The Density of Liquids and an Introduction to Graphing

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I. Learning Objectives

The scientist will be able to:

1. Use the top-loading balance, volumetric flask, and transfer volumetric pipet in a competent fashion.
2. To make serial dilutions for the study of the properties that vary by concentration of a dissolved material.
3. Use experimental data to calculate percent error.
4. Use experimental data to create a graph of solution property versus concentration.
5. Use a linear regression to determine the concentration of a solute from the property value of a solution.

II. Introduction

1. Density

In this experiment, you will create a standard curve of the % concentration by weight of a solute, sugar, versus its density. Density is an intensive property and is defined as the mass of a substance per unit volume.

$$d = \frac{m}{v} \qquad (1)$$

Once the stock solution is prepared, it will be used to make a series of solutions that are progressively less concentrated. The density of each will be determined and plotted against its concentration. This type of plot is known as a standard curve. You will then be provided with a sugar solution of unknown concentration and asked to determine its concentration using the standard curve data.

2. Solutions

A solution is a homogeneous mixture of two chemicals in which each chemical retains its chemical properties. That means that when a solution is created the chemicals are not reacting with each other, no bonds are broken or formed. Liquid solutions are the most common, but solutions can actually be found in any state of matter. Metal alloys such as bronze and steel are examples of solid solutions, and air is an example of a gaseous solution.

A binary solution consists of two components, the solute and the solvent. The solute is the chemical that is dissolved into the solvent. In this lab you will be creating aqueous sugar solutions. An aqueous solution is one in which water is the solvent.

3. Concentration

Concentration is a measure of the amount of solute in a given amount of solution. There are numerous different units for concentration; in this lab we will use percentage solution, also known as weight-volume percent (% w/v). Percentage solution is the mass of solute in grams dissolved in 100 mL of solution.

$$\% \text{ w/v} = \left(\frac{\text{mass of solute}}{\text{mL of solution}}\right) \text{X}100 \quad (2)$$

4. Preparing Solutions and Making Dilutions

In order to prepare a solution you first need to determine the mass of solute needed for a given volume. In the following example we will calculate the mass of sugar needed to prepare 500 mL of solution with a concentration of 30.0 % w/v.

$$\text{Mass of solute} = \left(\frac{\text{Concentration}}{100 \text{ mL}}\right)(\text{Volume of solution}) \quad (3)$$

$$\text{Mass of sugar} = \left(\frac{30.0 \text{ g}}{100 \text{ mL}}\right)(500 \text{ mL}) = 150 \text{ g} \quad (4)$$

In the above example, the percentage is written as a conversion factor in the form of $(\text{mass of solute}) / (100 \text{ mL of solution})$. Once you have one solution prepped you can use it to make more solutions. This referred to as creating dilutions. A dilution is a solution with a weaker concentration created from a solution with a stronger concentration. Dilutions are made by adding more solvent, thus decreasing the ratio of solute to solvent in the solution. In this experiment you will be creating a serial dilution, in which you use each dilution to create the next dilution (solution A is used to create B, B is used to create C, C is used to create D …).

In order to determine the concentration of a dilution we use the dilution formula:

$$C_1V_1 = C_2V_2 \quad (5)$$

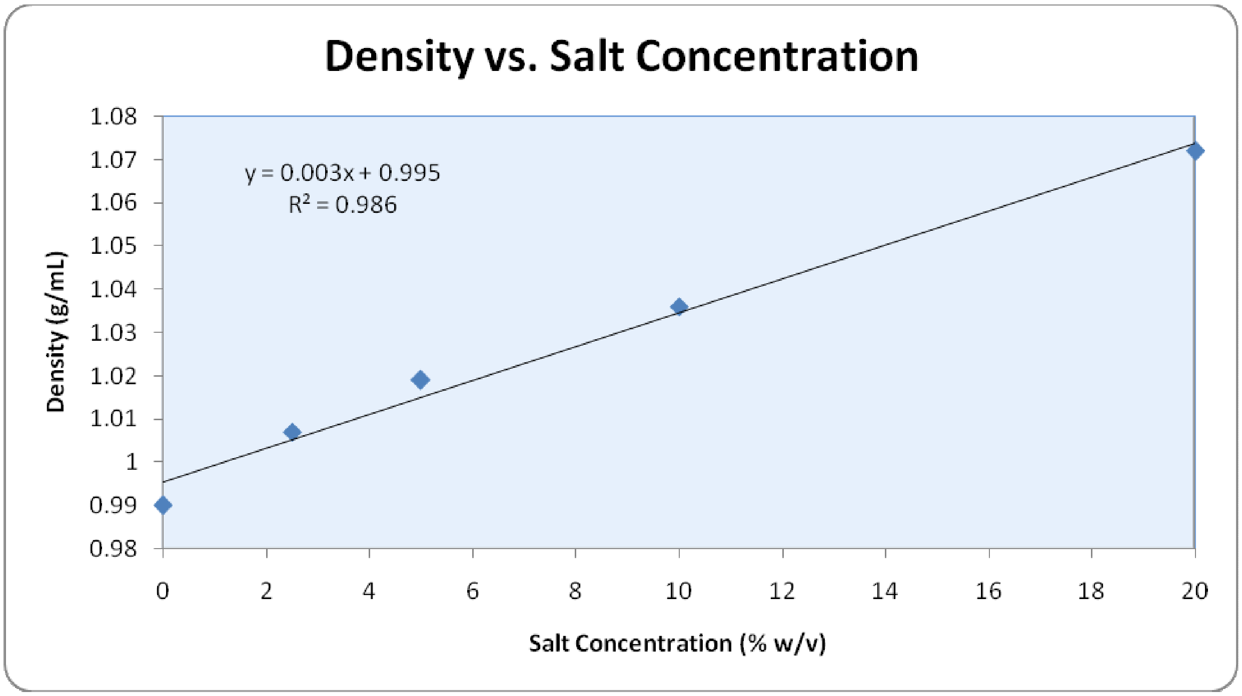
Where C_1 and V_1 are the initial concentration and volume, and C_2 and V_2 are the diluted concentration and volume. For example we can make a dilution by taking 100.0 mL of our 30.0 % w/v solution and creating a new solution with a volume of 150.0 mL. The concentration of the diluted solution can be found using the dilution formula:

$$C_2 = \frac{C_1V_1}{V_2} = \frac{(30.0 \text{ \% w/v})(100.0 \text{ mL})}{150.0 \text{ mL}} = 20.0 \text{ \% w/v} \quad (6)$$

5. Standard Curves

A standard curve is created by plotting a measured property vs. concentration and then fitting the data with a curve, a mathematical equation that best represents the data. In the simplest cases, the curve is a straight line and takes the form of $y = mx + b$. A standard curve can be used to quantitatively determine the concentration of an unknown solution. In this experiment you will create a standard curve of density vs. percentage solution by measuring the density of various dilutions.

The data will be plotted using Excel (see the appendix attached to the end of this lab handout, also available on the lab website). When creating a graph the independent variable should be plotted on the x-axis, and the dependant variable on the y-axis. An example of such a regression is shown in the Chart below. Notice the equation for the least squares line in the upper left hand corner. It is a product of the regression routine. In this equation, x represents % concentration by weight-volume and y represents the density. Also note the R^2 value, this is a measure of the correlation between the data and the fitted line. The closer this value is to one the better the correlation.



After plotting the concentration of the dilute solutions versus their measured density and making the graph as shown above, you will be given a sugar solution with an unknown concentration and be asked to determine its concentration. This is done by determining its density and using the graphical data determined for the diluted sugar solutions.

The concentration of the unknown solution can be determined by using the information from the linear regression line, for this example it is (y-0.9953)/.0039 = x = concentration).

II. Experimental Procedure

1) Stock Solution Preparation

1.1 Obtain a concentration of sugar (weight-volume percent) to use for this part of the experiment. Record it in your notebook.

1.2 Determine the mass of sugar needed to prepare a 100.00 mL solution with the given concentration.

1.3 Weigh out the sugar into a small beaker. You do not need to get the exact amount calculated in step 1.2, but should be within 0.5 g. Record the exact mass of sugar in your notebook. Use this value to determine the exact concentration of your stock solution.

1.4 Fill a 100.00 mL volumetric flask approximately half way with deionized (DI) water. Carefully transfer the sugar to the volumetric flask. Rinse the beaker out with a small amount of DI water, add this to the flask. Use your squirt bottle to rinse any sugar stuck to the neck of the flask down into the water.

1.5 Stopper the flask and swirl until the sugar has dissolved. Once the sugar has dissolved fill the flask up to the calibration mark with DI water. Stopper the flask and shake.

1.6 Label this flask "Sugar Solution A - ___%" (include the concentration in the blank space).

2) Determine the density of the stock solution

2.1 Rinse a 10.00 mL volumetric pipette with the sugar solution. Pipette 10.00 mL of the solution into a dry, pre-weighed beaker. Determine the density of the solution.

3) Creating a Serial Dilution

3.1 Rinse a 25.00 mL volumetric pipette with Solution A. Pipette 25.00 mL of solution A into a dry 50.00 mL volumetric flask. Fill the volumetric flask to the calibration mark with DI water. Cap and shake as before. Calculate the concentration and label the flask "Sugar Solution B - ___%".

