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Density Lab

The simplest way to describe density is that some objects of the same size (volume) are heavier than others. Consider an aluminum bicycle compared to a steel bicycle. Which one would you prefer to carry up three flights of stairs to your apartment? Different materials possess different densities. King Hiero's crown is a classic story about this.

King Hiero of Syracuse (275 BC) commissioned a crown to celebrate a victory. He weighed out a mass of gold, selected a design and hired a goldsmith. The crown he received back before the celebrations had the same weight as the gold he had send to the goldsmith. However, rumors got back to the king that he was being swindled. That the goldsmith kept some of the gold and replaced it with silver while manufacturing the crown.

With no time to waste and wanting to be fair, Hiero then commissioned Archimedes to determine if the goldsmith was honest but was not to damage the crown (it was expertly crafted after all). Archimedes pondered all of this while taking a bath. As he observed water pouring over the edge while getting into the bath vessel, he suddenly realized the solution! He yelled "Eureka," which means "I have it," and ran home to work on the problem.

What he realized was that the volume of water displaced by an irregularly shaped object dropped into a full vessel was equal to the volume of the object. He then measured the volume of water displaced in a full vessel when an equal weight of gold was dropped into the vessel, when an equal weight of silver was dropped into the vessel, and then when the "gold" crown was dropped into the vessel. The silver displaced more water than the gold because silver has a lower density. The crown did not match the equivalent amount of gold - more water was displaced then should have been. Therefore the crown was a mixture of gold and silver as the rumors had claimed and the goldsmith was punished.

Archimedes published a book on mathematics, but this story is not in it. The story was told by a different author. Speculation then is that this method was just legend and not sufficiently accurate to determine the guilt of the goldsmith. Later investigators claim he used a balance and a system of levers along with the water displacement and then used "Archimedes principal" to more accurately determine the difference in densities between pure gold and the "gold" crown. "Archimedes principal" says that "The buoyant force of a submersed object is equal to the mass of liquid the object displaces" We will use this principal in the first part of the experiment.

This lab consists of five parts. In the first part you will rank three colored sugar solutions from most dense to least dense. In the second you will determine their actual densities and graph those densities verses percent sucrose in Excel. In the third you will determine the density of an aluminum bar by water displacement and find the density of an unknown object. In the fourth section you will determine if an old coin is real (silver) or fake. And in the last section you will look for periodic trends with density, comparing several elements in the periodic table.

Calculations

$d = \frac{m}{V}$ where d is density (g/L, kg/mL, etc.), m is mass (g, kg, etc.), and V is Volume (L, mL, etc.)

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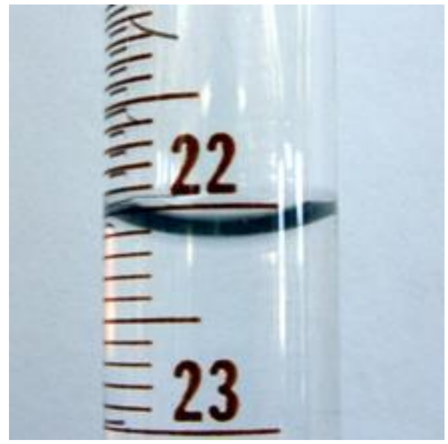
Errors in calculations: It is important to carry your measurements accurately in all of your experiments. Your work is only as accurate as your least accurate measurement. In a first semester chemistry class most determinations in the lab will need to have three or four significant figures in the calculations. In this experiment, this means using all of the numbers on the scale when weighing something and reading graduated glassware to a 0.02 accuracy. For example, a flask might weigh 32.8965 g and after adding a solution it might weigh 32.9114 g. The difference for the mass of the solution is 0.0149 g. If you rounded or didn't record the complete masses from the scale, you would not have three significant digits to continue your calculations.



In order to read a graduated cylinder accurately to the nearest 0.02 mL, you use an estimation technique. Use the thickness to the line to be 0.02 mL and estimate how many lines you could draw to reach the bottom of the meniscus. (The example on the right should be read as 22.12 mL) Your accuracy will be measured against the known values in this lab, but you also need to calculate your precision and report it as a ± value after your results for the percent sucrose concentration in part two of this lab.

