Lab Report Guidelines

The University of North Carolina at Chapel Hill

Physics 281L

1 General Guidelines

Scientific results are useless if they are not communicated effectively. Even the most ground-breaking experiments or well-motivated theories are worth nothing if other scientists cannot read about and understand the science. The following guidelines may seem onerous and nitpicky, but for better or for worse, scientists frequently spend years perfecting scientific techniques, only to be judged by their writing skills. The hope is that these lab reports will serve as some preparation for effective communication of scientific work.

1.1 Audience

In this class you should treat every lab report as if it were intended to be read and understood by a student who has completed freshman-level physics courses (*e.g.* PHYS 118 and 119), but who has not taken PHYS 281. This is important enough to repeat: **write to your peers – not your instructor.**

1.2 The Lab Report as a Persuasive Argument

In the end, each lab report is a sales pitch – a persuasive argument to convince your reader that your conclusions are correct. As such, each section of your report should be thought of as evidence to sway your reader to agree with your conclusions. Humans (and scientists in particular!) tend to be skeptical, so you need to be persuasive. Convince your reader that your experiment was designed correctly, and that the data you took is trustworthy, and especially that your uncertainties and their sources are accurately analyzed. At this point students often ask, "What if I believe that my results are *not* trustworthy. Should I embellish the truth in order to make my argument more persuasive?" The answer is a resounding **no**. You might have to adjust your conclusions, but you never alter or fake your data. Remember, an experiment is only valid if others can repeat it. Do your best to obtain good data that you feel comfortable presenting, but if in the end your data may be flawed, convince your reader of exactly what went wrong, and present specific improvements that can be made in future iterations of the experiment to improve the results. Rarely does everything go right in real-world scientific experiments. Learning how to present negative or inconclusive results is an important skill.

One of the most important components of your argument is the abstract. Details about how to write an abstract will be presented in the next section, but for now we will stick to the big picture. The abstract is a summary of your argument. You should motivate and present your conclusions in just a few sentences. This section of a report is especially important because the vast majority of the time, scientists do not read past the abstract. It is your job to write your abstract well enough that the reader will feel compelled to read the rest of the paper.

A plot is worth a thousand data points. If a reader makes it past the abstract of the paper, their next move will often be to flip directly to the results section to look for plots. If the plots are absent or too hard to understand, they will likely give up. Spend quality time designing your figures so that they are easy to understand and have maximal impact. Pay attention to details such as units, axis labels, and scaling.

1.3 Writing Style

Your lab report should read as a quality piece of professional English writing. You should strive for maximum clarity and precise language. This does not mean that you should write in eloquent Shakespearian verse – it simply means that you should write to be understood. To this end, proofreading is very important. Read your report aloud, or better, have someone else read it aloud. Identify English mistakes, as well as awkward or confusing sentences, and fix them. Your audience will not find your argument persuasive if they are constantly distracted by writing errors.

This is a physics course, so your reports will include symbols and equations. Despite this, your sentences still need to flow logically. Be sure to explain the meaning of your mathematical steps, equations, and acronyms such that your audience could hear the report read aloud, and still understand its meaning.

2 Report Format and Layout

The general layout of your reports should follow the scheme outlined below, with section titles clearly labeled. The precise content of each section can be slightly subjective, and might change from time to time, but you should attempt to match this layout as closely as possible. The *required* format for all reports is a PDF typeset in LaTeX. Specifically, you should use the "reprint" layout option of the REVTeX document class. This is the format used by all American Physical Society (APS) journals. A convenient template for your lab reports (using REVTeX 4.2) is provided on Sakai for your use. ***Your lab report should not exceed 5 pages in length.*** The *best* lab reports are generally about 4 pages long.

2.1 Section Content

- **Abstract:** A concise summary of the work covered at length in the main body of the article. It should motivate your work, provide a (very brief) description of the methods used, and present your result(s) and conclusion(s). *Concision is essential in your abstract!* It should be a tight, well-proofread ∼4-8 sentences. The abstract should be accessible to a peer who has not seen this experiment before. As such, there should be no math or undefined abbreviations.
- **Introduction:** A presentation of the background, objectives, and approach for this experiment which prepares audience members with varied interests, experiences, and background knowledge for the subsequent sections of the report. Your audience will enter this section potentially knowing very little about this experiment. What are the objectives of this experiment, and why are they important (historically, currently, or both)? At a basic level, how will you fulfill your objectives? Provide some physical intuition to help the reader understand what a physicist might expect the outcome of the experiment to be, but remember that you are writing for a wide audience. Avoid detailed math, and define any abbreviations you need to use. Remember to cite your sources.
- **Theoretical Background:** A rigorous account of the physics underlying your experiment. For example, if you fit your data to some physical model, you should start with first principles and known equations, and derive that physical model. This will include mathematical steps, *but most importantly, it will include written explanations for those steps – sentences should outnumber equations.* Make sure that a hypothetical PHYS 281 student who has not yet performed this experiment would be able to follow your steps and understand their justifications. Try to strike a balance between presenting enough detail and keeping the math succinct.
- **Methods:** A detailed account of your procedure written with the intent of giving future experimenters the ability to repeat your work, and reproduce your results. Describe the apparatus and/or algorithms you used in detail, and explain how you used them to make measurements and analyze your data. Make sure to include equipment settings and important parameters. Since the target audience of your report is a hypothetical peer who has not yet seen this experiment, make sure to explain your procedure in sufficient detail that they could easily repeat your experiment without a lot of guesswork.
- **Results:** A presentation of what you found. Though it may take a great deal of time and effort to produce results from your experiment, this section should be fairly easy to write. All you need to do is

