DENSITY AND MASS PERCENT MEASUREMENTS TO DETERMINE SUGAR CONTENT

Objective: The mass percent of sugar present in various beverages will be determined by comparing their measured densities to a set of standard sugar-water solutions. The standard sugar-water solutions are first used to construct a calibration curve, which is employed to determine the sugar concentration in a selection of commercial beverages.

Background

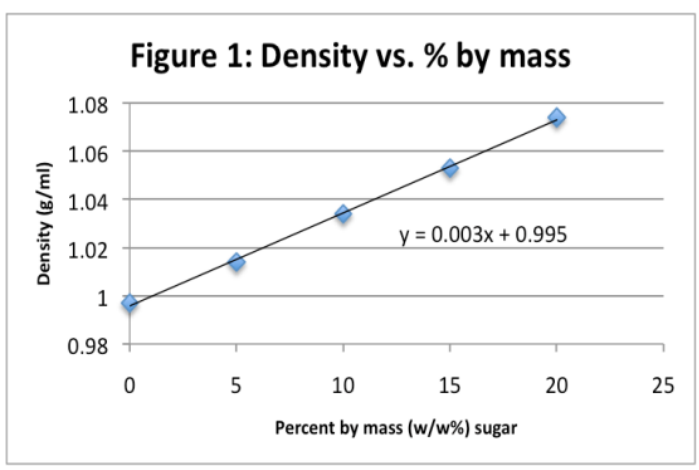
While a substance cannot be identified by its mass or volume alone, when these two physical properties are combined to give a *density*, the ratio of mass per unit volume (eq. 1), this gives a characteristic physical property that can be used to identify a substance. Density is an *intensive property* that does not depend on the amount of the substance. The density of any material can be determined by measuring the mass and volume of a sample of the substance and then dividing the mass by the volume. The mass of a substance can be measured directly using a balance; the volume of a liquid can also be measured directly using glassware, such as a graduated cylinder, a buret or a pipettete.

$$density = \frac{mass}{volume} \qquad (1)$$

The density of a *solution* depends on it part on *concentration*, which is defined by the amount of solute dissolved in the solvent. As the concentration of solute increases, the density of the solution also increases. Concentration can be expressed in a variety of units; one convenient way to express concentration is in units of weight percent (w/w%, mass %), which corresponds to the number of grams of solute that are present in 100 g of solution (eq. 2). For example, a 10 w/w% salt solution can be prepared by dissolving 10 g of salt, e.g., NaCl, in 90 g of water, yielding a final mass of solution of 100 g. If the density of a solution (*y*-axis) is plotted on a graph as a function of the concentration of solute (*x*-axis), a regular trend can be observed in which density is directly proportional to concentration. Thus, we can see experimentally that a 20 w/w% salt solution does indeed have a greater density than a 10 w/w% salt solution (graph, Figure 1).

$$\text{Percent by Mass} = \frac{\text{Mass of Solute}}{\text{Mass of Solution}} \times 100 \qquad (2)$$

Standard solutions are solutions with known concentrations. They are usually made in/with volumetric glassware so that their concentrations are known with a high degree of accuracy. Standards can be made from a solid or from another ('stock') solution. If the densities of several *standard* solutions of known concentration are determined experimentally, a *calibration curve* (graph, Figure 1) can be constructed that shows the straight-line relationship between the density of a solution and the concentration of solute. This calibration curve can then be used to find the concentration of solute (w/w%) in an unknown solution(s).



Most commercial beverages on the market today are aqueous solutions (water is the solvent) that are sweetened with sucrose (better known as table sugar). Diet versions of these beverages employ sugar substitutes to reduce the number of calories in a serving. In the regular version of these drinks, sugar is the solute with the greatest concentration, and other solutes that may be present, such as electrolytes, flavorings, colorings, caffeine, preservatives, etc., are present in relatively small amounts; thus, the density of a given beverage is primarily dependent on sugar content.

In this experiment, you will first prepare four solutions with different concentrations of sugar that are based on the mass percent (mass % or w/w%) of sugar. Then, you will measure the density of water and the densities of the four standard solutions you prepared. You will graph your data to determine the relationship between density and the mass % of sugar (as defined by the line-of-best-fit). After measuring the densities of selected commercial beverages, the calibration curve for your standard sugar solutions will then be used to determine their sugar content.

