Advanced Laboratory Physics 302 / 318
Department of Physics
Case Western Reserve University
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Instructors:

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The objectives of this laboratory course are to:

- Carry out complex experiments independently, with minimal prepared instructions.
- Measure and quantitatively characterize physical phenomena.
- Learn physics in a laboratory setting.
- Improve laboratory skills in planning, trouble-shooting, documenting and carrying out measurements.
- Improve ability to analyze and rigorously interpret scientific data, including sources of statistical and/or systematic error.
- Communicate laboratory work orally and in concise, clear writing.

In this course you will undertake independent experimentation with research-grade instrumentation and computer-aided data acquisition and control. You will practice thinking about and solving real problems in order to obtain quantitative results. You are expected to be critical in evaluating your data and to develop a professional manner in recording your work and communicating your ideas. Along the way you will learn new measurement techniques and physics concepts.

Over the course of the semester each student will perform three experiments, each lasting 9 to 10 laboratory periods, that is, 5 weeks for experiment 1, and 4.5 weeks for experiments 2 and 3. You will work closely with your partner on the execution of the experiment and gathering of data, **but should work independently on data analysis and interpretation.** Some conferring and sharing of ideas is appropriate and natural during the execution and analysis phases, but you will get more from the course if you grapple with the data independently, as on problem sets for lecture courses. The written report must be prepared independently – further details are below.

At the completion of the experiment, remove personal data and experiment control files from your lab computer and return all cabling, tools, etc. to the tool chest, nearby drawers, wall racks, etc., so that the next group can make a fresh start in an orderly work environment. Power cords, GPIB cables, and custom dedicated cables may be left in place – ask the instructors if you are uncertain.

During experiments 2 and 3, your apparatus may be in use on Monday, Wednesday and Friday mornings by students in the graduate lab course. When this is the case (consult the instructor) some communication between you and the other groups will go a long way to minimizing confusion. **Keep careful notes of cabling arrangements and instrument settings and be prepared to efficiently review them at the beginning of each period.**

Instruction manuals and other information in the lab files are NOT to be taken from the laboratory except briefly to make photocopies. There are some books and a folder of photocopied references in Room 314. Be considerate of your classmates and return the references to the folder. Sign out any books taken out of the laboratory other than to the copy room. A number of books have not been returned in the past…

Some of the equipment you are using is easy to damage if misused. In most cases, problems can be avoided if sufficient time is taken to read appropriate manuals and be alert to unexpected behavior, e.g., excessive heating, cooling, current draw, event rates, sparking, etc. Please let instructors know if equipment appears to be malfunctioning. Check with the instructors if you plan to leave equipment running overnight for extended data runs.

You are free to store program and data files on the hard disks under your own directory. It would be wise to keep copies of your files by putting them on a "thumb drive" or copying to your own computer over the network. The equipment is shared by the undergraduate and graduate laboratory courses, including the computers so keep copy of your interfacing program that cannot be altered by others. At the end of the experiment, remove your data, control and other files from the computer.

RESEARCH NOTEBOOK AND REPORTS

Information pertaining to the performance of the experiment **must be written in a bound notebook** by each student. This notebook is not a finished document; it is a continuing, working record from which you should be able to reconstruct just what you did in the lab. It is a good practice to write everything in the notebook, even scribbles or raw ideas that you are developing since scraps of paper tend to get lost. To be effective, it is not practical to keep a notebook that is free of errors, missteps, cross-outs, etc, but it should be neat enough so you can follow what you did. Keep in mind that you may be referring back to information that is weeks old; don't rely on your memory – an isolated number, equation, or filename may seem clear when you are writing it, only to appear obscure in hindsight. Include brief sentences and annotations to yourself to explain what you are doing. The notebook is also a useful place to write out brief plans of what you are going to do, and can be invaluable in picking up where you have left off in the previous lab period. To combat the urge to be overly neat or correct (a problem for some!) and to avoid erasing information that may be useful later, all notebook entries should be in pen.

Data that is acquired through a computer need not be transcribed into the notebook but a record of what you did, the date and time, and the conditions under which the data were taken should be in the notebook, along with the name of the file where it is stored.

The notebook is to be examined by the instructor following the grading of the written reports. Each student should keep their own notebook and is required to analyze the data and write a report, independently. You can consult your partner, reason out issues, and generally collaborate, but both partners must contribute significantly to all aspects of the experiment and do independent analysis and reporting.

Reports are to be submitted electronically in pdf format (directions will be given at the appropriate time), unless otherwise instructed. Reports submitted after the deadline will have points deducted. Use Word or LaTeX or similar word-processor programs to write up your report.

