

## Requirements for the Laboratory Reports

Each student is required to write an individual formal report for each experiment. The lab reports are due at the beginning of the following lab session.

Your lab report should “tell a story”: explain what you did, and what you concluded from your work. The report should be a short scientific paper readable by a peer: a student in your major who didn’t perform this lab but otherwise has same general background as you. Writing lab reports at this level is practice in the kind of writing and analysis you would perform professionally on real research projects, just as keeping your lab book should build good habits for your scientific record keeping for real research projects.

### Length of Report

There is no standard length to a regular lab report. You need to explain the concepts and the process sufficiently, but do not write pages of description when a few words and a figure will suffice.

The length of the final advanced lab report is limited to 12 to 20 pages including figures (double spaced, 11 pts fonts).

### Grading of the Regular Laboratory Reports

The laboratory reports should be prepared using a word processor, such as MS Word or LaTeX, with imported graphics and images when applicable. Hand-written reports will not be accepted. The following sections must be included (a typical assignment of points for grading is shown in brackets).

#### Title and Abstract [1]

Include title, your name and the name of your partner at the top of the title page.

State the major result of the experiment. For example: “A Michelson interferometer was used to determine the difference in wavelength of the sodium D lines. A value of  $5.9 \pm 0.2 \text{ \AA}$  was found, which agrees with the accepted value.”

#### Introduction [1]

Summarize the main ideas of the experiment and the relationship to the appropriate theory. A sketch of the experiment should be included.

#### Procedure [1]

Describe essential experimental procedure.

#### Results, answers to questions [4]

Present data in tables or graphs when possible. Include fits when appropriate.

Answer questions posed in lab instructions, or by your TA/instructor.

\* Measurement quality counts. Your goal is to present reliable and careful measurement. Your results will be compared with those obtained by the TAs and other students.

#### Analysis & Discussion [2]

Analyze data and compare quantitatively with expectations. Error estimates must always be given. Do not recopy all the raw data for your report. Give examples and/or the range of the numerical values where appropriate. Do the measurements with the error estimates agree with theory? If not, can you suggest possible sources of the discrepancy?

#### Conclusion [1]

Summarize your key results and uncertainties. Discuss inconsistencies and possible systematic errors. Did you find what you expected? What can you conclude based on your results? What improvements would you make if you were to repeat the measurements?

## Examples

Click [here](#) for a write-up example.

A sample of a lab report from PHY 192 in the Department is [here](#).

A link lab report document is available as a .doc Word document from PHY 192. Click [here](#) to download.

The MIT Junior Lab course website provides an APS style report example and TeX/LaTeX template. You can also find several very useful links to writing resources. Check <http://web.mit.edu/8.13/www/writtensum.shtml>.

### *Grading of the Advanced Laboratory Reports (Lab #10)*

In addition to the requirements for a regular report, you should include further background literature research, develop a more comprehensive theoretical model, and discuss related applications. This advanced lab reports will be evaluated according to standards of technical writing commonly used by publishers of professional journals. Your report will be judged in terms of the following five criteria.

#### **1. Grammar and Syntax (10%)**

Use whole sentences with appropriate grammar and syntax. Please do not use colloquial or slang terms. Also, please PROOFREAD your reports before submission -- and I don't mean just check the spelling. You are practicing for your profession, so take some pride in the results of your efforts and submit the best report that you can.

#### **2. Organization and Presentation (10%)**

Organize in a reasonable way. Use paragraphs, and indent at the start of paragraphs, except for the first paragraph of a section, or skip lines between un-indented paragraphs. Label all figures, tables, and equations and refer to all of them in your text. Do not include something if you don't refer to it. Attribute all items taken from other sources, such as figures or equations.

#### **3. Quality of Data and Experimental Procedure (20 %)**

The best data is obtained when you know what you are doing. So, please read the lab experiment handout before coming to lab. Examine your data as much as you can before the lab period is over. If they do not conform to what you expect, consult with your instructor and be prepared to retake the data if necessary.

