University of Illinois at Urbana-Champaign Department of Physics

Physics 401 Classical Physics Laboratory

LABORATORY REPORTS FOR PHYSICS 401

Contents

Revised 8/2009.

1. OBJECTIVES OF THE LABORATORY

The primary goal of Physics 401, Classical Physics Laboratory, is to develop in the student an understanding of the experimental basis of physics by doing structured laboratory exercises in classical mechanics and classical electricity and magnetism. In this course the student will

1. acquire basic concepts related to the experiments;
2. become familiar with modern experimental instrumentation;
3. learn how to make reliable measurements;
4. understand the precision of a measurement;
5. learn how to do calculations with proper significant figures;
6. learn how to do data analysis and graphical analysis;
7. learn how to write a laboratory report;
8. learn the advantages and limitations of computers in experiments; and,
9. learn how to approach an experiment systematically.

2. LABORATORY NOTEBOOK AND LABORATORY REPORT

There are 7 laboratory exercises (not including the introductory lab) and a final project for the fourteen weeks of the semester. Each laboratory exercise is described in a laboratory write-up. These write-ups are available on the web as pdf files. They are also available in the laboratory room, ESB 6103, the day of your section. The write-ups contain references and a limited amount of theoretical material. The theoretical material should allow you to make a correspondence with material from lecture courses and textbooks. The theoretical material is more of a summary than a textbook. One goal of this course is to promote independent learning---please seek out information if you do not understand something.

The write-ups also contain a description of the instrumentation used in the laboratory exercise and a description of the measurements. The write-ups contain specific question that you will answer in the course of your measurements in the laboratory or the course of your analysis outside of the laboratory. Your laboratory work must be recorded in a laboratory notebook. You will need two laboratory note books. One notebook is used for the first, third, etc. labs, and the other for the second, fourth, etc. labs. Your laboratory notebook is an integral part of your laboratory report which will be read and graded on a weekly basis by your laboratory teaching assistant. While your teaching assistant has one of your notebooks, you will use the other notebook to record your laboratory work. The report and lab book for each laboratory is due at your next laboratory session (i.e., if you have a two-week lab over weeks 5 and 6, the report and lab book are due at the beginning of the new lab on week 7).

Your laboratory notebook is the primary record of your laboratory work. You record what you measure and observe in your laboratory notebook. Your laboratory notebook should be organized, but it does not have to be pretty. Some measurements are best recorded in a table. In some laboratory exercises the measurements are logged by a computer. A print out of the data should be placed in your notebook. A crucial element in all experimental work is the constant attention to the validity of the data. In our laboratory exercises you can expect that you can obtain valid data with proper technique. How will you know if your data is good data? In many exercises some quantity is measured, e.g. the decay time of an RC circuit, while some quantity is varied, e. g. the resistance of the resistor in the circuit. We have an expectation that there should be some understandable dependence of one on the other. (In fact, in this simple example we expect that decay time should be inversely proportional to the resistance.) There is no more powerful way to identify a trend than to make a graph. A rough graph can be an invaluable aid to a successful experiment. In many cases you will be asked to make a good graph for your laboratory report, but you should also make a rough graph in your laboratory notebook when you are making your measurements. In other exercises a calculation may be useful in verifying the validity of the data. In many cases you will be asked to make detailed calculation in your laboratory report, but you should also make a sample calculation in your laboratory notebook when you are making your measurements.

What you put in your notebook will depend on the laboratory exercise. Here are some items that should be included when appropriate.

1. Give the title of the laboratory exercise, the date, your partner's name, and the TA's name.

2. Sketch your setup. A good free hand drawing should be fine or you can use some simple computer program. Label the equipment and record the inventory number or serial number and model number. (Anomalous results may be traced to equipment in need of recalibration or repair.) Also label the quantities you need to measure.

3. Many of the laboratory exercises are in several parts. Identify which part you are working on. A phrase or sentence describing the purpose of the measurement may be useful.

4. Many of the laboratory exercises give explicit instructions for what should be varied and what should be measured. In other exercises some judgement is required. In these cases estimate the range of values you should consider, the number of data points you may need to measure and how accurate you should measure them. **Therefore, it is important to read the handout ahead of time.**

5. Record all your data and all your observations directly into your laboratory notebook, not on a scratch paper. Remember that the original data are the most important pieces of information and never risk them by jotting down on a scratch paper. Also note down the proper unit and uncertainty of each measurement. If a measurement is wrong, cross out with a single line - do not erase it. It may be useful later in diagnosing if you have a problem. Write as neatly as possible.

