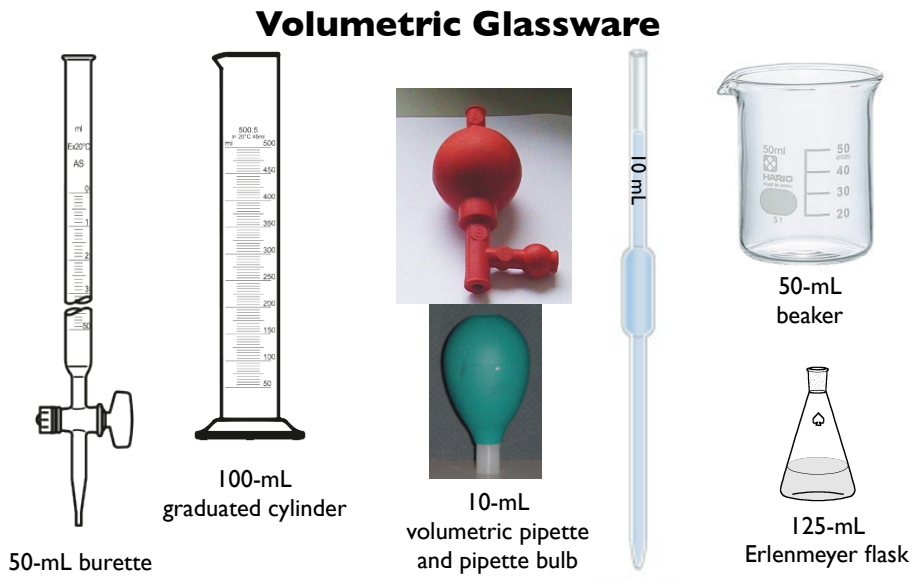
Experiment 1. Determination of the Density of Water and an Unknown Solid Sample

In this experiment you will:

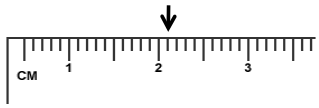
- Measure the volume of water using a graduated cylinder, volumetric pipette, beaker, and burette in order to compare their precision
- Determine the density of deionized water
- Determine the density of an unknown object
- Analyze the accuracy and precision of your results

BACKGROUND



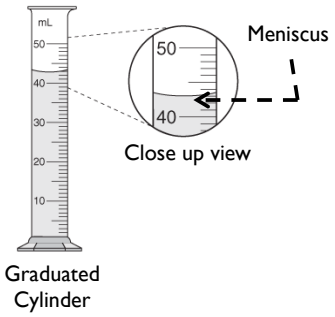
Throughout this experiment, and for the rest of Chemistry 210 laboratory, you will make a number of measurements. A *measurement* is a number you generate with an appropriate unit that describes the number. Examples of measurements are the mass of an object or the volume of a liquid used in a chemical reaction. When recording your data on the lab reports and lab notebooks, always include the units with the measured numbers. Recording a mass of 10 has no value or meaning because it is not clear if it represents 10 pounds, 10 grams or some other quantity. In Part A, a graduated cylinder, volumetric pipette, a beaker, and a burette will be used to measure liquid volume in milliliters (mL). In Part B, the density of pure water and an unknown object will be determined in grams per milliliters (g/mL).

Measuring devices in the laboratory are subject to some error and it is impossible to make exact measurements. Scientists record all the digits of a measurement that are known exactly, plus the first one that is uncertain. These digits are referred to as *significant digits*. In analog instruments, such as rulers and thermometers, the experimenter is responsible for determining the correct number of significant figures in the measurements. Digital instruments, such as an analytical electronic balance, are designed to limit themselves to correct number of significant digits, and their readings are properly given. Below are several examples of measurements.



