8.6 Concentration

Boosting a dead car battery with jumper cables can be hazardous. Conventional car batteries are made up of lead and lead(IV) oxide plates immersed in a concentrated solution of sulfuric acid. Some hydrogen gas is produced during the normal operation of the battery. Hydrogen is highly flammable and can be ignited by a spark. Normally this gas escapes through small vents in the battery. If ventilation is poor, an explosive mixture of hydrogen and air accumulates around the battery. The slightest spark caused by the incorrect use of the jumper cables could initiate an explosion that blows the battery apart, sending concentrated sulfuric acid and casing fragments in all directions. Chemical burns caused by concentrated sulfuric acid are painful and can be disfiguring. Fortunately, the sulfuric acid that you typically use in high school laboratories is much less concentrated than battery acid.

Different industries and organizations measure concentration in different ways. First we will look at the convention used in most laboratories. In Section 8.8 we will explore how concentration is described in other settings.

Amount Concentration

Recall from Section 8.2 that the term "concentration" is used to describe the quantity of solute per unit volume of solution. A concentrated solution contains a relatively large quantity of dissolved solute per unit volume of solution. Conversely, a dilute solution contains a relatively low quantity of solute per unit volume (Section 8.2, Figure 5). For example, the sulfuric acid your school buys is far too concentrated to be used in most investigations. Your teacher will carefully dilute this solution by adding small quantities of it to water. It is then ready for use during your investigations (**Figure 1**).

LEARNING TIP

Diluting Acids
The process of diluting an acid releases so much thermal energy that it can cause water to boil. That is why concentrated acids are always added to water and never the other way around. Water is less dense than acid. If water were added to a concentrated acid, the water would float on top of the acid. The intense heat generated at the boundary between the water and acid causes the water to boil, splattering corrosive acid around. It can even cause the beaker to shatter. Remember: Always Add Acid.

amount concentration (*c*) the amount (in moles) of solute dissolved per litre of solution; unit symbol mol/L

Figure 1 Steam forms when concentrated acid is added to water. When diluting acids, always add acid to water.

Chemists find it most convenient to express solution concentrations in terms of the amount (in moles) of solute per litre of solution. Traditionally, this was called the molar concentration or molarity of the solution, and used the unit symbol "*M*."

According to IUPAC, the governing body that regulates naming conventions in chemistry, the terms "molar concentration" and "molarity" are no longer correct. They have been replaced with the term "amount concentration." The **amount concentration**, *c*, of a solution is determined by dividing the amount (in moles) of solute, *n*, by the volume (in litres) of the solution, *V*:

$$\text{amount concentration} = \frac{\text{amount of solute (in mol)}}{\text{volume of solution (in L)}} \qquad c = \frac{n}{V}$$

The units of amount concentration are mol/L. **Table 1** gives the amount concentration of common stock acid solutions. A **stock solution** is a concentrated solution that is to be diluted to a lower concentration prior to actual use.

Table 1 Amount Concentrations of Common Stock Acid Solutions

Stock acid	Amount concentration (mol/L)
hydrochloric acid, $HCl(aq)$	12
nitric acid, $HNO_3(aq)$	16
sulfuric acid, $H_2SO_4(aq)$	18

stock solution a concentrated solution that is used to prepare dilute solutions for actual use

Tutorial 1 Using the Amount Concentration Formula

When you are given any two values for amount concentration, amount of solute, and volume of solution, use the concentration formula:

$$c = \frac{n}{V}$$

When using this formula always check that:

- the equation is rearranged correctly to solve for the required variables
- amount is expressed in mol
- volume is expressed in L. The most common conversion you will encounter is mL to L and vice versa. Recall that 1 mL = 1×10^{-3} L. For example, 5.0 mL = 0.0050 L or 5.0×10^{-3} L.

After completing a calculation, check that the number of significant digits in the final answer agrees with the least number of significant digits in the calculation. Also check that your final answer is numerically correct and its units are correct.

