

PHYSICS 2150 — EXPERIMENTAL MODERN PHYSICS

Spring 2008

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Introduction: Physics 2150 serves as your introduction to “modern” experimental physics: the experiments you will do here are those that, over the course of the twentieth century, established the basis of much of our understanding of the physical world and laid the foundation for technologies ranging from microelectronics to nuclear weapons.

Attendance: To complete the course, you must attend at least 12 of the 14 laboratory sessions and turn in the homework assignment. You must take all experimental data during your regularly scheduled lab period. If for some reason you must come to the lab outside your scheduled lab time, check with your lab instructor first so that arrangements can be made.

Selection of Experiments: There are 12 experiments set up in the laboratory, listed below. There are two independent set-ups of most experiments, and two people can work as partners (see discussion below), allowing a maximum of 4 people in a given section to work on most experiments at one time. Experiments are categorized as “basic” and “advanced.”

You are expected to complete six of these experiments during the semester. You may choose any set of experiments, subject to the condition that two must be from the advanced group. You should begin the semester with a basic experiment.

Reports and Writing: In Physics 2150, there will be more emphasis on writing than in Physics 1140, the introductory lab. The student is expected to compose clear statements of the objective, procedure, and conclusions for each experiment. This requirement reflects the fact that in science, communication is as important as laboratory work.

Grading The maximum grade you can receive per experiment is 10 points. Thus, the maximum number of points you can accumulate from six laboratory experiments in Physics

2150 is 60. If you choose the Compton experiment or the Millikan Oil Drop experiment, then it is possible to earn an additional 3 points. There is a sign up sheet for your laboratory section posted on one of the two interior doors along the north wall of the Physics 2150 lab area. Schedule yourself for a particular experiment by placing your name in the proper entry space for the relevant time period. Remember, allow yourself *two weeks* for all experiments except the Millikan and Compton experiments which require *three weeks*.

Schedule: The first lecture is on Tuesday, January 15, 2008. Lectures are held in Duane G125 at 4pm and all students in Physics 2150 should attend. The laboratory sections will meet beginning Thursday, January 17, 2008. There are 14 weeks in the Spring semester during which the Physics 2150 lab will be open. The last lab day is Tuesday, April 29, 2008.

After you have completed an experiment, your lab report should be turned in for grading. You should complete your experiments and submit them for grading on a regular basis until you have completed the six experiments as described above. Due dates are below:

- First report by 4:00pm Thursday, January 31, 2008
- Second report by 4:00pm Friday, February 22, 2008
- Third report by 4:00pm Friday, March 7, 2008
- Fourth report by 4:00pm Friday, March 21, 2008
- Fifth report by 4:00pm Friday, April 18, 2008
- Last report by 4:00pm Friday, May 2, 2008

The object of having a schedule is to have you become familiar with the grading system at an early stage and to provide feedback on how you are progressing in the course. These are definite deadlines and credit will be deducted for late reports (see Grading section below)! Reports should be placed in the “black box” by 4:00pm of the day they are due. Lab reports may be submitted for grading anytime before the above dates and you are encouraged to turn them in for grading on a regular basis, as they are completed, without waiting for deadlines.

Lectures: There will be five lectures given on Tuesdays in Duane G125 at 4pm, from January 15 to February 12, 2008. The lectures will cover the subjects in Chapters 5 through 9 and Chapter 11 of John Taylor’s book, “An Introduction to Error Analysis,” and will treat examples of error analysis as applied to specific Physics 2150 experiments. NOTE: Physics 2150 students should be familiar with the material contained in chapters 1 through 4 of this text. The purpose of the lectures will be to give you a basic introduction to experimental analysis. The quality of your lab reports and a significant component of your course grade will depend upon the way in which you analyze your data and assess the contribution of various errors.

Homework Assignment: A homework assignment related to the material presented in the lectures will be handed out at the last lecture. The assignment will consist of problems of the

types at the end of Chapters 5–9 and 11 of Taylor’s book “An Introduction to Error Analysis” but will often utilize concepts from many chapters. Your solutions to these problems are to be placed in the “black box” for grading. The homework should be worked individually and the deadline will be announced in class. The problems will be graded on the basis of 10 points toward your grade.