to present the results of your experiment along with uncertainty. Plots and (to a lesser extent) tables are good ways of communicating your results. This section should not include that many mathematical equations. Instead, refer back to your Theory and Methods sections when explaining details such as how you fit your data, and how measurements were used to calculate your results. Uncertainty analysis should be presented in the result section (including an honest assessment of weird data). Show the formulae you used to calculate uncertainty, and if you did not account for uncertainty in all measured values, justify this. There is, however, no need for exhaustive steps or sample calculations. (Please do not include elementary steps in calculus or algebra.)

- **Discussion and Conclusions:** An interpretation of the previous section. Discuss the meaning of your results – do they support previous hypotheses and agree with previous experiments? Or do they provide evidence against previous work? Also discuss potential sources of uncertainty, and how *specifically* they may have affected your results. (i.e. would the numerical results have increased or decreased?) Try to anticipate questions that your audience might have by acknowledging potential weakness in your experiment or the analysis, and arguing for the sufficiency of your approach. Conclude with a concise rendition of your results, focusing on the big picture. You should *never* write, “From this lab I learned...”
- **Acknowledgments:** For group reports, briefly record how you divided the work amongst yourselves. Be sure to record everyones’ contributions to data collection, as well as analysis, and writing. In all reports, acknowledge any help you received from others.
- **References:** Cite your sources. These should include history and theory from publications, books, or websites. Include numerical citations throughout the text. There is no need to get caught up in any specific bibliography format – just be consistent. Citations should be ordered by first appearance rather than alphabetically.

3 Grading and Due Dates

Each lab report will be graded out of 100 points as follows:

Warmup	-	**5 pts**	(completed prior to lab)
Abstract	-	**15 pts**	
Introduction	-	**10 pts**	
Theoretical Background	-	**15 pts**	
Methods	-	**10 pts**	
Results	-	**15 pts**	
Discussion and Conclusions	-	**15 pts**	
Acknowledgments	-	**2 pts**	
References	-	**3 pts**	
Style	-	**10 pts**	(proper formatting, error-free, and persuasive)

Remember that lab reports must not exceed 5 pages in length.

Lab reports are generally due 30 minutes prior to the start of the following laboratory period. Check the assignments section of Sakai or the course calendar for details.

4 Tips and Common Mistakes To Avoid

The following is a list tips for writing good lab reports. Feel free to suggest additions to this list as the term progresses. This is a long list, and we don’t expect you to internalize everything immediately. Instead, focus on the previous section, and just skim these tips for now. We will draw your attention to specific recommendations as needed.

4.1 General Formatting Issues

- **Figure Labels:** Figure axes should always be labeled with both the quantity being plotted, and the units of that quantity. If a quantity is unitless, you should specify this by writing "arbitrary units," or "a.u."
- **Referencing and Captioning Figures:** When you include figures or tables in your report, make sure to reference and explain them in the text, while also providing a caption that explains them. This means that there will be some redundancy between the text and the caption. A reader should be able to read either and still understand the table or figure.
- **Numbering Equations:** When an equation appears on its own line, it should be numbered sequentially starting with 1. To reference back to that equation later, you may refer to its number. Equations should be numbered even if you never reference them.
- **Tables:** Use tables to present numerical results where a plot is not appropriate. Be sure to put units in the headings (not on every line). Be careful with tables! Your goal is to sell your conclusions to your audience. Before using a table, think to yourself, "Would a plot be a more persuasive way of presenting these results?"
- **Leading Zeros:** For clarity, be sure to include the leading zero in numbers less than 1. For example, write 0.2, not .2.
- **Y vs. X:** When referring to figures, "y vs. x" or "y as a function of x" means that y is on the vertical axis, while x is on the horizontal axis.
- **Italicized Variables, Upright Units:** In your writing, be sure to differentiate variables from other characters by typesetting them in italics. On the other hand, units and numbers should <u>never</u> be italicized. For example, the Bohr radius is $a_0 = \hbar/(m\alpha c) = 0.53 \times 10^{-10}\,\mathrm{m}$, where m is the electron rest mass, but m is length in meters. Also note the space between the number and the unit.
- **Multiplication Symbol:** Use the × symbol (not the letter "x") to indicate multiplication. In LaTeX, you can use `\times`.