Example 1: Measuring Length

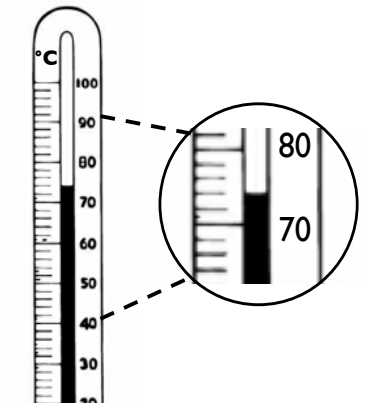
The ruler markings are every 0.1-centimeter. The correct reading is **2.12 cm**. The first 2 digits **2.1**2 are known exactly. The last digit 2.1**2** is uncertain. You may have instead estimated it as 2.11 cm.



When measuring liquid volumes, the graduated scale must be read from the lowest point of the curved surface of the liquid – the *meniscus*.

The graduated cylinder markings are every 1-milliliter. The correct reading is **43.0 mL**. The first 2 digits **43**.0 are known exactly. The last digit 43.**0** is uncertain. Even though it is a zero, it is significant and must be recorded.

Example 2: Measuring Volume of a Liquid



The thermometer markings are every 2-degrees. The correct reading is **74.0 °C**. The first 2 digits **74**.0 are known exactly. The last digit 74.**0** is uncertain. You may have instead estimated it as 74.2 °C.

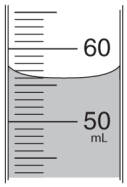
Example 3: Measuring Temperature

*****NOTE*** The measuring devices used in this laboratory activity may have different scales than the ones shown in these examples. Thus, be sure to make it a regular habit to check the scales of all the equipment used in the laboratory.**

Let's Practice:

Read the volume in the diagram below. Report your answer in the line, including the correct number of significant figures and units.

Answer: _____



When making measurements in the laboratory, it is important to be accurate and precise. *Accuracy* is a measure of how close an experimental value is to the true, accepted value. *Precision* refers to the degree of uncertainty in a measurement. For example, a mass measurement of 45.34 g has an uncertainty of $\pm$ 0.01 g, while a measurement of 45.3 g has an uncertainty of $\pm$ 0.1 g. Since the measurement of 45.34 g has less uncertainty, it is the more precise measurement. In general, the more decimal spaces provided by the instrument, the more precise the measurement will be.

Density is an *intensive* property of matter. A substance will have a characteristic density at a given temperature and pressure. The quantity of the substance present does not matter. Other physical properties with intensive properties include melting point and solubility. Density is a ratio of the mass and volume of a substance. Mass and volume are both *extensive* properties – the greater the quantity of material, the larger the mass and volume.

$$Density = \frac{mass}{Volume} \qquad D = \frac{m}{V}$$

In chemistry we often express density in units of g/cm^3 for solids, and g/mL for liquids and solutions.

a. The mass of metal cylinder 8.012 g that occupies 4.00 cm^3. Calculate the density in g/cm^3.

density = mass/volume
= 8.012 g/4.00 cm^3
= 2.003 g/cm^3 from calculator
= **2.00 g/cm^3** 3 significant figures

b. The mass of the empty graduated cylinder is 35.101 g. If 12.33 g of water are added to this graduated cylinder, what is the total mass?

total mass = 35.101 g + 12.33 g
= 47.431 g from calculator
= **47.43 g** 2 decimal places

Review on Significant Figures

In the first part of the laboratory activity, a study of density will be conducted using measurements from four different types of volumetric glassware: a 10-mL graduated cylinder, a 10-mL volumetric pipette, a 50-mL beaker, and a 50-mL burette. The concepts of precision, accuracy, and statistical nature of experimental data will also be introduced.

In the determination of density of an unknown object, your unknown will be one from the following list.

Unknown Metals	**Unknown Minerals**
Aluminum	Agate
Copper	Garnet
Iron (Steel)	Hematite
Lead	Jasper
Zinc	
Lead-tin solder (alloy of two metals)	

In addition to the densities of the unknowns, you can use the physical properties of metals and minerals, as well as the color(s) of the samples to help identify them by comparison to the literature reports of these properties. The chemical, physical, and physiological properties of all chemicals utilized in the general chemistry laboratory can be found in the Materials Safety Information website http://hazard.com/msds/ or the *Handbook of Chemistry and Physics*.

