Experiment 1

Introduction to Uncertainty Analysis using Excel

Before starting this experiment read through and understand the file titled “Uncertainty Analysis Instructions” located on Pilot for your lab course.

For this experiment you will use an Excel spread sheet already generated for this experiment and found in the Content section on Pilot. This file is named “Density Block and Cylinder Worksheet”. Select the file and then **Download** the file and **Open** the file **in Excel**. The Download button is below the preview of the file when you open the file in Pilot.

Notice at the bottom of the spread sheet that there are tabs marked “Sheet 1” and “Sheet 2”. Sheet 1 has the data for the Rectangular Solid Block, while Sheet 2 has the data for the Right Circular Cylinder.

Rectangular Block Right Circular Cylinder

Looking at Sheet 1 (Rectangular Block) you will see four tables, each having five measurements. These measurements vary by a slight amount due to the block not being a perfectly shaped block, and due to the person reading the measuring devices (a centimeter scale and a mass scale, in this case). Both of these contribute to random uncertainties in measuring, as detailed in the Uncertainty Analysis Instructions. For the purpose of showing how uncertainty in the measurements is involved only 5 measurements of each quantity are measured. However, if a multitude of measurements are made for each quantity it would be seen that most of the measurements are very close to being the same, while other measurements are slightly higher, and slightly lower than this value. This value turns out to be the mean of all of the measurements (or average of all of the measurements). If you plot the frequency of each of the measured values (these are not the values from any of the tables on the spread sheet) you will get what is called a Bell Curve distribution.

The majority of the measurements reside in ± one standard deviation about the average value (approximately 2/3 of all of the measured values). You will use the standard deviation of a set of measured quantities to represent the total of the random uncertainties.

The systematic uncertainties, listed in the measurement tables, are attributed to the manufacturing of the measuring devices (centimeter ruler and mass balance). All of these uncertainties (systematic uncertainty and standard deviation) are to be combined resulting in what is called a Total Uncertainty for each of the measured quantities.

To start, you will need to determine the average values for the Length, Width, Height, and Mass of the block. To do this, click on the empty cell below “Avg. L (cm)” and type: =AVERAGE(B4:B8)

B4 represents the first data entry in the table and is in the cell B4. B8 is the last entry in the table. Instead of actually typing B4:B8, you can either a) click on the cell B4, and then hold down the shift key and click on the cell B8, or b) you can “click and drag” starting on B4 and drag down, ending on B8. All of these result in selecting the five data points from B4 to B8. Don’t forget the parentheses, beginning and ending. Then, hit enter and you should have the average value for Length. You can check this with a calculator. Repeat this process for Width, Height, and Mass.

The standard deviation is done the same way. Click on the box below “St. Dev. (cm)” and type: =STDEV(B4:B8)

From the Uncertainty Analysis Instructions you found that the Total Uncertainty of a measured quantity is found using the following equation:



Where δ represents the Total Uncertainty, σ represents the Standard Deviation, and sys. represents the Systematic Uncertainty. To write this equation in Excel type: =SQRT(B11^2+0.05^2) and hit enter. This will only give you the Total Uncertainty for Length. Notice that you are using the cell B11 in which you calculated the Standard Deviation. The value of 0.05 is the Systematic Uncertainty as listed in the table for Length.

Now, determine the Standard Deviations and the Total Uncertainties for Width, Height, and Mass.

To determine the Volume of the block you will use the Avg. L, the Avg. W, and the Avg. H. Since this is a rectangular block (or prism) the Volume is found from the equation:

Click on the cell below where it states “Volume (cm3)” and type: =B11\*E11\*H11

These are the three cells that contain the average Length, the average Width, and the average Height. You could also have clicked on the cells instead of typing their positions. The asterisks represent multiplication.

Volume is a derived quantity, made up of multiplying three measured quantities. Since it is a derived quantity we use a different equation to determine the Total Uncertainty for it. The general form of the equation from the Uncertainty Analysis Instructions is:

If two measured quantities are being multiplied or divided the Fractional Uncertainty in their answer is:



Notice that Fractional Uncertainties are being used in this equation. A Fractional Uncertainty is just the Total Uncertainty divided by the Average value of the measured quantity. The term on the left side of the equation represents the Fractional Uncertainty of what you are trying to determine, with the Total Uncertainty on top of the fraction the unknown we are trying to find.

Let’s apply this to

The Volume is the answer, or the derived quantity. L, W, and H are each of the average measured quantities from the tables. So,

Since we are looking for δV, we can multiply V over and get:

Change this into an equation that Excel will understand. Type for the Total Unc. for Volume:

=B22\*SQRT((B17/B11)^2+(E17/E11)^2+(H17/H11)^2)

This will give you the Total Uncertainty associated with the Volume of the block.

