Lab Notebook and Report Guidelines

Physics 128 Summer 2024

Kelly Pawlak, David Cannell, and Everett Lipman

Lab Notebook

Your lab notebook should be a complete record of the entire experiment that anyone with a physics education can read and make sense of *without the manual*. Notebooks will be graded as follows:

Clarity, neatness, and records (10 points): Your lab notebook should be easily readable, with pages in chronological order. It should contain a record of the procedures you performed, when they were performed (which day, and if necessary, at what time), and whom you were working with. A brief description should be presented prior to each measurement, preferably with relevant equations numbered for reference. Any anomalies or problems with processes and equipment should be documented as they are found so you can later support any hypotheses you develop regarding unexpected results.

Work required by the lab manual (20 points): Your lab manual-related work should be clearly indicated (for example, boxed, set apart with a large title, or starred). Specify the number of the problem, or if it is not numbered, the manual page on which it appears. See the end of this handout for experiment-specific exceptions to what is required by the lab manuals.

Raw data and computed quantities (20 points): Data should be neatly recorded in tables with uncertainties. Relevant observations/comments should follow immediately after the raw data are presented. If your data are digital, you can print raw plots and include them with the notebook copy. You should then email the TA a copy of your digital data by the lab report due date. Any comments and observations should still be written in your notebook. *Your data must always explicitly include your uncertainty estimates.* For digital measurements, report the uncertainty given in the equipment documentation. If that is not available, and you cannot determine the uncertainty in any other way, assume an uncertainty of one count in the least significant digit. Computed quantities should be clear and reference by number any relevant equations from your summary.

Error discussion and analysis (30 points): You should designate a *separate page* (or more, if necessary) for deriving the error propagation related to each formula your data analysis requires. Work should be presented at a level of detail sufficient for the reader to see, for example, how you computed derivatives of complex expressions. Final equations should be numbered. Include a discussion of overall uncertainty which references these derived equations by number, and clearly explains why you have chosen to include or neglect various contributions to your results.

Results, conclusions, and discussion (20 points): The final page(s) of your notebook for a given lab should summarize the experimental results and explicitly compare measured and accepted values, noting whether the differences are in accord with your estimated uncertainties. You should briefly record, based on your observations and understanding of the relevant physics, where problems, if any, arose in the experiment. Identify your largest source(s) of error and make a note of how you think the experiment could be improved, if possible.

Writing Your Lab Report

You may at first find writing a good report challenging, as in very hard to do well. In a nutshell, you must learn to think as much like someone in your intended audience as you can. The same idea applies to preparing a research talk, giving a lecture, etc. This means taking a large mental step back from the experiment you have just carried out, or the theory you have just developed. The problem is that you know pretty much everything about what you have done, but your reader doesn't know much at all, and even worse, may not be sure he or she even cares! To combat this situation, you must use the first paragraph or two to convince the potential reader that your report is worth further scrutiny.

Once you have the reader interested, you must retain that interest as long as you can. The best way to do this with another physicist is to be clear, and this means you must develop your results step by logical step. Ask yourself, "Where can I begin, that is likely to be easily understood?" Then ask, "What can I add next that builds on what I have already written?" Go along in this way, building up an organized logical presentation of your work step by step. Always read what you write with the mindset that you don't know anything about it, except what you have already read. This is all easier said than done! In the early stages of the writing process, a well-thought-out *outline* can be very helpful.

Clear writing will be critical in your future career; physicists who write well are the ones who get research funding in academia, and they are the ones who rise to positions of major responsibility in industry (which is where most physicists spend their professional lives).

A Physics 128 lab report should be a concise description of your work on and results from a given experiment. Each report should start with a page containing only the title and abstract, followed by no more than 4 pages of text (using normal fonts and margins). Your grade will suffer if your report significantly exceeds this limit for no good reason. There is *no limit on the number of figures, tables and equations*, which do not count toward the 4-page text limit. All figures and tables must include brief captions.

Prepare your report using LaTeX in a **double-spaced, single-column format** ("preprint"). Reports will be graded as follows:

Title and abstract (10 points): Choose a descriptive title and write a concise stand-alone summary of what question you investigated, what measurements you made, what results you got, and the conclusions you reached. There are no hard and fast rules, but you should devote about one sentence to each of these four items. Your abstract should explicitly report the *value(s) obtained* with uncertainties, the *accepted value(s)* with uncertainties, and *whether or not these are mutually consistent*. Abstracts for actual research papers are placed in searchable data archives and read without the paper, so you must be able to convey the essence of your work in this format.