Analyzing errors is an important part of any experiment. In this experiment, you will want to consider both the accuracy and precision of your data. *Accuracy* is how close your measured values are to the accepted values for the density of the material. The percent error between this experimental value and the true density value is a measurement of accuracy.

$$\%\ error = \left| \frac{experimental - accepted}{accepted} \right| x\,100$$

Precision is how close your measurements are to one another. Precision can be measured in a variety of ways. Standard deviation calculations work well for a large number of measurements. For a smaller number of measurements, a relative range can be calculated.

$$relative\ range = \left| \frac{high\ value - low\ value}{average\ value} \right| x\,100$$

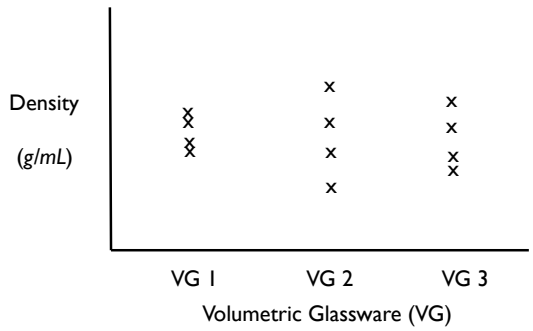
Statistical analysis of the three data sets will be carried out in this laboratory activity, including calculations and *average* density and *standard deviation*. The average value ($\bar{x}$) is defined as the sum (Σ) of each of the measurements (x_i) divided by the total number of measurements (*N*). Standard deviation essentially indicates the degree to which a set of measured values deviate from the average value.

$$\bar{x} = \frac{\sum x_i}{N} \qquad average\ value$$

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N-1}} \qquad standard\ deviation$$

Data sets with a wide range of values (for example, see VG 2 data in the following Scatter Plot) will have a larger standard deviation and are associated with less precise measurements compared to data sets with a narrow range of values (VG 1). With this information, the precision of the measurement obtained using the three types of volumetric glassware can be compared.

Scatter Plot – Density vs. Volumetric Glassware (VG)



In experimental data one or more data sets will appear not to "fit in" with other. These points are called *outliers* – values that occur far outside the range defined by the rest of the measurements. A rough way to identify an outlier is that it lies beyond two standard deviations from the average value. Those values may be excluded from the data set to avoid distortion of the results.

The following video link is a tutorial that will help you understand how to calculate *average* and *standard deviation* in Excel: http://www.youtube.com/watch?v=62i1fqKhNhg.

The following video link is a tutorial that will help you understand how to calculate *average* and *standard deviation* using your graphic calculator: http://www.youtube.com/watch?v=DMOXzwC2vzg and http://www.youtube.com/watch?v=C9Tkal4Zd-Y

DENSITY EXPERIMENT • PRE-LAB ASSIGNMENT

Begin each pre-lab assignment on a new page of your laboratory notebook. **ALL elements of the pre-lab MUST be completed before an experiment is started.** The COPY page from your laboratory notebook and pre-lab questions handout (from lab manual) will be collected as you enter the lab. The original pages must stay in your laboratory notebook.

Reading	☐ Experiment – Lab Manual Pages/Handout ☐ Laboratory Handbook: Section III - Weighing and Section IV Measuring Liquid Volumes ☐ *Chemistry*, 6th ed. by Silberberg: Chapter 1 or *General Chemistry*, 5th ed. by Olmsted and Williams
Heading	☐ Title of experiment and number ☐ Your name ☐ Dates of the experiment
Purpose	☐ Explain briefly, in your own words, the purpose of Part A & B.
General Strategies	☐ **Summarize**, in your own words, the procedure of Part A & B ☐ **Explain** how you will use the information to determine the density. ☐ Do not **plagiarize**.
Data Tables	☐ Prepare a data table on the laboratory notebook. See lab manual.
Pre-Lab Questions	☐ Answer the Pre-lab questions from lab manual.