The report should follow the style and content that is used in physics research journals, for which your references may provide an example. If in doubt, consult the AIP Style Manual, which is free and online, and easily found with a Google search. In the great debate over active versus passive voice you may choose for yourself what sounds best to you but maintain a consistent style. Most contemporary journal articles in experimental physics are written in the active voice.

Keep in mind the report is the final product of your research. It need not be long, but it must be comprehensive and contain the physics that you wish others to learn from you. You should write assuming a readership with a training level in physics comparable to your own but with no specific knowledge of the specific phenomena you are studying. The report must be clearly written and follow accepted rules for grammar and spelling. **Note that the only recommended text for the course is Strunk and White's "The Elements of Style".** This is a grammar book and should thus convey to you the importance that your instructors places on well written prose. Carefully proofread your writing and allow time for revisions. Poor writing, typos, and a choppy narrative will greatly detract from high quality laboratory and analysis work.

The report should contain the following sections:

An **abstract** that summarizes the report in a half page or less. The abstract should report high-level numerical findings, including notable discrepancies with accepted values. The abstract is completely distinct from the main report, and is not meant to replace the introduction. Likewise, the main report should "start from scratch" and not read as a continuation of the abstract.

An **introduction** that concisely describes the nature of the physical phenomena that is treated in the experiment and summarizes the theory. Do not copy derivations of formulas out of other books and articles; merely state the relevant equation, defining all quantities, and give a reference to the source. The introduction is not to be a description of your experiment or results, but it should bring the reader to understand the theory behind your experiment and the reason for doing it.

A section, or sections, presenting a description of the **apparatus and procedure** used. The level of detail should be modest – you are not attempting to write an instruction manual for the experiment, but rather providing enough detail so that the reader can understand the tools, methods and procedures that form the basis of your measurement. Likewise, this part of the report is not a "core dump" of your lab notebook. Present the information in a logical order, not necessarily chronologically. Your narrative should make clear to the reader not just what you are presenting but also how it fits into the overall story. Avoid a disjointed presentation of facts which you only bring together; use context to your advantage in communicating to the reader.

A section, or sections, presenting the **results** and their interpretation. Graphical presentation is encouraged. An error estimate should always accompany a numerical result. The estimate should be determined by objective and rigorous error analysis techniques wherever possible. Discuss sources of systematic errors as quantitatively as possible; refrain from speculations if they cannot be supported with quantitative estimates. Unsupported or presumed sources of error will greatly weaken your report; it is far better to accept and describe the limitations of what you've measured with a high degree of rigor than to draw unsupported conclusions. It is assumed that students in this course are familiar with error analysis methods at the level of Bevington: Data Reduction and Error Analysis for the Physical Sciences (McGraw Hill, 1969)

A list of **references**.

All figures must be numbered and referred to in the text. All figures must have captions that provide a sentence or two explaining the content of the figure. Most material and all detailed explanations should be in the main text. **Appendices** are for long calculations that would disrupt the flow of the text. Computer programs are not part of the report. If you use figure from another source, include an attribution in the caption (eg, "Reproduced from reference [7]", "Annotated based on figure 5 from reference [2]", etc.)

Written material in the report must be the original work of the individual student submitting the report. Graphs, diagrams and tables may be shared between partners working on the experiment (but not with students who have performed the experiment at other times).

GRADING POLICY

Report due dates will be distributed by email. For your planning purposes, reports will typically be due about a week following the completion of the experiment. **Plan accordingly.**

The grade received for an experiment will be based on two criteria: how well you performed as a physicist and how well you communicated the results. To elaborate on the first of these two points, the task of an experimental physicist is to perform measurements designed to test a physical model and to interpret the results in terms of theory. It involves an intimate connection between an understanding of physical theory, the actions one takes in the laboratory, and the interpretation of the results. Any comparison of data and theory is incomplete without an assessment of the limitations of the measurements, that is, statistical and systematic errors in the measurements. A student who acquires a lot of data but who fails to understand its significance (or lack of significance) can expect a low grade in the experiment, no matter how aesthetically pleasing the report may be.

The total grade for an experiment will be 60 points, distributed as follows:

> 20 points: Comprehension of physical phenomena and laboratory techniques as evinced by the student's work in the lab, ongoing discussions of the experiment with the instructors, and the overall quality of the results.
>
> 20 points: Contents of report, introductory material, presentation of data, and validity of data analysis (including statistical and systematic errors), and conclusions.
>
> 20 points: Expository style, writing quality, clarity and form of report.

SAFETY REQUIREMENTS

General Safety Issues

You have an obligation to be aware of hazards that exist for your experiment and to carry out the appropriate precautionary actions. EVEN IF YOUR INSTRUCTOR ALLOWS YOU TO WORK IN THE LABORATORY OUTSIDE OF SCHEDULED HOURS, YOU MAY NOT WORK ALONE. OSHA places legal restrictions on our facilities and procedures. Some common sense rules follow, but ongoing attention on your part is necessary.

