

## Experiment 5C

FV 5-15-12

### PHYSICAL MEASUREMENTS: THE DENSITY OF A SOLUTION<sup>1</sup>

**MATERIALS:** 25 mL graduated cylinder; 25 mL pipet; 50 mL buret; 100 mL beaker; plastic bottle with cap; plastic dropper; degassed Coke<sup>®</sup> and Diet Coke<sup>®</sup>.

**PURPOSE:** The purpose of this experiment is twofold: (1) to compare the precision of common volumetric glassware; (2) to determine the densities of different aqueous solutions.

**LEARNING OBJECTIVES:** By the end of this experiment, the student should be able to demonstrate proficiencies in the following areas:

1. Identify and use the following volumetric glassware: graduated cylinder, buret and pipet.
2. Calculate the density of a solution.
3. Describe the differences in the precision of the volumetric glassware used.
4. Describe the relationship between experimental measurements, precision and significant figures.
5. Apply the rules for significant figures.
6. Explain the difference between intensive and extensive quantities.

**PRE-LAB:** Read over the experiment and complete the pre-lab questions on p.E5C-9 before the lab. Print out this lab experiment and bring it with you to the laboratory. In addition, read and sign the Safety Agreement on p. E5C-10 and bring this with you to lab along with your laboratory goggles.

#### DISCUSSION:

**Principles:** Any characteristic that can be used to describe or identify matter is called a *property*. Properties can be classified in a variety of ways. One common classification sorts properties as physical properties and chemical properties. *Physical* properties, like color or mass, are those which can be determined without changing the chemical makeup of the material. Weighing an object does not change it, so mass is a physical property. *Chemical* properties, on the other hand, rely on a chemical change. For example, iron reacts with oxygen to form rust. Rusting is a chemical property. Another common way to distinguish the properties of a substance is to classify them as extensive or intensive properties. For an *extensive* quantity, the value of the property depends on the amount of material. For example, the mass of an iceberg is much larger than the mass of an ice cube, because there is more ice in the larger sample. Therefore, mass is an extensive quantity. In contrast, the value of an *intensive* quantity does not depend on the amount of material. Temperature, for example, is an intensive quantity: an ice cube and an iceberg can both be at 0°C, regardless of their vastly different sizes. We will encounter many different quantities that can be used to characterize matter. The ability to classify such properties in these ways will be very useful.

*Density* is a quantity that can be used to describe a sample, or even identify one from a limited set of possibilities. This property can be used for both pure materials and mixtures. Density is defined as the ratio of the mass divided by the volume. It is often expressed in derived units of g/cm<sup>3</sup> for solids, or g/mL for liquids, including solutions. Knowing the density of a substance can be quite useful because it is often easier to measure the volume of a liquid rather than its mass. When both the volume and density are known, the mass is readily determined. Like other properties of matter, density can be classified into two of the categories described above. You may already be able to classify density as a 'physical' or 'chemical' property. In this experiment, we will deduce whether density is an 'extensive' or 'intensive' property.

Since density is the ratio of mass to volume, we can determine the value of the density of a sample by measuring these two properties, and dividing them according to the definition. We have already seen how mass can be measured with the laboratory balance, so now we must examine how to measure volume. In the laboratory, the volume of a liquid (either

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<sup>1</sup>Adapted from R.S. Herrick, L.P. Nestor and D.A. Benedetto, *J. Chem. Educ.*, **76**, 1411 (1999).

a pure substance or a solution) is measured with volumetric glassware. Some of the most common types of volumetric glassware are the graduated cylinder, the buret, and the pipet. The graduated cylinder and buret are both long tubes of uniform bore, etched with markings (graduations) to indicate the volume of the liquid. Both are filled by pouring the liquid into the top. Material is delivered from the graduated cylinder simply by pouring, while a stopcock is used with the buret to achieve finer control. There are two kinds of pipets, but the type most often used for quantitative work is the “transfer pipet”. This is a long thin tube of glass, often with an enlarged central region (to hold more liquid), and it has one end tapered to a very fine tip. Usually, there is *only one* marking on a transfer pipet, since it is calibrated to deliver (TD) only one volume of liquid. A transfer pipet is filled by placing the fine tip into a container of liquid, and then using a rubber suction bulb to draw the liquid up into the pipet. The liquid level within the pipet is adjusted until it is exactly at the calibration line. The filled pipet is then brought to the receiving vessel, and the sample allowed to flow into the receiver until no more liquid drains out. Any liquid remaining in the tip at this time should be left in the tip, since the transfer pipet is calibrated to deliver the specified volume with liquid remaining in the tip.