Introduction (20 points): Provide the reader with a short summary of the context for your work, what you have done, and why it is important. This is your chance to get the reader interested enough to read the rest of the report (the abstract got them to this point). This section should include a very brief overview of the relevant physics, with important equations numbered using the LaTeX environment. The background discussion should be connected clearly to your experimental procedure. For example, if you are investigating the value of the gravitational constant G, you should tell your reader that you are using a torsion balance, how the measurement works, including relevant equations as necessary, and why this approach was chosen. Historical narratives about the origins of various physical laws or experiments are unnecessary and are discouraged.

Experimental Methods (10 points): Explain how you did the measurement. This should be a few paragraphs with at least one diagram or photo. Describe your apparatus, the signal path from sensor to raw data, and how your data were recorded. If your experiment required calibration, give a summary of your calibration data, uncertainties, and procedure to convince your reader that it was done properly.

Raw Data (20 points): Present the raw data *with uncertainties*. These data should be in a table and/or a graph with error bars if appropriate. You should explicitly and quantitatively identify sources of systematic and random errors as appropriate.

Results (30 points): Present your analyzed data as one or more tables or plots. *Use relevant physical variables.* For example, plot intensity versus calibrated wavelength rather than intensity versus scan time. You must provide in this section the final equations you used to propagate any significant sources of error. Make sure your results are connected to the underlying physics. Large discrepancies between final results and accepted values should be accounted for in a quantitative way, using the relevant equations, your propagated uncertainties, and your understanding of any important systematic errors that may be present. This section should make clear how much each important source of error contributes to the uncertainty in your final result. The reader should be convinced that you have neither underestimated nor overestimated the precision of the measurement.

Discussion (10 points): Explain why your results from the previous section did or did not meet the expectations you had for the precision of this experiment. If your results are poor, try to provide a convincing and complete explanation for why. Regardless of how good your results are, discuss how the experimental precision and/or accuracy could be improved, making use of concepts from your error analysis. For example, by how much could you improve the final results by increasing experiment run time? Discuss how improved or alternative experiments could give more accurate or precise results.

General considerations: Avoid “unscientific” descriptions such as (but not limited to): “around x”, “like x,” and “probably” — be specific and quantitative. Do not tell your reader you have a “big noise-to-peak ratio.” State roughly what the ratio is, even if it is an estimate. If you are claiming your results have been affected by something, give supporting evidence. Also, remember that this is a physics experiment and your data must ultimately be described in terms of the physical phenomena and equations.

Rules for Figures

Every figure must have a caption, which is a few sentences saying what the figure is. You must provide captions even if the text is perfectly clear about the figure, as it should be. The reason for the captions is that an expert in the field should be able to look at your figures, read the captions, and pretty much know what you have done and what he or she thinks of it. For this reason, preparing all the figures and the captions early in the writing process is a good idea, and usually makes it much easier to write the report.

Figures should be placed in the text near, but after, where they are first mentioned. Sometimes it is necessary to place figures at the top of the same page where they are first mentioned, but placement on previous pages should be avoided. Each caption goes right under its figure with a small space separating them. A figure should be identified at the beginning of its caption. For an example, see Fig. 1, a graph I made of the wind speed at National Airport when I was trying to figure out the best time of day to go sailing out of Alexandria, VA.

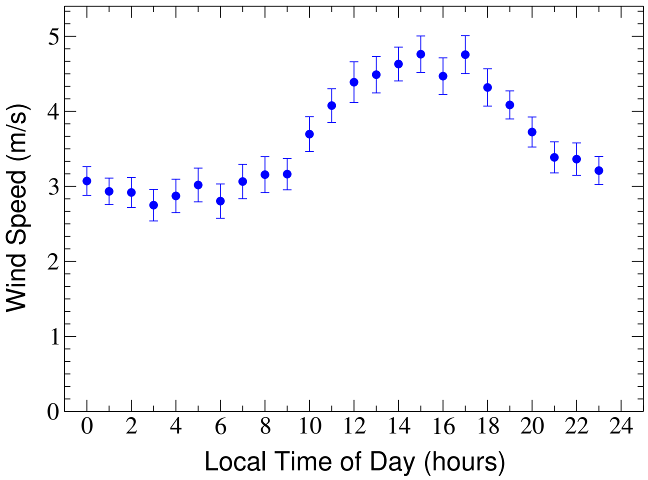

Figure 1: Wind speed at National Airport, August 14, 2001–October 20, 2001. Data shown are averages of measurements gathered from the National Airport website at one-hour intervals over a 67-day period. 1-σ error bars represent sample standard deviations. The data clearly indicate that the best time for sailing on the Potomac is mid-afternoon.

