

## Investigation 1: Density of Materials

**Question:** *What is density? How can we determine the density of solids and liquids? How do we determine the density of crystalline and semi-crystalline polymers?*

### Pre-lab required reading

[Openstax Chemistry](#): Sections 1.4 – 1.6

[Safety Rules](#)

[Keeping a Laboratory Notebook](#)

[Presentation of Experimental Data](#)

[Use of Volumetric Glassware – General](#)

[Use of Volumetric Glassware – Buret](#)

[Balance Use](#)

### Safety and Waste Disposal

- Hazardous waste should be placed into containers available.

### Background

The density of a material is an intrinsic property, meaning it is not depend on the amount of material one has. Density, represented by the Greek symbol rho ( $\rho$ ), is the ratio of the mass ( $m$ ) to volume ( $V$ ) of a given substance:

$$\rho = \frac{m}{V} \text{ usually in g/cm}^3 \text{ or g/mL} \quad (1)$$

Mass and volume are extrinsic properties (dependent on amount of material); however, their ratio is always constant. Density is often important in choosing an appropriate material for a given application. For example, moving boxes are made of cardboard, which is relatively strong but has a low density ( $\rho = 0.69 \text{ g/cm}^3$ ). A large box can be made while still being light. Imagine a box made of another strong material, steel ( $\rho = 7.85 \text{ g/cm}^3$ ). The same volume of material would be much heavier.

There are several methods for determining the density of a given material. The 3 main methods are direct measurement, indirect measurement, and buoyancy. In the direct method, the dimensions of the material are measured, and the volume is calculated. The mass is determined using a balance. The indirect method is based on water displacement. Archimedes, a Greek scientist, realized that the volume of irregularly shaped objects could be determined by submerging them in water. The volume of water that is displaced is equal to the volume of the object. It is known now that this is only an approximation of the volume; however, it is still an effective method. The third method is related to another concept from Archimedes, buoyancy. An object will be suspended in a liquid that has approximately the same density. The most common application of this is in density columns. A large column is filled with a mixture of liquids with varying densities. The object of interest is submerged in the column and floats in the column where the liquid has the same density. A mixture of two miscible liquids has a density that is related to the volume fraction, or percentage, of each:

$$\rho_{mix} = v_A \rho_A + v_B \rho_B \quad (2)$$

where liquid A is mixed with liquid B.  $v_A$  is the volume fraction of liquid A, and  $v_B$  is the volume fraction of liquid B. A simpler technique is to use a liquid with a lower density than the object of interest so that it will sink to the bottom. Then, a second liquid is added in small, volumetric intervals until the object is suspended in the liquid mixture. When it is suspended, the density of the liquid mixture is equal to the density of the object.

The purpose of this lab is to introduce proper lab analysis techniques and to become familiar with common lab equipment. In addition, the concepts of precision and accuracy will be discussed. The density of

several different materials will be determined using a variety of techniques. It is important to use proper technique to ensure that all measurements are precise and accurate to present high quality scientific data.

## Procedure

### Week 1: Methods for finding the density of liquids and solids

#### Density of Common Liquids

Using first a 50-mL graduated cylinder, measure out an assigned aliquot of the following liquids into a clean dry weighed beaker: ethanol, deionized (DI) water, and ethylene glycol. Determine the mass of the aliquot of liquid using a balance. Repeat the measurement of your assigned aliquot with a buret. Your data will be pooled with the class such that each liquid has multiple measurements with both pieces of glassware. Is the graduated cylinder or buret more precise? Would you expect the 10-mL graduated cylinder to be more precise than the 50-mL graduated cylinder?

#### Metal Identification Using Density

*Part A:* The density of solid materials can be determined using two techniques. For the first density determination, measure the appropriate dimensions of the sample using a ruler. Measure the dimensions in inches and millimeters. Calculate the volume. Next, determine the mass of the sample using a balance. Calculate the density. This is the direct technique.

*Part B:* The second technique to be used is displacement. Add 20.0 mL of DI water to a 50-mL graduated cylinder. To measure the volume of the solid sample, submerge it in the water and record the change in water volume. Use the mass value from Part A. Calculate the density and compare to the value in Part A. Of the methods used, which should be the most accurate?