With any of these pieces of equipment, properly reading the scale or mark is essential, if the full precision of the device is to be obtained.<sup>2</sup> For aqueous solutions, the meniscus (the concave surface of the liquid in the glass) should be read at the bottom of the curve. Also, the reading should be performed with the eye at the level of the meniscus, in order to avoid parallax errors. With the graduated cylinder and buret, the reading is made by interpolating the position of the meniscus between adjacent graduations. Since you are estimating a value between the graduations, you should read (and record) these devices to one decimal place *beyond* that of the smallest graduation (i.e., include one uncertain digit beyond the certain digits). With the transfer pipet, no interpolation is possible - either the meniscus is on the mark and the volume delivered is exactly the calibrated value, or the meniscus is not on the mark and the volume is unknown. Information and tutorials on reading scales are available in a number of locations.<sup>3</sup>

A final issue in the use of volumetric glassware is cleanliness. If the glass walls of the container are not clean, droplets of the sample will cling to the glass, and the volume delivered will be less than expected. It is also good practice to rinse the glassware with the solution to be used, before the actual quantitative transfer. This will minimize changes in concentration of the actual sample, which might be caused by water or other reagents remaining in the glassware. Careful attention to cleaning and rinsing glassware is required for the best quantitative results.

Although the three types of volumetric glassware examined in this experiment can perform the same function, they are generally used in different ways, depending on the nature of the operation and the accuracy or precision required. As indicated above, we will determine the densities of our two solutions by measuring the masses and volumes, and dividing those values. In each case, the mass will be determined with an analytical balance. With a precision of about 4 parts per million (4 ppm) for these samples, the balance also happens to be the most precise measuring device used in the experiment. A calculated quantity such as density cannot be any more precise than the *least* precise component of the calculation. Since all of the volume measurement devices are less precise than the balance, the precision of the calculated density will reflect the precision of the volume measurement. That, in turn, depends on the type of glassware *and the skill of the operator*. We can get an idea of the relative precision of the calculated density values just by looking at a list of measurements taken by the class. The volumetric device giving more “certain digits” (the ones everyone agrees on) in the density should have a higher precision. Thus the collection and comparison of results from all midshipmen in the section will highlight the differences among these pieces of glassware. (A true determination of the precision of the measuring device would be done with repeated measurements in a similar way, but involving only *one* operator and one *individual* pipet, buret, etc. That procedure would remove any complicating effects caused by varied operator skill or manufacturing variations in the pieces of glassware. For our purposes, however, the procedure of the experiment is sufficient. For a detailed discussion of precision, accuracy, significant figures and error analysis, see Appendices B, E and J on the online lab system for General Chemistry ( <http://www.chemistry.usna.edu/manual/append.htm> ).

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<sup>2</sup>See Appendix E.

<sup>3</sup>See, for example, <http://www.dartmouth.edu/~chemlab/techniques/buret.html> and <http://www.dartmouth.edu/~chemlab/techniques/pipet.html>, Prof. Oliver Seely, California State University, Dominguez Hills, accessed 10 August 2001.

## PROCEDURE:

The instructor will assign one of the two sample solutions, either Coke<sup>®</sup> or Diet Coke<sup>®</sup>, to each midshipman. Each midshipman will perform all of the measurements on their single assigned sample solution. Results from all midshipmen will be collected and distributed such that each has all density values from all midshipmen for both sample solutions.

Make sure that your glassware is clean before you start. If it is not, clean it with soap and water, and then rinse with tap water, and finally with distilled water. Your instructor may give you additional directions on cleaning as well.