#### **4. Quality of Graphical Presentation (20%)**

Give titles to your tables and graphs, and label them with a number. If the data have units, please include them in a consistent manner. Use points on a graph to show measured data and lines to show functions and equations. Do not connect the data points unless you intend to linearly interpolate between points.

#### **5. Discussion (35%)**

Your technical writing should indicate your understanding of the topic. Your report should not be simply a list of what you did but a discussion of the significance of what you did. Show that you know the theory behind the observations. Use your figures and tables to clarify your discussion. **Answer all questions posed in the handout for the lab.**

#### **6. Grader's Prerogative (5%, or more bonus points)**

(Self-explanatory)

## A 'Comprehensive' Style Guide for Laboratory Reports

### **Introduction**

As a scientist, probably the most fundamental means you will use to communicate with colleagues is through reports and papers that summarize your research. The material you will write about is often complex and non-intuitive. Because of this fact, it is very important that you learn to write these reports *clearly* and *concisely*. To do this well often requires significant practice. Laboratory reports are one of the more important opportunities to develop in this area.

In real research, the utility of an experiment is to test some hypothesis or theoretical model. In the labs you will implement this quarter, the theory is well established. However, it will be very useful for you to approach these experiments from the point of view that the theory is not well known; after all, this may well be your first introduction to the theory.

The result of your experiments will fall into one of three categories:

- (1) the data support the theory within the experimental uncertainties,
- (2) the data do not support the theory within the experimental uncertainties, or
- (3) the experimental uncertainties do not allow for a meaningful comparison between the data and the theory.

Conclusion (3) is often, if not usually, a disappointment, because it means that one has to either admit severe deficiencies in the data-taking technique or to revisit the experimental method used and search for a better way to go about making the measurement (of course, this is a very common outcome in real experiments!) However, an honest researcher will report this when necessary. Each week, try to answer the question: into which of these three categories does your experiment fall?

### **Writing Your Lab Reports -- the Writing Should "Flow":**

Remember the three C's: concise, clear, and complete. Break your text into sections that flow one to the next. Many layouts are possible, and you have the freedom to choose the one that works best in the particular context.

The following sections must be included.

#### Title

Title of experiment. Include your name and the name of your partner at the top of the title page.

#### Abstract

This briefly states the major result of the experiment. For example: "A Michelson interferometer was used to determine the difference in wavelength of the sodium D lines. A value of  $5.9 \pm 0.2 \text{ \AA}$  was found, which agrees with the accepted value."

#### Introduction

This summarizes the main ideas of the experiment and the relationship to the appropriate theory. A sketch of the experiment should be included.

#### Analysis & Discussion

Analyze data and compare quantitatively with expectations. Error estimates must always be given.

#### Conclusion

A brief statement summarizing your results is needed here.

Here are a couple of examples with some variations:

**Example 1:**

1. Title Page (including date, number of lab, name of partners)
2. Abstract
3. Introduction
4. Experimental Setup
5. Data Analysis & Discussions
6. Conclusions

**Example 2:**

1. Title Page (including date, number of lab, name of partners)
2. Abstract
3. Background/Introduction
4. Observations
5. Analysis and Discussion
6. Conclusions

Try to tailor your section headings to match the lab activities, rather than formatting your lab to fit a set of fixed headings. You need to write a brief abstract that is placed at the front of the report and that states what you did and any conclusions you reached. In the main text, include a section that describes the context and relevance of what you did, a discussion of the experimental procedures, your results, and then your conclusions (at the end). **Diagrams of setups are particularly useful in lab reports.** These can be very simple – they do not have to be artistic. Include relevant dimensions that are necessary in any equations in the description. **In each lab procedure handout, there will be a few questions that you will need to answer.**

All required material in your lab write-ups should be typed on a word processor, both for ease of submission and for archiving. This includes equations, figures, data tables, and answers to any questions. Handwritten pages will not be accepted. Include captions with figures and data tables. Number your equations, data tables, and figures and refer to them by number, e.g., “As demonstrated by Eq. 1, ...”, “As shown in Fig. 2, ...”, etc. Equations are typically numbered in parentheses located flush with the right margin, while figures and tables are numbered in their captions. The lists of equations, figures, and tables are numbered separately.

