EXPERIMENT 3

Density Determinations

OBJECTIVE

Density is an important characteristic property of matter, and may be used as a method of identification. In this experiment, you will determine the densities of regularly and irregularly shaped solids as well as of pure liquids and solutions.

INTRODUCTION

The density of a sample of matter represents the mass contained within a unit volume of space within the sample. For most samples, a "unit volume" means 1.0 mL (1.0 cm³). The units of density, therefore, are quoted in terms of grams per milliliter (g/mL) or grams per cubic centimeter (g/cm³) for most solid and liquid samples of matter.

Since we seldom deal with exactly 1.0 mL of substance in the general chemistry laboratory, we usually say that the density of a sample represents the mass of the specific sample divided by its particular volume.

\[
\text{density} = \frac{\text{mass}}{\text{volume}}
\]

Because the density does in fact represent a ratio, the mass of any size sample, divided by the volume of that sample, gives the mass of 1.0 mL of the same sample.

Densities are usually determined and reported at 20°C (around room temperature) because the volume of a sample, and hence the density, will often vary with temperature. This is especially true for gases, with smaller (but still often significant) changes for liquids and solids. References (such as the various chemical handbooks) always specify the temperature at which a density was measured.

Density is often used as a point of identification in the determination of an unknown substance. In later experiments, you will study several other physical properties of substances that are used in the identification of unknown substances. For example, the boiling and melting points of a given substance are characteristic of that substance and are used routinely in identification of unknown substances. Suppose an unknown's boiling and melting points have been determined, but on consulting the literature, it is found that more than one substance has these boiling and melting points. The density of the unknown might then be used to distinguish the unknown. It is very unlikely that two substances would have the same boiling point, melting point, and density.

Density can also be used to determine the concentration of solutions in certain instances. When a solute is dissolved in a solvent, the density of the solution will be different from that of the pure solvent itself. Handbooks list detailed information about the densities of solutions as a function of their composition (typically, in terms of the percent solute in the solution). If a sample is known to contain only a single solute, the density of the solution could be measured experimentally, and then the handbook could be consulted to determine what concentration of the solute gives rise to the measured density of the solution.

The determination of the density of certain physiological liquids is often an important screening tool in medical diagnosis. For example, if the density of urine differs from normal values, this may
indicate a problem with the kidneys secreting substances that should not be lost from the body. A determination of specific gravity is almost always performed during a urinalysis (specific gravity represents the ratio of a sample’s density to the density of water under the same conditions).

Several techniques are used for the determination of density. The method used will depend on the type of sample and on the level of precision desired for the measurement. For example, devices have been constructed for determinations of the density of urine that permit a quick, reliable, routine determination. In general, a density determination will involve the determination of the mass of the sample with a balance, but the method used to determine the volume of the sample will differ from situation to situation. Several methods of volume determination are explored in this experiment.

For solid samples, different methods may be needed for the determination of the volume, depending on whether or not the solid is regularly shaped. If a solid has a regular shape (e.g., cubic, rectangular, cylindrical), the volume of the solid may be determined by geometry:

- For a cubic solid, volume = (edge)^3
- For a rectangular solid, volume = length × width × height
- For a cylindrical solid, volume = π × (radius)^2 × height

If a solid does not have a regular shape, it may be possible to determine the volume of the solid from Archimedes’ principle, which states that an insoluble, non-reactive solid will displace a volume of liquid equal to its own volume. Typically, an irregularly shaped solid is added to a liquid in a volumetric container (such as a graduated cylinder) and the change in liquid level determined.

For liquids, very precise values of density may be determined by pipeting an exact volume of liquid into a sealable weighing bottle (this is especially useful for highly volatile liquids), and then determining the mass of liquid that was transferred with the pipet. A more convenient method for routine density determinations for liquids is to weigh a particular volume of liquid as contained in a graduated cylinder.

**SAFETY PRECAUTIONS**

- Protective eyewear approved by your institution must be worn at all times while you are in the laboratory.
- The unknown liquids may be flammable, and their vapors may be toxic. Keep the unknown liquids away from open flames, and do not inhale their vapors. Dispose of the unknown liquids as directed by the instructor.
- Dispose of the metal samples in the container designated for their collection. Do not put into the trash container. Do not spill the metal samples on the floor or benchtop.

**APPARATUS/REAGENTS REQUIRED**

Unknown liquid sample, metal samples (regularly-shaped and irregularly-shaped), sodium chloride
PROCEDURE

Record all data and observations directly in your notebook in ink.

1. **Determination of the Density of Solids**

   Obtain a *regularly-shaped* solid and record its identification number. With a ruler, determine the physical dimensions (e.g., length, width, height, radius) of the solid to the nearest 0.2 mm. From the physical dimensions, calculate the volume of the solid.

   Determine the mass of the regularly shaped solid to at least the nearest mg (0.001 g). From the mass and volume, calculate the density of the solid.

   Obtain a sample of *irregularly-shaped* metal pellets (shot) and record the identification code number. Weigh a sample of the metal of approximately 50 g, but record the actual mass of metal taken to the nearest mg (0.001 g).

