# Lab-report writing guidelines
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## 1. General

The lab report is the document that describes the experiment setup, the physics behind it, the results from the experiment and what can be concluded from them. For this class, we want you to learn how to write an article in the style of a scientific journal. So, forget about including hand-drawn graphs or street lingo. It has to look as something you would send to a serious journal for publication. You should assume your audience to be physicists with the same knowledge as your peers, but without a detailed knowledge of your experiment.

Our lab reports will be *at most eight pages*, including tables and graphs, and will have the following structure (with corresponding grade percentages): title (5%), abstract (10%), introduction (15%), theoretical background (20%), experimental procedure (15%), analysis (20%), conclusion (10%) and references (5%). Make these parts of the lab easy to identify with sections headings and numbering because they are graded separately. Some journals (in particular the Physical Review Letters (PRL), which you should see as a good model to follow) do not strictly follow this structure, but this will make good practice.

Here are some general but useful tips:

- It is not possible to write a good lab report in one shot in a couple of days. Always start with a draft, proofread and come back to this guideline and use it as a checklist. Then go back and produce a second draft. Repeat this process until you are satisfied with your report. This process of drafting and "grooming" is essential and is how physicists publish. Nobody ever goes to print with their first draft.

- Read from more than one source. Your class textbook will rarely be enough. Look up more advanced books like graduate physics textbooks, relevant research papers (those from the American Teachers Journal are a good source) and websites. Your depth of knowledge about the topics you discuss is absolutely transparent in your text, and will of course weigh in the grading.

- A method that works for many people is to write first the experimental procedure, the analysis and the conclusion, and only afterwards the title, the abstract and the introduction.

## 2. Scientific writing

One of the most important features of modern scientific articles is *conciseness*. As the amount of information out there for someone to read is simply too much, people specialize in particular topics and want to find and read through relevant information fast. It is thus important to reach a balance between detail and briefness in writing a paper. When editing your paper, ask yourself the following questions: Would eliminating this line make my paper unreadable or illogical? Is this line relevant enough to be included?

A related and equally important point is *objectivity*. When interpreting the scope of your results, what matters is your logical thoughts and your reasoning, not how excited you are, or whether you were sitting on a chair or a stool. For example, *"We then saw beautiful circular patterns on the glass!"* sounds subjective because of the word *"beautiful"* and the exclamation point. Your writing style should be impersonal and somewhat detached.

Here are a few tips on how to write a clear, objective paper:

- Every paragraph should deal with a specific point. A too long paragraph is usually one that would be clearer if split. Aim to write paragraphs with at most five or six lines.

- The most important line in a paragraph is the first one. A paragraph's first sentence should hint the reader what the rest of the paragraph will be about.

- Use a mixture of the active and passive voice. Any sentence can be written actively or passively. For instance, *"The tiger caught a steer"* is written in the active voice, and *"The steer was caught by the tiger"* is in the passive. Using too much of the active will draw too much attention to yourself while using too much passive will make it seem as though you were never directly involved in the experiment.

- Mix short and long sentences to make your text more lively. Too many short sentences will make your text sound choppy, and too long sentences are always difficult to read.

- Use the right terms. If you use slang, your readers will take your paper less seriously. For example, *"The electrons are 'boiled off' the cathode by an AC voltage"* sounds too informal because of the expression *"boil off"*, even if boiling is a good analogy of the real phenomenon. *"The electrons are thermoionically separated from the cathode, after applying an AC voltage to it."* sounds better. A scientific paper is supposed to be technical, so use the correct technical terms.

- Refrain from using contractions. Write "do not", not "don't".

- Use a spell checker and look up people's names before writing them. "Versus" is not spelled "verses", and "Max Planck" is not "Max Plank".

