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"Are the Densities of Coke and Diet Coke Different?"[1]

PURPOSE AND LEARNING OBJECTIVES

To introduce common laboratory equipment. To learn how to use an analytical balance. To learn to perform volume measurements using different pieces of glassware. To evaluate precision and accuracy of these measurements. To measure and compare densities of Coke and Diet Coke. To verify that density is an intensive property.

PRINCIPLES

Density, d, is defined as mass, m, per unit volume, V, and has units of kg/m^3 or g/ml:

$$d = \frac{m}{V} \quad (1)$$

Density is a physical property of a substance and can also be classified as an **intensive** property since it is independent of the amount of material examined. To determine density of a substance experimentally, one needs to measure its mass and its volume (equation 1). In this experiment, you will measure and compare the densities of Coke and Diet Coke. You will also perform a set of measurements to verify that density is an intensive property. In addition, you will evaluate the precision and accuracy of different pieces of glassware used for volume measurement and delivery.

[1]Adopted from Herrick, R. S.; Nestor, L. P.; Benedetto, D. A. J. *Chem. Ed.* **1999**, *76*, 1411.

Precision and Accuracy

Accuracy is defined as the extent to which a measured value agrees with the true value of the quantity measured. **Precision** is an agreement between two or more measurements that have been carried out in exactly the same fashion (describes the reproducibility of a measurement).

The errors in measurements can be classified as either systematic or random. A **systematic error** causes an error of the same magnitude and in the same direction each time the measurement is made and can be due to the experimental method or a flaw in the equipment. A systematic error reduces the accuracy of the measurement, but the precision can still be good. **Random error** occurs from minor random variations in the quantities measured due to the limitations of the measuring process itself. Random error can be positive or negative. It is always present and cannot be completely eliminated. Random errors affect the precision of a measurement. To improve on the precision, measurements are often repeated several times and the **average** or mean value is reported:

$$\overline{X} = \frac{x_1 + x_2 + \ldots + x_n}{n}, \qquad (2)$$

where $x_1, x_2, \ldots, x_n$ are repeated individual measurements and n is the number of measurements. The magnitude of random error can be mathematically represented by the **standard deviation:**

$$s = \sqrt{\frac{\Sigma(x_i - \overline{X})^2}{n-1}}, \qquad (3)$$

where $x_i = x_1, x_2, \ldots, x_n$. Note, that standard deviation is a measure of precision of an experiment but provides no information about its accuracy. Both average and standard deviation are usually reported for an experimentally measured value in the following form:

Average value ± Standard deviation

Since the standard deviation is an estimate of the random error of the experiment, only **ONE significant figure** should be reported for the standard deviation. The value of the standard deviation *determines* the number of significant figures in the average value. **The last significant figure retained in the average value should be in the same decimal position as the standard deviation.** For example, consider the following set of experimental data:

Measurement #	1	2	3	4	5
Mass of a sample (g)	4.012	4.015	4.011	4.009	4.015

From this data set, the average mass of a sample and the standard deviation of the measurements can be calculated as follows:

$$\overline{X} = \frac{4.012 + 4.015 + 4.011 + 4.009 + 4.015}{5} = 4.0124 \text{ g}$$

$$s = \sqrt{\frac{[(4.012 - 4.0124)^2 + (4.015 - 4.0124)^2 + (4.011 - 4.0124)^2 + (4.009 - 4.0124)^2 + (4.015 - 4.0124)^2]}{5-1}}$$

$$= 0.0026$$

The mass of a sample measured in this example should be reported as

$$4.012 \pm 0.003 \text{ g}$$

Significant Figures

The significant figures in the calculated results are determined by following some simple rules, which are outlined in Table 1.

Table 1. Significant Figures

Quantity	Number of Significant Figures
238	3
670	2 or 3
670.00	5
0.0002	1
0.053	2
0.053000	5
6.022×10^{23}	4

Briefly, nonzero digits are always significant. Leading zeros are not significant. For example, a quantity of 0.053 has two significant figures (5 and 3). Trailing zeros in the numbers that have decimal point are always significant. For example, a quantity of 0.053000 has five significant figures (5, 3, 0, 0, and 0). Captive zeros are always significant. For example, a quantity of 0.0503 has three significant figures (5, 0, and 3). When mathematical operations are performed, the following rules of assigning significant figures apply:

1. In the addition or subtraction of quantities, the number of significant figures in the answer is determined by the least certain quantity. In other words, the last significant figure retained in the answer should be in the same decimal position as the last digit in the least certain quantity. For example,

$$\begin{array}{r} 95.1 \\ \underline{+\ 12.7544} \\ 107.8\underbrace{544}_{\textit{Not significant}} \end{array}$$

   The number 107.8544 should be rounded to 107.9 as the final answer.

