Unit 3

Solutions and Solubility

"I take great joy in being a scientist, not least because I was diagnosed as an epileptic when I was just 15, in Grade 10. I had been told that because of the epilepsy I could never go to university, much less study science. However, I did succeed in science. Being an epileptic is one of the major reasons that I directed my research and studies in the direction that I did. In studying aqueous solutions, I was not dealing with chemicals that were explosive and dangerous to handle. My studies also fit my inclinations. I love to think in three dimensions and contemplate how crystals form from solutions, and also how they dissolve. As a university researcher, I have the freedom to study what I am interested in, whereas in an industrial position I would be told what to research. My current focus is on solutions formed from crystalline aluminum hydroxide, which is amphoteric (it can act as an acid or a base). In acid solutions, its chemistry is important for environmental reasons; in basic solutions it is important in the extraction of aluminum from ore."

Susan Bradley, Assistant Professor, Department of Chemistry, University of British Columbia

Overall Expectations

In this unit, you will be able to

- understand the properties of solutions, the concept of concentration, and the importance of water as a solvent;
- prepare, analyze, and react solutions using qualitative and quantitative methods;
- relate the scientific knowledge of solutions and solubility to a variety of technological, societal, and environmental examples, including water quality

Unit

3

Solutions and Solubility

Are You Ready?

Technical Skills and Safety

1. In this unit you will work with many different solutions.
   (a) What should you do immediately if some solution is spilled on your hand?
   (b) Draw or describe the WHMIS symbol for a corrosive substance.

Knowledge and Understanding

2. Copy and complete the classification scheme in **Figure 1**.

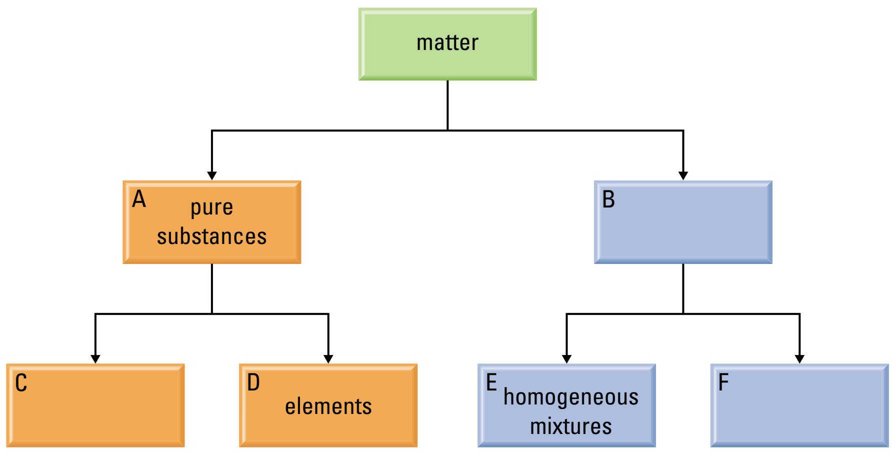


Figure 1
A classification of matter

3. Match each of the substances in **Table 1** to the classification categories illustrated in **Figure 1**.

Table 1

Substance	A or B	C or D or E or F
(a) vinegar		
(b) pure water		
(c) sulfur		
(d) air		
(e) milk		

4. Distinguish between ionic and molecular compounds based on their
   (a) chemical name or formula
   (b) empirical (observable) properties

5. In **Table 2**, match each term in Column A with its corresponding description in Column B.

Table 2

A		B	
(a)	compound	A.	Cannot be broken down into simpler substances
(b)	solution	B.	Contains two or more visible components
(c)	element	C.	Can be identified with a single chemical formula
(d)	heterogenous mixture	D.	A mixture of two or more pure substances with a single visible component

6. Write the missing words from the following statement in your notebook.

   According to modern atomic theory, an atom contains a number of positively charged __________, determined by the ______ _______ of the element, and an equal number of negatively charged __________.
7. Atoms of the representative elements form ions. Using calcium and fluorine as examples, draw electron dot diagrams showing atoms and ions.
8. Draw a diagram to illustrate the model of a small sample (a few particles) of
   (a) sodium chloride
   (b) water
9. What is the type of bond between the atoms of a water molecule? What are the types of bonds between the molecules of water in a sample?
10. Refer to the list of substances in **Table 3** to answer the following questions.
    (a) Which substances have London (dispersion) forces present between the molecules?
    (b) Classify each substance as polar or nonpolar.
    (c) Which substance would be expected to have hydrogen bonding as part of the intermolecular forces between the molecules?
    (d) Distinguish between intermolecular and intramolecular forces.

Table 3

Substance	Chemical formula	Use
propane	$C_3H_{8(g)}$	propane barbeques
ethanol	$C_2H_5OH_{(l)}$	in gasohol (gasoline-alcohol fuel)
dichloromethane	$CH_2Cl_{2(l)}$	paint stripper

11. According to the kinetic molecular theory, how does increasing temperature affect the speed of the particles that make up a substance?
12. Write balanced chemical equations, including states of matter at SATP, for reactions involving the following pairs of reactants.
    (a) aqueous iron(III) chloride and aqueous sodium hydroxide
    (b) aqueous silver nitrate and copper
    (c) sulfuric acid and aqueous potassium hydroxide
    (d) aqueous chlorine and aqueous sodium bromide
13. Classify each of the reactions in question 12 as a single or a double displacement reaction.
14. What does the coefficient represent in a chemical equation?
15. To dispose of a sodium sulfide solution, an excess of aqueous aluminum sulfate is added. What mass of precipitate can be obtained from a solution containing 12.5 g of sodium sulfide?

Chapter

6

The Nature and Properties of Solutions

In this chapter, you will be able to

- describe and explain the properties of water, and demonstrate an understanding of its importance as a universal solvent;
- explain the formation of solutions involving various solutes in water and nonpolar solutes in non-aqueous solvents;
- use the terms solute, solvent, solution, electrolyte, concentration, standard solution, stock solution, and dilution;
- solve solution concentration problems using a variety of units;
- develop the technological skills for the preparation of solutions;
- determine qualitative properties of solutions;
- provide examples of solutions involving all three states;
- provide consumer and commercial examples of solutions, including those in which the concentration must be precisely known;
- explain the origins of pollutants in natural water.

Is there such a thing as pure, natural water? Certainly it can't be found in the oceans. In Samuel Taylor Coleridge's classic poem, *The Rime of the Ancient Mariner*, written in 1798, an old seafarer describes the desperation of becalmed sailors, drifting without fresh water under the fierce sun, driven mad with thirst:

> *Water, water, everywhere,*
> *Nor any drop to drink.*

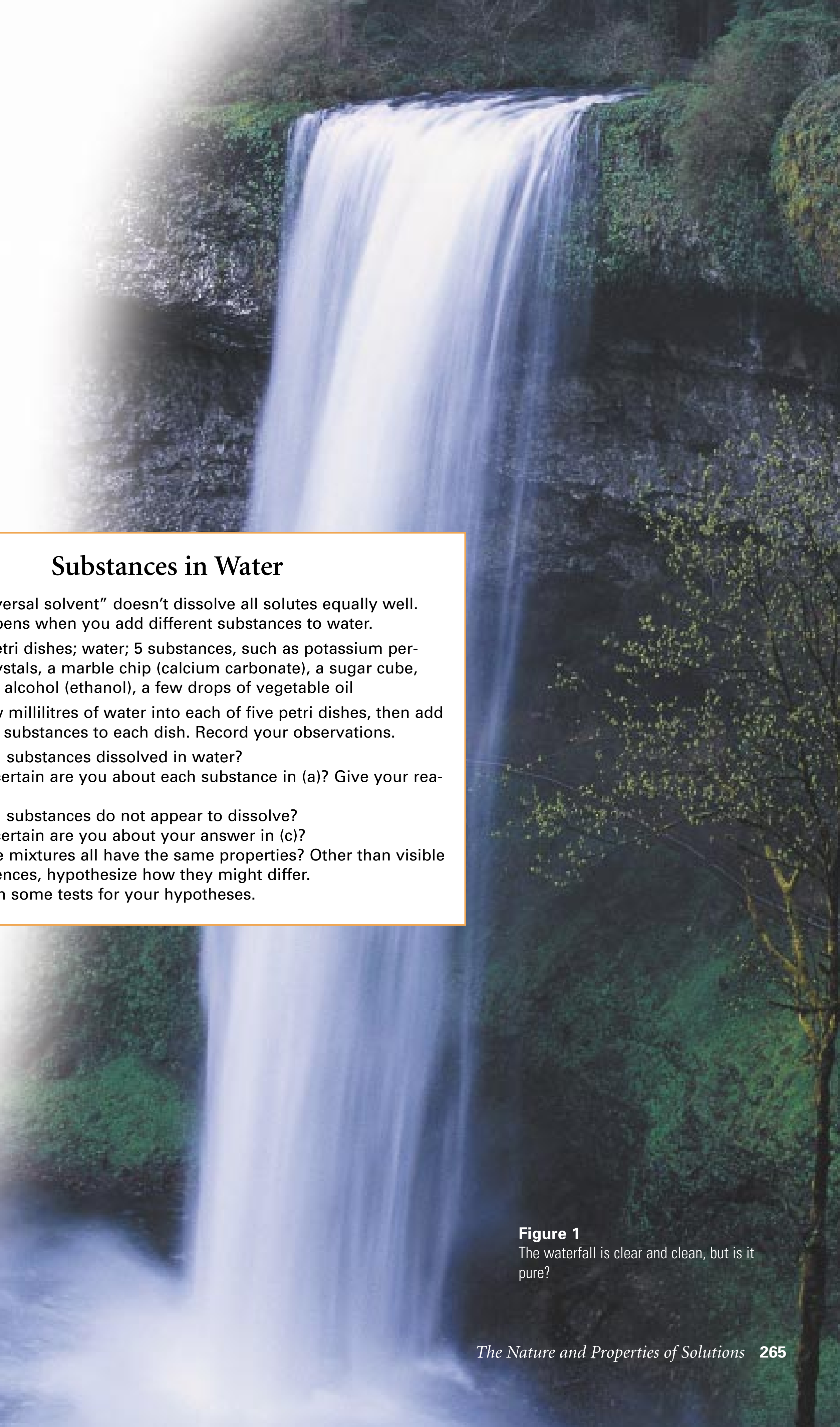
Drinking the water of the sea, which is rich in dissolved solutes, can be fatal. Today, seagoing ships carry distillation equipment to convert salt water into drinking water by removing most of those solutes.

Fresh water from lakes and rivers, which we depend on for drinking, cooking, irrigation, electric power generation, and recreation, is also impure. Even direct from a spring, fresh water is a solution that contains dissolved minerals and gases. So many substances dissolve in water that it has been called "the universal solvent." Many household products, including soft drinks, fruit juices, vinegar, cleaners, and medicines, are aqueous (water) solutions. ("Aqueous" comes from the Latin *aqua* for "water," as in aqueduct and aquatics.) Our blood plasma is mostly water, and many substances essential to life are dissolved in it, including glucose and carbon dioxide.

The ability of so many materials to dissolve in water also has some negative implications. Human activities have introduced thousands of unwanted substances into water supplies. These substances include paints, cleaners, industrial waste, insecticides, fertilizers, salt from highways, and other contaminants. Even the atmosphere is contaminated with gases produced when fossil fuels are burned. Rain, falling through these contaminants, may become acidic. Learning about aqueous solutions and the limits to purity will help you understand science-related social issues forming around the quality of our water.

Reflect on your Learning

1. (a) List some substances that can dissolve in water.
   (b) Classify the substances into two or more categories.
2. Are there any types of substances that generally do not dissolve in water? Why not?
3. Both table salt and table sugar dissolve in water to produce clear, colourless solutions. Using your present knowledge, what is similar in the formation of these two solutions? What is different?



Try This **Activity**

Substances in Water

Even the "universal solvent" doesn't dissolve all solutes equally well. See what happens when you add different substances to water.

Materials: 5 petri dishes; water; 5 substances, such as potassium permanganate crystals, a marble chip (calcium carbonate), a sugar cube, a few drops of alcohol (ethanol), a few drops of vegetable oil

- Pour a few millilitres of water into each of five petri dishes, then add one of the substances to each dish. Record your observations.
  - (a) Which substances dissolved in water?
  - (b) How certain are you about each substance in (a)? Give your reasons.
  - (c) Which substances do not appear to dissolve?
  - (d) How certain are you about your answer in (c)?
  - (e) Do the mixtures all have the same properties? Other than visible differences, hypothesize how they might differ.
  - (f) Design some tests for your hypotheses.

Figure 1
The waterfall is clear and clean, but is it pure?

DID YOU KNOW ?

Misleading Labelling

Milk is sometimes labelled as "homogenized," meaning that the cream is equally distributed throughout the milk. This use of the word does not match the chemistry definition of homogeneous. Using the strict chemistry definition, milk is not a homogeneous mixture, but a heterogeneous mixture. Milk is not a solution.

6.1 Defining a Solution

Many of the substances that we use every day come packaged with water. We buy other substances with little or no water, but then mix water with them before use. For example, we may purchase syrup, household ammonia, and pop with water already added, but we mix baking soda, salt, sugar, and powdered drinks with water. Most of the chemical reactions that you see in high school occur in a water environment. Indeed, most of the chemical reactions necessary for life on our planet occur in water.

Because so many substances dissolve in it, water is often referred to as the universal solvent. Of course, this is an exaggeration. Not all things dissolve in water. Imagine if they did; we would not be able to find a container for water.

Before restricting our study to mixtures involving water, we will review the more general definition and types of a solution.

Solutions

solution: a homogeneous mixture of substances composed of at least one solute and one solvent

homogeneous mixture: a uniform mixture of only one phase

solute: a substance that is dissolved in a solvent (e.g., salt, NaCl)

solvent: the medium in which a solute is dissolved; often the liquid component of a solution (e.g., water)

Solutions are **homogeneous mixtures** of substances composed of at least one **solute** and one **solvent**. Liquid-state and gas-state solutions are clear (transparent)—you can see through them; they are not cloudy or murky in appearance. Solutions may be coloured or colourless. Opaque or translucent (cloudy) mixtures, such as milk, contain undissolved particles large enough to block or scatter light waves. These mixtures are considered to be heterogeneous.

It is not immediately obvious whether a clear substance is pure or is a mixture, but it is certainly homogeneous. Homogeneous mixtures in the liquid state and the gas state are always clear with only one phase present. If you were to do a chemical analysis of a sample of a homogeneous mixture (i.e., a solution), you would find that the proportion of each chemical in the sample remains the same, regardless of how small the sample is. This is explained by the idea that there is a uniform mixture of particles (atoms, ions, and/or molecules) in a solution. Empirically, a solution is homogeneous; theoretically, it is uniform at the atomic and molecular level.

Both solutes and solvents may be gases, liquids, or solids, producing a number of different combinations (**Table 1**). In metal alloys, such as bronze or the mercury amalgam used in tooth fillings, the dissolving has taken place in liquid form before the solution is used in solid form. Common liquid solutions that have a solvent other than water include varnish, spray furniture polish, and gasoline. Gasoline, for example, is a mixture of as many as 400 different hydrocarbons and other compounds (**Figure 1**). These substances form a solution—a homogeneous mixture at the molecular level. There are many such hydrocarbon solutions, including kerosene (a Canadian-invented fuel for lamps and stoves), and turpentine (used for cleaning paintbrushes). Most greases and oils will dissolve in hydrocarbon solvents.

Table 1: Classification of Solutions

Solute in solvent	Example of solution
gas in gas	oxygen in nitrogen (in air)
gas in liquid	oxygen in water (in most water)
gas in solid	oxygen in solid water (in ice)
liquid in gas	water in air (humidity)
liquid in liquid	methanol in water (in antifreeze)
liquid in solid	mercury in silver (in tooth fillings)
solid in liquid	sugar in water (in syrup)
solid in solid	tin in copper (in bronze)

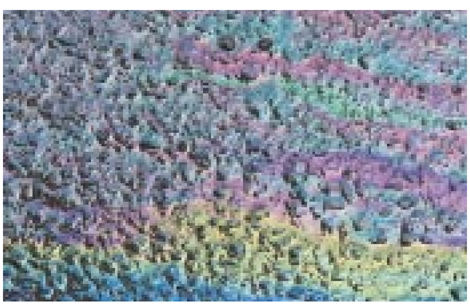


Figure 1
Gasoline, shown here in a spill on asphalt, is a nonaqueous solution containing many different solutes (mostly hydrocarbons such as benzene and paraffin) in an octane solvent. The composition of gasoline is not fixed: It varies with the source of the raw material, the manufacturer, and the season.

Other examples of liquids and solids dissolving in solvents other than water include the many chemicals that dissolve in alcohols. For example, solid iodine dissolved in ethanol (an alcohol) is used as an antiseptic (**Figure 2**). Aspirin (acetylsalicylic acid, ASA) dissolves better in methanol (a poisonous alcohol) than it does in water, for example, when doing chemical analyses. Of course, it should never be mixed with alcohol when ingested. Some glues and sealants make use of other solvents: acetic acid is used as a solvent of the components of silicone sealants. You can smell the vinegar odour of acetic acid when sealing around tubs and fish tanks.

