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## UNIT 3

## Matter as Solutions, Acids, and Bases

**Chapter 6 *Acids and Bases***

Answers to Questions for Comprehension, notes on Figures and Web Links appear throughout the chapter.

# Teaching Unit 3: Matter as Solutions, Acids, and Bases

(32% of the course time; approximately 40 hours)

**Student Textbook pages 158–251**

## General Outcomes

- Investigate solutions and describe their physical and chemical properties.
- Describe acid and base solutions qualitatively and quantitatively.

## Contents



## Content Summary

Solution chemistry is vitally important in our bodies, in the atmosphere, in the oceans, lakes and rivers, and in many industrial processes. In this unit, students will learn the concepts and skills fundamental to understanding and investigating solution chemistry. They will study the various types of solutions, their properties, and the factors that affect solubility. They will learn about the various ways that concentration may be expressed and discover the skills and techniques involved in working experimentally with solutions. Students will learn how to distinguish between strong and weak acids and bases, and how chemists use the pH scale and acid-base indicators to express the degree to which a solution is acidic or basic.

Chapter 5 begins by identifying the components of a solution and by illustrating types of solutions with examples. The dissolving process is described in terms of solute-solute, solvent-solvent, and solute-solvent interactions, and the energies involved in each interaction. An important property of an aqueous solution is its electrical conductivity, and students conduct an investigation to distinguish between electrolytes and non-electrolytes. The different solubility terms are introduced with guidelines for predicting which ion combinations are soluble and which combinations are insoluble in water. Students investigate how the solubility of potassium nitrate in water changes with temperature and, by combining their results with those from other groups, will plot a solubility curve. The factors affecting the solubility of gases in water are discussed, with examples related to heat pollution caused by emissions of warm water to lakes, and gases dissolved in the blood of scuba divers. This chapter teaches the importance of solution concentration, including the different ways of describing solution concentration. This is illustrated by examining the problem of mercury pollution by biomagnification and bioaccumulation. Chapter 5 concludes with the calculations and experimental techniques used by chemists to prepare and dilute standard solutions.

A fundamental property of an aqueous solution is its acidity, and this is explored in Chapter 6. Students will learn how to identify a solution as acidic, basic, or neutral and will review the rules for naming acids and bases. Explaining the properties of acids and bases introduces the Arrhenius theory, which students are able to test by experiments. An important principle of the scientific method—that theories are adjusted or discarded as the result of experiments—is well illustrated by development of the modified Arrhenius theory of acids and bases. A careful distinction is made between strong and weak acids and strong and weak bases, and students will design and carry out an investigation to classify some unknown solutions. A comparison of the ionization of monoprotic acids with polyprotic acids is made, and reactions of monoprotic bases and polyprotic bases in water are discussed. The concentration of ions in water leads to the pH concept, and how the pH of a solution may be measured using indicators or a meter. Students will investigate the effect of dilution on the pH of an acidic solution. The pOH scale is introduced, and students will have the opportunity to solve problems relating to pH, pOH, and ion concentration. Throughout the chapter, acid-base chemistry is illustrated by applications in the home, the environment and industry.

## Curriculum Fit

This unit builds on *Science 8*, Unit A: Mix & Flow of Matter; *Science 9*, Unit B: Matter and Chemical Change; *Science 9*, Unit C: Environmental Chemistry; *Science 10*, Unit A: Energy and Matter in Chemical Change.

In *Science 8*, Unit A: Mix & Flow of Matter, students were introduced to fundamental concepts such as the properties of fluids, the components of a solution, and concentration. They also investigated the factors affecting solubility. In Unit E, Freshwater and Saltwater Systems, students analyzed human impacts on aquatic systems.

In *Science 9*, Unit B: Matter and Chemical Change, students were introduced to exothermic and endothermic changes, and to caustic materials. They extended their knowledge of chemical nomenclature, and described chemical reactions using word equations and chemical formulas. In *Science 9*, Unit C: Environmental Chemistry, students learned about acids and bases. They measured the pH of water samples and considered how pH affects the environment; they described the effects of acids and bases on living things. They applied and interpreted measures of concentration (in parts per million, billion, or trillion), and they looked at how living things ingest or absorb harmful materials such as DDT or mercury.

In *Science 10*, Unit A, students learned how to classify acids and bases on the basis of properties such as conductivity and pH. They became familiar with the formulas and names of some common acids, and they wrote chemical equations to describe reactions. Students used a solubility chart to predict the relative solubility of an ionic compound in water. The mole concept was introduced as was the law of conservation of mass. They looked at a number of environmental concerns, including the handling, storage and disposal of strong acids. In *Science 8, 9,* and *10*, there was an emphasis on the Workplace Hazardous Materials Information System (WHMIS) and safe practices in the laboratory.

In *Chemistry 20*, Unit C, the foundation is laid for the study of stoichiometry in Unit D. In the next unit, students' knowledge of chemical equations will be extended to include net ionic equations. They will use mole ratios in chemical equations and perform stoichiometric calculations. Students will investigate acid-base titrations involving strong monoprotic acids and strong monoprotic bases. In Chapter 5, the concept of equilibrium is introduced when discussing saturated solutions. The concept of reversible change should be carefully established because it will be important later, in Chapter 6, for understanding weak acids and weak bases. Equilibrium and the acid-base concepts in this unit are essential to the studies in *Chemistry 30*, Unit 8: Chemical Equilibrium Focussing on Acid-Base Systems.

## Core Concepts

| Concept | Outcome | Text Reference |
|---|---|---|
| Solutions and solution concentrations are applied in many common products, including medicines, beverages and household products. They are important in the environment, in chemical processes, and in scientific studies. | 20–C1.1sts<br>20–C1.2sts | Section 5.1, pp. 166-167; 173; 182<br>Section 5.3, pp. 184-185; 187; 189<br>Section 5.4, p. 199 |
| Solutions are homogeneous mixtures. Various combinations of solute and solvent phases are possible. | 20–C1.1k | Section 5.1, pp. 166-168 |
| The dissolving process involves solute-solute, solvent-solvent, and solute-solvent interactions. The sum of energies involved in each interaction determines whether a particular dissolution is an endothermic or an exothermic process. | 20–C1.3k | Section 5.1, pp. 168-170; Section 5.2, p. 177 |
| Ionic compounds that dissolve in water conduct electricity and are called electrolytes. Aqueous solutions that do not conduct electricity are called non-electrolytes. | 20–C1.4k | Section 5.1, pp.172-173 |
| Water is a prerequisite for many chemical reactions. Water separates and disperses the ions in an electrolyte. It acts as a transport medium for ions, and for the molecules of a non-electrolyte. | 20–C1.2k | Section 5.1, p.173 |
| The solubility of a solute is the amount of solute that will dissolve in a given quantity of solvent at a specified temperature. Aqueous solubilities are usually expressed in g solute per 100 mL water at 20 °C. | 20–C1.9k | Section 5.2, p.176 |
| In a saturated solution, a state of equilibrium exists between the solute and the solvent. | 20–C1.10k | Section 5.2, pp.178-179 |
| The solubility of most solids in a liquid solvent:<br>• increases with temperature.<br>• is not affected by pressure. | 20–C1.9k | Section 5.2, p.181 |
| The solubility of a gas in a liquid solvent:<br>• decreases with temperature.<br>• increases with increased pressure of the gas above the liquid. | 20–C1.9k | Section 5.2, pp.181-182 |
| Concentration and solubility characteristics are important factors in determining the safe limits of substances that may be ingested or released to the environment. | 20–C1.4sts<br>20–C1.5sts<br>20–C1.3sts | Section 5.3, p.189<br>Section 5.3, pp.184; 187<br>Section 5.4, Investigation 5.C, p.199 |
| Concentration is the quantity of solute per quantity of solution | 20–C1.5k | Section 5.3, pp.184-187 |