2. In the multiplication or division of quantities, the answer is rounded to the same number of significant figures as the quantity with the least number of significant figures. For example,

$$145.1 \times 12.7544 = 1850.\underbrace{6634}_{\textit{Not significant}}$$

The number 1850.6634 should be rounded to 1851 as the final answer.

3. When a combination of addition/subtraction and multiplication/division is performed, the above rules apply in each portion of the calculation. For example,

   $(145 + 4.8005) \times 0.025749 = 3.86$

In the multi-step calculations, always retain all the listed digits in the figures through to the final calculation. Only round off the final result by applying the rules described above. This approach helps to avoid errors that may result from rounding too frequently.

SAFETY

WEAR SAFETY GOGGLES

MATERIALS

Coke, Diet Coke.

PROCEDURE

Your TA will divide the laboratory section into two groups. One group will perform all the measurements using Coke; the other group will use Diet Coke. You will perform your own measurements but then share your data with the rest of the students. This data pooling will allow you to have large enough data sets necessary to determine whether the densities of Coke and Diet Coke are statistically different. In addition, you will be able to verify that density is an intensive property.

Part 1. "Are the densities of Coke and Diet Coke different?"

1. Obtain about 100 ml of Coke or Diet Coke (as assigned by your TA) into an empty beaker and take it to your bench.

2. Measure and record the temperature of your liquid sample.

3. Label and weigh two smaller (30 ml or 50 ml) beakers using an analytical balance. Record the mass to the nearest 0.0001 gram.

4. Dispense 5 ml of your sample into each of the labeled beakers using a 5 ml volumetric pipette.

5. Weigh the beakers containing the sample and record the mass to the nearest 0.0001 gram.

6. Repeat the procedure (steps 3 through 5) with two 5 ml portions of your sample this time using 10 ml graduated cylinder for volume measurement and delivery.

7. Obtain a 50 ml burette. Clean the burette and rinse it well with deionized water. Rinse the burette with small amounts of your sample. Mount the burette, close the stopcock, and fill the burette with your sample (Coke or Diet Coke) about half way full. Drain some of the solution through the stopcock into an empty beaker. Make sure that the burette tip is filled with solution and that there are no air bubbles inside the tip of the burette.

8. Label and weigh two smaller beakers using an analytical balance. Record the mass to the nearest ±0.0001 g.

9. Record the initial burette reading to ±0.01 ml.

10. Dispense about 5 ml of your sample into the first beaker.

11. Record the final burette reading to ±0.01 ml.

12. Repeat the procedure for the second trial. Calculate the exact volume delivered by the burette for each trial.

	Trial 1	Trial 2
Initial Burette Reading (ml)		
Final Burette Reading (ml)		
Volume Delivered (ml)		

13. Calculate the density of your sample for each measurement. Record all your data.

	Volumetric Pipette		Graduated Cylinder		Burette	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Mass of Empty Beaker (g)						
Mass of Beaker + Liquid Sample (g)						
Mass of Liquid Sample (g)						
Volume Delivered (ml)						
Calculated Density (g/ml)						

14. Enter your numbers for calculated densities (total of six) into the designated computer so that other students can use your results. The computer program written in *Microsoft Excel* will compile all of the student's data into a general graph. Make sure, you print out your own copy of the compiled data table and the graph at the end of laboratory period and attach them to your report.

15. Using the class data from the compiled data table, calculate the average and the standard deviation for Coke and Diet Coke. Make sure, you use the right number of significant figures when reporting the final results.

Sample	Average Density ± Standard Deviation (g/ml)		
	Pipette	Grad. Cyl.	Burette
Coke			
Diet Coke			

Part 2. "Does the size of the sample affect the density?"
Every student within a Coke and Diet Coke sub-group will be assigned the specific volume that (s)he will be responsible for. As a group, you will perform the density measurements for a range of different volumes. Once again the data will be pooled to answer the question of whether the size of a sample affects the density of soda.

