

Density of Matter  
Chemistry 1215 Experiment #3

**Objective**

There are two objectives for this experiment. The first is to use density measurements to determine the percent composition of an unknown isopropyl alcohol:water mixture. The second objective is use density to determine the identity of an unknown metal.

**Introduction**

Density is a derived quantity defined as mass divided by volume (Equation 1). At any given temperature, the density of a pure substance is a constant and is considered a physical property that can be used to identify that substance.

$$d = m/V \qquad \text{Equation 1}$$

The SI units for density are g/mL for liquids, g/L for gasses, and g/cm<sup>3</sup> for solids. Because the density of a substance is dependent on temperature, densities are usually reported at a specific temperature. The density of a pure substance in its solid state is usually greater than its density in a liquid state. Water is an exception to this rule. Liquid water has a maximum density of 1.000 g/mL at 3.8 °C. On the other hand, solid water, ice, has a density of 0.9168 g/mL. The result is that ice floats in water.

Densities of substances are usually determined indirectly based on the mass and the volume of the substance. Mass is determined by measurement on a balance or scale. Analytical balances used for density measurements are usually very accurate instruments that measure masses to the nearest 0.0001 g.

The volume of a liquid is determined using volumetric glassware such as a volumetric pipet, a graduated cylinder, or a pycnometer. Measurements made with volumetric pipets are usually more accurate and more precise than those made with graduated cylinders.

The volume of regularly shaped solid objects such as spheres, cylinders, and cubes, can be calculated mathematically from their measured dimensions. For example, the volume of a cylinder with a radius, *r*, of 5.00 mm (0.500 cm) and a height, *h*, of 20.0 cm can be calculated using equation 2.

$$V = \pi r^2 h = \pi (0.500 \text{ cm})^2 (20.0 \text{ cm}) = 15.7 \text{ cm}^3 \qquad \text{Equation 2}$$

Measurement of the volume of an irregularly shaped object requires more ingenuity. For this measurement we can use what has become known as the Archimedes principle (named after the Greek philosopher, Archimedes of Syracuse). For our purposes, Archimedes' principle simply states that the volume of a solid object immersed in a liquid is equal to the volume of liquid it displaced. The limitation of Archimedes' principle in this case is that the solid object must be more dense than the liquid (or it will float) and the object must be completely immersed in the liquid.

Once the mass and the volume of a substance have been measured the density is calculated using equation 1. The density of a substance is a physical property of that

substance and can be used in identifying its chemical identity. A list of densities of several metals and solvents at 20°C is given in Table 1.

**Table 1.**

Element	Density (g/cm <sup>3</sup> )	Compound	Density (g/mL)
Aluminum	2.70	Water (l)	0.997
Copper	8.96	Water (s) 0°C	0.9168
Lead	11.36	Ethyl alcohol	0.789
Magnesium	1.74	Ethyl ether	0.713
Zinc	7.13	DMSO	1.100
Osmium	22.57	Hexane	0.664
Gold	19.31	Chloroform	1.484

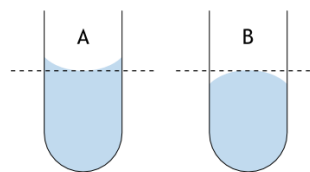
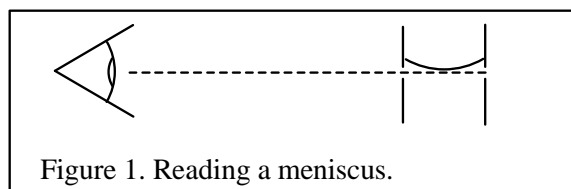
## Procedure

### I. Determining the concentration of an unknown solution of isopropyl alcohol.

In this part of the experiment you will determine the concentration of an unknown solution of rubbing (isopropyl) alcohol in water. The density of the alcohol solution depends on the relative proportion (concentration) of alcohol dissolved in the water. To find the relationship between the density of the solution and its concentration, you must create a calibration curve by determining the densities of several solutions of known concentration then drawing a graph of the density versus concentration. Accurate measurements will result in a straight line. One can then determine the concentration of an unknown isopropyl alcohol solution by calculating its density then using either the graph itself or the equation for the line defined by the graph.