Sample Problem 1: Calculating Amount Concentration

Sulfuric acid is a solution of hydrogen sulfate, H_2SO_4, in water. When concentrated, it is extremely corrosive (**Figure 2**). A 25.0 mL sample of concentrated sulfuric acid contains 44 g of hydrogen sulfate. Calculate the amount concentration of the solution.

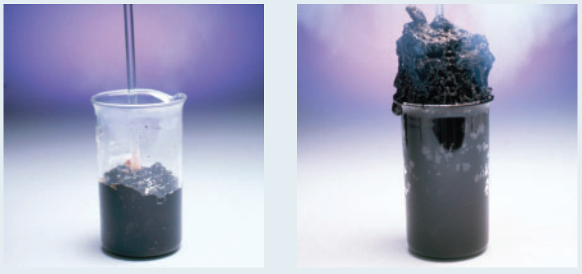

Figure 2 Concentrated sulfuric acid can decompose sucrose (table sugar) into black carbon and water vapour.

Given: volume of solution, $V_{H_2SO_4}$; mass of hydrogen sulfate, $m_{H_2SO_4}$

Required: amount concentration of sulfuric acid, $c_{H_2SO_4}$

Analysis: $c_{H_2SO_4} = \frac{n_{H_2SO_4}}{V_{H_2SO_4}}$

Solution:

Step 1. If necessary, convert the volume of the solution to litres. Amount concentration is equal to the amount of solute dissolved *per litre of solution*. Thus, if the volume of the solution is given in units other than litres, you will have to convert the volume into litres using the appropriate conversion factor.

$$V_{H_2SO_4} = 25.0\ \cancel{mL} \times \frac{1 L}{1000\ \cancel{mL}}$$

$$V_{H_2SO_4} = 2.50 \times 10^{-2}\ L$$

Step 2. If necessary, convert the mass of solute to amount of solute. Amount concentration is equal to *the amount of solute* dissolved per litre of solution. Thus, if the mass of the solute is given in the problem statement instead of the amount of solute, then you will have to convert the mass of solute into amount of solute.

$$n_{H_2SO_4} = 44\ \cancel{g} \times \frac{1\ mol_{H_2SO_4}}{98.08\ \cancel{g}}$$

$$n_{H_2SO_4} = 0.4486\ mol\ \text{[2 extra digits carried]}$$

UNIT TASK **BOOKMARK**

You will use amount concentration values when you perform the analysis involved in the Unit Task on page 498.

Figure 3 The product label on chlorine bleach warns against mixing it with other substances. Toxic fumes may be produced.

Step 3. If necessary, rearrange the concentration equation in the appropriate form. Then substitute in the values, and solve the equation.

$$c_{H_2SO_4} = \frac{n_{H_2SO_4}}{V_{H_2SO_4}}$$

$$= \frac{0.4486 \text{ mol}}{2.50 \times 10^{-2} \text{ L}}$$

$$c_{H_2SO_4} = 18 \frac{\text{mol}}{\text{L}}$$

Statement: The amount concentration of the concentrated sulfuric acid solution is 18 mol/L.

Sample Problem 2: Calculating Volume

Household chlorine bleach is a 0.067 mol/L solution of sodium hypochlorite, NaClO (**Figure 3**). What mass of sodium hypochlorite is required to prepare 225 mL of bleach?

Given: concentration of solution, $c_{NaClO} = 0.067$ mol/L; volume of solution, $V_{NaClO} = 225.0$ mL

Required: mass of sodium hypochlorite, m_{NaClO}

Analysis: To determine the mass of sodium hypochlorite you first need to find the amount. Use the amount concentration equation to determine the amount of sodium hypochlorite in one litre of solution.

$$c_{NaClO} = \frac{n_{NaClO}}{V_{NaClO}}$$

Solution:

Step 1. Convert the volume of the solution to litres.

$$V_{NaClO} = 225.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$V_{NaClO} = 0.225 \text{ L}$$

Step 2. Write the appropriate form of the concentration equation, substitute in the values, and solve.

$$n_{NaClO} = c_{NaClO}V_{NaClO}$$

$$= \frac{0.067 \text{ mol}}{1 \text{ L}} \times 0.225 \text{ L}$$

$$n_{NaClO} = 0.01508 \text{ mol [2 extra digits carried]}$$

Step 3. Convert the amount of solute to mass.

$$m_{NaClO} = 0.01508 \text{ mol} \times \frac{74.44 \text{ g}}{1 \text{ mol}}$$

$$m_{NaClO} = 1.12 \text{ g}$$

Statement: The mass of sodium hypochlorite required to prepare 225 mL of bleach is 1.12 g.

