8.3 The Concentration of Solutions

Section Preview/ Specific Expectations

In this section, you will

- **solve problems** involving the concentration of solutions
- **express** concentration as grams per 100 mL, mass and volume percents, parts per million and billion, and moles per litre
- **communicate** your understanding of the following terms: *concentration, mass/volume percent, mass/mass percent, volume/volume percent, parts per million, parts per billion, molar concentration*

Material Safety Data Sheet

Component Name	CAS Number
PHENOL, 100% Pure	108952

SECTION III: Hazards Identification

- Very hazardous in case of ingestion, inhalation, skin contact, or eye contact.
- Product is corrosive to internal membranes when ingested.
- Inhalation of vapours may damage central nervous system. Symptoms: nausea, headache, dizziness.
- Skin contact may cause itching and blistering.
- Eye-contact may lead to corneal damage or blindness.
- Severe over-exposure may lead to lung-damage, choking, or coma.

Figure 8.15 **Should phenol be banned from drugstores?**

Phenol is a hazardous liquid, especially when it is at room temperature. It is a volatile chemical. Inhaling phenol adversely affects the central nervous system, and can lead to a coma. Inhalation is not the only danger. Coma and death have been known to occur within 10 min after phenol has contacted the skin. Also, as little as 1 g of phenol can be fatal if swallowed.

Would you expect to find such a hazardous chemical in over-the-counter medications? Check your medicine cabinet at home. You may find phenol listed as an ingredient in throat sprays and in lotions to relieve itching. You may also find it used as an antiseptic or disinfectant. Is phenol a hazard or a beneficial ingredient in many medicines? This depends entirely on **concentration**: the amount of solute per quantity of solvent. At high concentrations, phenol can kill. At low concentrations, it is a safe component of certain medicines.

Modern analytical tests allow chemists to detect and measure almost any chemical at extremely low concentrations. In this section, you will learn about various ways that chemists use to express the concentration of a solution. As well, you will find the concentration of a solution by experiment.

Concentration as a Mass/Volume Percent

Recall that the solubility of a compound at a certain temperature is often expressed as the mass of the solute per 100 mL of solvent. For example, you know that the solubility of sodium chloride is 36 g/100 mL of water at room temperature. The final volume of the sodium chloride solution may or may not be 100 mL. It is the volume of the solvent that is important.

Chemists often express the concentration of an *unsaturated* solution as the mass of solute dissolved per volume of the *solution*. This is different from solubility. It is usually expressed as a percent relationship. A **mass/volume percent** gives the mass of solute dissolved in a volume of solution, expressed as a percent. The mass/volume percent is also referred to as the *percent (m/v)*.

$$\text{Mass/volume percent} = \frac{\text{Mass of solute (in g)}}{\text{Volume of solution (in mL)}} \times 100\%$$

Suppose that a hospital patient requires an intravenous drip to replace lost body fluids. The intravenous fluid may be a saline solution that contains 0.9 g of sodium chloride dissolved in 100 mL of solution, or 0.9% (m/v). *Notice that the number of grams of solute per 100 mL of solution is numerically equal to the mass/volume percent.* Explore this idea further in the following problems.

PROBEWARE

If you have access to probeware, do the Chemistry 11 lab, "Concentration of Solutions" now.

Sample Problem

Solving for a Mass/Volume Percent

Problem

A pharmacist adds 2.00 mL of distilled water to 4.00 g of a powdered drug. The final volume of the solution is 3.00 mL. What is the concentration of the drug in g/100 mL of solution? What is the percent (m/v) of the solution?

What Is Required?

You need to calculate the concentration of the solution, in grams of solute dissolved in 100 mL of solution. Then you need to express this concentration as a mass/volume percent.

What Is Given?

The mass of the dissolved solute is 4.00 g. The volume of the solution is 3.00 mL.

Plan Your Strategy

There are two possible methods for solving this problem.

Method 1

Use the formula

$$\text{Mass/volume percent} = \frac{\text{Mass of solute (in g)}}{\text{Volume of solution (in mL)}} \times 100\%$$

Method 2

Let x represent the mass of solute dissolved in 100 mL of solution. The ratio of the dissolved solute, x, in 100 mL of solution must be the same as the ratio of 4.00 g of solute dissolved in 3.00 mL of solution. The concentration, expressed in g/100 mL, is numerically equal to the percent (m/v) of the solution.

Act on Your Strategy

Method 1

$$\text{Percent (m/v)} = \frac{4.00\text{ g}}{3.00\text{ mL}} \times 100\%$$
$$= 133\%$$

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Method 2

$$\frac{x}{100\ \text{mL}} = \frac{4.00\ \text{g}}{3.00\ \text{mL}}$$

$$\frac{x}{100\ \text{mL}} = 1.33\ \text{g/mL}$$

$$x = 100\ \cancel{\text{mL}} \times 1.33\ \text{g/}\cancel{\text{mL}}$$

$$= 133\ \text{g}$$

The concentration of the drug is 133 g/100 mL of solution, or 133% (m/v).

