Boston University Physics Department

PY 408 Laboratory Reports and Notebooks

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Introduction: This laboratory will give you an opportunity to perform exercises in the lab that have a number of ingredients that are good practice for future scientific or technical work. You will have the opportunity to work with apparatus and measuring instruments somewhat more sophisticated than what you encountered in freshman and sophomore laboratories. And you will be expected to do somewhat more sophisticated data analysis including proper error analysis. To the extent possible, these labs will also connect to the material you are studying in PY 408 lecture and homework.

Structure and Elements of a Laboratory Report

Life is full of reports.[1] Whatever you do beyond your university training will require the writing of reports of some sort, usually for the person you work for. The ability to write concise insightful reports will be invaluable.

You have been given a template for your laboratory report. It is not required that you slavishly follow this outline. It is intended more to give you an idea for a workable structure to the document. Of course, there are some basic elements that should always be present. You should have a clear title sufficient to identify the experiment(s) performed. You should list your name and the names of any lab partners you worked with. Proper citation of the efforts of your colleagues is an essential part of academic and scientific practice. The citations in this document are a reasonable example[2]. You should date your report.

In the report, you are expected to state your objectives and the means by which you tried to achieve them. This will include a description of the apparatus used and a description of the techniques employed. In a scientific document of this sort, you should strive to give sufficient detail so that another experimenter could replicate your work, or so that you could replicate it yourself some time later. You are expected to represent your data, either by tables of numbers, or by graphs. At the end, you are expected to draw some conclusions.

In some cases, you may also provide appendices. These could consist of photocopies of lab notebook pages with raw data, background calculations too lengthy for the body of the text, or examples of raw data such as printouts of computer-aided data.

Your Laboratory Notebook

Central to the ability to write a good report is to keep a good record of what you did in the laboratory, the importance of a carefully kept laboratory notebook cannot be overstated. The lab notebook is where you write down as much detail as possible, including sketches, notes on what worked and what didn't, as well as your original data. Paper is cheap and you will not fill your lab notebook by the end of the semester- use the pages liberally.

You should be careful to not alter your data. It is acceptable to write in further notes after lab, or perform final calculations. These should be dated and identified as such. Your lab notebook is an official record of what went on in the laboratory. Later in your career, such notebooks may assume a role of central importance. Priority for filing a patent on an invention may be claimed by the records in a properly kept laboratory notebook. Remember that your lab notebook is a *primary source* and should not be altered in any way.

Please see the separately provided summary of notebook practices. It is important to date your work, preferably every page. You should work in ink and cross out errors. Red ink should rarely be used, only for important notices.

You may find it useful to put printouts from the computer in your notebook. These should be trimmed with scissors and neatly taped in. No loose pieces of paper flying around! Sometimes, reducing a figure will be needed to neatly fit in your lab book- a photocopier is provided for this purpose.

You may be wondering if paper notebooks are becoming obsolete in the age of computers. The answer is, tentatively, "yes". In many experimental collaborations, notebooks are kept electronically, i.e. by some software program. This can be quite powerful when the research team puts effort into it. For personal scientific notes, Microsoft OneNote (PC) or Circus Ponies Notebook (Mac) seem to be popular choices. These can be quite effective in cutting and pasting electronic information of all kinds including graphs. For the purposes of the PY 408 lab, however, I suggest you stick with paper and pen. Walk before you fly, and develop good habits now.

Numerical and Graphical Representation of Data

As part of your report, you will be presenting numerical results. For nearly all final results, you should be stating (a) a central value, (b) with the appropriate number of significant digits, (c) with the uncertainty in that measured number, and (d) the proper units of measurement. Therefore, one of the angular frequencies found in the anharmonic oscillator lab might be reported as:

$$5.449 \pm 0.005 \text{ radians/second}.$$

Here, the number of significant digits (4) is somewhat better than 1%, consistent with the uncertainty of 0.005 radians/second, as necessitated by the small effect being measured. For a scientist or technical person, recording the proper number of significant digits and units of measure is as important as good grammar and spelling for a literature major.

It is almost always advantageous to present a collection of data graphically. Such graphical representation will often reveal the relationship between different measurements in a convincing fashion. You should be making computer-generated (not hand drawn) graphs for inclusion in your lab report. There are several software programs which you can use. Spreadsheet programs such as Microsoft Excel, Google Documents, Numbers (in iWork) [3], and OpenOffice generally have a means of making a graph. Unfortunately, these programs are oriented towards business users and coercing them to make a graph that a scientist would be happy with is often quite a struggle. Below I show a graph made in Excel 2008 (Mac) after adjusting many settings. Notice that the axes are labeled, there is a grid in both x and y, the numbers are nicely formatted; these are all available under Chart Options. The differences are cosmetic, but in your future life as scientists your colleagues and bosses will appreciate some attention to detail.

