

Introduction To Laboratory Practices for Upper-level labs (Full Version)

[Changes from the [ILP for Introductory Labs](#) are marked in Red.]

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Departmental Policy On Laboratory Attendance And Reports

1. Attendance and participation in lab is required to pass the lecture portion of the course.
2. Each student is expected to attend laboratory on the regularly scheduled day unless:
 - a. *an exchange of days* with another student has been arranged with the consent of both laboratory instructors.
 - b. *advance arrangements* have been made by a student who knows ahead of time that he or she will be unavoidably absent, due to participation in a University-sponsored activity or due to compelling personal reasons.
3. An experiment not performed at the scheduled time will receive a failing grade unless:
 - a. one of the arrangements above has been made;
 - b. a bona fide emergency arises, in which case the instructor may make an adjustment.
4. Experimental work can usually be completed during the three-hour lab period. If the completed report has not been turned in, the student is expected to be in the laboratory working on it until 4 p.m. Your lab instructor will establish a deadline for handing in labs if more time is needed.
5. Each week's laboratory work will be evaluated with a single grade based on the report and the experimental work performed.
6. Points may be deducted from your report for certain violations: not creating a graph as the data is collected (unless instructed to do so by the instructor); collecting data on scrap paper; recopying results. These points are elaborated upon below.
7. Your lab partner may help you but may not do your work for you. To report your partner's work as if it were your own is plagiarism. (Check the *Student Handbook*, under '[Academic Honesty](#)' if you are unsure as to what constitutes plagiarism. It is your responsibility to be aware of the rules.)

Laboratory Notebook

Your notebook is to be the journal of your laboratory experience, containing both your observations and your analysis of these observations. You are asked to adopt the following conventions in this introductory course.

A. Overall:

1. *Reports*: **Informal** lab reports will be made **in your lab notebook**.
2. *Neatness*: A reasonable neatness and orderliness in your original record help you to communicate your results to the reader. However, the lab report is a **working** journal and **should not** look as if it is a copy of

material recorded elsewhere. **Points will be deducted by your instructor for recopying data!!** Include in your lab report all papers used to reach your final conclusions: the lab instructor should not have to guess how you got there. Use *only* a black or blue pen (**not pencil**) for your report and calculations. Other colors are too difficult to read.

B. The Informal Lab Report:

- 1) *Title*. Enter at the top of the first page of each report: the name of the experiment, the date, your name and your partner's name.
- 2) *Introduction*. Describe the experiment you are about to perform. Ideally you should include information gleaned from your library research before lab time. Be sure to properly cite any information you pull from other sources, including your lab instructions. **DO NOT** rewrite anyone else's exact words without quotation marks, even the words from the lab instructions. This would be plagiarism, and is dealt with harshly.
- 3) *Sketch of experiment*. This helps you and your reader to visualize what you did in your experiment. If you refer to any quantities in your report that can be shown on the diagram, label them on the diagram. *Be sure that labels in sketches and tables are consistent* (e.g., if you use 'x' for distance in your table, don't use 'd' in your sketch to describe the same measurement!).
- 4) *Data Section*. Record your original observations in your report as you collect them. Use tables to keep data neat and organized.
- 5) *Sample Calculation*. It will be tedious to present all your calculations; show one sample of each in sufficient detail to demonstrate how your results were obtained.
- 6) *Graphs*. These include hand-drawn and computer graphs, and will be discussed below.
- 7) *Conclusion*. This is a **brief** (never more than a half page) summation of your results and conclusions drawn from them. **It should be written in paragraph form, and should do the following three things, in order:**
 - a) *What you did*. Use one or two sentences to describe what you did in lab. What was the experiment, what quantities did you measure or calculate, what was the ultimate goal. Assume that your audience is a classmate who had to miss lab this week.
 - b) *Your results*. Present your major results -- not your individual data points -- in sentence form.
 - c) *What these results told you*. You set out to investigate nature today. What did you find out? By the way, among your instructor's least favorite phrases are the words "human error". If the human has made an error, s/he needs to go back and fix whatever it is. Focus here instead on what you have discovered about the universe. For example, if you are trying to measure some quantity whose value appears on the inside flap of your textbook, you should report on whether the "accepted" value is consistent with your findings.

Formal Lab Reports

In upper-level laboratory courses, you will be called upon to give a more thoughtful description of your laboratory work, in the form of a Formal Lab Report. In *Modern Physics* (Phys 221/2), you will be expected to submit a small number of each semester's laboratory projects as Formal Lab Reports. In the more advanced lab courses, you may be expected to submit all of your lab work as Formal Lab Reports.

