# Some General Information for Intermediate and Advanced Laboratory

## Lab Reports

**The lab notebook**.
You should have a lab notebook that you keep with you while you perform the labs. There are many small, but important pieces of information that you should keep track of to help you when it comes time to do the analysis of your data and to write your lab report. For example, if you use a Labview "virtual instrument" interface to take data you should make a note of what the filename was (it will be something with the extension .vi). Settings on knobs and dials of your equipment or anything that you think may be important if you had to redo the experiment. Not all of this information will need to go into the lab report, but you may need information that you do not initially realize. This is especially true if you have an unexpected result or if you want to test an idea you have concerning a systematic error.

Most labs begin with some exploratory data taking. This is preliminary data that help you understand the apparatus and make sure that it is working. Along with this you should do some simple "back of the envelope" calculations (only in this case you should write them in your notebook and not on an envelope). The purpose of these short calculations is to get a feel for the magnitudes and units of the quantities you are going to be working with and to trace though how you are going to get from the raw data to your final result. If something is not adding up you should speak with the instructor and find out what is wrong. You don't want to take large quantities of data only to discover later that you have one component of the experiment that is broken or one that is not connected properly. For example, if you are doing the Hall effect experiment all you need to do is take a couple of measurements of the Hall voltage at different values of the magnetic field and drift current and you can get an estimate of the Hall coefficient. In doing this you will need to recognize the physical units of measurement involved. It is best to stick with MKSA units, but there are some exceptions (For example, the electron-volt "eV" is a common alternative to the Joule as an energy unit).

You should include your own sketch of the apparatus. The sketch is a diagram which shows the basic components used in the experiment. It should be possible from the sketch to determine what you are measuring and what equipment you are using to measure it. You will need a sketch in your lab report. A sketch is a schematic and not a photograph. The point is to show the functional relations of the various pieces of equipment used and not their front panels. The idea is to avoid any unnecessary complications in your description.

In some cases you will have large data files taken on the computer. In some cases you will be able to write your data by hand into your notebook. Even in the case of computer data acquisition you should make some readings directly from the meters and write them into your lab notebook so that you can check these numbers against what is written in the data files. Sometimes the units of the numbers in the computer data files may not be what you are expecting. If you make data files while you are performing an experiment you should make a note of what the file names are and of the directory in which they are being stored together with notes helping you to remember which experimental conditions correspond to each file.  You should also record the date on which the data were taken.

You should use ink to make entries in your notebook.  Normally, it is a good idea not to destroy data even if you think that they are "bad".  Sometimes you will find this data useful in testing an idea later on.  To avoid confusion you can put a line through a table of data that you know are not correct and make a note of what went wrong.

In every experiment you will need to understand the "propagation of errors" from the uncertainties in the raw data to the uncertainties in the derived quantities.  For example, in the photoelectric effect experiment you have uncertainties in the stopping voltage that results in zero current and in the wavelength of the incident photons.  These uncertainties will relate to an uncertainty in the determination of Planck's constant and of the work-function of the photo-cathode though the equations which describe the photoelectric effect.  All propagation of error calculations should be done neatly in your lab notebook and you will need them when you write your lab report.

**Analysis of data**

In addition to back-of-the-envelope calculations and the propagation of error calculations you will have to analyze your experimental data.  To do this it is very useful to use a computer program (this is also helpful for plotting your results). Any computer program that you want to use for this is fine as long as you can make it clear how you have performed the calculations (it should be clearly indicated how the computations were done both in your notebook and in your lab report).  For your convenience we have an Excel spreadsheet program called Polyfit that you can download from the course web page and modify as you like.  Use of computers is essential in experimental work both for data taking as well as for analysis.  Appendix B in *Experiments in Modern Physics* is a short guide to using the MATLAB language.

**The lab report**

Although you will work in groups of two or possibly three, **it is important that each student write their own lab report**.  There are some things that you will only see when you try to put them in your own words.  Lab write-ups are limited to 5 pages maximum of text not counting graphs and appendices.  Any graphs or tables discussed in the text should have a number and should be included in the text.  Supplementary plots may be included in an appendix.  Data analysis tables and calculations should be in an appendix (no page limit).  Writing a clear and concise lab report is actually more difficult than writing a long rambling document.  The majority of problems arise when students wait until a day or two before the lab is due to analyze the data and then discover that there is a major problem that requires more data.  Most labs cannot be done in a single session and they cannot be analyzed in a single day.