The general idea of the lab reports is to follow the format of real research papers as closely as possible. If you would like some examples of what such papers really look like, check AIP Style Manual <http://www.aip.org/pubservs/style.html>, or go to read articles on APS (American Physical Society) Journals <http://publish.aps.org/>, or OSA (The Optical Society) Journals <http://www.opticsinfobase.org/>.

**The Certainty of Uncertainty**

Every measurement exhibits some associated uncertainty. A good experimentalist will try to evaluate the level of uncertainty, which is specified along with the measured value (e.g.,  $10.4 \pm 0.1$  mm), which are then graphed as “error bars” along with the measured numerical value).

In these labs, it is very important for you to do this too. In particular, it is helpful to decide which of the three possible results mentioned above that applies to your data. How can you do this? One way is to make what you think is a reasonable decision about the uncertainty. For example, if you measure a length with a ruler, maybe you can only measure the length to some fraction of the smallest rule division. Another way is to measure the uncertainty. That is, take the same measurement multiple times. The average value is then used as the final measurement, and the uncertainty is related to the standard

deviation of the individual values. We will discuss these ideas more thoroughly as the class goes on, but you should be prepared to estimate uncertainties for as many measurements as you can. The measurements are usually expressed as the mean value  $\mu$  plus or minus ( $\pm$ ) the uncertainty, which generally is standard deviation  $\sigma$  of the measurement. **Be sure to specify the units used in any measurements! Also watch the number of significant figures; just because your spreadsheet calculates to 7 or 8 places does not mean that this level of precision is merited!**

Present your data in numbered tables and include captions that clearly specify the source of the data. Once you have assessed the uncertainty of your measurements, you still need to estimate the uncertainty of any derived results. For example, if your measurements of “a” is 10 units  $\pm 1.5$  and “b” is 5 units  $\pm 0.5$ , then what is the derived measurement of  $c = a + b$ ? or  $d = a \times b$ ? You should not report precision above and beyond what is warranted. For example, I often see students report 5+ decimal places of precision in numbers derived from observations measured with an uncertainty of more than 10%. This is ridiculous (to put it mildly!).

Two well-known and very useful references on the topic of precision and the propagation of errors are: “*Data Reduction and Error Analysis in the Physical Sciences*” by Phillip R. Bevington (McGraw-Hill Science/Engineering/Math; 3rd edition, July 23, 2002), and “*An Introduction to Error Analysis – The Study of Uncertainties in Physical Measurements*”, by John R. Taylor (University Science Books; 1997).

### **Equations and Subscripts:**

You will need to include equations and subscripts in your lab write-ups, so you need to have the means to do so. Subscript fonts are available in most word processors and equation fonts in many. For example, Microsoft Word™ includes a rudimentary “Equation Editor”, and add-on software (such as MathType™ from MathSoft) also is available. You might consider investing in a scientific word processor that includes equation, graphing, and curve-fitting features — many are available, and the time you are likely to save over the course of your college career will easily outweigh the cost and learning time.

### **Graphics and Images**

I encourage you to include graphical displays of various kinds into your lab reports. For example, you can use a digital camera to photograph your lab setups and include them in your reports. Labeled diagrams are particularly useful in laboratory reports and should be included. This is an obvious place where the old motto certainly applies: “One picture is worth 1024 words.” Include the figures in the text near their first reference and not as a collection at the end of the report.

You can (and should) display data graphically. You may use a spreadsheet program such as Microsoft Excel for simple plots. To produce more professional scientific graphs, you can use the graphing tools such as Igor Pro installed on our lab computers. If you would like to install a copy of Igor Pro on your own laptop for course work, please contact Dr. Lai or Mr. Mark Olson. Also, reference any graphics taken from other sources, including the lab description handout. Include legends on graphs if useful. If you use color in your graphs but submit black-and-white output, make sure that your graphs are readable! Number your figures and include captions that clearly describe what is pictured. If you fit lines or curves to data points in graphs (such as by linear regression), then you need to state what was done.