The text *Experimentation*, by D. C. Baird, provides useful information on how to assemble a Formal Lab Report. In addition, there is an online example <Insert link here> of the overall format expected of Formal Lab Reports in the SLU Physics Department, which also contains helpful comments on the style and substance of the report. Be aware that the example is a relatively short report. You will be expected to go into greater detail the higher the level of the lab course, all the way up to your Senior Lab Project.

A. Overall

B. Formal Lab Report Structure:

1. *Title page.* This should be a separate page that contains a descriptive title, your name, the course title, the date and an Abstract.
The Abstract. The Abstract should have the same format as the Conclusion of your Informal Lab Report. It should describe:
 - What you did
 - Your results
 - What these results told you.
2. *Introduction.* Describe in general terms what this experiment is all about. Explain why this experiment or this phenomenon is of interest.
3. *Theory.* A formal lab report should show that you understand the physics behind the phenomenon being studied in the laboratory. You want to convey this to the reader.
4. *Procedure.* This should not read like a cookbook recipe. *Describe* what you did; do not give instructions.
5. *Data and Calculations.* This is where you present your data and graphs. Give enough description in words so that the reader can follow what you are doing. Do not assume that the reader already understands. Do not assume that the mathematical equations explain what you are doing with sufficient clarity..
6. *Discussion.* Elaborate on what these results told you. Do they support some theory? Do they support some theory over a limited range? Do they disprove a theory? If you wind up trusting the theory and not your experimental data, you will need to explain why you did not go back and take better data..

Data

A. Overall:

1. *Data* are direct observations you make which may include:
 - a. sketches of the apparatus showing measuring points.
 - b. verbal descriptions of phenomena.
 - c. numbers you obtain from measurements.
2. *Promptness.* The data must be **written down at once in your notebook**, just as you see them at the time you see them. Do not collect data on scratch paper, then recopy. ***Points will be deducted by your instructor for recopying data!!*** Inference must be drawn or calculations made only after the data have been recorded.
3. *Mistakes.* Recorded data **are not to be altered or erased**, even if they are wrong. Too often, people erase good data by mistake and regret the erasure almost immediately. If you later decide an observation was wrong, cancel it by drawing a single line through it that leaves it readable. (You may change your mind once again.)
4. *Tables.* Create tables (described in [B2](#) below) to organize your data; be sure to use a ruler to make straight lines. This enables both you and the reader to identify the data at a glance.

B. Numerical Data:

1. *Definition.* Only the numbers you actually read are data.

Example: If a rod whose length you are measuring has one end near the 13.5 cm mark on a scale and the other end near 45.8 cm, the data are 13.5 cm and 45.8 cm. The length of the rod is not

itself a datum but a calculation made by subtracting one datum from another. **Do not introduce errors into your work by doing mental arithmetic before you write the numbers down.**

2. *Tables.* Sets of similar data are easier to process if they are put into tables.
 - a. Let your table grow as you collect data; don't draw lines before you begin the experiment!
 - b. Enter multiple measurements of a quantity on individual rows. Use a single horizontal line to separate groups of measured quantities.
 - c. Use a *single line* to cross out obviously erroneous data, and include an explanation for its exclusion below the table. *Do not* erase, rewrite, or scribble vigorously over erroneous data!

A sample data table appears below.

Sample Data Table

Initial Position, X_i (cm)	Final Position, X_f (cm)	Travel Time, t (sec)	Average Time, $\langle t \rangle$ (sec)	Total Distance, $X = X_f - X_i$ (cm)	Velocity, $v = X/\langle t \rangle$ (cm/s)
10.0	23.1	1.52	1.51	13.1	8.66
		1.53			
		1.49			
	55.8	2.36	2.37	45.8	19.3
		4.57			
		2.39			
		2.37			

3. *Repetition.* No number need be entered as a datum more often than it is read. (Note the "Initial Position" column in the example above.)
4. *Include a leading zero!* If you collect a measurement of two tenths of a centimeter, record it as "0.2 cm", not ".2 cm". Omitting the leading zero makes the datum difficult to read, and can lead to calculation errors.

Calculation

A. Significant Figures:

1. *Single observation.* The result of a measurement is reported as a sequence of digits together with the units in which the measurement was made.

Example: 2.38 m or 238 cm

- a. The *first significant figure* refers to the largest multiple (or sub-multiple) of the basic unit that is reported.