4.2 Writing Style

- **Voice:** In technical writing, you generally have two choices: you can write in the **passive voice** ("data was taken"), or in the **active voice** ("we took the data.") You may use either voice in your lab reports, but be sure not to switch back and forth. If you use the active voice, be sure to use first person plural pronouns: "we" – not "I."
- **Equations as Prose:** In technical writing, even though equations usually appear on their own line, they must be presented as part of a sentence. This means that you should use proper punctuation and sentences structure as though each equation were a word in the sentence. Here is an example where this has been done correctly:

  Coulomb's law states that the electric force, F, between two charged particles is

  $$F = k\frac{q_1 q_2}{r^2}, \tag{1}$$

  where q_1 and q_2 are the charges of the two particles, r is the distance between the particles, and k is Coulomb's constant given by

  $$k = \frac{1}{4\pi\varepsilon_0} \approx 9 \times 10^9\,\mathrm{Nm^2/C^2}. \tag{2}$$

- **Repeated Words:** Words or phrases, especially those with two or more syllables, repeated in a small amount of space distract the reader. Moreover, they cause the writing to sound unprofessional. For example:

Avoid: Attach the *pendulum bob* to the string so that the *pendulum bob* hangs freely beneath the *pendulum bob* holder.

Improved Alternative: Attach the pendulum bob to the string so that the mass hangs freely beneath the stand.

Note that while it would be tempting to replace the second instance of "the pendulum bob" with "it," this would lead to an ambiguous sentence: is the bob or the string hanging freely?

- **Affect vs. Effect:** "Affect" is a verb, which can often be replaced by the word "alter." *Example: The power setting **affects** (alters) the brightness of the light.* "Effect" is usually a noun, which can replaced by the word "consequences." *Example: The **effects** (consequences) of air temperature on laser output are negligible.* (Annoyingly, "effect" can also be used as a verb meaning "to produce, cause, or come into being," as in the common phrase, "to effect change." Luckily, this sense of the word will be much less likely to appear in lab reports.)

4.3 LaTeX-Specific Tips

- **Quotation Marks:** Use `‘‘` for open quotes (that's two presses of the key to the left of the number 1 on your keyboard), and `''` for close quotes (that's two presses of the apostrophe key). This will produce nice-looking quotes like "this." If you use the quote marks key, you will get ”ugly-looking backwards quotes.”
- **Typesetting Units:** Use the `\mathrm` command to produce non-italicized units in the equation environment. For example, to get $\Delta x = 5.3\,\mathrm{m}$, I wrote, `$\Delta x = 5.3 \, \mathrm{m}$`. I also inserted a comma-length space between the number and the units using the `\,` command.
- **Multi-Character Exponents and Subscripts:** To write e^x, you may simply type `e^x`, but if you want a more complicated exponent such as $e^{x^2+y^2}$, you need to wrap the exponent in braces: `e^{x^2 + y^2}`.
- **Big Parenthesis:** As seen in

$$\sigma_y = \sqrt{(\frac{\partial y}{\partial a})^2\sigma_a^2 + (\frac{\partial y}{\partial b})^2\sigma_b^2}, \tag{3}$$

the `(` and `)` symbols make small parenthesis that look ugly when used with fractions. To make parenthesis that automatically adjust to be the correct height, use `\left(` and `\right)`. The result is

$$\sigma_y = \sqrt{\left(\frac{\partial y}{\partial a}\right)^2\sigma_a^2 + \left(\frac{\partial y}{\partial b}\right)^2\sigma_b^2}. \tag{4}$$

Much better! The same logic applies to other grouping symbols such as `\left[` and `\left{`.

- **Referencing Equations, Figures, and Tables:** When you add a label to an equation using the `\label{}` function, you can use the `\ref{}` function to reference that equation by number, even if the order of the equations changes. For example, Coulomb's law is expressed in Eq. 1.

The LaTeXcode for Eq. 1 is

```
\begin{equation} \label{eq:coulomb}
F = k \frac{q_1 q_2}{r^2}
\end{equation}
```

...and the previous sentence's LaTeXcode is

```
For example, Coulomb's law is expressed in Eq.\,\ref{eq:coulomb}.
```

I arbitrarily labeled the equation as "eq:coulomb," and then referenced it using that same key in the `\ref{}` function. The same principles apply to other objects such as figures and tables.