Experiment 1
Measurement and Density

Learning Objectives:

- To be able to measure the mass and volume of liquid samples using different laboratory instruments
- To distinguish between accuracy and precision, and determine sources of errors
- To be able to generate individual density data, and obtain and analyze statistical interpretations from class data

Experimental Objectives:

- To determine the density of a known liquid (Coca-Cola® variants) using several different glassware and instrument
- To compare class data and examine the accuracy and precision of each technique
- To use deductive reasoning to identify an unknown liquid

Introduction:

Density

Matter has mass and volume. Mass is a measure of the amount of material an object has and is usually given in grams (g) or kilograms (kg). Volume is defined as the amount of space an object occupies and is usually expressed as the units liters (L), meters cubed (m^3), and gallons (gal). Density is defined as the ratio of the mass of an object to the volume it occupies. Different materials can have different densities and density can be used to identify a substance.

$$\text{Density } (\rho) = \frac{\text{Mass (M)}}{\text{Volume (V)}}$$

Density is an intensive property, meaning it does not depend on the size of the object. A 1 mL sample of water, for example, has the same density as 1 gal of water. Mass and volume are extensive physical properties of matter, and vary with the size of the sample.

Measurement

The mass of a liquid or solid can be measured using a balance. There are 2 kinds of balances in the general chemistry laboratory: the analytical balance and the top-loading balance. The difference is in the uncertainty in the measurement displayed by the instrument (Table 1).

Table 1. Uncertainties of instruments in the lab:

Instrument	Uncertainty
Digital analytical balance	± 0.0001 g
Top-loading digital balance	± 0.01 g
25 mL graduated cylinder	± 0.3 mL
50 mL buret	± 0.05 mL
25 mL volumetric flask	± 0.08 mL
25 mL volumetric pipet	± 0.03 mL

When doing mass measurements, it is important that the substance is at room temperature because substances that are not at room temperature can generate air currents that will affect the measurement of sensitive balances (i.e., analytical balance).

Figure 1. A digital Analytical Balance (left) and a digital Top loading balance (right).

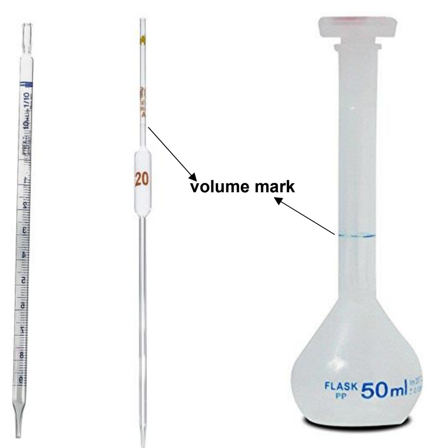

Figure 2. 10 mL graduated pipette (left), 20 mL volumetric pipet (center) and a 50 mL volumetric flask (right).

Several methods can be used to measure liquid volumes. The least accurate method is the use of the marked graduations on a beaker or Erlenmeyer flask (Table 1). More commonly, a graduated cylinder is used, which has graduations in increments of 1 or 0.1 mL. More accurate measurement of volume can be made using graduated pipets, volumetric pipets, and volumetric flasks (Figure 2).

In order to measure the volume of a liquid precisely, the “top” of the liquid can be referenced consistently by looking at the “meniscus” (usually a concave curve in the upper surface of the liquid) at eye level (Figure 3).

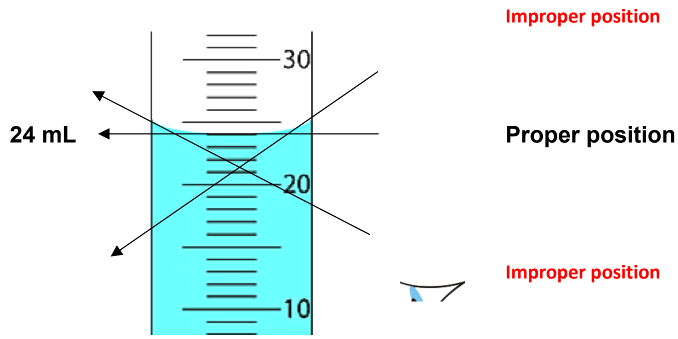

Figure 3. Reading the volume of a liquid in a graduated cylinder.