Example: In 2.38 m, the first significant figure reports that the measured length was two (and perhaps a bit more) meters. If you had reported the length as 0.00238 km, the '2' would still be the first significant figure. **Leading zeros are not "significant".**

- b. The *least significant figure* is the last multiple of the basic unit that was observed.

Example: The '8' in 2.38 m or in 238 cm is the last significant figure. The observer feels that the length is closer to 238 cm than to either 237 cm or 239 cm. Still, there is some uncertainty about that '8'. **The last significant figure reported in any measurement is uncertain.**

- c. A measurement should be reported in such a way that the number of significant figures it represents is obvious.

Example: When the speed of light is reported as 300,000,000 m/s the inference is made that this has 9 significant figures. If it were reported as 3×10^8 m/s, only the 3 represents a significant figure and so the result is given to only one significant figure. 3.0×10^8 m/s suggests two significant figures, and 3.00×10^8 m/s suggests three.

2. *Combined result.* When two measurements are combined, the uncertainty in the computed result depends on the uncertainty of each of the measurements and on the way they are combined. *The final result should not have any more significant figures than the least accurate (most uncertain) measurement.*
3. *Rounding errors.* Rounding error can be introduced in the process of calculations. Your calculator retains many more digits than the significant figures you will be recording. Error is introduced when you round a calculated value, and then use that rounded value in subsequent calculations. Learn how to use the “memory” function of your calculator to retain subsequent values, and only round your final result.

B. Percent Difference:

Comparing numbers. You can compare two numbers by calculating the percent difference between them. Do this by subtracting the two numbers and dividing by the average of the two. *Note: There is usually no more than one significant figure in percent differences.*

Example: Two measurements of the same object give the length as 4 cm or as 5 cm. The percent difference is calculated as:

$$\frac{(5-4)cm}{\frac{1}{2}(5+4)cm} = 0.2\bar{2}$$

Since only one of the digits in this figure is significant, we shall call it 20%.

Graphs

During many experiments, you will first draw a “trial” graph, *as you collect your data*. The theory will be discussed before the experiment begins, so you will have an idea of what the graph should look like (linear, exponential, etc.). The trial graph lets you see this theory develop, and check for any radical deviations, possibly due to a calculation or measurement error. This allows you to check your calculations or repeat a measurement, before the configuration of your apparatus changes.

Note: You **must** create your trial graph as you collect your data. ***Points will be deducted from your lab report grade if a graph is not available when requested by your instructor!!***

To aid in the creation of your trial graph, the first data points collected should reflect the extremes of the experiment when possible (shortest time, longest time; shortest distance, longest distance; etc.). After these two points are collected, you will be able to determine what the magnitude and scale of your axes should be. After these two points are plotted, continue to collect data to fill in the gap between them. You should collect enough data so that there are no significant gaps left in the graph.

To analyze the graph, you will enter your data into a computer, and again produce a graph. The computer graphs will be printed, and handed in with your report. Details on creating and analyzing graphs generated by a computer are the subject of the first experiment.

Both types of graphs must follow the conventions outlined below:

1. *Title:* Every graph must have a title. A title should consist of words describing what quantities are being plotted against each other **and a brief description of the system being studied**. The title should be sufficiently descriptive to be understood without reading the rest of the report. ‘Period as a function of pendulum length for a physical pendulum’ would be a much better title than ‘T vs. L’.

2. *Axis labels:* Each axis must be labeled, giving both the *quantity* and the *units* in which it is measured. If the axis represents force in units of hundreds of Newtons, you might label it 'force (100 Newtons)' or 'F (10^2 N)'.
3. *Axis scale:* For the trial graph, try to fill as much of the page as possible, but don't overdo it. The smallest grids of the graph should be in units of 1, 2, 5, or any of these numbers multiplied by a power of 10. It is very difficult to plot points between the grid lines or to read those points off of a graph in which each block is, say, 3, 6, or 0.8 units.
4. *Plotting individual data points:* In order to make individual data points on your trial graph highly visible, but retain the precision of marking them, you should surround a single tiny dot with a larger symbol, such as a circle, triangle, or square. *Do not* use a cross or an 'x' to mark data points!
5. *Indicating slope points:* On a graph of linear data, use a small cross or 'x' to indicate the points used to determine slope. If possible, place the coordinates of that point next to the symbol. Slope points should be *widely separated* as close to the ends of your best fit line as possible; **never use data points to calculate slope!**