Practice

SKILLS HANDBOOK A6

1. The food industry uses calcium chloride, $CaCl_2$, to make processed foods, such as pickles, taste saltier without adding sodium chloride. What is the amount concentration of a 750 mL sample of a calcium chloride solution that contains 1.5 mol of calcium chloride? T/I [ans: 2.0 mol/L]
2. Phosphoric acid, H_3PO_4, is the active ingredient in many consumer products designed to remove rust. What is the amount concentration of a solution that contains 63 g of phosphoric acid in 250 mL? T/I [ans: 2.6 mol/L]

3. Fructose, $C_6H_{12}O_6$, is a natural sugar in apple juice. A person with diabetes must be aware of the quantity of sugar she consumes. The amount concentration of fructose in a certain brand of apple juice is 0.67 mol/L. What mass of fructose is present in a 250 mL bottle of apple juice? T/I [ans: 30 g]
4. Soap makers use a 6.0 mol/L solution of sodium hydroxide, NaOH, to make soap. What volume of solution can be prepared using 125 g of sodium hydroxide? T/I [ans: 520 mL]

Preparing Solutions

SKILLS HANDBOOK A3.2, A3.3, A3.7

standard solution a solution for which the precise concentration is known

Many chemical reactions involve aqueous solutions. Often, these reactions are conducted quantitatively. In order to give reliable data, it is important that the solutions be carefully prepared with known concentrations. A solution of a known concentration is called a **standard solution**. In the laboratory, standard solutions are often prepared in volumetric flasks (**Figure 4**). A volumetric flask is a pear-shaped container with an elongated neck. Each size of volumetric flask is designed to contain a certain volume of solution, +/− 0.1 mL at a specific temperature (often 20 °C).

Solutions are prepared by first dissolving a known quantity of solute in about one-quarter of the volume of the solvent, such as water. Then, additional solvent is carefully added until the bottom of the solution's meniscus lines up with the calibration mark on the flask. The final volume of the standard solution prepared in **Figure 5** is 250.0 mL.

Figure 4 Volumetric flasks come in a variety of sizes.

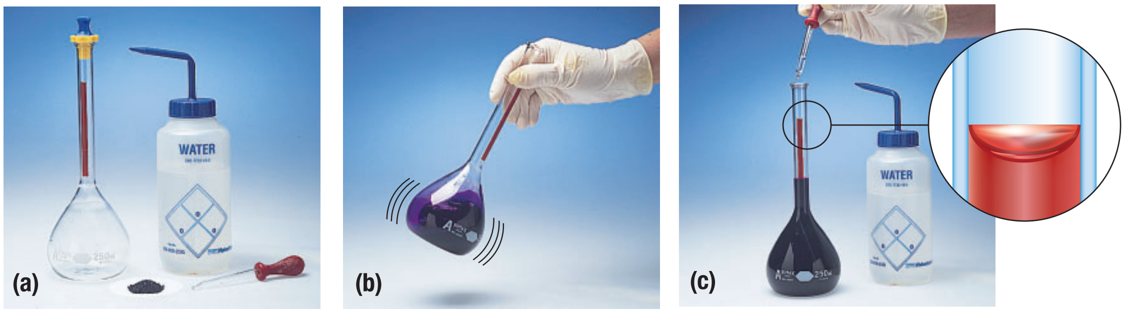

Figure 5 (a) To prepare a 250 mL sample of potassium permanganate solution, you will need a volumetric flask, distilled water, a dropper, and the required mass of potassium permanganate, $KMnO_4$. (b) First dissolve the solid $KMnO_4$ in about 100 mL of distilled water. (c) Use a dropper to add distilled water until the bottom of the meniscus lines up with the calibration mark on the flask.