## 3. Title

The first crucial point you want to know is that *the title and the abstract always form a self-contained unit*, separate from the rest of the paper. When readers browse through scientific journals or electronic pre-print archives, they are usually only interested in very specific topics. Usually, websites show a list of titles and upon clicking on a title, the abstract is displayed. The title, then, should give readers as much information as possible about the paper, so that readers can decide whether they want to read the abstract, and perhaps the rest of the paper.

Good titles are rich in keywords and specific terms, and have as few inessential words ("investigation", "experiment", "lab") as allowed by grammar and syntax. A readable title should be also concise, so aim at writing yours in one line.

Write your title in boldface and in a font slightly bigger than that of the rest of the paper. Under the title, write your full name and the name of your institution (UT Austin). Do not refer to the class (PHY353L) or to "the lab".

Example 1:

**Spectral lines of Na and He using a monochromator**
*Name Lastname*
Physics Department, University of Texas at Austin

Example 2:

**Microwave diffraction with a Gunn diode**
*Name Lastname*
Physics Department, University of Texas at Austin

Examples of bad titles: "Black Body Experiment", "Speed of Light Lab".

## 4. Abstract

The abstract is the second part in the self-contained unit mentioned above. In essence, the abstract is a short version of the article, and it has almost the same parts as the paper as a whole. The abstract has a motivation, describes the experiment, and lists the results and the conclusions.

The abstract should be a single paragraph of no more than eight lines. Avoid starting the abstract with inessential phrases such as "In this experiment, . . . ". The "Abstract" title should be centered and is never numbered.

Never refer to literature or to an equation in the body of the paper. Doing so would force the reader to look at the rest of the paper, and would defeat the purpose of our self-contained unit. Never add tables or figures either, as the idea is to keep the abstract short.

Avoid writing equations, but if you do, write them in the same paragraph as the rest of the text, without going over to a separate line, and explain the notation. Write numerical results with uncertainties, physical units and the correct number of significant figures. Do not forget to mention whether the theoretically expected values agree with your numerical results within the bound of uncertainty.

Example:

Abstract

Microwaves facilitate the study of optical phenomena, as scales are in the order of centimeters in contrast to microns. We measured Brewster's angle of a polyethylene panel using a Gunn-diode microwave transmitter and a resonant-cavity microwave receiver. For the 2.85 cm microwaves produced by the transmitter, we found a Brewster's angle of (57.8± 0.4) degrees, which agrees with the literature value of 57.6 degrees. These results are in accord with the theory of reflection and refraction of light by a medium.

## 5. Introduction

The purpose of the introduction is twofold: it provides the general motivation for doing the experiment, and it embeds your work in a larger research context. Good introductions accurately describe the current state of knowledge in the area where your work belongs, and correctly assess the true impact of your research.

Since the introduction has a persuasive goal, its structure is more crucial than that of other sections. We will follow a *three-paragraph structure*. Each paragraph has a very specific role as we will see below, and it is vital that you respect these roles.

The first paragraph reminds the reader about the current status of the broader area of physics of which your work is part. You should avoid going to the extreme of being overly general or ambiguous. For example, if your paper is about the superconductivity of YBCO, then your first paragraph should talk about high-temperature superconductors, the lack of a microscopic theory to describe them, and the possible future applications they could have. See this example of first paragraph about special relativity:

> The theory of special relativity is extremely important in modern physics. It describes many phenomena, such as time dialation, which contradict classical theories of physics for fast- moving reference frames but which agree with classical theories when all reference frames are moving much slower than the speed of light [1]. These phenomena have been experimentally verified and differences between classical theory and relativistic theory are significant for high-velocity reference frames. Thus, relativity theory is vital for performing experiments and calculations in many fields of physics today.