PRE-LAB ASSIGNMENT Name: _____

Please answer the following questions to submit with your pre-lab assignment at the beginning of the laboratory period. Show all work and units. **Express all answers to the correct number of significant digits**.

1. Consider MASS, VOLUME, and DENSITY.

   a) Which are extensive and which are intensive properties?

   b) Which property is the most useful in helping to identify unknowns and why?

2. What four types of volumetric glassware will you be using in this activity?

3. Josephine obtains a silvery metallic unknown. She masses the metal and finds that she has 60.55g. When she places the metal in a graduated cylinder that contains 25.2 mL of water, the final volume is 32.2 mL.

Metal	Density (g/cm^3)
Chromium	7.19
Cadmium	8.65
Molybdenum	10.28
Nickel	8.908
Zinc	7.14

   a) Calculate the change in volume (ΔV) of water in the graduated cylinder.

      Number of significant digits in final answer _____

   b) Calculate the density of the metal.

      Number of significant digits in final answer _____

   c) Cordelia's teacher gives her a list of possible unknowns: chromium, cadmium, molybdenum, nickel, or zinc. What is the identity of her sample?

(continue on back)

d) Calculate the absolute error of the density measurement. *Absolute error* is determined by subtracting the "true" value from the experimental value. Absolute error = Experimental value – True value.

Number of significant digits in final answer _____

e) If her identification is correct, what is the percent error of her value?

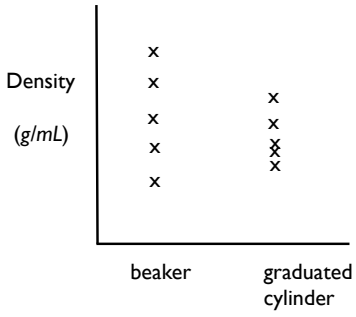
Number of significant digits in final answer _____

f) Was Cordelia accurate? Was she precise? Explain.

4. A group of students determine the density of a sample of liquid ethylene glycol. Each student uses a graduated cylinder to obtain the ethylene glycol volume and a balance to obtain the ethylene glycol mass. Their density values are shown in the table below.

a) Determine the average density and the standard deviation in this density data set. You may use your graphic calculator or Excel.

Student	Density (g/mL)
1	1.11
2	1.21
3	1.30
4	1.01
5	1.13



b) During the second part of the laboratory activity, the students decide to determine the density of ethylene glycol using a beaker. The results are displayed in the graph above, along with those obtained using the graduated cylinder. Which glassware yielded the more precise measurements? Explain.

PROCEDURE

All the glassware should be cleaned and rinsed with deionized water before starting the experiment.

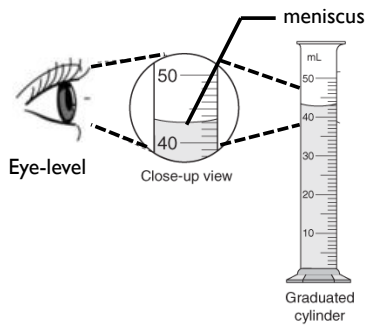
PART A. ***Precision in laboratory instrumentation and density of water***

