

Aluminum Density: An Exercise in Propagating Uncertainties and Graphical Analysis

All steps will be typed as an example of a formal lab report. Please follow the steps so you get everything in your report you need to have. We will be using digital scales and Vernier calipers for the measurements.

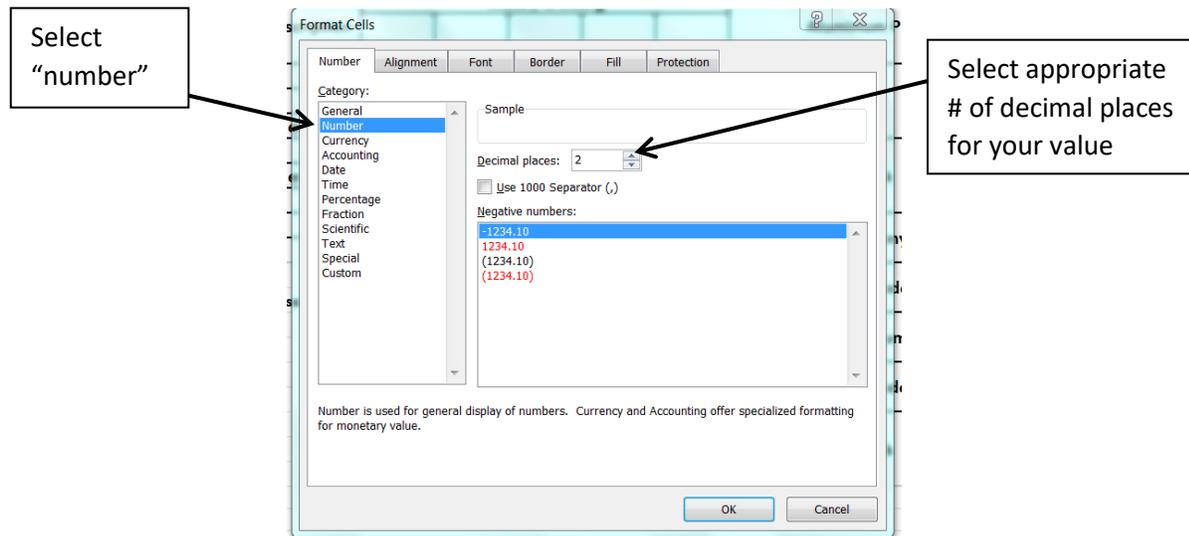
Step 1: Collect and Record Data

1. Create a data table in which to record 5 trials for mass and all dimensions necessary to calculate volume. Each trial should come from a different set of measurements, which in this lab equates to using different pieces of aluminum
 - a. Note: recording data should be organized in a rough draft form first; when you get all your data collected, you may realize that when you type it up it will fit better in 2 tables rather than all in 1
 - b. There are 8 “styles” of aluminum pieces you should be measuring, each specifically labeled in its tray or dish:
 - i. Small block
 - ii. Large block
 - iii. Flat slab
 - iv. Small, short cylinder
 - v. Small skinny cylinder
 - vi. Medium cylinder, Sm diameter
 - vii. Medium cylinder, larger diameter
 - viii. Large, Wide cylinder

Step 3: Analyze Data

1. **First**, make sure you’ve organized your raw data (that you collected) into a more formal data table (possibly more than one—make sure a table fits on a page without carrying-over to the next page, and make sure that your paper is in portrait orientation)
2. Create additional table(s) in your own Excel File to report your calculated average masses and the average dimensions. Recommended titles would be: **Table 3: Average Aluminum Piece Masses, with uncertainties** and **Table 4: Average Aluminum Piece Dimensions, with uncertainties**. You will need to repeat the column of “aluminum piece description” so that you can connect your averaged data with the original data. You will need 1 column for average mass, 1 column for the uncertainties of the average mass, 1 column for each of the average dimensions, and 1 column each for those dimensions’ uncertainties.
3. When you are ready to enter data, start this step (but not until your columns are labeled!)
 - a. Click on the cell for the average mass of the “flat Slab”. Type **=AVERAGE(** then click and highlight the 5 cells with the masses for the flat slab). Hit “enter” and the average will be done for you.
 - b. Hover over the bottom right corner until your cursor becomes a **+**. Click, then drag down the list of your aluminum pieces. When you reach the bottom of the list, release your mouse button, and the averages will be done.