No food or beverages are to be brought into the laboratories. This restriction is good practice, required by the CWRU Department of Occupational and Environmental Safety (D.O.E.S.) and mandated by the Nuclear Regulatory Commission in the case of those rooms that are marked "Radioactive Materials". Students violating these prohibitions will not be permitted to work in the laboratory outside of normal class hours. If you require sustenance, it must taken outside the lab.

Some experiments in this laboratory involve the use of radioactive sources. Many of these sources are relatively weak (less than 10 microcuries) and are sealed in plastic. Under our current procedures these sealed sources are the only ones that students are permitted to handle. The following rules apply to the use of these sources:

1) The sources are to be used in Room 314B. Sources may be used in Room 314 with the instructor's permission. Under no circumstances are they to be taken outside Room 314.

2) Sources are to be checked out from the instructor when needed and returned no later than the end of the lab period. An exception is made if and when long data-taking runs are required, eg, for the Compton scattering experiment.

3) All possible preparatory work that can be done before obtaining the sources should be done.

4) Do not place any mechanical stress on the sources. They should not be held in place by clamps nor should any weight be placed on them.

5) Always reduce your exposure to radiation from the sources as much as possible. Minimize the amount of time that you handle them. Store sources behind lead bricks for shielding. When using a source in an experiment, shield as much radiation from the source as possible, consistent with performing the experiment.

6) If any mechanical failures of a source is observed (cracks, for example) notify the instructor at once and do not touch the source.

7) Prior to signing out sources for use outside of normal hours, a student must take Radiation Safety Training offered by D.O.E.S. Check their website for scheduling: http://does.cwru.edu.

The only two intense sources in the lab are the americium-beryllium neutron source and the high activity Cs-137 source used for the Compton scattering experiment. Under no circumstances is theCs-137 source to be dismantled (with the exception of the brass cover plate and cylindrical lead plug).

When using any source, its location must be labeled with one of the magenta on yellow "Radioactive Material" warning signs. These signs are kept in the radioactive sources cabinet in Room 314B. The sign must be removed when a source is no longer present.

Wash hands after handling lead (Pb) shielding bricks.

Electrical Safety

Voltages in the l00-l0,000 volt range are more dangerous than those above or below because your muscles contract and you are unable to "let go". Around such hazards use only one hand near the equipment to hold probes and other tools. Voltages of l-3 kV are common to operate photomultiplier tubes (PMTs). Keep high voltage (HV) supplies off when changing connections. Turn HV supplies to "standby" whenever changing ranges or polarity on them. This will avoid damage to preamplifiers.

Mechanical Safety

When setting up an experiment, use proper clamps and supports so that the apparatus is stable and would not fall if you accidentally bump it or trip on a cable. Route cables along the back and around equipment, never across an aisle or dangling from lab tables.

Cryogenic

Safety rules for handling cryogenic fluids are in the DOES Safety Manuals in room 314. You should be thoroughly familiar with these instructions before handling liquid nitrogen and liquid helium. With regard to LHe, you must first perform a transfer under the supervision of the instructor before attempting one on your own.

High Magnetic Fields

Safety rules for the use of high magnetic fields are posted at the appropriate stations and are in theDOES Safety Manuals in room 314. Never use the superconducting magnet in the continuous (or "persistent") mode without help from the instructor.

The potentially most dangerous situation is a quench of the 2D Hall experiment magnet at high current. If the magnet quenches, a voltage $V = L\, dI/dt$ appears across the magnet terminals where $L = 0.4$ H is the inductance of the magnet. We have taken precautions and this condition should not arise. However, any student working on this experiment must read and comply with the safety protocol.

Optical Safety

Be careful of eye damage, especially by a laser in a darkened room. Be aware that various arc lamps and open arcs emit damaging ultraviolet light that is not necessarily absorbed by plasticshields or plastic lens eye glasses. Protocol for using lasers is included in the DOES manual.

Chemical Safety

Chemicals used in this laboratory are regulated by OSHA. Use chemicals only in the hood in Room 311. All containers holding chemicals must be marked to indicate their contents. Supply containers should bear warning labels that indicate the type and degree of the hazards associated with the contents. Flammable liquids should be stored in the yellow, fireproof "Flammable Materials" cabinet located beside the hood. Other chemicals should be stored under the hood. Used chemicals should be stored in a sealed container labeled "Used" along with the name of thechemical.

Material Safety Data Sheets (MSDS) can be accessed on the Web via the DOES web site (go to http://does.cwru.edu and click on "Chemical Safety"). MSDS sheets for most chemicals stored in Room 311 are in a manila envelope attached to the side of the hood. You must study them to familiarize yourself with the hazards and precautions associated with any chemicals that you use.