Science Education Collection

Determining the Density of a Solid and Liquid

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Overview

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The ratio of the mass of a substance to its volume is known as the mass density or, simply, the density of the substance. Density is expressed in units of mass per volume, such as g/mL or kg/m^3. Because the density of a substance does not depend on the amount of substance present, density is an “intensive property”.

To measure the density of a sample of material, both the mass and volume of the sample must be determined. For both solids and liquids, a balance can be used to measure mass; however, methods for determining volume are different for solids and liquids. As liquids can flow and take the shapes of their containers, glassware such as a graduated cylinder or volumetric flask can be used to measure the volume of a liquid. The volume of an irregularly-shaped solid can be measured by submersion in a liquid — the difference in volume caused by addition of the solid is equal to the volume of the solid.

This demonstration illustrates the methods for measuring the density of solids and liquids. Using a volumetric flask and an analytical balance, the density of ethanol can be determined. Using a graduated cylinder, analytical balance, and water as the displaced liquid, the density of zinc metal can be determined.

Principles

By definition, all matter has mass and occupies volume. The density of a substance is the ratio of its mass to its volume. At constant temperature and pressure, the density of a substance is constant.

$$\rho = \frac{m}{V}$$

Density is an intensive property of a substance that doesn’t depend on the amount of substance present. Thus, density can be used to identify an unknown pure substance if a list of reference densities is available, and the experimenter can choose a convenient amount of substance to work with when measuring density.

To measure the density of a sample of a substance, it is necessary to measure its mass and volume. Mass is typically measured using an analytical balance, a precise instrument that relies on the force exerted by the sample due to gravity. The container to hold the sample (also used to measure volume) is weighed and tared, so only the sample mass appears on the balance display when the sample is added to the container.

For liquids, this container is typically a volumetric flask, which has one marking that corresponds to a specific volume. The container is filled to the line with the liquid sample and weighed again after the empty flask has been tared. The measured density is the ratio of the measured mass to the volume indicated on the flask.

Most solid substances are irregularly shaped, which complicates volume determination. It is inaccurate, for example, to determine the volume of a powder by measuring its dimensions. Instead of directly measuring dimensions or using glassware like a volumetric flask, it is necessary to make use of a liquid displacement method to measure the volume of an irregularly shaped solid. A graduated cylinder containing a known volume of liquid (in which the solid is insoluble) is tared. The solid is added to the cylinder, and the total mass is weighed again to determine the mass of the solid. Addition of the solid causes an upward displacement of the liquid, resulting in a new volume reading. The volume of the solid is equal to the change in volume due to liquid displacement (*i.e.*, the difference in liquid volume before and after adding solid).

$$V_{\text{solid}} = \Delta V = V_f - V_i$$

As for liquids, the measured density of a solid sample is the ratio of the measured mass to the measured volume.

Procedure

1. Determination of the Density of Liquid Ethanol

1. Place a clean and dry 50-mL volumetric flask on an analytical balance.
2. Press the “Tare” or “Zero” button on the balance. The balance should read 0.000 g.
3. Use a buret funnel to add 45 mL of liquid ethanol to the volumetric flask.
4. Use a Pasteur pipette to add the final 5 mL of liquid, just until the bottom of the liquid’s meniscus touches the marking on the flask.
5. Weigh the volumetric flask again and record the mass of the ethanol.
6. For best results, repeat steps 1.1 – 1.5 twice more to obtain two additional density measurements.

2. Determination of the Density of Solid Zinc Metal

1. Add approximately 40 mL of water to a clean and dry 100-mL graduated cylinder. Record the exact volume of the water.
2. Place the cylinder and water on an analytical balance. Press the “Tare” or “Zero” button on the balance. The balance should read 0.000 g.
3. Add approximately 10 zinc pellets to the graduated cylinder. Record the new volume of the water plus zinc pellets using the liquid level after addition of the zinc (**Figure 1**).