Check Your Solution

The units are correct. The numerical answer is large, but this is reasonable for an extremely soluble solute.

Sample Problem

Finding Mass for an (m/v) Concentration

Problem

Many people use a solution of trisodium phosphate, Na_3PO_4 (commonly called TSP), to clean walls before putting up wallpaper. The recommended concentration is 1.7% (m/v). What mass of TSP is needed to make 2.0 L of solution?

What Is Required?

You need to find the mass of TSP needed to make 2.0 L of solution.

What Is Given?

The concentration of the solution should be 1.7% (m/v). The volume of solution that is needed is 2.0 L.

Plan Your Strategy

There are two different methods you can use.

Method 1

Use the formula for (m/v) percent. Rearrange the formula to solve for mass. Then substitute in the known values.

Method 2

The percent (m/v) of the solution is numerically equal to the concentration in g/100 mL. Let x represent the mass of TSP dissolved in 2.0 L of solution. The ratio of dissolved solute in 100 mL of solution must be the same as the ratio of the mass of solute, x, dissolved in 2.0 L (2000 mL) of solution.

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Act on Your Strategy

Method 1

$$\text{(m/v) percent} = \frac{\text{Mass of solute (in g)}}{\text{Volume of solution (in mL)}} \times 100\%$$

$$\therefore \text{Mass of solute} = \frac{\text{(m/v) percent} \times \text{Volume of solution}}{100\%}$$

$$= \frac{1.7\% \times 2000 \text{ mL}}{100\%}$$

$$= 34 \text{ g}$$

Method 2

A TSP solution that is 1.7% (m/v) contains 1.7 g of solute dissolved in 100 mL of solution.

$$\frac{1.7 \text{ g}}{100 \text{ mL}} = \frac{x}{2000 \text{ mL}}$$

$$0.017 \text{ g/mL} = \frac{x}{2000 \text{ mL}}$$

$$x = 0.017 \text{ g/mL} \times 2000 \text{ mL}$$

$$= 34 \text{ g}$$

Therefore, 34 g of TSP are needed to make 2.0 L of cleaning solution.

Check Your Solution

The units are appropriate for the problem. The answer appears to be reasonable.

Practice Problems

1. What is the concentration in percent (m/v) of each solution?
   - **(a)** 14.2 g of potassium chloride, KCl (used as a salt substitute), dissolved in 450 mL of solution
   - **(b)** 31.5 g of calcium nitrate, $Ca(NO_3)_2$ (used to make explosives), dissolved in 1.80 L of solution
   - **(c)** 1.72 g of potassium permanganate, $KMnO_4$ (used to bleach stone-washed blue jeans), dissolved in 60 mL of solution
2. A solution of hydrochloric acid was formed by dissolving 1.52 g of hydrogen chloride gas in enough water to make 24.1 mL of solution. What is the concentration in percent (m/v) of the solution?
3. At 25°C, a saturated solution of carbon dioxide gas in water has a concentration of 0.145% (m/v). What mass of carbon dioxide is present in 250 mL of the solution?
4. Ringer's solution contains three dissolved salts in the same proportions as they are found in blood. The salts and their concentrations (m/v) are as follows: 0.86% NaCl, 0.03% KCl, and 0.033% $CaCl_2$. Suppose that a patient needs to receive 350 mL of Ringer's solution by an intravenous drip. What mass of each salt does the pharmacist need to make the solution?

Concentration as a Mass/Mass Percent

The concentration of a solution that contains a solid solute dissolved in a liquid solvent can also be expressed as a mass of solute dissolved in a mass of solution. This is usually expressed as a percent relationship. A **mass/mass percent** gives the mass of a solute divided by the mass of solution, expressed as a percent. The mass/mass percent is also referred to as the *percent (m/m)*, or the *mass percent*. It is often inaccurately referred to as a weight (w/w) percent, as well. Look at your tube of toothpaste, at home. The percent of sodium fluoride in the toothpaste is usually given as a w/w percent. This can be confusing, since weight (*w*) is not the same as mass (*m*). In fact, this concentration should be expressed as a mass/mass percent.

$$\text{Mass/mass percent} = \frac{\text{Mass of solute (in g)}}{\text{Mass of solution (in g)}} \times 100\%$$

For example, 100 g of seawater contains 0.129 g of magnesium ion (along with many other substances). The concentration of Mg^{2+} in seawater is 0.129 (m/m). *Notice that the number of grams of solute per 100 g of solution is numerically equal to the mass/mass percent.*

The concentration of a solid solution, such as an alloy, is usually expressed as a mass/mass percent. Often the concentration of a particular alloy may vary. Table 8.3 gives typical compositions of some common alloys.