| Concept | Outcome | Text Reference |
|---|---|---|
| Acids and bases have been used throughout history to solve technological problems in a variety of applications. | 20–C2.1sts | Chapter 6, p. 206<br>Section 6.1, p. 208; Investigation 6.A, pp. 210-211<br>Section 6.2, pp. 223; 225<br>Section 6.3, p. 227 |
| Acids, bases and neutral solutions can be distinguished empirically using indicators, pH and conductivity measurements, and characteristic chemical reactions. | 20–C2.2k | Section 6.1, Investigation 6.A, pp. 210-211 |
| In the modified Arrhenius theory:<br>• an acid is a substance that reacts with water to produce $H_3O^+(aq)$ in aqueous solution.<br>• a base is a substance that dissociates or reacts with water to produce $OH^-(aq)$ in aqueous solution. | 20–C2.7k<br>20–C2.8k | Section 6.1, pp. 216-217 |
| A strong acid ionizes nearly 100% in water; a weak acid reacts very little in water to form $H_3O^+(aq)$. | 20–C2.10k | Section 6.2, pp. 218-222 |
| A strong base dissociates 100% into ions in water; a weak base reacts very little in water to form $OH^-(aq)$. | 20–C2.10k | Section 6.2, pp. 220-222 |
| Monoprotic acids have only one hydrogen atom per molecule that ionizes in water; polyprotic acids have two or more hydrogen atoms per molecule that ionize in water. | 20–C2.11k | Section 6.2, p. 222 |
| Monoprotic bases dissociate or react with water in one step;<br>polyprotic bases dissociate or react with water in two or more steps. | 20–C2.11k | Section 6.2, p. 223 |
| A reaction between an acid and a base ("neutralization" reaction) involves hydronium and hydroxide ions reacting to form water. | 20–C2.9k<br>20–C2.2sts | Section 6.2, pp. 224-225 |
| pH is the negative base-ten logarithm of the molar concentration of hydronium ions in a solution:<br>$pH = -\log[H_3O^+(aq)]$ | 20–C2.3k | Section 6.3, pp. 227-228 |
| When the logarithm of a measured value is recorded (such as pH or pOH), only the digits to the right of the decimal point are considered significant. | 20–C2.4k | Section 6.3, p. 228 |
| An acid-base indicator is any chemical substance that changes colour in an acidic or a basic solution. | 20–C2.6k | Section 6.3, pp. 230-233 |
| pOH is the negative base-ten logarithm of the molar concentration of hydroxide ions in a solution:<br>$pOH = -\log[OH^-(aq)]$ | 20–C2.3k | Section 6.3, pp. 235-237 |
| For a dilute solution at 25 °C,<br>pH + pOH = 14.00 | 20–C2.3k | Section 6.3, pp. 237-238 |
| Acid deposition lowers the pH below that of normal rainwater (pH = 5.6). Acid deposition is caused by burning fossil fuels and smelting metals | 20-C2.2sts | Section 6.3, p. 238 |

## Beyond the Core Concepts

| Concept | Text Reference |
|---|---|
| In the Arrhenius theory:<br>• an acid is a substance that ionizes to form $H^+(aq)$ in aqueous solution.<br>• a base is a substance that dissociates to produce $OH^-(aq)$ in aqueous solution. | Section 6.1, pp. 212-213 |
| Acid-base theories have been modified as the result of new observations. | Section 6.1, pp. 215-217 |

## Related Skills

| Skills | Outcome | Text Reference |
|---|---|---|
| A solubility table can be used to predict which combinations of ions are soluble, and which combinations of ions are insoluble | 20-C2.2s | Section 5.1, pp.171-172 |
| Students will design and carry out an investigation using a conductivity tester to classify various solutes as either ionic or molecular. | 20–C1.2s | Section 5.1, Investigation 5.A, p.174 |
| Students will investigate how temperature affects the solubility of a solid solute in water, and by combining their results with those from other groups will plot a solubility curve. | 20–C1.2s<br>20–C1.3s<br>20–C1.4s | Investigation 5.B, pp.180-181 |
| Students will solve problems related to the concentration of substances in a solution (including ions) using the following equations:<br>• Percent by mass ($m/m$) = $\frac{\text{Mass of solute (g)}}{\text{Mass of solution (g)}} \times 100\%$<br>• Concentration in ppm = $\frac{\text{Mass of solute (g)}}{\text{Mass of solution (g)}} \times 10^6$ ppm<br>• Concentration in ppb = $\frac{\text{Mass of solute (g)}}{\text{Mass of solution (g)}} \times 10^9$ ppb<br>• Molar concentration (mol/L) = $\frac{\text{Amount of solute (mol)}}{\text{Volume of solution (L)}}$ | 20–C1.5k<br>20–C1.6k<br>20–C1.6k<br>20–C1.7k<br>20–C1.8k | Section 5.3, pp.185-195 |
| Students will perform calculations related to the concentration and/or volume of a diluted solution and the quantities of solution and water used when diluting a stock solution. | 20–C1.7k<br>20–C1.11k | Section 5.4, pp. 197-198 |
| Students will use a balance and volumetric glassware to prepare solutions of specified concentration. | 20–C1.2s | Section 5.4, Investigation 5.D, pp. 200-201 |
| Students will use colour intensity to compare the concentrations of solutions. | 20–C1.2s | Section 5.4, Investigation 5.D, pp. 200-201 |
| Given the name or formula of an acid or a base, students will recall its formula or name. | 20–C2.1k | Section 6.1, p. 209 |
| Students will design and carry out an investigation to write an empirical definition for acids and an empirical definition for bases. | 20–C2.1s | Section 6.1, Investigation 6.A, pp. 210-211 |
| Students will use the Arrhenius theory of acids and bases to predict the acidity or alkalinity of a solution, and check their predictions using a pH meter. | 20–C1.1s<br>20–C2.1s<br>20–C2.2s<br>20–C2.3s | Section 6.1, Investigation 6.B, p. 214 |
| Students will design and carry out an investigation to identify unknown solutions as being a strong acid, strong base, weak acid, weak base, neutral ionic solution or molecular solution. | 20–C2.1s<br>20–C2.2s<br>20–C2.3s | Section 6.2, Investigation 6.C, p. 221 |

| Skills | Outcome | Text Reference |
|---|---|---|
| Students will assess the risks and benefits of using and transporting acidic and basic substances, and communicate their findings to the class using a computer presentation. | 20–C1.4s | Section 6.2, Thought Lab 6.1 p. 225 |
| Students will calculate pH and pOH, $[H_3O^+(aq)]$ and $[OH^-(aq)]$, of acidic and basic solutions with the correct number of significant digits using the following equations:<br>• $pH = -\log[H_3O^+(aq)]$<br>• $pOH = -\log[OH^-(aq)]$<br>• $[H_3O^+(aq)] = 10^{-pH}$<br>• $[OH^-(aq)] = 10^{-pOH}$<br>• pH + pOH = 14.00 (at 25 °C) | 20–C2.3k<br>20–C2.4k | Section 6.3, pp. 228-230;<br>pp. 235-237 |
| Students will determine the pH of an unknown solution using different acid-base indicators. | 20–C2.3s<br>20–C2.6k | Section 6.3, Investigation 6.D, p. 232 |
| Students will investigate the effect of dilution on the $[H_3O^+(aq)]$ and pH of an acid. | 20–C2.2s<br>20–C2.5k | Section 6.3, Investigation 6.E, p. 234 |
| Students will research drain cleaning products and the causes and effects of acid deposition, and describe some technologies to reduce acid deposition. | 20–C2.4s | Section 6.3, pp. 238-239<br>Chapter 6 Review, p. 245 |

## Activities and Target Skills

| Activity | Target Skills |
|---|---|
| Chapter 5: Solutions | |
| Launch Lab: Sink or Float?, p. 156 | ■ Inferring properties of solutions |
| Investigation 5.A: Classifying Solutions, pp. 174-175 | ■ Designing a procedure to identify the type of solution<br>■ Describing procedures for safe handling, storing, and disposal of materials used in the lab<br>■ Using a conductivity apparatus to classify solutions |
| Investigation 5.B: Plotting Solubility Curves, pp. 180-181 | ■ Performing an investigation to determine the solubility of a solute in a saturated solution<br>■ Selecting and using appropriate numeric and graphical representation to communicate results |
| Thought Lab 5.1: Expressing Concentration, p, 185 | ■ Compare the ways in which concentrations of solutions are expressed in household products and environmental studies |
| Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis, p. 199 | ■ Researching collectively the risk–benefit issue of pollution of waterways by the release of effluents<br>■ Proposing a plan for reducing the impact on the environment |
| Investigation 5.D: Preparing and Diluting a Standard Solutions, pp. 200-201 | ■ Using a balance and volumetric glassware to prepare solutions of specified concentration<br>■ Using experimental data to determine the concentration of a solution<br>■ Describing procedures for safe handling, storing, and disposal of materials used in the laboratory |

| Activity | Target Skills |
|---|---|
| Chapter 6: Acids and Bases | |
| Launch Lab: The Colour of Your Breath, p. 207 | ■ Testing pH in acids and bases |
| Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210-211 | ■ Designing a procedure to determine the properties of acids and bases<br>■ Conducting investigations into relationships and using a broad range of tools and techniques |
| Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases, p. 214 | ■ Describing procedures for safe handling, storage, and disposal of materials used in the laboratory<br>■ Using a pH meter to determine the acidity and/or alkalinity of a solution |
| Investigation 6.C: Differentiating between Weak and Strong Acids and Bases, p. 221 | ■ Describing procedures for safe handling, storage, and disposal of materials used in the laboratory<br>■ Investigating and solving problems of prediction, calculation, and inference |
| Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, p. 225 | ■ Assessing, qualitatively, the risks and benefits of producing, using, and transporting acidic and basic substances |
| Investigation 6.D: Determining the pH of an Unknown Solution with Indicators, p. 232 | ■ Using indicators to determine the pH for a variety of solutions |
| Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid, p. 234 | ■ Constructing a table or graph to compare pH and hydronium ion concentration<br>■ Using a pH meter to determine acidity of a solution |

# Conceptual Challenges

## Section 5.1

- For most students, amalgams and alloys are unfamiliar solutions. Compare a sample of a pure metal, such as iron, with an alloy, such as steel. Make clear that the solute(s) is/are present in the smallest quantity while the solvent is present in the largest quantity in the solution. For example, samples of stainless steel consist of iron as the solvent with varying quantities of carbon, chromium, nickel, and other metals as solutes.
- Students may have difficulty understanding the concepts of energy required and energy released. To better illustrate the concept, build molecular models for water and sodium chloride. You must include hydrogen bonds that are weaker between the water molecules. Reinforce the concept of energy required to break bonds as you break the lattice bonds in the crystal and the hydrogen bonds in the water. Similarly, reinforce that energy is released when new intermolecular bonds are formed. The demonstration above may also be used to discuss the differences in how ionic and molecular substances dissolve. Ionic bonds are broken, freeing ions, while only intermolecular bonds are broken between molecules.