### Part A. Graduated Cylinder

1. Empty any residual liquid from the plastic bottle. Cap the bottle, and make sure that the outside of the plastic bottle and cap is dry. (Because we will determine mass by difference, it will be unnecessary to perform the difficult task of completely drying the inside.) Using the analytical balance, weigh the empty plastic bottle with cap. Record the mass, including units, for Trial I in the Data Section.
2. Using the 100 mL beaker, obtain approximately 60 mL of your assigned solution from the laboratory stock bottle. Record the identity of the solution in the Data Section.
3. Rinse the graduated cylinder with the sample solution you are about to use. To *rinse* the glassware, place a small amount of the solution in the cylinder, manipulate the glassware until all interior surfaces have been contacted by the solution, and then discard the rinse.
4. Fill the graduated cylinder to the 25 mL mark with the sample solution. (You may find it easier to fill to ~24 mL, and then add the last amount with a plastic dropper. For colored solutions, holding a white card behind the cylinder will make it easier to read the scale.) Record the volume, with units and the correct number of significant figures, in the Data Section.
5. Pour the “25 mL” sample into the previously weighed plastic bottle. Recap the bottle, and use the analytical balance to determine the mass of the capped bottle plus sample. Record the mass, including units, in the Data Section.
6. Repeat Steps A.4 and A.5. It is NOT necessary to discard your earlier sample first; as long as you know the mass before and after a sample addition, you will be able to determine the mass of the liquid transferred. Record the data from Trial II in the Data Section. Since you did not discard the earlier sample, the first mass for Trial II will be the same as the last mass for Trial I.

### Part B. Buret

1. Empty any residual liquid from the plastic bottle. Cap the bottle, and make sure that the outside of the plastic bottle and cap is dry. Using the analytical balance, weigh the empty plastic bottle with cap. Record the mass, including units, for Trial I in the Data Section.
2. Using the 100 mL beaker, obtain approximately 60 mL of your assigned solution from the laboratory stock bottle.
3. Rinse the buret with the assigned sample solution. It is not necessary to fill it completely; just add a small amount of solution and manipulate the buret until all interior surfaces have been contacted. Discard the rinses.
4. Mount the buret on a stand, using a buret clamp. Fill the buret close to the 0 mL mark with the sample solution. Drain out some liquid until you are sure that there are no air bubbles in the glass tip below the stopcock. (It may take about 10 mL to do so.) It is convenient to adjust the volume to a whole number reading. It is not really necessary, however, since all volume measurements are determined by difference.
5. Record the initial volume, with units and the correct number of significant figures, in the Data Section. Deliver a “25 mL” sample into the previously weighed plastic bottle, and record the final volume in the Data Section. (You want a volume as close as possible to exactly 25 mL, to facilitate comparisons with the other pieces of glassware. However, you should record the exact volume delivered, even if it is slightly off the target value.) Recap the bottle, and use the analytical balance to determine the mass of the capped bottle plus sample. Record the mass.

6. Repeat Steps B.4 and B.5. (Again, it is NOT necessary to discard your earlier sample first. It is also not necessary to refill the buret completely; just add enough to ensure that there is sufficient material to deliver the entire 25 mL sample from the *calibrated* portion of the glassware.) Record the data from Trial II in the Data Section.

### Part C. Pipet

1. Empty any residual liquid from the plastic bottle. Cap the bottle, and make sure that the outside of the plastic bottle and cap is dry. Using the analytical balance, weigh the empty plastic bottle with cap and record the mass.
2. Using the 100 mL beaker, obtain approximately 60 mL of your assigned solution from the laboratory stock bottle.
3. Rinse the pipet with the assigned sample solution. (Place the fine tip of the pipet in the beaker containing the sample. Squeeze the air out of the rubber suction bulb, and apply it to the top of the pipet. Slowly draw solution into the pipet by relaxing your grip on the rubber bulb. It is not necessary to fill the entire pipet. Manipulate the pipet to contact all interior surfaces, and discard the rinse by draining it through the tip.)
4. Place the pipet in the beaker containing the sample. You can control the flow more easily if the tip of the pipet gently rests against the *bottom* of the beaker. Use the rubber suction bulb to slowly draw solution into the pipet. Draw the sample until the liquid level is above the calibration line. (You may have to apply suction more than once.) Remove the rubber bulb, and quickly seal the top of the pipet with your finger, preventing the liquid from running out. Raise the pipet out of the beaker, and allow the sample to drain until the bottom of the meniscus is just at the calibration line.
5. Deliver the measured “25 mL” sample contained in the pipet to the previously weighed plastic bottle. Allow it to drain completely. Any drops clinging to the outside of the pipet tip should be touched off into the plastic bottle. However, the thin film *inside* the tip should be left there. Do not use your bulb to blow out the remaining liquid. Recap the bottle, and use the analytical balance to determine the mass of the capped bottle plus sample. Record the mass, including units, for Trial I in the Data Section. Record the volume, with units and the correct number of significant figures, in the Data Section. (See Appendix E. A properly used pipet should deliver 25.00 mL of liquid at the calibration temperature. The effect of temperature changes will be very small here, and we will ignore them.)
6. Repeat Steps C.4 and C.5 as done previously. Record the data from Trial II in the Data Section.

### Clean Up:

1. Rinse all glassware with distilled water. Lay the graduated cylinder on its side, and allow it to drain. Invert the beaker and plastic bottle and place them on a paper towel to allow them to drain. Invert the buret and mount it in the buret clamp on the ring stand, with stopcock open; allow it to drain. Before leaving, return equipment to the bin from which it was originally obtained. At your station, leave on the bench top only the material that was originally there.
2. Wipe down your work area of the lab bench with a damp sponge.
3. As directed by your instructor, complete through page E5C-8 and record the class results on the Summary Table provided.

Name \_\_\_\_\_

Section \_\_\_\_\_

Partner \_\_\_\_\_

Date \_\_\_\_\_

**DATA SECTION**  
**Experiment 5C**

Sample solution identity \_\_\_\_\_

**Part A. Graduated Cylinder**

	<b>Trial I</b>	<b>Trial II</b>
Mass of capped plastic bottle before sample added	_____	_____
Mass of capped plastic bottle with sample	_____	_____
Mass of "25 mL" sample	_____	_____
Volume of sample delivered	_____	_____

**Part B. Buret**

	<b>Trial I</b>	<b>Trial II</b>
Mass of capped plastic bottle before sample added	_____	_____
Mass of capped plastic bottle with sample	_____	_____
Mass of "25 mL" sample	_____	_____
Initial buret reading	_____	_____
Final buret reading	_____	_____
Volume of sample delivered	_____	_____

**Part C. Pipet**

	<b>Trial I</b>	<b>Trial II</b>
Mass of capped plastic bottle before sample added	_____	_____
Mass of capped plastic bottle with sample	_____	_____
Mass of "25 mL" sample	_____	_____
Volume of sample delivered	_____	_____

**DATA TREATMENT**  
**Experiment 5C**

For all calculations, be sure to report your answer with units and the correct number of significant figures<sup>4</sup>. Your instructor may require you to check with him or her *before* you enter values on the chalkboard. Show your work in the area provided.

**Part A. Graduated Cylinder**

(A.1) Calculate the density of your sample, as determined with a graduated cylinder, for both Trial I and Trial II.

Trial I Density \_\_\_\_\_

Trial II Density \_\_\_\_\_

(A.2) Calculate the average value of the density that you determined for the sample, using a graduated cylinder. Report this value below and on the chalkboard.

Average Density, graduated cylinder \_\_\_\_\_

**Part B. Buret**

(B.1) Calculate the density of your sample, as determined with a buret, for both Trial I and Trial II.

Trial I Density \_\_\_\_\_

Trial II Density \_\_\_\_\_

(B.2) Calculate the average value of the density that you determined for the sample, using a buret. Report this value below and on the chalkboard.

Average Density, buret \_\_\_\_\_

**Part C. Pipet**

(C.1) Calculate the density of your sample, as determined with a pipet, for both Trial I and Trial II.

Trial I Density \_\_\_\_\_

Trial II Density \_\_\_\_\_

(C.2) Calculate the average value of the density that you determined for the sample, using a pipet. Report this value below and on the chalkboard.

Average Density, pipet \_\_\_\_\_

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<sup>4</sup> See Appendix B, - Significant Figures.

### SUMMARY OF CLASS RESULTS

Parts A, B and C:

SAMPLE 1: _____				SAMPLE 2: _____			
Average Density (g/mL)				Average Density (g/mL)			
Midn	A. Grad. Cylinder	B. Buret	C. Pipet	Midn	A. Grad. Cylinder	B. Buret	C. Pipet
1				1			
2				2			
3				3			
4				4			
5				5			
6				6			
7				7			
8				8			
9				9			
10				10			

**QUESTIONS**  
**Experiment 5C**

1. Based on the summary of class results, which of the three pieces of volumetric glassware gave the greatest precision? Explain your answer.

2. Significant figures include all *certain* digits, and one *uncertain* digit. Based on the summary of class results, how many significant figures are appropriate for reporting the density based on volume measurements made with:

graduated cylinder \_\_\_\_\_ buret \_\_\_\_\_ pipet \_\_\_\_\_

Explain your answer for the graduated cylinder.

3. Question 2 ignored the mass measurement, which was necessary to determine the density in each case. Explain why the number of significant figures in these mass measurements could be ignored, when evaluating the number of significant figures in the density of the samples.

4. What, if anything, can be said about the accuracy of the measurements made with the three different pieces of volumetric glassware? Explain your answer.

5. Which solution had the highest density, Coke® or Diet Coke®? \_\_\_\_\_  
Why do you think this is the case?

Name \_\_\_\_\_

Section \_\_\_\_\_

Date \_\_\_\_\_

**PRE-LAB QUESTIONS**  
**Experiment 5C**

1. These measurements were reported for the mass of a single sample in the laboratory made by different midshipmen using a top loading balance: 32.54 g, 32.67 g, 32.48 g, 32.72 g, and 32.35 g.

(a) Based on these measurements, what is the average mass of the sample?

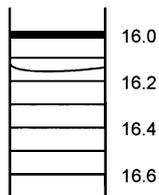
(b) How many significant figures should appear in the result?

2. Calculate the average deviation for the data given.

DATA  
SET

3.69  
3.68  
3.67  
3.69  
3.68  
3.69  
3.66

3. What is the correct reading of the volume of liquid in the buret? Remember, the generally accepted rule for measuring volumes is to estimate one more digit beyond the digit associated with the closest spaced markings.



## CHEMISTRY LABORATORY SAFETY AGREEMENT

Before working in the chemistry laboratory, read carefully the safety precautions and techniques for handling chemicals described in <http://www.chemistry.usna.edu/manual/safety.pdf>. **Give this agreement, signed and dated, to your laboratory instructor on the first day of lab.**

When you are in the laboratory, THINK about what you are doing at all times.

1. Always wear approved chemical splash goggles and lab aprons in the laboratory.
2. Do not attempt any unauthorized experiments. Follow directions carefully.
3. Know the location and operation of safety equipment.
4. Bring only necessary materials into lab. Book bags, jackets, covers, etc., are to be left in the hallway.
5. Never work alone in the laboratory.
6. Never eat or drink in the laboratory. Do not bring water bottles into the laboratory.
7. Use the fume hood for experiments. Keep lab stools at the tables, NOT by the hoods.
8. Keep your work area uncluttered. Clean up your area before leaving lab. Lower the hood sashes.
9. Use only equipment that is in good condition.
10. Dispose of waste and excess materials according to your laboratory instructor's directions.
11. No horseplay in the laboratory.
12. Do not sit or lean on laboratory work surfaces.
13. Handle chemicals with caution.
  - (a) Read labels carefully.
  - (b) Use only the amount required.
  - (c) Leave reagent containers in their proper places.
  - (d) Clean up all spills immediately.
  - (e) Label all chemical containers.
14. Thoroughly wash your hands any time you leave the laboratory.
15. Immediately report all accidents and physical/chemical injuries, no matter how minor, to your laboratory instructor. Be ready to take immediate action as needed to assist any injured classmate.
16. Do not leave the laboratory without your instructor's approval.

I have carefully read all the safety precautions on the pages at the website above and recognize that it is my responsibility to observe them throughout my chemistry course.

Name \_\_\_\_\_ Signature \_\_\_\_\_  
Course \_\_\_\_\_ Section \_\_\_\_\_  
Instructor \_\_\_\_\_ Date \_\_\_\_\_