Another rule about figures is that you ***must*** refer to each figure in the text, and you must refer to them in order. You cannot refer to Fig. 2 before you say a word about Fig. 1, and you cannot just avoid saying anything at all about Fig. 3!

You should use symbols and axis labels that are large enough so that when you reduce the figure to a width of 8 cm, the result is clear and pleasing to the eye. The reason for this is that most figures are reduced to single-column width in journals, and the columns are 8.57 cm (3 3/8 inches) wide for most physics journals.

To show both data and theory on the same graph, use discrete symbols for the data, and a smooth curve for the theory. This is quite important. Remember that theories are continuous, and data are not. ***Do not connect adjacent data points with straight lines!*** While this provides some measure of comfort to people who blush at the sight of naked data, you are a physicist, and should realize that straight lines between randomly scattered data points are not only meaningless, they are misleading. Only data and theoretical curves should appear on graphs.

Each data point on a graph should have 1-σ error bars to indicate the measurement uncertainty[1]**.** The only exception to this rule is when error bars would result in too much clutter, for

---

[1] Error bars should represent 1 σ of uncertainty *in the point you plotted!* For example, say you made ten measurements of a pendulum period at each of five different angles, and you found the standard deviation was 0.05 s for the

example with multiple data sets. In that case, it is good to indicate the uncertainty in the figure caption, or in some other manner. Uncertainty in your measurement of the independent variable (x) is often small enough that horizontal error bars are not needed. If this is not the case, you can use both vertical and horizontal error bars.

Color can be very effective in figures (see Fig. 2), but should be used with restraint. In a graph, only color those few items which you choose to highlight, leaving most of the figure in black and white. Avoid meretricious use of colored text and backgrounds. Never use yellow on a white background.

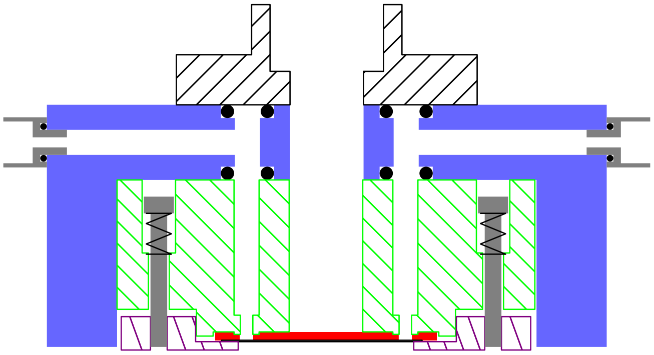

Figure 2: Microfluidic device clamp. This figure, drawn by UCSB physics graduate student Shawn Pfeil, takes good advantage of color, but uses cross-hatching so that the figure is still useful when printed in black and white.

Some journals print only in black and white, and others charge very high prices to print color figures. Design your color figures so that they are still effective in black and white. In Fig. 2, cross-hatching is used so that different parts of the apparatus will be distinct in black and white.

Plot different data sets using different symbols. Common choices for symbols to represent data are solid circles, squares, triangles, and inverted triangles, as well as crosses, plus signs, and asterisks. Different theoretical curves are distinguished by solid, dashed, dotted, and dash-dotted lines.

Style and Content Guidelines

In order to make your report look professional, you should pay attention to the following rules:

- Use only metric (SI) units.
- Plot physical quantities of interest, not readings from your meter. If you are using a diode-array spectrometer, plot wavelength, not diode number. If using a laser power meter, plot

---

ten measurements at 30°. If you make a quick and dirty graph for which you select one measurement at random from each of the 5 angles, then the size of the error bars should be 0.05 s above and below the point at 30°. If, on the other hand, you choose to average the measurements and plot the mean value for each angle, then your error bars should represent the *standard deviation of the mean!* In this case, for 30°, that would be $\sigma/\sqrt{N} = 0.016$. See section 4.4 of Taylor's book for more information.

milliwatts of optical power, not millivolts of meter output. If your calibration is uncertain, say so.

