Measure g

PHYS-315 L. McLane (adopted from L. Barton) Spring 2021

Intro

This activity is designed to get you used to taking data and to familiarize you with data analysis and plotting using `Python`. You will measure the gravitational acceleration g.

Prelab/Theory

Derive the period of a simple pendulum in your lab notebook. First do this on pen and paper, and then insert a copy of this into your digital notebook. If you would like it to look “pretty” you can try to use Microsoft equation editor in OneNote (you can also use LaTeX to generate equations if you know how). Otherwise you will have to take a picture of your derivation and insert the image into your digital notebook.

If you plot T vs L the data will not form a line. So instead we will “linearize” the data by plotting T^2 vs L, which should be linear. “Linearizing” data is a common practice in science, as your eye is a remarkably good “linearity detector”.

Note: When we say “Plot item 1 vs. item 2” we are saying that item 1 is on the y-axis and item 2 is on the x-axis. This might be the opposite of what you initially think. Please remember this as this is standard terminology in science.

Next identify how you will extract g from the slope.

Finally go back to the spring mini-lab you did earlier in the week and complete the sections about propagating the error in the fitting parameters to the error in the spring stiffness and effective mass. The mini-lab is part of this prelab. Also make sure all the appropriate details/plots/equations/results are inserted into your Notebook.

Measurements

Tie a metal sphere on a string that is between one and two meters long. Suspend it. Use a stop watch and time 10 full oscillations of this simple pendulum (think: why are you measuring the time for ten oscillations instead of one?). Record the starting angle you used. Measure the length of the string. For any quantities measured make sure to record the estimated uncertainty.

Think about how to get the uncertainty on your timing. Rather than just looking up a random human “reaction time” from the internet, determine yours! Record the same event (either one or ten oscillations, it doesn’t matter) multiple times, and then use the average and standard deviations of this event to determine your typical reaction time.

Make sure the raw data makes it into the notebook! There are a ton of ways to do this but a table of the raw data needs to be in the notebook. Also make sure you have some kind of sketch/image of your experiment this will be a good habit for all experiments going forward.

Shorten the string, or wind it up to a shorter length, and measure the new length. Since we are trying to be systematic, make sure the angle is the same as before. Repeat the measurement of time for 10 full oscillations at the new length. Do this for five or six different lengths ranging from a few centimeters up to two meters (keeping the angle constant). Tabulate your raw data in your lab notebook.

Now choose a length you like, and repeat the experiment but this time by varying the angle. If the period of a pendulum is angle independent it should not change. Take enough data until you are satisfied that the angle dependence will be observed (if it exists).

In Lab - Notebook Entries

In addition to the data, while you are **in lab** be sure to include

1. Your "theory" derivation,
2. A description and/or a picture of your set up,
3. A description in words of what you're doing, any procedural notes,
4. An estimate of the random uncertainty in each parameter you're measuring (and how you determined that uncertainty), and
5. Any ideas that may occur to you, as you take data, about possible systematic errors.

Error propagation

You have measured the period T with uncertainty δT. In order to plot a line, you need the period squared, T^2 and its uncertainty. To compute the uncertainty in T^2 recall the rules for error propagation. If our function is given by:

$$f(T) = T^2$$

then the uncertainty in f is:

$$\delta f = \sqrt{(\frac{\partial f}{\partial T})^2 (\delta T)^2} = |\frac{\partial f}{\partial T}| \delta T$$

I will leave this calculation as an "exercise for the reader". There are other "tricks" you can use to memorize error for specific types of equations (polynomials, power laws, etc.) but in reality it's usually just easier to go back to simple derivatives.

Data Plots

Use `Python` to plot T vs L and T^2 vs L, with uncertainties. You can either calculate T^2 and its uncertainty beforehand (say in an Excel-like program) and copy it into a .txt file, OR use Python to calculate them from your raw data. Either way is fine. Fit the second plot with a straight line with `Python`. Note that it is best to do a **weighted** fit, where the data points with small uncertainties count more heavily than the ones with large uncertainties. The script given in the mini-lab already accounts for this.

Plot the data and the fit together; again make it a nice plot with labels, key, error bars, etc. Be sure to record the fit parameters with their uncertainties.

At this point, you should feel comfortable with several steps you'll use many times this year: creating a data file, doing minor algebraic manipulations on the data, using `Python` to produce a plot, fitting a line to data and plotting it along with the data, and saving the plot to an image file. These steps are the mechanics of a lot of our data analysis. Now we can move on to trying to actually get something useful from your data.

Analysis

From the fit parameters and their uncertainty, find g with uncertainty. Show in your lab notebook what algebraic steps you did to relate slope s to g. Follow the "propagation of error" rules for how to convert slope s with uncertainty, $s \pm \delta s$ to g with uncertainty, $g \pm \delta g$.

For your data set where you varied the angle, plot T vs θ and determine where the small angle approximation breaks down. A qualatative method for this is good enough.

Winding Down

By now you should have three plots you like, your plain period vs length, the period squared vs length, and period of the oscillation vs angle. You also should have the output from your curvefitting. The g you've computed should agree with the known reasonably well.

Make sure you have recorded any information before you leave the lab (data your partner took, diagrams, derivations). This stuff needs to end up in the digital notebook so don't forget it. It is best practice to do these things while in class rather than waiting to do them last minute. As with all labs, this lab is