The formula for standard deviation is: $s = \sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n-1}}$ where x_i is the individual calculation, $\bar{x}$ is the average, n is the number of calculations, and Σ is the summation symbol which means "add up what follows." (*See the instructions on page 9 for using Excel to calculate standard deviations using the formula above.*)

Experimental

Qualitative determination of densities; exploration of buoyancies of sugar solutions

You will be given three sugar solutions colored red, yellow, and blue. Your task is to rank their densities from highest density to lowest density. Obtain 10-20 mL of each colored sucrose solutions in three small beakers. Label and place a disposable pipette in each one. Choose a color, take one of your test-tubes and place 1.0 mL in the bottom using the disposable pipette. Carefully try to layer one of the other solutions on top. Does the color you laid on top stay on top or settle to the bottom? Which one is denser? Try another pair of colors in a different test-tube. Which one of these is denser? After you have discovered the order of densities using pairs of solutions, try layering all three in one test-tube. You should have the densest on the bottom and the least dense on the top and see if the layers stay in the same order. If they do record the order on the Experimental results page.

Quantitative determination of densities; calculation of the densities of the sugar solutions

First you need to calibrate a disposable pipette. Choose one and label it. Place a small beaker on the scale and tare the scale to 0.000 add drops of water to the beaker counting each drop until the scale reads 1.000 grams. This is the number of drops your pipette needs to deliver 1.000 mL because the density of water is 1.00 g/mL. Take three clean, dry, labeled, 125 or 150 mL Erlenmeyer flasks and weigh each on the scale recording their masses on the results page. Choose a color and pipette exactly 1.00 mL in each flask using the same number of drops calculated earlier. Reweigh the flasks and record their masses on the results page. Find the mass of each sample by subtraction. Calculate the density of each sample remembering you pipetted 1.000 mL into each flask. Find the average and standard deviation and record them. Report your standard deviation as a ± value after the average.

Choose a new clean pipette and repeat this above procedure for each of the other two colors.

Using excel (see below), graph your results. Your y axis should be density and x axis should be mass % sucrose. Graph your three averages and a value of 1.00 g/mL for the density of pure water. Apply a trend line to get the best fit of your data to a straight line and observe the R^2 value. From Statistics, an R^2 value of 1 is a perfect line and the closer your value is to 1 the less error you have in this part of the experiment. Record your equation of the line and R^2 on the results page. Attach your Excel graph to the report.

Density by water displacement; determination of the density of an Al bar

Take a small beaker and weigh it. Obtain a dry aluminum bar or pellets of around 25 g, place it in the beaker and accurately weigh it as described earlier. Record both of these on the results page and find the difference. Now take a 100 mL graduated cylinder and add about 25 mL water and accurately read and record the volume. Carefully slide the aluminum down the side without spilling or splashing the water. Read the new volume, record the volume of aluminum plus water, find the difference, and calculate the density.

Repeat this procedure with the unknown provided.

Is it real? Determining if a silver coin is silver using density measurements

In the recitation before this lab your TA demonstrated the water displacement technique using 10 suspect silver coins. You were to record their measurements on the experimental results sheet (If you haven't, go find them and get the measurements). Each class has three coins to share for this lab, first weigh one to the 0.0001 position on the scale and then measure it using a caliper provided. Fill in all the data on the results sheet and answer the questions listed.

Density trends

Determine the density for the elements requested under the density trend table using the same technique as used for determining the density of aluminum. Fill in all the densities in the abbreviated periodic table including the ones given for the elements listed under the table and answer all the questions on the experimental results sheet.

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Qualitative determination of densities; exploration of buoyancies of sugar solutions

List the order of the three colored sucrose solutions from highest density to lowest density.