- c. Click on the cell for the average mass' uncertainty for the “flat slab”. Type $=0.5*(MAX($ (then click and highlight the 5 cells with the masses for the flat slab) $- MIN($ (then click and highlight the 5 cells with the masses for the flat slab)) , hit enter. This has given you half the range of data of your masses, which is used for the uncertainty.
- d. Again, hover over the bottom right corner until your cursor becomes a +. Click, then drag down the list of your aluminum pieces. When you reach the bottom of the list, release your mouse button, and the uncertainty calculations will be done.
- e. **Format cells!** Now all you need to do is format the cells so that the correct number of decimal places appears. Start with the uncertainties—make sure they are all showing as 1 sig. fig. formatting the cells, rather than just typing in the rounded value, will allow your calculations to automatically change if you change any data.
 - i. **Right click** on a cell or a highlighted group of cells. Select **format cells...** from the menu that appears. You'll get this pop-up window:



- f. Repeat for your Table 4: Average Dimensions. You'll end up with 2 tables of average calculations done and formatted...with less work than if you did all the calculations by hand! 😊

4. Create a 5th data table to show calculated volumes for each object. You'll be using the calculated averages of the dimensions.

- a. For this set of calculations, you'll have to enter the equations (formulas) in separately for each line—no click and drag tool for this, as each is done differently.
- b. For each rectangular prism volume (blocks and slab):
 - i. Select the destination cell
 - ii. Type = (click on cell for length)*(click on cell for width)*(click on cell for height) then hit "enter" and the volume will be calculated for that object.
- c. For uncertainties of the rectangular prism, use the following equation:
 - i. Select the destination cell
 - ii. Type = ((cell for Δlength)/(cell for length) + (cell for Δwidth)/(cell for width) + (cell for Δheight)/(cell for height))*(cell with calculated volume) then hit enter. The absolute uncertainty for the volume will be in the destination cell. You just need to adjust precision. ☺
- d. For the cylinders (use the data below as an example):

	H	I	J	K	L
21			Height	3.17	0.05
22		Small, Skinny Cylinder	Diameter	0.48	0.05
23			Height	5.60	0.05

- i. To get the volume, you need to use the equation $\pi(d/2)^2 \cdot h = V_{\text{cylinder}}$
- ii. For the small, skinny cylinder, your formula would look like:

Small, Skinny Cylinder	=PI()*((K22/2)^2)*K23
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iii. For the other cylinders, same formula, different cells.

- e. Uncertainty in the cylinders will be similar to that for the blocks, but you'll have 2 of the diameter uncertainties and the one height uncertainty. The formula (again, using the above data cells) would look like:

40	Small, Skinny Cylinder	1.013352	=(L22/K22)*2+(L23/K23))*J40
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- f. Once you've finished the formulas for each of the volumes and uncertainties, just format the cells to get the appropriate precision for both the uncertainties and the volumes.

- g. Double-check all your data tables for appropriate precision, and you're ready for the next step! ☺ If the precision is in correct, highlight the cells, right-click, and choose "format cells..." from the menu. In the pop-up window, select "number", then choose the appropriate number of decimal places so that your uncertainty is 1 sig. fig and your measurement's precision matches its uncertainty.

Step 4: Graphing Data

1. Open LoggerPro
2. Double-click in the Column heading labeled “Y”. Rename this column “Average Mass”, and in the box for units, type “g”
3. Double-Click in the column heading labeled “X”. Rename this column “Average Volume”, and in the box for units, type cm^3 . (note: there is a drop-down menu where you can select superscripts for your units. It makes it look neater and cleaner than writing cm^3 (not even a correct unit) or cm^3)
4. Go to your Excel file and highlight and copy the cells from your average mass data table—values only, no uncertainties.
5. In the LoggerPro file, click in the first cell of the column for Mass, then “ctrl-V” to paste the data from Excel into LoggerPro.
6. Repeat that process for the column of volume values.

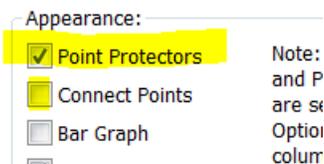
Note: You should now see the beginnings of the graph. The axes are labeled with the column headings from the LoggerPro data set, and there are data points visible on the graph.

7. We now want to add uncertainties into our graph. In the menu bar at the top, select: **Data** → **new manual column...** and in the window that pops up, you’ll be able to add the column heading for Mass uncertainty. Repeat the process for the Volume uncertainty. Copy the uncertainty values from your Excel file and paste them into the LoggerPro file.

