PHY180 Uncertainty Lab (2020)

1 Requirements

You and your classmates will investigate the question "How long does a standard piece of paper (8.5" by 11") take to fall 1.00 meters if released from rest from a horizontal orientation?" (*i.e.* the slow way) You are required to make the following two predictions:

- If you take three data points at random from any of my classmates, I expect that two of the three will lie within the range defined by $X \pm Y$.
- If you separately average the data taken by three of my classmates, I expect that two of the three averages will lie within the range defined by $X \pm Z$.

Furthermore, you must justify your choices of X, Y and Z based on the data you take, and you must describe the relationship between Y and Z.

Given that you do not want all 3 values to fall within your stated prediction ranges, make sure you do not overestimate your uncertainties (Y, Z).

Note: the values of Y and Z, by convention, should only have 1 significant figure, while the number of significant figures of X should be determined by the value of Y and Z. Thus your second statement is likely to have X with one more significant figure than the first statement, even though they are derived from the same data. Examples: 1.4 s $\pm$ 0.2 s, 1.43 s $\pm$ 0.05 s.

You can do anything you wish to take your data, but you must document your procedure so that other people could repeat your results. You can assume the other people are competent at science so you do not need to explain how to measure distances or times. However, you must explain what measuring devices you used. For example, if you used a meter stick or a tape measure to measure 1.00 meters above the floor, mention that without explaining how you used it.

The focus of this lab is understanding and quantifying the uncertainties of experimental data. As well, you should practise how to present your results so that they are easy for the reader to understand. This is typically done via well-labelled graphs.

2 Grading

You will be graded based on the following equally-important criteria:

- How well you describe what you did to collect your data
- How well you present your data
- How well you analyze your data, with emphasis on quantifying the uncertainties
- How well you justify the two predictions you must make
- Overall clarity of your paper (style)

3 Advice

You should do 40 trials (that is, time the same paper falling the same distance 40 different times). Calculate the average value and the standard deviation of the first 5, 10, 20 and 40 trials. If x_i are the data values, the average value ($\bar{x}$) is defined as

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i$$

and the standard deviation (σ) is defined as

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (\bar{x} - x_i)^2}.$$

Note that Excel (and similar spreadsheet apps) will easily calculate both the average and the standard deviation for you, and conveniently will also make plots based on the data.

If you plot a scatter plot (just data points, no connecting lines) of σ as a function of N, I predict you will find little variation. If you plot $\frac{\sigma}{\sqrt{N}}$, I predict you will have a value which decreases with increasing N. One of these is typically used to represent the statistical uncertainty of each datum (which should be Y of your first prediction), and the other is typically used to represent the statistical uncertainty of the average (or mean) (which should be Z of your second prediction).

There are at least 3 different sources of uncertainty when you measure a height of 1 meter. There is the precision of the instrument which is hopefully quite small. There is the limitation of your ability to use the device (typically based on eyesight and/or how unsteady your hands are). And there is the difference between what you measure and what it represents, in this case it's your ability to hold the paper so its centre of mass is actually where you tried to measure it to be. You should do your best to recognize, describe, and quantify all sources of uncertainty, but you only need to use the largest value as the uncertainty of your position measurement.

A similar set of considerations apply to when you measure the time. **You must clearly explain these uncertainty sources and estimate their values.** In addition, your uncertainty in the position measurement will affect the uncertainty of your time measurement, since if you release it from a height other than 1 meter then you will have measured the wrong time. Once again, recognize, describe and quantify all sources of time uncertainty but only use the largest value.

Finally, compare your measurement uncertainty with the statistical uncertainty from having multiple trials, and again determine which is largest. If your measurement uncertainty is largest, you need a better method of timing each drop in order to improve your experiment. If your statistical uncertainty is largest, you need to take more data in order to improve your experiment. In either case, you should clearly state which scenario is true for you, but **you do not need to buy better equipment or do more than 40 trials**.

Note: if your time measurement uncertainty is larger than your statistical uncertainty then all 40 of your results will be the same (within uncertainty) and then your Y and Z values will be the same. This is because if you very accurately measure the same thing hundreds of times, with no fluctuations in results, then you don't really have more than one datum and so the uncertainty of the average is not a meaningful quantity.

Your raw data is perhaps best presented in the form of a histogram. You should include in your histogram vertical lines depicting the values X, Y and Z you use for the predictions. Also, please include a table of all 40 results as an appendix.

Every graph and table should have a title, labelled axes with units (unless it's clearly a unit-less quantity based on the axis label), and a caption explaining its significance and any other features (such as any vertical lines you add to the histogram).

4 Handing it in

Submit a PDF or DOC file through Quercus by 8 am on September 23, 2020. The late penalty is 3% per calendar day for up to 5 days, after which it gets zero. Your paper should have a brief (2-3 sentence) introduction, a description of what you did, graphs to demonstrate your results, a thorough analysis of all the uncertainties, a conclusion with your two predictions and a justification for the values therein, and an appendix with a table of your data.