## Section 5.2

- Although this unit does not compare organic solvents with water, students will often know the summary "like always dissolves like." If this is mentioned, students should be told that while this is a useful generalization, there are exceptions. For example, acetic (ethanoic) acid is totally miscible in water due to the formation of hydrogen bonds, but it is also soluble in non-polar solvents such as benzene and carbon tetrachloride.
- While it is usually true that the solubility of a solid in a liquid increases with an increase in temperature, this is not always so. If you live in an area with hard water, students should examine the heating element in a kettle for evidence of the scale that deposits with use. The decreased solubility in water of sodium sulfite, calcium acetate, or lithium sulfate at higher temperature can easily be demonstrated.

## Section 5.3

- Some students confuse concentration and amount, and a careful distinction between these terms must be made. By convention, the amount of a substance is measured in moles. Solution concentration is frequently expressed as molar concentration, which is a ratio of moles of solute to litres of solution. Stating molar concentration does not give the amount of dissolved solute; the volume must also be known. This can be demonstrated by showing the relative effects of 1 drop of concentrated sulfuric acid (0.05 mL of

18 mol/L $H_2SO_4$(aq)) and 9 L of 0.1 mol/L sulfuric acid on pieces of paper towel. While both contain 0.9 moles of acid molecules, a single drop of the concentrated acid eats through paper towel leaving a carbonized patch. Dropping a towel into a plastic bucket of the diluted acid (1 drop in 9 L) causes no change.

## Section 6.1

- Given the formula of a compound, students may find it difficult to classify the compound as acidic, basic, or neutral, and to predict how many hydrogen atoms per molecule will ionize when an acid dissolves in water. For example, some students may believe methanol, $CH_3OH$, is an acid because of the hydrogen atoms it contains, while other students may say it is a base because it contains the OH group. Until students learn how bond strength and electronegativity affect acid strength, it may be best to have them memorize a list of the common strong acids: HCl(aq), HBr(aq), HI(aq), $HNO_3$(aq), $HClO_4$(aq), and $H_2SO_4$(aq) (for the first ionization only).

## Section 6.2

- The terms "strength" and "concentration" are often confused. Reinforce that "concentrated" (having a high concentration of particles in mol/L) is different from "strong" (dissociates 100%) and "weak" (dissociates much less than 100%) is different from "dilute" (having a low concentration of particles in mol/L). In fact, the percent of acid molecules that ionize when a weak acid is diluted increases. For example, a sample of ethanoic (acetic) acid becomes a slightly stronger acid when it is diluted.

## Section 6.3

- Depending on the timing of the math curriculum, logarithms may be new to students. You may find it easier to teach the concept as a process than to teach the entire theory of how logarithms translate into significant digits. Students often drop the decimal or round off a value too soon. Explain the source of error this introduces. Go through the correct significant digits procedure for pH values—only count those numbers after the decimal as significant. Suggest students review Appendix D, "Math and Chemistry" for information on significant digits.
- Students often believe that only pH values of 1 to 14 exist. The pH scale is most useful for aqueous solutions of weak acids and weak bases. Sometimes the pH scale is used for dilute solutions of strong acids or strong bases. The pH scale is not used for concentrated solutions of a strong acid or a strong base because the concentration of hydronium or hydroxide ions can be calculated from the molar concentration directly. The pH of concentrated hydrochloric acid, 12 mol/L gives a pH = –1.1; for 18 mol/L sulfuric acid, the pH = –1.3. The 8 mol/L sodium hydroxide solution used to make soap from animal fat has pH = 14.9.

## Using the Unit 3 Preparation Feature

The unit opener has been designed to establish a social, technical, and environmental context for the science in the unit. Use the unit opener to introduce the general unit topics within that context, and ask the Focussing Questions to guide students' thinking.

The Unit Preparation feature has been included in order to ensure that students are familiar with the science from previous courses that relates specifically to the material they are about to study. Encourage students to take the Unit Prequiz (found at **www.albertachemistry.ca,** Online Learning Centre, Student Edition) to gauge their recall, noting that if they are familiar with the background science, their experience with this unit will be much easier.

The Unit 3 Preparation feature covers 4 pages, and topics reviewed include: properties of molecular and ionic compounds, acids and bases, pH scale, measuring pH, and the protocol for naming compounds. **BLM 5.0.1 (AST) Classification of Matter Review** and **BLM 5.0.1A (ANS) Classification of Matter Review Answers** have been prepared for the review. They are on the CD-ROM that accompanies this Teacher's Resource, or they can be found at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition (password required).

# UNIT 3: COURSE MATERIALS

| Chapter, Section | Item Description | Suggested Quantity (assume 40 in class) | Text Activity |
|---|---|---|---|
| **Chapters 5, 6** | safety goggles | 40 pairs | Chapter 6 Launch Lab; Investigations: 5.A, 5.B, 5.D, 6.A, 6.B, 6.C, 6.D, 6.E |
| **Chapters 5, 6** | nonlatex disposable gloves | 40 pairs | Chapter 6 Launch Lab |
| **Chapters 5, 6** | aprons | 40 | Chapter 6 Launch Lab; Investigations: 5.A, 5.B, 5.D, 6.A, 6.B, 6.C, 6.D, 6.E |
| **Chapter 5, Chapter Opener** | 500 mL beaker<br>large container for water<br>diet cola<br><br>regular cola<br><br>water | 2 per student<br>1 per student<br>1 can per student, unopened<br>1 can per student, unopened | Launch Lab: Sink or Float?, p. 165 |
| **Chapter 5, Section 5.1** | conductivity apparatus<br>50 mL beakers<br>disposal/waste container<br>solutions of:<br>– 1-propanol, $C_3H_7OH(aq)$<br>– hydrochloric acid, $HCl(aq)$<br>– sodium chloride, $NaCl(aq)$<br>– sodium hydroxide, $NaOH(aq)$<br>– sucrose, $C_{12}H_{22}O_{11}(aq)$ | 1 per group<br>6 per group<br>1<br><br>25 mL per group<br>25 mL per group<br>25 mL per group<br>25 mL per group<br>25 mL per group | Investigation 5.A: Classifying Solutions, pp. 174–175 |
| **Chapter 5, Section 5.3** | graduated pipette<br>balance<br>Scoopula®<br>400 mL beaker (for solvent)<br>stirring rod<br>pipette bulb<br>two-holed stopper to fit the test tube with a thermometer inside<br>retort stand<br>test tube clamp<br>thermometer clamp<br>large test tube<br>hot plate<br>potassium nitrate $KNO_3(s)$<br>distilled water | 1 per group<br>1<br>1 per group<br>1 per group<br>1 per group<br>1 per group<br>1 per group<br><br>1 per group<br>1 per group<br>1 per group<br>1 per group<br>1 per group<br>15 g per group<br>300 mL per group | Investigation 5.B: Plotting Solubility Curves, pp. 180–181 |

| Chapter, Section | Item Description | Suggested Quantity (assume 40 in class) | Text Activity |
|---|---|---|---|
| **Chapter 5, Section 5.4** | pipette (or graduated cylinder) | 1 per group | Investigation 5.D: Preparing and Diluting a Standard Solution, pp. 200–201 |
| | electronic balance | 1 | |
| | Scoopula® | 1 per group | |
| | 100 mL volumetric flask (with stopper) | 2 per group | |
| | 100 mL beaker | 1 per group | |
| | 250 mL beaker | 2 per group | |
| | stirring rod | 1 per group | |
| | funnel | 1 per group | |
| | pipette bulb | 1 per group | |
| | large test tube | 1 per group | |
| | medicine dropper | 1 per group | |
| | light box, overhead projector, or spectrophotometer | 1 | |
| | copper (II) sulfate pentahydrate, $CuSO_4 \bullet 5H_2O(s)$ | 1 stock bottle | |
| | distilled water | | |
| | grease pencil or marker | 5 | |
| | prepared standard solutions of $CuSO_4 \bullet 5H_2O(s)$ in test tubes, labelled 1–6 | 1 set per group | |
| | paper towel | 1 piece per group | |
| **Chapter 6, Chapter Opener** | 250 mL Erlenmeyer flask | 1 per group | Launch Lab: The Colour of Your Breath, p. 207 |
| | 100 mL graduated cylinder | 1 per group | |
| | stopwatch or clock with second hand | 1 per group | |
| | tap water | | |
| | bromothymol blue indicator | 25 mL per group | |
| | 0.10 mol/L NaOH(aq) in a dropper bottle | 25 mL per group | |
| | straws | 1 per person | |
| **Chapter 6, Section 6.1** | spot plate | 1 per group | Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210–211 |
| | dropper | 1 per group | |
| | conductivity tester | 1 per group | |
| | red and blue litmus paper | 1 piece per group | |
| | pH paper and/or pH meter | 1 per group | |
| | solutions of the following:<br>-hand soap<br>-laundry detergent<br>-glass cleaner<br>-antacid<br>-milk<br>-sour milk<br>-carbonated water<br>-soda pop (carbonated)<br>-soda pop (flat)<br>-apple juice<br>-vinegar<br>-baking soda<br>-water and table salt solution | 30 mL of each solution per group | |
| | 0.10 mol/L NaOH(aq) in a dropper bottle (optional) | 1 per group | |
| | 0.10 mol/L HCL(aq) in a dropper bottle (optional) | 1 per group | |
| | short strips of magnesium ribbon | 1 per group | |
| | test tube | 1 per group | |
| | 50 mL beakers | 1 per solution being tested per group | |

| Chapter, Section | Item Description | Suggested Quantity (assume 40 in class) | Text Activity |
|---|---|---|---|
| **Chapter 6, Section 6.1** | pH paper/pH meter<br>distilled water<br>solutions:<br>-0.10 mol/L $NaOH(aq)$<br>-0.10 mol/L $NaCl(aq)$<br>-0.10 mol/L $C_{12}H_{22}O_{11}(aq)$<br>-0.10 mol/L $HCl(aq)$<br>-0.10 mol/L $NH_3(aq)$<br>-0.10 mol/L $CH_3COOH(aq)$<br>-0.10 mol/L $NaHCO_3(aq)$ | 1 per group<br><br><br>100 mL<br>100 mL<br>100 mL<br>100 mL<br>100 mL<br>100 mL<br>100 mL | Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases, p. 215 |
| **Chapter 6, Section 6.2** | spot plate<br>conductivity tester<br>pH meter<br>or red and blue litmus paper<br>steel wool<br>solutions of the following:<br>-neutral molecular: $C_{12}H_{22}O_{11}$ (aq)<br>-neutral ionic: NaCl (aq)<br>-strong acid: 0.10 mol/L HCl (aq)<br>-strong base: 0.10 mol/L NaOH (aq)<br>-weak acid: 0.10 mo/L $CH_3COOH$ (aq)<br>-weak base: 0.10 mol/L $NH_3$ (aq)<br>short strips of magnesium ribbon or zinc<br>50 mL beakers<br>test tube | 1 per group<br>1 per group<br>1 per group<br>6 pieces per group<br>10<br>30 mL of each per group<br><br><br><br><br><br><br>10 pieces<br>1 per solution per group<br>1 per solution per group | Investigation 6.C: Differentiating between Weak and Strong Acids and Bases, p. 221 |
| **Chapter 6, Section 6.3** | spot plates or small test tubes<br>medicine droppers<br>indicator solutions:<br>-methyl orange<br>-methyl red<br>-bromothymol blue<br>-phenolphthalein<br>testing solutions:<br>-0.1 mol/L hydrochloric acid<br>-0.1 mol/L sodium hydroxide<br>-0.1 mol/L sodium carbonate<br>-0.1 mol/L acetic acid | 1 per group<br>8 (1 per solution)<br>2 mL of each per group<br><br><br><br><br>10 mL of each per group | Investigation 6.D: Determining the pH of an Unknown Solution with Indicators, p. 232 |
| **Chapter 6, Section 6.3** | 10 mL graduated cylinder (or graduated pipette)<br>100 mL beaker<br>small beaker or test tube<br>stirring rod<br>universal indicator paper (pH paper)<br>pH meter (optional)<br>0.10 mol/L hydrochloric acid<br>distilled water | 2 per group<br>1 per group<br>1 per group<br>1 per group<br>10 per group<br>1 per group<br>10 mL per group<br>750 mL | Investigation 6.E: The Effect of Dilution on the $[H_30^+(aq)]$ and pH of an Acid, p. 234 |

# CHAPTER 5 SOLUTIONS

## Curriculum Correlation

**General Outcome 1: Students will investigate solutions, describing their physical and chemical properties.**

| | Student Textbook | Assessment Options |
|---|---|---|
| **Outcomes for Knowledge** | | |
| **20–C1.1k** recall the categories of pure substances and mixtures and explain the nature of homogeneous mixtures | Chapter 5 Launch Lab: Sink or Float? p. 165<br>Classifying Solutions, Section 5.1, p. 166-168<br>Investigation 5.D: Preparing and Diluting a Standard Solution, Section 5.4, p. 200 | Chapter 5 Launch Lab: Sink or Float? Analysis: 1, 2, p. 165<br>Investigation 5.D: Preparing and Diluting a Standard Solution, Extension: 3, Section 5.4, p. 200<br>Questions for Comprehension: 1, 2, Section 5.1, p. 168<br>Section 5.1 Review: 2, 3, 7, p. 175<br>Chapter 5 Review: 1-4, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 1, p. 248-251 |
| **20–C1.2k** provide examples from living and nonliving systems, that illustrate how dissolving substances in water is often a prerequisite for chemical change | Chapter 5 Launch Lab: Sink or Float? p. 165<br>Solutions in Water, Section 5.1, p. 168-170, 173 | Chapter 5 Launch Lab: Sink or Float? Analysis: 1, 2, p. 165<br>Questions for Comprehension: 3-5, Section 5.1, p. 170<br>Section 5.1 Review: 3-6, p. 175<br>Chapter 5 Review: 4, 5, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 2, 30, 35, 38, 43, p. 248-251 |
| **20–C1.3k** explain dissolving as an endothermic or an exothermic process | Processes of Dissolving, Section 5.1, p. 168-170 | Questions for Comprehension: 3-5, Section 5.1, p. 170<br>Chapter 5 Review: 5, 9, 12, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 2, p. 248-251 |
| **20–C1.4k** differentiate between electrolytes and nonelectrolytes | Molecular Compounds in Solution, Section 5.1, p. 172-173<br>Investigation 5.A; Classifying Solutions, Section 5.1, p. 174 | Investigation 5.A; Classifying Solutions, Analysis: 1-3, Section 5.1, p. 174<br>Questions for Comprehension: 7, Section 5.1, p. 175<br>Chapter 5 Review: 4, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 13, 46, p. 248-251 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **20–C1.5k** express concentration in various ways, i.e., moles per litre of solution, percent by mass, parts per million | The Concentration of Solutions, Section 5.3, p. 184-195<br>Sample Problem: Solving for Percent by Mass, Section 5.3, p. 186<br>Sample Problem: Calculating Parts per Million, Section 5.3, p. 188<br>Sample Problem: Calculating the Concentration of a Solution in mol/L, Section 5.3, p. 190<br>Sample Problem: Calculating Ion Concentration in mol/L, Section 5.3, p. 192 | Questions for Comprehension: 9, Section 5.2, p. 177<br>Practice Problems: 1-5, Section 5.3, p. 186<br>Practice Problems: 6-10, Section 5.3, p. 188<br>Practice Problems: 11-16, Section 5.3, p. 191<br>Practice Problems: 17-22, Section 5.3, p. 193<br>Practice Problems: 23-26, Section 5.3, p. 194<br>Practice Problems: 27-30, Section 5.3, p. 195<br>Throughout Chapter 5<br>Chapter 5 Test<br>Unit 3 Review: 3, 4, 6-10, 12, 15, 23, 24, 25, 30, 42, p. 248-251 |
| **20–C1.6k** calculate, from empirical data, the concentration of solutions in moles per litre of solution and determine mass or volume from such concentrations | Sample Problem: Calculating the Concentration of a Solution in mol/L, Section 5.3, p. 190<br>Sample Problem: Calculating Mass from Concentration in mol/L, Section 5.3, p. 193 | Practice Problems: 11-16, Section 5.3, p. 191<br>Practice Problems: 23-26, Section 5.3, p. 194<br>Section 5.3 Review: 1-15, p. 196<br>Chapter 5 Review: 16-25, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 3, 4, 6-10, 12, 15, 23, 24, 25, 30, 39, 40, 4s2, p. 248-251 |
| **20–C1.7k** calculate the concentrations and/or volumes of diluted solutions and the quantities of a solution and water to use when diluting | Preparing and Diluting Solutions, Section 5.4, p. 197-201<br>Sample Problem: Diluting a Standard Solution, Section 5.4, p. 197<br>Investigation 5.D: Preparing and Diluting a Standard Solution, Section 5.4, p. 200 | Practice Problems: 31-33, Section 5.4, p. 198<br>Investigation 5.D: Preparing and Diluting a Standard Solution, Extension: 4, Section 5.4, p. 200<br>Section 5.3 Review: 1, 3-15, p. 196<br>Chapter 5 Review: 24, 25, 30, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 10, 15, 23, 36, p. 248-251 |
| **20–C1.8k** use empirical data and ionization/dissociation equations to calculate the concentration of ions in a solution | Molar Concentrations of Ions in Solution, Section 5.3, p. 191<br>Sample Problem: Calculation Ion Concentration in mol/L, Section 5.3, p. 192 | Questions for Comprehension: 7, 8, Section 5.1, p. 175<br>Practice Problems: 17-22, Section 5.3, p. 193<br>Section 5.3 Review: 9, p. 196<br>Chapter 5 Test<br>Unit 3 Review: 28, 30, 31, 43, p. 248-251 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **20–C1.9k** define solubility and the factors that affect it | Solubility, Section 5.2, p. 176-177, 181-182 | Section 5.1 Review: 1, p. 175<br>Questions for Comprehension: 6, Section 5.1, p. 172<br>Questions for Comprehension: 9, Section 5.2, p. 177<br>Section 5.2 Review: 1, 2, 4, 5, 7, p. 183<br>Section 5.3 Review: 1, p. 196<br>Chapter 5 Review: 26-30, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 5, 28, 41, p. 248-251 |
| **20–C1.10k** explain a saturated solution in terms of equilibrium, i.e., equal rates of dissolving and crystallization | Solubility, Section 5.2, p. 176-179<br><br>A Closer Look at a Saturated Solution, Section 5.2, p. 177-179 | Questions for Comprehension: 9, Section 5.2, p. 177<br>Questions for Comprehension: 10, 11, Section 5.2, p. 179<br>Section 5.2 Review: 1, 3, 6, 7, p. 183<br>Chapter 5 Review: 7, 8, 12, 30, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 4, 22, 29, p. 248-251 |
| **20–C1.11k** describe the procedures and calculations required for preparing and diluting solutions. | Preparing and Diluting Solutions, Section 5.4, p. 197-198<br><br>Sample Problem: Diluting a Standard Solution, Section 5.4, p. 197 | Practice Problems: 31-33, Section 5.4, p. 198<br><br>Section 5.3 Review: 1-15, p. 196<br>Section 5.4 Review: 1-11, p. 202<br>Chapter 5 Review: 24, p. 204-205<br>Chapter 5 Test<br>Unit 3 Review: 10, 15, 23, 36, p. 248-251 |
| **Outcomes for Science, Technology and Society (Emphasis on social and environmental contexts)** | | |
| **20–C1.1sts** explain how science and technology are developed to meet societal needs and expand human capabilities by<br>■ *providing examples of how solutions and solution concentrations are applied in products and processes, in scientific studies and in daily life* | Chapter 5 Launch Lab: Sink or Float? p. 165<br>Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189 | Chapter 5 Launch Lab: Sink or Float? Analysis: 1, 2, p. 165<br>Connections: Biomagnification and Bioaccumulation: 3, Section 5.3, p. 189<br>Chapter 5 Review: 26-30, p. 204-205<br>Unit 3 Review: 41-51, p. 248-251 |
| **20–C1.2sts** explain that science and technology are influenced and supported by society and have influenced, and been influenced by, historical development and societal needs by<br>■ *comparing the ways in which concentrations of solutions are expressed in chemistry laboratories, household products and environmental studies* | Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189 | Connections: Biomagnification and Bioaccumulation: 1-3, Section 5.3, p. 189<br><br>Chapter 5 Review: 26-30, p. 204-205<br>Unit 3 Review: 41-51, p. 248-251 |
| **20–C1.3sts** explain that scientific and technological activity may arise from, and give rise to, such personal and social values as accuracy, honesty, perseverance, tolerance, open-mindedness, critical-mindedness, creativity and curiosity by<br>■ *explaining the Responsible Care® program developed by the Canadian Chemical Producers' Association* | Connections: Biomagnification and Bioaccumulation: 3, Section 5.3, p. 189<br><br>Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis, Section 5.4, p. 199 | Connections: Biomagnification and Bioaccumulation: 2, 3, Section 5.3, p. 189<br><br>Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 1-6, Section 5.4, p. 199 |
| **20–C1.4sts** explain how science and technology have both intended and unintended consequences for humans and the environment by<br>■ *explaining the significance of biomagnification in increasing the concentration of substances in the ecosystem* | Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189 | Connections: Biomagnification and Bioaccumulation: 1, 2, Section 5.3, p. 189<br><br>Unit 3 Review: 41-51, p. 248-251 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **20–C1.5sts** explain that the appropriateness, risks and benefits of technologies need to be assessed for each potential application from a variety of perspectives, including sustainability by<br>■ *explaining the role of concentration in risk/benefit analysis for determining the safe limits of particular substances, e.g., pesticide residues, heavy metals, chlorinated or fluorinated compounds, pharmaceuticals.* | Thought Lab 5.1: Expressing Concentration, Section 5.3, p. 185<br><br>Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189 | Thought Lab 5.1: Expressing Concentration, Analysis: 1, 2, Section 5.3, p. 185<br><br>Connections: Biomagnification and Bioaccumulation: 1, 2, Section 5.3, p. 189<br>Unit 3 Review: 41-51, p. 248-251 |
| **Skill Outcomes (Focus on decision making)** | | |
| **Initiating and Planning** | | |
| **20–C1.1s** ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by<br>■ designing a procedure to identify the type of solution<br>■ designing a procedure for determining the concentration of a solution containing a solid solute<br>■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information. | Investigation 5.A; Classifying Solutions, Section 5.1, p. 174<br><br>Investigation 5.B: Plotting Solubility Curves, Section 5.2, p. 180<br><br>Thought Lab 5.1: Expressing Concentration, Section 5.3, p. 185<br>Investigation 5.D: Preparing and Diluting a Standard Solution, Section 5.4, p. 200 | Investigation 5.A; Classifying Solutions, Analysis: 1-3, Conclusion:4, Extensions: 5, 6, Section 5.1, p. 174<br>Investigation 5.B: Plotting Solubility Curves, Analysis: 1-4, Conclusion: 5, Applications: 6, 7, Section 5.2, p. 181<br>Thought Lab 5.1: Expressing Concentration, Analysis: 1, 2, Section 5.3, p. 185<br>Investigation 5.D: Preparing and Diluting a Standard Solution, Extension: 3, 4, Section 5.4, p. 200 |
| **Performing and Recording** | | |
| **20–C1.2s** conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by<br>■ using a conductivity apparatus to classify solutions<br>■ performing an experiment to determine the concentration of a solution<br>■ using a balance and volumetric glassware to prepare solutions of specified concentration<br>■ performing an investigation to determine the solubility of a solute in a saturated solution. | Investigation 5.A; Classifying Solutions, Section 5.1, p. 174<br><br>Investigation 5.B: Plotting Solubility Curves, Section 5.2, p. 180<br><br>Investigation 5.D: Preparing and Diluting a Standard Solution, Section 5.4, p. 200 | Investigation 5.A; Classifying Solutions, Analysis: 1-3, Conclusion:4, Extensions: 5, 6, Section 5.1, p. 174<br>Investigation 5.B: Plotting Solubility Curves, Analysis: 1-4, Conclusion: 5, Applications: 6, 7, Section 5.2, p. 181<br><br>Investigation 5.D: Preparing and Diluting a Standard Solution: 2-4, Section 5.4, p. 200 |
| **Analyzing and Interpreting** | | |
| **20–C1.3s** analyze data and apply mathematical and conceptual models to develop and assess possible solutions by<br>■ using experimental data to determine the concentration of a solution<br>■ *evaluating the risks involved in safe handling, storage and disposal of solutions in common use in the laboratory and in the home.* | Investigation 5.D: Preparing and Diluting a Standard Solution, Section 5.4, p. 200<br><br>Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis, Section 5.4, p. 199 | Investigation 5.D: Preparing and Diluting a Standard Solution: 2, 4, Section 5.4, p. 200<br><br>Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 3-6, Section 5.4, p. 199 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **Communication and Teamwork** | | |
| **20–C1.4s** work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by<br>■ comparing personal concentration data with the data of other groups<br>■ *selecting and using appropriate numeric, symbolic, graphical and linguistic modes of representation to communicate ideas, plans and results*<br>■ *using integrated software effectively and efficiently to incorporate data, graphics and text*<br>■ *collectively researching the risk/benefit issue of pollution of waterways by the release of effluents and proposing a plan for reducing the impact on the ecosystem.* | Investigation 5.B: Plotting Solubility Curves, Section 5.2, p. 180<br>Thought Lab 5.1: Expressing Concentration, Section 5.3, p. 185<br>Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 2-6, Section 5.4, p. 199 | Investigation 5.B: Plotting Solubility Curves, Analysis: 1-4, Conclusion: 5, Applications: 6, 7, Section 5.2, p. 181<br>Thought Lab 5.1: Expressing Concentration, Analysis: 1, 2, Section 5.3, p. 185<br>Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 1-6, Section 5.4, p. 199 |

**General Outcome 2: Students will describe acid and base solutions qualitatively and quantitatively.**

| | Student Textbook | Assessment Options |
|---|---|---|
| **Outcomes for Knowledge** | | |
| **20–C2.10k** differentiate between strong acids and bases and weak acids and bases, qualitatively, on the basis of ionization and dissociation | Acids: Molecular Electrolytes, Section 5.1, p. 173 | Section 5.1 Review: 6, p. 175 |
| **Outcomes for Science, Technology and Society (Emphasis on science and technology)** | | |
| **20–C2.1sts** explain that the goal of technology is to provide solutions to practical problems by<br>■ *relating the concept of pH to solutions encountered in everyday life, e.g., pharmaceuticals, shampoo and other cleaning products, aquatic and terrestrial environments, blood/blood products* | Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189 | Connections: Biomagnification and Bioaccumulation: 3, Section 5.3, p. 189 |
| **20–C2.2sts** explain that technological problems often have multiple solutions that involve different designs, materials and processes and have both intended and unintended consequences by<br>■ *providing examples of processes and products that use knowledge of acid and base chemistry, e.g., pulp and paper industry, food preparation and preservation, cleaning aids, sulfuric acid in car batteries, treating accidental acid or base spills using neutralization and dilution*<br>■ *explaining the significance of strength and concentration of solutions in everyday life, e.g., pharmaceuticals, chemical spills, transportation of dangerous goods, toxicity.* | Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189 | Connections: Biomagnification and Bioaccumulation: 2, Section 5.3, p. 189 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **Skill Outcomes (Focus on problem solving)** | | |
| **Communication and Teamwork** | | |
| **20–C2.4s** work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by<br>■ *collectively researching the relation between sulphuric acid and industrialization* | See Curriculum Correlation for Chapter 6 | See Curriculum Correlation for Chapter 6 |
| ■ *assessing technologies used to reduce emissions leading to acid deposition* | Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 2-6, Section 5.4, p. 199 | Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 1-6, Section 5.4, p. 199 |

# Chapter 5

# Solutions

**Student Textbook pages 164–205**

## Chapter Concepts

**Section 5.1 Classifying Solutions**

- The process of dissolving can be endothermic or exothermic.
- Substances can be classified as electrolytes or non-electrolytes.
- Dissolving substances in water is often a prerequisite for chemical change.

**Section 5.2 Solubility**

- Solubility is affected by several factors and can be determined in a laboratory.
- Solutions can be described as saturated, unsaturated, or supersaturated.

**Section 5.3 The Concentration of Solutions**

- The concentration of a solution and its ions can be calculated and can be expressed in a variety of ways.
- Concentration values can be used in a risk–benefit analysis to determine safe limits of particular solutes.

**Section 5.4 Preparing and Diluting Solutions**

- Solutions can be prepared and diluted to specific concentrations with proper procedures and calculations.

## Common Misconceptions

- Students misclassify alcohols as ionic compounds, mistaking the OH end of the formula for a hydroxide ion. Ensure students are familiar with the common complex (polyatomic) ions. Use Appendix C to help them recognize common cations and anions (e.g., in methanol the $CH_3$ group is not a cation they should recognize, nor should they write $CH_3OH \rightarrow CH^{3+} + OH^-$).
- Conductivity depends on solubility. However, many students believe that all ionic compounds form conducting solutions.
- Paper filtration is a physical method used to separate heterogeneous mixtures, not a method to remove ionic solutes from solution. Although some solute may get embedded in the filter paper, most will pass through as part of the homogeneous solution.
- Solution concentration is a measure of the amount of solute relative to the amount of solution, not to the solvent. There is a difference between 100 mL of water and 100 mL of solution. However, the one may approximate the other for dilute solutions.
- Students should be aware of the limitations of their solubility table. It does not cover molecular compounds or solutions made with solvents other than water. The solubility of substances can also be referenced in *The CRC Handbook of Chemistry and Physics* and other resources.
- When preparing a dilute solution from a standard solution, students may need reminding that the moles of solute in the concentrated solution in the pipette are the same as in the dilute solution in the volumetric flask. The number of particles is the same, only the concentration is different once water is added to dilute the solution.
- Students may believe that a solution containing undissolved solute is, or will form, a supersaturated solution. The term "supersaturated solution" is first mentioned in Section 5.2, page 176, and misconceptions can be addressed after the introduction to saturated solutions and equilibrium on page 178. A supersaturated solution contains more solute than it would if the dissolved solute were in equilibrium with the undissolved solute. This can be demonstrated by adding a crystal of sodium acetate to a supersaturated solution of sodium acetate in water: http://www.stevespanglerscience.com/experiment/00000078
- Students often use incorrect and vague terms when describing solutions, or when distinguishing a solution from a pure liquid. For example, they may believe that the dissolving and melting processes are the same. These terms are often mixed up, probably because the result of both processes is usually a liquid. A solution forms when a solute dissolves in a solvent; a substance melts when its temperature is above the melting point. Remind students that, when heated, ice melts and a solute such as sugar can be dissolved in the water. Kitchen applications offer many opportunities for a discussion of the difference between melting and dissolving.
- Students will sometimes state that all solutions are pure liquids. This misconception is reinforced in many advertisements for "pure" beverages, such as orange juice. A pure liquid consists of only one substance. A solution consists of at least two different substances. When a pure liquid is evaporated there is no residue, but when a solution is evaporated there is often (though not always) a residue.
- As a solubility term, "insoluble" easily leads to the misconception that no amount of an insoluble substance enters into solution. This is not true. All ionic compounds, even those that we classify as "insoluble" dissolve to some slight extent in water.
- It is a common misconception that the amount of gas dissolved in a solvent is proportional to the total pressure of gases above the solution. In fact, the amount of gas dissolved in a solvent is proportional only to the partial pressure of that gas above the solution.
- Students often do not realize that gases dissolve better in cold water as opposed to hot. They expect all things to dissolve better as the temperature is increased. Some simple demonstrations can clear up this misconception: Fill a beaker half full of tap water and watch as it first appears cloudy and then clears from the bottom of the beaker to the top within a short period of time. These are the gases that are escaping from the solution as the air temperature

of the room warms the water. Also, most students will have experienced the taste of a room temperature soda beverage compared with the same type of beverage taken from the refrigerator. The warmer beverage tastes "flatter" than the cold drink because it contains less dissolved carbon dioxide.

## Helpful Resources

### Books and Journal Articles

- Michael J. Sanger, "Using Particulate Drawings to Determine and Improve Students' Conceptions of Pure Substances and Mixtures," *Journal of Chemical Education*, Vol. 77, No. 6, June 2000, p. 762
- Letcher, Trevor M. and Battino, Rubin, "An Introduction to the Understanding of Solubility," *Journal of Chemical Education*, Vol. 78, No. 1, January 2001, p. 103

### Web Sites

Web links related solutions can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre, and log on to the Instructor Edition. Choose Teacher Web Links.

### List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Editions, BLMs.

**Number (Type) Title**
5.0.1 (AST) Classification of Matter Review
5.0.1A (ANS) Classification of Matter Review Answer Key
5.0.2 (HAND) Launch Lab: Sink or Float?
5.0.2A (ANS) Launch Lab: Sink or Float? Answer Key

5.1.1 (OH) The Dissolving Process
5.1.2 (OH) Writing Dissociation Equations
5.1.3 (AST) Solubility and Writing Dissociation Equations Quiz
5.1.3A (ANS) Solubility and Writing Dissociation Equations Quiz Answer Key
5.1.4 (HAND) Investigation 5.A: Classifying Solutions
5.1.4A (ANS) Investigation 5.A: Classifying Solutions Answer Key

5.2.1 (OH) Dissolving and Crystallizing in a Saturated Solution
5.2.2 (HAND) Investigation 5.B: Plotting Solubility Curves
5.2.2A (ANS) Investigation 5.B: Plotting Solubility Curves Answer Key
5.2.3 (OH) The Effect of Temperature on the Solubility of Solids

5.3.1 (HAND) Thought Lab 5.1: Expressing Concentration
5.3.1A (ANS) Thought Lab 5.1: Expressing Concentration Answer Key
5.3.2 (AST) Calculations Involving Percent by Mass, Parts per Million, and Parts Per Billion
5.3.2A (ANS) Calculations Involving Percent by Mass, Parts per Million, and Parts Per Billion Answer Key
5.3.3 (AST) Calculating Molar Concentration
5.3.3A (ANS) Calculating Molar Concentration Answer Key
5.3.4 (OH) Molar Concentration of Ions in Solution
5.3.5 (AST) Calculating the Molar Concentration of Ions in Solution
5.3.5A (ANS) Calculating the Molar Concentration of Ions in Solution Answer Key
5.3.6 (AST) Calculating Mass and Volume from Concentration
5.3.6A (ANS) Calculating Mass and Volume from Concentration Answer Key
5.3.7 (AST) Mixed Concentration Problems
5.3.7A (ANS) Mixed Concentration Problems Answer Key

5.4.1 (AST) Dilution Calculations
5.4.1A (ANS) Dilution Calculations Answer Key
5.4.2 (HAND) Performing a Risk-Benefit Analysis
5.4.3 (HAND) Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis
5.4.3A (ANS) Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis Answer Key
5.4.4 (HAND) Preparing Solutions
5.4.5 (HAND) Diluting Solutions
5.4.6 (HAND) Investigation 5.D: Preparing and Diluting a Standard Solution
5.4.6A (ANS) Investigation 5.D: Preparing and Diluting a Standard Solution Answer Key

5.5.1 (AST) Chapter 5 Test
5.5.1A (ANS) Chapter 5 Test Answer Key

## Using the Chapter 5 Opener

**Student Textbook pages 164–165**

## Teaching Strategies

- Have students classify a number of samples such as coins, pop, and sand as mixtures or pure substances, and explain their choices.
- Review how to classify ionic and molecular compounds based on properties such as state, melting point, and colour.
- Students should be familiar with the terms endothermic and exothermic. A good example, used later in the chapter, is hot and cold packs. Athletic cold packs are common in schools and provide a Science, Technology, and Society connection for understanding these terms. Heat energy changes can then be linked to physical changes such as dissolving.
- A review of intermolecular bonding and polarity of molecular compounds in Chapter 2 will help students

understand solution formation, classification, and properties.