Table 8.3 The Composition of Some Common Alloys

Alloy	Uses	Typical percent (m/m) composition
brass	ornaments, musical instruments	Cu (85%) Zn (15%)
bronze	statues, castings	Cu (80%) Zn (10%) Sn (10%)
cupronickel	"silver" coins	Cu (75%) Ni (25%)
dental amalgam	dental fillings	Hg (50%) Ag (35%) Sn (15%)
duralumin	aircraft parts	Al (93%) Cu (5%) other (2%)
pewter	ornaments	Sn (85%) Cu (7%) Bi (6%) Sb ((2%)
stainless steel	cutlery, knives	Fe (78%) Cr (15%) Ni (7%)
sterling silver	jewellery	Ag (92.5%) Cu (7.5%)

Figure 8.16, on the following page, shows two objects made from brass that have distinctly different colours. The difference in colours reflects the varying concentrations of the copper and zinc that make up the objects.

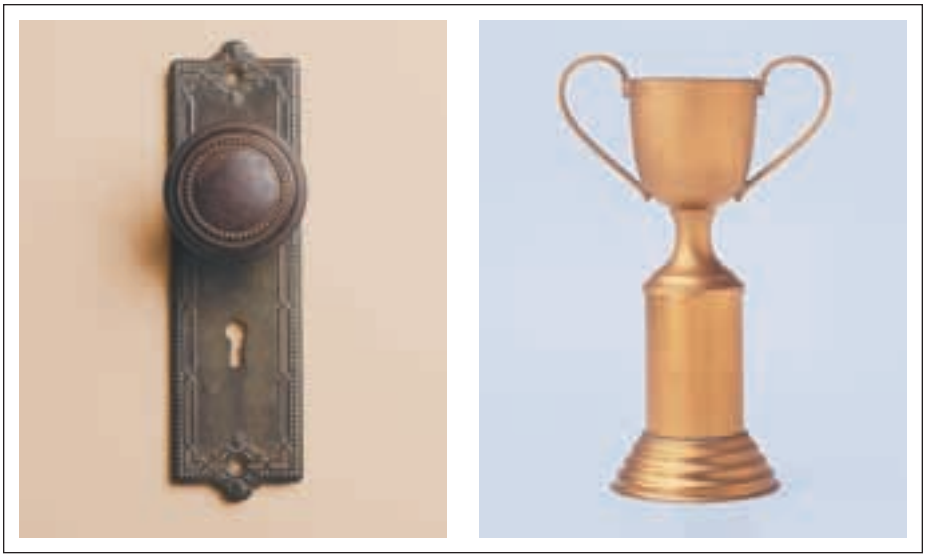

Figure 8.16 **Brass can be made using any percent from 50% to 85% copper, and from 15% to 50% zinc. As a result, two objects made of brass can look very different.**

Sample Problem

Solving for a Mass/Mass Percent

Problem

Calcium chloride, $CaCl_2$, can be used instead of road salt to melt the ice on roads during the winter. To determine how much calcium chloride had been used on a nearby road, a student took a sample of slush to analyze. The sample had a mass of 23.47 g. When the solution was evaporated, the residue had a mass of 4.58 g. (Assume that no other solutes were present.) What was the mass/mass percent of calcium chloride in the slush? How many grams of calcium chloride were present in 100 g of solution?

What Is Required?

You need to calculate the mass/mass percent of calcium chloride in the solution (slush). Then you need to use your answer to find the mass of calcium chloride in 100 g of solution.

What Is Given?

The mass of the solution is 23.47 g. The mass of calcium chloride that was dissolved in the solution is 4.58 g.

Plan Your Strategy

There are two methods that you can use to solve this problem.

Method 1

Use the formula for mass/mass percent.

$$\text{Mass/mass percent} = \frac{\text{Mass of solute (in g)}}{\text{Mass of solution (in g)}} \times 100\%$$

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The mass of calcium chloride in 100 g of solution will be numerically equal to the mass/mass percent.

Method 2

Use ratios, as in the previous Sample Problems.

Act on Your Strategy

Method 1

$$\text{Mass/mass percent} = \frac{4.58\ \cancel{g}}{23.47\ \cancel{g}} \times 100\%$$
$$= 19.5\%$$

Method 2

$$\frac{x\ \text{g}}{100\ \text{g}} = \frac{4.58\ \text{g}}{23.47\ \text{g}}$$
$$\frac{x\ \cancel{g}}{100\ \cancel{g}} = 0.195$$
$$x = 19.5\%$$

The mass/mass percent was 19.5% (m/m). 19.5 g of calcium chloride was dissolved in 100 g of solution.

Check Your Solution

The mass units divide out properly. The final answer has the correct number of significant digits. It appears to be reasonable.

Practice Problems

5. Calculate the mass/mass percent of solute for each solution.

(a) 17 g of sulfuric acid in 65 g of solution

(b) 18.37 g of sodium chloride dissolved in 92.2 g of water
Hint: Remember that a solution consists of both solute and solvent.

