Lab Reports as Scientific Papers

Your lab reports for Physics 134 may be quite different from the short lab summaries you have prepared for other courses. A Physics 134 report should be in the style of a scientific research publication: a self-contained exposition of the question, the approach you took to answering it, and the results you obtained. The report should be understandable and convincing to, let's say, a future junior physics major, without reference to either the lab manual or your lab notebook. Your lab report is both a scientific investigation *and* a piece of writing, so **good writing is important**.

Your report should respect the conventions described in the American Institute of Physics "Guide for Metric Practice," which is available on the department website at writing. **Please write in LaTeX using the documentclass revtex4-2 to use RevTeX 4.2**, the standard for submission to APS and AIP journals. See the Department LaTeX page for more information on getting started with LaTeX and for using RevTeX. A sample RevTeX report is posted on Sakai.

Suggestions for writing the report

- Remember your audience, and make sure your paper is clear and compelling to a reader who is unfamiliar with the Physics 134 experiments. You might ask a friend who isn't in Physics 134 to read your draft and tell you what they think they learned from it.

- The heart of a physics paper is the graph (or graphs) that summarize your principal results. Everything that appears in your paper before this figure leads up to the figure, and everything that appears after it discusses its significance. To lead up to your central figure, you must motivate your investigation (answer the "so what?" question), explain the approach you took in your investigation, and explain your setup and procedure in enough detail to clearly define all the data shown in the figure. To discuss the significance of your central figure, you must explain the logical or theoretical basis for your interpretation of the figure, interpret the figure (including uncertainties!) fairly, and suggest possible extensions and applications of your work.

- Refer to the specific content guidelines on the next page.

- Examine past lab reports or sample scientific articles, paying attention to style and format choices. For example, all figures should have figure numbers and informative captions. Figures should "float" to the top or bottom of a page, and should therefore be referenced in at least one appropriate place in the main body of the paper by number, *not position*. That is, do not reference the "figure below," since its position may shift during typesetting. Numbered in-text citations should refer to entries in a later "References" section. An example report is posted on Sakai in both source and PDF format.

- *Your lab report should be self-contained so that a reader can find it clear and convincing without referring to material that is only contained in the lab manual or your lab notebook. Figures should be made properly (see the section on Graphs below) and saved for inclusion in a vector graphics format (e.g., PDF), not a bitmapped format (e.g., PNG or JPG).*
- Reports should be submitted to your Sakai drop box, both in source and pdf format. Prepare a folder for each report, and place figures and source files (.tex or .ltx) in the folder.
- The scientific community and funding agencies place increasing importance on data archiving. In that spirit, you should upload your data to the same drop box folder that contains the corresponding report, in the format(s) you employ (typically spreadsheets and Igor experiment files).

Specific content guidelines

Except for the title and abstract, these are merely guidelines for the information your report should contain, NOT requirements or even suggestions for section headings within your report. Organize the main body of your report in any way that tells the story of your investigation clearly and logically. ***Focus on your own work, the choices you made, the approach you took, the data you took and its analysis.***

Title Your report should begin with a *title* .

Abstract Next comes a 2–5-sentence *abstract* saying what you set out to measure/investigate, what method you used, *and* what results you found. This is something like the thumbnail version of the rest of your report. After the abstract, start the text of the report itself; the main body should *not* refer back to the abstract.

Introduction/Motivation

- What question are you investigating? Do not assume that the reader is familiar with Physics 134 experiments already, so be sure to give some context.
- Why is this investigation interesting? (for example, illustration of an important principle? relationship to a technology? Discrepancies that many groups have seen and you can explain? Particular challenge? Other?)
- What if any expectations and/or hypotheses did you have as you started the data-taking? Why?

Theory and Methods

- Write this for a reader who *does not know* what you did in lab or what equipment you had available to you. This should be a logical exposition of what you did to obtain the final result, and *why* each step was important or relevant. Attention to detail is important.

- Make sure all symbols are defined at their first use; use acronyms sparingly.
- Carefully labeled drawings are very helpful. These should be referenced from the text by Fig. # and pushed to either the top or bottom of the page.
- Consider presenting some theoretical background for your investigation. You need not show each step of a derivation, but the starting points (including approximations and assumptions) should be clearly set up, and the final result should be prominently reported.