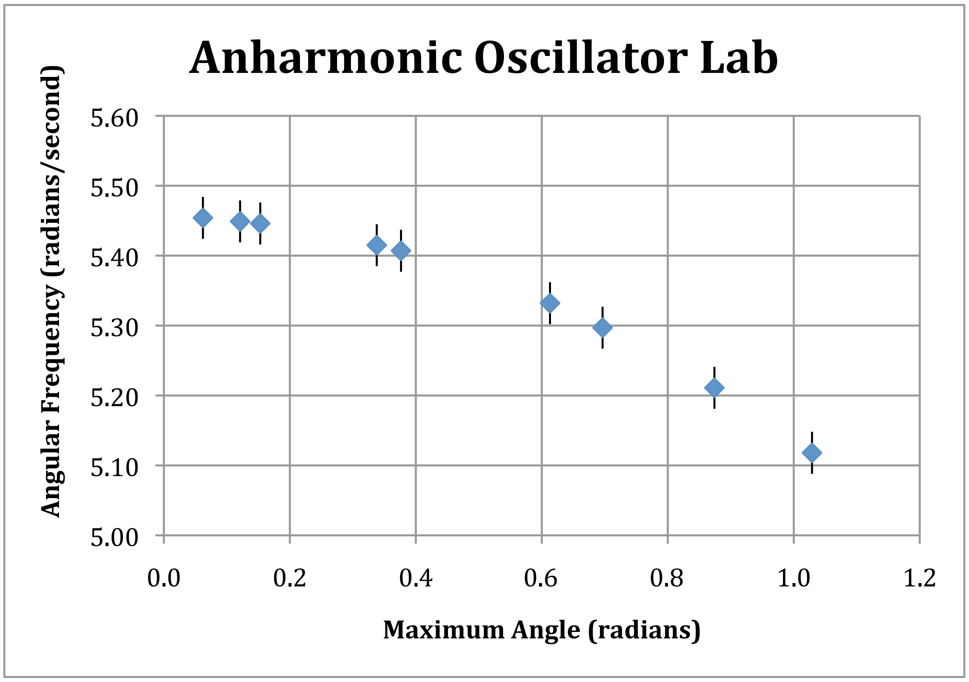

Figure 1. A graph made using Microsoft Excel. Data were entered as two columns. Error bars of fixed size were added by double clicking on the data which opens Format Data Series. Cosmetic adjustments were made to the axis ranges, titles, gridlines etc.

Another software tool that is freely available is called gnuplot. It runs on Unix, Windows, and Mac OS (under Unix). I actually recommend gnuplot as it is oriented towards science and not business, and has several useful addons such as curve fitting. More information about gnuplot can be found at www.gnuplot.info, and there are many examples and other helpful hints that can be found online[4]. Below is the same data plotted with gnuplot, and the gnuplot commands are also listed. A text file called "anharmonic.dat" was created with three columns of numbers in it, separated by spaces.

Mathematica can also make plots (see `ErrorListPlot`). Again, the cosmetics leave a lot to be desired but can be adjusted with some effort.

```
gnuplot> set term aqua font "Times-Roman,24"
gnuplot> set xlabel "Maximum Angle (radians)"
gnuplot> set ylabel "Angular frequency (rad/sec)"
gnuplot> set grid
gnuplot> set point 0.2
gnuplot> set xrange [0:1]; set yrange [1.14:1.34]
gnuplot> plot "period-data.dat" title "Phys. Pendulum" with errorbars 1
gnuplot> replot 1.152*(1+x**2/16)
gnuplot> replot 1.152*(1+x**2/16+11*x**4/3072)
```

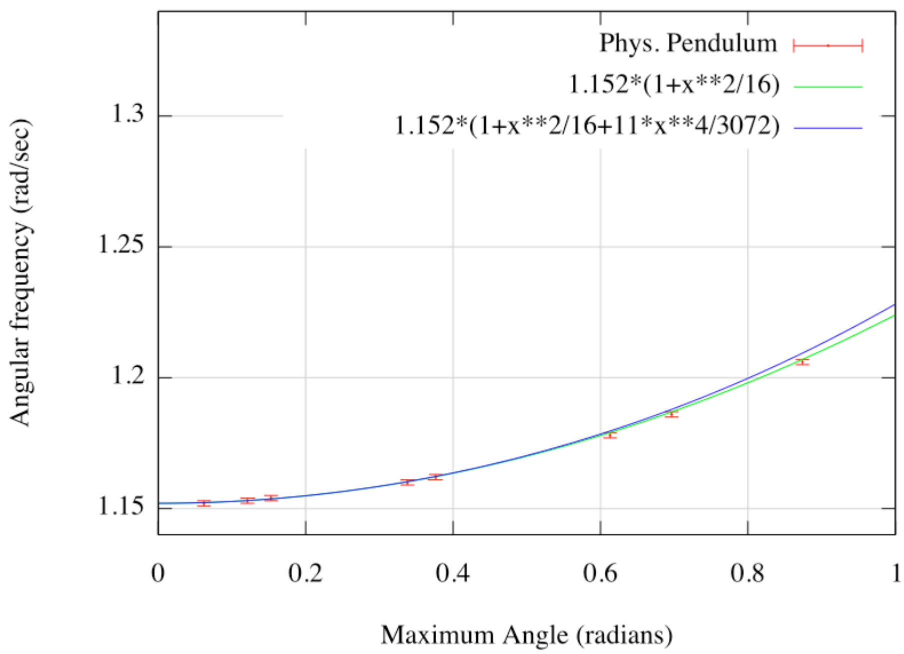

Figure 2. A graph made using gnuplot with an overlay of theoretical curves.

There area few other things to note about graphs. By convention a graph referred to as "B versus A" has quantity B plotted on the vertical or *y*-axis and quantity A plotted on the horizontal or *x*-axis. Usually, quantity A is one that one that you control in your experiment and quantity B is the result of a measurement. Usually you know A much better than you measure B, so error bars are often plotted only for quantity B, as vertical lines. Axes should be labeled with meaningful titles and the units of measure.

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[1] Sections of text in this document are originally in Laboratory Experiments in Mechanics, Vibrations, and Waves (DRAFT August 2000) by B. Lee Roberts.

[2] In Microsoft Word, these endnotes are accomplished by the menu Insert → Footnote… command which will bring up a dialogue box. You may have to adjust some preferences to get sequentially numbered endnotes at the back of the document, which is the preferred scheme.

[3] It seems that Google Documents and Numbers will not support error bars.

[4] http://sparky.rice.edu/gnuplot.html
http://www.cs.hmc.edu/~vrable/gnuplot/using-gnuplot.html