1. Record the room temperature using your thermometer.

2. Obtain a 100-mL beaker, obtain approximately 50 mL of deionized water.

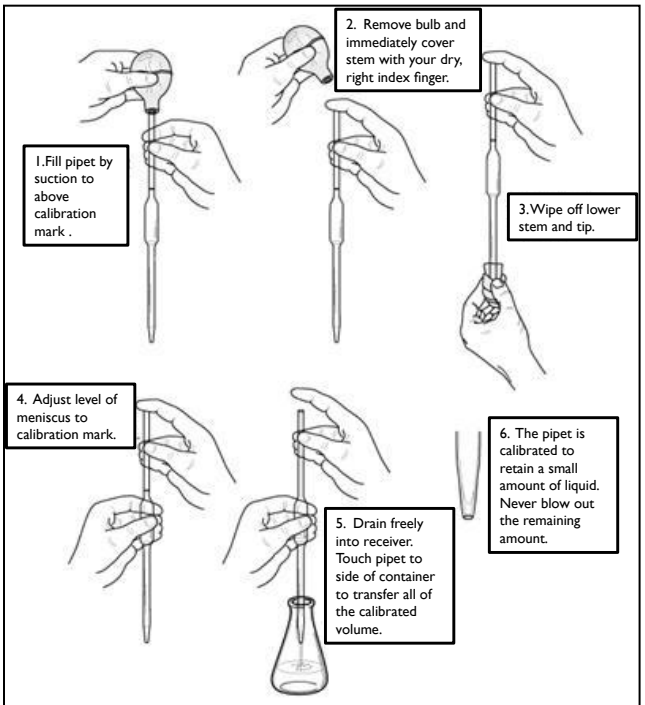
3. *10-mL Graduated Cylinder*:

   a. Mass a clean, **dry** 50-mL beaker. Record the mass in grams to the full precision given by the electronic balance.
   b. Fill the graduated cylinder with approximately 10 mL of deionized water, and record the actual volume used. To how many significant figures should the volume be recorded?
   c. Transfer the deionized water into the 50-mL dry pre-weighed beaker and mass the beaker with the water. Record the mass in grams, calculate the mass of water and calculate the density of water for this trial.
   d. Record all data to the appropriate number of significant digits in your laboratory notebook.
   e. Dry the small 50-mL beaker. You will use it in #4.



Note: The correct way to read the volume of a liquid is to hold the graduated cylinder with the meniscus at eye level as show in the drawing. Always read the level of the liquid at the bottom of the meniscus.

4. *10-mL Volumetric Pipette*:



Transferring Volume with Volumetric Pipet

a. Mass a clean, **dry** 50-mL beaker. Record the mass in grams to the full precision given by the electronic balance.

b. The instructor will demonstrate the correct use of the volumetric pipette.

c. Transfer exactly 10 mL of deionized water from the 150-mL beaker to the 50-mL dry pre-weighed beaker. Record the mass in grams, calculate the mass of water and calculate the density of water for this trial.

d. Record the volume used from the pipette and the combined mass of the beaker and water. To how many significant figures should the volume be recorded?

e. Dry the small 50-mL beaker. You will use it in #5.

5. *50-mL Burette*:
    a. Mass a clean, **dry** 50-mL beaker. Record the mass in grams to the full precision given by the electronic balance.
    b. The instructor will demonstrate the correct use of the burette.
    c. Fill the burette with deionized water from the 150-mL beaker and record the initial burette reading.
    d. Drain ~10 mL of water into the 50-mL dry pre-weighed beaker. Record the actual volume used (final – initial burette reading) and the mass of the beaker with water.
    e. To how many significant figures should the volume be recorded?
    f. Dry the small 50-mL beaker. You will use it in #6.

6. *50-mL Beaker:*

    a. Mass a clean, **dry** 50-mL beaker.
    b. Fill the beaker with approximately 10-mL of deionized water, and record the actual volume to the best of your abilities. To how many significant figures should the volume be recorded?
    c. Mass the beaker with the water. Record the mass in grams, calculate the mass of water and calculate the density of water for this trial.

7. For each of the data collected from the graduated cylinder, volumetric pipette and the burette, calculate the density of deionized water to the correct number of significant figures.
8. Share with the class the four density values obtained and record the results of the entire class on your laboratory notebook. You should have at least 10 density values for each type of volumetric glassware used above.

PART B. ***Measuring the density of an irregular object by water displacement***.