The second paragraph explains how your research connects with previous work on the topic. Here it is absolutely important to *cite as many relevant references* as you can. Being thorough about this tells that you are knowledgeable about the present state of research on the area, and that you are aware of what has been done and what has not. This clarifies what your experiment is supposed to prove, or how it improves other people's work. Every article you cite must be listed in the References, and here you just need to write its reference number to cite it ("Anderson *et al* [2] proved that . . . "). See the following example of a second paragraph about the Franck-Hertz experiment:

> The theoretical foundation for the Franck-Hertz experiment began in 1814 when Fraunhofer realized that certain atoms emitted light with wavelengths corresponding to dark lines in the solar spectrum [1]. Another important discovery that preluded the Franck-Hertz experiment occured in 1900, when Planck discovered that energy is quantized. Planck's dis- covery eventually led to Bohr's atomic model, in which he hypothesized that atoms have only quantized energy levels and that atoms can only absorb and emit energies equal to the difference in energy between two quantized energy levels [2]. Bohr proposed an experiment to test his hypothesis, which was unwittingly performed in 1914 by Franck and Hertz, even though Franck and Hertz were unaware of Bohr's hypothesis [3]. The results of the Franck-Hertz experiment not only provided strong evidence for Bohr's atomic model but also agreed with earlier experiments on spectral lines, which further supported the idea of quantized energy levels in atoms.

In the third paragraph you should summarize your experimental procedure, emphasizing the technique and the components. It is not customary to write numerical results here, but in any case you can describe qualitatively what you obtained in the experiment. You should describe your steps using the *past tense*. See this example of third paragraph about Brownian motion:

> For this experiment, we used a dilute solution of 1 $\mu$m diameter latex spheres in water and measured their motion using a video camera. We then used a computer to find the precise displacement as a function of time for many latex spheres observed. We then plotted the displacement vs. time of the microspheres, and from the slope of this graph we calculated the Boltzmann constant.

## 6. Theoretical background

The Theory section has two goals: to introduce the theory underlying the experiment, and to show or deduce the equations that you will use in your Analysis section. Without the theory, the experiment would just be a bunch of funny observations with no logical explanation. Also, the equations of the theory will allow you to test it quantitatively (in the Analysis section) and to see whether the theory is consistent.

First, you should strive to keep your discussion relevant to the experiment. You do not need to explain or define too basic concepts (kinetic energy, capacitance, angular momentum, etc.), nor give their formulas, which are assumed to be known by the reader. The other extreme is non-trivial concepts that are only partially relevant to the discussion, but whose explanation would require too much space. For example, in the electron diffraction experiment, thermionic emission is important because it is what allows the metal electrons to become free, but it is not the main point the experiment. In these cases, you should simply write a brief description of these concepts, and cite one or more references where the reader can find more information about them. Example:

> Superconductors are classified as either Type I or Type II. Type I superconductors are usually pure metals, and have a very low critical temperature and critical magnetic field [5, 6]. Type II superconductors [7] are normally ceramic compounds, and many of them have a high enough critical temperature that they can be taken to their superconductive state using inexpensive liquid nitrogen. Our YBCO disk is a Type II superconductor.

In general, do not be sparing in *citing literature*, both for relevant and irrelevant parts of the theory. They connect your paper to previous work or basic literature on the topic, and make your paper much easier to read to beginners.

Formulas are vital in the Theory section, and can be numbered and written in a new line if they are important enough, or they can simply be embedded in a paragraph like the rest of the text. If an equation is short, too basic or you will not refer to it anywhere else, just keep it in the paragraph. On the other hand, if the equation is long or it will be referred to in the data analysis or at any other point, do put in a separate line.

Equations in separate lines should be centered and numbered. The formula number should be written inside round brackets, next to the right margin of the paper. Also, although an equation in a separate line is not explicitly inside a paragraph, it still continues to be part of the preceding paragraph, and so the rules of punctuation still apply. One normally puts a comma or a period at the end of the formula, depending on whether you want to end or continue the paragraph. In any case, new notation introduced by the formula should be explained right below it. Example:

> (...) with wavelength $\lambda$. The relativistic expression for the electron's energy $E$ is
>
> $$E = \sqrt{p^2c^2 + m^2c^4}, \tag{1}$$
>
> where $p$ and $m$ are electron's momentum and mass, respectively, and $c$ is the speed of light.