Grading: The letter grade you receive for this course is directly related to the number of points you receive on your laboratory reports and on the homework assignment. As stated previously, you can obtain a maximum of 60 points for your laboratory reports (plus up to 6 points for the 3 week experiments) and 10 points for the homework assignment. We try to have an average of 7 points out of 10 for each laboratory section for the laboratory reports. Generally, if you receive a score that puts you in the upper half of the class you will receive an A or B.

Late labs will be penalized on the following schedule:

- Less than one week late: One point penalty per weekday
- One to two weeks late: 5 points penalty
- Two weeks or more late: lab will not be accepted

Due to schedule constraints at the end of the semester, no labs will be accepted after May 5.

In order to receive an IW or an IF you must have certifiable excuse for not completing the course and you must make an explicit arrangement with your lecturer. If you are not doing the required work, drop the course. This advice is offered with your protection in mind. Should a problem arise which forces you to drop the course after the deadline, you will receive an F rather than an incomplete if you have a failing grade at the time.

Procedural Matters:

1. You will be provided a lab notebook with alternating white and yellow pages. Use the carbon paper to make a copy of all your work on the yellow sheets, which can be detached. The yellow sheets should be turned in with your lab report, along with any supplemental material or computer output.
2. Your lab notebook is the record of your work. Number all pages of your notebook, and do NOT remove any white pages. You will keep possession of your lab notebook outside of class, and you will be responsible for replacing it in the event of loss.
3. Each week your instructor will check with you during the lab to see if you have taken data. Your data *must* be initialed by your instructor. Your instructor will record: the date, the fact that you’ve taken data, your partners name, should you have one, and the experiment title. In the event you are working in the lab when no instructor is present, then have the lab coordinator, Jerry Leigh, initial your data.
4. Should your instructor fail to check your data during class, it is your responsibility to see that it is done before you take your lab book out of the lab. *A student who*

wishes to have an experiment graded which contains significant data that have not been properly signed by the instructor can expect a maximum grade of 8 out of 10 possible points on that experiment.

5. The work you hand in must be your own. Although it is entirely permissible for you to take data in partnership with another student, and to discuss your lab work with other students and instructors or anyone else, the work you present for grading must be the product of your own effort. *No two students should present identical (or only superficially different) analyses and conclusions.*
6. When you have completed an experiment and have the laboratory report written, leave your lab notebook in the “black box” in front of the lab coordinator’s office. Your experiment will be graded and returned to you in your laboratory section.
7. Upon the return of your lab report, read carefully through the experiment that has just been graded so that you can benefit in future reports from the instructor’s comments.

Preparation for Lab: Since the time in which you have access to the laboratory is limited, you should prepare yourself for the lab by reading and studying the experiment instructions before coming to class. There are video-tape presentations of the experiments which are available for viewing. Be sure to read any pertinent information posted near the experiment since some of the experiments have changed since the instructions were last revised during the Carter administration. Once you have decided on an experiment then you must sign up to reserve the experiment for yourself. If you have prepared for the experiment, but you have not reserved it ahead of time and it is already taken, then you will be asked to prepare for another experiment.

Lab Partners: You may perform the experiments either individually or with a partner. Groups larger than two are not permitted and only **two experiments may be done with the same partner**. If you work with a lab partner you should analyze the data separately. When working with a partner make sure you each have an equal share of the actual data taking responsibilities.

Supplies: Both the laboratory manual “Introductory Modern Physics Experiments,” and the lab notebook in which you will write laboratory reports, will be handed out free in the lab. These are provided by your student course fees. Therefore, the only text you will need to buy, if you do not already have a copy from Physics 1140, is “An Introduction to Error Analysis,” by John R. Taylor, University Science Books, Second Edition, 1997.

Equipment Calibration:

- Calibration for instruments used in all experiments can be treated as follows:

- Oscilloscopes:

$$\frac{\Delta V}{V} = 0.05$$

- Analog Voltmeters and Ammeters:

$$\frac{\Delta V}{V} = \frac{\Delta I}{I} = 0.03 \text{ unless otherwise stated.}$$

- Digital meters: Calibration uncertainty posted by the apparatus.