Procedure

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Safety

- Wear departmentally approved eyewear while doing this experiment.
- Never pipette by mouth. Always use a rubber bulb or pipette pump.
- Do not ingest any solids or solutions as glassware may be contaminated with other chemicals.

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Chemical Hazards

Sucrose – skin, eye and respiratory irritant

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<u>**Notes**</u>:
If you spill any solutions when making up a sample, discard and start again.
You are using volumetric pipettes, which are calibrated to deliver the indicated volume ***without*** blowing out the remaining drop.
Remember to rinse/prep your pipette when switching to a different solution.
All solutions may be disposed of down the drain.

Part I – Constructing a calibration curve of standard sugar solutions

a. Preparing standard sugar solutions

1. Obtain five 125 or 250 ml Erlenmeyer flasks and label them A-E.
2. Flask A will contain only deionized (DI) water. Do not place any sugar in Flask A.
3. Measure the mass of empty Flask B. Transfer ~2 grams of sugar into Flask B. **Note**: These masses are approximate; **actual** masses should be recorded in your data table with the correct number of significant digits provided by the balance used.
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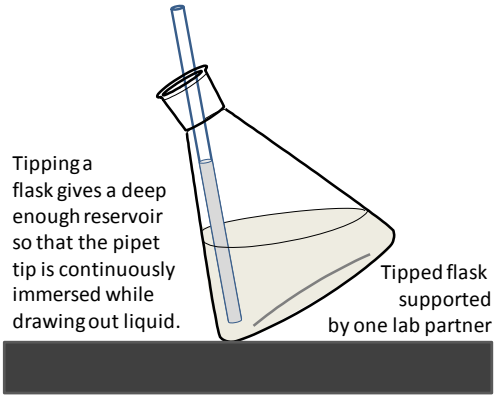
4. Add about 40 mL of deionized water (grad. cylinder) in small portions to the sugar in Flask B, swirling gently to dissolve all sugar. The precise *volume* of amount water is not needed, because the solution concentrations are being determined *by mass* alone.
5. Place Flask B back on the balance and record the total mass of this solution in your data table. Correct for the mass of the empty flask to determine the mass of the solution alone.
6. Repeat steps 3-5 for Flasks C-E, using the following masses of sugar

Solution	**A**	**B**	**C**	**D**	**E**
~Mass sugar (g)	none	2	4	6	8

b. Determining densities of the standard sugar solutions

Keep in mind that the purpose of the next steps is to repeatedly (3x ea.) measure the density of solutions A – E by repeatedly measuring the mass of 10.00 mL of the solutions. The container that catches the 10.00 mL sample can be anything convenient (100 mL beaker). DO NOT pipette directly on the balances: other students need to use them too and there is the real risk of spilling sugar solutions on the electronics.

1. Obtain a 10.00 ml volumetric pipette and pump. Whenever a new solution is used, a small portion of the solution should be drawn up and the pipette rinsed with this small sample that is then discarded.
2. Record the mass of an empty, dry 100 or 150 mL beaker.
3. Use the pipette to carefully measure 10.00 mL of the first solution to be tested. Transfer this to the previously massed beaker, and measure the mass of this beaker and solution sample.



4. Repeat step 3 two more times, with a second and then a third 10.00 sample of the solution being tested. Record an accurate mass of the beaker and solution each time more solution is added. Remember, masses are always additive. Therefore the mass of each 10.00 mL addition can be found by successive subtraction of the preceding beaker + solution mass.
5. Repeat steps 2-4 for the remaining 4 solutions.

Part II – Determining mass percent (w/w%) sugar in commercial beverages

1. Obtain ~40 mL of each beverage you will measure in clean, dry 50 or 100 ml beakers. Record the caloric and sugar content per serving and serving size from each commercial bottle.
2. Measure the density of this commercial beverage using the same procedure (steps 1 – 5 above) you employed for the standard sugar solutions.

Pre-Lab Questions

1. **a.** If 6.09 g of sodium chloride are mixed with 35.50 g of water, what is the mass % (w/w%) salt in the solution?

   b. If another solution has a mass of 35.50 g and is made with 6.09 g of sodium chloride, is the mass % (w/w%) salt the same? Defend your answer.

