## Densities of Liquids and Solids

## Performance Goal

4-1 Calculate the density of a liquid or a solid from experimental data.

## CHEMICALOVERVIEW

One of the physical properties that characterize a substance is its density, which is defined as its mass per unit volume. Mathematically,

$$
\begin{equation*}
\text { Density }=\frac{\text { mass }}{\text { volume }} \tag{4.1}
\end{equation*}
$$

According to this equation, density is equal to the ratio of the mass of a sample of a substance to the volume it occupies. The density of a solid is normally expressed in grams per cubic centimeter $\left(\mathrm{g} / \mathrm{cm}^{3}\right)$, the density of a liquid in grams per cubic centimeter or grams per milliliter ( $\mathrm{g} / \mathrm{mL}$ ), and the density of a gas in grams per liter ( $\mathrm{g} / \mathrm{L}$ ).

To determine the density of a substance, you must measure both the mass and volume of the same sample of the substance. Density is then calculated by dividing the mass by the volume, as indicated in Equation 4.1. Mass is measured by the usual weighing techniques. The volume of a liquid may be measured in a graduated cylinder. The dimensions of a solid with a regular geometric shape (rectangular block, cylinder, sphere) may be measured with a ruler, and these measurements can then be used to calculate the volume. The volume of a solid with an irregular shape may be determined by measuring the volume of a liquid displaced when the solid is immersed in the liquid.

In Part 1 of this experiment you will be asked to determine experimentally the density of a known substance and then to calculate the percent error in your determination. Percent error is defined by the following equation:

$$
\begin{equation*}
\text { Percent error }=\frac{\text { error }}{\text { accepted value }} \times 100 \tag{4.2}
\end{equation*}
$$

The "error" is the difference between the experimental value and the accepted value. Error is expressed as an absolute value, i.e., a numerical
value without regard for algebraic sign. Absolute value is indicated by enclosing the quantity between vertical lines. Thus Equation 4.2 becomes

$$
\begin{equation*}
\text { Percent error }=\frac{\mid \text { experimental value }- \text { accepted value } \mid}{\text { accepted value }} \times 100 \tag{4.3}
\end{equation*}
$$

## SAFETY PRECAUTIONS AND DISPOSALMETHODS

Safety hazards in this experiment cannot be identified precisely because of the wide variety of chemicals that might be used as liquid unknowns. This uncertainty dictates that all liquids be regarded as potentially dangerous and treated accordingly. This includes the known liquid, trichloroethane. Liquid samples should be obtained from a dispensing station in the hood. If taken from the hood, liquids should be in containers that are stoppered or covered with a plastic sheet or metal foil. Some unknowns may be flammable; they should therefore be kept away from open flames. When you are finished with them, discard them as directed by your instructor. Avoid contact between all liquids and your skin; if it occurs, wash the exposed area thoroughly with soap and water. Safety glasses must be worn at all times.

Depending on the nature of your liquid unknown, disposal directions will be given by your instructor. Trichloroethane should be collected in a stoppered bottle.

## PROCEDUE

NOTE: All mass measurements are to be recorded in grams to the nearest 0.01 g or 0.001 g if so instructed. Length measurements are to be recorded in centimeters to the nearest 0.1 cm . Record liquid volume measurements in milliliters to the nearest 0.1 mL .

## 1. Density of a Liquid

A. Your $50-\mathrm{mL}$ graduated cylinder and a piece of plastic wrap (e.g., Saran wrap) to cover the opening constitute your "container" (see page 10) for Part 1 of this experiment. Being sure the cylinder is clean and dry, weigh it and the Saran wrap-the container-to the nearest 0.01 g on a centigram balance. Record the mass in the proper number of significant figures on your work page.
B. Take the cylinder and plastic wrap to the hood. Pour 12 to 15 mL of 1,1,1-trichloroethane into the cylinder; do not attempt to make the amount exactly 12, 13, 14, or 15 mL . Cover the cylinder with the plastic wrap. Estimate the volume to the nearest 0.1 mL (see page 9 on reading volume), and record that value to the proper number of significant figures.
C. After making sure the outside of the cylinder is dry, measure and record the mass of the container plus liquid on the centigram balance.
D. Dispose of your liquid as directed by your instructor.
E. In the same manner, collect data for finding the densities of one or more unknown liquids, as required by your instructor. Be sure to record the identification number of each unknown.

## 2. Density of a Regular Solid

Select one or more of the solid unknowns provided for this experiment and record its identification number. Determine and record its mass to the nearest centigram. Make whatever measurements may be necessary to calculate the volume of the object, listing these measurements to the closest 0.1 cm . Because these objects are of various shapes, the data table contains blank spaces in which to describe the shapes and identify the measurements (length, diameter, etc.) that are made.
A. Place 20 to 25 mL of water into the cylinder from Part 1. Record the volume to the nearest 0.1 mL . Determine the mass of the cylinder plus water to the nearest centigram. This is the mass of the container for Part 3.
B. Select and record the identification number of one of the unknown irregular solids provided for this experiment. Place enough of the solid into the graduated cylinder to cause the liquid level to rise by more than 10 milliliter markings. Be sure all of the solid is below the surface of the liquid. Record the volume to the nearest 0.1 mL . Also measure the mass of the container and its contents to the nearest centigram.
C. Dispose of your solid material into the recovery facility that has been set up in your laboratory. Be careful not to mix unknown solids.
D. Repeat Steps 3A and 3B for as many unknowns as are required by your instructor, or for a second run with the same unknown.

CALCULATIONS
Be sure to include units in the results of all calculations. Also be sure to express those results in the correct number of significant figures.