Figure 2
Tincture of iodine is a solution of the element iodine and the compound potassium or sodium iodide dissolved in ethanol. It is used to prevent the infection of minor cuts and scrapes.

The chemical formula representing a solution specifies the solute by using its chemical formula and shows the solvent by using a subscript. For example,

$NH_{3(aq)}$	ammonia gas (solute) dissolved in water (solvent)
$NaCl_{(aq)}$	solid sodium chloride (solute) dissolved in water (solvent)
$I_{2(al)}$	solid iodine (solute) dissolved in alcohol (solvent)
$C_2H_5OH_{(aq)}$	liquid ethanol (solute) dissolved in water (solvent)

By far the most numerous and versatile solutions are those in which water is the solvent (**Figure 3**). Water can dissolve many substances, forming many unique solutions. All **aqueous solutions** have water as the solvent and are clear (transparent). They may be either coloured or colourless. Although water solutions are all different, they have some similarities and can be classified or described in a number of ways. This chapter deals primarily with the characteristics of aqueous solutions.

aqueous solution: a solute dissolved in water

Figure 3
Concentrated hydrochloric acid (often sold under its common name, muriatic acid) contains hydrogen chloride gas dissolved in water. It is used to etch concrete before painting it, clean rusted metal, and adjust acidity in swimming pools.

Properties of Aqueous Solutions

Compounds can be classified as either electrolytes or nonelectrolytes. Electrolytes are solutes that form solutions that conduct electricity. At this point we will restrict ourselves to compounds in aqueous solutions. Compounds are **electrolytes** if their aqueous solutions conduct electricity. Compounds are **nonelectrolytes** if their aqueous solutions do not conduct electricity. Most household aqueous solutions, such as fruit juices and cleaning solutions, contain electrolytes. The conductivity of a solution is easily tested with a simple conductivity apparatus (**Figure 4**) or an ohmmeter. This evidence also provides a diagnostic test to determine the class of a solute—electrolyte or nonelectrolyte. This very broad classification of compounds into electrolyte and nonelectrolyte categories can be related to the main types of compounds classified in Chapter 2. Electrolytes are mostly highly soluble ionic compounds (e.g., $KBr_{(aq)}$), including bases such as ionic hydroxides (e.g., sodium hydroxide, $NaOH_{(aq)}$). Most molecular

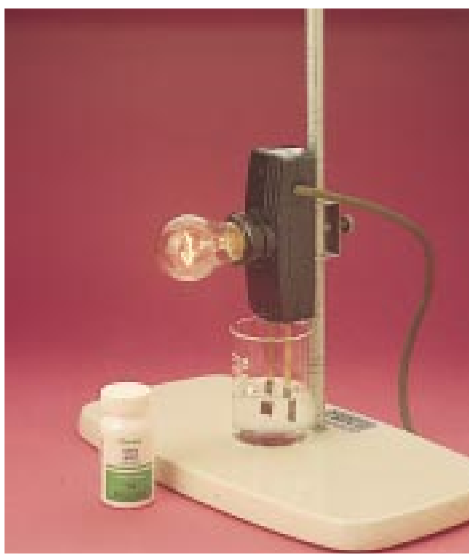


Figure 4
The bulb in this conductivity apparatus lights up if the solute is an electrolyte.

electrolyte: a compound that, in an aqueous solution, conducts electricity

nonelectrolyte: a compound that, in an aqueous solution, does not conduct electricity compounds (e.g., ethanol, $C_2H_5OH_{(aq)}$) are nonelectrolytes, with the exception of acids. Acids (e.g., nitric acid, $HNO_{3(aq)}$) are molecular compounds that, in aqueous solution, conduct electricity.

Another empirical method of classifying solutions uses litmus paper as a test to classify solutes as **acids**, **bases**, or **neutral** substances. Acids form acidic solutions, bases form basic solutions, and most other ionic and molecular compounds form neutral solutions (**Table 2**).

acid: a substance that, in aqueous solution, turns blue litmus paper red

base: a substance that, in aqueous solution, turns red litmus paper blue

neutral: a substance that, in aqueous solution, has no effect on either red or blue litmus paper; neither acidic nor basic

Note: these are empirical definitions, based on the results of the litmus test. Later in this unit, you will encounter theoretical definitions.

Table 2: Properties of Solutes and Their Solutions

Type of solute	Conductivity test
electrolyte	light on conductivity apparatus glows; needle on ohmmeter moves compared to the control
nonelectrolyte	light on conductivity apparatus does not glow; needle on ohmmeter does not move compared with position for the control
Type of solution	**Litmus test**
acidic	blue litmus turns red
basic	red litmus turns blue
neutral	no change in colour of litmus paper

Investigation 6.1.1

Qualitative Chemical Analysis

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ○ Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

In this investigation you will design and carry out a chemical analysis of four compounds (calcium chloride, citric acid, glucose, and calcium hydroxide) to find out which is which. Complete the **Experimental Design** and **Materials** section of the report. You will use the diagnostic tests discussed so far: the conductivity test and the litmus test. After conducting your tests, complete the **Analysis** and **Evaluation** sections.

Question

Which of the white solids labelled 1, 2, 3, and 4 is calcium chloride, citric acid, glucose, and calcium hydroxide?

Experimental Design

You may use litmus paper and the conductivity apparatus. Like all such tests, the conductivity and litmus tests require control of other variables. For example, the temperature of the solution and the quantity of dissolved solute must be kept the same for all substances tested, to allow valid analysis of any evidence collected.

(a) In a short paragraph, plan your tests for this experiment, including independent, dependent, and important controlled variables.

(b) Write a Procedure in which you will use your tests, including safety precautions. (If necessary, refer to MSDS information for the four solids.) Have your Procedure approved by your teacher.

Calcium hydroxide is corrosive. Do not touch any of the solids. Wear eye protection, gloves, and an apron.

Materials

(c) Prepare a list of all materials, including chemicals and equipment. Note that this experiment can easily be done on a small scale using a spot or well plate. Be sure to include safety and disposal equipment.

Procedure

1. Carry out your Procedure, recording your observations in a suitable format.

Analysis

(d) Using the evidence you have collected in your experiment, answer the Question: Which of the white solids labelled 1, 2, 3, and 4 is calcium chloride, citric acid, glucose, and calcium hydroxide?

Evaluation

(e) Evaluate the evidence by critiquing the Experimental Design, Materials, and Procedure. Look for any flaws, sources of error, and possible improvements. Overall, how certain are you about your answer to the Question?

Practice

Understanding Concepts

1. Classify the following mixtures as heterogeneous or homogeneous. Justify your answers.
   (a) fresh-squeezed orange juice
   (b) white vinegar
   (c) red wine
   (d) an antique bronze dagger
   (e) a stainless steel knife
   (f) an old lead water pipe
   (g) humid air
   (h) a cloud
   (i) a dirty puddle
2. Which of the following are solutions and which are *not* solutions?
   (a) milk
   (b) apple juice
   (c) the gas in a helium-filled balloon
   (d) pop
   (e) pure water
   (f) smoke-filled air
   (g) silt-filled water
   (h) rainwater
   (i) 14K gold in jewellery
3. State at least three ways of classifying solutions.
4. (a) What is an aqueous solution?
   (b) Give at least five examples of aqueous solutions that you can find at home.
5. Using the information in **Table 3**, classify each of the compounds as either an electrolyte or a nonelectrolyte. Provide your reasoning.
6. (a) What types of solutes are electrolytes?
   (b) Write a definition of an electrolyte.
7. Describe the solutes in the following types of solutions:
   (a) acidic
   (b) basic
   (c) neutral
8. Electrolytes are lost during physical activity and in hot weather through sweating. The body sweats in order to keep cool—cooling by

Table 3

Compound	Class
methanol	molecular
sodium chloride	highly soluble ionic
hydrochloric acid	acid (molecular)
potassium hydroxide	base (ionic hydroxide)

Figure 5
Gatorade is a drink that its manufacturer recommends to athletes, to restore electrolytes to the body.

evaporation of water. Sweating removes water and the substances dissolved in the water, such as salts and other electrolytes. We replace lost electrolytes by eating and drinking. By law the ingredients of a food item are required to be placed on the label in decreasing order of quantity, as they are in Gatorade (**Figure 5**), a noncarbonated drink.

(a) Classify the ingredients of Gatorade as electrolytes or nonelectrolytes. How does the number and quantity of electrolytes and nonelectrolytes compare?
(b) Which ingredients contain sodium ions? Which contain potassium ions? Are there more sodium or potassium ions in the drink?
(c) Does the most energy in the drink come from proteins, carbohydrates, or fats (oils)?
(d) What three chemical needs does the drink attempt to satisfy?

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ○ Predicting
- ○ Planning
- ○ Conducting
- ○ Recording
- ● Analyzing
- ○ Evaluating
- ○ Communicating

Lab Exercise 6.1.1

Identification of Solutions

For this investigation assume that the labels on the four containers have been removed (perhaps washed off in a flood). Your task as a laboratory technician is to match the labels to the containers, using a litmus indicator and conductivity apparatus to identify the solutions.

You are provided with the Evidence gathered. Complete the **Analysis** section of this report.

Question

Which of the solutions labelled 1, 2, 3, and 4 is hydrobromic acid, which is ammonium sulfate, which is lithium hydroxide, and which is methanol?

Experimental Design

Each solution is tested with both red and blue litmus paper and with conductivity apparatus. The temperatures of the solutions and the procedures are controlled.

Evidence

Table 4: Properties of the Unknown Solutions

Solution	Red litmus	Blue litmus	Conductivity
1	red	blue	none
2	red	red	high
3	red	blue	high
4	blue	blue	high

Analysis

(a) Analyze the Evidence and use it to answer the Question: Which of the solutions labelled 1, 2, 3, and 4 is hydrobromic acid, which is ammonium sulfate, which is lithium hydroxide, and which is methanol? Justify your answer.

Section 6.1 Questions

Understanding Concepts

1. (a) Construct a table that has a column heading Solute (with sub-headings of Solid, Liquid, and Gas), and a row heading Solvent (with sub-headings of Solid, Liquid, and Gas). Complete the table, including examples for as many categories as possible.
   (b) What three kinds of solutions, in your experience, are most common?
2. Include the following terms in a concept map built around the subject "Solutions": solute, solvent, gas, liquid, solid, water, homogeneous mixture, aqueous solution, electrolyte, nonelectrolyte, acid, base, and neutral.
3. Kerosene is a hydrocarbon solution. Name two more examples.
4. Paints are generally sold as alkyd (oil-based) or latex (water-based). To dilute these paints or to clean the paintbrushes, what solvents must be used for each type? Be specific, and explain why each solvent is appropriate.
5. Classify each compound as an electrolyte or a nonelectrolyte:
   (a) sodium fluoride (in toothpaste)
   (b) sucrose (table sugar)
   (c) calcium chloride (a road salt)
   (d) ethanol (in wine)
6. Based upon your current knowledge, classify each of the following compounds (**Figure 6**) as forming an acidic, basic, or neutral aqueous solution, and predict the colour of litmus in each solution.
   (a) $HCl_{(aq)}$ (muriatic acid for concrete etching)
   (b) $NaOH_{(aq)}$ (oven and drain cleaner)
   (c) methanol (windshield washer antifreeze)
   (d) sodium hydrogen carbonate (baking soda)

Figure 6
Everyday chemicals form acidic, basic, or neutral solutions.

Applying Inquiry Skills

7. Imagine that you are to plan an investigation to discover which of the compounds listed in **Table 5** are acids, bases, or neutral, and which are electrolytes or nonelectrolytes. You will first use the chemical formulas to make a **Prediction** for each compound, and then plan an **Experimental Design** to test your predictions.

   Question
   Which of the chemicals listed in **Table 5** are acids, bases, neutral, electrolytes, nonelectrolytes?

   Prediction
   (a) Predict the answer to the Question by copying and completing **Table 5**.

Table 5: Predicting Properties of Compounds

Substance	Acidic/Basic/Neutral	Electrolyte/Nonelectrolyte
$C_3H_7OH_{(l)}$ (a rubbing alcohol)	?	?
calcium hydroxide (slaked lime)	?	?
$H_3PO_{4(aq)}$ (for manufacturing fertilizer)	?	?
glucose (a product of photosynthesis)	?	?
sodium fluoride (in toothpaste)	?	?

(continued)

Experimental Design

(b) Write an experimental design for this investigation.

Making Connections

8. Since grease dissolves in gasoline, some amateur mechanics use gasoline to clean car, bicycle, or motorcycle parts in their basements. Why is this an unsafe practice? What precautions would make the use of gasoline for this purpose safer?

Reflecting

9. Consider what our lives would be like if water really was a universal solvent. What would our planet look like? What would we look like?

6.2 Explaining Solutions

Water is common and familiar, but it is also a unique chemical and solvent. Aqueous solutions can be found everywhere—in nature, in homes, in stores, in laboratories, and in industries. There are many other liquids; some, like hydrocarbons, are found naturally and many others are synthetic. Can anything else act as a solvent? What determines which solute dissolves in which solvent?

INQUIRY SKILLS

- ○ Questioning
- ● Hypothesizing
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- ○ Planning
- ○ Conducting
- ○ Recording
- ● Analyzing
- ● Evaluating
- ○ Communicating

Lab Exercise 6.2.1

Testing a Hypothesis on Dissolving

Your task is to create and test a hypothesis concerning what kinds of substances dissolve in each other. To be scientific, a hypothesis must be able to be tested empirically against the real world. For ease of testing, choose the liquids as solvents.

You are to complete the **Hypothesis**, **Prediction, Analysis,** and **Evaluation** sections of the report.

Question

Do water, table salt, table sugar, motor oil, gasoline, and ammonia dissolve in each other?

Hypothesis

(a) Create a testable hypothesis about what classes of substances dissolve in each other.

Prediction

(b) Write predictions based upon your Hypothesis—which of the provided chemicals will dissolve in each other? For each Prediction, use your Hypothesis to provide the reasoning behind the Prediction.

Experimental Design

Each of the solutes is mixed with the specified liquid solvent to determine if it dissolves (**Figure 1**). The quantities of solute and solvent, the temperature, and the stirring are controlled variables.

Figure 1
If a gas dissolves in water, then the water rises in the test tube.

Experimental Design

(b) Write an experimental design for this investigation.

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Evidence

Table 1

Solute	Solvent	
	Water	**Gasoline**
salt	soluble	not soluble
sugar	soluble	not soluble
motor oil	not soluble	soluble
ammonia	soluble	not soluble

Analysis

(c) Answer the Question using a summary of the evidence collected.

Evaluation

(d) What are some sources of error or uncertainty in this experiment?
(e) Suggest some improvements you can make to the Materials and Procedure if this experiment were to be repeated.
(f) Are your predictions verified, falsified, or inconclusive? Justify your answer by comparing the experimental and predicted results.
(g) Based on your answer to (f), is your Hypothesis acceptable?

Practice

Understanding Concepts

1. How can you tell from a molecular formula whether a substance is polar? List four categories, with examples of each.
2. How can you tell from a molecular formula whether a substance is nonpolar? List two categories, with examples of each.

Explaining Water Mixtures

How can we explain the properties of solutes and solvents? We could use models, such as the concepts of molecules, atoms, electrons, and bonds or forces. In Chapter 2 we used the concept of **intramolecular forces** (i.e., covalent bonds) to describe, explain, and predict the chemical formulas of molecular substances. We use another concept to explain the physical properties of substances: the concept that there are forces holding molecules close to each other. These forces act between molecules, and so are called **intermolecular forces**.

intramolecular force: a specific attraction within a molecule

intermolecular force: an attraction between molecules

Now we have the challenge of explaining why some substances dissolve in a given solvent, but others do not. Let us start with aqueous solutions. Why do only some chemicals dissolve in water? Why are some chemicals mutually attracted to one another?

Molecular Substances in Water

We have gathered evidence and made some generalizations about which substances, including water, contain polar molecules (Chapter 2). Let us now find out if polarity has an effect on solubility. For example, we could test the hypothesis that polar substances dissolve in polar substances and nonpolar solutes in nonpolar solvents ("like dissolves like"). In other words, do like-polarity substances dissolve in each other?

DID YOU KNOW ?

Intra/Inter

The prefix "intra" is used in "intramural" as well as in "intramolecular." It means "within."

The prefix "inter" means "between," as in "interschool competitions," "the Internet," and "intermolecular forces."

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ○ Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

Toluene, ethylene glycol, and mineral oil are flammable.

Toluene and propanol are toxic. Wear eye protection, gloves, and a laboratory apron. Avoid contact with all liquids and dispose of mixtures according to your teacher's instructions.

Investigation 6.2.1

Polar and Nonpolar Solutes

The purpose of this investigation is to test the hypothesis that molecular substances with similar polarity dissolve in each other—"like dissolves like."

Complete the **Materials** and **Procedure** sections. Be sure to include all necessary safety precautions and equipment. When these have your teacher's approval, carry out the investigation, record your **Evidence**, and complete the **Analysis** and **Evaluation** sections of the report.

Question

Do water ($H_2O_{(l)}$), ethylene glycol ($C_2H_4(OH)_{2(l)}$), toluene ($C_7H_{8(l)}$), and mineral oil (a mixture of hydrocarbons, $C_xH_{y(l)}$) dissolve in each other (**Figure 2**)?

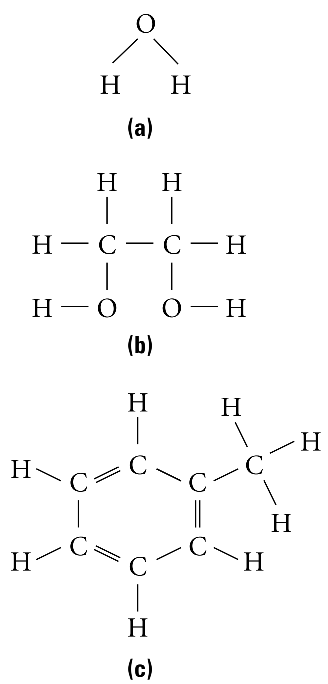


Figure 2
(a) Water
(b) Ethylene glycol
(c) Toluene

Hypothesis/Prediction

According to the hypothesis that like-polarity substances dissolve in each other, water and ethylene glycol will dissolve in each other, but not in toluene or mineral oil, and toluene and mineral oil will dissolve in each other. The reasoning behind this prediction is that water and propanol contain polar molecules while toluene and mineral oil contain nonpolar molecules.

Experimental Design

Water, ethylene glycol, toluene, and mineral oil are mixed in pairs (**Figure 3**). The independent variable is the kind of chemicals used (polar or nonpolar); the dependent variable is whether the substances dissolve; and the controlled variables are volume, temperature, and mixing.

(a) Plan and write a Procedure as a numbered list of steps. Be sure to include safety considerations and a disposal step.

Figure 3
If two liquid layers are apparent, then the liquids have low solubility.

Materials

(b) List all materials, including sizes and approximate quantities.

Procedure

1. With your teacher's approval, carry out your procedure. Record your observations in a suitable format.

Analysis

(c) Do water, propanol, toluene, and mineral oil dissolve in each other? Indicate which substances dissolve in each other and which do not.

Evaluation

(d) Evaluate the evidence by critiquing the Experimental Design, Materials, and Procedure. Look for any flaws, sources of error, and opportunities for improvement. Overall, how would you judge the quality of the evidence?

(e) Assuming that the evidence was of suitable quality, judge the prediction and hypothesis. Are they valid?

The Effects of Polarity and Hydrogen Bonds

Ethylene glycol, a chemical with polar molecules, has a high solubility in water. Chemists have a theoretical explanation for this: Polar solute molecules are surrounded and suspended in solution by polar solvent molecules (**Figure 4**).

How do chemists explain the extraordinary solubility in water of solutes with hydrogen bonding capability, such as ethylene glycol? In Chapter 2, you saw that the higher than expected boiling points of some pure substances could be explained by hydrogen bonding. Recall that any substance with a hydrogen (H) atom covalently bonded to a N, O, or F atom can "hydrogen bond" to its own molecules to increase the intermolecular forces beyond the strength of London and dipole–dipole forces. Also recall that water has two hydrogen atoms bonded to an oxygen atom, which, in turn, has two lone-pairs of electrons to take part in hydrogen bonding with other water molecules.

Now consider that, when water is the solvent, there is a potential for solutes with N, O, or F lone-pairs or with a H—N, H—O, or H—F bond to form hydrogen bonds with water. For example, ammonia, $NH_{3(g)}$, has a very high solubility in water (as in household ammonia). Ammonia fulfills both criteria: It has a lone pair of electrons that could accept a positively charged hydrogen for sharing; and it has three hydrogens to share with the two lone-pairs on a nearby water molecule (**Figure 5**). When multiple hydrogen bonding is possible, we would predict an especially high solubility. More importantly, if both the solute and the solvent have H—N, H—O, or H—F bonds, then evidence suggests that the attractions and the solubility are high.

The explanation for the high solubility of ammonia is both logical and consistent, and can be tentatively accepted on that basis. The next test for any concept is its ability to predict an outcome. Can our concept for explaining solubility successfully predict solubilities in an experiment?

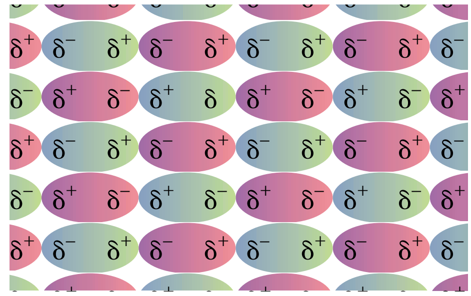


Figure 4
Polar solute molecules (in red) are surrounded by polar solvent molecules (in green). The dipole–dipole attractions explain the increase in solubility.

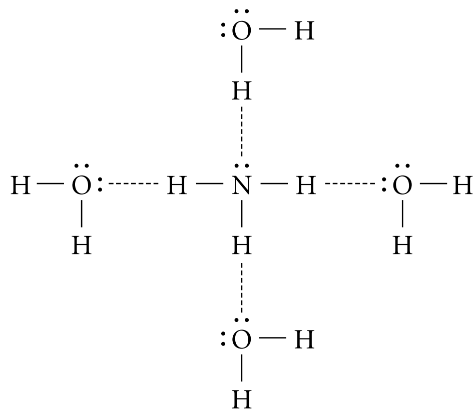


Figure 5
Multiple hydrogen bonds between ammonia and water result in a very high solubility for ammonia, much higher than expected from London and dipole–dipole intermolecular forces. Hydrogen bonding is the main reason for this high solubility, but there are other factors, which you will discover in Chapter 8.

Lab Exercise 6.2.2

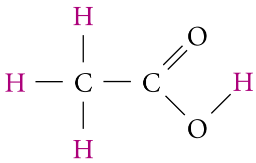
Predicting High and Low Solubilities

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ○ Conducting
- ○ Recording
- ● Analyzing
- ● Evaluating
- ○ Communicating

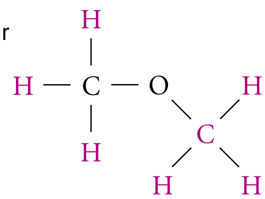
We have created a concept concerning the solubilities of molecular substances: polar solutes dissolve in polar solvents, and nonpolar solutes dissolve in nonpolar solvents. In this exercise, we will use this concept and the information in **Table 2** and **Figure 6** (page 276) to predict the solubilities of a variety of substances in water. The procedure has been carried out, and the observations of solubilities are presented as a table of evidence. Complete the **Prediction**, **Analysis**, and **Evaluation** sections of the report.

(a) acetic acid

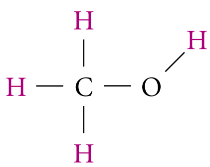


(b) carbon dioxide

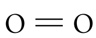
(c) dimethyl ether



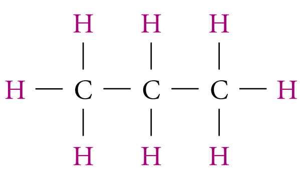
(d) methanol



(e) oxygen



(f) propane



(g) tetrachloromethane

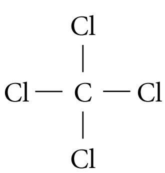


Figure 6
Structural formulas of some molecular substances

Table 2: Intermolecular Forces in Water

Chemical	Formula	Intermolecular force
acetic acid	$HC_2H_3O_{2(l)}$	LF, D-D, many H-B
carbon dioxide	$CO_{2(g)}$	LF, some H-B
dimethyl ether	$CH_3OCH_{3(g)}$	LF, D-D, some H-B
methanol	$CH_3OH_{(l)}$	LF, D-D, many H-B
oxygen	$O_{2(g)}$	LF, some H-B
propane	$C_3H_{8(g)}$	LF
tetrachloromethane	$CCl_{4(l)}$	LF

Key:
LF London forces   D-D dipole–dipole forces   H-B hydrogen

Question

Which of the substances listed in **Table 2** have high solubility in water? Which have low solubility in water?

Prediction

(a) Use the concepts of polarity and hydrogen bonding to predict the relative solubility in water for each substance listed under Materials. You may use general terms such as low and high, or simply rank the solubilities. Provide your reasoning for your prediction.

Materials

acetic acid, $HC_2H_3O_{2(l)}$
carbon dioxide, $CO_{2(g)}$
dimethyl ether, $CH_3OCH_{3(g)}$
methanol, $CH_3OH_{(l)}$
oxygen, $O_{2(g)}$
propane, $C_3H_{8(g)}$
tetrachloromethane, $CCl_{4(l)}$
water
test tubes
stirring rods

Evidence

Table 3: Solubility of Molecular Compounds in Water

Chemical	Solubility
acetic acid	very high
carbon dioxide	low
dimethyl ether	high
methanol	very high
oxygen	low
propane	very low
tetrachloromethane	very low

Analysis

(b) Answer the Question: Which of the substances have high solubility in water? Which have low solubility in water?

Evaluation

(c) What additional observations would be useful to improve the quality of the Evidence?
(d) Compare the experimental and predicted results and evaluate the Prediction.

Practice

Understanding Concepts

3. Distinguish between intramolecular and intermolecular forces.
4. Suppose someone spilled some gasoline while filling a gas tank on a rainy day.
   (a) If some gasoline ran into a puddle of water, would it dissolve in the water? What evidence would support your prediction?
   (b) What rule did you use to predict whether dissolving will occur?
   (c) How does this rule apply to the gasoline-water mixture?
5. Windshield washer fluid contains methanol dissolved in water.
   (a) Why does methanol dissolve well in water? Explain in terms of intermolecular forces.
   (b) Draw a Lewis structure of a methanol molecule and several water molecules to show possible hydrogen bonds. (Use dashed lines to represent H-bonds.)
   (c) What would you expect to be the relationship between the number of possible hydrogen bonds and the solubility? Why?

Ionic Compounds in Water

Water is the most important solvent on Earth. The oceans, lakes, rivers, and rain are aqueous solutions containing many different ionic compounds and a few molecular solutes. As you know, there are some ionic compounds that dissolve only very slightly in water, such as limestone (calcium carbonate) buildings and various other rocks and minerals. Nevertheless, many more ionic compounds dissolve in water than in any other known solvent.

Why are ionic compounds so soluble in water? The key to the explanation came from the study of electrolytes. Electrolytes were first explained by Svante Arrhenius who was born in Wijk, Sweden, in 1859. While attending the University of Uppsala, he became intrigued by the problem of how and why some aqueous solutions conduct electricity, but others do not. This problem had puzzled chemists ever since Sir Humphry Davy and Michael Faraday experimented over half a century earlier by passing electric currents through chemical substances.

Faraday believed that an electric current produces new charged particles in a solution. He called these electric particles ions (a form of the Greek word for "to go"). He could not explain what ions were, or why they did not form in solutions of substances such as sugar or alcohol dissolved in water.

In 1887 Arrhenius proposed a new hypothesis: that particles of a substance, when dissolving, separate from each other and disperse into the solution. Nonelectrolytes disperse electrically neutral particles throughout the solution. As **Figure 7** shows, molecules of sucrose (a nonelectrolyte) separate from each other

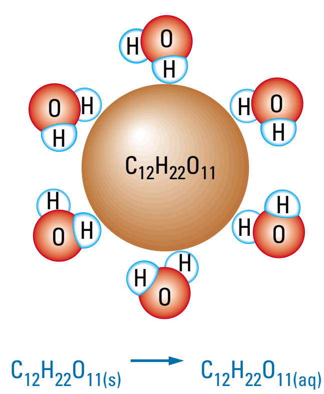


Figure 7
This model illustrates sucrose dissolved in water. The model, showing electrically neutral particles in solution, agrees with the evidence that a sucrose solution does not conduct electricity.

and disperse in an aqueous solution as individual molecules of sucrose surrounded by water molecules.

But what about the conductivity of solutions of electrolytes? Arrhenius' explanation for this observation was quite radical. He agreed with the accepted theory that electric current involves the movement of electric charge. Ionic compounds form conducting solutions. Therefore, according to Arrhenius, electrically charged particles must be present in their solutions. For example, when a compound such as table salt dissolves, it **dissociates** into individual aqueous ions (**Figure 8**). The positive ions are surrounded by the negative ends of the polar water molecules, while the negative ions are surrounded by the positive ends of the polar water molecules. Dissociation equations, such as the following examples, show this separation of ions.

dissociation: the separation of ions that occurs when an ionic compound dissolves in water

$$NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

$$(NH_4)_2SO_{4(s)} \rightarrow 2\ NH^{+}_{4(aq)} + SO^{2-}_{4(aq)}$$

Notice that the formula for the solvent, $H_2O_{(l)}$, does not appear as a reactant in the equation. Although water is necessary for the process of dissociation, it is not consumed and hence is not a reactant. The presence of water molecules surrounding the ions is indicated by the subscript $_{(aq)}$.

DID YOU KNOW ?

Getting Your Vitamins

Some vitamins, whose molecules are non-polar, are soluble in fats. Fat-soluble vitamins include Vitamins A, D, and E. Other vitamins, whose molecules are polar, are soluble in water. Water-soluble vitamins include Vitamin C, the B vitamins, and pantothemic and folic acids. The fat soluble vitamins must be ingested with fatty foods. Like dissolves in like.

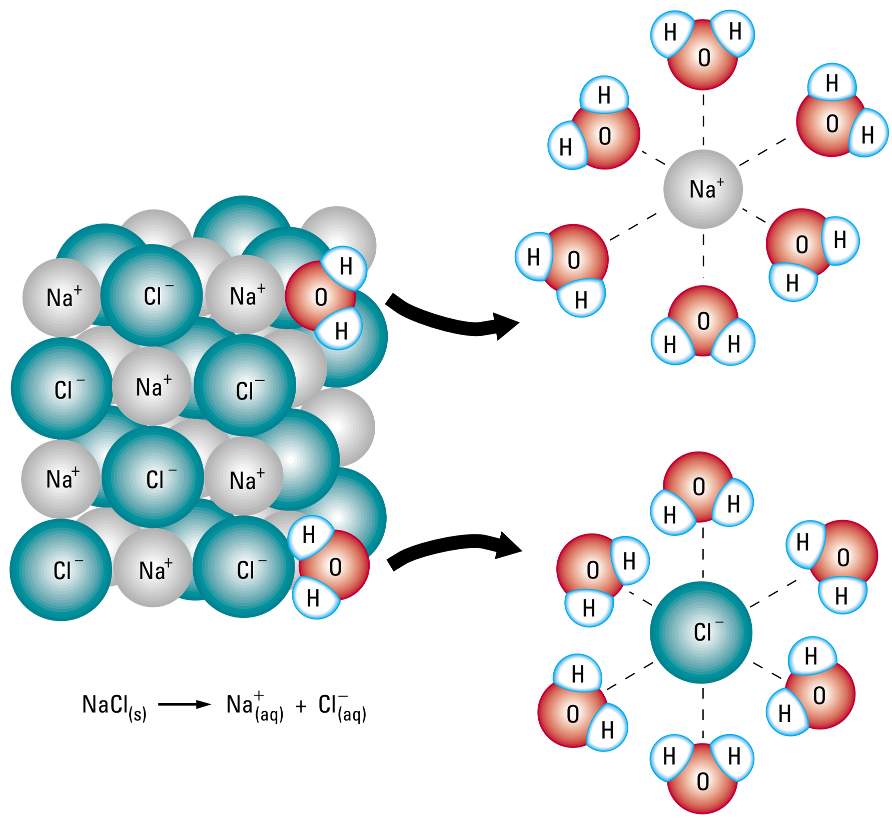


Figure 8
This model represents the dissociation of sodium chloride into positive and negative ions.

Practice

Understanding Concepts

6. A sugar cube and a lump of table salt are put into separate glasses of water.
   (a) Note as many observations as you can about each mixture.

(b) According to theory, how is the dissolving process similar for both solutes?
(c) According to theory, how are the final solutions different?
(d) What theoretical properties of a water molecule help to explain the dissolving of both solutes?

7. Write equations to represent the dissociation of the following ionic compounds when they are placed in water:
(a) sodium fluoride
(b) sodium phosphate
(c) potassium nitrate
(d) aluminum sulfate
(e) ammonium hydrogen phosphate
(f) cobalt(II) chloride hexahydrate

Explaining Nonaqueous Mixtures

We now have an explanation for the solubility of ionic compounds (electrolytes) and molecular substances (nonelectrolytes) in water. The next question is, why do nonpolar solutes (e.g., grease) dissolve in nonpolar solvents (e.g., kerosene)? These chemicals do not show evidence of either polar molecules (dipoles) or hydrogen bonding. The third intermolecular force that we can look to for an explanation is the London (dispersion) force. London forces are weak intermolecular forces, and can explain the relatively low boiling points of nonpolar and non-hydrogen bonding compounds. Similarly, they can explain why these same compounds dissolve in each other to form solutions (**Figure 9**).

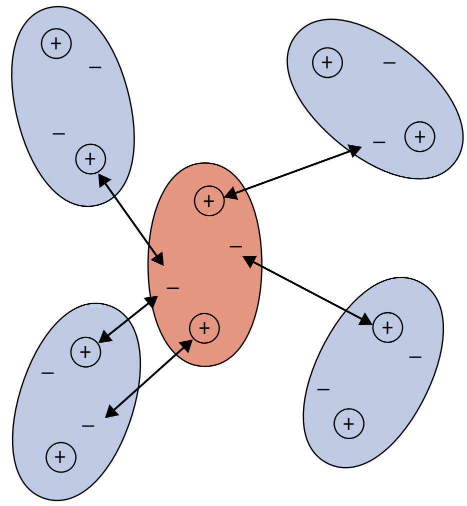


Figure 9
London (dispersion) forces are believed to be responsible for nonpolar solutes (red) dissolving in nonpolar solvents (blue).

Water—"The Universal Solvent"

Seventy-five percent of Earth is covered with water—both liquid and solid. All forms of life, including animals and plants, depend upon the life-supporting fluid called water. Water dissolves so many more substances than any other liquid that it is not surprising that water is often referred to as the "universal solvent." This success as a solvent is due to three features of water molecules: their small size; their highly polar nature; and their considerable capacity for hydrogen bonding.

Practice

Understanding Concepts

8. Describe as many properties of water as you can, using diagrams where necessary. Classify the properties as either empirical or theoretical.

9. If you get some grease from a bicycle chain on your pants, what kind of solvent would be best to dissolve the grease? Explain your choice.

10. (a) Which of $C_6H_{14(l)}$ and $C_6H_{12}O_{6(s)}$ is more soluble in water, and why?
(b) Which of $C_2H_5OH_{(l)}$ and $CH_3OCH_{3(g)}$ (**Figure 10**) is more soluble in water, and why?
(c) Which of $Na_2CO_{3(s)}$ and $CO_{2(g)}$ is more soluble in water, and why?

11. There is a series of gaseous compounds in which one carbon molecule is bonded to four other atoms: CH_4, CH_3Cl, CH_2Cl_2, $CHCl_3$, and CCl_4.
(a) Which of these five compounds are most likely to dissolve in water?
(b) Which are most likely to dissolve in a nonpolar solvent, such as hexane? Briefly justify your answers.

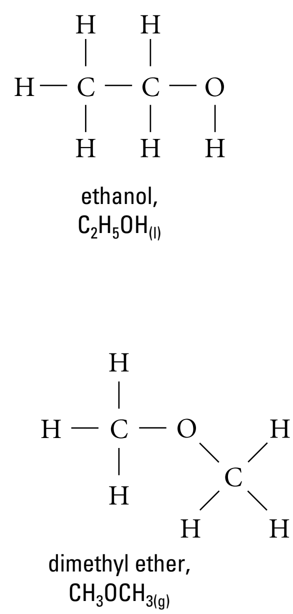


Figure 10
The shapes of molecules can often help us predict their solubility.

12. Laboratory evidence indicates that butanol, $C_4H_9OH_{(l)}$, has a higher solubility in gasoline than methanol, $CH_3OH_{(l)}$. Create a theoretical hypothesis to explain this evidence.

Applying Inquiry Skills

13. For an explanation to be accepted by the scientific community, what criteria are used to judge the explanation?

Making Connections

14. Water and soap are not always sufficient to clean clothes, especially when they are stained with grease or oil. Dry cleaners clean clothes without water.
    (a) What solvents are used and what are their properties?
    (b) What health regulations relate to these solvents and their use in the dry cleaning industry?

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Section 6.2 Questions

Understanding Concepts

1. Why is water such a good solvent for so many substances? In your answer refer to the properties of water, and describe them at the molecular level.
2. (a) From your own observations, which of the following substances dissolve in each other and which do not?
    (i) water and gasoline
    (ii) oil and vinegar
    (iii) gasoline and grease
    (iv) sugar and water
    (v) water and alcohol

   (b) Were your answers based on empirical or theoretical knowledge? Provide your reasoning.
3. Which of the following substances dissolve in each other and which do not? Give reasons for your predictions.
    (a) $H_2O_{(l)}$ and $C_8H_{18(l)}$
    (b) $HC_2H_3O_{2(l)}$ and $H_2O_{(l)}$
    (c) $CCl_{4(l)}$ and $HCl_{(aq)}$
    (d) $H_2O_{(l)}$ and $C_3H_7OH_{(l)}$
    (e) $N_{2(g)}$ and $H_2O_{(l)}$
4. Order the chemicals—ammonia, methane, and methanol—in terms of increasing solubility in water. Provide your reasoning.

Applying Inquiry Skills

5. Aqueous solutions of salt and sugar are mixed to determine whether salt dissolves in sugar. Critique this experimental design.
6. Plan an investigation to discover whether $C_6H_{6(l)}$ or $C_6H_5OH_{(l)}$ has a higher solubility in water. Provide the Question, Prediction, Experimental Design, and Materials.

Making Connections

7. A scientist is developing a glue suitable for children to use. What properties should the glue have? What should be the chemical properties of the compounds in the glue?

6.3 Solution Concentration

concentration: the quantity of a given solute in a solution

dilute: having a relatively small quantity of solute per unit volume of solution

concentrated: having a relatively large quantity of solute per unit volume of solution

Most aqueous solutions are colourless, so there is no way of knowing, by looking at them, how much of the solute is present in the solution. As we often need to know the amount of solute in the solution, it is important that solutions be labelled with this information. We use a ratio that compares the quantity of solute to the quantity of the solution. This ratio is called the solution's **concentration**. Chemists describe a solution of a given substance as **dilute** if it has a relatively small quantity of solute per unit volume of solution (**Figure 1**). A **concentrated** solution, on the other hand, has a relatively large quantity of solute per unit volume of solution.

In general, the concentration, c, of any solution is expressed by the ratio

$$\text{concentration} = \frac{\text{quantity of solute}}{\text{quantity of solution}}$$

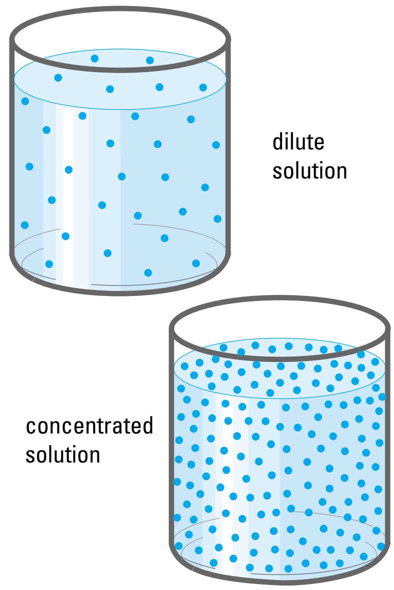

Figure 1
The theoretical model of the dilute solution shows fewer solute entities (particles) per unit volume compared with the model of the concentrated solution.

Percentage Concentration

Many consumer products, such as vinegar (acetic acid), are conveniently labelled with their concentration ratios expressed as percentages (**Figure 2**). A vinegar label listing "5% acetic acid (by volume)" means that there are 5 mL of pure acetic acid dissolved in every 100 mL of the vinegar solution. This type of concentration is often designated as % V/V, percentage volume by volume, or percentage by volume.

$$c_{HC_2H_3O_2} = \frac{5\ \text{mL}}{100\ \text{mL}} = 5\%\ \text{V/V}$$

In general, a percentage by volume concentration may be defined as

$$c = \frac{v_{solute}}{v_{solution}} \times 100\%$$

Sample Problem 1

A photographic "stop bath" contains 140 mL of pure acetic acid in a 500-mL bottle of solution. What is the percentage by volume concentration of acetic acid?

Solution

$$v_{HC_2H_3O_{2(l)}} = 140\ \text{mL}$$
$$v_{HC_2H_3O_{2(aq)}} = 500\ \text{mL}$$
$$c_{HC_2H_3O_2} = \frac{140\ \text{mL}}{500\ \text{mL}} \times 100$$
$$c_{HC_2H_3O_2} = 28.0\%\ \text{V/V}$$

The percentage by volume concentration of acetic acid is 28.0%.

Another common concentration ratio used for consumer products is "percentage weight by volume" or % W/V. (In consumer and commercial applications, "weight" is used instead of "mass," which explains the W in the W/V label.) For example, a hydrogen peroxide topical solution used as an antiseptic is 3% W/V (**Figure 2**). This means that 3 g of hydrogen peroxide is in every 100 mL of solution.

Figure 2
The concentrations of different consumer products depend on the product and sometimes the brand name. Concentrations are usually expressed as a percentage.

$$c_{H_2O_2} = \frac{3\text{ g}}{100\text{ mL}}$$

$$c_{H_2O_2} = 3\%\text{ W/V}$$

In general, we write a percentage weight by volume concentration as

$$c = \frac{m_{\text{solute}}}{v_{\text{solution}}} \times 100\%$$

A third concentration ratio is the "percentage weight by weight," or % W/W:

$$c = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 100\%$$

Sample Problem 2

A sterling silver ring has a mass of 12.0 g and contains 11.1 g of pure silver. What is the percentage weight by weight concentration of silver in the metal?

Solution

$m_{Ag} = 11.1\text{ g}$

$m_{\text{alloy}} = 12.0\text{ g}$

$$c_{Ag} = \frac{11.1\text{ g}}{12.0\text{ g}} \times 100\%$$

$$c_{Ag} = 92.5\%\text{ W/W}$$

The ring is 92.5 % W/W silver.

Very Low Concentrations

parts per million: unit used for very low concentrations

In studies of solutions in the environment, we often encounter very low concentrations. For very dilute solutions we choose a concentration unit to give reasonable numbers for very small quantities of solute. For example, the concentration of toxic substances in the environment or of chlorine in a swimming pool is usually expressed as **parts per million** (ppm, $1{:}10^6$) or even smaller ratios, such as parts per billion (ppb, $1{:}10^9$) or parts per trillion (ppt, $1{:}10^{12}$). These ratios are used for liquid and solid mixtures and are a special case of the weight by weight (W/W) ratio. One part per million of chlorine in a swimming pool corresponds to 1 g of chlorine in 10^6 g of pool water. Because very dilute aqueous solutions are very similar to pure water, their densities are considered to be the same: 1 g/mL. Therefore, 1 ppm of chlorine is 1 g in 10^6 g or 10^6 mL (1000 L) of pool water, which is equivalent to 1 mg of chlorine per litre of water. Small concentrations such as ppm, ppb, and ppt are difficult to imagine, but are very important in environmental studies and in the reporting of toxic effects of substances (**Table 1**).

Table 1: Parts per Million, Billion, and Trillion

1 ppm	1 drop in a full bathtub
1 ppb	1 drop in a full swimming pool
1 ppt	1 drop in 1000 swimming pools

We can express the parts per million (ppm) concentration using a variety of units. Choose the one that matches the information given in the example you are calculating. For aqueous solutions,

$$\begin{aligned} 1\text{ ppm} &= 1\text{ g}/10^6\text{ mL} \\ &= 1\text{ g}/1000\text{ L} \\ &= 1\text{ mg/L} \\ &= 1\text{ mg/kg} \\ &= 1\ \mu\text{g/g} \end{aligned}$$

Sample Problem 3

Dissolved oxygen in natural waters is an important measure of the health of the ecosystem. In a chemical analysis of 250 mL of water at SATP, 2.2 mg of oxygen was measured. What is the concentration of oxygen in parts per million?

Solution

$m_{O_2} = 2.2 \text{ mg}$

$v_{O_2} = 250 \text{ mL or } 0.250 \text{ L}$

$$c_{O_2} = \frac{2.2 \text{ mg}}{0.250 \text{ L}}$$

$$= 8.8 \text{ mg/L}$$

$$c_{O_2} = 8.8 \text{ ppm}$$

The oxygen concentration is 8.8 ppm.

mole: the amount of a substance; the number of particles equivalent to Avogadro's number (6.02×10^{23}); the number of carbon atoms in exactly 12 g of a carbon-12 sample; the unit of stoichiometry

molar concentration: the amount of solute, in moles, dissolved in one litre of solution

Molar Concentration

Chemistry is primarily the study of chemical reactions, which we communicate using balanced chemical equations. The coefficients in these equations represent amounts of chemicals in units of **moles**. Concentration is therefore communicated using **molar concentration**. Molar concentration, *C*, is the amount of solute in moles dissolved in one litre of solution.

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

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

The units of molar concentration (mol/L) come directly from this ratio. The symbol *C* denotes a molar quantity, just as *M* is molar mass, but *m* is mass.

Molar concentration is sometimes indicated by the use of square brackets. For example, the molar concentration of sodium hydroxide in water could be represented by $[NaOH_{(aq)}]$.

DID YOU KNOW ?

What's M?

Although it is not an SI unit, some chemists use the unit "molar," M, to express molarity or molar concentration (**Figure 3**). 1 M = 1 mol/L.

Figure 3
Sulfuric acid in the laboratory may have a molar concentration of 17.8 mol/L.

Sample Problem 4

In a quantitative analysis, a stoichiometry calculation produced 0.186 mol of sodium hydroxide in 0.250 L of solution. Calculate the molar concentration of sodium hydroxide.

Solution

$n_{NaOH} = 0.186 \text{ mol}$

$v_{NaOH} = 0.250 \text{ L}$

$$C_{NaOH} = \frac{0.186 \text{ mol}}{0.250 \text{ L}}$$

$$C_{NaOH} = 0.744 \text{ mol/L}$$

The sodium hydroxide molar concentration is 0.744 mol/L.

Practice

Answers

2. 7.5% V/V
3. 32% W/V
4. 4.8% W/W
5. 8 mg
6. 5.4 ppm
7. (a) 1/1000
   (c) 30 μg
8. 1.8 mol/L

Understanding Concepts

1. What are three different ways of expressing the concentration of a solution?
2. Gasohol, which is a solution of ethanol and gasoline, is considered to be a cleaner fuel than just gasoline alone. A typical gasohol mixture available across Canada contains 4.1 L of ethanol in a 55-L tank of fuel. Calculate the percentage by volume concentration of ethanol.
3. Solder flux, available at hardware and craft stores, contains 16 g of zinc chloride in 50 mL of solution. The solvent is aqueous hydrochloric acid. What is the percentage weight by volume of zinc chloride in the solution?
4. Brass is a copper-zinc alloy. If the concentration of zinc is relatively low, the brass has a golden colour and is often used for inexpensive jewellery. If a 35.0 g pendant contains 1.7 g of zinc, what is the percentage weight by weight of zinc in this brass?
5. If the concentration of oxygen in water is 8 ppm, what mass of oxygen is present in 1 L of water?
6. Formaldehyde, $CH_2O_{(g)}$, is an indoor air pollutant that comes from synthetic materials and cigarette smoke. Formaldehyde is controversial because it is a probable carcinogen. If a 500-L indoor air sample with a mass of 0.59 kg contained 3.2 mg of formaldehyde, this would be considered a dangerous level. What would be the concentration of formaldehyde in parts per million?
7. Very low concentrations of toxic substances sometimes require the use of the parts per billion (ppb) concentration.
   (a) How much smaller is 1 ppb than 1 ppm?
   (b) Use the list of equivalent units for parts per million to make a new list for parts per billion.
   (c) Copper is an essential trace element for animal life. An average adult requires the equivalent of a litre of water containing 30 ppb of copper a day. What mass of copper is this per kilogram of solution?
8. A plastic dropper bottle for a chemical analysis contains 0.11 mol of calcium chloride in 60 mL of solution. Calculate the molar concentration of calcium chloride.

Making Connections

9. Toxicity of substances for animals is usually expressed by a quantity designated as "LD_{50}." Use the Internet to research the use of this quantity. What does LD_{50} mean? What is the concentration in ppm for a substance considered "extremely toxic" and one considered "slightly toxic"?
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Reflecting

10. How is your report card mark in a subject like a concentration? What other ratios have you used that are similar to concentration ratios?

Calculations Involving Concentrations

Solutions are so commonly used in chemistry that calculating concentrations might be the primary reason why chemists pull out their calculators. In associated calculations, chemists and chemical technicians also frequently need to calculate a quantity of solute or solution. Any of these calculations may involve percentage concentrations, very low concentrations, or molar concentrations. When we know two of these values—quantity of solute, quantity of solution, and concentration of solution—we can calculate the third. Because concentration is a ratio, a simple procedure is to use the concentration ratio (quantity of solute/quantity of solution) as a conversion factor. This approach parallels the one you followed when using molar mass as a conversion factor.

Suppose you are a nurse who needs to calculate the mass of dextrose, $C_6H_{12}O_{6(s)}$, present in a 1000-mL intravenous feeding of D5W, which is a solution of 5.0 % W/V dextrose in water. The conversion factor you need to use is the mass/volume ratio.

$$m_{C_6H_{12}O_6} = 1000\ \cancel{mL} \times \frac{5.0\ g}{100\ \cancel{mL}}$$

$$m_{C_6H_{12}O_6} = 50\ g$$

In some calculations you may want to find the quantity of solution, in which case you will have to flip the ratio to quantity of solution/quantity of solute. This is then the appropriate conversion factor.

For example, what volume of 30.0% W/V hydrogen peroxide solution can be made from 125 g of pure hydrogen peroxide? You know that the answer must be greater than 100 mL because 125 g is greater than 30.0 g (the quantity in 100 mL). Notice how the units cancel to produce the expected volume unit, millilitres, when we use the volume/mass ratio.

$$v_{H_2O_2} = 125\ \cancel{g} \times \frac{100\ mL}{30.0\ \cancel{g}}$$

$$v_{H_2O_2} = 417\ mL$$

Thinking about the quantity given and the concentration ratio helps to ensure you are calculating correctly. This method also works for other concentration ratios.

The quantities of solute and solution may be expressed as mass and volume respectively, so the appropriate conversion ratio would be a mass/volume ratio.

Sample Problem 5

A box of apple juice has a fructose (sugar) concentration of 12 g/100 mL (12% W/V) (**Figure 4**). What mass of fructose is present in a 175-mL glass of juice? (The chemical formula for fructose is $C_6H_{12}O_6$.)

Figure 4
The label on a box of apple juice gives the ingredients and some nutritional information, but not the concentration of the various solutes.

Solution

$$C_{C_6H_{12}O_6} = \frac{12\ g}{100\ mL}$$

$$v_{\text{apple juice}} = 175\ mL$$

$$m_{C_6H_{12}O_6} = 175\ \cancel{mL} \times \frac{12\ g}{100\ \cancel{mL}}$$

$$m_{C_6H_{12}O_6} = 21\ g$$

There are 21 g of fructose in each glass of apple juice.

Sample Problem 6

People with diabetes have to monitor and restrict their sugar intake. What volume of apple juice could a diabetic person drink, if his sugar allowance for that beverage was 9.0 g? Assume that the apple juice has a sugar concentration of 12 g/100 mL (12% W/V), and that the sugar in apple juice is fructose.

Solution

$$c_{C_6H_{12}O_6} = \frac{12\text{ g}}{100\text{ mL}}$$

$$m_{C_6H_{12}O_6} = 9.0\text{ g}$$

$$v_{C_6H_{12}O_6} = 9.0\ \cancel{\text{g}} \times \frac{100\text{ mL}}{12\ \cancel{\text{g}}}$$

$$v_{C_6H_{12}O_6} = 75\text{ mL}$$

The person could drink 75 mL of apple juice.

When you are given a concentration in parts per million (ppm) you may choose from among a variety of conversion factors. If, for example, you are given a value of 99 ppm for biomagnification of DDT in a 2-kg gull, what mass of DDT is present? Since the mass, rather than the volume, of the gull is given, use 99 ppm as 99 mg/kg rather than 99 mg/L. The concentration ratio is 99 mg/kg. Note the cancellation of kilograms.

$$m_{DDT} = 2\ \cancel{\text{kg}} \times \frac{99\text{ mg}}{1\ \cancel{\text{kg}}}$$

$$m_{DDT} = 0.2\text{ g (rounded from 198 mg)}$$

Sample Problem 7

A sample of well water contains 0.24 ppm of dissolved iron(III) sulfate from the surrounding rocks. What mass of iron(III) sulfate is present in 1.2 L of water in a kettle?

Solution

$$c_{Fe_2(SO_4)_3} = 0.24\text{ ppm} = \frac{0.24\text{ mg}}{1\text{ L}}$$

$$v = 1.2\text{ L}$$

$$m_{Fe_2(SO_4)_3} = 1.2\ \cancel{\text{L}} \times \frac{0.24\text{ mg}}{1\ \cancel{\text{L}}}$$

$$m_{Fe_2(SO_4)_3} = 0.29\text{ mg}$$

The mass of iron dissolved in the water in the kettle is 0.29 mg.

Sample Problem 8

A sample of laboratory ammonia solution has a molar concentration of 14.8 mol/L (**Figure 5**). What amount of ammonia is present in a 2.5 L bottle?

Solution

$$C_{NH_3} = \frac{14.8 \text{ mol}}{1 \text{ L}}$$

$$v_{NH_3} = 2.5 \text{ L}$$

$$n_{NH_3} = 2.5 \cancel{\text{L}} \times \frac{14.8 \text{ mol}}{1 \cancel{\text{L}}}$$

$$n_{NH_3} = 37 \text{ mol}$$

The amount of ammonia present in the bottle is 37 mol.

You should always check that your answer makes sense. For example, in Sample Problem 8, 14.8 mol/L means that there is 14.8 mol of ammonia in 1 L of solution. Therefore, 2.5 L, which is greater than 1 L, must produce an amount greater than 14.8 mol.

In some situations you may know the molar concentration and need to find either the volume of solution or amount (in moles) of solute. In these situations use either the volume/amount or amount/volume ratio. Notice that the units of the quantity you want to find should be the units in the numerator of the conversion factor ratio.

Figure 5
Aqueous ammonia is purchased for science laboratories as a concentrated solution. What is the concentration of the solute?

Sample Problem 9

What volume of a 0.25 mol/L salt solution in a laboratory contains 0.10 mol of sodium chloride?

Solution

$$C_{NaCl} = \frac{0.25 \text{ mol}}{1\text{L}}$$

$$n_{NaCl} = 0.10 \text{ mol}$$

$$v_{NaCl} = 0.10 \cancel{\text{mol}} \times \frac{1 \text{ L}}{0.25 \cancel{\text{mol}}}$$

$$v_{NaCl} = 0.40 \text{ L}$$

You need 0.40 L of salt solution to provide 0.10 mol of sodium chloride.

Practice

Understanding Concepts

11. Rubbing alcohol, $C_3H_7OH_{(l)}$, is sold as a 70.0% V/V solution for external use only. What volume of pure $C_3H_7OH_{(l)}$ is present in a 500-mL (assume three significant digits) bottle?
12. Suppose your company makes hydrogen peroxide solution with a generic label for drugstores in your area. What mass of pure hydrogen peroxide is needed to make 1000 bottles each containing 250 mL of 3.0% W/V $H_2O_{2(aq)}$?
13. The maximum acceptable concentration of fluoride ions in municipal water supplies is 1.5 ppm. What is the maximum mass of fluoride ions you would get from a 0.250-L glass of water?

Answers

11. 0.350 L
12. 7.5 kg
13. 0.38 mg

Answers

14. 4.1 mol
15. 0.25 mol
16. 0.403 L
17. 54 mL

14. Seawater contains approximately 0.055 mol/L of magnesium chloride. What amount, in moles, of magnesium chloride is present in 75 L of seawater?
15. A bottle of 5.0 mol/L hydrochloric acid is opened in the laboratory, and 50 mL of it is poured into a beaker. What amount of acid is in the beaker?
16. A household ammonia solution (e.g., a window-cleaning solution) has a concentration of 1.24 mol/L. What volume of this solution would contain 0.500 mol of $NH_{3(aq)}$?
17. A student needs 0.14 mol of $Na_2SO_{4(aq)}$ to do a quantitative analysis. The concentration of her solution is 2.6 mol/L $Na_2SO_{4(aq)}$. What volume of solution does she need to measure?

Making Connections

18. When shopping for a floor cleaner, you have a choice between a dilute solution that is used directly and a concentrated solution of the same chemical that is diluted with water at home. How would you decide which one to buy? Describe several criteria you would use.

Mass, Volume, and Concentration Calculations

While the mole is a very important unit, measurements in a chemistry laboratory are usually of mass (in grams) and of volume (in millilitres). A common chemistry calculation involves the mass of a substance, the volume of a solution, and the molar concentration of that solution. This type of calculation requires the use of two conversion factors—one for molar mass and one for molar concentration. Calculations using molar mass are just like the ones you did in Unit 2. For example, a chemical analysis requires 2.00 L of 0.150 mol/L $AgNO_{3(aq)}$. What mass of silver nitrate solid is required to prepare this solution? First, you must determine the amount of silver nitrate needed, in moles.

$$n_{AgNO_3} = 2.00\ \cancel{L} \times \frac{0.150\ \text{mol}}{1\ \cancel{L}}$$

$$n_{AgNO_3} = 0.300\ \text{mol}$$

You can then convert this amount into a mass of silver nitrate by using its molar mass, *M*. The molar mass of silver nitrate is 169.88 g/mol.

$$m_{AgNO_3} = 0.300\ \cancel{\text{mol}} \times \frac{169.88\ \text{g}}{1\ \cancel{\text{mol}}}$$

$$m_{AgNO_3} = 51.0\ \text{g}$$

The solution requires 51.0 g of solid silver nitrate.

If you clearly understand these two steps, you could combine them into one calculation.

$$m_{AgNO_3} = 2.00\ \cancel{L} \times \frac{0.150\ \cancel{\text{mol}}}{1\ \cancel{L}} \times \frac{169.88\ \text{g}}{1\ \cancel{\text{mol}}}$$

$$m_{AgNO_3} = 51.0\ \text{g}$$

In order to successfully combine the steps into one operation, as shown above, you need to pay particular attention to the units in the calculation. Cancelling the units will help you to check your procedure.

Sample Problem 10

To study part of the water treatment process in a laboratory, a student requires 1.50 L of 0.12 mol/L aluminum sulfate solution. What mass of aluminum sulfate must she measure for this solution?

Solution

$v_{Al_2(SO_4)_{3(aq)}} = 1.50\ L$

$C_{Al_2(SO_4)_3} = 0.12\ mol/L$

$M_{Al_2(SO_4)_3} = 342.14\ g/mol$

$$n_{Al_2(SO_4)_3} = 1.50\ \not{L} \times \frac{0.12\ mol}{1\ \not{L}}$$

$$= 0.180\ mol$$

$$m_{Al_2(SO_4)_3} = 0.180\ \not{mol} \times \frac{342.14\ g}{1\ \not{mol}}$$

$$m_{Al_2(SO_4)_3} = 61.6\ g$$

or

$$m_{Al_2(SO_4)_3} = 1.50\ \not{L} \times \frac{0.12\ \not{mol}}{1\ \not{L}} \times \frac{342.14\ g}{1\ \not{mol}}$$

$$m_{Al_2(SO_4)_3} = 61.6\ g$$

The student will need 61.6 g of aluminum sulfate.

Another similar calculation involves the use of a known mass and volume to calculate the molar concentration of a solution. This is similar to the examples given above, in reverse order.

Sample Problem 11

Sodium carbonate is a water softener that is a significant part of the detergent used in a washing machine. A student dissolves 5.00 g of solid sodium carbonate to make 250 mL of a solution to study the properties of this component of detergent. What is the molar concentration of the solution?

Solution

$m_{Na_2CO_3} = 5.00\ g$

$v_{Na_2CO_3} = 250\ mL$

$M_{Na_2CO_3} = 105.99\ g/mol$

$$n_{Na_2CO_3} = 5.00\ \not{g} \times \frac{1\ mol}{105.99\ \not{g}}$$

$$= 0.0472\ mol$$

$$C_{Na_2CO_3} = \frac{0.0472\ mol}{0.250\ L}$$

$$C_{Na_2CO_3} = 0.189\ mol/L$$

The molar concentration of the solution is 0.189 mol/L.

Practice

Understanding Concepts

19. A chemical technician needs 3.00 L of 0.125 mol/L sodium hydroxide solution. What mass of solid sodium hydroxide must be measured?
20. Seawater is mostly a solution of sodium chloride in water. The concentration varies, but marine biologists took a sample with a molar concentration of 0.56 mol/L. What mass of sodium chloride was there in the biologists' 5.0-L sample?
21. Acid rain may have 355 ppm of dissolved carbon dioxide, which contributes to its acidity.
    (a) What mass of carbon dioxide is present in 1.00 L of acid rain?
    (b) Calculate the molar concentration of carbon dioxide in the acid rain sample.
22. A brine (sodium chloride) solution used in pickling contains 235 g of pure sodium chloride dissolved in 3.00 L of solution.
    (a) What is the percent concentration (%W/V) of sodium chloride?
    (b) What is the molar concentration of sodium chloride?

Answers

19. 15.0 g
20. 0.16 kg
21. (a) 355 mg
    (b) 8.07 mmol/L
22. (a) 7.83% W/V
    (b) 1.34 mol/L

SUMMARY Concentration of a Solution

Type	Definition	Units
percentage		
%V/V	$c = \frac{v_{solute}}{v_{solution}} \times 100\%$	mL/100 mL
%W/V	$c = \frac{m_{solute}}{v_{solution}} \times 100\%$	g/100 mL
%W/W	$c = \frac{m_{solute}}{m_{solution}} \times 100\%$	g/100 g
very low (number)	$c = \frac{m_{solute}}{m_{solution}}$	ppm, ppb, ppt
molar	$C = \frac{n_{solute}}{v_{solution}}$	mol/L

Section 6.3 Questions

Understanding Concepts

1. What concentration ratio is often found on the labels of consumer products? Why do you think this unit is used instead of moles per litre?
2. Bags of a D5W intravenous sugar solution used in hospitals contain a 5.0% W/V dextrose-in-water solution.
    (a) What mass of dextrose is present in a 500.0-mL bag?
    (b) What is the concentration of D5W expressed in parts per million?
3. The maximum concentration of salt in water at 0°C is 31.6 g/100 mL. What mass of salt can be dissolved in 250 mL of solution?
4. An Olympic-bound athlete tested positive for the anabolic steroid nandrolone. The athlete's urine test results showed one thousand times the maximum acceptable level of 2 mg/L. What was the test result concentration in parts per million?
5. Bald eagle chicks living around Lake Superior were found to contain PCBs (polychlorinated biphenyls) at an average

concentration of 18.9 mg/kg. If a chick had a mass of 0.6 kg, what mass of PCBs would it contain?

6. If the average concentration of PCBs in the body tissue of a human is 4.00 ppm, what mass of PCBs is present in a 64.0-kg person?
7. Each 5-mL dose of a cough remedy contains 153 mg ammonium carbonate, 267 mg potassium bicarbonate, 22 mg menthol, and 2.2 mg camphor. What is the concentration of each of these ingredients in grams per litre?
8. To prepare for an experiment using flame tests, a student requires 100 mL of 0.10 mol/L solutions of each of the following substances. Calculate the required mass of each solid.
   (a) $NaCl_{(s)}$
   (b) $KCl_{(s)}$
   (c) $CaCl_{2(s)}$
9. An experiment is planned to study the chemistry of a home water-softening process. The brine (sodium chloride solution) used in this process has a concentration of 25 g/100 mL. What is the molar concentration of this solution?
10. What volume of 0.055 mol/L glucose solution found in a plant contains 2.0 g of glucose, $C_6H_{12}O_{6(aq)}$?

Making Connections

11. What would be the implications of selling medicines in much more concentrated solutions? Present points both in favour and against.
12. Why is it important for pharmacists, nurses, and doctors to establish a common system for communicating the concentration of solutions? Use the Internet to find out what system(s) they use and create a brief pamphlet containing advice and precautions concerning the concentrations of medicines. Your target audience will be medical professionals in training.

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6.4 Drinking Water

We land mammals have a very biased view of our planet: we think almost exclusively about its solid surface. The fact is, over 70% of Earth is covered with a dilute aqueous solution averaging about 4 km deep. That represents an absolutely staggering amount of water, and it is useful to us for a great number of things—*except* drinking. Only about 0.02% of the water on Earth is fresh water in lakes and rivers, and about 0.6% more is ground water soaked into the soil and porous rock of the planet's crust.

In Canada we are extremely fortunate to have access to the most abundant supply of fresh water in the world. Our natural water supply can be divided into two types: surface water and ground water. Our surface water is in the Great Lakes, the thousands of smaller lakes, and the rivers, streams, and springs that make Canada such a wonderful place to live. Our ground water is a huge, hidden underground resource made up of thousands of **aquifers**. All of these bodies of water are potential sources of drinking water.

aquifer: an underground formation of permeable rock or loose material that can produce useful quantities of water when tapped by a well concentration of 18.9 mg/kg. If a chick had a mass of 0.6 kg, what mass of PCBs would it contain?

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aquifer: an underground formation of permeable rock or loose material that can produce useful quantities of water when tapped by a well

Water is continually on the move: flowing downhill, moving between surface water and ground water, and following the hydrologic cycle (**Figure 1**). Given this abundant natural resource of water, it seems ironic that we have to be concerned about the state of our drinking water, but this is indeed the case. Canada's population is very concentrated, with more and more people living in urban or suburban areas in the southern portion of the country than elsewhere. Where people live in high concentrations, human activity almost invariably has an effect on the water supply.

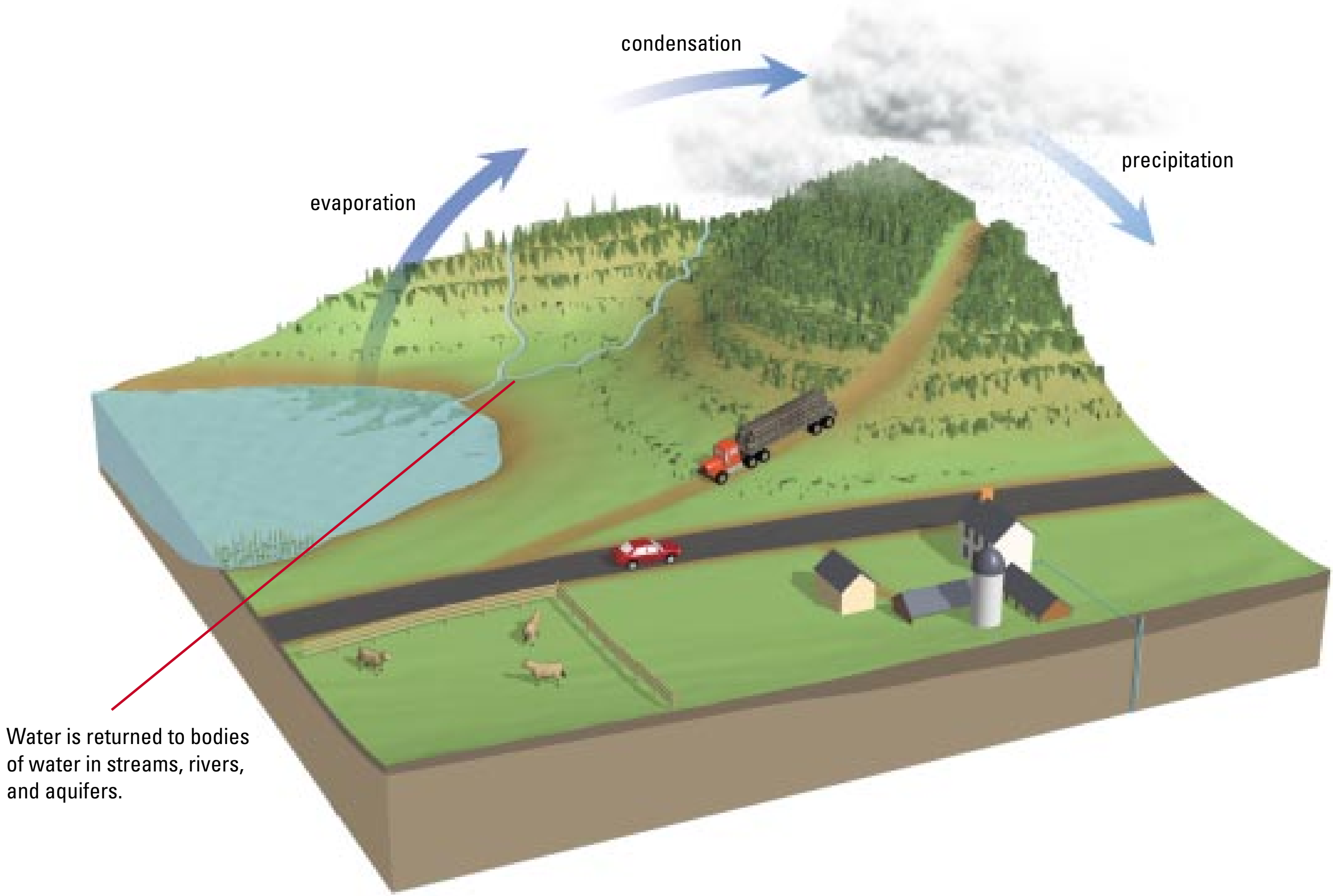

Figure 1
The hydrologic cycle provides the fresh water used by agriculture, mining, industry, and municipalities.

Of course, even completely natural, uncontaminated water contains many substances besides water molecules: living organisms, suspended particles, and a wide range of naturally occurring dissolved chemicals from the surrounding rocks and minerals. Calcium, magnesium, and sodium are the most common cations, while hydrogen carbonate, sulfate, and chloride are the most common anions. The concentration of naturally occurring ions varies widely from one body of water to another. For example, the ion concentration is 48 mg/L in Lake Superior, and 329 mg/L in the Grand River in southern Ontario.

Water Contamination

The advent of people, particularly large numbers of people living in fairly small areas, has changed the quantities and types of substances that find their way into the water. We call these substances, collectively, contaminants, and classify them into three categories: biological (including viruses, bacteria, and algae), physical (suspended particles that make the water appear "dirty"), and chemical (all dissolved substances, including metals, manufactured chemicals, and even artificially high levels of natural minerals).

Water has always contained contaminants, and always threatened the health of those who depend on it. So why do we need to be more concerned about contamination, and particularly chemical contamination, now than in the past? Quite simply, we are producing, transporting, and dumping larger quantities of a greater variety of chemicals now than at any time in the past. While biological contamination was most likely a leading cause of death and illness in earlier centuries, the 20th century's Industrial Revolution has placed a completely different set of stresses on our water supply: chemical contaminants. We are now using chemicals in every aspect of our lives, from growing our food to running our hand-held computers. And not all of these chemicals are staying neatly where we put them (**Figure 2**). They leak, they run off, they leach out, and they are dumped, and they end up in our water.

Figure 2
In this stream, pollution is visible, but this is not always the case.

The environment does have a certain tolerance for pollution. Many substances, if present only in low concentrations, can be broken down naturally. But in the quantities released and discarded by today's society, the overload of nitrates, phosphates, and industrial wastes eventually puts the aquatic ecosystem out of balance, leading to low oxygen levels. Fortunately, however, given enough time, this damage is reversible.

Sometimes the damage caused by pollutants in our waterways, including PCBs, dioxins, heavy metals, and some pesticides, cannot be reversed. These persistent chemicals are not broken down by natural processes. Even in tiny amounts some of these substances can cause serious harm. PCBs and dioxins are carcinogenic (cancer-causing), and heavy metals have been linked to impaired brain development in vertebrates. Such toxic chemicals seriously contaminate the Great Lakes, the Fraser River, and the St. Lawrence River. We can be certain that they are also in our ground water.

The most common sources of water pollution are listed in **Table 1**. Others include industrial leaks or spills; highway or railway accidents resulting in spills; byproducts from coal-fired power plants, old coal gasification sites, and petroleum refineries; underground waste disposal; and contaminants in rain, snow,

Table 1: Common Sources and Examples of Water Contamination

Source	Typical contamination
inadequate septic systems or leaky sewer lines	untreated sewage containing bacteria, nitrates, and phosphates
landfill leachate	heavy metals, e.g., mercury, lead, cadmium; bacteria; acids; organic compounds, e.g., benzene ($C_6H_{6(l)}$) and tetrachloroethylene ($C_2Cl_{4(l)}$)
road salt storage areas or road salt runoff	sodium, potassium, and calcium chlorides
livestock wastes	nitrates, heavy metals, bacteria
agricultural and residential use of fertilizers, including treated sewage sludge	nitrates and phosphates
crop and forest spraying	pesticides
leaky tanks or pipelines containing petroleum products	gasoline; other organic compounds
mining and mine tailings	sulfides; cyanides; sulfuric acid; toxic heavy metals, e.g., lead, mercury, cadmium, arsenic

landfill leachate: water that has filtered through or under garbage in a landfill site, picking up pollutants during its passage and dry atmospheric fallout. The possible dangers of the various pollutants are listed in **Table 2.**

Table 2: Environmental and Health Effects of Some Water Contaminants

Contaminant	Environmental or health effect
acid	kills soil bacteria; reduces plant growth
bacteria	cause infection, possibly resulting in illness or death
heavy metals	interfere with brain and nerve development in vertebrates
mineral solids	make water cloudy, inhibiting aquatic plant growth
nitrates and phosphates	encourage plant growth, sometimes resulting in algal blooms causing deoxygenation of water
organic compounds	poisonous or carcinogenic; sometimes interfere with oxygen diffusion into surface water
pesticides	toxic to many invertebrates; may bioaccumulate to levels toxic to vertebrates
salt	kills freshwater organisms; makes water unsuitable for drinking

We use both surface water and ground water as sources for drinking water. Large towns and cities generally use surface water for the huge volumes of water they supply to people and industries. Smaller towns and more isolated rural settlements are more often supplied by municipal wells drilled down into a suitable aquifer. Farms, cottages, and rural homes may be supplied by their own small private wells.

As a source of drinking water, ground water has traditionally been considered safer than surface water because of its filtration through soil (removing the suspended solids and many of the dissolved chemicals) and its long residence underground (killing the majority of microorganisms that cannot survive for more than a few days outside a host organism).

Water obtained privately, whether from wells or from nearby surface water, may be completely untreated. The quality of the water from these wells is the responsibility of the well's owner. However, all municipal supplies of drinking water have to be monitored and tested regularly, both before and after treatment, to ensure their safety.

All levels of government in Canada have some degree of responsibility in ensuring the safety of Canada's drinking water, resulting in a patchwork of policies. The provinces and territories are responsible for setting and enforcing standards to ensure adequate drinking water treatment, while municipal governments have the responsibility for supplying safe water to their residents as an essential public service. Federal–provincial water quality guidelines list the maximum acceptable concentration (MAC) of a large number of chemicals in our treated drinking water (**Table 3**). Water treatment procedures set up by municipal public utilities commissions must conform to these water quality guidelines. Chemical technicians at water-testing labs assess water quality by measuring the amounts of various substances in the water.

Practice

Understanding Concepts

1. List the three categories of contaminants, and give at least two examples of each.

2. Briefly describe some of the ways by which contaminants enter ground water or surface water.
3. What are the potential environmental and health hazards of leaky sewer pipes?
4. Describe how pollutants might enter our drinking water from a landfill site. Include a brief discussion of what the pollutants might be, and their possible effects.
5. Create a flow chart illustrating how three different contaminants enter the ground water.
6. If a water source contained the maximum acceptable concentration of tetrachloroethylene, given in **Table 3**, what mass of the chemical would be present in 250 L of bath water?
7. The values for maximum acceptable concentration in **Table 3** are based on an average daily intake of 1.5 L of drinking water. If a community's drinking water contained the maximum acceptable concentrations of cadmium, lead, and mercury, how much of each metal would an average person consume in a year?
8. A 10.00-mL sample of drinking water was tested and found to contain 5.4 mg of nitrate ion. How does the nitrate ion concentration compare with the maximum acceptable concentration given in **Table 3**?

Answers

6. 8 mg
7. 3 mg Cd, 5.5 mg Pb, 0.5 mg Hg
8. 12:1

Making Connections

9. Using the Internet, research at least three sources for information on the problem of ground water contamination. Write a brief article outlining the sources, results, and prevention of such contamination.
   Follow the links to Nelson Chemistry 11, 6.4.

GO TO **www.science.nelson.com**

10. Propose a solution to reduce the pollution of ground water. Pick one source of contamination and suggest how its effect could be minimized.

Table 3: MAC of Selected Chemicals in Canadian Drinking Water

Substance	Typical source	MAC (ppm)
arsenic	mining waste, industrial effluent	0.025
benzene	industrial effluent, spilled gasoline	0.005
cadmium	leached from landfill	0.005
cyanide	mining waste, industrial effluent	0.2
lead	leached from landfill, old plumbing	0.010
mercury	industrial effluent, **agricultural runoff**	0.001
nitrate	agricultural runoff	45.0
tetrachloroethylene	dry cleaners	0.03
trichloromethane	water chlorination	0.1

agricultural runoff: the surface water, with its load of pollutants in solution and in suspension, that drains off farmland

Water Treatment

What water treatment procedures are in place to achieve the increasingly high quality that we demand of our drinking water? Water from a natural source is often treated in a series of steps (**Figure 3**, page 296) to make it potable, or safe to drink. The most serious concern is safeguarding health, so disinfecting to kill harmful microorganisms is the most important part of the treatment process. Besides safety, the consumer is generally most concerned about appearance, taste, and odour.

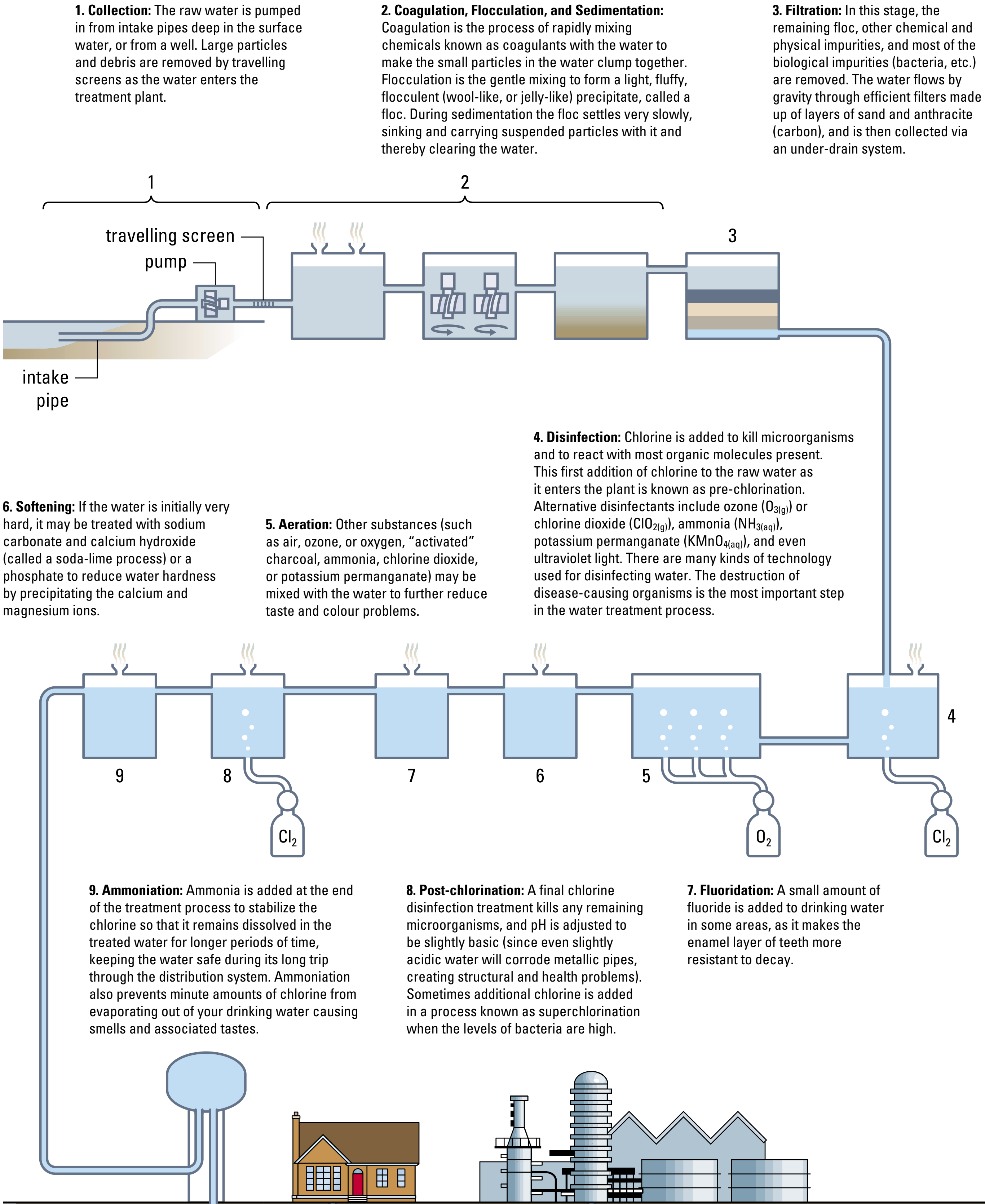

Figure 3
Although not all water treatment plants use all of these steps, all municipal water goes through some form of treatment.

When the water has passed through all these processes, it is then pumped out through the distribution system to industries, homes, and businesses.

This is, of course, an expensive process (**Figure 4**). Municipalities tend to try to find the least expensive way of achieving safe water, so occasionally water is distributed that is insufficiently treated.

Figure 4
Safe water treatment involves dealing with huge volumes daily with no margin of error allowable.

Try This **Activity**

Simulated Water Treatment

This simple activity lets you see what happens during the settling part of the water treatment process. You will use a widely available chemical known as alum, often sold at pharmacies. The term alum used commercially refers to one of the hydrates of: aluminum sulfate, $Al_2(SO_4)_{3(s)}$; sodium aluminum sulfate, $NaAl(SO_4)_{2(s)}$; potassium aluminum sulfate, $KAl(SO_4)_{2(s)}$; or ammonium aluminum sulfate, $NH_4Al(SO_4)_{2(s)}$. The container may or may not specify which compound—and it doesn't really matter for purposes of this activity. The substance is relatively harmless, and may be safely disposed of down the sink with lots of water.

Materials: alum, soil, household ammonia, 3 drinking glasses, 3 teaspoons

- Place 5 mL (about a level teaspoonful) of alum into a glass nearly full of local tap water at room temperature. Stir gently until solid crystals are no longer visible. Add a teaspoon of household ammonia and stir. What do you observe?
- Repeat with a second glass, but this time also add about 5 mL of soil to the glass before adding the alum.
- Stir only a teaspoon of soil into the water in the third glass.
- Place the glasses where they will not be disturbed and record your observations over the next several hours (preferably overnight, or a full 24 h).

(a) What differences can you see among the three tests, after several hours? Explain these differences.

(b) Why is the gelatinous precipitate normally separated in water treatment simply by allowing it lots of time to settle, rather than by filtration?

Figure 5
The contamination of Walkerton's water supply raised concerns about the processes in place to ensure a high quality of drinking water in Canada.

In Canada we have historically had small populations sharing huge water resources, so traditionally we have treated all our municipal water supplies, even though less than 2% of the daily water use of a typical Canadian is for drinking. This may change in the future. In fact, sales of bottled water for home consumption are increasing dramatically, indicating that Canadians are starting to think seriously about different water quality requirements. Perhaps it is not necessary that the water we use to wash our cars or water our gardens be as clean as the water we want to drink, cook in, or use to brush our teeth.

Ontarians received a wake-up call about our drinking water in the spring of 2000. There were unusually heavy rains in the southern part of the province, causing minor flooding in many areas. The rain saturated the ground, mixing surface contaminants with the water in the aquifers. In the town of Walkerton (**Figure 5**), this situation resulted in contamination of the drinking water, which turned out to be fatal for seven people and caused serious illness in hundreds more who suffered with nausea, severe cramps, and bloody diarrhea. The symptoms usually cleared in a few days, but about 5% of those affected developed complications, including kidney failure. The very young and the elderly were particularly susceptible. For months afterward, residents of Walkerton were required to boil their drinking water and to add household bleach to water used for washing hands and dishes.

The events in Walkerton sparked extensive investigations to determine what happened: what went wrong, who was to blame, and how such a tragedy could be avoided in the future. The town's water supply comes from three wells that draw from the ground water stored in the aquifer lying under the town. Engineers investigated the flow of ground water in the Walkerton area and established that, while it appears that the main problem was with one specific well, there were pathways to all three wells that would allow contamination to enter. Indications are that the Walkerton tragedy was due to agricultural runoff from cattle manure, which often carries bacteria. Usually, impurities are filtered out as the water percolates down, but it seems likely that this time water carrying a particularly virulent strain of *E. coli* bacteria found its way into the aquifer from which the town's water supply was drawn. This would not have been tragic had the town's water treatment system been working properly. Unfortunately, the chlorination system was not functioning, and contaminated water was delivered to all the homes depending on the town water supply. Although routine laboratory tests had shown that there were bacteria in the water, this information was not relayed to the people of Walkerton in time to prevent widespread infection. What is perhaps even more alarming is that similar contamination and chlorination failure had occurred several times during the previous five years. It seems that the incident in Walkerton was a disaster waiting to happen.

This unfortunate series of failures, in a system that most of us take for granted, has raised concerns about the safety of our drinking water. We are starting to pay more attention to our water, and asking questions about who is responsible for the quality of water in Canada.

It is clear that we can no longer take safe drinking water for granted. Our water supply is being polluted and people are becoming sick and dying from unsafe drinking water. While this has been happening for thousands of years, and is certainly still the case in many parts of the world, it is a situation that Canadians are unwilling to accept. Between 1970 and 1990 there was a five-fold increase in water consumption in Canada, so it is all the more important to consider improvements to municipal water treatment practices across the country. A major challenge in designing a better water policy for Canada is balancing the need to regulate and enforce drinking-water standards with the need to contain treatment costs.

Practice

Understanding Concepts

11. What is the most important step in freshwater treatment?
12. Prepare a two-column list of the steps in the purification of drinking water. In the first column, list the usual steps, and in the second column, list optional steps that would depend on local conditions.

Making Connections

13. Drinkable water is an important concern when hiking and camping in the backcountry; the natural water available may look clear and clean, but can be dangerous to your health. Use the Internet to research some portable technologies that are used to purify water. Include examples of both physical and chemical treatments.

    Follow the links for Nelson Chemistry 11, 6.4.

    GO TO **www.science.nelson.com**
14. Some bottles of "spring" water and "mineral" water are (perfectly legally) filled directly from a tap somewhere, and have not been further purified in any way. Look at several different brands of bottled water to find out what kinds of information are provided on the labels. Using this evidence plus any other evidence you want to introduce, decide whether it is worthwhile to buy bottled water. Outline and defend your position in a note for your school cafeteria.
15. Identify and describe a career that is related to water testing and treatment. Include a brief description of the job and the training required.

    Follow the links for Nelson Chemistry 11, 6.4.

    GO TO **www.science.nelson.com**

Explore an Issue

Take a Stand: Safe to Drink?

The Walkerton incident prompted a province-wide inspection of water treatment plants in Ontario. The inspectors found numerous problems, including substandard wells, insufficient sampling and analysis, problems with water treatment equipment, underqualified operators, and poor commmunication between the testing labs and the authorities.

How can you reduce the chances of your community being supplied with contaminated drinking water? Working in small groups, research the current state of the drinking water in your community. Your research should include the following components:

- the source and quality of the water before it is treated;
- possible sources of contaminants;
- testing standards for safe drinking water;
- treatment standards for municipal water.

Follow the links for Nelson Science 11, 6.4.

GO TO **www.science.nelson.com**

(a) Choose one aspect of the delivery of safe water to your tap. How might it be improved upon? Draft a letter to your local municipality, commending it on the strong points of its current water delivery practice while recommending improvements where you think they are needed.

DECISION-MAKING SKILLS

- ● Define the Issue
- ● Identify Alternatives
- ● Research
- ● Analyze the Issue
- ● Defend a Decision
- ○ Evaluate

Section 6.4 Questions

Understanding Concepts

1. List at least ten pollutants of water, and classify them as chemical, physical, or biological contaminants.
2. What immediate steps could a municipal water treatment facility take if it found that one of its water sources had become contaminated with a potentially harmful bacterium?
3. Why is it important that the maximum acceptable concentration of contaminants not be exceeded in drinking water? Give some specific examples in your answer.
4. Choose one specific contaminant of drinking water. Write a presentation on this contaminant. Include a diagram showing its possible sources, and information about its maximum acceptable concentration and its potentially damaging effects.
5. A technician in a water-testing laboratory finds that a sample of well water contains lead in a concentration of 0.01 g/L. Does the source of this water exceed the maximum acceptable concentration for drinking water?

Making Connections

6. On a small scale, such as in a laboratory, the main steps following the collection in the water purification sequence can be done in one or two beakers. On a large scale in a water treatment plant, a different design is used. Describe the general technological design for the sequence of water treatment and state why this design is used.
7. "Contamination of ground water is a human problem, rather than a wider environmental problem." Take a position on this statement and support it with research and reasoned arguments. Either write a letter to the editor of a local newspaper, or create a presentation that could be used at a town hall meeting of citizens in an area where the safety of the ground water is under threat.
8. Very precise technical equipment is used to test water samples. Why is this necessary?

6.5 Solution Preparation

When you mix up a jug of iced tea using a package of crystals and water, you are preparing a solution from a solid solute (actually, from several solid solutes). But when you mix the tea from a container of frozen concentrate, you are preparing a solution by dilution. Scientists use both of these methods to prepare solutions. In this course you will be preparing only aqueous solutions. The knowledge and skills for preparing solutions are necessary to complete some of the more complex laboratory investigations that come later in this course.

Preparation of Standard Solutions from a Solid

standard solution: a solution for which the precise concentration is known

Solutions with precisely known concentrations, called **standard solutions**, are routinely prepared in both scientific research laboratories and industrial processes. They are used in chemical analysis as well as for the precise control of chemical reactions. To prepare a standard solution, precision equipment is required to measure the mass of solute and volume of solution. Electronic bal-

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Figure 2
Volumetric glassware comes in a variety of shapes and sizes. The Erlenmeyer flask on the far left has only approximate volume markings, as does the beaker. The graduated cylinders have much better precision, but for high precision a volumetric flask (on the right) is used. The volumetric flask shown here, when filled to the line, contains 100.0 mL ± 0.16 mL at 20°C. This means that a volume measured in this flask is uncertain by less than 0.2 mL at the specified temperature.

Figure 1
In many school laboratories, electronic balances that measure masses to within 0.01 g or 0.001 g have replaced mechanical balances.

Activity 6.5.1

A Standard Solution from a Solid

In this activity you will practise the skills required to prepare a standard solution from a pure solid. You will need these skills in many investigations in this book.

Materials

lab apron
eye protection
copper(II) sulfate pentahydrate, $CuSO_4{\cdot}5H_2O_{(s)}$
150-mL beaker
centigram balance
laboratory scoop
stirring rod
wash bottle of **pure water**
100-mL volumetric flask with stopper
small funnel
medicine dropper
meniscus finder

Wear eye protection and a laboratory apron. Copper(II) sulfate is harmful if swallowed.

pure water: deionized or distilled water

Procedure

1. Calculate the mass of solid copper(II) sulfate pentahydrate needed to prepare 100.0 mL of a 0.5000 mol/L solution.
2. Obtain the calculated mass of copper(II) sulfate pentahydrate in a clean, dry 150-mL beaker.
3. Dissolve the solid in 40 to 50 mL of pure water.
4. Transfer the solution into a 100-mL volumetric flask. Rinse the beaker two or three times with small quantities of pure water, transferring the rinsings into the volumetric flask.
5. Add pure water to the volumetric flask until the volume is 100.0 mL.
6. Stopper the flask and mix the contents thoroughly by repeatedly inverting the flask.

Note: Store your solution for the next activity.

Answers

1. 3.55 g
2. 200 g
4. (a) 33.2 g
5. (a) 5.93 g

Figure 3
Hard-water deposits such as calcium carbonate can seriously affect water flow in a pipe.

Figure 4
Solutions of sodium hydroxide in very high concentration are sold as cleaners for clogged drains. The same solution can be made less expensively by dissolving solid lye (a commercial name for sodium hydroxide) in water. The pure chemical is very caustic and the label on the lye container recommends rubber gloves and eye protection.

dilution: the process of decreasing the concentration of a solution, usually by adding more solvent

stock solution: a solution that is in stock or on the shelf (i.e., available); usually a concentrated (possibly even saturated) solution

Practice

Understanding Concepts

1. To test the hardness of water (**Figure 3**), an industrial chemist performs an analysis using 100.0 mL of a 0.250 mol/L standard solution of ammonium oxalate. What mass of monohydrate ammonium oxalate, $(NH_4)_2C_2O_4 \cdot H_2O_{(s)}$, is needed to make the standard solution?
2. Calculate the mass of solid lye (sodium hydroxide) needed to make 500 mL of a 10.0 mol/L strong cleaning solution (**Figure 4**).
3. List several examples of solutions that you prepared from solids in the last week.

Applying Inquiry Skills

4. You have been asked to prepare 2.00 L of a 0.100 mol/L aqueous solution of cobalt(II) chloride dihydrate for an experiment.
   (a) Show your work for the pre-lab calculation.
   (b) Write a complete specific procedure for preparing this solution, as in Activity 6.5.1. Be sure to include all necessary precautions.
5. (a) A technician prepares 500.0 mL of a 0.0750 mol/L solution of potassium permanganate as part of a quality-control analysis in the manufacture of hydrogen peroxide. Calculate the mass of potassium permanganate required to prepare the solution.
   (b) Write a laboratory procedure for preparing the potassium permanganate solution. Follow the conventions of communication for a procedure in a laboratory report.

Preparation of Standard Solutions by Dilution

A second method of preparing solutions is by **dilution** of an existing solution. You apply this process when you add water to concentrated fruit juice, fabric softener, or a cleaning product. Because dilution is a simple, quick procedure, it is common scientific practice to begin with a **stock solution** or a standard solution, and to add solvent (usually water) to decrease the concentration to the desired level.

While there are no hard and fast rules, we often describe solutions with a molar concentration of less than 0.1 mol/L as dilute, while solutions with a concentration of greater than 1 mol/L may be referred to as concentrated.

Calculating the new concentration after a dilution is straightforward because the quantity (mass or amount) of solute is not changed by adding more solvent. Therefore, the mass (or amount) of solute before dilution is the same as the mass (or amount) of solute after dilution.

$m_i = m_f$ or $n_i = n_f$
m_i = initial mass of solute
m_f = final mass of solute
n_i = initial amount of solute (in moles)
n_f = final amount of solute (in moles)

Using the definitions of solution concentration ($m = vc$ or $n = vC$), we can express the constant quantity of solute in terms of the volume and concentration of solution.

$v_iC_i = v_fC_f$
C_i = initial concentration

C_f = final concentration
v_i = initial volume before dilution
v_f = final volume after dilution

This means that the concentration is inversely related to the solution's volume. For example, if water is added to 6% hydrogen peroxide disinfectant until the total volume is doubled, the concentration becomes one-half the original value, or 3%.

Any one of the values expressed may be calculated for the dilution of a solution, provided the other three values are known. (Note that the dilution calculation for percentage weight by weight (%W/W) will be slightly different because the mass of solution is used; i.e., $m_{solute} = m_{solution}c$.)

Many consumer and commercial products are purchased in concentrated form and then diluted before use. This saves on shipping charges and reduces the size of the container—making the product less expensive and more environmentally friendly. Citizens who are comfortable with dilution techniques can live more lightly on Earth (**Figure 5**).

Figure 5
You can save money and help save the environment by diluting concentrated products.

Sample Problem 1

Water is added to 0.200 L of 2.40 mol/L $NH_{3(aq)}$ cleaning solution, until the final volume is 1.000 L. Find the molar concentration of the final, diluted solution.

Solution

$v_i = 0.200$ L
$v_f = 1.000$ L
$C_i = 2.40$ mol/L

$$v_iC_i = v_fC_f$$

$$\underset{NH_3}{C_f} = \frac{v_iC_i}{v_f}$$

$$\underset{NH_3}{C_f} = \frac{0.200\ \cancel{L} \times 2.40\ \text{mol}/\cancel{L}}{1.000\ \text{L}}$$

$$= 0.480\ \frac{\text{mol}}{\text{L}}$$

The molar concentration of the final, diluted solution is 0.480 mol/L.

Alternatively, this problem can be solved another way:

$$n_{NH_3} = 0.200\ \cancel{L} \times \frac{2.40\ \text{mol}}{1.00\ \cancel{L}}$$

$$= 0.480\ \text{mol}$$

$$C_{NH_3} = \frac{0.480\ \text{mol}}{1.000\ \text{L}}$$

$$C_{NH_3} = 0.480\ \text{mol/L}$$

Again, the molar concentration of the final, diluted solution is 0.480 mol/L.

Sample Problem 2

A student is instructed to dilute some concentrated $HCl_{(aq)}$ (36%) to make 4.00 L of 10% solution (**Figure 6**). What volume of hydrochloric acid solution should the student initially measure to do this?

Solution

$c_i = 36\%$
$v_f = 4.00 \text{ L}$
$c_f = 10\%$

$$v_i c_i = v_f c_f$$

$$v_i = \frac{v_f c_f}{c_i}$$

$$= \frac{4.00 \text{ L} \times 10\%}{36\%}$$

$$v_i = 1.1 \text{ L}$$

The student should measure out 1.1 L of 36% hydrochloric acid to make 4.00 L of the dilute solution.

Figure 6
When diluting all concentrated reagents, especially acids, always add the concentrated reagent to water. When acids are mixed with water, heat is often produced. If a large amount of acid is added to a small amount of water, the water might boil and spatter the reagent out of the container. Remember "AAA": Always Add Acid.

The dilution technique is especially useful when you need to manipulate the concentration of a solution. For example, when doing scientific or technological research, you may want to slow down a reaction that proceeds too rapidly or too violently with a concentrated solution. You could do this by lowering the concentration of the solution. In the medical and pharmaceutical industries, prescriptions require not only minute quantities, but also extremely precise measurement. If the solutions are diluted before being sold, it is much easier for a patient to take the correct dose. For example, it's easier to accurately measure out 10 mL (two teaspoons) of a cough medicine than it is to measure one-fifth of a teaspoon, which the patient would have to do if the medicine were 10 times more concentrated.

The preparation of standard solutions by dilution requires a means of transferring precise volumes of solution. You know how to use graduated cylinders to measure volumes of solution, but graduated cylinders are not precise enough when working with small volumes. To deliver a very precise, small volume of solution, a laboratory device called a pipet is used. A 10-mL graduated pipet has graduation marks every tenth of a millilitre (**Figure 7**). This type of pipet can transfer any volume from 0.1 mL to 10.0 mL, and is more precise than a graduated cylinder. A volumetric pipet transfers only one specific volume, but has a very high precision. For example, a 10-mL volumetric (or delivery) pipet is designed to transfer 10.00 mL of solution with a precision of ± 0.02 mL. The volumetric pipet is often inscribed with TD to indicate that it is calibrated *to deliver* a particular volume with a specified precision. Both kinds of pipet come in a range of sizes and are used with a pipet bulb.

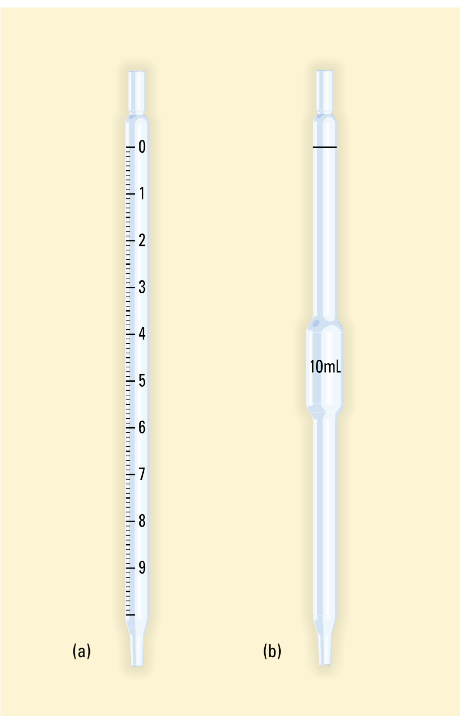

Figure 7
A graduated pipet (a) measures a range of volumes, while a volumetric pipet (b) is calibrated to deliver (TD) a fixed volume.

Activity 6.5.2

A Standard Solution by Dilution

The purpose of this activity is to practise the procedure and skills for precisely diluting the standard solution prepared in the previous activity (Activity 6.5.1).

Copper(II) sulfate is harmful if swallowed. Wear eye protection and a laboratory apron.

Use of a pipet bulb is essential. Do not pipet by mouth.

Materials

lab apron
eye protection
0.5000 mol/L $CuSO_{4(aq)}$ standard solution
150-mL beaker
10-mL graduated or volumetric pipet
pipet bulb
wash bottle of pure water
100-mL volumetric flask with stopper
small funnel
medicine dropper
meniscus finder

Procedure

1. Calculate the volume of a 0.5000 mol/L standard solution of $CuSO_{4(aq)}$ required to prepare 100.0 mL of a 0.05000 mol/L solution.
2. Add 40 mL to 50 mL of pure water to a clean 100-mL volumetric flask.
3. Measure the required volume of the standard solution using a 10-mL pipet.
4. Transfer the required volume of the initial (standard) solution into the 100-mL volumetric flask (**Figure 8(a)**).
5. Add pure water until the final volume is reached (**Figure 8(b)**).
6. Stopper the flask and mix the solution thoroughly (**Figure 8(c)**).

Analysis

(a) Why was 40 mL of water placed in the flask before adding the standard solution?
(b) Why wasn't 100 mL of water placed in the flask?

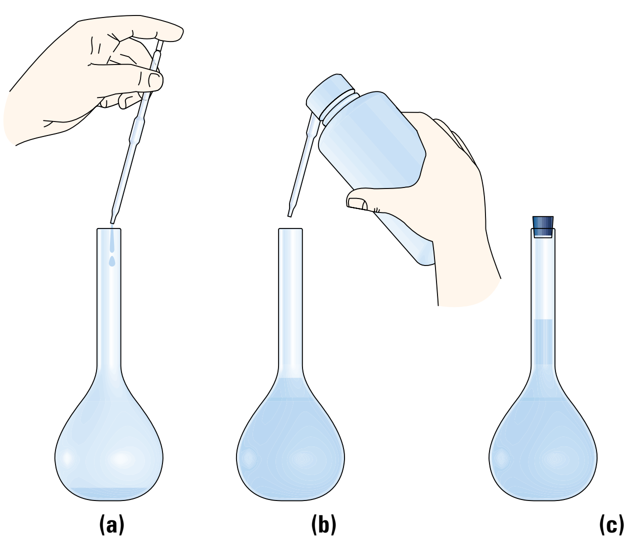

Figure 8
(a) The appropriate volume of $CuSO_{4(aq)}$ is transferred to a volumetric flask.
(b) The initial amount of copper(II) sulfate solute is not changed by adding water to the flask.
(c) In the final dilute solution, the initial amount of copper(II) sulfate is still present, but it is distributed throughout a larger volume; in other words, it is diluted.

Answers

6. 22.5 mL
7. (a) 2.50 mmol/L
   (b) 3.99 mg
8. (a) 1.000:25.00 or 4.000%
   (b) 25.00 times the volume

Practice

Understanding Concepts

6. Many solutions are prepared in the laboratory from purchased concentrated solutions. What volume of concentrated 17.8 mol/L stock solution of sulfuric acid would a laboratory technician need to make 2.00 L of 0.200 mol/L solution by dilution of the original, concentrated solution?
7. In a study of reaction rates, you need to dilute the copper(II) sulfate solution prepared in Activity 6.5.2, A Standard Solution by Dilution. You take 5.00 mL of 0.05000 mol/L $CuSO_{4(aq)}$ and dilute this to a final volume of 100.0 mL.
   (a) What is the final concentration of the dilute solution?
   (b) What mass of $CuSO_{4(s)}$ is present in 10.0 mL of the final dilute solution?
   (c) Can this final dilute solution be prepared directly using the pure solid? Defend your answer.
8. A student tries a reaction and finds that the volume of solution that reacts is too small to be measured precisely. She takes a 10.00-mL volume of the solution with a pipet, transfers it into a clean 250-mL volumetric flask containing some pure water, adds enough pure water to increase the volume to 250.0 mL, and mixes the solution thoroughly.
   (a) Compare the concentration of the dilute solution to that of the original solution.
   (b) Compare the volume that will react now to the volume that reacted initially.
   (c) Predict the speed or rate of the reaction using the diluted solution compared with the rate using the original solution. Explain your answer.
9. List several examples of dilutions you have made from more concentrated solutions in the last week.

Reflecting

10. "Precise dilution can produce solutions of much more accurate concentration compared with dilute solutions prepared directly by measuring the mass of the pure solute." Consider this statement. Under what circumstances would this statement *not* be true?

Section 6.5 Questions

Understanding Concepts

1. List several reasons why scientists make solutions in the course of their work.
2. (a) Briefly describe two different ways of making a solution.
   (b) When would it be most appropriate to use each method?
3. In a quantitative analysis for sulfate ions in a water treatment plant, a technician needs 100 mL of 0.125 mol/L barium nitrate solution. What mass of pure barium nitrate is required?
4. A 1.00-L bottle of purchased acetic acid is labelled with a concentration of 17.4 mol/L. A dyer dilutes this entire bottle of concentrated acid to prepare a 0.400 mol/L solution. What volume of diluted solution is prepared?

5. A 10.00-mL sample of a test solution is diluted in an environmental laboratory to a final volume of 250.0 mL. The concentration of the diluted solution is found to be 0.274 g/L. What was the concentration of the original test solution?

Applying Inquiry Skills

6. A chemical analysis of silver uses 100 mL of a 0.155 mol/L solution of potassium thiocyanate, KSCN. Write a complete, specific procedure for preparing the solution from the solid. Include all necessary calculations and precautions.
7. A laboratory technician needs 1.00 L of 0.125 mol/L sulfuric acid solution for a quantitative analysis experiment. A commercial 5.00 mol/L sulfuric acid solution is available from a chemical supply company. Write a complete, specific procedure for preparing the solution. Include all necessary calculations and safety precautions.
8. As part of a study of rates of reaction, you are to prepare two aqueous solutions of cobalt(II) chloride.
   (a) Calculate the mass of solid cobalt(II) chloride hexahydrate you will need to prepare 100.0 mL of a 0.100 mol/L cobalt(II) chloride solution.
   (b) Calculate how to dilute this solution to make 100.0 mL of a 0.0100 mol/L cobalt(II) chloride solution.
   (c) Write a list of Materials, and a Procedure for the preparation of the two solutions. Be sure to include all necessary safety precautions and disposal steps.
   (d) With your teacher's approval, carry out your Procedure.

Making Connections

9. It has been suggested that it is more environmentally friendly to transport chemicals in a highly concentrated state. List arguments for and against this position.
10. For many years the adage, "The solution to pollution is dilution" was used by individuals, industries, and governments. They did not realize at that time that chemicals, diluted by water or air, could be concentrated in another system later. Identify and describe a system in which pollutants can become concentrated.

Reflecting

11. Recall the work that you did in Grade 10 Science with reaction rates. You compared the reaction rate for a series of solutions with varying concentrations. Write the initial steps of a simple procedure to prepare the solutions for testing the reaction rates of, for example, zinc with stock hydrochloric acid. How have your knowledge and skills progressed since you did this investigation in Grade 10?

Chapter 6 Summary

Key Expectations

Throughout the chapter, you have had the opportunity to do the following:

- Explain the formation of solutions involving various solutes in water and nonpolar solutes in nonpolar solvents. (6.1, 6.2)
- Supply examples from everyday life of solutions involving all three states. (6.1)
- Describe and explain the properties of water, and demonstrate an understanding of its importance as a universal solvent. (6.2)
- Use the terms: solute, solvent, solution, electrolyte, leachate, runoff, concentration, standard solution, stock solution, and dilution. (all sections)
- Solve solution concentration problems using a variety of units. (6.3, 6.5)
- Explain the origins of pollutants in natural waters and identify maximum allowable concentrations of metallic and organic contaminants in drinking water. (6.4)
- Develop and use the technological skills for the preparation of solutions of required concentrations. (6.5)
- Describe consumer and commercial examples of solutions, including those in which the concentration must be precisely known. (6.5)

Key Terms

acid
aquifer
agricultural runoff
aqueous solution
base
concentrated
concentration
dilute
dilution
dissociation
electrolyte
homogeneous mixture
intermolecular force
intramolecular force
landfill leachate
molar concentration
mole
neutral
nonelectrolyte
parts per million
pure water
solute
solution
solvent
standard solution
stock solution

Make a Summary

1. Make four small concept maps to express each of the following central concepts. Draw them in the corners of a page.
   (a) electrolytes and nonelectrolytes
   (b) calculations related to concentration of solution
   (c) preparation of a solution from a solid solute and by dilution of an existing solution
   (d) the sources of water and pollution and the refining of water

   What central concept or substance can be used to link all of these concept maps? Add this central concept or substance to the centre of the page and link it to the four concept maps prepared above.

Reflect on your Learning

Revisit your answers to the Reflect on Your Learning questions at the beginning of this chapter.

- How has your thinking changed?
- What new questions do you have?

Chapter 6 Review

Understanding Concepts

1. What do all concentration units have in common?
2. In general, what type of solvent dissolves
   (a) ionic compounds?
   (b) polar compounds?
   (c) nonpolar compounds?
3. Water is capable of dissolving many things.
   (a) Provide some reasons, based on the theory you have studied, for water being "the universal solvent."
   (b) List some reasons for dissolving substances in water. Give examples for these reasons.
   (c) How does water's property as a powerful solvent affect our drinking water?
4. Write IUPAC names for the solute and solvent in the following household solutions:
   (a) brine, $NaCl_{(aq)}$
   (b) vinegar, $HC_2H_3O_{2(aq)}$
   (c) washing soda, $Na_2CO_{3(aq)}$
   (d) pancake syrup, $C_{12}H_{22}O_{11(aq)}$
   (e) vodka, $C_2H_5OH_{(aq)}$
5. Partly skimmed milk contains 2.0 g of milk fat (MF) per 100 mL of milk. What mass of milk fat is present in 250 mL (one glass) of milk?
6. A shopper has a choice of yogurt with three different concentrations of milk fat: 5.9% MF, 2.0% MF, and 1.2% MF (**Figure 1**). If the shopper wants to limit his milk fat intake to 3.0 g per serving, calculate the mass of the largest serving he could have for each type of yogurt.

Figure 1
The label tells us the concentration of milk fat in yogurt.

7. What volume of vinegar contains 15 mL of pure acetic acid (**Figure 2**)?

Figure 2
The label tells us the concentration of acetic acid in vinegar.

8. Water from a well is found to have a nitrate ion concentration of 55 ppm, a level considered unsafe for drinking. Calculate the mass of nitrate ions in 200 mL of the water.
9. Calculate the molar concentration of the following solutions:
   (a) 0.35 mol copper(II) nitrate is dissolved in water to make 500 mL of solution.
   (b) 10.0 g of sodium hydroxide is dissolved in water to make 2.00 L of solution.
   (c) 25 mL of 11.6 mol/L $HCl_{(aq)}$ is diluted to a volume of 145 mL.
   (d) A sample of tap water contains 16 ppm of magnesium ions.
10. The label on a bottle of "sports drink" indicates that the beverage contains water, glucose, citric acid, potassium citrate, sodium chloride, and potassium phosphate, as well as natural flavours and artificial colours. The label also indicates that the beverage contains 50 mg of sodium ions and 55 mg of potassium ions per 400 mL serving.
    (a) Write chemical formulas for all the compounds named on the label, and classify them as ionic or molecular. Further classify the molecular

compounds as acid or neutral. You may find the list of Common Chemicals in Appendix C useful in answering this question.
   (b) Which compound imparts a sweet taste to the beverage, and which imparts a tangy taste?
   (c) Calculate the concentration in parts per million of the sodium and potassium ions in the beverage.
11. Standard solutions of sodium oxalate, $Na_2C_2O_{4(aq)}$, are used in a variety of chemical analyses. What mass of sodium oxalate is required to prepare 250.0 mL of a 0.375 mol/L solution?
12. Phosphoric acid is the active ingredient in many commercial rust-removing solutions. Calculate the volume of concentrated phosphoric acid (14.6 mol/L) that must be diluted to prepare 500 mL of a 1.25 mol/L solution.
13. Laboratories order hydrochloric acid as a concentrated solution (e.g., 36% W/V). What initial volume of concentrated laboratory hydrochloric acid should be diluted to prepare 5.00 L of a 0.12 mol/L solution for an experiment?

Applying Inquiry Skills

14. Describe two methods used to prepare standard solutions.
15. What is a standard solution, and why is such a solution necessary?
16. Scientists have developed a classification system to help organize the study of matter. Describe an empirical test that can be used to distinguish between the following classes of matter:
   (a) electrolytes and nonelectrolytes
   (b) acids, bases, and neutral compounds
17. Standard solutions of potassium hydrogen tartrate, $KHC_4H_4O_{6(aq)}$, are used in chemical analyses to determine the concentration of bases such as sodium hydroxide.
   (a) Calculate the mass of potassium hydrogen tartrate that is measured to prepare 100.0 mL of a 0.150 mol/L standard solution.
   (b) Write a complete procedure for the preparation of this standard solution, including specific quantities and equipment.
18. In chemical analysis we often dilute a stock solution to produce a required standard solution.
   (a) What volume of a 0.400 mol/L stock solution is required to produce 100.0 mL of a 0.100 mol/L solution? (Note that the high precision of each of these solutions indicates that they are standard solutions.)
   (b) Write a complete procedure for the preparation of this standard solution, including specific quantities and equipment.
19. A chemistry student was given the task of identifying four colourless solutions. Complete the **Analysis** of the investigation report.

Problem

Which of the solutions labelled A, B, C, and D is calcium hydroxide? Which is glucose? potassium chloride? sulfuric acid?

Experimental Design

Each solution, at the same concentration and temperature, is tested with red and blue litmus paper and conductivity apparatus.

Evidence

Table 1: Litmus and Conductivity Tests

Solution	Red litmus	Blue litmus	Conductivity
A	stays red	blue to red	high
B	stays red	stays blue	none
C	red to blue	stays blue	high
D	stays red	stays blue	high

Analysis

(a) Which solution is which?

Making Connections

20. In March 1989, the *Exxon Valdez* oil tanker ran aground in Prince William Sound off Alaska, spilling 232 000 barrels of oil and causing extensive environmental damage (**Figure 3**). Use the Internet to research this event.
   (a) Do oil and water dissolve in each other? Provide some reasons for your answer.
   (b) What are some of the environmental effects of an oil spill such as the one from the *Exxon Valdez*?
   (c) What are some methods used to clean up spilled oil?
   (d) Should the transportation of oil by large tanker ships be prohibited? Discuss, including some risks and benefits of this practice.

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Figure 3
The oil spill from the *Exxon Valdez* attracted worldwide attention and a demand for more responsible transportation of oil.

21. Collect at least ten examples of common solutions. The solutes should represent the three states of matter, and there should be at least two different solvents. Present your samples in a display, with a description for each sample including, if known, the concentration of each solution. Each solution should be accompanied by a card indicating any necessary safety precautions, along with the reasons for these precautions.
22. It is vitally important that medicines be administered in the correct dosages. In a hospital setting, many substances are given intravenously as solutions. Research at least five intravenous solutions, and create a table showing the name of the solution, a typical concentration, and the medical purpose for which the solution is administered.
23. How do various pollutants get into natural water? Create a flow chart to illustrate the source, route, and potential health effect of each contaminant.
24. Use the Internet to discover the maximum acceptable levels of microorganisms and chemicals in drinking water. Read a summary of Health Canada's *Guidelines for Canadian Drinking Water Quality*.
    (a) Choose one potentially dangerous contaminant from Health Canada's list; find the MAC of that contaminant.
    (b) Find an example of a place where the MAC of your chosen contaminant has been exceeded in drinking water.
    (c) What were some of the problems resulting form this incident?
    (d) What steps were taken to correct the problem?

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Exploring

25. Reverse osmosis is a water treatment technique currently widely used for producing many brands of bottled water, and also for purifying seawater. Outdoor supply stores sell reverse osmosis kits for purifying water on wilderness trips, or as emergency equipment for use in lifeboats. Use the Internet to research reverse osmosis. Find the pressures needed to produce pure drinking water from seawater by this process. Find out under what circumstances reverse osmosis is commercially viable, and find an example of a reverse osmosis plant that is operating, desalinating seawater, today. Present your findings as if you were trying to convince a coastal community to install a reverse osmosis facility.

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26. When travelling in the wilderness or in another country, Canadians are sometimes advised to take chlorine tablets with them to put in their drinking water. Use the Internet to research the purpose of using these tablets, their ingredients, and their advertised effects.

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