Now that you know what Fractional Uncertainty means, determine the Fractional Uncertainties for Length, Width, Height, and Mass. You will use these Fractional Uncertainties to determine which measured quantity contributed the most uncertainty towards the answer we are looking for—the Density.

To determine the Density (Greek letter ρ) of the block you will use the average Mass and the Volume. Density is the ratio of the object’s Mass to its Volume.

Determine the Density of the block on the Excel spread sheet using what you have learned in this experiment.

To determine the Total Uncertainty of the Density we look at the general form given above and write:

Again, determine the Total Unc. of the Density using what you have learned.

Since the Density is the answer to what we are looking for we have to round both the Density final answer and the Total Uncertainty of the Density to the proper number of significant figures. Notice that both Density and Total Unc. cells have to their immediate right a place to write the values using the rules of significant figures. Refer to the beginning of the Uncertainty Analysis Instructions to determine the proper number of significant figures and record them. If you are not able to write the proper number of significant figures in the cell, right click on the cell and choose “format cells” from the drop down menu. You can then change the style from “General” to “Number” and choose the number of decimal places for your value to bring it to the proper number of significant figures.

Next is to show the Range of Density Values. The Range is from the lowest value (Density minus the Total Unc.) to the highest value (Density plus the Total Unc.). These low values and high values of the Range also follow the rules of significant figures.

On to Sheet 2 and the Right Circular Cylinder.

Determine the Averages, the Standard Deviations, the Total Uncertainties, and the Fractional Uncertainties for the Length L, the Diameter D, and the Mass M in the same manner as you did for the Rectangular Block. The Fractional Uncertainty for the Diameter D involves a factor of 2, as you will see below.

The Volume has a different equation. Since this is a cylinder the equation for its Volume is:

As you can see we are using the Diameter directly instead of determining the radius in the above equation. Another aspect of the equation is that the Diameter is squared. Once more we refer to the Uncertainty Analysis Instructions:

If a formula has a power involved in a measured quantity the Fractional Uncertainty can be determined (k is a constant value and not a measured value):



In this general equation involving two measured values, with one of them taken to a power we can see that C is like the Volume V, A is like the Length L, B is like the Diameter D having a power of n = 2, and finally the constant k is like π/4. Substituting and moving V over to the right-hand side of the equation results in:

Solve for the Volume and the Total Uncertainty of the Volume using Excel, placing the equations in the appropriate cells.

The equations for the Density and the Total Uncertainty of the Density are the same as for the Rectangular Block. Place the Excel equations into the appropriate cells and solve for these, along with determining the low value and the high value for the Range of Density Values. Don’t forget to write the answers using Sig. Fig.

Once you are finished with the Excel spread sheets save them. You will be turning them in as a single file to the Drop Box on Pilot (Experiment 1) for your lab course.

Results:

In your report type the densities and their associated total uncertainties for both the Rectangular Block and for the Right Circular Cylinder.

In addition, you will also turn in answers to the following Discussion Questions relating to this experiment to Drop Box (again, Experiment 1). Write these answers using Word.

Questions for Discussion:

Write your answers in complete sentences.

1. Both the Rectangular Block and the Right Circular Cylinder are made from the same common metal substance. Go online and find a table that lists the densities of metals and determine which metal the Block and Cylinder are made of. Are there any other metals on the table that you found that are close to, or may overlap with the metal you are stating when you consider the Range of Density Values? If there is another metal that could fit within the Range of Density Values what justification(s) can you use to state which one is more likely to be the actual metal? List the website that you found the table in your answer.
2. Fractional Uncertainties of Measured Quantities can tell you which measurement is causing the most uncertainty in the derived answer. Do a comparison and determine which measurement, one for the Rectangular Block, and one for the Right Circular Cylinder, that would need to be measured with more accuracy to lower its larger contribution to the overall Total Uncertainty.
3. When experimentally determining a physical quantity, such as the densities of the Block and Cylinder, it is considered to be in agreement with a handbook value if the handbook value falls within the Range of Values of the experimentally determined value. But, this does not really tell you how accurate the experimentally determined value is compared to the handbook value. To show how close the average experimental value is to the handbook value a percent error can be calculated. The equation for this is:

The absolute value is used to give a positive % error to compare it to an acceptable upper limit. Do some research online to see what a reasonable % Error maximum would be when comparing an experimentally determined value to a Handbook value. Then, determine the % Error for both the Block and Cylinder using the handbook value for the Density of the metal that you stated in Question 1 is the actual Density. How do these % Errors compare to the reasonable % Error maximum?

1. When used in physics experiments describe each of the following:
2. Accuracy
3. Precision
4. Uncertainty
5. Significant Figures