

Introduction To Laboratory Practices (Full Version)

January 2000

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*: Lab reports will be made on graph paper, which will be provided for you.
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 or pencil for your report and calculations. Other colors are too difficult to read.

B. The 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. *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!).
3. *Data Section.* Record your original observations in your report as you collect them. Use tables to keep data neat and organized.
4. *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.
5. *Graphs.* These include hand-drawn and computer graphs, and will be discussed below.
6. *Conclusion.* This is a **brief** (never more than a half page) summation of your results and conclusions drawn from them. Present a brief table that summarizes your numerical results. Report as a statement of fact the principal results of your experiment - a new measurement of 'g' or whether a spring obeys Hooke's law, for example. Note that you will not be "proving" a theory; rather, you will determine if your experiment behaved *as predicted* by the theory.

Next, evaluate your results – how reliable is the information on which you base your conclusion, what reservations do you have about it, how might you improve the experiment, etc.? Personal responses (such as "this experiment went very well") are *not* a legitimate part of a conclusion. Do not blame error on "human error"; the errors of the experimenters can be reduced by careful technique, or repeating the procedure. *Be specific*; what made a particular measurement difficult, or what aspects of the experiment lend themselves to greater uncertainty in measure? Don't be quick to blame the apparatus, unless you are positive that is the cause (this can usually be checked with other equipment).

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.

- 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.*
- 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:

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

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 for what experiment. 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 (10² 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!**