(c) 12.9 g of carbon tetrachloride dissolved in 72.5 g of benzene

6. If 55 g of potassium hydroxide is dissolved in 100 g of water, what is the concentration of the solution expressed as mass/mass percent?

7. Steel is an alloy of iron and about 1.7% carbon. It also contains small amounts of other materials, such as manganese and phosphorus. What mass of carbon is needed to make a 5.0 kg sample of steel?

8. Stainless steel is a variety of steel that resists corrosion. Your cutlery at home may be made of this material. Stainless steel must contain at least 10.5% chromium. What mass of chromium is needed to make a stainless steel fork with a mass of 60.5 g?

9. 18-carat white gold is an alloy. It contains 75% gold, 12.5% silver, and 12.5% copper. A piece of jewellery, made of 18-carat white gold, has a mass of 20 g. How much pure gold does it contain?

Concentration as a Volume/Volume Percent

When mixing two liquids to form a solution, it is easier to measure their volumes than their masses. A **volume/volume percent** gives the volume of solute divided by the volume of solution, expressed as a percent. The volume/volume percent is also referred to as the *volume percent concentration*, *volume percent*, *percent (v/v)*, or the *percent by volume*. You can see this type of concentration on a bottle of rubbing alcohol from a drugstore. (See Figure 8.17.)

$$\text{Volume/volume percent} = \frac{\text{Volume of solute (in mL)}}{\text{Volume of solution (in mL)}} \times 100\%$$

Read through the Sample Problem below, and complete the Practice Problems that follow. You will then have a better understanding of how to calculate the volume/volume percent of a solution.

Figure 8.17 **The concentration of this solution of isopropyl alcohol in water is expressed as a volume/volume percent.**

Sample Problem

Solving for a Volume/Volume Percent

Problem

Rubbing alcohol is commonly used as an antiseptic for small cuts. It is sold as a 70% (v/v) solution of isopropyl alcohol in water. What volume of isopropyl alcohol is used to make 500 mL of rubbing alcohol?

What Is Required?

You need to calculate the volume of isopropyl alcohol (the solute) used to make 500 mL of solution.

What Is Given?

The volume/volume percent is 70% (v/v). The final volume of the solution is 500 mL.

Plan Your Strategy

Method 1

Rearrange the following formula to solve for the volume of the solute. Then substitute the values that you know into the rearranged formula.

$$\text{Volume/volume percent} = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100\%$$

Method 2

Use ratios to solve for the unknown volume.

Continued ...

CHEM FACT

Archaeologists can learn a lot about ancient civilizations by chemically analyzing the concentration of ions in the soil where the people lived. When crops are grown, the crops remove elements such as nitrogen, magnesium, calcium, and phosphorus from the soil. Thus, soil with a lower-than-average concentration of these elements may have held ancient crops. Chlorophyll, which is present in all plants, contains magnesium ions. In areas where ancient crops were processed, the soil has a higher concentration of Mg^{2+}.

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Act on Your Strategy

Method 1

$$\text{Volume/volume percent} = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100\%$$

$$\text{Volume of solute} = \frac{\text{Volume/volume percent} \times \text{Volume of solution}}{100\%}$$

$$= \frac{70\% \times 500 \text{ mL}}{100\%}$$

$$= 350 \text{ mL}$$

Method 2

$$\frac{x \text{ mL}}{500 \text{ mL}} = \frac{70 \text{ mL}}{100 \text{ mL}}$$

$$x = 0.7 \times 500 \text{ mL}$$

$$= 350 \text{ mL}$$

Therefore, 350 mL of isopropyl alcohol is used to make 500 mL of 70% (v/v) rubbing alcohol.

Check Your Solution

The answer seems reasonable. It is expressed in appropriate units.

Practice Problems

Figure 8.18 **Antifreeze is a solution of ethylene glycol and water.**

10. 60 mL of ethanol is diluted with water to a final volume of 400 mL. What is the percent by volume of ethanol in the solution?

11. Milk fat is present in milk. Whole milk usually contains about 5.0% milk fat by volume. If you drink a glass of milk with a volume of 250 mL, what volume of milk fat have you consumed?

12. Both antifreeze (shown in Figure 8.18) and engine coolant contain ethylene glycol. A manufacturer sells a concentrated solution that contains 75% (v/v) ethylene glycol in water. According to the label, a 1:1 mixture of the concentrate with water will provide protection against freezing down to a temperature of –37°C. A motorist adds 1 L of diluted solution to a car radiator. What is the percent (v/v) of ethylene glycol in the diluted solution?

13. The average adult human body contains about 5 L of blood. Of this volume, only about 0.72% consists of leukocytes (white blood cells). These essential blood cells fight infection in the body. What volume of pure leukocyte cells is present in the body of a small child, with only 2.5 L of blood?

14. Vinegar is sold as a 5% (v/v) solution of acetic acid in water. How much water should be added to 15 mL of pure acetic acid (a liquid at room temperature) to make a 5% (v/v) solution of acetic acid? **Note:** Assume that when water and acetic acid are mixed, the total volume of the solution is the sum of the volumes of each.