- There is a heavy emphasis on quantitative aspects of solution concentration. Students will need a working knowledge of SI notation, unit conversions, and use of significant digits, as in Appendix.
- Students need to review writing ionic, molecular, and simple acid formulas. In *Science 10* they learned how to calculate molar mass ($M$) and moles of pure substance. They may need some practice calculating M for hydrates and complex ions, and a review of mole calculations using $n = \frac{m}{M}$.
- Samples of bottled water or labels from a number of locally available water containers could provide a starting point for a discussion on solutions: What's in water? Why pay for bottled water? Is water a pure substance or a solution? What's natural water? Distilled water? Just because it is natural, is it safe? It should be noted that some water contains safe natural levels of arsenic. Concentration and toxicity can be linked to the substances dissolved in the water. This discussion allows you to determine how aware students are of common solutions as well as providing a familiar context to start the chapter.
- Given a number of white crystalline samples in beakers (sugar, salt, Epsom salts), ask students to predict which would dissolve in water. Students were introduced to the use of the solubility table for ionic compounds in *Science 10*. A discussion of what they need to know and the steps required to use this table for accurate solubility predictions may be needed before solution theory is presented.

## Launch Lab Sink or Float?

**Student Textbook page 165**

### Purpose

Students observe the properties of two cans of cola drinks. They contrast and compare diet and regular cola as an introduction to classifying solutions based on their physical and chemical properties.

### Outcomes

- 20–C1.2k
- 20–C1.1k
- 20–C1.1sts

### Advance Preparation

| When to Begin | What to Do |
|---|---|
| 1 day before | ■ Ensure materials are available.<br>■ Photocopy **BLM 5.0.2 (HAND) Launch Lab: Sink or Float?** |

| Materials |
|---|
| ■ Large container for water<br>■ 500 mL beakers (2)<br>■ 1 can diet cola<br>■ 1 can regular cola |

### Time Required

15 minutes

### Helpful Tips

- Have students write predictions before the teacher demonstration to focus their observations.
- Colas at room temperature could be compared to results with refrigerated colas, leading to a discussion of the temperature-solubility relationship.
- Read the labels of each cola for ingredients. Discuss preservatives, flavouring agents, carbonation, and other additives.
- Use **BLM 5.0.2 (HAND) Launch Lab: Sink or Float?** and **BLM 5.0.2A (ANS) Launch Lab: Sink or Float? Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- Measure the mass of each of the colas, before they are opened and in the beakers, at the end of the class. Measure the mass of the empty cans. This information could be used to account for any difference in the amount of $CO_2$(g) in each cola or how quickly it comes out of solution, or if the cans were different.
- Introduce the concept of cola as a homogeneous solution. None of the individual ingredients can be observed. The use of a microscope would confirm this.
- Students can try the experiment with different brand names, non-cola beverages, or non-carbonated drinks and so manipulate different variables. This activity could include a discussion of the merits of sugar over artificial sweeteners.
- ***Expected Results*** The cans are the same size and made of the same material. The cans will contain the same volume of soft drink. However, the regular cola is sweetened with a sugar solution and sugar solutions are much more dense than water. The artificial sweetener in the diet cola will not make the solution as dense as will the sugar. Therefore, the sealed can of diet cola will probably float while the sealed can of regular cola will probably sink.

### Safety Precautions

- Do not drop or shake the colas before opening to avoid the loss of contents under pressure.
- Ensure students have read and understand "Safety in Your Chemistry Lab and Classroom" on pages xii–xv in the student textbook.
- Dispose of all materials safely in proper waste containers.

## Answers to Analysis Questions

1. The regular cola contains sugar, which is heavier than diet sweetener(s). Students may also comment that not only does sweetener weigh less than sugar, but because the average person is more sensitive to sweetener, manufacturers use much smaller amount to achieve the same sweeteness. Students may suggest that the diet cola has more dissolved gas, causing it to float. Differences in mass between the cans would also contribute to the results observed.
2. Students should account for the difference between the tendency of diet cola to float and of regular cola to sink using the empirical data collected during the demonstration. They should link what they already know about solutions, for example that the mass of the solution depends on what is dissolved in it.

## Assessment Options

- Assess students' participation in the class discussion surrounding this activity. You may want to use parts of Assessment Checklist 5 Learning Skills (see Appendix A).
- Have students write down what they already know about solutions and some questions they may have. Assessment is based on the completeness and thoughtfulness (not correctness) of the response.
- Collect and assess answers to Analysis Questions.

# 5.1 Classifying Solutions

**Student Textbook pages 166–175**

## Section Outcomes

Students will:

- explain the nature of homogeneous mixtures
- illustrate how substances dissolve and how this process is often a prerequisite for chemical change by using examples from living and non-living systems
- explain dissolving as an endothermic or an exothermic process
- distinguish between electrolytes and nonelectrolytes
- design a procedure to identify the type of solution
- classify solutions using a conductivity apparatus

### Key Terms

pure substance
heterogeneous mixture
homogeneous mixture
solution
solvent
solute
aqueous solution
endothermic
exothermic
electrolyte
non-electrolyte
dissociation equation
soluble
insoluble
slightly soluble

## Chemistry Background

- Students will review how matter is classified as pure substances and mixtures. Mixtures may be classified as homogeneous if they are uniform throughout and there is no evidence of separate substances. Heterogeneous mixtures have varying composition and can often be separated into their various components.
- Solutions are homogeneous mixtures made up of solutes dissolved in a solvent; the substance present in the smaller amount is the solute.
- Solutions may be solid-in-solid (alloys), solid-, liquid-, or gas-in-liquid, or gas-in-gas mixtures. The focus of this section is on solid, liquid, and gas solutes dissolved in water.
- Colloids are distinguished from solutions because of their heterogeneity. These mixtures contain clumps of particles that may be seen with a microscope.
- Students should be familiar with aqueous solutions and the fact that water is considered the universal solvent. What will be new is how the dissolving process is related to energy changes due to forces of attraction between molecules or ions. How well a solute dissolves in a solvent depends on the comparative strengths of the solute-solute and solute-solvent forces of attraction.
- The physical (temperature) change that occurs when a solute dissolves in water is due to the difference between the energy required to break the attractive forces and the energy released when new intermolecular bonds form.
- Lattice energy is the energy required to break an ionic crystal into separate ions. Hydration energy is the energy released when water molecules move among the ions and form new chemical bonds. If the lattice energy is less than the hydration energy, the process is exothermic. Otherwise, it is endothermic.
- Students can illustrate the ions present in an aqueous ionic solution by writing dissociation equations. In these equations both charge and atoms are conserved. For example: $Na_3PO_4(s) \rightarrow 3Na^+(aq) + PO_4^{3-}(aq)$. However, molecular compounds that dissolve in water remain as intact molecules (e.g., $H_2O_2(\ell) \rightarrow H_2O_2(aq)$).

## Teaching Strategies

- Use the visual of the Bow River in the chapter opener to have students share their definition of a solution and to identity solutions they have used today.
- A demonstration using molecular models could be used to review the difference between ionic and molecular solutions, and show why ionic solutions conduct electricity. Dissolvable paper, icing sugar, or some other water-soluble substance can be used to make the ionic models. Place each of the molecular models in a container filled with

water, close it and shake vigorously. The molecular models stay intact, while the ionic models break apart.

- Overhead masters and a quiz have been prepared for this section. You will find them with the Chapter 5 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
  **Number (Type) Title**
  5.1.1 (OH) The Dissolving Process
  5.1.2 (OH) Writing Dissociation Equations
  5.1.3 (AST) Solubility and Writing Dissociation Equations Quiz
  5.1.3A (ANS) Solubility and Writing Dissociation Equations Quiz Answers

## Answers to Questions for Comprehension

**Student Textbook page 168**

**Q1. (a)** In theory, air is a solution since it is a homogeneous mixture of gases, mostly nitrogen, oxygen, and argon. However, some students may recognize that the presence of particulates such as soot, pollen, dust, and water vapour make a heterogeneous mixture.

