

Lab Practices, Precautions, Notebooks and Reports

Precautions

- **No food or drink** are permitted in the lab.
- **DO NOT LOOK DIRECTLY INTO ANY LASER BEAM OR ANY SPECULAR REFLECTION OF A LASER BEAM.** The lasers in the lab put out 2 mW, more than needed for permanent eye damage.
- **DO NOT touch mirror surfaces, or any optical surface.** If a component is dirty, please consult the Lab Manager.
- In the diffraction experiment (Exp. 5) do not focus the *unattenuated* (i.e., not dimmed with a polarizer) laser light to a point on the linear array. Focus the beam on an index card in place of the array, then remove the card after dimming the beam.
- Use special care with the spatial filter pinholes (1-d diffraction experiments use these).
- The curtains around each lab station can easily be pulled out of their tracks. To avoid this, gather the curtain in small bunches and pull a small portion of the curtain at any one time
- Avoid leaning on optical tables.
- Mirrors, lenses should be covered when experiments are finished. When in doubt, ASK FOR INSTRUCTIONS.

Laboratory Work

Sign in and out on sheets provided with each experiment. Indicate any problems with the equipment so that it can be repaired promptly for use by the next group.

Suggestion: While in lab, visit the set-up for your choice of next week's experiment. That will help you understand the experiment instructions and get started quickly.

Notebooks

There are no formal reports in the usual sense. Experiment write-ups will be in the form of lab notebooks. There is a strict format for notebooks. You should obtain the following materials:

- Two cardboard "expansion report" covers. These are cardboard covers that allow hole-punched papers to be assembled into a bound notebook. An example purchased at the University Bookstore is the Oxford Esselte model 12905 (\$1.95). You will need two of these covers because you will need to be able to use one of the notebooks while the other is being graded.
- One (or more) pad(s) of green or tan "engineering" paper. This is the paper that has graph ruling on the back side of each sheet. The same type of paper is used in the electronics labs (physics 334).
- A package of "insertable notebook dividers". These are the notebook dividers that have the clear plastic tabs you can slip a label into.

Your reports will consist of the notes and drawings you make in lab (on the engineering paper), computer, plotter, or oscilloscope printouts (depending on the lab), and typed written material (to be described below) assembled into the report covers. Each lab report should be separated by one of the notebook dividers.

Each report should contain the following sections *in this order*:

1. In-class notes and data

The notes taken in class should conform to proper scientific record-keeping practices. This means that

- Each page should be numbered and dated with the day on which the work was done.
- Notes should be recorded in pen. Errors should be crossed out with a line or two. Do not use white-out, and *do not recopy your original notes*.
- Notes should be kept neatly. Give yourself space on the page. Lay out tables with columns so that they are easy to fill in and to read.
- ***Data should be recorded with proper, stated units.*** Failure to follow consistent unit usage is one of the main causes of incorrect work.
- Relevant conditions pertaining to various parts of the experiment are clearly stated, for example, light source, apertures, distances, and so forth (depending on the experiment).
- Specific operations or procedures that would be different from time to time are described in a few sentences.

The above list is neither complete nor minimal: what you record and how will depend on your experiment. ***The important point is to record the information one would need to reproduce your results.***

The first page of the report should have (1) the name of the experiment, (2) the names of all of the partners, and (3) the dates beginning and ending the experiment. *Do not make a cover sheet.*

Your in-class notes should also contain **annotated diagrams** of the apparatus. These diagrams (there may be one or more, depending on your experiment) should be ***original***: drawn by you (not drawn by your partner and not copied directly from the instructions); they should *clearly* show all of the light paths among the various components; they should *clearly* indicate any physical characteristics important to the experiment. Complex sub-components of the apparatus should have their own diagrams and annotations.

Annotations are important! The annotations should be copious and indicate the use and function of the various components of the apparatus. The annotations may be written directly on the diagrams or on a separate page.

The annotated diagram serves the purpose of a description of the “procedure” used in the experiment. *Do not write a step-by-step procedure that mimics the steps given in the instructions.* However, it is OK to write a few sentences on the overall operation of the experimental apparatus.

All records of data collection should contain an estimate of the uncertainty of the raw data if appropriate. In general, a few readings of a particular type of measurement should be used to estimate the reproducibility of that measurement. The usual rules apply: calculate a mean and a standard deviation. If the readings do not vary at all, the minimum uncertainty is taken to be equal to the least digit of the measuring device.

Every report must include a copy of the raw data. It is your responsibility to make copies of X-Y graphs, computer printouts or other data collected by the group as a whole. At least one person in the group should include the original data in his or her notebook.

2. Analysis of results

It is a good idea to run quick preliminary analysis of your data while you do the experiment. This helps prevent major errors in data recording as well as making clear any calibrations that may need to be done. Preliminary analysis should be noted as such. In general, however, most analysis will be done after data collection is over.

The specifics of the analysis will vary according to the experiment, but the following general guidelines pertain:

Graphs should take up at least a half-page, with a plot area filling most of that space. The axes should be labeled with the specific quantity and *its unit*. If the quantity does not have a unit or is arbitrary, make sure that is clear. The data set should fill most of the area of the graph, unless it is important to show its relationship to some point on the coordinate axes, such as zero.

Data points should *not* be connected by line segments. Data points *should* have error bars indicating the uncertainty of the data. Any lines drawn on the data sets should represent fits to the data or theoretical predictions. If more than one thing is plotted on a graph, a legend should be provided.

Spreadsheets should contain clear column and row headings and a description of what is being calculated. Any cells outside of the main tables should be annotated so that the meaning of their contents is obvious.

Do not assume the grader can decipher your spreadsheet by reading the numbers themselves.

