PHY 211

**Lab 1: Uncertainty**

Introduction

A central idea for all the laboratory experiments is UNCERTAINTY.

**Rule 1: Every measurement/calculation MUST also report the uncertainty in that measurement/ calculation in the form**

$$X= \overbar{X}\pm δX.$$

$\overbar{X}$ is the measured value. $δX$ is the uncertainty in that measurement. When we state that $X=\overbar{X}\pm δX$ we are promising the reader of the lab that we are certain that $X$ is between the values

$X\_{minimum}=\overbar{X}-δX$ and $X\_{maximum}=\overbar{X}+δX$.

**Example 1**

Imagine that we are given a nice straight piece of wire and told to measure the length. Using some measurement device like a ruler, we find that the length of the wire is $5.2 cm$. We must report exactly how close to $5.2 cm$ it is.

1. If we are absolutely certain that the length is between $L\_{minimum}= 5.19999 cm$ and $L\_{maximum}=5.20001 cm$, we would report: $L=\left(5.20000\pm .00001\right) cm.$ In this example $\overbar{L}=5.20000 cm$ and $δL= .00001 cm.$ This is a very *precise* measurement because $δL$ is so much smaller than $L$; it requires a significant investment of time and resources to measure a wire this carefully.

1. On the other hand, if our measurement tool is not very good or the wire is full of kinks, maybe we are only certain that the length of the wire is between $L\_{min}=5.087 cm$ and $L\_{max}=5.342 cm$, we would report: $L=\left(5.2\pm .2\right) cm$. This is not a *precise* measurement; however, we should be able to make this measurement in less than a minute with a basic ruler. In this example $\overbar{L}=5.2 cm$ and $δL= .2 cm$.

 Notice that both a) and b) follow the following rules for all uncertainties.

**Rule 2: The uncertainty in any measurement,** $δX,$ **can never be smaller than the half the smallest division on the measurement device.**

Most rulers have tick marks that are $1 mm$ apart, therefore any length that we get directly from a ruler must have an uncertainty that is $0.5 mm$ or larger.

 If a sensor is reporting that the temperature is $\overbar{T}=21.3℃$and the number is not changing at allthen the uncertainty will be $δT=.05℃$. On the other hand, if the sensor is fluctuating between $21.3℃$and$21.6℃$ we will use Rule 3 below because we are not certain what the value is.

**Rule 3: When writing the lab report, the uncertainty in any value,** $δX,$ **must have exactly ONE “significant figure.”**

To find $δX$ from a minimum and maximum we can use:

$$δX=\frac{X\_{max}-X\_{min}}{2}$$

Where we **ALWAYS ROUND UP** so there is one non-zero digit.

**Rule 4: The measured value,** $\overbar{X}, $**must be rounded to the precision of the uncertainty.**

To find $\overbar{X} $from a minimum and maximum we can use:

$$\overbar{X}=\frac{X\_{max}+X\_{min}}{2} $$

 Where we must round to exactly the same digit as the uncertainty.

To explore the rules above we will perform a series of straightforward experiments. Our goal for today is to answer the following question.

“How thick is one sheet of copier paper?”

Experiment 1.1- The Silly Experiment.

Equipment

1 sheet of paper

1 ruler or meter stick

Excel sheet- “Lab 1 Template”

Procedure

1. From Blackboard, Course Content, Lab Files open “Lab 1 Template.”
2. Before you make any modifications, save your Excel Template as “Lab 1-Names of group” in the folder “Section XXX” that can be found on the desktop.
3. Measure the thickness of the sheet of paper using the ruler. Record the minimum possible thickness that the paper might be in cell B5 in Excel. Record the maximum possible thickness of the paper in cell C5.
4. On a scrap of paper check to make certain that cells E5 and F5 are calculated correctly following Rules 3 and Rule 4.
5. Make sure that cell F5 obeys Rule 2. If not you will need to adjust your values in B5 and/or C5.

Analysis- None

Experiment 1.2 –Fancier Equipment.