______________   ________________   ________________

Quantitative determination of densities; calculation of the densities of the sugar solutions

Color of solution ____________   pipette _________ requires _________ drops to deliver 1.00 mL

Flask	A	B	C
Mass with sucrose			
Empty mass			
Difference			
Density g/mL			

Average _______________± _______g/mL

Color of solution ____________   pipette _________ requires _________ drops to deliver 1.00 mL

Flask	A	B	C
Mass with sucrose			
Empty mass			
Difference			
Density g/mL			

Average _______________± _______g/mL

Color of solution ____________   pipette _________ requires _________ drops to deliver 1.00 mL

Flask	A	B	C
Mass with sucrose			
Empty mass			
Difference			
Density g/mL			

Average _______________± _______g/mL

Record the equation of the line from your Excel graph __________________________________

And the R^2 value _______________Attach the graph to this page.

From your graph, what would be the density of a 21.5% sucrose solution? ________________________g/mL

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Density by water displacement; determination of an Al bar

Beaker with Al _________g

Empty beaker _________g

Difference ____________g

Graduated cylinder with Al ____________mL

Empty graduated cylinder ____________mL

Difference ____________mL

Density of Al _____________g/mL

Beaker with unknown _________g

Empty beaker _________g

Difference ____________g

Graduated cylinder with unknown __________mL

Empty graduated cylinder ____________mL

Difference ____________mL

Density of unknown _____________g/mL

Is it real? Determination of the density of a silver dollar

Archimedes water displacement was demonstrated by your TA. Determine the volume of water displaced by 10 suspect coins from the demonstration.

Final volume	Initial volume	Volume of 10 coins	Volume of 1 coin
mL	mL	mL	mL

Determine the mass of the coin you are given to +/- 0.0001 g accuracy. ______________g

What is the density by this method? _____________g/mL

Determine the volume of the coin after measuring its dimensions with a caliper.

Equation for a disk from Geometry is __________________

Diameter ____________cm

Radius ____________cm

Average thickness ___________cm

Volume of coin ____________ cm^3

Density of coin _____________ g/cm^3

Are the two methods the same?

Which do you think is more accurate? Why?

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Is the silver dollar silver? (Compare it to the reported density of silver.)

What metal do you think it is made of? Justify your answer by comparing it to other metal densities.

Density trends

Worksheet for calculating densities of several metals

Metal	Cr	Mo	W	Fe	Ni	Cu	Zn
beaker+ metal (g)							
Beaker(g)							
Difference (g)							
Graduated cylinder + metal (mL)							
Graduated cylinder (mL)							
Difference (mL)							
Density (g/mL)							

Some Transition elements from the periodic table

Symbol Name Density (g/mL)	Ti ________ ______	V ________ ______	Cr ________ ______	Mn _________ _______	Fe _____ _____	Co _______ _____	Ni _______ _____	Cu _______ _____	Zn _____ _____
Symbol Name Density (g/mL)	Zf	Nb	Mo ________ ______	Tc	Ru	Rh	Pd ______ n/d	Ag _______ _____	Cd ________ n/d
Symbol Name Density (g/mL)	Hf	Ta	W ________ ______	Re	Os	Ir	Pt ______ n/d	Au _______ _____	Hg ________ n/d

n/d = not determined

In the abbreviated periodic table above fill in the names of all the elements in the white boxes.

Determine the densities of Cr, Mo, and W using the water displacement method used for aluminum in section three, fill in their densities in the table above.

What trend do you observe?

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Determine the densities of Fe, Ni, and Cu using the water displacement method used for aluminum in section three, fill in their densities in the table above.

What trend do you observe?

The elements Ti, V, Mn, Co, Ag, and Au have densities that were determined earlier. The values are respectively:

4.5, 6.0, 7.21, 8.90, 10.47, and 19.3 g/cm^3

Add these density values to their corresponding elements in the white boxes above.

Determine the densities of Zn using the water displacement method used for aluminum in section three.

Fill in the name and density for Zn in the light gray box in the table above.

Does Zn follow your predicted trend?

This is common in chemistry, there are many exceptions to initially observed trends.

Additional questions

An unknown mass of gold displaces 100.0 mL of water in a container. What is the mass of the gold?

A sample of Ag has the same mass as gold above. What volume of water will it displace?