1. Obtain five solutions with the following concentrations of isopropyl alcohol (weight percent) in water 20%, 35%, 50%, 70%, and 100%.
2. Weigh a 10 mL graduated cylinder. The cylinder must be clean and dry. Use tongs or a test tube holder to handle the cylinder. Record the tare weight (empty cylinder weight) on the data sheet ( $m_1$ ).
3. Pour 5-6 mL of the first isopropyl alcohol solution of known concentration into the preweighed cylinder. Be careful not to spill on the outside of the cylinder. Read and record the volume of the cylinder to the nearest 0.1 mL on the data sheet ( $V_1$ ).

It is important to note that the liquid *in a glass container* has a concave (downward curved) surface, called a meniscus (see Figure 1). To determine the actual volume in a glass cylinder, read the level of the liquid at the bottom of the meniscus. Make sure that your eyes are at the same level as the bottom of the meniscus, and you see only a single concave line, not the surface. The surface of the liquid *in a plastic cylinder* is flat. When reading the volume, make sure that your eyes are at the level of the liquid surface.



A. The bottom of a concave meniscus,  
 B. The top of a convex meniscus

Note also that it is most convenient to perform the measurements starting with the lowest or highest concentration and continue in increasing or decreasing order.

4. Weigh the cylinder plus the alcohol solution and record the weight on the data sheet ( $m_2$ ).
5. Discard the alcohol into the waste container. Clean and dry the cylinder.
6. Repeat steps two through five with the remaining four known alcohol solutions.
7. Obtain an unknown alcohol solution. Record the unknown identification number. Repeat steps two through five with the unknown sample. Record the weights and volume on the data sheet.
8. Record the room temperature.

## II. Identification of an unknown metal

1. Obtain an unknown metal sample as assigned by the lab instructor and record its unknown number on your data sheet. Weigh an empty weighing dish ( $m_3$ ), add the metal sample and weigh again ( $m_4$ ). Record all weights on your data sheet. Refer to Table 2 for quantities of metal, size of graduated cylinder to use, and amounts of water use.
2. Record the volume of water in the graduated cylinder ( $V_2$ ). The number of decimal places will depend on the size of the cylinder.
3. Place the weighed unknown metal sample in the cylinder. Be careful not to lose any pieces of metal or to splash any water. Make sure that there are no air pockets trapped with the metal. Record the new volume of water in the cylinder ( $V_3$ ).
4. Measure and record the temperature of the water in the cylinder.
5. When you are done, pour the water into the sink then pour the metal sample onto a paper towel. Dry the sample and return it to its container on the cart.

**Table 2**

<b>Metal sample appearance</b>	<b>Amount of metal to use</b>	<b>Size of graduated cylinder to use</b>	<b>Amount of water to use in the cylinder</b>
Uniform silver pellets	10-15 pieces	10 mL	Approximately 5 milliliters
Irregular silver chunks	8 – 10 pieces	50 mL	Approximately 30 mL
Orange/red granules or spheres	Approximately 15 grams	10 mL	Approximately 5 mL
Tiny dark gray spheres	Approximately 30 grams	10 mL	Approximately 5 mL

**Calculations****I. Unknown alcohol**

1. Calculate the mass of each known alcohol solution used  $m_a = (m_2 - m_1)$ .
2. Calculate the density of each known alcohol solution ( $d = m_a/V_1$ ).
3. Draw a graph of the density of the solutions versus concentration in weight percent for the known solutions. Draw a best fit line through the points. You may drop a data point if it is obvious that the point doesn't lie on the line formed by the other points. Dropped points must be explained and justified in your discussion.
4. Determine the concentration of the unknown by graphical interpolation (refer to experiment 1 if needed). Show all your work.
5. Calculate the equation for your best fit line. Use the form  $d = mC + b$  where  $d$  = density,  $C$  = weight percent concentration,  $m$  = the slope, and  $b$  = the y-intercept.