3.2 Rinse a 25.00 mL volumetric pipette with Solution B. Pipette 25.00 mL of solution B into a dry 50.00 mL volumetric flask. Fill the volumetric flask to the calibration mark with DI water. Cap and shake as before. Calculate the concentration and label the flask "Sugar Solution C - ___%".

3.3 Rinse a 25.00 mL volumetric pipette with Solution C. Pipette 25.00 mL of solution C into a dry 50.00 mL volumetric flask. Fill the volumetric flask to the calibration mark with DI water. Cap and shake as before. Calculate the concentration and label the flask "Sugar Solution D - ___%

3.4 Repeat step 2.1 for solutions B, C, D, and DI water.

4) Determining the Density of an Unknown

4.1 Obtain approximately 20 mL of an unknown sugar solution in a small, clean, and dry Erlenmeyer flask. Record the identifying information from the unknown.

4.2 Return the unknown to the flask, repeat step 2.1 a second time.

III. Data Analysis

- Determine the True density of your stock sugar solution using the following equation:

  $$\text{Density} = [1.784 \times 10^{-5} (\% \text{ w/v})^2 + 3.729 \times 10^{-3} (\% \text{ w/v}) + 0.99886] (\text{g/cm}^3) \qquad (7)$$

- Determine the percent error of your stock sugar solution density measurement.

- Create a graph of density vs. sugar concentration in Microsoft Excel. Make sure that you title the graph, add labels to each axis, and add a trendline showing the equation and R^2 value.

- Use the equation of your trendline to determine the sugar content in your unknown.

Sample Notebook Pages

Table 1. Preparation of Stock Sugar Solution	
% w/v Sugar Solution Assigned	
Gross Weight of Sugar and beaker	
Weight of beaker	
Weight of Sugar	
Volume of Solution Prepared	
Concentration of Stock Sugar Solution	

Table 2. Densities of Sugar Solutions (All samples have 10.00 mL volumes)			
Solution	Concentration	Mass	Density
Stock Solution A			
B			
C			
D			
Pure DI Water	0%		

Table 3. Linear Regression Information	
Slope	
Intercept	
R^2 value	

Table 4. Concentration of Unknown Sugar Solution			
Run	Weight 10.00 mL	Density	Concentration
1			
2			

Unknown Designation Marking __________

Average Density for the "Unknown Sugar Solution" _______

Average Concentration of Sugar in the unknown _______

* Be sure to also include observations

IV. Post Lab Questions

1.) Concentrations may also be expressed in terms of percent-by-mass (% w/w). In which the concentration is the mass of the solute divided by the mass of the solution and then multiplied by 100. What changes would you need to make to the procedure to use % w/w instead of % w/v?

2.) On your graph, which variable is the independent variable and which is the dependent variable?

3.) Explain how the following errors would affect the calculated density. Indicate whether the density would be too high, too low, or unaffected.
   a.) A student failed to allow the volumetric pipette to completely drain into the beaker used for measuring the mass of the solution (step 2.1).
   b.) A student did not completely dry their beaker between measuring the mass of dilution samples, but still used the same empty mass for the beaker.
   c.) A student spilled some of solution C, and did not have 25 mL to make solution D. The student changed the procedure and pipetted 10 mL of solution C into a 20 mL volumetric flask to create solution D.

4.) Discuss possible sources of error in your density measurement of the stock solution (compared to the true density calculated using equation 7).

5.) What chemical was the solute?

V. Pre-Lab Questions

1. What is the concentration of a solution that is prepared by taking 10.00mL of a 15% solution and diluting it to 500 mL?

2. Why do we use pipettes for measuring volumes for dilutions rather than graduated cylinders?

3. What volume of 25% solution is needed to make 500 mL of a 10% diluted solution?

4. What does the term intensive property mean?

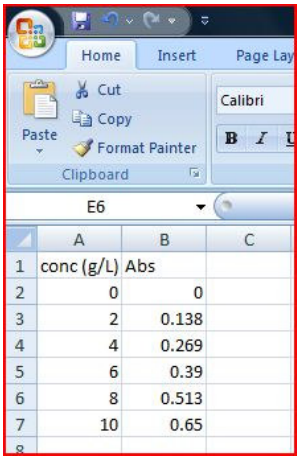
5. On a graph, what does the R^2 value indicate?