If you wanted to refer to this equation at a later point in the article, you should write "See Eq. (1)".

On the other hand, you avoid showing the full algebraic derivation of any formula. You should just give enough algebraic steps for the reader to be able to follow, and, more importantly, the physical arguments that support the derivation. Remember that the physical arguments are more important than the algebra itself. Example: You want to explain in your lab that an electron is accelerated by an electrostatic potential from A to B, starting from rest, and you know that at A the kinetic energy is zero and the potential energy is $eV$, while at B the kinetic energy is $mv^2/2$ and the potential energy is zero. Then, by conservation of energy, $eV = mv^2/2$. All this can be said concisely:

> An electron accelerated from A to B by an electrostatic potential $V$ will have a final kinetic energy $K = mv^2/2 = eV$ at B, by conservation of energy.

Finally, do not forget to include any expected values of constants or other quantities against which you want to compare your numerical results. For example, if your goal is to verify Bragg's law, and part of this verification is to check that you get the correct lattice spacings of graphite, then the known graphite spacings should be mentioned in the Theory section (citing the corresponding source), not in the Analysis.

## 7. Experimental procedure

The Experimental procedure section gives a detailed description of the experimental arrangement, its components, and the steps followed by you and your partner. The amount of detail should be enough for someone else to duplicate your experiment.

Since your experiment is a real event that occured at some point, as opposed to an idealistic or a future one, you should write sentences in the *past tense* (e.g., "We measured the voltage using ..."). Also, it is customary to write this section in *narrative style* (e.g., "We measured the resistance using a multimeter. Next, we turned on the power supply and took measurements of voltage and current ..."), as opposed to enumerating the experiment's steps.

Avoid writing in the manner used in cookbooks, so do not write a list the experiment's materials. Instead, mention every device's model name or number along the way as you explain the experiment ("We used a Keithley 2299 multimeter to measure ...").

For every quantity measured in the experiment, mention what device was used to measure it, in what increments, in what range, or in what scale, and with what uncertainty.

An important part of this section is the *schematic diagram* (See Fig. 1). This should be a drawing of the circuit or arrangement of components, including how each component was connected to the others. Never draw devices in innecessary detail (i.e., do not draw buttons, knobs or panels). If drawing an electric circuit, draw the usual symbols for resistance, capacitance, diodes, etc. Never include photographs of the equipment, as a diagram will actually be much clearer for someone who wants to duplicate the experiment.

Finally, avoid describing failed attempts and irrelevant or obvious steps in the procedure ("We checked the connections ...", "We wrote down the data ...").

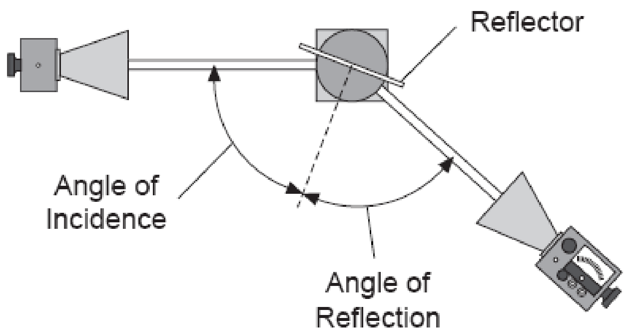


Figure 1: Example of a schematic diagram.

## 8. Analysis

The Analysis section has two objectives: to present a summary of the gathered data, and to show the logical implications of the experiment.

Normally, the amount of information obtained in the experiment will be too much (e.g, 200 measurements) to be shown in the lab report. Thus, data is usually put in a graph, if appropriate, or summarized in a table of representative quantities such as averages and standard deviations. On the other hand, you should show only as many graphs or tables as necessary. See more about style of graphs and tables in the corresponding sections below.