Results/Discussion

- Make sure quantities are well defined. Units and errors are also important.
- It is neither necessary nor desirable to include all your raw data in the paper, but it should be clear how the raw data were processed to obtain the included graphs. For example, how many trials contributed to each data point and error bar? How were important quantities measured?
- Explain the source of any quoted uncertainty estimates (statistical variation, instrument precision, etc.).
- Data should be analyzed (plotted, fitted, compared with theory, etc.) logically and understandably. Graphs should include titles, axis labels, units, and error bars. Fit formulas should correspond to appropriate theory. Data should be properly combined to give final answers that address the original question as far as possible. Uncertainties should be reasonably treated.
- Clearly state comparisons to theory or to "known" values, and include source citations or derivations if necessary for the theory or known values. Discuss the statistical significance (or lack thereof) of your result(s).

Conclusions

- What light do your data and analysis shed on the original question/hypothesis?
- If there is a firm theoretical prediction, does the experiment agree with the theory? If so, with what precision can you confirm theory? If not, by how much is it off (relative to uncertainty)?
- If the experiment was designed to measure an unknown quantity or effect, what is your result? How precise can you claim it is?
- What are the major sources of systematic and random error in your experiment? What extensions/improvements suggest themselves if you had 1 or 2 more lab sessions?
- Point out the relevance of your work to future Physics 134 experimenters or to other situations if appropriate.

Cite references where appropriate e.g., lab manual, textbooks, and other sources of inspiration. Each reference you include in a list at the end of your paper should be cited at one or more particular points in the body of the paper.

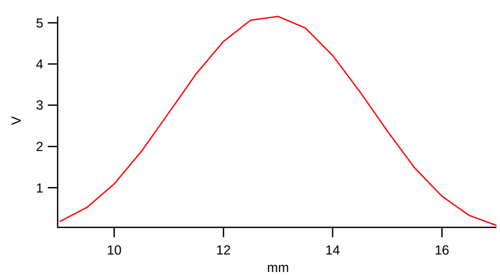
A Word on Scientific Graphs

Scientific results are nearly always communicated with graphs rather than tables, which are reserved for lists of parameters or other catalogs. While it can be satisfying to prepare a data plot by hand (if you have no other choice and a gun to your head), you will undoubtedly use some public-domain or commercial software package. Common choices include spreadsheets, MATLAB, R, matplotlib, Igor, *Mathematica*, Origin, or even tikz or pgfplots in LaTeX. In my experience, the default properties of scatter plots in most programs leave much to be desired and need to be modified, ideally in a consistent way to permit direct incorporation of plots into notebooks, presentations, publications, and posters. My thesis advisor, Eric Mazur, developed a template in Adobe Illustrator in the late 1980s and still insists that his graduate students and postdocs produce plots consistent with that template and a restricted color scheme. Consistency makes it easy to produce presentations spanning different projects (and even eras) without having to remake figures. Doing it right the first time, particularly if you have scripts to take away the tedium, is the way to go.

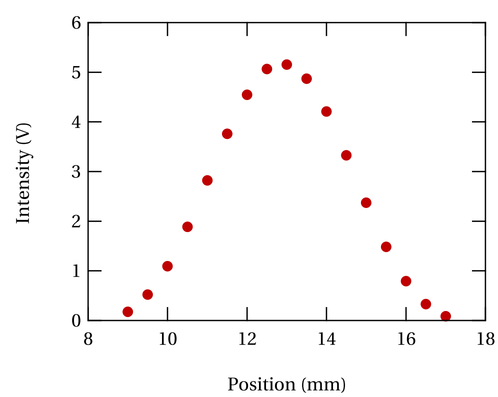
Since we will be using Igor Pro a fair amount in this course, I will illustrate the procedure using Igor Pro 7 and the HMC menu, which contains routines I have written to simplify the fixes. Let's take a look using some excellent data on the Fraunhofer diffraction pattern of a circular aperture that was taken by Chris Moore ('05) when he took the course in 2004. If I just use Igor's defaults, either from the menu, or using the command

```
Display Iw vs xw
```

I get a graph in which the data points are shown connected, axes are not mirrored, tick marks



(a) Default graph format in Igor Pro.



(b) After **FixGraph**.