Uncertainty calculations should be clearly laid out. Indicate how you feed in various uncertainties into your calculations and whether you have chosen to ignore the uncertainty in some quantities. You will need this information when you discuss the causes of uncertainty in your written portion.

Computer programs should be printed out and included in your report. Give comments within your code or else written on the paper stating what each part of the program does. In a computer program the variable names should be short but meaningful, for example: `refractionIndAir`, `speedLight`, `focalLeng2`, or `slitWidth3`. The names should be identified with hardware components or measured or derived quantities.

Formulas that are used to calculate results with spreadsheets, programs or even by hand should be written on or near the relevant parts of the report. Any formulas should be defined: state what they are for, and define any variable that may be unclear.

Final results should be clearly placed and labeled and should be stated using correct significant digits with uncertainty and with correct units. If a result does not have units, state that it is “unitless”. An effort should be made to compare your results to other results, if they may be found. You may need to run a literature search to determine whether your result agrees with a previously determined value. You are not absolved of needing to compare your results to the literature just because such values may not be stated in the experiment instructions. When you find a result to compare to, you must cite the source with enough information so that anyone could locate it. Many measurements are of known quantities (such as the speed of light), whereas other measurements may depend on apparatus specifics.

In either case, **you *must* assess the quality of your results and determine whether you think they are reasonable or not, based upon a coherent physical argument.**

Systematic error should be addressed. There is no general method for determining systematic error. Sometimes it may be evident because your result does not agree with a well-known result within the random uncertainty. Sometimes there is a trend in the data that does not conform to expectations, for example, you might expect different samples to give the same results but instead you see that the results differ significantly. Sometimes there is no clear indication of systematic error at all—in this case the experiment really does work well, or the random uncertainty is much larger than any disagreement with expectation.

Answers to specific exercises should be completed. A number of the experiment write-ups have explicitly stated exercises in the form of questions or problems to solve. Some questions will cover background material, and may be done independently of the experiment. Others will pertain to the experiment, and not be answerable until after you have completed it.

3. Written portion

The final part of the report should be typed. The written material will include two parts:

Part 1: Summary abstract *Please label each section*

Typical length: 1 - 2 pages.

The first paragraph should state the purpose of the experiment in one or a few sentences. The *purpose* of the experiment is distinct from the method or apparatus used, rather it is the overall goal(s) or motivation.

The second paragraph should describe the method(s) used to carry out the measurements in a general way, with specific details included according to whether they are particularly important to interpreting the final results. The description should not go into trivial details.

The third paragraph should state the main results of the experiment, including all important numerical results. Numerical results should be presented with correct significant digits, uncertainty, and units.

The fourth paragraph should assess the success of the experiment itself. That means, results should be compared to literature values (if available), and systematic error should be addressed: is there a systematic error, and if so, how do you know? If systematic error is present, what do you believe it arises from, and how might you check that hypothesis?

Part 2: Discussion of uncertainty (if appropriate)

Typical length: 1/2-1 page.

The discussion of uncertainty should be a critical assessment of the sources of uncertainty in your results. you need to provide a *sensible, logical, physical argument based upon your own experiment*, not unsupported speculation. In other words, do not cite a source of uncertainty that you cannot prove is evident in your results.

Treat *random uncertainty* first. To start, make sure you have included all parameters in your uncertainty analysis, at least insofar as you consider whether they contribute importantly to the final value of your uncertainty, *as presented in the summary abstract*. Then, after you have propagated the uncertainty using the usual techniques, check your percentage uncertainty against the percentage uncertainty of each of the parts that went into this final value, and determine the most important contributors. Finally, discuss why these factors are the most important. (It may be useful to make a table of the various contributors to your uncertainty to help you sort them out, but this should not appear in your written discussion.)

After you have analyzed the random uncertainties, discuss possible systematic error. A systematic error certainly exists if the expected value of what you measure lies outside the range of accepted values of well-known quantities, although there may be other indicators of systematic errors. It should be clear whether your result more than about 2 sigma away from what you wanted. If this is true, then you need to decide what aspect of the apparatus or method could cause this effect. Be qualitative in your discussion first, for example, could a change in the gain of some amp or a shift in a calibration factor account for the discrepancy? Then be quantitative: how much of a change in that parameter is necessary to cause the change in the result that you see? Is such a change a reasonable possibility? If it is, you have a good candidate for a “source of systematic uncertainty”; if not, you should keep looking.

Academic Honesty

Students working together are encouraged to discuss their analysis and results with each other (and with other students) but must independently generate their own written reports.

The way in which you estimate your uncertainties must ALWAYS be clearly shown. If you copy text from the lab instructions, you are wasting space. You are asked to give a brief statement in the introduction; this means in *YOUR* words.

When you quote a result that is not in many optics or physics texts, you need to give a citation, whether you obtain the results from the Internet, a book, or a friend. Best of all is to show how you got the result. For example, the definition of reduced mass needed for experiment 2 is in many texts, but how you use the wavelength splitting you measure to deduce the mass ratio of deuterium to hydrogen is something that needs to be explained. If you copy something from the Internet, give the complete link for the source. If you copy from a book, give the author(s), title, and year published.

Plagiarism is an offense punishable by expulsion from the university. If you don't know the meaning of the word plagiarism you might wish to look at

<http://depts.washington.edu/grading/issue1/honesty.htm>

or

<http://www.engr.washington.edu/org/processes/miscpolicy.htm>

To quote from the second:

ALWAYS make very clear reference to the source of the material you use and put the material taken in "quotation marks," no matter where you find it. This is perfectly acceptable and legitimate. DO NOT try to rewrite or change another person's work and pass it off as your own—this is very difficult to do and is easily detected. You can always use published writings as long as you give a formal reference and acknowledgment of the source. If the information comes from a conversation with a professor or another student, give their name and recognition that it is their thought.

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