- Variables representing physical quantities and constants are set in italic type: $F = ma$, not F = ma.
- Units are set in upright (not italic) type: 5 m/s, not 5 *m/s*.
- Use a space between a quantity and the associated units: 15.0 cm, not 15.0cm.
- In order to keep from splitting proper names and value/unit pairs at line breaks, use a ~ character to produce a non-breaking space: 1.0 m/s is written `1.0~m/s`.
- Properly typeset compound units: $\mathrm{mL\cdot mg^{-1}\cdot cm^{-1}}$,

  `mL\ensuremath\cdot mg$^{-1}$\ensuremath\cdot cm$^{-1}$`,

  not mL/mg/cm. The second form is ambiguous.
- When quoting an uncertainty, place the units (with a space) after the uncertainty[2]: 15.0 ± 0.2 cm, not 15.0 cm ± 0.2.
- Properly typeset equations: Ae^{-Bx}, not A*e^(-B*x).
- Set multi-letter subscripts in upright (roman) type: F_g or F_gravity (less desirable), not $F_{gravity}$. LaTeX does not space words properly in math mode, so you must do this, for example: `$F_\mathrm{gravity}$`, not `$F_{gravity}$`.
- When typesetting math, do this, which requires `\usepackage{amsmath}`:

  $$\int \left\{ \frac{d\left(\mathrm{cabin}\right)}{\mathrm{cabin}} \right\} = \mathrm{houseboat}$$

  ```
  \[ \int \left\{ \frac{d\left(\mathrm{cabin}\right)}{\mathrm{cabin}}
  \right\} = \mathrm{houseboat} \].
  ```

  Do not do this:

  $$\int \{\frac{d(cabin)}{cabin}\} = \log(cabin)$$

  ```
  \[ \int \{ \frac{d(cabin)}{cabin} \} = \log(cabin) \]
  ```
- When using nested delimiters, do this:

  $$\left\{\frac{\left[\frac{f(x+2h)-f(x+h)}{h}\right]-\left[\frac{f(x+h)-f(x)}{h}\right]}{h}\right\}, \quad \textbf{\textit{not}} \quad \left(\frac{\left(\frac{f(x+2h)-f(x+h)}{h}\right)-\left(\frac{f(x+h)-f(x)}{h}\right)}{h}\right).$$
- Keep the size of your report PDF file reasonable. If it exceeds 10 MB, you probably have photographs included at excessive resolution. Crop them or reduce the resolution. LaTeX can display the image at any size you like, regardless of the resolution.

---

[2] Strictly speaking, you should write 15.0 cm ± 0.2 cm or (15.0 ± 0.2) cm (see, for example, A. Thompson and B. N. Taylor, *Guide for the Use of the International System of Units (SI)*, NIST Special Publication 811, 2008). So long as there is no ambiguity, however, the form suggested above is fine for this class.

Exceptions to work required by lab manuals

You are required to do the exercises and answer the questions in the lab manuals for each experiment as follows. All titles refer to the links on the course web page.

- **Cavendish.** Complete all exercises and answer all questions.
- **Cloud Chamber.** In the *Lab Manual* by Ben Monreal, follow all instructions and answer all questions. Do all "Basics" experiments in section 4.1, but in section 4.2, do only "Multiple Scattering."
- **Electron Properties.** Complete all exercises and answer all questions.
- **Gamma Ray Spectroscopy.** In the *Gamma Ray Introduction* manual by Ben LaRoque, complete goals 1, 2, and 4, answer all questions, and follow the directions in section 4.
- **HD Shift.** Complete all exercises and answer all questions.
- **Interferometry.** Complete all exercises and answer all questions.
- **Johnson Noise.** Complete all exercises and answer all questions.
- **Laser Properties.** Complete all exercises and answer all questions, except in the section on the Zeeman effect, which cannot be measured with our equipment.
- **Mössbauer Spectroscopy.** Do all exercises, plus analysis questions 1, 2, 3, and 5. If you are unable to answer the analysis questions in one lab period, move on and come back later as time permits.
- **Muon Lifetime.** Complete all exercises and answer all questions. If any part of the lab cannot be completed because of equipment problems, contact your TA and the staff immediately.
- **Pulsed Nuclear Magnetic Resonance (PNMR).** Follow the instructions and answer the questions in the *Summary of tasks required for PNMR lab* by Nate Conrad. In the *University of Washington Paper* section 2.3, do only Exercise 1.