A crown made of a mixture of gold and silver having the same mass as the pure gold sample above displaced a volume of 136 mL of water. What is the percent gold in the crown?

$$\%gold\ by\ mass = \frac{V_{crown} - V_{silver}}{V_{gold} - V_{silver}} \times 100$$

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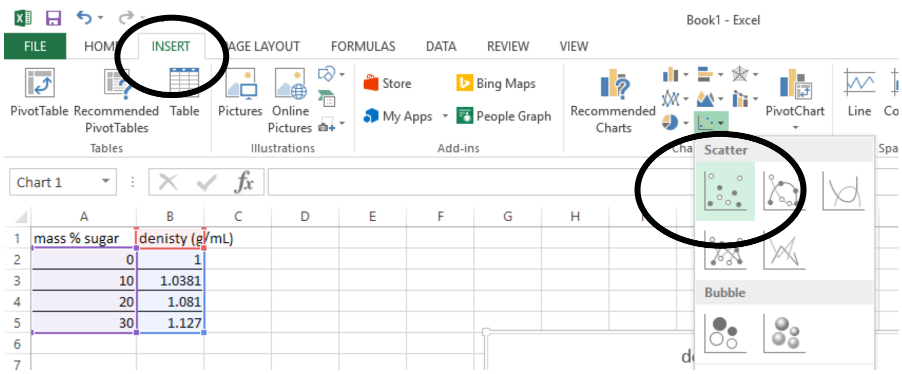
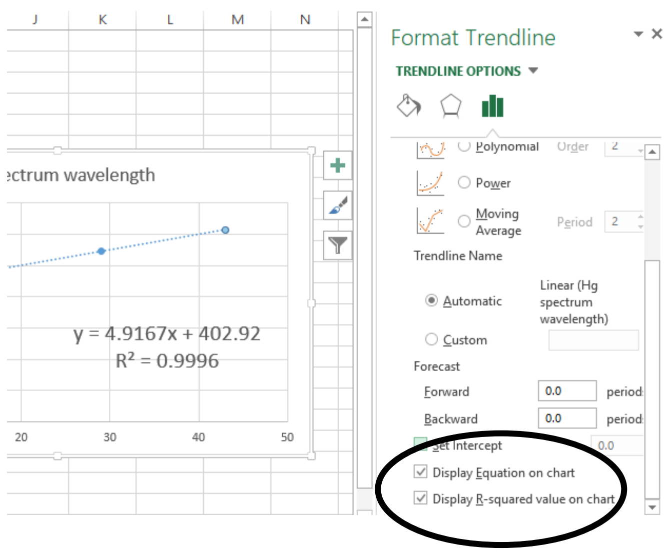
Using Excel

1. Making graph from data that you obtained.
    a. Put data in an Excel spreadsheet as shown in Table 1 for the Density of sugar solution.
    b. The x axis data is placed in the left hand column and the corresponding y axis data in the right hand column.
    c. Highlight the x and y columns with the mouse.
    d. Select from tab menu Insert > Charts > Scatter chart

mass % sugar	Density (g/mL)
0	1
10	1.0381
20	1.081
30	1.127

Table 1. Density of sugar solution





    e. Right click on any data point on your graph, select Add trendline from scroll down menu.

    f. On the right side, pick option of display equation, and display R^2 value.

    g. Ideally, R^2 is 1. Thus, your BEST graph is the one has R^2 value is closest to 1.

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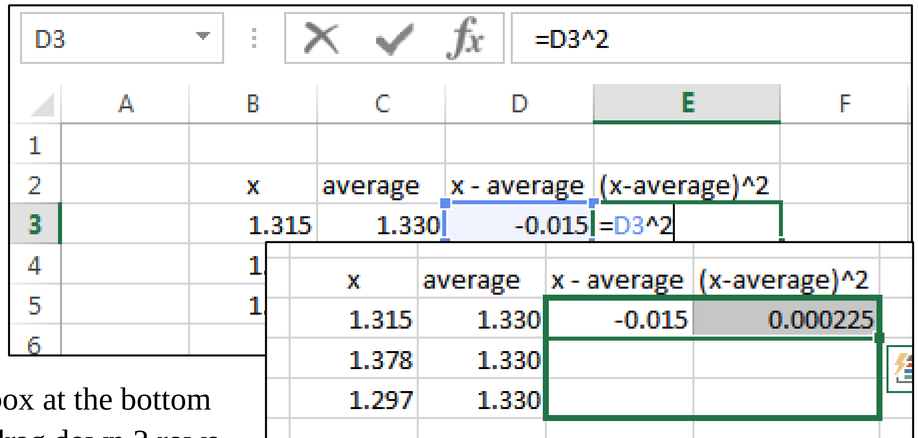
<u>Finding Standard Deviation with Excel</u>