It may be difficult to transfer the solid directly into the volumetric flask without spillage. To avoid this problem you could first pour the solid into a beaker and add about a quarter of the total volume of water. Pour the solution into the volumetric flask, followed by the water used to thoroughly rinse out the beaker. Finally, add water until the bottom of the solution's meniscus lines up with the calibration mark on the flask.

8.6 Summary

- The concentration of a solution is the quantity of dissolved solute per unit volume of solution.
- Amount concentration is the amount (in moles) of solute dissolved per litre of solution. The units of amount concentration are mol/L.
- Amount concentration is determined using the equation $c = \frac{n}{V}$.
- "Amount concentration" is the preferred IUPAC term for solution concentration (replacing molar concentration and molarity).
- Samples taken from a stock solution are diluted to prepare solutions for use in the laboratory.
- A solution of known concentration is called a standard solution.

Investigation 8.6.1

Preparing a Standard Solution from a Solid (p. 412)
This is your opportunity to learn the skills necessary to make an aqueous solution of known concentration.

8.6 Questions

1. Differentiate between the following pairs of terms: K/U
   (a) concentration and solubility
   (b) a concentrated solution and a saturated solution
2. Briefly describe how to dilute a sample of concentrated acid to about half its original concentration. K/U
3. Silver nitrate, $AgNO_3$, solutions are sometimes used to determine the salt content of food. What is the amount concentration of 500.0 mL of a solution that contains 34.0 g of silver nitrate? T/I
4. A 2.0 mol/L solution of potassium hydroxide, KOH, is used to precipitate toxic metal ions from industrial waste. What mass of potassium hydroxide is required to prepare 1.5 L of this solution? T/I
5. Sodium carbonate, Na_2CO_3, can be used to regulate the acidity of swimming pools. What volume, in millilitres, of a 0.45 mol/L solution contains 35.0 g of sodium carbonate? T/I
6. A solution of sodium oxalate, $Na_2C_2O_4$, is used to analyze for the presence of calcium ions in water. Water quality technicians typically use a 0.100 mol/L solution for this analysis. What volume, in millilitres, can be prepared using 33.5 g of solid sodium oxalate? T/I
7. What mass of copper(II) sulfate pentahydrate is required to prepare 450 mL of a 0.20 mol/L solution? (Be sure to consider the water molecules when you calculate the molar mass of this compound.) T/I
8. Sulfuric acid is one of the most widely used and important industrial chemicals (**Figure 6**). Why do you think it is more economical for companies to purchase concentrated sulfuric acid rather than a safer, more dilute solution? K/U T/I A

Figure 6 The transportation of concentrated sulfuric acid is carefully regulated.

9. A school purchases concentrated solutions of ethanoic (acetic) acid, $HC_2H_3O_2(aq)$, and sulfuric acid, $H_2SO_4(aq)$. The acids are supplied in 1 L containers. The amount concentration of both solutions is 18 mol/L. Which solution has the greatest mass? Why? T/I
10. Cholesterol, $C_{27}H_{46}O$, is a waxy substance found naturally in the body. Under some circumstances cholesterol can clog the arteries. Health Canada recommends that the total cholesterol concentration in the blood not exceed 6.2×10^{-3} mol/L. If you have about 4.7 L of blood, what is the maximum mass of cholesterol that your blood should contain? T/I
11. Consider the design of a 250 mL beaker and a 250 mL volumetric flask (**Figure 7**). Why do you think chemists prefer to use the volumetric flask when preparing solutions of precise concentrations? K/U

Figure 7 Which vessel is better for precisely measuring 250 mL?

12. (a) Why do you think it is important to store standard solutions in sealed containers?
    (b) Predict the effect on the concentration of a sodium chloride solution if it is stored in an open container. Use the equation $c = \frac{n}{V}$ in your answer. T/I A
13. IUPAC makes decisions about the correct terminology that should be used in chemistry. The organization stated that "amount concentration" should be used in place of "molar concentration." What is the benefit of having a body, such as IUPAC, making decisions such as this? What are the drawbacks? Who might be in favour of, and who might oppose, their decisions? T/I A