Organization of Lab Notebooks

1. Write on the white pages only, using the carbon paper to produce a copy on the yellow pages. Write in ink, and never erase anything! It's bad record-keeping, and it also causes the yellow copy to become illegible.
2. Number every page in the notebook (the white page and its copy should have the same number). Use the first page for a table of contents. Enter the title and page number of each experiment.
3. Never remove a (white) page.
4. The first thing written on any page (during data taking or write-up) is the date.
5. Write your name on the bottom edge of the notebook in large visible letters.
6. Date each page as it is used and date the start of each day's work.
7. Each lab period, record the name of your lab partner, or make an entry stating "no lab partner."
8. Primary Data: Primary data comprise all measured quantities that you collect in the course of an experiment. Such data should be recorded directly in your notebook; use a pen. Never erase primary data. If you make a mistake while taking a measurement, draw a line through the corresponding entry and write a brief explanatory comment. You must turn in your entire data set from your notebook with your report, and you must refer explicitly in your report to the page locations of the primary data.

Your Lab Report

The purpose of the record of an experiment is to explain clearly and concisely what you are trying to do, what you actually did, what you actually observed, and what you concluded from your observations. It is essential that your report be professionally presented: this means you should use a good word processing program, and you *must* write in clear, uncluttered, unambiguous English. Aside from this general requirement, there is no preferred format for reporting scientific/engineering results; as your career develops you will decide which reporting style works best for you. However, in Physics 2150 we require you structure your reports in the following form:

1. Experiment Title
2. Objective: - A one or two sentence description of the basic intent of the experiment. Your objective should be phrased in terms of what you intend to measure or what theory you will test, not as a statement about your personal learning.
3. Technique: Describe qualitatively in a paragraph or two the idea (or ideas if there are several distinct parts) of the experiment. What are the essential elements of the experiment that (in principle) will enable an effect to be observed or a quantity to be measured? There should be some physics in this section.

4. Apparatus: Include a labeled schematic drawing, indicating how the experiment works. Briefly describe the function of any unusual (special purpose) apparatus.
5. Procedure: This should consist of a summary of the process you followed while carrying out the experiment. Note unexpected occurrences. Discuss any special problems of measurement and the apparatus, and the approach you took to solve them. This section should contain enough detail to enable you to return after a six month hiatus and repeat the experiment without referring to the lab manual. Use your own words (don't simply paraphrase the related section in the lab manual). You should describe what you actually did in the first person.
6. Data Analysis and results: This is a key section of your report. The complete data set appears here; the data are analyzed and the sought-after experimental results are derived and reported with their associated experimental uncertainties. You should incorporate:
 - i) Plots of data or results (title, axis labels, units and scales). The use of tables is strongly recommended.
 - ii) Calculation of results. A complete, detailed numerical sample calculation of each type, including units and conversion factors must be included. If computer calculations are used, the printed computer output with complete identification of quantities written on it should be attached to this section and explicitly referred to at an appropriate point in your report.
 - iii) For each experimental result you report, a correct estimate of its uncertainty. The complete expression of a final result will consist of your "best value," the estimated uncertainty, and the proper units. The uncertainties should include statistical and systematic uncertainties separately.
7. Conclusions: A discussion which summarizes your results, compares them to accepted values, treats the basis for assigning errors if you choose not to discuss this in the previous section, etc. In addition to determining the difference with respect to the accepted value, you should determine the discrepancy (using the combined statistical and systematic uncertainty) and the significance of the discrepancy. If appropriate, you can mention the important source(s) of uncertainty and possible ways to improve on them. If you observed anything puzzling, or if you care to digress about possible hidden sources of error that you suspect might explain an unexpectedly large discrepancy, then do it here. Don't simply muse about possibilities; if you have suspicions, you should back them up with reasonable quantitative estimates. You can lose points by simply making unsubstantiated or incorrect guesses.
8. Things to avoid in writing your report:
 - Vagueness: All language should be precise. Avoid words like "approximately," "sort of," et cetera. You can lose points by simply making unsubstantiated or uninformative statements. *Never* attribute uncertainties to nondescript causes like "experimental error" or "equipment error" or that standby of pre-med physics labs, "human error." Statements like these will instantly cause your report to be marked down.
 - Nonscientific conclusions: You should report precisely worded scientific conclusions, *i.e.* "We found the mass of an electron to be $0.532 \pm 0.019 \text{ MeV}/c^2$ " or "We verified the hypothesis that electric charge is quantized." Do not include

