1.12: Density and Specific Gravity

Learning Objectives

- Define density and specific gravity.
- Perform calculations involving both density and specific gravity.

After trees are cut, logging companies often move these materials down a river to a sawmill where they can be shaped into building materials or other products. The logs float on the water because they are less dense than the water they are in. Knowledge of density is important in the characterization and separation of materials. Information about density allows us to make predictions about the behavior of matter.

Density

A golf ball and a table tennis ball are about the same size. However, the golf ball is much heavier than the table tennis ball. Now imagine a similar size ball made out of lead. That would be very heavy indeed! What are we comparing? By comparing the mass of an object relative to its size, we are studying a property called **density**. Density is the ratio of the mass of an object to its volume.

$$\text{density} = \frac{\text{mass}}{\text{volume}} \tag{1.12.1}$$

$$D = \frac{m}{V} \tag{1.12.2}$$

Density is usually a measured property of a substance, so its numerical value affects the significant figures in a calculation. Notice that density is defined in terms of two dissimilar units, mass and volume. That means that density overall has *derived units*, just like velocity. Common units for density include g/mL, g/cm^3, g/L, kg/L, and even kg/m^3. Densities for some common substances are listed in Table $1.12.1$.

Table 1.12.1: Densities of Some Common Substances

Liquids and Solids	Density at 20$^\circ\text{C}$ (g/mL)	Gases	Density at 20$^\circ\text{C}$ (g/L)
Ethanol	0.79	Hydrogen	0.084
Ice (0°C)	0.917	Helium	0.166
Corn oil	0.922	Air	1.20
Water	0.998	Oxygen	1.33
Water (4°C)	1.000	Carbon dioxide	1.83
Corn syrup	1.36	Radon	9.23
Aluminum	2.70		
Copper	8.92		
Lead	11.35		
Mercury	13.6		
Gold	19.3		

The SI units of density are kilograms per cubic meter $\left(\text{kg/m}^3\right)$, since the kg and the m are the SI units for mass and length respectively. In everyday usage in a laboratory, this unit is awkwardly large. Most solids and liquids have densities that are conveniently expressed in grams per cubic centimeter $\left(\text{g/cm}^3\right)$. Since a cubic centimeter is equal to a milliliter, density units can also be expressed as g/mL. Gases are much less dense than solids and liquids, so their densities are often reported in g/L. Water has a density of 1.0 g/mL.

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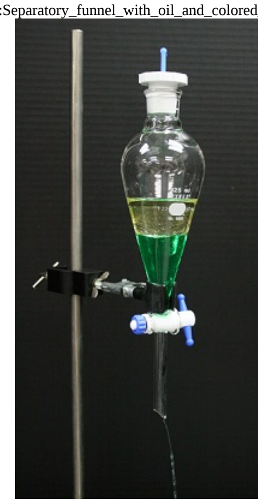

Figure 1.12.1: Separatory Funnel containing oil and colored water to display density differences. (CC BY-SA 3.0; PRHaney vai Wikipedia).

Because of how it is defined, density can act as a conversion factor for switching between units of mass and volume. For example, suppose you have a sample of aluminum that has a volume of 7.88 cm^3. How can you determine what mass of aluminum you have without measuring it? You can use the volume to calculate it. If you multiply the given volume by the known density (from Table 1.12.1), the volume units will cancel and leave you with mass units, telling you the mass of the sample:

Start with Equation 1.12.1

$$\text{density} = \frac{m}{V}$$

and insert the relavant numbers

$$\frac{2.7g}{cm^3} = \frac{m}{7.88\,cm^3}$$

Cross multiplying both sides (right numerator x left denominator = left numerator x right denominator), we get the following expression with answer and appropriate unit.

$$7.88\ \cancel{cm^3} \times \frac{2.7\ g}{\cancel{cm^3}} = 21g \text{ of aluminum}$$

Since most materials expand as temperature increases, the density of a substance is temperature dependent and usually decreases as temperature increases. You known that ice floats in water and it can be seen from the table that ice is less dense. Alternatively, corn syrup, being denser, would sink if placed in water.

Example 1.12.1

An $18.2\ \text{g}$ sample of zinc metal has a volume of $2.55\ \text{cm}^3$. Calculate the density of zinc.

Solution

Step 1: List the known quantities and plan the problem.

