because these things are quite representative of those used in research laboratories.

> Understanding what the various complicated pieces of equipment do and how they do it, how to calibrate and optimize the performance of the apparatus to mitigate sources of systematic error and maximize signal-to-noise ratio, how to recognize good data and efficiently collect it, and, finally, how to accurately and completely document your laboratory work are among the most important of the course's objectives.

Schedule for the term and lab conduct

During the first week of the term you will email a completed **Lab Scheduling Form** to the course instructor. These forms will be used to schedule lab sections, and you will be assigned to a weekly 3-hour laboratory section.

The second week of the term each lab section period will be devoted to instruction regarding data analysis, theory testing, and the mandatory use of the course data analysis software, **CurveFit**. This software is in the form of an application package for *Mathematica*®, so you should install Caltech's site-licensed *Mathematica*® on your personal computer.

> **There will be no scheduled recitation the second week of the term, but you will attend your scheduled lab session.** The laboratory instructor will give you a lecture and lead a discussion regarding the important topics of data and error analysis. Bring your laptop to this session, and you will be shown how to install and use the **CurveFit** add-on package.

The second week session will also be used to set up a recitation time with your TA. Recitations and experiments commence the third week of the term. Everyone will attend their individual recitations with their TAs starting that week. All students will perform the mandatory Experiment 2 during this first week of actual laboratory sessions. The experiments are described here:

http://www.sophphx.caltech.edu/Physics_6/Experiment_List.pdf

That file also includes links to the laboratory notes for each of the experiments. Review the following pages of this document and the additional links it refers to in order to help you prepare for recitation and for lab.

You are expected to attend all scheduled weekly recitations and laboratory sessions. If you must miss a session, you must make prior arrangements with your TA. You may not attend some other lab section without the approval of your TA and the TA of the other section. **You must have a recitation with your TA before you can perform each experiment.**

The general schedule flow for each week of the rest of the term goes as follows:

1. ***Choose an experiment.*** Sign up for each week's experiment by initialing the appropriate box on the lab schedule for your section. The schedule is in a large, loose-leaf binder on top of the section mailboxes outside 202 Bridge. Any course announcements or changes to the notes will be posted on the bulletin board in this area.
2. ***Recitation.*** Come to your recitation thoroughly prepared, having studied the notes for the experiment and completed the prelab problems. Adequate preparation will require study of the experiment notes for 1 to 2 hours, depending on the experiment. At recitation your TA will return your lab notebook and discuss your previous week's work as well as question you about the upcoming experiment. Prelab preparation and recitation requirements are described here:

   http://sophphx.caltech.edu/Physics_6/Lab_Notes_Guidance/Recitation.pdf

3. ***In-lab work and data collection.*** Come to your scheduled 3-hour lab session prepared to perform the experiment. Study the procedure for the experiment and thoroughly understand how you will analyze your data. Plan your setup and data acquisition so that you will be as efficient and effective as possible during lab; the 3-hour time period should be sufficient to collect all required data. Know when the data you have collected are sufficient to effectively analyze and evaluate the relevant theory and determine estimates of the theory's free parameters.

You must thoroughly document your efforts in a bound lab notebook – not in some separate document (other than computer data acquisition files). Computer document files and any other extra documentation or notes must be printed and permanently attached to pages in your notebook; **your notebook must be a complete record of the work you performed.**

Your lab notebook is a working document, not a polished publication, but the writing must be legible and organized. In-lab notetaking is described here:

http://sophphx.caltech.edu/Physics_6/Lab_Notes_Guidance/InLabNotes.pdf

Before you leave the lab take a look at your data and perform some initial data reduction. Computer data files should be saved or archived to the lab network drive. **Make sure you have the data you need in order to complete your analysis of the theory and answer interesting questions!**

Clean up your experiment area before leaving the lab. Check with your TA to see which experimental equipment should be turned off and which should be left powered. Some equipment takes a long time (hours or even days) to stabilize once turned on.

4. ***Data analysis and conclusions.*** In the next few days following lab complete the data analysis for the experiment and include it in your lab notebook. Use plenty of space and clearly highlight important findings and conclusions regarding the adequacy of the relevant theory and estimates of numerical values for the theory's free parameters. Always write down the formulas you use, and always include units with numerical quantities. Label graphs and their axes; clearly differentiate real data from theoretical curves or fits.

All results should include an error analysis at the level of the text Elementary Physical Data Analysis. Propagate errors. Include difference plots (residuals) of fits versus data. Use χ-squared calculations in your analyses. Use the *CurveFit* package for *Mathematica*® for data analyses.