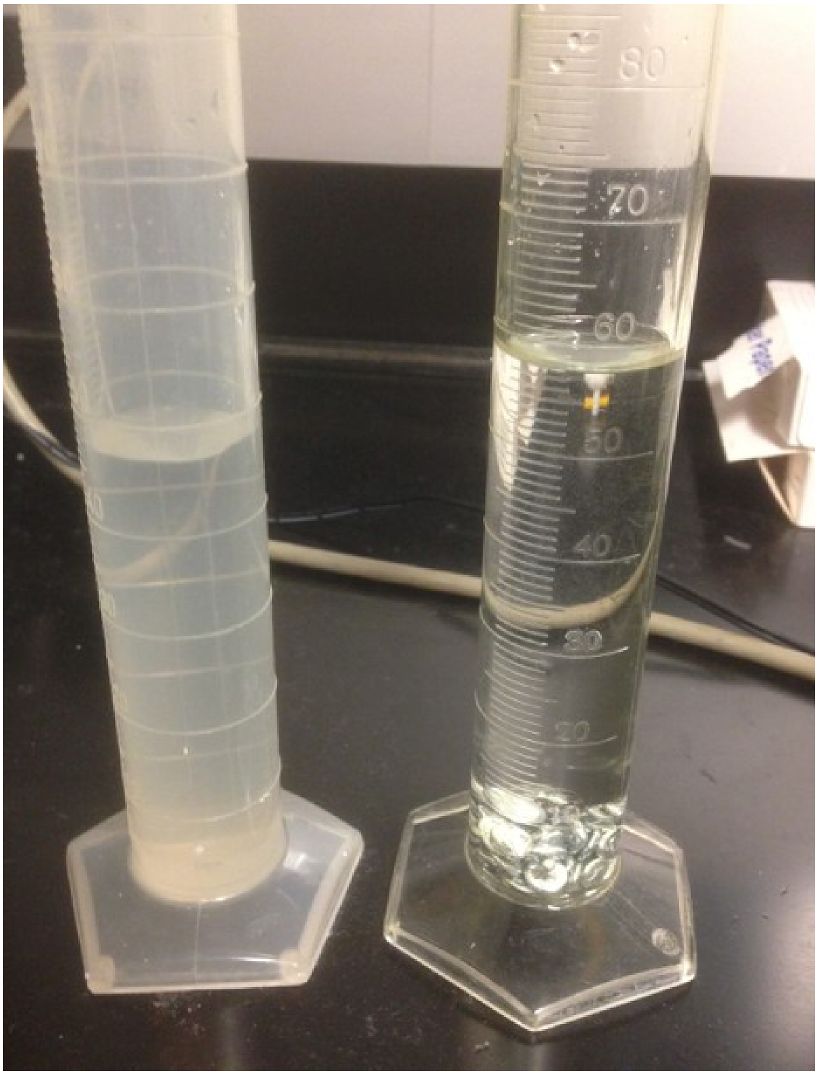

Figure 1. Zinc added to the cylinder on the right causes the water level to be displaced upward.

4. Weigh the cylinder, water, and zinc pellets on the balance. Record the mass of the zinc pellets.
5. For best results, repeat steps 2.1 – 2.4 twice more to obtain two additional density measurements.

Results

Table 1 lists results for the determination of the density of ethanol using a 50-mL volumetric flask. Densities were calculated by dividing the measured mass by 50.0 mL. The mean measured density was 0.789 ± 0.001 g/mL. **Table 2** lists results for the determination of the density of a sample of zinc metal using a 100-mL graduated cylinder and the liquid displacement method. Note that the measured densities are constant (within experimental error) for both substances. **Table 2**, in particular, demonstrates that density is independent of the amount of substance studied.

Trial	Mass of Ethanol (g)	Volume of Ethanol (mL)	Density (g/mL)
1	39.448	50.0	0.789
2	39.392	50.0	0.788
3	39.489	50.0	0.790

Table 1. Results for the determination of the density of ethanol using a 50-mL volumetric flask.

Trial	Mass of Zinc (g)	Volume of Zinc (mL)	Density (g/mL)
1	5.6133	0.9	6.2
2	7.6491	1.2	6.3
3	8.2164	1.3	6.3

Table 2. Results for the determination of the density of a sample of zinc metal using a 100-mL graduated cylinder and the liquid displacement method.

Applications and Summary

Density is a characteristic intensive property of a substance. Thus, density measurements can be used to identify an unknown pure substance if a list of possible reference densities is available. For example, density can be used to distinguish between metals similar in outward appearance (**Figure 2**).

In contexts where very low or very high mass is desirable, density is a critical material property. Materials engineers carefully consider the density of materials for construction in these contexts. For example, the bodies of some lightweight laptop computers are made of aluminum, one of the least dense metals. Lightweight tennis rackets contain titanium, another low-density metal.

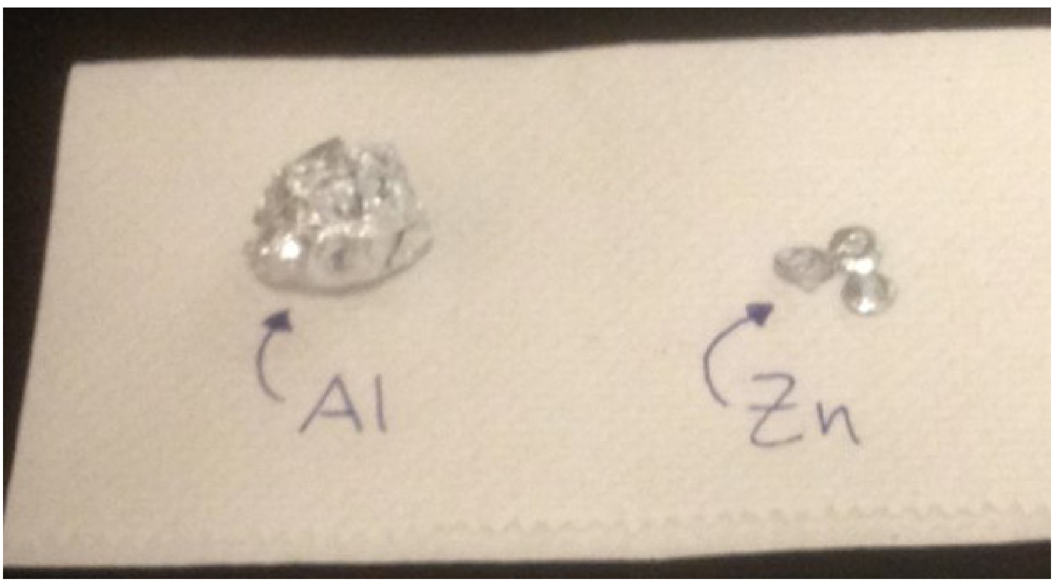

Figure 2: Equivalent masses of aluminum (Al) and zinc (Zn) metal. The zinc metal occupies a much smaller volume due to its higher density.