2. According to the label, a grape soda contains 48 g of sugar per 355 ml serving. If the density of the beverage is 1.052 g/ml, what is the mass % (w/w%) sugar concentration in the soda?

3. A student prepared a set of solutions of sodium chloride in water as shown in the table. The masses of the aqueous salt solutions were measured in triplicate for 10.00 ml samples of the salt standards and an unknown commercial beverage.
   - **i.** Calculate the density of each solution.
   - **ii.** Use Excel to graph solution density (*y*-axis) vs. percent by mass (w/w%) salt for the standards and determine the best fit for the data points. Attach this graph to your pre-lab.
   - **iii.** Use the line-of-best-fit to calculate the mass % salt in the unknown based on the calculated density: _____

Solution	**Mass solution, g (average)**	**Sample volume, ml**	**Density, g/ml**
0.0%	9.95	10.00	
5.21%	10.14	10.00	
10.45%	10.34	10.00	
14.80%	10.53	10.00	
20.05%	10.74	10.00	
Unknown	10.42	10.00	

Data, Calculations and Results

Part I – Constructing a calibration curve of standard sugar solutions

a. Preparing standard sugar solutions

Solution	Mass sugar (g)	Mass solution (g)	Percent by mass (w/w%) See eq. 2
A	0.000		
B			
C			
D			
E			

b. Determining densities of the standard sugar solutions

	Masses (g)					
Solution	**empty beaker**	**Trial 1**	**Trial 2**	**Trial 3**	**Avg. mass of 10.00 mL**	**Density (g/ml)**
A		**bk + soln**	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		
B		**bk + soln**	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		
C		**bk + soln**	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		
D		**bk + soln**	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		
E		**bk + soln**	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		

iii. Calculate the mass of solution for each trial by subtracting the initial mass from the mass after an additional sample of solution is added. Calculate the average mass for each standard sugar solution.

iv. Calculate the density of each standard sugar solution. Show an example calculation.

v. In Excel, construct a graph from the calculated density vs. mass percent (w/w%) sugar. Label and title your graph appropriately. Attach this graph to your report.

vi. Equation for the line-of-best-fit _____ R^2 _____

Part II – Determining mass percent (w/w%) sugar in commercial beverages

	Masses (g)					
Beverage Identity	**empty beaker**	**Trial 1**	**Trial 2**	**Trial 3**	**Avg. mass of 10.00 mL**	**Density (g/ml)**
		bk + soln	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		
		bk + soln	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		
		bk + soln	**bk + soln**	**bk + soln**		
		soln only	**soln only**	**soln only**		

i. Record the mass of solution for each trial and calculate the average mass for each beverage sample.

ii. Calculate the density of each beverage. Show one example calculation.

iii. Based on the beverage density, use the line of best fit from the calibration curve constructed in Part I to determine the mass percent (w/w%) sugar in each beverage. Show an example calculation.

Beverage Identity	**Serving Size (mL)**	**Sugar content per serving (g)**	**Calories per serving**	**Experimental Density (g/mL)**	**Experimental Mass percent sugar**

Record the serving size and caloric data from the bottle for each beverage.

Post-Lab Questions

1. a. Water has a reported density of 0.998 g/ml at room temperature. Treating this as the accepted value, calculate the percent error of your average value of density for pure water (A, 0% sugar) at room temperature.

   b. Water has a reported density of 1.00 g/ml at 4°C. Was your room temperature value for the density of pure water (A, 0% sugar) higher or lower than 1.00 g/ml? Why do you think the density value was off in that direction?

2. If you placed samples of each type of beverage in a closed bottle and placed them in a tub of water, which ones would float and which ones would sink?

3. A key assumption in this experiment is that sugar concentration is the primary factor affecting the density of the solutions. Colorants in such beverages are intensely colored and so can be used in small amounts. Does this validate the key assumption of this experiment? Explain.

4. Based on the information you recorded from the beverage bottles, calculate the Calories per ml for each beverage.

5. Compare the mass % sugar in each beverage with their Calorie contents. Account for any similarities or differences.