opinions (“This lab was great,” “This was a hard lab”). Do not include personal statements such as “We learned about the Hall effect.”

- Blaming the equipment: Your task is to produce the best measurement possible given the equipment available. The limitations of the equipment should be treated scientifically, as terms in your uncertainty calculation. Do not use any section of the report for venting or complaining! A statement that, say, “the calibration of the galvanometer limits the precision of this measurement” is good; a statement that “this galvanometer should be replaced” or “We had to use a crummy galvanometer” is bad. (Note that this doesn’t mean you should shy away from commenting on how an experiment could be improved.)
- Confusion between “error” and “discrepancy:” When you compare your results with their related “accepted” values, be aware that the word “discrepancy” has a meaning different from “error.” In physics, “error” is generally a synonym for “uncertainty.” It’s purely a function of how precise your equipment and analysis are, not the answer you got or how far it is from the textbook value.
- Ungrammatical English: You’re expected to learn how to write professional reports. Good language is a critical aspect of this.
- Second-person writing: Do not write the procedure as a list of commands: you are writing a report, not a manual. The procedure should be a past-tense, first-person narrative of what *you* did.
- Excessive computer output: MathCAD can easily perform a repetitive calculation on a large set of data and report all the individual steps for each data point. This is completely useless and renders a lab report unreadable. You should give a detailed *explanation* of the basic calculation for a single data point, then give the result in compact table form for all the data points.

Physics 2150 Experiments:

The list of experiments follows, with advanced experiments indicated by an asterisk. At least two of your six experiments must be advanced. However, these are (surprise!) more difficult and should not be attempted as the first experiment of the semester.

| No. | Name | Weeks |
|-------|--|-------|
| 1. | Charge-to-Mass Ratio of the Electron | 2 |
| * 2. | The Millikan Oil Drop Experiment | 3 |
| 3. | Michelson’s Interferometer | 2 |
| 4. | Rest Mass of the K^0 Meson | 2 |
| 5. | The Photoelectric Effect | 2 |
| * 6. | The Compton Effect | 3 |
| * 7. | Electron Diffraction from Crystals | 2 |
| 8. | Emission Spectra and the Balmer Series | 2 |
| 9. | The Franck-Hertz Experiment | 2 |
| * 10. | Radioactive Decay of ^{220}Rn | 2 |
| 11. | Magnetic Torque | 2 |
| * 12. | The Hall Effect | 2 |

* Advanced experiment

Hints for Specific Experiments:

Remember to look for additional notes or values posted on or near the apparatus.

- E-1** e/m (2 setups)- Make several independent measurements of I_o at the lowest voltage.
- E-2** Millikan (2 setups) - Do not attempt this experiment as your first.
- E-3** Michelson (2 setups) - Take precautions against micrometer backlash in this experiment.
- E-5** Photoelectric Effect (2 setups) - you should use the least-squares straight line fitting routine to analyze your calibration and voltage vs frequency data.
- E-6** Compton Effect (single setup) - This is an excellent 3 week experiment.
- E-7** Diffraction from Crystals (single setup) - Use nominal tube voltages of 6, 8, and 10 kV. The actual value to be used in computations is posted on the apparatus.
- E-8** Emission Spectra (2 setups) - This is the most precise experiment if done with care. In addition to determining an uncertainty in h based on the four “measured” values of h , you should determine expected uncertainty in h_{meas} based on your calibration curve and your uncertainty in determining the refraction angles.
- E-9** Franck-Hertz (2 setups) - Draw a sketch of a typical “scope” pattern for both parts I and II. Clearly identify what is being plotted. In part I record the voltmeter readings corresponding to each current peak. Then take the differences between neighbor peak voltage values.
- E-10** Thorium Decay (single setup) - You should use Mathcad fitting routines to assist you in analyzing data. Remember rules for Poisson statistics to get uncertainties.
- E-11** Magnetic Torque (2 setups). No special hints.
- E-12** Hall Effect (one setup) - You may observe some evidence of a non-linear V_{Hall} vs B dependence at higher B values. This is to be expected. You may wish to use the least squares routine to determine R_H . If you do not observe significant non-linear behavior at high B , then you should sit back and think before leaping into analysis.