1. Obtain the specific volume assignment from your TA. You should continue working with the same type of soda (Coke or Diet Coke) that you were working with earlier in Part 1 of the procedure.

2. Repeat steps 8 through 12 of Part 1 of the procedure with the assigned volume of your sample. Record your data.

	Trial 1	Trial 2
Mass of Empty Beaker (g)		
Mass of Beaker + Liquid Sample (g)		
Mass of Liquid Sample (g)		
Initial Burette Reading (ml)		
Final Burette Reading (ml)		
Volume Delivered (ml)		

3. Enter the mass and the volume obtained for your sample into the designated computer, which will compile all of the student's data and plot mass as a function of volume for each soda. Determine the density of the Coke and Diet Coke from the corresponding plots. Make sure, you print out your own copy of the graphs at the end of laboratory period and attach them to your report.

Sample	Density (g/ml) determined from the plot
Coke	
Diet Coke	

WASTE DISPOSAL

Dispose of your Coke and Diet Coke samples into the sink.

DISCUSSION QUESTIONS

For Part 1, report the obtained average densities along with the standard deviations for both Coke and Diet Coke (make sure to use the right number of significant figures).

Would you expect the densities of Coke and Diet Coke to be different? Explain why.

Based on your experimental data from Part 1, are the densities of Coke and Diet Coke different? Explain your answer.

Based on your experimental data from Part 2, are the densities of Coke and Diet Coke different? Explain your answer.

For Part 1, how do densities of Coke and Diet Coke compare to the density of water (see Table 2 for reference)? Provide the most plausible explanation for the results of this comparison with water. Make sure, the comparison is done at the same temperature.

Evaluate the accuracy of the glassware used.

Compare the precision of the volumetric pipette, graduated cylinder, and the burette based on your experimental results.

Were you able to verify that density is an intensive property?

Explain how the plot of a mass of a sample as a function of its volume helped you in density determination.

Identify the possible sources of error in this experiment.

Table 2. Density of water in the range 0–50 °C[2]

Temperature (°C)	Density (g/cm^3)
0	0.99984
10	0.99970
20	0.99821
30	0.99565
40	0.99222
50	0.98803

PRE-LAB QUESTIONS

1. List three pieces of glassware that will be used for volumetric measurements in Part 1 of the experimental procedure.

2. What is the main objective of Part 1 of the experimental procedure?

3. Why will you need to share your data from Part 1 with the rest of the class?

4. What is the main objective of Part 2 of the experimental procedure?

5. Suppose you have a sample with a density of 0.5 g/ml. Sketch out a graph of the mass of this sample as a function of its volume.

POST-LAB QUESTIONS

1. Determine the number of significant figures for the following quantities:

   a) 700.0

   b) 5×10^{12}

   c) 250

   d) 0.089060

2. Calculate and report the result using the correct number of significant figures:

   a) $10826.3 + 15.90 - 972 =$

   b) $\dfrac{8.1672 \times 0.14 \times 1.151}{0.009} =$

[2]Lide, D. R. *Handbook of Chemistry and Physics,* 71st ed.; CRC Press, **1990.**

c) $\frac{(118.72 - 74)}{15.01} =$

d) $17.1780 + 5.8 \times 71.2 =$

3. A rectangular metal sheet made out of stainless steel has a mass of 136.892 kg. The sheet is 4 mm thick, 24 inches wide and 7.00 m long. Calculate the density of stainless steel. Report your answer using the correct number of significant figures. Show your work.

4. Rewrite the following measurements of the average ± experimental error using the correct number of significant figures:

   a) 708.1254 ± 0.0570 g

   b) 1230.8 ± 28 ml

   c) 0.0897892 ± 0.0000109 g

   d) 14.82 ± 1.0 M

5. When a handful of gold-colored metal beads is placed into a graduated cylinder containing 11.5 ml of water at 20 °C, the water level rises to 46 ml. The mass of the empty graduated cylinder is 92.42 g. The total mass of a graduated cylinder with the water and the beads is 412.0 g. Calculate the density of the metal that the beads are made from. Report your answer using the correct number of significant figures. Show your work.

LITERATURE

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