Your column headings should look something like this:

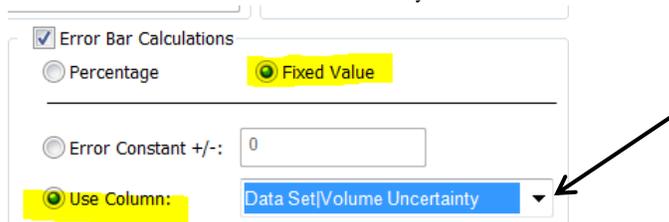
	Data Set			
	Volume (cm^3)	mass (g)	Unc Vol (cm^3)	Unc Mass (g)
1				
2				
3				

8. **Auto Scale**—in the top menu bar, look for the big Blue Capital A—click on that to automatically scale your data to fit the space of the graph.
9. **“Graph Options”**
 - a. Double-click anywhere in the graph. A window will pop up called “Graph Options”. Here you can add a title—be sure the title is specific about what data the graph is showing us. For example, “The Relationship Between Mass and Volume of Aluminum Samples” is an appropriate title. “M vs V” is not.
 - b. Also in this Graph Options tab, you may need to un-check “connect points” and check on “Point Protectors”. Some versions of LoggerPro have this as default, and for some you need to fix it. We do not want a connect-the-dot graph!



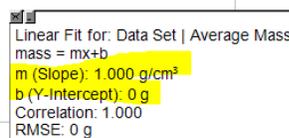
10. “Column Options”

- Double-click in the column heading for Volume. In this window (click on the “Options” tab), you can change the appearance of the point protectors if you don’t like the default shape and/or color. You don’t need to, but it does give you a place to put a little of your personality into the graph. ☺ (Only the point protectors for the y-axis variable actually show up on the graph.)
- In the lower right section of the options tab, there is an option to select “Error Bar Calculations”. Check that box.
 - Select “Fixed Value”
 - Select “use Column”
 - Select the label for the uncertainty values for the column you selected.



- Repeat the process for your Mass values in order to get uncertainty listed for those values as well.
- Best Fit line:**
 - In the menu bar, select **Analyze**→**Linear Fit**

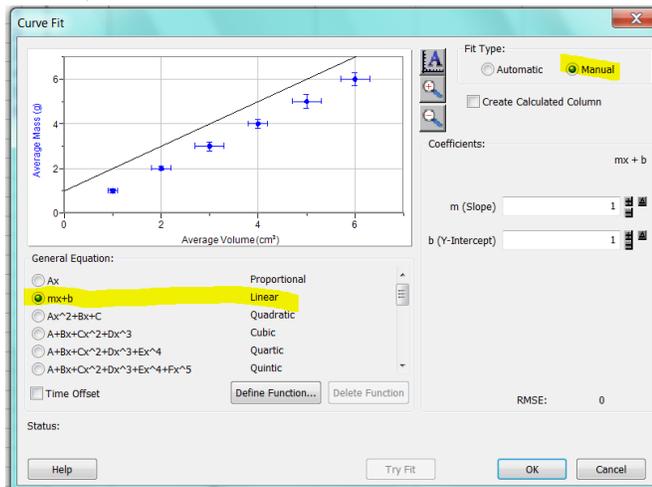
- OR** In the menu button, select the button that looks like this: 
- Either will automatically fit a best-fit curve (in this case, line) to your data.
- In the box that pops up you’ll be given the generic equation for the line and the values for the slope (m) and y-intercept (b). Those are the only 2 values in the box we care about—we don’t do the statistical analysis that correlations and RMSE are used for.



d. Max and Min Slope lines

- The purpose of having Max and Min slopes on a graph is to allow you to estimate the uncertainty in the slope of your line. The steepness of the max and min slopes are dependent on your data’s precision (individual points and as a whole).
- The Max and Min slopes should, for the most part, be representative of the steepest possible slope your data, with uncertainties, would allow, as well as the shallowest possible slope.
- To do this:
 - Select **Analyze**→**Curve Fit...**

- In the window that pops up, select **linear**, and in the upper right-hand corner, select **manual**



- A line with a slope of 1 and y-intercept of 1 will appear on the graph. Click **OK**.
 - Double-click in the dialogue box for this new line, and in the bottom right corner you'll want to check the box for **enable line drag**.
 - This puts little diamonds on the line so you can click and drag it to the slope you want. Line up the bottom left part of the line so that it passes through the lower parts of the lower error bars. Line up the top right part of the line so that it passes through the upper parts of the upper error bars.
 - When you are satisfied with the positioning of your line, Double-click in the dialogue box again and un-check the "enable line drag" choice.
 - Repeat steps 1-6 one more time, but this time create the minimum slope by passing the lower end through the upper part of the lower error bars and the upper end of the line through the lower part of the upper error bars.
- iv. The uncertainty of your average slope (the original linear slope through your data) is equivalent to half the range of your max and min slope:

$$\Delta slope = \frac{(Max\ slope\ value) - (min\ slope\ value)}{2}$$