History of the development of modern physics

bold: in this lab; *italic:* theory.

1879 Stefan radiation law

1879 **Hall effect**

1893 Wien radiation law

1885 **Balmer series**

1887 Michelson Morley experiment

1887 *Electromagnetic waves (Hertz)*

- 1896 **Radioactive decay (Becquerel)**
- 1897 **Thomson e/m**
- 1900 *Planck quantum hypothesis*
- 1900 **Photoelectric effect (Lenard, Millikan)**
- 1905 *Einstein quantization of light*
- 1905 *Einstein special relativity*
- 1909 **Millikan oil drop**
- 1911 Nuclear atom (Rutherford)
- 1913 *Bohr model*
- 1914 **Franck-Hertz**
- 1923 **Compton effect**
- 1924 *deBroglie hypothesis*
- 1925 **Davisson-Germer electron diffraction**
- 1926 *Quantum mechanics (Schrödinger, Heisenberg)*
- 1947 **Discovery of neutral kaon**

Other policies set by the University

Disability issues: If you qualify for accommodations because of a disability, please submit to me a letter from Disability Services in a timely manner so that your needs may be addressed. Disability Services determines accommodations based on documented disabilities. Contact: 303-492-8671, Willard 322, and <http://www.colorado.edu/disabilityservices>.

Religious observances: Campus policy regarding religious observances requires that faculty make every effort to reasonably and fairly deal with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. See full details at http://www.colorado.edu/policies/fac_relig.html. Please contact me if you will miss a lecture or laboratory session due to a religious observance to arrange an appropriate remedy.

Classroom behavior: Students and faculty each have responsibility for maintaining an appropriate learning environment. Students who fail to adhere to such behavioral standards may be subject to discipline. Faculty have the professional responsibility to treat all students with understanding, dignity and respect, to guide classroom discussion and to set reasonable limits on the manner in which they and their students express opinions. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, culture, religion, politics, sexual orientation, gender variance, and nationalities. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. See policies at <http://www.colorado.edu/policies/classbehavior.html> and http://www.colorado.edu/studentaffairs/judicialaffairs/code.html#student_code.

Honor code: All students of the University of Colorado at Boulder are responsible for knowing and adhering to the academic integrity policy of this institution. Violations of this policy may include: cheating, plagiarism, aid of academic dishonesty, fabrication, lying, bribery, and threatening behavior. All incidents of academic misconduct shall be reported to the Honor Code Council (honor@colorado.edu; 303-725-2273). Students who are found to be in violation of the academic integrity policy will be subject to both academic sanctions from the faculty member and non-academic sanctions (including but not limited to university probation, suspension, or expulsion). Other information on the Honor Code can be found at <http://www.colorado.edu/policies/honor.html> and <http://www.colorado.edu/academics/honorcode>.

Discrimination & sexual harassment: The University of Colorado at Boulder policy on Discrimination and Harassment <http://www.colorado.edu/policies/discrimination.html>, the University of Colorado policy on Sexual Harassment and the University of Colorado policy on Amorous Relationships applies to all students, staff and faculty. Any student, staff or faculty member who believes s/he has been the subject of discrimination or harassment based upon race, color, national origin, sex, age, disability, religion, sexual orientation, or veteran status should contact the Office of Discrimination and Harassment (ODH) at 303-492-2127 or the Office of Judicial Affairs at 303-492-5550. Information about the ODH and the campus resources available to assist individuals regarding discrimination or harassment can be obtained at <http://www.colorado.edu/odh>.