1. Obtain approximately 20 - 60 *grams* of the unknown sample assigned by your instructor. You will use the same amount of unknown sample in all the trials.
2. Record the unknown number and physical appearance in the laboratory notebook.
3. Mass the **dry** unknown sample.
4. Fill the 50-mL **plastic** graduated cylinder about half full of water. Record the precise volume. *Be sure to estimate the last digit.*
5. Add the sample to the plastic graduated cylinder and record the new volume. You should observe an approximately 20 mL water displacement in the graduated cylinder.
6. Calculate the volume of the unknown.
7. Calculate the density.
8. Repeat the above procedure for a second and third sample of the same unknown.
9. Calculate the average of your good trials.
10. Calculate a relative range.
11. If your sample densities vary significantly (relative range > 5%), you may need to obtain additional samples of this unknown and conduct 2 or more additional trials. Consult your instructor if you are unsure.
    NOTE: **If the relative range is greater than 5%, repeat the experiment until you have three density readings with relative range less than 5%.**
12. Research and record in your discussion section the densities and physical appearances of the possible unknowns.
13. Identify the unknown sample based on its density and physical appearance.
14. Based on your assignment of the identity of the unknown, calculate the percent error for your experimental density.

SAMPLE DATA TABLE

Copy into your lab notebook before LAB – DO NOT Record data on this sheet! Record ALL data directly in your notebook. This is a REQUIREMENT of the experiment.

Experimental Data Part A.

	10-mL Graduated Cylinder	10-mL Volumetric Pipette	50-mL Burette	50-mL Beaker
Mass of empty dry 50-mL beaker (g)				
Mass of 50-mL beaker + water (g)				
Mass of water only (g)				
Actual volume of water used (mL)				
Density of water (g/mL)				
Temperature (°C)				

Complete in your LAB NOTEBOOK PRELAB

Class Density Values (in g/mL) Part A

Measurement	10-mL Graduated Cylinder	10-mL Volumetric Pipette	50-mL Burette	50-mL Beaker
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				

Complete in your LAB NOTEBOOK PRELAB

Data Analysis Part A

1. For each of the four-density class data sets, determine the average density and the standard deviation. Remember the units.

	Average	Standard Deviation
Graduated Cylinder		
Volumetric Pipette		
Burette		
Beaker		

Complete in your LAB NOTEBOOK PRELAB

2. Are there any outliers in the three data sets in the data table? Explain using supporting calculations, how you identified these outliers.
3. Re-calculate the average and standard deviation for each data set, omitting the outliers.

	Average	Standard Deviation
Graduated Cylinder		
Volumetric Pipette		
Burette		
Beaker		

Complete in your LAB NOTEBOOK PRELAB

Part B - Density of Unknown Metals

Unknown # _____	Trial #1	Trial #2	Trial #3
Mass of unknown (g)			
Volume of water (mL)			
Volume water + sample (mL)			
Volume sample (mL)			
Density sample (g/mL)			
Average density sample (g/mL)			

Sample identity	
Physical appearance	
Literature value – density of material (*Handbook of Chemistry and Physics*) (g/mL)	
Relative Range	
Percent Error	

Complete in your LAB NOTEBOOK PRELAB

<u>IMPORTANT NOTE:</u> On occasion, you will be provided with a sample data table to copy into your notebook. However, you will analyze the information you need to collect, and prepare an appropriate table to organize that information.

Error Analysis Questions

1. In Part A (determining the density of water), if the graduated cylinder wasn't dried before recording its mass, how would the final calculation for the density of water be affected? Would it be overestimated, underestimated or remain unaffected? Explain your reasoning.

2. In Part A, if water droplets were above the meniscus when recording the volume and mass of water, how would the final calculation for the density of water be affected? Would it be overestimated, underestimated or remain unaffected? Explain your reasoning.

3. In Part B (determining the density of an unknown metal), if water droplets splashed out of the graduated cylinder when adding the metal, how would the final calculation for the density of the unknown be affected? Would it be overestimated, underestimated or remain unaffected? Explain your reasoning.