An important point is that the Analysis section is not the right place to introduce theoretical information, concepts or formulas. All that should have been discussed in the Theoretical background section. In the Analysis section you simply use the concepts and formulas already presented, and infer results and conclusions.

Numerical results should be presented with the *correct physical units, uncertainties, and the right number of decimals and significant figures.* Failing to do this is an apparently innocent, but actually terrible mistake. Physical units tell what physical quantity the measurement represents , and uncertainties, significant figures and decimals tell the accuracy of your measurement. Missing any of these elements makes your numerical result *meaningless.*

Numerical results are also usually compared to quantity known from the theory or from previous experiments. These expected values of the measurements should have been mentioned in the Theory section. In the Analysis, you should compare your numerical results to the expected ones, declaring whether the expected value agrees with the numerical result within the bounds of uncertainty. Example:

> (...) Our calculated value of Planck's constant, found using Eq. (3), is $(4.09 \pm 0.06) \times 10^{-15}$ eV$\cdot$ s. This agrees with the known value of $4.15 \times 10^{-15}$ eV$\cdot$s within error bounds.

Of course, to have written uncertainties, you need to have done an error propagation analysis before writing this section. That said, never write any error propagation formulas in this section. We will check your error propagation formulas when you present your paper draft, but you do not need to include them in the paper.

To finish the Analysis section, write what can be concluded from the results (i.e., was the theory verified by your observations?), explain the main sources of error in the experiment (refrain from mentioning human error), and describe ways in which the experiment could be improved. If your results did not agree with the theory, explain why this could have happened.

## 9. Conclusion

The Conclusion summarizes the results of the experiment. To begin, remind the readers what the experimental setup and the objective of the experiment were. Next, write the main results, including numerical results as well as the theoretical or expected values corresponding to them, and mention whether the theory was verified by the results or not. Preferably, write your conclusion in one paragraph with less than eight lines.

Be careful not to exaggerate in what can be inferred from the experiment. For instance, never say that you "proved a theory" (a theory can only be verified, never definitely proven), or that "these results are only possible if (...)" (exclusive words such as "never", "only" are subjective unless used in a mathematical sense). Use moderate expressions such as "our results are in accord with the theory", "our results verify the predictions of such theory", etc.

## 10. References

This is an enumerated list of all bibliographical sources cited in your report. You should number your references in the order in which they were cited in the text. The references are the place where more information can be found about topics discussed only superficially in your article.

As an example, we show how to cite a journal article, a book and a website:

> [1] A. A. Belavin, A. M. Polyakov, A. S. Schwarz and Yu. S. Tyupkin, *Phys. Lett.*, **59B**, 85 (1975).
>
> [2] S. Coleman, *Aspects of superconductivity*, Cambridge University Press, Cambridge, 1985.
>
> [3] Physics IL Classical Mechanics, MIT Open Courseware, `http://ocw.mit.edu/OcwWeb/index.htm`. Retrieved April 12, 2009.

Notice the reference numbers, [1], [2], [3]. The reference [1] should be the first one to be cited in the paper, the reference [2] the second one, and so on. The journal title is usually written abbreviated in italics ("*Phys. Lett.*"); the journal volume is commonly written in boldface ("**59B**"); the page number is written in normal text ("85") and the year is written in round brackets ("(1975)"). Notice that the website URL is written in monospace style.

## 11. Tables

Every column in a table should be labelled with the name of the quantity corresponding to the column and its physical units. Table entries should have the right number of decimal

| Angle (deg.) | Voltage (V) | Current (mA) (± 0.01 mA) |
|---|---|---|
| 0.31± 0.01 | 0.066± 0.011 | 0.7 |
| 0.42± 0.01 | 0.048± 0.021 | -0.5 |
| 0.46± 0.01 | 0.023± 0.017 | -0.5 |
| 0.49± 0.01 | 0.038± 0.010 | -0.5 |
| 0.53± 0.01 | 0.037± 0.009 | -0.5 |
| 0.58± 0.01 | 0.057± 0.012 | -0.5 |

Table 1: Example of table.

places, significant figures and should include uncertainties. If all the entries share the same uncertainty, you can write it together with the column label. If different entries have different uncertainties, put the uncertainties on the same column as the main values, separating main value from uncertainty with the symbol ±. See Table 1 for an example.