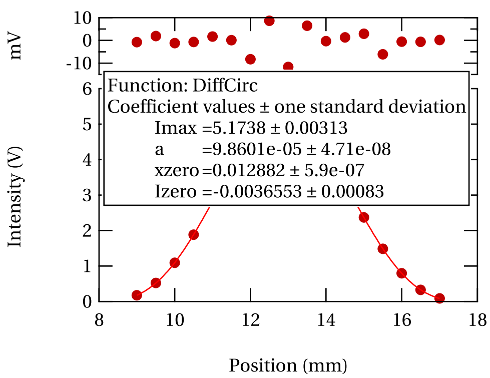
Figure 1: The **FixGraph** command from the HMC menu performs a number of operations on a graph to put it more standard form, including setting the aspect ratio, displaying data points as discrete points, adding error bars if found, and labeling axes from the plotted wave names.

go out instead of in, and the font is a bit on the small size, as shown in Fig. 1a. It is preferable to represent discrete points with markers, not a continuous curve, unless they are quite numerous. If I now use the **Fix Graph** command from the HMC menu, these issues are corrected (Fig. 1b).

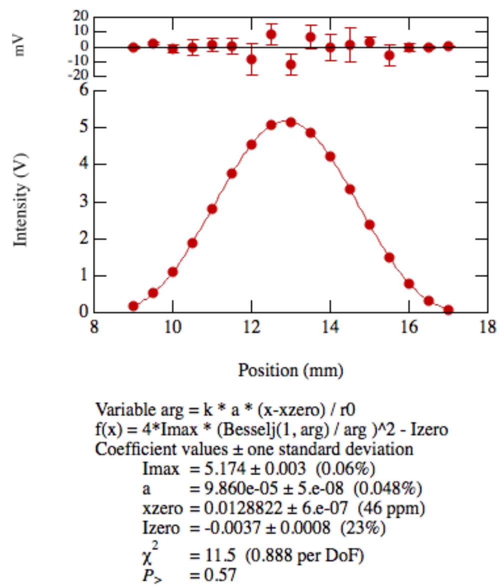
The graph isn't finished, however: we have not yet compared the data to theoretical expectations. In this case, the expected dependence of intensity on position x is given by

$$I(x) = I_0 + A\left(\frac{2J_1[ka(x-x_0)/r_0]}{ka(x-x_0)/r_0}\right)^2 \tag{1}$$

where x_0 is the position of the peak, $k = 2\pi/\lambda$, a is the radius of the aperture, and r_0 is the distance from the aperture to the detector plane. See Appendix A for details on how to define this fitting function in Igor Pro. After performing a nonlinear least squares fit and asking Igor to add the residuals to the plot, we get the rather inconvenient graph shown in Fig. 2a. However, running the **Add ChiSq Information** command from the HMC menu moves the fitting information to a more convenient location and adds important additional information, including the value of χ^2. Most of the graphs you will generate in the course will likely have this information displayed on them to guide your discussion of the extent of agreement between the data you have taken and theoretical expectations. For a formal publication, however, you would remove this information



(a) After fitting



(b) After **Add ChiSq Information**.

Figure 2: The **Add ChiSq Information** command moves the fit information out of the way, includes the code for the fitting function, adds the values of χ^2 and $\tilde{\chi}^2$, and copies the error bars to the residuals. It also adds buttons at the top of the graph to move the fit information to the right side and to compute and display normalized residuals.

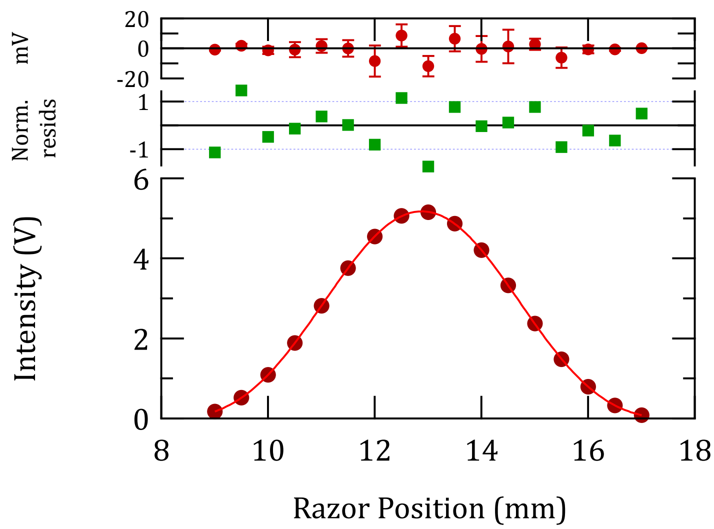


Figure 3: An example graph showing light intensity vs razor position for the Fraunhofer diffraction pattern from a circular aperture. Data taken by Chris Moore ('05) in 2004.

and summarize the necessary parts in the figure's caption. Figure 3 shows such a finished graph, to which a panel of normalized residuals has been added using the button at the top of the graph that is installed by the **Add Chisq Information** command. For your technical report, you should prepare clean graphs such as this one.