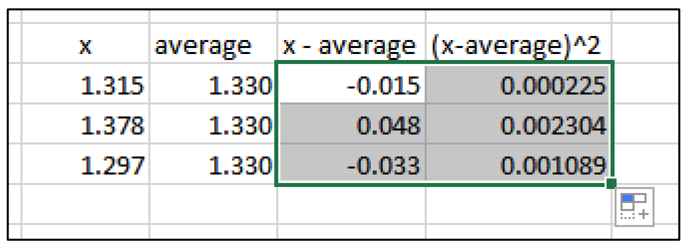
Set up your Excel sheet like table shown below, with the numbers in a column, and the average in the column next to them. The labels are just to make things easier for you.

Select the next cell in your first row (here in my example D3), then type an equals sign, =, click on the first number (here B3), then type a minus sign, -, then click the average next to it (here C3), then press ENTER.

Then select the next cell (here E3) and type an equals sign, =, and click the previous cell (here D3), then type ^2, press ENTER. This will square the value for the value in that cell.

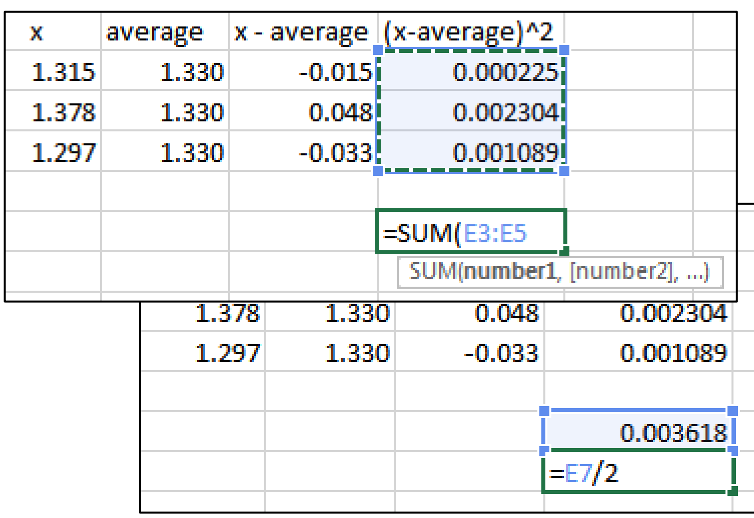


Then click and drag to select cells D3 and E3. While selected, click the little box at the bottom right-hand corner of the selection, then drag down 2 rows. This will copy the formulas to the other cells.

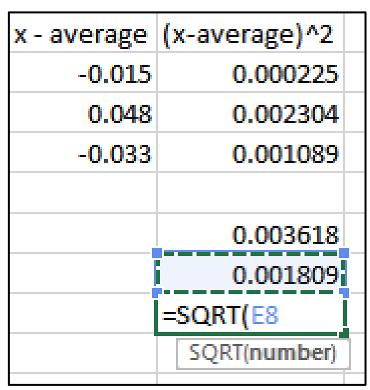


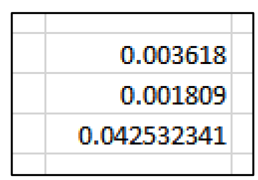
Then find the sum of the cells by selecting a blank cell, then typing: =sum, select the sum function from the dropdown box, then click and drag to select the 3 cells. Press ENTER.

This value is $\Sigma(x_i - \bar{x})^2$



Then you can divide this number by n-1, then find the square root by using the SQRT function.





> Note: If you use the standard deviation function in Excel, =STDEV.P(value1,value2,…). Excel will give a value smaller than the value that is calculated from the procedure above.
>
> The reason is the program divides by n, instead of (n-1); the formula that we use.