Introduction

One aspect of Physics is to describe the physical world. In this class, we are concerned primarily with describing objects in motion and objects acted upon by one or more forces. We will begin by looking at motion.

When describing the motion of an object, it is necessary to take measurements and then report these numbers appropriately. When reporting information from a measurement, it is important to consider both the mode of reporting as well as the accuracy of the numbers to be reported. By mode, we mean that information can be represented many ways. Examples in physics include textual, graphical, numerical and pictorial representations.

In this Activity, you will look at numerical representations. Whenever numbers are used to report information, careful consideration must be given to the level of accuracy.

Goals: When you have mastered this document, you should be able to:

- Define what is meant by “uncertainty” in physics measurement.
- Report measured values with uncertainty as value ± range.
- Give adequate reasons for the uncertainty reported for any measurement.

Reporting Measured Values

Making Measurements: When reporting values, it is important to consider the number of significant digits. Think about how accurately you can measure an object with your meter stick. It is not very likely that you would measure your desk to be 1.3478364732 meters wide because your meter stick does not measure to 0.0000000001 parts of a meter. However, you ought to be able to measure to better than 1 meter and usually better than 1 cm!

How Many Digits: In physics one records to one digit past the digit represented by the finest mark on the measuring device. For example with a meterstick marked to millimeters, a reading would be written to one digit past the millimeter digit as in 3.4563 m. This means the measurement was 3 meters, 45 centimeters, another 6 millimeters and an estimate of 3/10s of a millimeter. This could have been reported as 345.63 cm or 3456.3 mm.

Determining the Uncertainty:

Uncertainty calculation depends on the type of measurement taken, the type of instrument used, and the nature of the measurand. The result, the best reported value with the uncertainty is the measurement.

Single Reading Measurement (Called a Type B Measurement):

When it is not practical or possible to make multiple readings, a single measurement will be made and the uncertainty depends on the type of measurement device.

Single Digital Readings: What is the uncertainty of the time as read from a stop watch or timer? Determine the width of the rectangle by considering the rounding to the last digit displayed. The most probable reading is between the two ends of the rectangle.
As an example, consider a reading from a cell phone stopwatch. For a single reading of 0:19.2 we would read 0 minutes and 19.2 seconds. The diagram would then look like the graph shown below. When you report the value, you report:

the best approximation +/- uncertainty

You would then report:

\[ t = (19.2 +/- 0.05) \text{ sec.} \]

**Note:** The standard uncertainty is actually only part of the width of the rectangle. We will learn about this in the next quarter of physics. We will use the entire width as the uncertainty for the remainder of this course.
**Single Analog Readings:** What is the uncertainty of position based on the placement of a ball-bearing on a track? This is an example of a single measurement made from an analog scale. The analog scale in this case is the meterstick. You must decide where you can say that the probability is zero that the reading is beyond a particular point. In this way you determine the edges of the triangle’s base.

As an example, consider a reading from a meterstick. For a single reading of 24.53 cm we would read 24 cm and a little past the 5 mm mark. It is clear that the reading was no lower than 24.50 and no greater than 24.56. The diagram would then look like the graph shown below. When you report the value, you report:

- the best approximation +/- uncertainty

You would then report:

\[ t = (24.53 +/- 0.03) \text{ sec.} \]

In an analog reading, the amount of uncertainty is a judgment call. It will not always be +/- 0.03. It may be +/- 0.01 or 0.02 or 0.05. You will have to decide based on the space between the marks and the physical situation around the measurement.

**Note:** The standard uncertainty is actually only part of the width of the rectangle or triangle pdf. You will learn about this in later studies. We will use the entire width as the uncertainty for the remainder of this course.
Multiple Reading Measurement (Called a Type A Measurement):

Next, let’s consider uncertainty, when it is possible to gather many measurements of the same thing. Many students have measured the height of a projectile fired straight up. The list of values is given below. Notice that all the measurements are given to the same number of digits past the decimal.

As you can see, there are a variety of measurements for the same distance. This variety has to do with uncertainty. All physical measurements, and therefore all data, have some degree of uncertainty. This tells the reader how accurate the measurement is.

What you want to report is the most likely measurement. One way to find this from a list of many measurements is to find the average. Around this average are a number of other likely measurements. These can be reported as a range on both sides of the average. You can approximate the range by looking at the minimum and maximum measurements. (If you have had some statistics, you may know of better methods, but this one will do for now.) Other factors to take into consideration are the measuring instrument you are using and the method that you are using.

Create a Histogram: When you have an outlier, it can throw off your average and create a range that is much larger than the bulk of the data suggests. When this happens, the only way to know is to see a picture of the spread and grouping of your measurements. One method is to draw a histogram on a piece of graph paper.
**Check your data for outliers:** An outlier is a reading that is clearly beyond the bulk of the data and looks odd because it is so removed from all other measurements. A handy rule for this class is to never remove more than 10% of your values as outliers. In the above example, there are 20 measurements. It seems that there is one outlier. Note that sometimes there are no outliers. If there had been a situation where it seemed like 3 outliers, then more measurements would have to be taken. 10% of 20 measurements is only 2 outliers. Therefore to check for 3 outliers, there would have to be at least 30 measurements. Since there is only 1 outlier, the 20 measurements are more than enough.

**Alternate to a Histogram:**

Do not attempt to do a histogram in Excel unless you are VERY SURE that you know how. You CANNOT simply make a column graph. If you are unsure about histograms, you may, instead, use a number line with plotted and grouped x markings to show the reading groupings.

**Find the Uncertainty:** Find the Average of all the measurements without the outliers. Use all the values from your group to find the average. Also record the Minimum measurement and the Maximum measurement. These are called the extremes.

**Hint:** Average is the sum of all measurements divided by the number of measurements.

Calculate the difference between each extreme and the average. Choose the largest value as the uncertainty. In this case, 0.05 > 0.04 so 0.05 is the uncertainty.

**Round and Report the Result**

Report the result as value ± uncertainty. For example, using the sample above the result would be reported as

\[(76.55789 \pm 0.04789) \text{ cm}\]

It is generally correct to record the value and the uncertainty to the same number of places past the decimal. If you have an uncertainty with more digits, round to 1 or 2 significant figures. In this case we would round to 0.048 for two significant figures. Then, round your average value to the same digit past the decimal. In this case, the
uncertainty is rounded to the column of thousandths. So we will need to round the average to the same column giving: 76.558 cm. Don’t report more digits than you measured. In this case we measured to the tenths column only so we need to go back and round the uncertainty to 1 significant figure and then round the average accordingly.

Now we would report: \((76.56 \pm 0.05)\) cm

You will be expected to include work for calculating your uncertainty of measured data for every lab done in this course.

Often, you will also have to report the uncertainty in a table header. In this case, a table header for a full lab where different heights were measured, would look like the following:

<table>
<thead>
<tr>
<th>Heights (cm) +/- 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.34</td>
</tr>
<tr>
<td>76.56</td>
</tr>
<tr>
<td>112.90</td>
</tr>
</tbody>
</table>

Notice that the value reported above is only one of the many data points taken in this lab and is only one value in the table. The value of 40.34 cm in the table was probably the result of averaging many readings. Likewise the value of 112.90 cm.

You do NOT need to do uncertainty calculations of every height. You need only do it once for height. If time measurements were taken, you would also report an uncertainty for time.

Notice also that the uncertainty is reported for all height measurements in the header of the table along with the variable name and units.