6. Make graphs and do calculations to verify the validity of the data. If you discover an error, you can repeat the measurement immediately. Unfortunately, it is not usually possible to gain access to the equipment after your scheduled laboratory period.

7. It may be useful to make inferences or conclusions, definite or tentative, in the laboratory notebook while doing the laboratory exercise. Write as much as sensible. You can always ignore false inferences and conclusions.

LAB REPORT:

The laboratory report should be a largely self-contained presentation of your work on the laboratory exercise. The laboratory report should be well-organized and complete. The basic idea should be to convince the reader that you comprehend the physics behind the experiment, understood how to make proper measurements and interpret your data in an appropriately analytical manner, i.e., using error analysis correctly, and making proper and insightful conclusions. Here are additional guidelines which you should follow in making your laboratory report.

1. Give the title of the laboratory exercise, the date you did the exercise, your partner's name, and the TAs name. Identify the page numbers of your laboratory notebook for the laboratory exercise.

2. Write a ~150 word abstract outlining the experiment, your results, and your conclusions.

3. Describe the theoretical unpinning of the experiment.

4. Describe the purpose of the laboratory exercise, i.e. what you measured and why you measured it.

5. A good drawing or a copy of the drawing of the setup from the laboratory write-up may be useful in the presentation.

6. The original data should be transcribed to a well-organized and well-labeled table(s).

7. All calculations must be clearly shown with appropriate units and uncertainties. For error analysis of the experiment, also indicate briefly the principle sources of error. Sample calculations for each different type of numerical result should be in your final report. In addition to these calculations, one sample calculation for each different type of *uncertainty* should be included. When appropriate, calculate the reduced χ^2 of a fit and describe its significance.

8. Any graph requested in the laboratory exercise write-up should include a title and axes labeled with units. Graphs should be done on a computer. (Origin is best for this.) Refer to them in the text and discuss what the plots are "telling you." Where appropriate, write the fitting function and χ^2 on the plot in the blank space. A common crutch to writing scientific papers is to get the plots first, and then write "around" the plots.

9. Your report should include conclusions and discussions about your results. You should comment on any startling, unusual, or questionable results (or uncertainties) which you obtained. You should include, when appropriate, a comparison between your observations and theoretical expectations. You must answer questions asked in the handout. Your answers should be brief---not more than a paragraph or two. We want you to learn to think "physically" about the world. Don't just say that something happens, say why it happens and point to correspondences with physical models.

10. The laboratory report should be written on a word processor. Use of MS office (or something similar like Pages).

You must hand in your laboratory notebook (with your raw data) along with your report.

The length of the report depends on the complexity of the experiment. We don't have a set page number or word count; write what is necessary and not much more.

11. Cautionary words: "Do not write anything in your report that you don't believe or can't back up. This comment applies to physics, error bars, and the results from software packages." From Lyman Page. Not following this advice can get you in hot water here and in life in general.

12. NOTE ON STYLE: Write in full sentences and paragraphs and use simple sentence structure unless you are an experienced writer. Use the active voice, put statements in a positive form, and use definite, specific, and concrete language. When in doubt, consult a style manual. One such book is *The Elements of Style* by Strunk and White, but there are many available.

3. TABLES

Here is an example of a good table. In one of the laboratory exercises the resistances of two resistors, X_1 and X_2, and their series and parallel combinations, X_s and X_p, are measured. The measured series and parallel combinations are compared to calculation. A good Table might look something like this:

Name	Value (Ω)	Uncertainty (Ω)
X_1 (Exp)	200.5	± 0.1
X_2 (Exp)	99.95	± 0.04
X_s (Exp)	300.4	± 0.2
X_p (Exp)	66.68	± 0.03
X_s (Calc)	300.5	± 0.1
X_p (Calc)	66.70	± 0.02

Note: Uncertainty for the DMM: below 200 Ω = ± (0.02% of reading + 2 counts);
above 200 Ω = ± (0.02% of reading + 1 count).

As a practical matter use the notation of the laboratory exercise write-up in tables and calculations so that your teaching assistant can easily read and grade your report.

