MASS, VOLUME, AND DENSITY MEASUREMENTS

INTRODUCTION

Two of the most frequently made measurements in the chemical laboratory are the determination of mass and volume.

Mass is generally measured by instruments called **balances**. Not all balances however are the same; some are capable of giving you more accurate answers than others. The least accurate one used here is the **top-loading electronic decigram balance** which can weigh an object to the nearest 0.1 g. The **centigram balance** can weigh to the nearest 0.01 g, and the most accurate one you will use is the **top-loading precision electronic balance** which is capable of weighing to the nearest 1 mg or 0.001 g.

Volumes of liquids are measured with the aid of **graduated cylinders**, **pipets**, and **burets**. For the time being you will only be using the graduated cylinder for direct determination of liquid volumes. The measurements of volumes of solid objects is not as straightforward as it is with liquids. In some cases, when dealing with regular solids such as cubes, cylinders, or prisms, it is quite possible to calculate the volumes by measuring the pertinent dimensions of the object. Some formulas for the calculation of volumes of regular solids are given below:

cube	$V = P^3$	**(1)**
rectangular prism	$V = P\,w\,h$	**(2)**
sphere	$V = 4/3\,\pi\,r^3$	**(3)**
cylinder	$V = \pi\,r^2\,h$	**(4)**
frustum	$V = 1/3\,\pi\,h\,(r_1^2 + r_1r_2 + r_2^2)$	**(5)**

where:

P = length in centimeters
w = width in centimeters
h = height in centimeters
r = radius in centimeters
π = 3.14 ...

Volumes of liquids are expressed in units of **milliliters** (mL) while volumes calculated from the geometry of the object will be given in **cubic centimeters** (cm^3 or cc). For our purposes 1 mL is equal to 1 cm^3.

In the case of irregularly shaped objects a method known as **volume by liquid displacement** can be used. If we fill a 100 mL graduated cylinder to the 50 mL mark and if we then introduce the solid object into the cylinder, and assuming that the object does not float, the liquid level will then rise to a new mark. The difference between the two liquid levels represents the desired volume. In another version of the same method, a container is filled completely with liquid, usually water, and when the object is submerged a certain amount of liquid overflows and can be captured. The volume of liquid can either be measured directly or can be weighed. Knowing the mass of liquid and the density we can get the volume. This method of determining volume is easy to carry out and is more accurate due to the high accuracy possible in weighing. In the case of objects that float, it is of course necessary to make sure that all of the substance is completely submerged in the liquid by pushing them down.

Knowing the mass and volume of an object allows the calculation of its density. **Density** is defined as the mass divided by the volume of the object.

$$density = \frac{mass}{volume} \qquad \textbf{(6)}$$

Mass should be expressed in units of grams and volume in units of mL or cm^3. Note, from the table below, that the density of water is 1 g≅ mL^{-1}.

The general physical law relating to floating objects is known as **Archimedes' Principle**. It states that a body wholly or partly immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced.

$$buoyant\ \ force = (den. of\ \ fluid)(acc. due\ to\ gravity)(vol. of\ \ immersed\ object) \qquad \textbf{(7)}$$

In the special case of floating objects one can also express the principle as: "A floating body displaces a volume of liquid whose weight equals that of the floating body." Archimedes' Principle can be used to determine specific gravities of solids. The applicable relationship is given in Equation (8).

$$specific\ gravity = \frac{weight\ of\ \ object\ in\ air}{weight\ of\ \ object\ in\ air\ -\ weight\ of\ \ object\ in\ water} \qquad \textbf{(8)}$$

<u>PROCEDURE</u>

You will be asked to determine the density of a number of objects. Some of them have a regular geometric shape so that you can measure and calculate their volumes. Others are irregular and volumes must be determined by liquid displacement.

Weigh all objects on the **three different** balances provided. Record the masses with the appropriate significant figures. Determine the volumes of all objects by all the possible methods. Again make an estimate of the number of significant figures that should be used for the various volume measurements.

Make a table in your laboratory notebook which clearly lists all the objects and the various mass and volume measurements.

CALCULATIONS

In your laboratory notebook, calculate the density of each object. Give the maximum number of significant figures that you feel are justified on the basis of the data used and explain your reasoning for the number of significant figures you use.

QUESTIONS

1. How many significant figures should you report for an object weighing exactly fifteen grams which was weighed accurately on a top-loading balance?

2. Give an estimate of the accuracy with which you can measure volumes with your 50 mL graduated cylinder.

3. What is the volume of 35.7 g of water?

4. What can you say about the numerical value of the density of a substance which floats in water?

5. Calculate the density of a brass cube which weighs 277.21 g in air and 244.55 g in water.

A table of densities is given below, it should give you a picture of the range of densities of ordinary substances. It will help you identify the nature of the substances you used in the experiment.

Table 1.

Substance	Density, g≅ mL^{-1}	Substance	Density, g≅ mL^{-1}
air	0.001205	iron	7.86
agate	2.6	ivory	1.83-1.92
aluminum	2.70	lead	11.34
asphalt	1.8	marble	2.6-2.84
basalt	2.4-3.1	mercury	13.59
beeswax	0.96	oxygen gas	0.001429
bone	1.7-2.0	paraffin	0.87-0.91
butter	0.86-0.87	NaCl	2.18
concrete	2.7-3.0	hard rubber	1.19
chalk	1.9-2.8	silver	10.50
clay	1.8-2.6	starch	1.53
copper	8.92	sugar	1.59
cork	0.22-0.26	water	1.00
diamond	3.52	wood (birch)	0.51-0.77
glass	2.4-2.8	wood (cedar)	0.49-0.57
gold	19.3	wood (maple)	0.62-0.90
helium	0.000178	wood (oak)	0.60-0.90
hydrogen	0.0000899	wood (pine)	0.37-0.60
ice	0.917	zinc	7.14