Experimental Errors

Chemistry is an experimental science, and experiments involve measurements. Experimentally determined values for physical properties (like mass and volume of an object, heat produced from a reaction) may differ from their “true” (i.e., correct) values because it is nearly impossible to measure a “true” value. ***Experimental error*** is the difference between the true value and a value that is determined by experimental neasurement. It is a natural consequence of the limitations of the techniques, measurements, and interpretations of the results of an experiment. Experimental error can never be eliminated; however, a thorough understanding of the experimental theories and procedures will enable you to take proper steps to minimize errors. The most important factor in performing experiments is to collect data as truthfully and reliably as humanly possible and to report the data “as is.“

As discussed previously, there is uncertainty (error) with any measurement due to the inherent limitations of the measuring equipment and the manner in which it is used (Table 1). Experimental error can be divided into two broad categories that are associated with measurements: ***systematic or determinate error*** and ***random or indeterminate error***.

Systematic error has assignable causes and remains unchanged each time an experiment is repeated. It can make all replicate measurements either too high or too low, but not both. This may occur due to faulty or miscalibrated instrumentation, personal error (failure to use an instrument correctly) or reagent error (impurity, contamination, wrong concentration). In density measurements, for example, systematic errors could arise from the repeated use of a contaminated sample.

Random error is caused by unknown and unpredictable factors during an experiment. It affects a measurement in both positive (high) and negative (low) directions with indeterminate probability. An example is the error arising from the vibration of a table supporting an analytical balance. Another source is an instrument is pushed to the extremes of its operating limits. Both of these random error sources could cause an analytical balance, for example, to show differences in the least significant digit of a 0.5040 g sample, by displaying weights of 0.5041 g, 0.5039 g and 0.5042 g. during repeated measurements. Unlike systematic errors, the effect of random errors can be minimized by averaging many measurements.

Accuracy and Precision of Data

Data analysis is an integral aspect of laboratory experiments, and is a skill that will be taught and emphasized throughout this course. To perform proficient data analysis, the measurements made during an experiment must be accurate and precise. The ***accuracy*** of a measurement pertains to how close the measured value is to the accepted or correct value. ***Precision*** refers to the reproducibility of a measurement, comparing several measured values obtained in the same way. For example, a student measured the volume of a liquid sample three times, using the same instrument each time. She obtained values of 2.50, 2.53, and 2.52 mL. These measurements are precise because there is only a 0.03 mL difference between the highest and lowest values. However, if the correct volume of the sample was actually 3.50 mL, the accuracy of the data would be low because the difference of 0.99 mL between the true value and the average of the three measurements is relatively large.

The accuracy and precision of data and measurements depend on an experimenter's techniques and on the quality of the measuring tools. One of the goals of this class is to teach students how to acquire data in the laboratory that are as accurate and as precise as possible, using the techniques and equipment that are available. In any experiment, data collected are evaluated by comparison with known and established values ("true" values), by doing a literature search and comparison with previously obtained data, by employing experimental techniques to decrease uncertainty sources, and by using statistical methods to analyze and manipulate collected data.

This first laboratory experiment will demonstrate the measurement of mass and volume using different types of equipment, demonstrate the difference between precision and accuracy, and use these skills to determine and calculate the density of an unknown substance.

Materials:

- 2 plastic bottles with cap
- 25 mL graduated cylinder
- 2 - 25 mL volumetric pipets
- Bulbs or pumps
- 50 mL Buret

Chemicals:

- Coca-Cola ®
- Coke Zero ®

Safety

Laboratory safety is one of the most important lessons you will learn from the general chemistry laboratory classes. Practicing effective safety procedures protects yourself and the people around you. At all times, appropriate personal protective equipment (PPE), which include eye goggles, long pants, closed-toed shoes, and shirts covering your shoulders/neck/back must be worn. Occasionally, you will use gloves to handle certain chemicals. Throughout the semester, you will learn about the potential hazards in a chemistry laboratory (e.g., toxic and/or caustic chemicals, fires, poisonous gases, very hot or cold apparatus, and broken glassware), and how to perform experiments safely.

The first part of this lab session will consist of an introduction and safety training in the laboratory, and demonstrations of important safety equipment for use in case of an emergency (e.g., fire extinguishers, eyewash fountains, fire blankets, and safety showers). At all times, handle all chemicals carefully. If you come into contact with any chemical, flush any affected exposed area of your body with large amounts of water (15 minutes) and alert your TA. All chemical wastes must be disposed of in the appropriately labeled waste containers.
If any solids or liquids are spilled on or around the balances, **clean it up**!

Experimental Procedure:

Part I: Determining the Densities of Coke© and Coke Zero©

- Use the analytical balance and the top-loading balance for all weight measurements. If possible, use the same balance of each type for all measurements.
- Get two of the plastic bottles with cap, and label each for Coke and Coke Zero.
- Do the following procedures first, using Coke.