4. SIGNIFICANT FIGURES

Significant figures in a number are all of the digits that are obtained directly from the measurement. The number of significant figures does not include thoses leading zeros that are included only to indicate the position of the decimal point. A trailing zero is a significant figure.

1) Uncertainties and percent uncertainties are always reported to one (or two) significant figures -- never three or more. For example:

Never acceptable:

$\Delta X_1 = \pm 0.14014313\ \Omega$

$\Delta X_1 = \pm 0.1401\Omega$

Occasionally acceptable: $\Delta X_1 = \pm 0.14\ \Omega$

Always acceptable: $\Delta X_1 = \pm 0.1\ \Omega$

2) The number of significant figures given in reporting a result is determined by the uncertainty for that result.

Not acceptable:

$X_1 = 200.5123456 \pm 0.1\ \Omega$

$X_1 = 200 \pm 0.1\ \Omega$

$X_1 = 200.51 \pm 0.1\ \Omega$

Acceptable: $X_1 = 200.5 \pm 0.1\ \Omega$

3) If you know the value of a result (for example X_1) and the uncertainty of that result (ΔX_1), the percent uncertainty is simply

$$\text{Percent uncertainty in } X_1 = \left|\frac{\Delta X_1}{X_1}\right| \times 100$$

4) Here are a few examples which illustrate the number of significant figures and the (implied) precision of the number.

Value	# of significant figures	Remarks

4	1	range from 3.5 to 4.5 gives %precision=(0.5/4)x100=13%
4.0	2	1.3% precision
4.00	3	0.13% precision
0.2254	4	leading zero not significant
21340	4 or 5	leading zero may be significant or it may just indicate decimal point
2.1340×10^4	5	
2.134×10^4	4	

6) Examples of calculations which retain the correct number of significant figures are shown below. Note that you should generally keep the number of significant figures of the factor with the least number of significant figures.

Calculation	Acceptable	Unacceptable
2.18×3.216 Precision of factors is *[0.2%]* × *[0.02%]*	7.01 *[0.07%]*	7.01088 *[0.00007%]* 7.011 *[0.007%]* 7.0 *[0.7%]*
47.0×0.26 Precision of factors is *[0.1%]* × *[2%]*	12 *[4%]*	12.22 *[0.04%]* 12.2 *[0.4%]*
$0.58 \div 346$ Precision of factors is *[0.9%]* × *[0.01%]*	0.00168 *[0.3%]*	0.0016763 *[0.003%]* 0.001676 *[0.03%]*
$21.6 \div 5.49827$ Precision of factors is *[0.2%]* × *[0.00009%]*	3.93 *[0.2%]*	3.92851 *[0.0001%]*

7) It is okay (in fact preferable) to keep ‘’internally” a higher number of significant figures when doing a sequence or a series of lengthy, but precise calculations. Truncation of intermediate results could skew the final result. However, when it comes time to

present the final results in a report, common sense should prevail and the results should be presented with the appropriate number of significant figures.

5. NUMBERS YOU SHOULD KNOW BY HEART (not all necessary for Phy401)

FUNDAMENTAL
Speed of light: $c = 3 \times 10^{8}$ m/s
Plank's constant: $h = 6.6 \times 10^{-34}$ J s
Boltzman's constant: $k_B = 1.4 \times 10^{-23}$ J/K
Charge on an electron: $e = 1.6 \times 10^{-19}$ C

ENERGY AND LENGTH SCALES
kT at room temperature: 1/40 eV
1 cm^{-1} = 30 GHz
Visible light: ~400 to 780 nm; ~400 THz
hν for visible light: 2 eV

ATOMS
Diameter of an atom: 10^{-10} m
Binding energy of hydrogen: 13.6 eV
Mass of electron: 9.1×10^{-31} kg = 511 keV/c^2
Mass of proton: 940 MeV (c=1) ~ 1 GeV/c^2

ATMOSPHERE
Pressure: 1 atmosphere ~ 15 PSI ~ 760 Torr ~ 1×10^{5} N/m^2 (Pascal)

EARTH AND SUN
Magnetic field of Earth: 0.5 G
Mass of Earth: 6×10^{24} kg
Radius of Earth: 6.4×10^{6} m
Distance to Sun: 1.5×10^{11} m = 1 AU