References

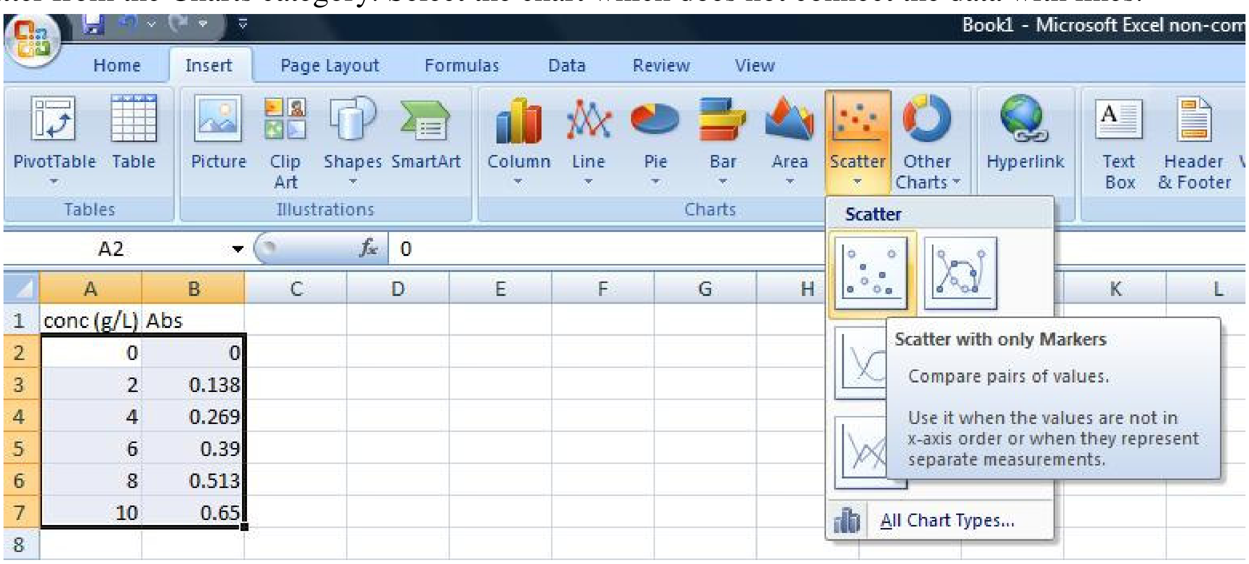
K. I. Peterson, "*Measuring the Density of a Sugar Solution*", **J. Chem. Ed.**, 85, *2008*, 1089-1090.

Appendix - Linear Regression with Excel 2007

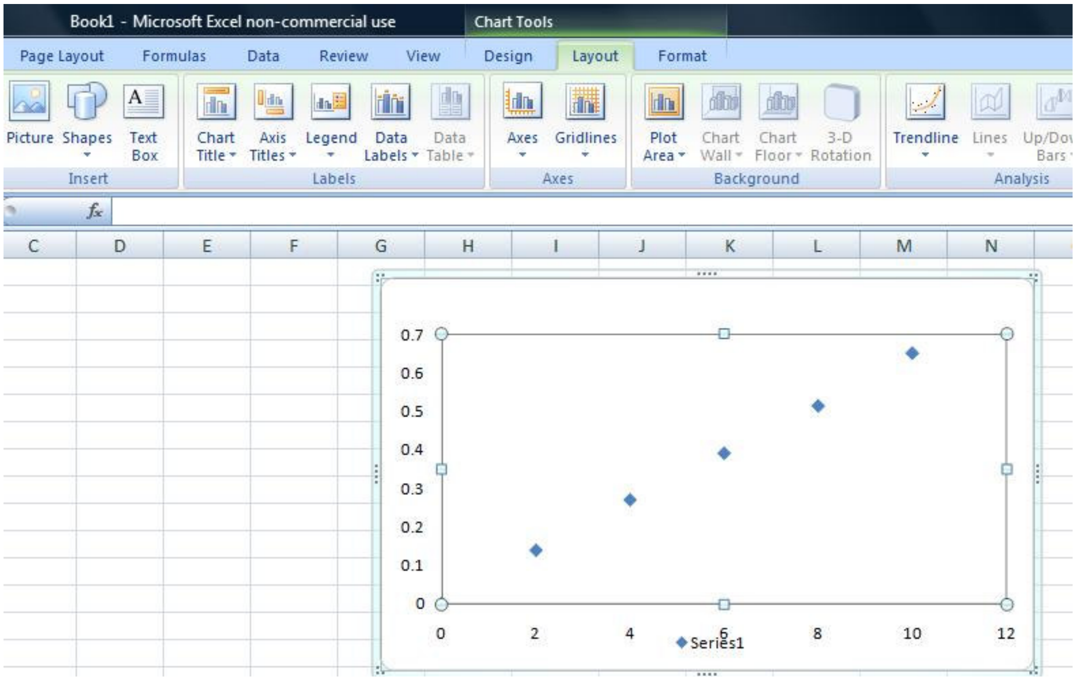
1.) Enter your data in the worksheet. X-data should go in column A, and the corresponding Y-data in column B. Do not include units or the unknown.