LAB REPORT GUIDELINES

The lab report section includes work recorded during the lab, your analysis and discussion of data and results, and your conclusions. ***The discussion and conclusion sections should be word-processed.***

Heading	☐ Title of experiment and number ☐ Your name ☐ Dates of the experiment
Data/Observations/ Results	☐ ORIGINAL QUANTITATIVE DATA (signed carbonless data pages from your lab notebook) ☐ Qualitative data (observations) – provide the unknown appearance in your lab report. It may help in identification of unknown
Calculations/Results	☐ Show all of your calculations! Include units. Report your final results with the correct number of significant figures. The format of each calculation should be as follows: Sample calculation: **HEADING:** Calculation of density of unknown #126 **FORMULA:** $D = m / V$ **SUSTITUTE:** $D = 29.232\,g / 4.8\,cm^3$ **SOLVE:** $D = 6.09 \quad (unrounded)$ $D = 6.1\,g / cm^3$ ☐ For Part A, include only one sample calculation of the average and the standard deviation. **If there are multiple rearrangements or steps in the solutions, show them all.**
Discussion/Theory/ Results/Error Analysis	In this section, you will explain the experiment, evaluate, discuss your results, and analyze errors in paragraph form. Complete for each section. The discussion section should be typed. Part A. *Precision in the laboratory instrumentation and density of water* ☐ Explain how you determined the density of water and report your average value and standard deviation for the class data. Appropriately relate these to the precision and accuracy of the experiment. ☐ Based on your analysis of the four data sets without the outliers, rank the volumetric glassware used from least to most precise. Explain how you determined this order. ☐ Report the literature value for the density of water at the temperature you measured it. Part B. *Density and identification of the unknown* ☐ Explain how you determined the density of the unknown and report your average value for the density. ☐ Explain why density can be used to help identify your unknowns, but mass or volume cannot. ☐ Provide a list of the densities and physical properties of the possible unknowns.

	☐ Identify the unknown sample. If a definitive identification cannot be made, explain which unknowns .are possible and how you made that determination ☐ Report your percent error and relative range. Appropriately relate these to the precision and accuracy of the experiment. *Error Analysis (Part A & B)* **Be specific about where errors may have arisen. Focus on how you can you get more precise or accurate results, rather than what you did "wrong".** ☐ Discuss (identify and explain) which measuring device may have limited your precision. What could help to improve the precision of the experiment? ☐ Discuss any additional error in Part A and B. Give at list 3 other sources of error. ☐ Include the error analysis questions.
Conclusions	Your conclusions should include: ☐ Density of water for all the volumetric glassware used in the experiment. ☐ Experimental density and proposed identity of your unknown ☐ The conclusion section should be typed.
Post-Lab Questions	☐ Answer the post-lab questions on the lab manual. ☐ Show complete work on all questions.

POST-LAB QUESTIONS Name: _____

Please answer the following questions in the spaces provided and submit with your lab report. Show all work and units. Express all answers to the correct number of significant digits.

1. Look up the density of water at 5.0º, 20.0º, 22.0º, 25.0º, and 30.0ºC (http://www2.volstate.edu/CHEM/Density_of_Water.htm). Does temperature affect density? Is temperature a significant source of error for our experiment?

2. In attempting to calculate the density of chloroform, $CHCl_3$, Xander determines the following densities: **1.28** g/mL, **1.24** g/mL, **1.19** g/mL, **1.22** g/mL, **0.812** g/mL, and **1.17** g/mL.

   A) Would it be reasonable for Xander to leave out any values in calculating the average? Why or why not? (Consider your answer here in responding to the rest of the question.)

   B) Calculate the average density of chloroform from his data.

   C) What is the relative range?

   D) If the accepted density of chloroform is 1.48 g/mL, what is the percent error?

   E) Was Xander's data accurate? Was it precise? Explain.

(continued on back)

3. What would be the volume of iron metal equal to 200.0 g of iron? If the metal were a cube, what would be the length of one edge of the cube?

4. What radius (in mm) must a steel (iron) ball bearing have if it is to have a mass of 3.25 g?

$$V_{sphere} = \frac{4}{3}\pi r^3$$

5. Volume can measured using beakers or graduated cylinders of different sizes or using rulers. Compare the precision of a 50 mL beaker to a 50 mL graduated cylinder. Would a beaker or graduated cylinder be a better choice for measuring volume and why?