General guidance and an example of a portion of a data analysis section are provided here:

http://sophphx.caltech.edu/Physics_6/Lab_Notes_Guidance/AnalysisGuidance.pdf
http://sophphx.caltech.edu/Physics_6/Lab_Notes_Guidance/AnalysisPages.pdf

Place your lab notebook in the designated mailbox for your section so that it may be graded. The deadline for completing your analysis and submitting your notebook will be specified by your TA.

Grading

To pass the course you must successfully complete 6 weeks of experiments. You may do more work if you wish, in which case your grade will be based on your best 6 grades. The last week of the term will serve as a make-up week so that you may complete this requirement or to perform an additional experiment in order to attempt to improve your grade.

Your section TA will assign your grades for each experiment. At the end of the term the course instructors will meet with all TAs to standardize student letter grades among the various sections. The course instructors make the final decisions regarding the course grades awarded at the end of the term.

The grade for each experiment will be awarded on the basis of a maximum of 100 points. The maximum score of 100 points for an experiment will be distributed as follows:

- 20 points: Your preparation at recitation (including your prelab problem solutions). Understand the theory and how the data relate to it! Understand the equipment and procedure!
- 40 points: Your in-lab performance, in-lab note taking, in-lab point estimates of the values of the theory's free parameters, and the quality and sufficiency of your data. Don't just be a technician working through a procedure without understanding!
- 40 points: Your post-lab data analysis and conclusions. Look for the physics, and evaluate theories quantitatively and critically. Use the experiments to answer or pose interesting questions! Use the data to determine the values of fundamental constants of nature (with uncertainties). Don't leave a wiggle on a plot unnoticed if it is more than just noise.

Your TA will assign numerical grades for each of the above three segments of your work; the total will then be the grade for that experiment. Letter grades for the term will be assigned at the final grading meeting, and the grading will be done "on a curve." You can ***roughly estimate*** your letter grade for any particular experiment using a standard scheme of approximately 94 or above: A, 90–93: A−, 87–89 B+, etc. A maximum score of 100 points is very hard to achieve, as is a final course grade of A+:

The grade of A+ is reserved for only a very few — far less than 10% of our students earn this honor. Only by consistently going beyond the vague limits of the experiments outlined in the notes and exceeding the normal expectations of even the best Caltech students can you expect to earn the singular honor of an A+ grade.

Collaboration policy

The course collaboration policy is simple to state:

> **Students will work individually on all experiments. You may not examine another student's prelab problem solutions, data, or analysis (from this or any previous term).**
>
> **You may not use another student's data (from this or any previous term) and analyze it as though it were your own without express permission from your TA.**
>
> **Exception:** you may examine another student's work and discuss it with the student only in the case of those experiments for which both you and the other student have already completed and received grades.

The exception stated above should allow students to discuss ways to improve their prelab preparation, in-lab performance, analysis, and documentation practices for future experiments.

Late Policy

A simple statement of the late policy is that:

> **Unexcused failure to submit work by the specified deadline or to arrive late for scheduled activities (recitation, lab section) will result in a points penalty applied to your grade.** The later you are for a particular event or deadline, the larger the penalty. Repeated lateness will result in ever-increasing penalties. **The need to complete and submit homework sets for another class is no excuse.**

Your TA will determine and assess late penalties, but you may assume that any unexcused delay in the submission of work or unexcused delay for the appearance at scheduled events (recitation or lab) will result in at least the equivalent of a one letter-grade penalty (about 10 points out of 100).

> If either of the course instructors discerns that you exhibit a general habit of tardiness or disregard of deadlines, then he may impose an additional penalty to your final grade.

Unexcused tardiness for the lecture and discussion on data analysis scheduled for the second week of the term will result in a penalty assessed against your grade for Experiment 2.

Laboratory safety

Physics laboratories may be considered to be "industrial environments" similar to high-tech machine shops. You must be aware of your environment and be careful that you don't get hurt.

There are very heavy items (magnets, lead shielding, etc.), high-voltage and high-current power supplies, compressed and liquefied gasses, toxic chemicals, ultraviolet and laser light sources, and radioactive materials, to name a few of the many potential hazards. Additionally, there are many sharp little bits of wire and other metals on the floor which can easily stick into skin. To mitigate your chances of injury, heed the following rules:

- **General prudential rule:** be aware of your surroundings, and if you feel that some activity may be unsafe, discuss it with the laboratory instructor!
- Wear clothing suitable for a lab environment, **including shoes.**
- No eating in the lab. **Wash your hands after you leave the lab.**
- **Know where the lab first-aid kit is located.**
- Beware of high voltages and high current power supplies – they can kill.
- Wear safety glasses when soldering, etc., or when exposed to ultraviolet lamps.
- Be wary of lasers and don't let a beam hit your eyes. If necessary, wear safety glasses.
- Don't get injured by cryogenic materials such as LN2 or dry ice.
- Keep body parts, power cords, etc., away from drive belts on vacuum pumps.