## 1. Density of a Liquid

Find the mass of the liquid by difference-by subtracting the mass of the container from the mass of the container plus liquid. The density of the liquid is found by dividing the mass of the liquid sample by its volume, as indicated in Equation 4.1. Percent error may be calculated by substituting into Equation 4.3; be careful of significant figures in the result. The accepted value for the density of $1,1,1$-trichloroethane is $1.34 \mathrm{~g} / \mathrm{mL}$.

## 2. Density of a Regular Solid

The volume of a rectangular solid is calculated by multiplying the length by the width by the height: $V=l \times w \times h$.

The volume of a cylinder is the area of the base times the height. The area of a circle is $\pi d^{2} / 4$, where $d$ is the diameter. Thus

$$
V_{\text {cylinder }}=\frac{\pi d^{2} h}{4}
$$

The value of $\pi$ to eight decimal places is 3.14159265 ; the number of places to which you should round it off is left to you.

The volume of a sphere is found from the following equation:

$$
V_{\text {sphere }}=\frac{\pi d^{3}}{6}
$$

Once you have calculated the volume of the unknown solid, its density may be found by substituting into Equation 4.1, as before.

## 3. Density of an Irregular Solid

Both the mass and the volume of the sample are found by difference. Density is again calculated by substitution into Equation 4.1.

## Experiment 4

## Advance Study Assignment

1. The volume of an unknown liquid is 28.6 mL and its mass is 32.2 grams. Calculate the density of the liquid.
2. When 95.0 g of an unknown metal are submerged in water in a graduated cylinder, the water level rises from 38.2 to 49.5 mL . Calculate the density of the metal.
3. The accepted value for the density of a certain metal is $5.48 \mathrm{~g} / \mathrm{cm}^{3}$. Calculate the percent error in a laboratory experiment that yields a value of $5.2 \mathrm{~g} / \mathrm{cm}^{3}$. Express this result in the proper number of significant figures.

## Experiment 4

## Work Page

## Part 1—Density of a Liquid

| Liquid <br> (List identification <br> number of unknowns) | Trichloroethane | Unknown | Unknown | Unknown |
| :--- | :--- | :--- | :--- | :--- |
| Mass of container + liquid (g) |  |  |  |  |
| Mass of container (g) |  |  |  |  |
| Mass of liquid (g) |  |  |  |  |
| Volume of liquid (mL) |  |  |  |  |
| Density (g/mL) |  |  |  |  |
| Percent error (trichloroethane only) |  |  |  |  |

"Accepted" value for density of 1,1,1-trichloroethane: $1.34 \mathrm{~g} / \mathrm{mL}$.

## Calculation Setups for Density Determinations:

## Calculation Setups for Percent Error for Trichloroethane:

## Part 2—Density of a Regular Solid

| Unknown Number |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
| Shape of unknown |  |  |  |  |
| Volume of unknown $\left(\mathrm{cm}^{3}\right)$ |  |  |  |  |
| Mass of unknown $(\mathrm{g})$ |  |  |  |  |
| Density $\left(\mathrm{g} / \mathrm{cm}^{3}\right)$ |  |  |  |  |

## Calculation Setups for Determination of Volumes of Unknowns:

For each unknown, list the measurements taken and show calculation setup.

## Experiment 4

## Work Page

Part 3-Density of an Irregular Solid

| Unknown Number |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
| Mass of container + liquid + solid (g) |  |  |  |  |
| Mass of container + liquid (g) |  |  |  |  |
| Mass of solid (g) |  |  |  |  |
| Volume of liquid + solid (mL) |  |  |  |  |
| Volume of liquid (mL) |  |  |  |  |
| Volume of solid $\left(\mathrm{cm}^{3}\right)$ |  |  |  |  |
| Density $\left(\mathrm{g} / \mathrm{cm}^{3}\right)$ |  |  |  |  |

Calculation Setups for Density Determinations:

## Experiment 4

## Report Sheet

## Part 1—Density of a Liquid

| Liquid <br> (List identification number <br> of unknowns) | Trichloroethane | Unknown | Unknown | Unknown |
| :--- | :--- | :--- | :--- | :--- |
| Mass of container + liquid (g) |  |  |  |  |
| Mass of container (g) |  |  |  |  |
| Mass of liquid (g) |  |  |  |  |
| Volume of liquid (mL) |  |  |  |  |
| Density (g/mL) |  |  |  |  |
| Percent error (trichloroethane only) |  |  |  |  |

"Accepted" value for density of 1,1,1-trichloroethane: $1.34 \mathrm{~g} / \mathrm{mL}$.

## Calculation Setups for Density Determinations:

## Calculation Setups for Percent Error for Trichloroethane:

## Part 2—Density of a Regular Solid

| Unknown Number |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
| Shape of unknown |  |  |  |  |
| Volume of unknown $\left(\mathrm{cm}^{3}\right)$ |  |  |  |  |
| Mass of unknown $(\mathrm{g})$ |  |  |  |  |
| Density $\left(\mathrm{g} / \mathrm{cm}^{3}\right)$ |  |  |  |  |

## Calculation Setups for Determination of Volumes of Unknowns:

For each unknown, list the measurements taken and show calculation setup.

## Experiment 4

## Report Sheet

## Part 3-Density of an Irregular Solid

| Unknown Number |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
| Mass of container + liquid + solid (g) |  |  |  |  |
| Mass of container + liquid (g) |  |  |  |  |
| Mass of solid (g) |  |  |  |  |
| Volume of liquid + solid (mL) |  |  |  |  |
| Volume of liquid (mL) |  |  |  |  |
| Volume of solid $\left(\mathrm{cm}^{3}\right)$ |  |  |  |  |
| Density (g/cm $\left.\mathrm{cm}^{3}\right)$ |  |  |  |  |

## Calculation Setups for Density Determinations:

