SECTION 8.3

Concentrations of Solutions

Benzoic acid, $C_6H_5COOH(s)$, is commonly used as a food preservative and as an ingredient in cosmetics, germicides, and medications for treating fungus infections. It occurs naturally in cranberries, such as the ones shown in **Figure 8.16**, and in most other types of berries. However, benzoic acid is moderately toxic. If too large a quantity is consumed, it causes abdominal pain, nausea, and vomiting. When benzoic acid is added to food, the mass is typically no more than 0.1 percent of the mass of the food. The World Health Organization recommends that people limit their daily consumption of benzoic acid to 5 mg per kilogram of body mass.

Benzoic acid is not the only chemical that can be dangerous if the *concentration* is too great. The proportions of many chemicals in food, medicines, and the body often determine whether the chemicals are harmful or beneficial.

Concentration is the quantity of solute per unit quantity of solution or unit quantity of solvent. This section describes several of the most commonly used measures of concentration. All of these measures express concentration in terms of unit quantities of solution.

Key Terms

concentration
concentrated
dilute
percent (m/v)
percent (m/m)
percent (v/v)
parts per million (ppm)
parts per billion (ppb)
molar concentration

concentration the ratio of the quantity of solute to the quantity of solvent or the quantity of solution

Figure 8.16 The cranberry is a North American fruit. Aboriginal peoples mixed cranberries with ground meat. The benzoic acid in the berries preserved the meat and allowed it to be stored for a long time. The concentration of benzoic acid was high enough to be toxic to micro-organisms, but not high enough to be toxic to humans.

Expressing Concentration

Qualitatively, a solution can be described as **concentrated** or **dilute**. A concentrated solution contains many particles of solute per unit quantity of solution, whereas a dilute solution contains relatively few solute particles. Concentration is a *ratio* of the quantity of solute to the quantity of solution. A concentrated solution contains a high ratio of solute to solution, whereas a dilute solution contains a low ratio of solute to solution.

Most calculations that involve solutions require quantitative measures of concentration. These measures enable you to compare the concentrations of different solutions and to find the amount of a substance in a given volume of solution. The simplest quantitative measures of concentration are stated as a quantity of solute per unit quantity of solution. For example, a solution with a concentration of 10 g of solute per litre of solution is clearly a bit more dilute than a solution with a concentration of 11 g of the same solute per litre of solution.

concentrated having a high ratio of solute to solution

dilute having a low ratio of solute to solution

Calculating Percent Concentrations

Ratios of solute to solution are commonly expressed as percents. These measures of concentration are referred to as *percent concentrations*. Each percent concentration is a ratio multiplied by 100. These ratios always refer to the *solution as a whole*—they are not ratios of solute to solvent.

There are three common methods for expressing percent concentration:

- mass/volume percent, or percent (m/v)
- mass percent, or percent (m/m)
- volume percent, or percent (v/v)

Mass/Volume Percent

percent (m/v) a ratio of the mass of solute to the volume of solution, expressed as a percent

A mass/volume percent, or **percent (m/v)**, expresses the mass of solute dissolved in a volume of *solution* as a percent:

$$\text{percent (m/v)} = \frac{\text{mass of solute [in grams]}}{\text{volume of solution [in millilitres]}} \times 100\%$$

This formula expresses the concentration of a solution as a percentage relative to a concentration of 1 g/mL. The units for percent (m/v) concentration are % g/mL, but these units are usually not indicated. The notation "% (m/v)" is used instead. The Sample Problem below demonstrates how to calculate a percent (m/v) concentration.

Sample Problem

Finding Percent (m/v) Concentration

Problem

An intravenous solution for a patient was prepared by dissolving 17.5 g of glucose in distilled water to make 350 mL of solution. Find the percent (m/v) concentration of the solution. (Treat the zero in 350 mL as a significant figure.)

What Is Required?

You need to calculate the percent (m/v) concentration.

What Is Given?

You know the mass of the dissolved solute: 17.5 g
You know the volume of the solution: 350 mL

Plan Your Strategy	Act on Your Strategy
Write the formula for percent (m/v) concentration.	$\text{percent (m/v)} = \frac{\text{mass of solute [in grams]}}{\text{volume of solution [in millilitres]}} \times 100\%$
Substitute the given data to calculate the concentration.	$\text{percent (m/v)} = \frac{17.5\text{ g}}{350\text{ mL}} \times 100\% = 5.00\%$ The concentration of glucose in the intravenous solution was 5.00% (m/v).

Check Your Solution

The answer appears reasonable since the number of grams of solute is much less than the number of millilitres of solution. The answer is a percent and has three significant digits, the same as the given information.

Sample Problem

Using Percent (m/v) Concentration to Find Mass

Problem

Sucrose sugar syrups can have percent concentrations that are greater than 100% (m/v). Find the mass of sucrose in 475 mL of 166% (m/v) sugar syrup.

What Is Required?

You need to calculate the mass of sucrose.

What Is Given?

You know the concentration of the solution: 166% (m/v)
You know the volume of the solution: 475 mL

Plan Your Strategy	Act on Your Strategy
Write the formula for percent (m/v) concentration.	$\text{percent (m/v)} = \dfrac{\text{mass of solute [in grams]}}{\text{volume of solution [in millilitres]}} \times 100\%$
Rearrange the formula to solve for the mass of solute.	$\dfrac{\text{percent (m/v)}}{100\%} = \dfrac{\text{mass of solute [in grams]}}{\text{volume of solution [in millilitres]}}$ $\text{mass of solute [in grams]} = \dfrac{\text{percent (m/v)}}{100\%} \times \text{volume of solution [in millilitres]}$
Substitute the known values to calculate the mass of sucrose, *m*.	$m = \dfrac{166\cancel{\%}\ \text{g/}\cancel{\text{mL}}}{100\cancel{\%}} \times 475\ \cancel{\text{mL}} = 788\ \text{g}$ The mass of sucrose in the sugar syrup is 788 g.

Check Your Solution

The mass in grams of solute is greater than the volume in millilitres of solvent, which is reasonable since the concentration is greater than 100% (m/v). The answer has three significant digits, the same as the given information.

Practice Problems

1. A pharmacist adds 20.0 mL of distilled water to 30.0 g of a powdered medicine. The volume of the solution formed is 25.0 mL. What is the percent (m/v) concentration of the solution?
2. A solution contains 21.4 g of sodium nitrate, $NaNO_3(s)$, dissolved in 250 mL of solution. Find the percent (m/v) concentration of the solution.
3. A chemist slowly evaporated 1.80 L of a 1.75% (m/v) solution of calcium nitrate, $Ca(NO_3)_2(aq)$. What mass of solute should the chemist obtain?
4. What mass of potassium permanganate must be dissolved to make 2.0 L of a 4.0% (m/v) solution?
5. A chemist measured 25.00 g of water and bubbled hydrogen chloride gas into the water. The resulting solution had a mass of 26.68 g and a volume of 25.2 mL. Determine the percent (m/v) concentration of the solution.
6. A student carefully evaporated all the water from an 80.0 mL salt solution. She found that the mass of the residue from the sample was 1.40 g. Calculate the percent (m/v) concentration of the salt solution.
7. A household bleach has a concentration of 4.60% (m/v) of sodium hypochlorite, NaOCl(aq). What mass of sodium hypochlorite does a 2.84 L container of this bleach contain?
8. Ringer's solution contains 0.86% (m/v) NaCl(aq), 0.03% (m/v) KCl(aq), and 0.033% (m/v) $CaCl_2(aq)$. Calculate the mass of each of these compounds in a 300 mL bag of Ringer's solution.
9. What volume of 5.0% (m/v) solution of sodium chloride, NaCl(aq), can be made using 40 g of NaCl(s)?
10. How would you prepare 400 mL of a 3.5% (m/v) solution of sodium acetate?

Mass Percent

percent (m/m) a ratio of mass of solute to mass of solution, expressed as a percent

The concentration of a solution that contains a solid solute dissolved in a liquid solvent can be expressed as a percent ratio of the mass of the solute to the mass of the solution. This method for expressing concentration is called mass percent, or **percent (m/m)**.

To calculate the percent, the masses of the solute and solution must be expressed in the same units.

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

Mass percent values are sometimes referred to as *weight/weight* or *(w/w) percents*. If you see a concentration expressed as percent (w/w), treat it as percent (m/m).

The concentration of a solid solution is usually expressed as a mass percent. For example, sterling silver consists of 92.5% silver and 7.5% copper (or sometimes a mixture of copper and other metals), where the percents are mass ratios. Sterling silver that is made with 7.5% copper could be described as a 7.5% (m/m) solution of copper dissolved in silver. Stainless steel, shown in **Figure 8.17**, is a solution of chromium and nickel dissolved in iron. Solid solutions of two or more metals, such as sterling silver or stainless steel, are often called *alloys*. The Sample Problem below demonstrates a calculation using percent (m/m) concentration.

Figure 8.17 Cooking pans are often made with 18/8 stainless steel, which contains 18% (m/m) chromium and 8% (m/m) nickel in iron.
Explain *Why is iron considered to be the solvent in stainless steel?*

Sample Problem

Using Percent (m/m) Concentration to Find Mass

Problem

Find the mass of pure silver in a sterling silver ring that has a mass of 6.45 g.

What Is Required?

You need to find the mass of pure silver in the ring.

What Is Given?

You know the mass of the ring: 6.45 g
You know the concentration of silver in sterling silver alloys: 92.5% (m/m)

Plan Your Strategy	Act on Your Strategy
Write the formula for percent (m/m).	$\text{percent (m/m)} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$
Rearrange the equation to solve for the mass of solute.	$\text{percent (m/m)} \times \text{mass of solution} = \text{mass of solute} \times 100\%$ $\text{mass of solute} = \frac{\text{percent (m/m)} \times \text{mass of solution}}{100\%}$
Substitute the given data to find the mass of silver.	$\text{mass of solute} = \frac{92.5\cancel{\%} \times 6.45\text{ g}}{100\cancel{\%}} = 5.97\text{ g}$ The mass of pure silver in the ring is 5.97 g.

Check Your Solution

The answer is reasonable because the mass of silver is close to the mass of the ring.

Practice Problems

11. Calculate the percent (m/m) concentration of a solution that contains 11 g of pure sodium hydroxide in 75 g of solution.

12. A physiotherapist makes a footbath solution by dissolving 120 g of magnesium sulfate (Epsom salts), $MgSO_4$(s), in 3.00 kg of water. Calculate the percent (m/m) of magnesium sulfate in the solution. (**Hint**: Remember to use the mass of *solution*.)

13. How much chromium, nickel, and iron would you need to make a 500 kg batch of 18/8 stainless steel, which is steel made with 18% (m/m) chromium and 8% (m/m) nickel in iron?

14. When evaporated, a sample of a solution of silver nitrate, $AgNO_3$(aq), leaves a residue with a mass of 3.47 g. The original sample had a mass of 43.88 g. Calculate the percent (m/m) concentration of the silver nitrate solution.

15. A solution is made by dissolving 12.9 g of carbon tetrachloride, $CCl_4(\ell)$, in 72.5 g of benzene, $C_6H_6(\ell)$. Calculate the percent (m/m) concentration of carbon tetrachloride in the solution.

16. Since pure gold is quite soft, gold jewellery is usually made with an alloy. An 18 karat gold alloy contains 75% (m/m) gold. How much of this alloy can a jeweller make with 8.00 g of pure gold?

17. Surgical steel is an iron alloy that is easy to clean and sterilize. It contains 12 to 14% (m/m) chromium. Calculate the minimum mass of chromium in a 40 g instrument made from surgical steel.

18. Pure iron is a relatively soft metal. Adding carbon to iron makes a type of steel that is much stronger than pure iron. Calculate the percent (m/m) concentration of carbon in a 5.0 kg steel bar that contains 85 g of carbon.

19. A technician who was monitoring the health of a lake analyzed a sample of water from the lake. The sample had a mass of 155 g and contained 1.12 mg of dissolved oxygen. Calculate the percent (m/m) concentration of oxygen in the sample.

20. A mining company in Sudbury reported mining 6.91×10^5 t of ore, from which it extracted 1.68×10^3 t of nickel, 1.6×10^4 t of copper, and 1.6 t of platinum. What is the percent (m/m) concentration of each metal in the ore?

Volume Percent

When two liquids are mixed to form a solution, it is easier to measure their volumes than their masses. Volume percent, or **percent (v/v)**, is the ratio of the volume of solute to the volume of solution, expressed as a percent:

percent (v/v) a ratio of the volume of solute to the volume of solution, expressed as a percent

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

Solutions that are sold in pharmacies and hardware stores are often labelled with volume percent concentrations, as shown in **Figure 8.18**. The next Sample Problem demonstrates a calculation using percent (v/v) concentration. When doing these calculations, the volumes used must have the same units. Note that the volume of solution produced by dissolving one liquid in another is usually not equal to the sum of the volumes of the two separate liquids.

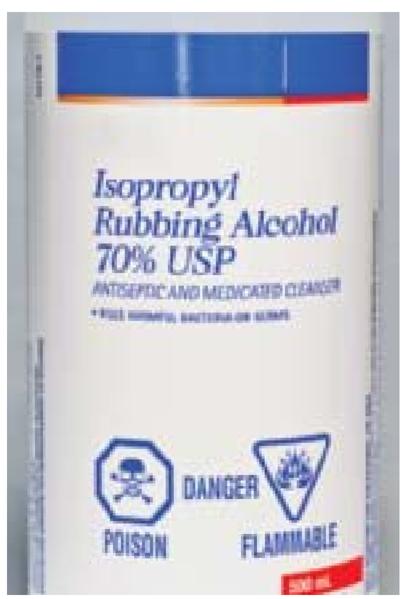


Figure 8.18 This bottle of rubbing alcohol is 70% (v/v) isopropyl alcohol, $C_3H_8O(\ell)$. USP stands for *United States Pharmacopeia*, which is a document that establishes medicine standards in the United States, Canada, and other countries.

Sample Problem

Using Percent (v/v) Concentration to Find Volume

Problem

Acetic acid, $CH_3COOH(\ell)$, is a liquid at room temperature. How much pure water should be added to 15.0 mL of pure acetic acid to make a 5.00% (v/v) solution of acetic acid? Assume that the total volume of the solution equals the sum of the volumes of the water and the acetic acid.

What Is Required?

You need to calculate the volume of the solvent, water.

What Is Given?

You know the concentration of the acetic acid: 5.00% (v/v); You know the volume of the solute: 15.0 mL

Plan Your Strategy	Act on Your Strategy
Write the formula for percent (v/v).	$\text{percent (v/v)} = \dfrac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$
Rearrange the equation to solve for the volume of the solution.	$\text{percent (v/v)} \times \text{volume of solution} = \text{volume of solute} \times 100\%$ $\text{volume of solution} = \dfrac{\text{volume of solute} \times 100\%}{\text{percent (v/v)}}$
Substitute the given data, and calculate the volume of the solution.	$\text{volume of solution} = \dfrac{15.0\text{ mL} \times 100\cancel{\%}}{5.00\cancel{\%}} = 300\text{ mL}$
Subtract the volume of the solute from the volume of the solution.	volume of solvent = 300 mL – 15.0 mL = 285 mL Thus, 285 mL of pure water should be added to make a 5.00% (v/v) solution.

Check Your Solution

The answer is reasonable. The volume of water that should be added is less than the volume of the solution, but much more than the volume of the acetic acid. The answer has three significant digits, the same as the given information.

Practice Problems

21. The rubbing alcohol that is sold in pharmacies is usually a 70% (v/v) aqueous solution of isopropyl alcohol. What volume of isopropyl alcohol is present in a 500 mL bottle of this solution?

22. If 80 mL of ethanol is diluted with water to a final volume of 500 mL, what is the percent (v/v) concentration of ethanol in the solution?

23. A particular brand of windshield washer fluid contains 40% (v/v) methanol. How much pure methanol does a 4.0 L container of this fluid contain?

24. A concentrated solution of engine coolant contains 75% (v/v) ethylene glycol in water. The label tells consumers to use a 1:1 mixture of the concentrate with water in their cars. Determine the approximate volume of pure ethylene glycol in an automotive cooling system that contains 6.0 L of the diluted solution.

25. Describe how to prepare a 5.00% (v/v) solution with 50.0 mL of pure ethylene glycol.

26. Gasoline sold in Ontario must contain at least 5.0% (v/v) ethanol. How much ethanol is a driver likely to get when buying 30 L of gasoline?

27. A vending machine mixes a liquid flavour concentrate with water in a ratio of 1:10 to make coffee. Determine the percent (v/v) concentration of the flavour concentrate in the drink.

28. Your teacher has 4.0 L of a 15% (v/v) solution of sulfuric acid in water. What will the volume of the solution be if it is diluted to 10% (v/v)?

29. Two concentrations of the same cleaning chemical are mixed: 6.0 L of a 75% (v/v) solution and 14.0 L of a 25% (v/v) solution. What is the concentration of the resulting solution?

30. You need 125 mL of white vinegar, which has a concentration of 5.0% (v/v) of acetic acid. You are out of white vinegar. However, you do have pickling vinegar with a concentration of 8.5% (v/v) of acetic acid. How much pickling vinegar should you dilute to substitute for the white vinegar?

Very Small Concentrations

Very dilute solutions have concentrations that are much less than 1% (m/m). For such solutions, it is often convenient to express concentrations in terms of **parts per million (ppm)** or **parts per billion (ppb)**. A concentration of 1 ppb is extremely dilute. For example, one part per billion of water in a full swimming pool that is 10 m long, 5 m wide, and 2 m deep is only 0.1 mL. However, there are some chemicals that can have serious health effects at a concentration of 1 ppb.

Both parts per million and parts per billion are fractions, with the mass of the solute divided by the mass of the *solution*:

parts per million (ppm) a ratio of solute to solution $\times 10^6$

parts per billion (ppb) a ratio of solute to solution $\times 10^9$

Parts per million

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

Parts per billion

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

Sample Problem

Calculating Concentration in ppm

Problem

Health Canada's guideline for the maximum mercury content in commercial fish is 0.5 parts per million (ppm). When a 1.6 kg salmon was tested, it was found to contain 0.6 mg of mercury. Would this salmon be safe to eat?

What Is Required?

You need to find the concentration of mercury in the salmon, in parts per million, and then determine if this concentration is less than Health Canada's guideline.

What Is Given?

You know the allowable level of mercury: 0.5 ppm
You know the mass of the salmon: 1.6 kg
You know the amount of mercury in the salmon: 0.6 mg

Plan Your Strategy	Act on Your Strategy
Write the formula for ppm.	$\text{ppm} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^6$
Substitute the given data. Express both masses in grams so that you can cancel the units.	$\text{ppm} = \frac{0.6\text{ mg}}{1.6\text{ kg}} \times 10^6 = \frac{6 \times 10^{-4}\text{ g}}{1.6 \times 10^3\text{ g}} \times 10^6 = 0.4$
Compare the calculated concentration to Heath Canada's guideline.	The concentration of mercury is 0.4 ppm, which is less than the maximum in the guideline. Therefore, the salmon would be safe to eat.

Check Your Solution

The answer appears to be reasonable. The units divided correctly, and the answer has one significant digit, the same as the number of significant digits in the mass of mercury.

Practice Problems

31. A sample of lake water has a mass of 310 g and contains 2.24 mg of dissolved oxygen. Calculate the oxygen concentration in parts per million.

32. The agricultural use of the pesticide DDT has been banned in Canada since 1969 because of its effect on wildlife. In 1967, the average concentration of DDT in trout taken from Lake Simcoe, in Ontario, was 16 ppm. Today, the average concentration is less than 1 ppm. What mass of DDT is present in a 2.2 kg smallmouth bass contaminated with 16 ppm of DDT?

33. Dry air contains about 0.000 07% (m/m) helium. Express this concentration in parts per million.

34. A fungus that grows on peanuts produces aflatoxin, a potentially deadly toxin. A quality control inspector tests a 100 g sample from a shipment of peanuts to check that it contains no more than 25 ppb of aflatoxin. What mass of aflatoxin would the sample contain if the concentration is 25 ppb?

35. A sample of water contains one atom of lead for every million water molecules. Calculate the concentration of lead, in parts per million, in this sample.

36. The concentration of chlorine in swimming pools is generally kept in the range from 1.4 to 4.0 mg/L. A pool contains 3.0 ppm of chlorine. Is this concentration within the acceptable range? Show your work, and explain your reasoning. (**Hint:** 1 L of water has a mass of 1 kg.)

37. Water supplies that contain more than 500 ppm of dissolved calcium carbonate, $CaCO_3(aq)$, are considered unacceptable for most domestic purposes. What is the maximum mass of calcium carbonate that would be acceptable in a 250 mL sample of tap water?

38. Since 1991, house paint produced in Canada must contain less than 600 ppm of lead. What is the maximum mass of lead permitted in a can that contains 7.0 kg of paint?

39. Cadmium is a highly toxic metal. The average level of cadmium in the blood of Canadians is about 0.35 ppb. At this level, what mass of cadmium would be present in 1.5 kg of blood?

40. Find the concentration, in parts per million, of a solution that contains 0.1 g of solute per litre.

Molar Concentration

molar concentration the amount (in moles) of solute dissolved in 1 L of solution

Percent concentrations are easy to determine from simple mass and volume measurements. However, calculations for reactions often involve the amount (in moles) of reactants and products. For this reason, a measure of concentration based on the amount of solute is particularly useful. **Molar concentration** (or *molarity*) is the amount (in moles) of solute dissolved in 1 L of *solution*.

$$\text{molar concentration} = \frac{\text{amount of solute [in moles]}}{\text{volume of solution [in litres]}}$$

The symbol for molar concentration is *c*. Thus, the formula for molar concentration can be written as

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

where n is the amount of solute in moles, and V is the volume of solution in litres. The units for molar concentration are moles per litre (mol/L).

In the past, the symbol "M" was often used for mol/L. However, IUPAC and other international standards recommend writing "mol/L" for clarity. The symbol M is used for other quantities. Writing "mol/L" also helps you check the units when you perform a calculation.

Molar concentration is especially useful to chemists because it is directly related to the number of solute particles in a solution. Given the molar concentration and volume of a solution, you can easily find the amount (in moles) of dissolved solute. Molar concentrations are the most convenient form for stoichiometry calculations that involve reactions in solutions, as you will see in **Chapters 9** and **10**.

Molar Concentrations of Ions

An extra step is often needed for calculations of the concentrations of ions when an ionic compound dissolves in water. A solution of sodium chloride contains the same amount of sodium and chloride ions because NaCl(aq) dissociates to give equal numbers of these ions:

$$NaCl(aq) \longrightarrow Na^{+}(aq) + Cl^{-}(aq)$$

However, a solution of calcium chloride has twice as many chloride ions as calcium ions:

$$CaCl_2(aq) \longrightarrow Ca^{2+}(aq) + 2Cl^{-}(aq)$$

Thus, the molar concentration of chloride ions is twice the molar concentration of calcium ions. You can use the chemical formula of an ionic substance to determine the numbers of ions formed and the ratio of the molar concentrations of the different ions. The analogy shown in **Figure 8.19** will help you visualize the dissociation of ionic compounds that contain more than one ion of the same type.

Figure 8.19 A bicycle contains two wheels, just as each formula unit of magnesium chloride contains two chloride ions.

***Describe** another object with components that can be separated in the same ratio as the ions in magnesium chloride.*

Sample Problem

Calculating Molar Concentrations

Problem

A student dissolved 0.212 mol of iron(III) chloride, $FeCl_3(s)$, to make a 175 mL solution. Find the molar concentration of the solution and the concentrations of the ions in the solution.

What Is Required?

You need to calculate the concentration of iron(III) chloride.
You must also determine the concentration of iron(III) ions and chloride ions.

What Is Given?

You know the amount of iron(III) chloride in the sample: 0.212 mol
You know the volume of the solution: 175 mL

Plan Your Strategy	Act on Your Strategy
Write the formula for molar concentration and substitute the known values to find the molar concentration of iron(III) chloride.	$c = \frac{n}{V} = \frac{0.212 \text{ mol}}{175 \text{ mL}} = \frac{0.212 \text{ mol}}{0.175 \text{ L}} = 1.2114 \text{ mol/L}$
Write the chemical equation for the dissociation of iron(III) chloride.	$FeCl_3(aq) \longrightarrow Fe^{3+}(aq) + 3Cl^{-}(aq)$
Use the coefficients in the chemical equation to find the molar concentrations of the ions.	$c_{Fe^{3+}} = \frac{1.2114 \text{ } \cancel{\text{mol FeCl}_3}}{\text{L}} \times \frac{1 \text{ mol Fe}^{3+}}{1 \text{ } \cancel{\text{mol FeCl}_3}} = 1.21 \text{ mol/L Fe}^{3+}$ $c_{Cl^-} = \frac{1.2114 \text{ } \cancel{\text{mol FeCl}_3}}{\text{L}} \times \frac{3 \text{ mol Cl}^-}{1 \text{ } \cancel{\text{mol FeCl}_3}} = 3.63 \text{ mol/L Cl}^-$ The concentrations of $FeCl_3(aq)$ and $Fe^{3+}(aq)$ are both 1.21 mol/L, and the concentration of $Cl^{-}(aq)$ is 3.63 mol/L.

Check Your Solution

The concentration of iron(III) chloride has the correct units and significant digits. The concentration of chloride ions is three times the concentration of iron(III) ions, which reflects the formula $FeCl_3$.

Sample Problem

Calculating Mass from Molar Concentration

Problem

To replace lost fluids and electrolytes, patients often receive an infusion of an intravenous solution immediately after surgery. The most commonly used intravenous solution, normal saline, contains 0.154 mol/L of sodium chloride, NaCl(aq). This concentration is close to the concentration that is normally found in the bloodstream. However, for some patients, the intake of sodium must be carefully monitored. Calculate the mass of sodium in a 500 mL bag of normal saline solution. Assume that the volume of the solution is accurate to three significant figures.

What Is Required?

You need to calculate the mass of sodium in the bag of solution.

What Is Given?

You know the molar concentration of sodium chloride: 0.154 mol/L
You know the volume of the solution: 500 mL
You know the molar mass of sodium according to the periodic table: 22.99 g/mol

Plan Your Strategy	Act on Your Strategy
Determine the molar concentration of sodium ions in the solution.	The chemical formula is NaCl. There is 1 mol of Na^{+}(aq) for each mole of NaCl(aq). Therefore, the concentration of sodium ions is 0.154 mol/L.
Rearrange the concentration formula to isolate *n*, the amount of sodium.	$c = \frac{n}{V}$ $n = cV$
Substitute the known values to calculate *n*.	$n = (0.154\ \text{mol}/\cancel{\text{L}})(0.500\ \cancel{\text{L}})$ $= 0.0770\ \text{mol}$
Write the formula to find the mass of sodium in the solution.	$m = nM$ *M* is the molar mass of sodium.
Look up the molar mass of sodium.	$M = 22.99\ \text{g/mol}$
Calculate the mass, *m*, of sodium in the solution.	$m = nM$ $= (0.0770\ \cancel{\text{mol}})(22.99\ \text{g}/\cancel{\text{mol}})$ $= 1.77\ \text{g}$ The mass of sodium in a 500 mL bag of normal saline solution is 1.77 g.

Check Your Solution

The mass is reasonable because 0.154 mol/L is a low concentration, so the mass of solute in solution should be a small amount. The units are correct because the question asked to find a mass, and grams is a unit of mass. The number of significant digits is correct because values given in the problem each have three significant digits.

Practice Problems

41. Find the molar concentration of each saline solution.
  a. 0.60 mol NaCl(s) dissolved in 0.40 L of solution
  b. 0.90 g NaCl(s) dissolved in 100 mL of solution

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

43. Calculate the molar concentration of each solution.
  a. 14 g of copper(II) sulfate, $CuSO_4(s)$, dissolved in 70 mL of solution
  b. 5.07 g of sucrose, $C_{12}H_{22}O_{11}(s)$, dissolved in 23.6 mL of solution
  c. 1.1 g of calcium nitrate, $Ca(NO_3)_2(s)$, dissolved in 70 mL of solution

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

45. Find the mass of solute in each aqueous solution.
  a. 28 mL of 0.045 mol/L calcium hydroxide, $Ca(OH)_2(aq)$
  b. 50 mL of 4.0 mol/L acetic acid, $CH_3COOH(aq)$
  c. 5.31 L of 0.675 mol/L ammonium phosphate, $(NH_4)_3PO_4(aq)$

46. Calculate the molar concentrations of the ions in each solution.
  a. 18 g of sodium sulfate, $Na_2SO_4(s)$, dissolved in 210 mL of solution
  b. 15 g of ammonium phosphate, $(NH_4)_3PO_4(s)$, dissolved in 98 mL of solution
  c. 20 mg of calcium phosphate, $Ca_3(PO_4)_2(s)$, dissolved in 1.7 L of solution

47. A student dissolves 28.46 g of silver nitrate, $AgNO_3(s)$, in water to make 580 mL of solution. Find the molar concentration of the solution.

48. Formalin is an aqueous solution that is made by dissolving formaldehyde gas, HCHO(g), in water. A saturated formalin solution has a concentration of about 37% (m/v). This concentration is used to preserve biological specimens. Calculate the molar concentration of 37% (m/v) formalin.

49. What volume of a 0.555 mol/L aqueous solution contains 12.8 g of sodium carbonate, $Na_2CO_3(aq)$?

50. Zinc oxide, ZnO(s), has a solubility of 0.16 mg/100 mL in water at 30°C. Find the molar concentration of a saturated solution of zinc oxide at 30°C.

Different Measures for Different Solutions

Table 8.6 summarizes various ways that concentration can be measured. In the next section, you will find out how to prepare a solution with a specific concentration.

Suggested Investigation

Plan Your Own Investigation 8-C, Determining the Concentration of a Solution

Table 8.6 Measures of Concentration

Type of Concentration	Formula	Common Application
Concentration as a Percent • mass/volume percent	$\text{percent (m/v)} = \frac{\text{mass of solute [in grams]}}{\text{volume of solution [in millilitres]}} \times 100\%$	• intravenous solutions, such as a saline drip
• mass percent	$\text{percent (m/m)} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$	• concentration of metals in an alloy
• volume percent	$\text{percent (v/v)} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$	• solutions prepared by mixing liquids
Very Small Concentrations • parts per million	$\text{ppm} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^6$	• safety limits for contaminants, such as mercury or lead in food or water
• parts per billion	$\text{ppb} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^9$	
Molar Concentration	$\text{molar concentration} = \frac{\text{amount of solute [in moles]}}{\text{volume of solution [in litres]}}$ $c = \frac{n}{V}$	• solutions used as reactants

Section 8.3 REVIEW

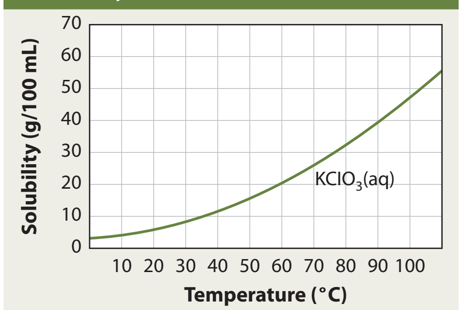
Section Summary

- The concentration of a solution can be stated in terms of the ratio of the volumes or masses of the solute and the solution, using percent (m/v), percent (m/m), or percent (v/v).
- Small concentrations can be expressed as parts per million (ppm) or parts per billion (ppb).
- Molar concentration is calculated by dividing moles of solute by litres of solution.

Review Questions

1. **C** Use diagrams to explain the difference between a concentrated solution and a dilute solution.
2. **C** Use a Venn diagram to compare the terms "solubility" and "concentration."
3. **T/I** A 50 g sample of seawater is found to contain 0.02 g of sodium chloride.
   a. State the concentration of sodium as a mass percent.
   b. Express the concentration of sodium in parts per million.
4. **T/I** Calcium carbonate, $CaCO_3(aq)$, may be naturally present in household water supplies. Suppose that a toilet tank holds 6.0 L of water, and the water contains 90 ppm of calcium carbonate. What mass of calcium carbonate is in the water in the tank?
5. **A** Aldrin and dieldrin are pesticides that used to be allowed for the control of soil insects. In Ontario, the maximum allowable total concentration of aldrin plus dieldrin in drinking water is 0.7 ppb. If a 250 mL sample of drinking water is found to contain 0.0001 mg of aldrin and dieldrin, does the concentration exceed the standard? Explain.
6. **T/I** A researcher distilled an 85.1 mL sample of a solution of liquid hydrocarbons. The distillation process separated out 20.3 mL of hexane. Find the percent (v/v) concentration of hexane in the solution.
7. **T/I** Phosphoric acid, $H_3PO_4(aq)$, can be used to remove rust. Find the molar concentration of an 85% (m/v) solution of phosphoric acid in water.
8. **A** The concentration of a certain ionic compound in aqueous solution is 0.186 mol/L. It is the only solute in the solution. The concentration of potassium ions in the same solution is 0.558 mol/L. Explain why the concentrations of ions in the solution are different. What might the ionic compound be?
9. **T/I** Since the Industrial Revolution, the atmospheric concentration of carbon dioxide has increased from 280 parts per million to 380 parts per million. The mass of Earth's atmosphere is estimated to be 5.3×10^{18} kg. What mass of carbon dioxide has been added to Earth's atmosphere?
10. **T/I** Use this solubility curve to help you determine the molar concentration of a saturated solution of potassium chlorate, $KClO_3(aq)$, at 30°C.

Solubility Curve for Potassium Chlorate



11. **A** The Canadian Ambient Air Quality Objective for ground-level ozone is 82 ppb. What is the maximum mass of ozone, $O_3(g)$, allowed per cubic metre of air? The density of air is 1.2 kg/m^3.
12. **T/I** One teaspoon of table salt is added to the water in a swimming pool. The swimming pool is 10 m long, 5.0 m wide, and 2.0 m deep. One teaspoon of table salt has a mass of 4.5 g. Calculate the concentration (in parts per billion) of table salt in the water. Assume 10 m has two significant digits.
13. **A** The concentration of dissolved iron(II) ions, $Fe^{2+}(aq)$, in a sample of ground water is 7.2×10^{-5} mol/L. Is this concentration an acceptable level if the recommended maximum level is 300 ppb? Show your work, and explain your reasoning.
14. **T/I** A pharmacist dilutes a 10% (m/v) saline solution until the final volume is four times the initial volume. Find the molar concentration of sodium chloride in the diluted solution.
15. **A** A researcher who was studying toxic algae measured the concentration of phytoplankton as 5×10^{-4}% (m/v). Phytoplankton are microscopic plants.
    a. Explain why phytoplankton suspended in seawater is not a solution.
    b. Discuss whether mass/volume concentration is a valid measure for mixtures that are not solutions.