Known

- $\text{Mass} = 18.2\ \text{g}$
- $\text{Volume} = 2.55\ \text{cm}^3$

Unknown

- $\text{Density} = ?\ \text{g}/\text{cm}^3$

Use Equation 1.12.1 to solve the problem.

Step 2: Calculate

$$D=\frac{m}{V}=\frac{18.2 \text{ g}}{2.55 \text{ cm}^3}=7.14 \text{ g/cm}^3 \tag{1.12.3}$$

Step 3: Think about your result.

If 1 cm^3 of zinc has a mass of about 7 grams, then 2 and a half cm^3 will have a mass about 2 and a half times as great. Metals are expected to have a density greater than that of water and zinc's density falls within the range of the other metals listed above.

Since density values are known for many substances, density can be used to determine an unknown mass or an unknown volume. Dimensional analysis will be used to ensure that units cancel appropriately.

Example 1.12.2

1. What is he mass of 2.49 cm^3 of aluminum?
2. What is the volume of 50.0 g of aluminum?

Solution

Step 1: List the known quantities and plan the problem.

Known

- Density $= 2.70 \text{ g/cm}^3$
- 1. Volume $= 2.49 \text{ cm}^3$
- 2. Mass $= 50.0 \text{ g}$

Unknown

- 1. Mass $=? \text{ g}$
- 2. Volume $=? \text{ cm}^3$

Use the equation for density, $D=\frac{m}{V}$, and dimensional analysis to solve each problem.

Step 2: Calculate

$$1.\ \ 2.49 \text{ cm}^3 \times \frac{2.70 \text{ g}}{1 \text{ cm}^3}=6.72 \text{ g} \tag{1.12.4}$$

$$2.\ \ 50.0 \text{ g} \times \frac{1 \text{ cm}^3}{2.70 \text{ g}}=18.5 \text{ cm}^3 \tag{1.12.5}$$

In problem 1, the mass is equal to the density multiplied by the volume. In problem 2, the volume is equal to the mass divided by the density.

Step 3: Think about your results.

Because a mass of 1 cm^3 of aluminum is 2.70 g, the mass of about 2.5 cm^3 should be about 2.5 times larger. The 50 g of aluminum is substantially more than its density, so that amount should occupy a relatively large volume.

Specific Gravity

Specific gravity is the ratio of the density (mass of a unit volume) of a substance to the density of a given reference material, often a liquid.

$$\text{specific gravity}=\frac{\text{Density of a substance}(\ g/\cancel{mL})}{\text{Density of the water at the same temperature}(\ g/\cancel{mL})} \tag{1.12.6}$$

If a substance's relative density is less than one then it is less dense than water and similarly, if greater than 1 then it is denser than water. If the relative density is exactly 1 then the densities are equal. For example, an ice cube, with a relative density of about 0.91, will float on water and a substance with a relative density greater than 1 will sink.

A *hydrometer* is an instrument used for measuring the specific density of liquids based on the concept of buoyancy (Figure 1.12.2). A hydrometer usually consists of a sealed hollow glass tube with a wider bottom portion for buoyancy, a ballast such as lead or mercury for stability, and a narrow stem with graduations for measuring. The liquid to test is poured into a tall container, often a graduated cylinder, and the hydrometer is gently lowered into the liquid until it floats freely. The point at which the surface of the liquid touches the stem of the hydrometer correlates to relative density. Hydrometers can contain any number of scales along the stem corresponding to properties correlating to the density.

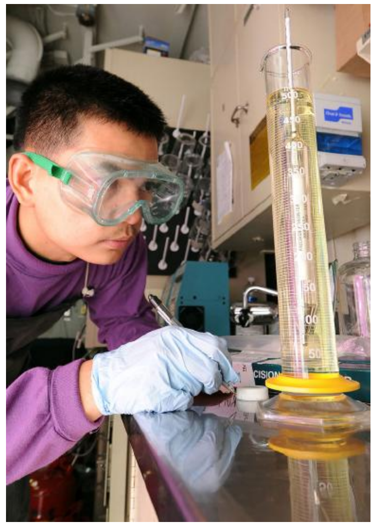

Figure 1.12.2: A US Navy Aviation Boatswain's Mate tests the specific gravity of JP-5 fuel. (Public Domain; U.S. Navy via Wikipedia)

Summary

- Density is the ratio of the mass of an object to its volume.
- Gases are less dense than either solids or liquids.
- Both liquid and solid materials can have a variety of densities.
- For liquids and gases, the temperature will affect the density to some extent.

Contributors and Attributions

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