The text of your lab report should be much like the draft of a scientific paper that you would submit for publication in a journal.

Basic Structure of the Report: Limit yourself to 5 typed pages of text.

The basic components of the report are as follows:

a. Abstract: 100 words or less in which you tell what you did and what you found. If you measured some quantity (say for example the Hall constant) then you should state it here *along with your error estimate and the appropriate units*.

b. Theory/Introduction: This section provides a **brief** description of the theory related to the experiment. All the theory you need will be found in the course text or in the lab manual. However, you may want to use other references from the library. By all means avoid derivations of standard formulas (this could go in an appendix). However, you will need to state the physical laws and principles that are the starting point for the experiment.

c. Experimental details: This is a description of the experiment. You should have a simple sketch of the apparatus, and a simple explanation of the concept of the experiment. Every experiment is designed to get at some physical effect. There is always a strategy of some kind. You need to describe that strategy here.

d. Results and analysis: Here is where you state what your results are. In most labs you have more than one result and each one has an associated error. Often there is more than one possible source of error so you should try to identify which source of error is the largest. **A result without an error estimate is useless**. If you had to calibrate your equipment then you should include the results of these calibrations- sometimes this is best accomplished with a plot. All plots need to be labeled and to have units and scales on the axis. It has to be clear what physical quantities are being plotted. Unlabeled plots of *x* verses *y* are of no value.

e. Conclusions: The most crucial part in an experiment is the point where you try to make conclusions based on your results. This is where you look at the results and try to determine:

    - Does the conventional theory describe your data to within the experimental errors? Were the errors dominantly random or systematic?

    - If the dominant error source was random, what was the source? What could be done to improve the experiment (improve its design so that the random errors are smaller)?

- If the dominant error source was systematic, was the problem in the theory or in the design of the experiment? Was the problem an assumption used in the analysis? If you have an idea concerning a systematic error you should try to think of a way to **test your idea**. In some cases you may want to re-analyze your data according to your improved idea. Is there a way to correct your analysis or the theory to get rid of the systematic error? This is often a very tricky task, but an absolutely crucial step in experimental science.

f. References: (not included in the five page limit) This is where you state what sources you used (text, lab notebook, books from the library, etc).

g. Appendices: (not included in the five page limit) This is where you can put summary data tables, derivations etc. (as mentioned above) that do not fit into the text of your report. They should be organized and readable. The most important thing is data tables and plots of raw data so that – if something is wrong – it is possible to tell what went wrong.

**Talks**

During the last couple of lectures of the semester, each of you will give a short conference style talk – 12 minutes plus three minutes for questions – on one of the labs that you have done. You should not choose the same lab as your lab partner for this. The purpose of this mini-conference is to give you practice in scientific communication.

**Tips for good talks (Based on the APS Advice to speakers).**

Step back from the details of your research and think about what the audience might like to learn from your work. Keep it simple- remember that less is more.

Organization
Your talk should include:

1. Statement of hypothesis and purpose of the research.
2. Description of methods of investigation.
3. Inclusion of data collected and what was learned.
4. Conclusions based on the data collected.
5. Emphasis on significance of highlights of the research.

Audio-Visuals

1. Supporting audio-visuals must be concise, uncluttered and readable from a distance.
2. Audio-visuals should amplify your oral presentation, not duplicate it.
3. Choose the medium that will optimally display your information – don't use words if a picture will convey it more clearly (graphs, tables, charts, etc.).

4. Use:
    a. Line graphs to show trends
    b. Bar graphs to compare magnitudes
    c. Pie graphs to demonstrate relative portions of a whole.
5. If you require special a-v, don't wait until the last minute to request it.
6. I usually figure on about one slide-per-minute.  If you have 20 slides for a 12 minute talk you are definitely going to go overtime.

Delivery

1. Prepare notes that highlight the salient points of your talk.
2. Practice the delivery of your talk prior to your presentation along with your slide or transparency sequence being sure to fit your talk into the time allocated to you.
3. Use simple sentences; avoid jargon, highly specialized vocabulary and unfamiliar abbreviations.
4. Think about questions you might be asked about your work and be prepared with well-thought out answers, being mindful of the limited time for Q and A.