**II. Unknown metal**

1. Calculate the volume of your unknown metal ( $V_m = V_3 - V_2$ ).
2. Calculate the mass of the metal used ( $m_m = m_4 - m_3$ ).
3. Calculate the density of the unknown metal ( $d = m_m/V_m$ ).
4. Identify the unknown metal by comparing your calculated density with the densities of metals in Table 1.
5. Calculate the percent error for your determined density.  
 $\% \text{ error} = |( \text{your experimental value} - \text{table value} ) / ( \text{table value} )| \times 100\%$

## Data Sheet

### I. Isopropyl Alcohol

Weight % concentration of alcohol	Mass of empty cylinder, g ( $m_1$ )	Mass of cylinder plus alcohol, g ( $m_2$ )	Mass of alcohol solution, g ( $m_a = m_2 - m_1$ )	Volume of alcohol solution, mL ( $V_2$ )	Density of alcohol solution, g/mL ( $d = m_a/V_1$ )
Standards					
Unknown	Sample # ___				

### II. Unknown metal

Water temperature \_\_\_\_\_

Unknown metal number \_\_\_\_\_

Mass of empty cylinder, g $m_3$	Mass of cylinder plus sample, g $m_4$	Mass of sample, g $m_m = m_4 - m_3$	Initial volume, mL $V_2$	Final volume, mL $V_4$	Sample volume $V_m = V_4 - V_3$	Metal density $d = m_m/V_m$

Observations:

Calculations:

Discussion of Results:

Chemistry 1215, Experiment 3: Density of matter, **Pre-lab assignment**

Name \_\_\_\_\_

1. On a recent excursion chemistry student extraordinaire, Melvin Blackthorne, found a gold colored coin at a flea market. The vendor priced the coin (just for you) at \$200, claiming it was pure gold. Being a well equipped traveler Melvin pulled out a graduated cylinder and a battery powered balance. The coin had a mass of 18.82 g and raised the water level in the cylinder from 5.2 mL to 7.3 mL. What is the density of the coin? Based on information in Table 2 of the lab protocol, what is the major constituent of the coin? Show all calculations.
2. While on his trip Melvin was fortunate enough to take a sea voyage into the Antarctic. When the ship had a close encounter with an iceberg, Melvin estimated the volume of the iceberg at  $35,000 \text{ m}^3$ . Given that the density of ice is  $0.9168 \text{ g/cm}^3$ , what is the mass of the iceberg in metric tons (1 metric ton = 1000 kg)?
3. In your own words explain how Archimedes' principle can be used to measure the volume of an irregularly shaped solid.
4. Upon returning home, Melvin got involved in a water fight with his girlfriend, Melinda. He observed that the water balloon he was holding was a nearly perfect sphere with a diameter of 10.7 cm. Since the volume of a sphere is  $V = 4/3\pi r^3$ , what volume of water ( $d = 1.000 \text{ g/mL}$ ) is about to impact Melinda's head?

Chemistry 1215, Experiment 3: Density of Matter, **Post-lab exercises.**

Name \_\_\_\_\_

1. What effect will trapped air bubbles have on the calculated density of a solid if the volume is measured using Archimedes' principle? Explain your answer. Will the measurement be higher or lower than the correct value?
2. A sealed 260. mL bottle containing 248 mL of water ( $d_{20} = 1.000 \text{ g/mL}$ ) was placed in a freezer at  $-20^{\circ}\text{C}$ . When the water freezes ( $d_{-20} = 0.9168 \text{ g/mL}$ ) will the bottle rupture? Show all calculations and explain your answer.
3. What factors govern the accuracy of your density measurement? Hint: think about how you measure mass and volume. Which measurement is likely to determine the number of significant figures used in your answer? Explain
4. Using your experimentally determined straight line equation (or your carefully drawn graph) calculate the density of a 15% and an 85% solution of isopropyl alcohol.