**Table 1:** Density Data for common metals<sup>1</sup>.

Metal	Density (g/cm <sup>3</sup> )
Magnesium	1.74
Aluminum	2.70
Chromium	7.15
Iron	7.87
Nickel	8.90
Copper	8.96
Molybdenum	10.2
Silver	10.5
Lead	11.3
Palladium	12.0

### Week 2: Density of semi-crystalline and amorphous polymers

In the plastics industry, many of the material's properties are dependent on the amount of crystalline (ordered solid) and amorphous (disordered "liquid") polymer within the sample. Polymers are long, chain-like molecules (amorphous chains are similar to a bowl of cooked spaghetti) which give plastic its unique properties. Because of their chain-like nature, it is difficult to form an ordered crystalline structure; therefore, they are not 100% crystalline like most small molecules, thus giving them the name 'semi-crystalline.' Crystals within the sample can provide strength to resist breaking. They are also large enough to diffract light, making the sample opaque. Amorphous polymers are more flexible and pliable and are transparent because they do not diffract light. It is, therefore, important to know what percentage of the polymer sample is crystalline and what percentage is amorphous to predict the product properties. This is often called the percent crystallinity.

As one can imagine, the density of amorphous and crystalline portions of a polymer sample are different. Crystals are higher in density (typically), while amorphous areas have lower density. Because the crystals are closely-packed chains, the amount of material in a given volume is higher. The overall density of a

sample provides insight into what percentage, or fraction, of the material is crystalline. The overall density ( $\rho_{\text{over}}$ ) is a weighted average of the amorphous ( $\rho_a$ ) and crystalline densities ( $\rho_c$ ).

$$\rho_{\text{over}} = w_c \rho_c + w_a \rho_a \quad (3)$$

where,  $w_c$  is the mass fraction that is crystalline and  $w_a$  is the mass fraction that is amorphous. The percent crystallinity of the sample is  $w_c \times 100\%$ .

**Team Goal:** Your team has been hired by the Carson Chiruks Toy Company to conduct density tests on a set of common polymer samples to determine the percent crystallinity. Carson Chiruks Toys is looking to use one of these polymers for a new self-propelled vehicle for toddlers. It is imperative that these measurements are **accurate** and **precise** to ensure that the material will have the proper mechanical and optical properties for vehicle safety. In scientific experimentation, it is important to confirm results through reproducibility. Two ways in which to accomplish this are: 1) to take multiple measurements (also good for precision) and 2) to use two independent measurement techniques. Using the information and experience obtained in Week 1, devise an experimental plan to analyze the percent crystallinity in the polymer samples. The list of samples and relevant density data are listed below. If a polymer sample has the same density as a liquid mixture, would it float, sink or be suspended in the mixture? If a polymer sample has a density in between two common liquids, how could you precisely measure the two liquids?

### Polymer Samples

polyethylene (PE) milk jug  
 polypropylene (PP) Tupperware®  
 polystyrene (PS) coffee cup  
 polystyrene-polybutadiene rubber (SBR) tire (*density will be fraction of S and B*)

**Table 2:** Density Data for common liquids and polymeric materials

	Density (g/cm <sup>3</sup> )	
	solid	liquid <sup>1</sup>
Ethanol	-	0.789
Water	-	0.997
Ethylene Glycol	-	1.113
Glycerol	-	1.261
Corn Syrup	-	1.380
	<b>cryst.<sup>2</sup></b>	<b>amorph.<sup>2</sup></b>
Poly(ethylene)	0.962	0.855
Poly(propylene)	0.938	0.852
Poly(ethylene terephthalate)	1.455	1.333
Poly(styrene)	-	1.055
Styrene-butadiene rubber	1.010 (B)	1.055 (S)
Poly(amide) (Nylon)	1.220	0.989
Poly(carbonate)	-	1.200

### References

<sup>1</sup> Haynes, W.M., Ed.; *CRC Handbook of Chemistry and Physics*, 92<sup>nd</sup> Ed. (Internet Version); CRC Press/Taylor and Francis: Boca Raton, FL, **2012**

<sup>2</sup> Brandup, J., Immergut, E.H., Grulke, E.A., Eds.; *Polymer Handbook*, 4<sup>th</sup> Ed.; Wiley and Sons: New York, **1999**