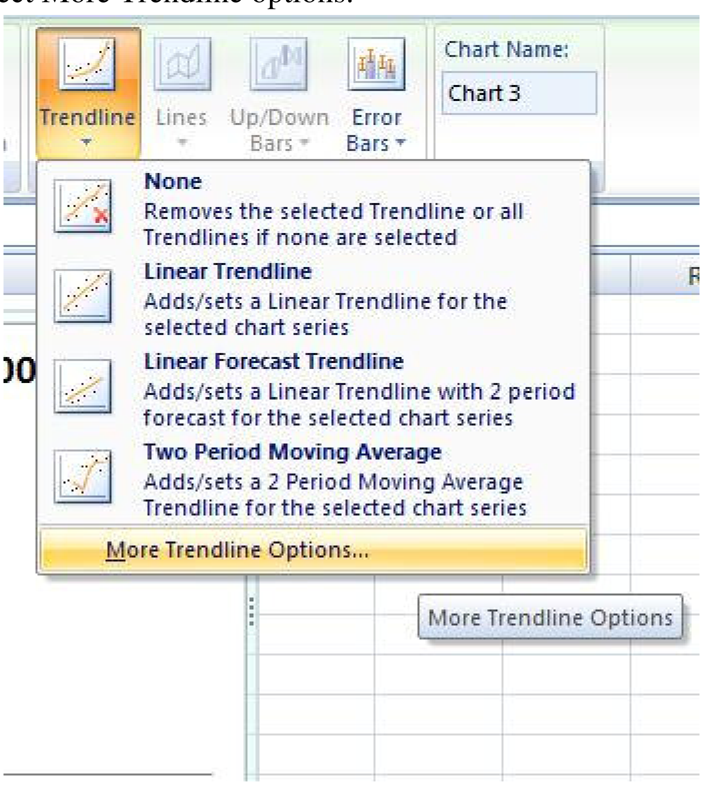
2.) Highlight the cells you typed your data into, then select Insert from the ribbon and choose Scatter from the Charts category. Select the chart which does not connect the data with lines.



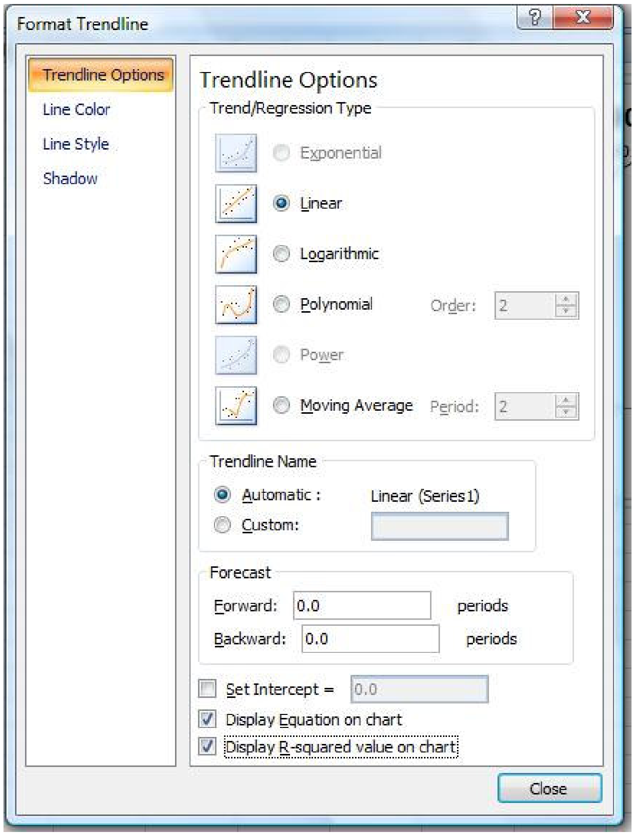
3.) Now you should have a chart inserted into your worksheet. To add a title and labels go to the Layout tab in the ribbon. You can also use the options under the Design tab to modify the look of your graph to fit your desires.



4.) To add a line of best fit (linear regression in this case), click on Trendline in the Layout tab. Select More Trendline options.



5.) In the window that appears, select linear for the Trend/Regression type and click on the checkboxes for "Display Equation on chart" and "Display R-squared value on chart".



6.) Now your graph should be ready to print.