Chem 1A Density Lab: Measurements, uncertainty, significant figures, and density, an intensive physical property.

Measurements of Properties

In chemistry we are interested in substances and their properties. We are particularly interested in **intensive physical properties** since these can be used for substance identification. An **extensive physical property depends on the amount** of substance while an **intensive physical property** does not. For example mass, volume, number of moles, etc. are extensive properties while density, molar mass, molar volume, boiling point, freezing point, etc. are intensive physical properties. **Taking the ratio of any two extensive physical properties results in an intensive physical property which may be used to identify the substance!**

Jumping ahead – a "mole" is the chemist's "dozen".
A mole happens to be a big number, $N_A = 6.022 \times 10^{23}$. Since atoms and molecules are extremely small, chemists think in moles of atoms or moles of molecules of substances because molar amounts are substantial enough to be measured and observed in the laboratory. **Don't worry (at least not yet) about why this particular number was chosen for the mole. Think of the "mole" as the chemist's "dozen", i.e. just like a "dozen" means 12 of something, a "mole" means 6.022×10^{23} of something. So number of moles of a substance is an extensive physical property, i.e. a measure of how much pure stuff there is in a particular sample (just like the mass is a measure of how much stuff there is in a sample).**

Examples of intensive physical properties arising from ratios of extensive properties:
molar mass = mass/number of moles;
molar volume = volume/number of moles;
density = mass/volume;

So molar mass, molar volume, and density are intensive physical properties unique to, and useful for identifying, particular substances!

In this lab you will measure the extensive properties mass and volume directly for various objects and then divide mass by volume to get the intensive property density. In other words, you will indirectly measure the density by directly measuring the mass and volume.

Uncertainty in Measurements

Any measurement has an uncertainty which is characteristic of the instrument used to carry out the measurement. It is important that the result of any measurement be communicated with its uncertainty so that the quality of measurement is known.

For example, measurement uncertainty can be communicated either
directly: e.g. measured mass of an object = 3.542 $\pm$ 0.002 grams, or
indirectly: e.g. measured mass of the same object = 3.542 grams, **where in this last case it is understood that the rightmost digit (here the 2) is uncertain and that this particular reported measurement has four significant figures.** So communicating the correct number of significant figures is just a shortcut way to communicate uncertainty, i.e. knowing the correct number of sig. figs is the same as knowing what the uncertain digit is (the digit farthest to the right which has meaning).

This lab will be graded heavily on the quality of your reported measurements: 1) are the correct units included? 2) are the correct number of significant figures reported?

Propagating Uncertainty in Calculations

Density is a derived quantity which is calculated from the directly measured quantities mass and volume. The uncertainty in any derived quantity obviously depends on uncertainties in the quantities which are directly measured, but how? **Here we give rough rules of thumb for propagating the number of significant figures in calculations which give reasonable uncertainty estimates for derived quantities.** These rules can be justified with the theory of calculus of errors which is beyond the scope of this class.

Multiplication and/or Division Rule:

For any quantity derived by multiplication or division, **the number of significant figures in the derived quantity is the same as the least number of significant figures in the directly measured quantities.**

Addition and/or Subtraction Rule:

For any quantity derived by addition or subtraction, **the number of decimal places in the derived quantity is the same as the least number of decimal places in the directly measured quantities.** So, significant figures can be gained and lost in addition and subtraction.

Uncertainty in a derived quantity can then be estimated from the number of significant figures and/or decimal places using the appropriate rule. **This lab will be graded heavily on correct propagation of uncertainty (by way of the above rules of thumb) in derived quantities.**

Use of Density as a Conversion Factor between Mass & Volume

Any intensive property determined from the ratio of two extensive properties (like density) can also be used as a **conversion factor** from one extensive property to the other. **Density, for example, is a conversion factor between mass and volume or between volume and mass.**

Pre-lab Exercise - Use dimensional analysis to answer the following questions:

a) Diamond and graphite are two different forms of pure elemental carbon with densities of 3.51 g/cc and 2.25 g/cc respectively. What volume would be occupied by a 0.50 g diamond? What volume would be occupied by a 0.50 g piece of graphite?

b) A "carat" is a unit of mass defined as exactly 1/5 of a gram, i.e. there are exactly 5 carats in a gram. How many carats would a 1.0 mL diamond have?

c) (optional) What are the mass and volume of the world's largest natural diamond? What volume would it occupy if the carbon was converted to graphite?

Density Lab - Chem 1A Fall 2018

Name:__________________ Lab Partner Name:________________

Title: Determining the Density of Several Solid Objects and a Liquid.

In this experiment, densities of three objects of different compositions will be determined: a rectangular object (called a parallelpiped), a cylindrical object, and a spherical object. Also, for each object the density will be determined in at least two different ways corresponding to different ways of making measurements (i.e. use of different measuring devices). For a given object we expect two density results from different procedures to agree with each other to within the uncertainty of the sloppiest (most uncertain) result. However, each derived result will have a different estimated uncertainty depending on the devices used. **For your first chosen object, for each direct measurement and for each derived result indicate the absolute uncertainty, the relative uncertainty, and the number of significant figures needed.**

Mass Measurements:

Mass will be measured directly with **1) an analytical balance** (in the balance room), or **2) with a centigram balance** (on the lab benches). **What are the estimated absolute uncertainties associated with each instrument? Include units in your answers!**

Analytical balance (absolute) uncertainty:_______________________

Precision balance (absolute) uncertainty:________________________

Centigram balance (absolute) uncertainty:_______________________

Volume Measurements:

Volume will be measured by 1) using a caliper to measure one or more dimensions followed by application of a geometrical formula, or 2) using a graduated cylinder to get the object volume by difference between two liquid level measurements (volume by displacement). In both cases volume is actually a derived quantity requiring correct application of the sig. fig. rules to propagate uncertainty from the initial measurement(s)! What are the estimated absolute uncertainties associated with each instrument? Include units!

Caliper (absolute) uncertainty:__________________________

Graduated cylinder absolute uncertainties: 50mL:______25mL:_______10mL:_______

Useful formulas for method 1:

Volume of a Sphere = $\frac{4\pi}{3} r^3 = \frac{\pi}{6} \mathbf{d^3}$, **where d = 2r is the diameter**.

Volume of a Cylinder = $\pi r^2 l = \frac{\pi}{4} \mathbf{d^2} \boldsymbol{l}$, **where d = 2r is the diameter and *l* is the length.**

Volume of a Parallelpiped = ***lwh*** , **where *l* is the length, *w* is the width, and *h* is the height.**

Remember that one milliliter equals one cubic centimeter! Or 1mL ≡ $1cm^3$ ≡ 1cc by definition!

Measuring Densities of Solids – Data and Results

Record your object set ID number here (from the plastic bag):_________________

Solid Object Type (color, shape, texture, etc.):_**parallelpiped**___________________

Method 1 **Measurements (Data)**

Mass	**Volume**
(using analytical balance)	(using caliper data)
Mass: ____________	Length:___________
	Width:____________
	Height:____________
	Calculated Volume:______________ (volume = length x width x height)

Result (Calculated Density):______________________

Method 2 **Measurements (Data)**

Mass	**Volume**
(using centigram balance)	(using graduated cylinder)
Mass: ____________	Volume liquid only:___________
	Volume liquid plus object:___________
	Calculated Volume (by difference):_____________ $V_{object} = V_{l+s} - V_l$

Result (Calculated Density):______________________

Hint: You will get the best results by using the smallest graduated cylinder you can get away with! Why? Another hint: If your two answers don't agree within uncertainty, you probably did something wrong.

Measuring Densities of Solids – Data and Results

Record your object set ID number here (from the plastic bag):_________________

Solid Object Type (color, shape, texture, etc.):_**cylinder**___________________

Method 1 **Measurements (Data)**

Mass	**Volume**
(using analytical balance)	(using caliper data)
Mass: ____________	Length:___________
	Diameter:____________
	Calculated Volume:______________
	(volume = $\frac{\pi}{4}\mathbf{d^2 l}$)

Result (Calculated Density):______________________

Method 2 **Measurements (Data)**

Mass	**Volume**
(using centigram balance)	(using graduated cylinder)
Mass: ____________	Volume liquid only:___________
	Volume liquid plus object:___________
	Calculated Volume (by difference):_____________
	$V_{object} = V_{l+s} - V_l$

Result (Calculated Density):______________________

Hint: You can report one more decimal place than the graduated cylinder has markings for. For example if your graduated cylinder has markings every 0.1 mL then you can read it to 0.01 mL. Why?

Measuring Densities of Solids – Data and Results

Record your object set ID number here (from the plastic bag):_________________

Solid Object Type (color, shape, texture, etc.):_**sphere**___________________

Method 1 **Measurements (Data)**

Mass **Volume**

(using analytical balance) (using caliper data)

Mass: ____________ Diameter:___________

Calculated Volume:______________

(volume = $\frac{\pi}{6}$ $\mathbf{d^3}$)

Result (Calculated Density):______________________

Method 2 **Measurements (Data)**

Mass **Volume**

(using centigram balance) (using graduated cylinder)

Mass: ____________ Volume liquid only:___________

Volume liquid plus object:___________

Calculated Volume (by difference):_____________

$V_{object} = V_{l+s} - V_l$

Result (Calculated Density):______________________

Hint: Double check that your results have the right number of significant figures from the Rules of Thumb on page 2!

Measuring Densities of Liquids – Data and Results

Liquid A, B, or C (use a different liquid than your lab partner):_______________

Data		**Results**
Analytical Balance Data	**Measured Volume (using graduated cylinder):**	**Calculated Density** (show calculation)
	_______________	______________
Mass empty graduated cylinder:		
_______________		
Mass graduated cylinder + liquid:		
_______________		
Calculated Mass (by difference):		
______________		

Liquid A, B, or C (now swap liquids with your lab partner):_______________

Data		**Results**
Analytical Balance Data	**Measured Volume (using graduated cylinder):**	**Calculated Density** (show calculation)
	_______________	______________
Mass empty graduated cylinder:		
_______________		
Mass graduated cylinder + liquid:		
_______________		
Calculated Mass (by difference):		
______________		

Discussion of Results including accuracy and precision:

1. Obtain the true value of the liquid densities from Peter or the TA and calculate for each liquid the

% error = $\frac{|\,true - measured\,|}{true}$ x 100. This is an estimate of **accuracy** of your results.

2. For each liquid (A and B separately), obtain your partner's results for that particular liquid and calculate the

% difference = $\frac{|\,yours - partner's\,|}{average}$ x 100. This is an estimate of the **precision** or **reproducibility** of your results.

Accuracy is how close your measurement is to a "true value" while **precision** is how reproducible your measurement is when repeated multiple times. **In lab we are interested in both accuracy and precision.** Future labs may require repeating an experiment until reasonable precision and/or accuracy is demonstrated. Upon learning to write lab reports you will learn to recognize and discuss sources of uncertainty including lack of accuracy and/or precision in your measurements and results. This is an important part of any "Results & Discussion" section of your lab report.

3. Of the two procedures you used to determine densities of solid objects, which do you trust more and why? Be careful here! How well do you know the geometries?

4. If someone you don't know tries to sell you a gemstone as diamond for a bargain price, what would you do first?

Density determination of a rock or mineral.

Your instructor will lend you a rock or mineral sample. Using what you learned above, measure the density of that sample. What technique will you use? If measuring the volume by difference, what size of graduated cylinder will you need?

Be sure to record all measurements (data) with correct units and sig. figs. And appropriately use the sig. fig. rules for propagating uncertainty to estimate the uncertainty in your measured density.

Ask your instructor the identity of the rock or mineral. Then look up its density on the internet and compare with your result.