Centered below the table, you should write a caption such as "Table 1.". Here you can add a brief description of the table contents too.

Tables should be embedded in the article (as opposed to put at the end of the paper), and should be placed as close as possible to the part of the text where they are referred to. Always refer to a Table by its number (e.g., "See Table 1.", not "See table below."). Tables should be numbered according to the order in which they are referred to in the text, and they are enumerated separately from Figures.

## 12. Figures

All diagrams, plots, graphs and pictures (but not tables) are referred to collectively as "Figures". Figures should be enumerated in the order in which they are referred to in the text, and they are enumerated independently from Tables. Figures also have a caption centered below them. Figures are similarly placed as close as possible to the part of the text where they are mentioned. To refer, we use its number (e.g., "See Fig. 1'.', not "See figure below'.').

Plot axes should include the name of the quantity to which they correspond ("Length squared", "Diffraction angle", etc.) and correct physical units. Physical units can be accompanied by powers of ten to avoid writing too big or too small numbers (e.g, "$10^3$4 cm.V.s").

All data points in a plot should include error bars. Of the two quantities being plotted, one will usually have considerably bigger error bars than the other. (Experiments are normally designed to depend on a parameter with relatively low uncertainty.) *The quantity with the bigger error bars should always go on the Y-axis.* This is because most statistical formulas (least-squares fits, $\chi$-square parameter, etc.) depend only on the error in Y and ignore the error in X. In this sense, it is acceptable to not include X-axis error bars in your graphs.

If a graph includes a least-squares fit or another kind of fit, the fit equation should have uncertainties in all its coefficients. This is crucial because results are usually computed from these coefficients, and if these don't have uncertainties, neither will your results, which is unacceptable. On the other hand, as the full equations can be a bit long, it is sometimes better to put the fit equations in the text body, not in the figure.

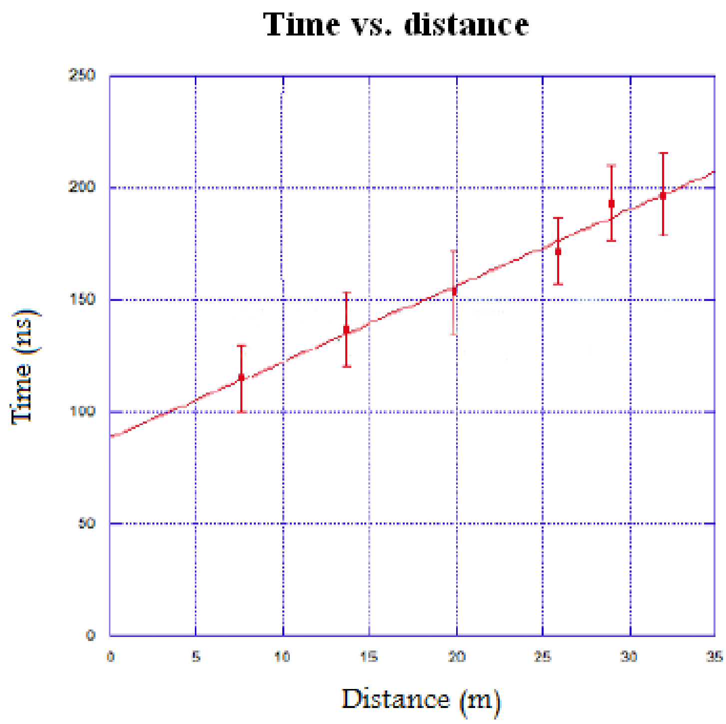


Figure 2: Example of a figure. Notice error bars, axes with names and physical units.