Concentration in Parts per Million and Parts per Billion

The concentration of a very small quantity of a substance in the human body, or in the environment, can be expressed in **parts per million (ppm)** and **parts per billion (ppb)**. Both parts per million and parts per billion are usually mass/mass relationships. They describe the amount of solute that is present in a solution. Notice that parts per million does not refer to the number of particles, but to the *mass* of the solute compared with the *mass* of the solution.

$$\text{ppm} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 10^6$$

or

$$\frac{\text{Mass of solute}}{\text{Mass of solution}} = \frac{x\ \text{g}}{10^6\ \text{g of solution}}$$

$$\text{ppb} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 10^9$$

or

$$\frac{\text{Mass of solute}}{\text{Mass of solution}} = \frac{x\ \text{g}}{10^9\ \text{g of solution}}$$

Math LINK

One part per million is equal to 1¢ in $10 000. One part per billion is equal to 1 s in almost 32 years.

What distance (in km) would you travel if 1 cm represented 1 ppm of your journey?

A swimming pool has the dimensions 10 m × 5 m × 2 m. If the pool is full of water, what volume of water (in cm^3) would represent 1 ppb of the water in the pool?

Sample Problem

Parts per Billion in Peanut Butter

Problem

A fungus that grows on peanuts produces a deadly toxin. When ingested in large amounts, this toxin destroys the liver and can cause cancer. Any shipment of peanuts that contains more than 25 ppb of this dangerous fungus is rejected. A company receives 20 t of peanuts to make peanut butter. What is the maximum mass (in g) of fungus that is allowed?

What Is Required?

You need to find the allowed mass (in g) of fungus in 20 t of peanuts.

What Is Given?

The allowable concentration of the fungus is 25 ppb. The mass of the peanut shipment is 20 t.

Plan Your Strategy

Method 1

Convert 20 t to grams. Rearrange the formula below to solve for the allowable mass of the fungus.

$$\text{ppb} = \frac{\text{Mass of fungus}}{\text{Mass of peanuts}} \times 10^9$$

Method 2

Use ratios to solve for the unknown mass.

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Act on Your Strategy

Method 1

First convert the mass in tonnes into grams.

$20\text{ t} \times 1000\text{ kg/t} \times 1000\text{ g/kg} = 20 \times 10^6\text{ g}$

Next rearrange the formula and find the mass of the fungus.

$$\text{ppb} = \frac{\text{Mass of fungus}}{\text{Mass of peanuts}} \times 10^9$$

$$\therefore \text{Mass of fungus} = \frac{\text{ppb} \times \text{Mass of peanuts}}{10^9}$$

$$= \frac{25\text{ ppb} \times (20 \times 10^6\text{ g})}{10^9}$$

Method 2

$$= 0.5\text{ g}$$

$$\frac{x\text{ g solute}}{20 \times 10^6\text{ g solution}} = \frac{25\text{ g solute}}{1 \times 10^9\text{ g solution}}$$

$$x\text{ g} = (20 \times 10^6\text{ g solution}) \times \frac{25\text{ g solute}}{1 \times 10^9\text{ g solution}}$$

$$= 0.5\text{ g}$$

The maximum mass of fungus that is allowed is 0.5 g.

Check Your Solution

The answer appears to be reasonable. The units divided correctly to give grams. **Note:** Parts per million and parts per billion have no units. The original units, g/g, cancel out.

Practice Problems

15. Symptoms of mercury poisoning become apparent after a person has accumulated more than 20 mg of mercury in the body.

(a) Express this amount as parts per million for a 60 kg person.

(b) Express this amount as parts per billion.

(c) Express this amount as a (m/m) percent.

16. The use of the pesticide DDT has been banned in Canada since 1969 because of its damaging effect on wildlife. In 1967, the concentration of DDT in an average lake trout, taken from Lake Simcoe in Ontario, was 16 ppm. Today it is less than 1 ppm. What mass of DDT would have been present in a 2.5 kg trout with DDT present at 16 ppm?

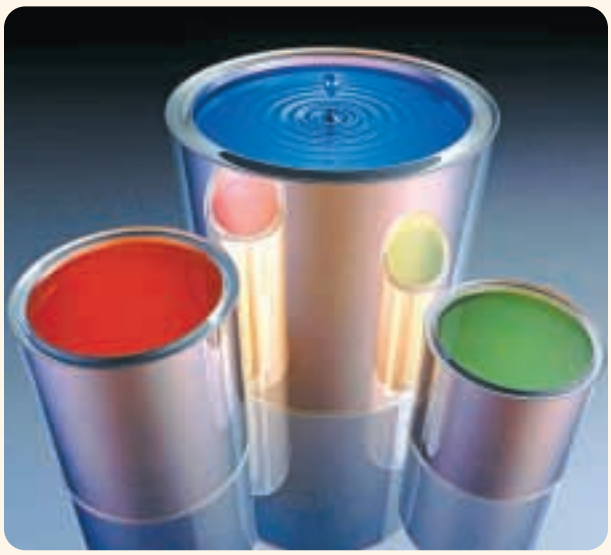
17. The concentration of chlorine in a swimming pool is generally kept in the range of 1.4 to 4.0 mg/L. The water in a certain pool has 3.0 mg/L of chlorine. Express this value as parts per million. (**Hint:** 1 L of water has a mass of 1000 g.)

18. Water supplies with dissolved calcium carbonate greater than 500 mg/L are considered unacceptable for most domestic purposes. Express this concentration in parts per million.

Careers in Chemistry

Product Development Chemist

A solvent keeps paint liquefied so that it can be applied to a surface easily. After the paint has been exposed to the air, the solvent evaporates and the paint dries. Product development chemists develop and improve products such as paints. To work in product development, they require at least one university chemistry degree.



Chemists who work with paints must examine the properties of many different solvents. They must choose solvents that dissolve paint pigments well, but evaporate quickly and pose a low safety hazard.

Product development chemists must consider human health and environmental impact when choosing between solvents. Many solvents that have been used in the past, such as benzene and carbon tetrachloride, are now known to be harmful to the health and/or the environment. A powerful new solvent called *d-limonene* has been developed from the peel of oranges and lemons. This solvent is less harmful than many older solvents. It has been used successfully as a cleaner for airport runways and automotive parts, and as a pesticide. Chemists are now studying new applications for d-limonene.

Make Career Connections

1. Use reference books or the Internet to find the chemical structure of d-limonene. What else can you discover about d-limonene?
2. To learn more about careers involving work with solvents, contact the Canadian Chemical Producers Association (CCPA).

Molar Concentration

The most useful unit of concentration in chemistry is molar concentration. **Molar concentration** is the number of moles of solute in 1 L of solution. Notice that the volume of the *solution* in *litres* is used, rather than the volume of the *solvent* in *millilitres*. Molar concentration is also known as *molarity*.

$$\text{Molar concentration (in mol/L)} = \frac{\text{Amount of solute (in mol)}}{\text{Volume of solution (in L)}}$$

This formula can be shortened to give

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

Molar concentration is particularly useful to chemists because it is related to the number of particles in a solution. None of the other measures of concentration are related to the number of particles. If you are given the molar concentration and the volume of a solution, you can calculate the amount of dissolved solute in moles. This allows you to solve problems involving quantities in chemical reactions, such as the ones on the following pages.

Sample Problem

Calculating Molar Concentration

Problem

A saline solution contains 0.90 g of sodium chloride, NaCl, dissolved in 100 mL of solution. What is the molar concentration of the solution?

What Is Required?

You need to find the molar concentration of the solution in mol/L.

What Is Given?

You know that 0.90 g of sodium chloride is dissolved in 100 mL of solution.

Plan Your Strategy

Step 1 To find the amount (in mol) of sodium chloride, first determine its molar mass. Then divide the amount of sodium chloride (in g) by its molar mass (in g/mol).

Step 2 Convert the volume of solution from mL to L using this formula:

$$\text{Volume (in L)} = \text{Volume (in mL)} \times \frac{1.000\ \text{L}}{1000\ \text{mL}}$$

Step 3 Use the following formula to calculate the molar concentration:

$$\text{Molar concentration (in mol/L)} = \frac{\text{Amount of solute (in mol)}}{\text{Volume of solution (in L)}}$$

Act on Your Strategy

Step 1 $\text{Molar mass of NaCl} = 22.99 + 35.45$

$$= 58.44\ \text{g/mol}$$

$$\text{Amount of NaCl} = \frac{0.90\ \text{g}}{58.44\ \text{g/mol}}$$

$$= 1.54 \times 10^{-2}\ \text{mol}$$

Step 2 Convert the volume from mL to L.

$$\text{Volume} = 100\ \cancel{\text{mL}} \times \frac{1.000\ \text{L}}{1000\ \cancel{\text{mL}}}$$

$$= 0.100\ \text{L}$$

Step 3 Calculate the molar concentration.

$$\text{Molar concentration} = \frac{1.54 \times 10^{-2}\ \text{mol}}{0.100\ \text{L}}$$

$$= 1.54 \times 10^{-1}\ \text{mol/L}$$

The molar concentration of the saline solution is 0.15 mol/L.

Check Your Solution

The answer has the correct units for molar concentration.

Sample Problem

Using Molar Concentration to Find Mass

Problem

At 20°C, a saturated solution of calcium sulfate, $CaSO_4$, has a concentration of 0.0153 mol/L. A student takes 65 mL of this solution and evaporates it. What mass (in g) is left in the evaporating dish?

What Is Required?

You need to find the mass (in g) of the solute, calcium sulfate.

What Is Given?

The molar concentration is 0.0153 mol/L. The volume of the solution is 65 mL.

Plan Your Strategy

Step 1 Convert the volume from mL to L using the formula

$$\text{Volume (in L)} = \text{Volume (in mL)} \times \frac{1.000\ \text{L}}{1000\ \text{mL}}$$

Step 2 Rearrange the following formula to solve for the amount of solute (in mol).

$$\text{Molar concentration (in mol/L)} = \frac{\text{Amount of solute (in mol)}}{\text{Volume of solution (in L)}}$$

Step 3 Determine the molar mass of calcium sulfate. Use the molar mass to find the mass in grams, using the formula below:

$$\text{Mass (in g) of } CaSO_4 = \text{Amount (in mol)} \times \text{Molar mass of } CaSO_4 \text{ (in g/mol)}$$

Act on Your Strategy

Step 1 Convert the volume from mL to L.

$$\text{Volume} = 65\ \cancel{\text{mL}} \times \frac{1.000\ \text{L}}{1000\ \cancel{\text{mL}}}$$
$$= 0.065\ \text{L}$$

Step 2 Rearrange the formula to solve for the amount of solute.

$$\text{Molar concentration} = \frac{\text{Amount of solute}}{\text{Volume of solution}}$$

$$\therefore \text{Amount of solute} = \text{Molar concentration} \times \text{Volume of solution}$$
$$= 0.0153\ \text{mol/L} \times 0.065\ \text{L}$$
$$= 9.94 \times 10^{-4}\ \text{mol}$$

Step 3 Determine the molar mass. Then find the mass in grams.

$$\text{Molar mass of } CaSO_4 = 40.08 + 32.07 + (4 \times 16.00)$$
$$= 136.15\ \text{g/mol}$$

$$\text{Mass (in g) of } CaSO_4 = 9.94 \times 10^{-4}\ \text{mol} \times 136\ \text{g/mol}$$
$$= 0.135\ \text{g}$$

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Therefore, 0.14 g of calcium sulfate are left in the evaporating dish.

Check Your Solution

The answer has the correct units and the correct number of significant figures.

Practice Problems

19. What is the molar concentration of each solution?

(a) 0.50 mol of NaCl dissolved in 0.30 L of solution

(b) 0.289 mol of iron(III) chloride, $FeCl_3$, dissolved in 120 mL of solution

(c) 0.0877 mol of copper(II) sulfate, $CuSO_4$, dissolved in 70 mL of solution

(d) 4.63 g of sugar, $C_{12}H_{22}O_{11}$, dissolved in 16.8 mL of solution

(e) 1.2 g of $NaNO_3$ dissolved in 80 mL of solution

20. What mass of solute is present in each aqueous solution?

(a) 1.00 L of 0.045 mol/L calcium hydroxide, $Ca(OH)_2$, solution

(b) 500 mL of 0.100 mol/L silver nitrate, $AgNO_3$, solution

(c) 2.5 L of 1.00 mol/L potassium chromate, K_2CrO_4, solution

(d) 40 mL of 6.0 mol/L sulfuric acid, H_2SO_4, solution

(e) 4.24 L of 0.775 mol/L ammonium nitrate, NH_4NO_3, solution

21. A student dissolves 30.46 g of silver nitrate, $AgNO_3$, in water to make 500 mL of solution. What is the molar concentration of the solution?

22. What volume of 0.25 mol/L solution can be made using 14 g of sodium hydroxide, NaOH?

23. A 100 mL bottle of skin lotion contains a number of solutes. One of these solutes is zinc oxide, ZnO. The concentration of zinc oxide in the skin lotion is 0.915 mol/L. What mass of zinc oxide is present in the bottle?

24. Formalin is an aqueous solution of formaldehyde, HCHO, used to preserve biological specimens. What mass of formaldehyde is needed to prepare 1.5 L of formalin with a concentration of 10 mol/L?

You have done many calculations for the concentration of various solutions. Now you are in a position to do some hands-on work with solution concentration. In the following investigation, you will use what you have learned to design your own experiment to determine the concentration of a solution.

Investigation 8-B

SKILL FOCUS

- Initiating and planning
- Performing and recording
- Communicating results
- Predicting

Determining the Concentration of a Solution

Your teacher will give you a sample of a solution. Design and perform an experiment to determine the concentration of the solution. Express the concentration as

(a) mass of solute dissolved in 100 mL of *solution*

(b) mass of solute dissolved in 100 g of *solvent*

(c) amount of solute (in mol) dissolved in 1 L of *solution*

Safety Precautions

When you have designed your investigation, think about the safety precautions you will need to take.

Materials

any apparatus in the laboratory

solution containing a solid dissolved in water

Note: Your teacher will tell you the name of the solute.

Procedure

1. Think about what you need to know in order to determine the concentration of a solution. Then design your experiment so that you can measure each quantity you need. Assume that the density of pure water is 1.00 g/mL.
2. Write the steps that will allow you to measure the quantities you need. Design a data table for your results. Include a space for the name of the solute in your solution.
3. When your teacher approves your procedure, complete your experiment.
4. Dispose of your solution as directed by your teacher.

Analysis

1. Express the concentration of the solution you analyzed as

   (a) mass of solute dissolved in 100 mL of *solution*

   (b) mass of solute dissolved in 100 g of *solvent*

   (c) molar concentration

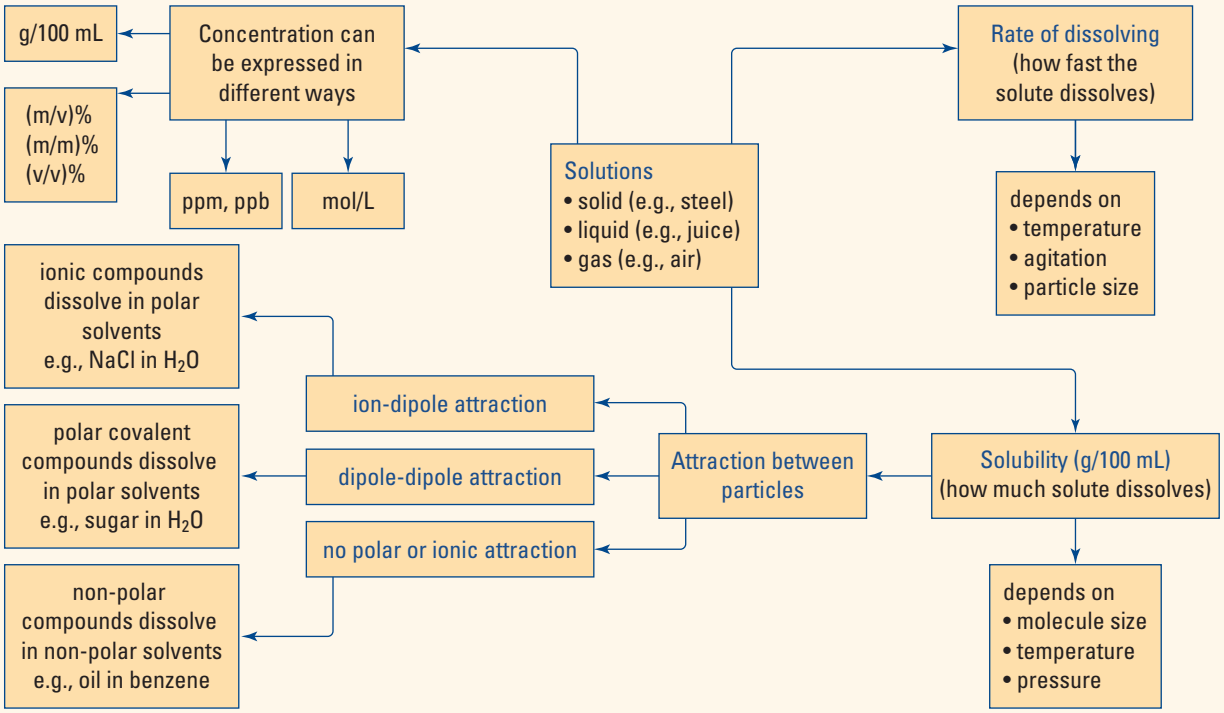
   Show your calculations.

Conclusions

2. List at least two important sources of error in your measurements.
3. List at least two important ways that you could improve your procedure.
4. Did the solute partially decompose on heating, producing a gas and another solid? If so, how do you think this affected the results of your experiment?

Concept Organizer

Summary of Sections 8.1 to 8.3



Section Wrap-up

You have learned about several different ways in which chemists express concentration: mass/volume, mass/mass, and volume/volume percent; parts per million and parts per billion; and molar concentration. The Concept Organizer above summarizes what you have learned in this chapter so far.

In section 8.4, you will learn how standard solutions of known concentration are prepared. You will also learn how to dilute a standard solution.

Unit Issue Prep

The concentration of a pesticide or other contaminant dissolved in water determines the level of pollution. If you wish to work on your Unit 3 Issue now, do some research on pesticides such as DDT, diazinon, and MCPA. What concentrations of these pesticides are unacceptable in water systems?

Section Review

1. I Ammonium chloride, NH_4Cl, is a very soluble salt. 300 g of ammonium chloride are dissolved in 600 mL of water. What is the percent (m/m) of the solution?
2. I A researcher measures 85.1 mL of a solution of liquid hydrocarbons. The researcher then distills the sample to separate the pure liquids. If 20.3 mL of the hydrocarbon hexane are recovered, what is its percent (v/v) in the sample?
3. I A stock solution of phosphoric acid is 85.0% (m/v) H_3PO_4 in water. What is its molar concentration?
4. MC Cytosol is an intracellular solution containing many important solutes. Research this solution. Write a paragraph describing the function of cytosol, and the solutes it contains.