   Add water to your 100-mL graduated cylinder to approximately the 50-mL mark. Record the exact volume of water in the cylinder to the precision permitted by the calibration marks of the cylinder, remembering to read the water level tangent to the meniscus.

   Pour the metal sample into the graduated cylinder, *making sure that none of the pellets sticks to the walls of the cylinder above the water level*. Stir/shake the cylinder to make certain that no air bubbles have been trapped among the metal pellets. (See Figure 3-1.)

   ![Figure 3-1. Measurement of volume by displacement. A non-soluble object displaces a volume of liquid equal to its own volume.](image)

Read the level of the water in the graduated cylinder, again making your determination to the precision permitted by the calibration marks of the cylinder. Assuming that the metal sample does not dissolve in or react with water, the change in water levels represents the volume of the metal pellets.

Calculate the density of the unknown metal pellets.

After blotting them dry with a paper towel, turn in the metal pellets to your instructor (*do not discard*).
2. **Density of Pure Liquids**

Clean and dry a 25-mL graduated cylinder (a rolled-up paper towel or a stream of compressed air may be used). Weigh the dry graduated cylinder to the nearest mg (0.001 g).

Add distilled water to the cylinder so that the water level is above the 20-mL mark but below the 25-mL mark. Use a thermometer to determine the temperature of the water in the cylinder to the nearest degree.

Reweigh the cylinder to the nearest milligram.

Record the exact volume of water in the cylinder, to the level of precision permitted by the calibration marks on the barrel of the cylinder, remembering to read the water level tangent to the meniscus.

Calculate the density of the water. Compare the measured density of the water with the value listed in the handbook for the temperature of your experiment.

Clean and dry the graduated cylinder.

Obtain an unknown liquid and record its identification number. Determine the density of the unknown liquid, using the method just described for water.

3. **Density of Solutions**

The concentration of solutions is often conveniently described in terms of the solutions’ percentage composition on a weight basis. For example, a 5% sodium chloride solution contains 5 g of sodium chloride in every 100 g of solution (which corresponds to 5 g of sodium chloride for every 95 g of water present).

Prepare solutions of sodium chloride in distilled water consisting of the following percentages by weight: 5%, 10%, 15%, 20%, 25%. Prepare 25 g of each solution (you do not have to prepare 100 g of each solution to be able to use the percentage composition). Make the weight determinations of solute and solvent to the nearest milligram.

Using the method described earlier for samples of pure liquids, determine the density of each of your sodium chloride solutions. Record the temperature of each solution while determining its density.

Construct a graph of the density of your solutions versus the percentage of NaCl the solution contains. What sort of relationship exists between density and composition?

Use a handbook of chemical data to determine the true density of each of the solutions you prepared. Calculate the error in each of the densities you determined.

**Example:**

Suppose it is desired to prepare 50.0 g of 7.5% calcium chloride solution. When we say we have a “7.5% calcium chloride solution,” we are implying this conversion factor:

\[
\frac{7.5 \text{ g calcium chloride}}{100.0 \text{ g solution}} = \frac{7.5 \text{ g calcium chloride}}{7.5 \text{ g calcium chloride} + 92.5 \text{ g water}}
\]

So, to prepare 50.0 g of 7.5% calcium chloride solution,

\[
50.0 \text{ g solution} \times \frac{7.5 \text{ g calcium chloride}}{100.0 \text{ g solution}} = 3.8 \text{ g calcium chloride needed}
\]

So, 3.8 g of calcium chloride and 46.2 g of water would be needed.
EXPERIMENT 3
Density Determinations

RESULTS/OBSERVATIONS

1. Density of Solids
   - ID number of regular solid
   - Shape of regular solid
   - Dimensions of regular solid
   - Calculated volume of solid
   - Mass of regular solid
   - Density of regular solid
   - ID number of metal pellets
   - Mass of metal pellets taken
   - Initial water level
   - Final water level
   - Volume of metal pellets
   - Calculated density of metal pellets

2. Density of Pure Liquids
   - Mass of empty graduated cylinder
   - Mass of cylinder plus water
   - Volume of water
   - Density of water
   - Temperature of water
   - Handbook density of water
   - ID number of unknown liquid
   - Mass of cylinder plus liquid
   - Mass of liquid
   - Volume of unknown liquid
   - Density of unknown liquid
3. **Density of Solutions**

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<th>% NaCl</th>
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**QUESTIONS**

1. What error would be introduced into the determination of the density of the regularly shaped solid if the solid were *hollow*? Would the apparent volume of the solid be larger or smaller than the actual volume? Would the density calculated be too high or too low?

2. What error would be introduced into the determination of the density of the irregularly shaped metal pellets if you had not stirred/shaken the pellets to remove adhering *air bubbles*? Would the density be too high or too low?

3. Your data for the density of sodium chloride solutions should have produced a straight line when plotted. How could this plot be used to determine the density of any concentration of sodium chloride solution?

4. Why was it necessary to determine the *temperature* during the determination of the density of the sodium chloride solutions? Which factor—mass or volume—used in calculating the density would be affected by temperature? Explain.