1. Put ~80 mL of the sample into a suitable beaker. The actual volume is not very important.
2. Rinse the inside of one of the plastic bottles with DI water. Make sure that the outside of the bottle is dry. The inside of the bottle does not have to be completely dry. (*Why?*).
3. **Cap** the bottle and weigh the empty container using both balances. Record your "empty" mass.
4. Measure 25 mL of the Coke using the graduated cylinder and transfer to the bottle.
5. Cap the bottle containing the Coke and get the new mass using both balances. Record the mass of container + sample.
6. Dispose of the soda down the drain. Rinse the bottle several times with DI water and dry the outside of the bottle.
7. Cap the bottle and weigh the empty container using both balances. Record the empty mass again.
8. Measure 25 mL of the Coke using the buret and transfer to the bottle. Each pair of students will share the sample that is in the burets between your stations. Make sure that you get the correct sample.
9. Cap the bottle containing the Coke and measure the new mass using both balances. Record the mass of container + sample.
10. Dispose of the soda down the drain. Rinse the bottle several times with DI water and dry the outside of the bottle.
11. Repeat steps # 7-10 using the 25 mL volumetric pipet for measuring the volumes. Ask your TA for help if you need assistance using the bulb or pump.
12. Repeat steps #1-11 using the Coke Zero sample.
13. When finished, you should have 24 mass measurements in your notebook.
14. Record all measurements in your notebook using the sample table below (Table 2).
15. Calculate the mass and density of the samples.
16. Enter all the density data into the spreadsheet program that will be handled by your TA.
17. Examine the plots generated by the class data and participate in the brief mid-lab discussion that your TA will conduct. Be sure to take notes during this time.

<u>Mid-lab Discussion</u>

- Examine the plot that is generated illustrating the scatter of the values obtained from class data.
- Your TA will lead a discussion regarding the class data. Try to participate and take notes.

Part 2: Is density an intensive or extensive property?

1. Using your assigned volume (between 2 and 30 mL), measure the density of Coke and Diet Coke, using the glassware and instrument that displayed the most precision according to the class data.
2. Write your obtained values on the board and make sure to copy your classmate's density data as well.
3. Plot mass vs volume for each soda (**post-lab**).
   Is density an intensive or extensive property?

Part 3: Identification of an unknown sample

Due to an equipment malfunction at the Coca-Cola factory, the labels for Coca-Cola, Diet Coke, Coke Zero, Coca-Cola Cherry and Coca-Cola Vanilla variants were not adhered to the cans. It is your job to determine the identity of the samples from the production line.

1. Write a **<u>brief</u>** procedure detailing how you will determine the identity of your unknown sample.
2. Consult your TA and carry out your procedure to determine the identity of your unknown sample.
3. Record all data and observations. Make sure that you record the number of your unknown.
4. Clean up all of your glassware by rinsing with DI water, and putting everything back into your respective drawers.
5. Leave the burets on top of your work benches.

Data and Analysis:

Table 2. Mass and Density Data for Coke and Diet Coke

Glassware		Analytical Balance		Top-loading balance	
		Coke	**Coke Zero**	**Coke**	**Coke Zero**
GRAD. CYL.	Mass of empty bottle (g)				
	Mass of bottle + sample (g)				
	Mass of 25 mL sample (g)				
	Density (g/mL)				
BURET	Mass of empty bottle (g)				
	Mass of bottle + sample (g)				
	Mass of 25 mL sample (g)				
	Density (g/mL)				
VOL. PIPET	Mass of empty bottle (g)				
	Mass of bottle + sample (g)				
	Mass of 25 mL sample (g)				
	Density (g/mL)				

Data for Part 2:

1. Assigned volume: _______ mL

	Coke	**Coke Zero**
Mass of empty bottle (g)		
Mass of empty bottle + sample (g)		
Mass of sample (g)		
Density of sample (g/mL)		

2. Class Data Sample Table
   a. Coke Data for the class

Volume of sample (mL)	Mass of sample (g)

Post Lab Exercises and Questions:

1. From Part 1, using the class data, calculate the average and standard deviation of the densities of Coke and Diet Coke.
2. Take **all** the of the data that were collected in the lab and organize into tables. Organize them using Word, Excel, or hand-writing. Include the average and standard deviation data that were just calculated in #1. Neatness and organization count!
3. Using the data of the class from Part 2, plot mass vs volume for the Coke and the Diet Coke samples.
4. Is density an intensive or extensive property? Explain your answer.
5. Comparing the graduated cylinder and volumetric pipet, which is more accurate? Why?
6. Comparing the graduated cylinder and volumetric pipet, which is more precise? Why?
7. Special calibration weights with very precisely known masses are used to calibrate the analytical balances in the lab. If you measure a 10.0000-gram calibration mass three times and get values of 10.0010, 10.0009, and 10.0011 grams, is the balance more accurate or more precise? Why? Is this an example of systematic or random error?
8. What are the possible sources of error in determining the identity of your unknown solutions?