Equipment

1 sheet of paper (the same sheet from Experiment 1.1)

1 caliper

1 micrometer

Procedure

1. If you are uncertain how to use the Caliper or the Micrometer please watch a 5 or 10 minute video on Youtube. Just google: “How to use caliper” or “How to use micrometer.” The lab computers also have the program “Fundamental Science Skills” which will help you be certain you know how to use the equipment.
2. Measure the thickness of the sheet of paper using the caliper and ruler. Record the appropriate values in Cells E11, E12, F11, and F12.
3. Make sure that cells F11 and F12 obey Rule 2.
4. On a scrap of paper check to make certain that cells B11, B12, C11 and C12 are calculated correctly following Rule 1. Notice, that one of the values is not correct. Using the equations in the cells nearby, correct the equation in the erroneous cell.

**Important information about Excel Formula:**

To let Excel know you are typing a formula, you must begin the entry with an equals sign “=”

 Excel uses cell references to do calculations. Because we do not want to spend all of our time typing equations, again and again, we will take advantage of *Absolute References* and *Relative References.*

 *Absolute References* always have “Dollar Signs” in them, like $B$2. When you copy and paste a formula into a new location, the Absolute references remain exactly the same and the new formula continues to reference the same cell.

 *Relative References* do NOT have “Dollar Signs” in them, like B2. While in a formula, B2 and $B$2 behave exactly the same. BUT when you copy and paste the formula into a new cell, all the references without dollar signs will reference a new cell based on where you do the copying.

Analysis

1. At this point you should notice that on the right side of the Excel a chart has been created to display your data. Every lab will have a CONCLUSION section which must contain a bar chart like this one.
2. All three bars represent the thickness of the paper, as you have measured it so far. Since you are still measuring the same sheet of paper, you must get the same answer. However, because the different equipment have different levels of precision, your three bars will not be identical.
3. If all of the bars on the graph overlap in the same region, then all three of your measurements agree**. If the bars of the graph do not all overlap in the same region, most likely you have made a mistake in your lab and you need to review the lab and look for mistakes** or physical reasons that your different measurements disagree.
4. Longer bars mean less precision, shorter bars indicate greater precision. But the most important feature of this graph is where all the bars overlap. The overlap region is the area where our two methods AGREE.

Experiment 1.3 –Lots of paper.

Equipment

Lots of copier paper

1 caliper or micrometer

Procedure

1. Get a stack of at least ten sheets of paper and count them carefully. Record the number of sheets in cell B21 in Excel.
2. Using your measurement tool measure the thickness of the stack. Record your measurement in cell C21.
3. Using at least 10 **additional** sheets each time, Repeat steps 1) and 2) until you have a total of ten measurements, filling the cells from B21 through C30 with your data. Notice B30 should have a number greater than 99.

Analysis

1. Because we are taking the time to measure the same thing multiple times, we will not need to get the uncertainty of each individual measurement. Instead, we will use the excel function “=Average(XX:YY)” to average all of our measurements and determine $\overbar{L}$. The excel function “=stdev.s(XX:YY)” finds the uncertainty of our measurements, $δL,$ using the formula from statistics called the “Standard Deviation.”
2. Notice that the Standard Deviation method is not limited by the smallest division of our measurement device. Therefore, we should have much more precise measurement of the paper thickness from this method.
3. Notice that there is a tradeoff between taking time to find the uncertainty of measurements directly, or taking lots of measurements to take advantage of the Standard Deviation formula, both methods require a significant investment of time. Sometimes you will be required to do it one way, and sometimes you will be required to do the other.

Conclusion

At this point you should have four measurements of the thickness of paper plotted on the graph in excel. Because all four are direct measurements of the paper’s thickness, all four should give overlapping results for the paper’s thickness. If this is not the case, you have done something significantly incorrect. (Maybe you were careless with your units, maybe you need to use the computer program “Fundamental Science Skills” to see if you are using the caliper or micrometer correctly, maybe you accidently altered the excel template formulas and need to find the mistake, or reopen the template and reenter your raw data.)

 You are now ready to open the Lab Report Template file. Each group member should write one or two sections depending on their assigned role.