Density and Dimensional Analysis

Objectives:

- To learn how to properly operate a laboratory balance.
- To determine the density of several substances.
- To use the technique of dimensional analysis to solve mathematical chemistry problems.
- To explore the variation in mass and volume measurements

Chemicals and Equipment Needed:

several solids for density measurements 100 mL graduated cylinder

Background

Density is a term used to express how mass is concentrated in space or how heavy something is for its size. If something has a large mass and occupies a small volume (like a lead fishing sinker), we say it is very dense. Scientifically, density (d) is defined as mass (m) divided by volume (v):

$$\boldsymbol{d = \frac{m}{V}} \qquad \textbf{Equation 1}$$

Normally, density is given in units of grams per milliliter (g/mL) or grams per cubic centimeter (g/cm^3) for solids and liquids, and grams per liter (g/L) for gases. Note that one milliliter is defined to contain *exactly* the same volume as one cubic centimeter.

The density of all materials changes with temperature. As the temperature increases, objects *usually* (though not always) expand, so the volume they occupy increases and the denominator, *V*, in the above equation gets larger. Therefore, since the mass of an object remains unchanged at different temperatures, the density usually decreases as objects get warmer. One notable exception is liquid water when it is near freezing. As pure liquid water warms from 0ºC to 4ºC, the density *increases* from 0.99984 g/mL to a maximum of 0.99998 g/mL. As the temperature of water warms above 4ºC, the density decreases (as you would expect).

In all of your future laboratory work and for all but the most accurate measurements, we assume that the density of pure water is 1.0 g/mL at room temperature.

Experimental Procedure

On the back bench, you will find rods of four unknown materials. Obtain one glass rod and one metal rod, dry them with a paper towel and record their appearance in your lab notebook. Verify that the balance is in the *grams* mode. Measure the mass of each dry rod to the nearest 0.001g and record the values in your lab notebook. Repeat the measurement of the mass of the rods five times each by completely removing from and replacing them to the balance. Record your measurements in your lab notebook.

An example of a data table you might write in your notebook:

Trial	Glass Rod Mass	Metal Rod Mass
1		
2		
3		
4		
5		

Place about 75 mL of water in a clean 100 mL graduated cylinder. Read and record the volume at the bottom of the meniscus to the nearest 0.1 mL by estimating between the graduations if necessary. Carefully and slowly slide the glass rod into the water of the graduated cylinder. **Do not drop the rod into the cylinder, as this will cause the**

base of the cylinder to break which will make your instructor unhappy. Read and record the new volume (at the bottom of the meniscus) to the nearest 0.1 mL. *In order to obtain accurate results, the water level must be above the level of the rod and below the 100.0 mL mark.* The difference between the two volumes is the volume of water displaced by the rod, i.e. the volume of the rod. Calculate the volume of the rods. Fill a graduated cylinder with ABOUT (to the closest whole integer) the same volume of water as you measured the rod volumes to be. Using the scale on the backbench, find the mass the volume of water that is about the same as the volume of the rod. Empty the graduated cylinder and repeat this measurement five times. Record your measured mass values in your notebook. Convert the mass of the water you measured to volume. (Since the density of water is 1.00 g/mL, the mass should be the same numerical value as your volume measurement. Example: 4.2 mL of water should weigh 4.2 grams) You will use this data to determine the uncertainty in your volume measurement.

Repeat the entire process with the metal rod. As before, to avoid breakage, do not drop the rod into the cylinder.

<u>Calculations</u>

1. Using Excel, find the average (or mean) and the standard deviation of your mass and volume measurements.
    a. Mass measurements: In Excel, input the mass measurements of the glass rod and metal rod in separate columns. Use the Excel “=AVERAGE( )” function to calculate the mean and the “=STDEVA( )” function to calculate the standard deviation of your two sets of mass measurements.
    b. Volume measurements: In Excel, input the mass of the water you measured with ABOUT the same volume as your rods. Convert these masses to volumes using the density of water. Use the Excel “=AVERAGE( )” function to calculate the mean and the “=STDEVA( )” function to calculate the standard deviation of your two sets of volume measurements.
2. From the average mass and average volume of each rod, calculate its density from Equation 1.
    a. In order to incorporate the uncertainty in your measurements, calculate the “low end” of your density range by the following method:

$$\text{low density} = \frac{\text{avg. mass}_{\text{rod}} - (2 \times \text{stand. dev.})}{\text{avg. vol}_{\text{rod}} + (2 \times \text{stand. dev.})}$$

    b. Calculate the “high end” of your density range by the following method:

$$\text{high density} = \frac{\text{avg. mass}_{\text{rod}} + (2 \times \text{stand. dev.})}{\text{avg. vol}_{\text{rod}} - (2 \times \text{stand. dev.})}$$

3. Using your average density and the range you calculated from parts 2a and 2b, determine the identity of the material from Table 1. Calculate the percent error of your result.

$$\textbf{Percent Error} = \frac{(\textit{your average value} - \textit{true value})}{\textit{true value}} \times \mathbf{100\%}$$

Do not ignore the sign of your percent error.

Table 1: Density of substances at 25ºC

Material	**Density (g/mL)**
pyrex glass	2.23
soda lime glass	2.47
zirconium oxide glass	5.89
aluminum	2.70
titanium	4.50
zinc	7.14
iron	7.86
nickel	8.90

4. Using the average density you determined for your glass rod, calculate the mass in milligrams of a piece of your glass that occupies $5.2 \times 10^{11} \mu m^3$.
5. Using the average density you determined for your metal rod, calculate the volume in cubic millimeters occupied by a piece of your metal with a mass of 1.7×10^{-3} kg.
6. The density of air at 25°C is around 1.2 g/L. Calculate the mass of air in pounds in a room that is 15 feet wide, 18 feet long and 12 feet high. Recall the definition of the liter: 1 L = 1 dm^3. Other possibly useful information: 2.54 cm = 1 in (exactly), 1 lb = 454 g (approximately)

<u>Results</u>

1. Experimental density, identity (with true density from Table 1) and % error for glass rod.
2. Same as #1 for metal rod.
3. Answers to questions 2 – 4.

<u>Questions</u>

How would you determine the density of a plastic rod if it was less dense than water?

You have a 4.0 ft × 4.0 ft square hot tub filled with water to a depth of 3 ft. If a 917.5 kg piece of aluminum is immersed in the water, by how many inches would the water level rise?

Possibly helpful information: 1 ft = 12 in, 1 in = 2.54 cm, 1 cm^3 = 1 mL