**(b)** Solution

**(c)** Pure substance

**(d)** Solution

**(e)** Element

**(f)** Heterogeneous mixture

**Q2. (a)** Solvent: water; solute: carbonic acid

**(b)** Solvent: water; solute: ethylene glycol

**(c)** Solvent: iron; solute: nickel

**(d)** Solvent: nitrogen; solute: oxygen, argon

## Chemistry File: Web Link

**Student Textbook page 168**

Researchers at the University of Calgary found that mercury contained in mercury amalgam fillings can damage neurons.

## Answers to Questions for Comprehension

**Student Textbook page 170**

**Q3.** Step1: Bonds broken between molecules of solute, endothermic.

Step 2: Bonds broken between molecules of solvent, endothermic.

Step 3: Bonds formed between solute and solvent molecules, exothermic.

**Q4.** If the amount of energy released during the formation of the new bonds is greater than the energy required to break the bonds in steps 1 and 2, the process will be exothermic.

**Q5.** Students should mention that when the forces of attraction between solute molecules are weaker than those between solute and solvent molecules, a substance dissolves. If the forces of attraction between solute molecules are stronger than those between solute and solvent molecules, the substance will not dissolve.

**Student Textbook page 172**

**Q6. (a)** $AgBr(s)$ (use solubility table)

**(b)** $Mg(NO_3)_2(aq)$ (because all nitrates are soluble)

**(c)** $(NH4)_3PO_4(aq)$ (because all compounds with ammonium ions are soluble)

**(d)** $CaCO_3(s)$ (use solubility table for the rest)

**(e)** $Ba(ClO_3)_2(aq)$

**(f)** $CsCH_3COO(aq)$

**(g)** $AlI_3(aq)$

**(h)** $KHCO_3(aq)$

## Chemistry File: Web Link

**Student Textbook page 173**

There are a variety of different sports drinks on the market. Most sports drinks contain water, electrolytes, and sugar. Some drinks also contain caffeine. Sports drinks were originally designed for athletes, but many non-athletes now drink them. Sports drinks can help athletes replenish electrolytes and sugar. However, the drinks contain extra calories and sugar, so they can contribute to dental decay and weight gain if they replace water intake.

# Investigation 5.A: Classifying Solutions

**Student Textbook page 176**

## Purpose

Students will review their knowledge of ionic and molecular compounds and examine several unknown solutions to classify them as either ionic or molecular based on their conductivity properties.

## Outcomes

- 20-C1.4k
- 20-C1.1s
- 20-C1.2s

## Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Ensure materials are available. |

| When to Begin | What to Do |
|---|---|
| 1 day before | ■ Collect materials.<br>■ Prepare solutions.<br>■ (Refer to Appendix I: How to Prepare a Solution in the student resource.)<br>■ Photocopy **BLM 5.1.4 (HAND) Investigation 5.A: Classifying Solutions.** |

| Materials |
|---|
| ■ conductivity apparatus<br>■ 50 mL beakers (6)<br>■ disposal/waste container<br>■ distilled water<br>■ 25 mL of the following solutions, labelled one to five of:<br>■ 1-propanol, $C_3H_7OH(aq)$<br>■ hydrochloric acid, HCl(aq)<br>■ sodium chloride, NaCl(aq)<br>■ sodium hydroxide, NaOH(aq)<br>■ sucrose, $C_{12}H_{22}O_{11}(aq)$ |

## Time Required

30 minutes

## Helpful Hints

- To save time, make larger groups or have one group of students do the investigation as a demonstration.
- Solutions of 0.10 mol/L should be adequate to measure conductivity.
- Review distinguishing between ionic and molecular compounds, theoretically and empirically. Check that students are able to classify sucrose and n-propanol as molecular based on their formulas. Salt should be classified as ionic because of the ions present its formula. Students often misclassify alcohols as basic ionic compounds, mistaking the OH group for a hydroxide ion. A review of common complex ions may help reduce confusion. Students may classify hydrochloric acid as a molecular compound or acid based on the information presented on p. 173.
- It is important to test distilled water and tap water for conductivity before testing the solutions made using them. This practice reinforces the value of controlled variables in experimental design. Students need to recognize that if "distilled" water conducts, then all solutions will conduct, regardless of the solute present.
- Remind students to clean and dry conductivity probes after each use to avoid contamination.
- Some conductivity testers are very sensitive and give multiple readings of conductivity. If a meter reading is evident for the water used, it can become the base of standard for comparison purposes. The test solutions can be compared to the base value and classified accordingly.
- Students should be familiar with the common names for the substances used in this investigation: rubbing alcohol, muriatic acid, table salt, lye, and sugar.
- If n-propanol is not available, any short-chained alcohol will work.
- Use **BLM 5.1.4 (HAND) Investigation 5.A: Classifying Solutions** and **BLM 5.1.4A (ANS) Investigation 5.A: Classifying Solutions Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** The hydrochloric acid, sodium chloride, and sodium hydroxide solutions will conduct electric current thus they are electrolytes. Ions are free to move in solution. (Note: The students could distinguish among these solutions by testing the pH.)

  The propan-1-ol and sucrose solutions will not conduct electric current and thus they are not electrolytes. There are no ions in the solutions. These are molecular compounds.

## Safety Precautions

- Ensure that students have read and understand "Safety in Your Chemistry Lab and Classroom" on pages xii–xv of the student textbook.
- If you are using a conductivity tester with two separate electrodes, ensure that students keep the electrodes well separated.
- Remind students that n-propanol is not drinking alcohol and it is poisonous.
- Solutions of acids and bases may be toxic and corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure your eye-wash station has been tested recently and any eye-wash bottles are filled.
- Dispose of all material safely in proper waste containers.

## Answers to Analysis Questions

1. n-propanol and sucrose are molecular solutions because they do not conduct electricity. Sodium chloride and sodium hydroxide are ionic solutions because they form conducting solutions. Hydrochloric acid is a molecular electrolyte, a molecular compound that forms ions in solution.
2. Students should know that ionic compounds contain charged particles called ions. These ions migrate through the water toward the charged electrodes, thus transferring electric charge. Molecular compounds are covalently bonded (share electrons) and exist as neutral molecules in solution. They are not attracted to the electrodes, so no (extra) electric charge is transferred.
3. Because all of the solutions are made using distilled water, the distilled water's conductivity must be accounted for. If the distilled water conducts, then all solutions will conduct, regardless of the solute present.

### Answer to Conclusion Question

**4. (a)** Results should generally match students' predictions. Reasons for discrepancies include: inability of students to classify the solutions correctly, failure of students to label the solutions; problems with the conductivity tester; the use of water that conducts; or the contamination of solutions.

**(b)** Aqueous ionic solutions are homogenous and conduct electricity. Molecular compounds (if soluble) form homogenous, non-conducting aqueous solutions. Some molecular compounds (acids) will conduct electricity.

### Answers to Extensions Questions

**5.** Sodium chloride—used as a preservative and as a flavoring agent.
Sodium hydroxide—used to make soap and other cleaning products, used in industry to neutralize acids.
Hydrochloric acid—sold in hardware stores for use as cement cleaner, used in industry to neutralize bases.
n-propanol—used to make esters, used as a solvent, sold as rubbing alcohol, used to manufacture oils, gums, and acetone.

**6.** Additional tests could include: the use of litmus paper; colour indicators; flammability; smell; and taste. **Safety precaution:** Students should be strongly discouraged from tasting or removing any materials used in the laboratory.

## Assessment Options

- Assess students' participation in class discussion on how to classify solutions. Assessment Checklist 5: Learning Skills could be used (see Appendix A).
- Collect and assess Analysis, Conclusion, and/or Extension Questions.

### Answers to Questions for Comprehension

**Student Textbook page 175**

**Q7.** Electrolytes: **(a)**, **(b)**, **(d)**, and **(h)**; non-electrolytes: **(c)** and **(f)**. Although $Mg(OH)_2(s)$ is only slightly soluble, a solution of $Mg(OH)_2(s)$ will conduct to a small degree.

**Q8.** When the reactants are dissolved in water, the solute particles separate, disperse, and collide with particles of other solutes, allowing the reaction to occur quickly.

## Section 5.1 Review Answers

**Student Textbook page 175**

**1. (a)** Methane is the solvent in natural gas, since it is the largest gaseous component (at 70–90%) of natural gas.

**(b)** Three solutes of natural gas are ethane, propane, and butane.

**2.** The moth pin is an example of a solution if it is made of more than one metal (an alloy). The pin made be made of brass (copper and zinc) or a solution of gold and other metals.

**3.** The sugar crystals contain sucrose molecules that require energy to separate. The heat energy from the hot coffee provides the energy for this endothermic process to occur more rapidly. Water molecules form bonds with the separated sucrose molecules causing the solution to release energy.

**4.** The amount of thermal energy released when the solvent (water) molecules bond with the solute (urea) molecules is much less than the amount of thermal energy used to break solvent-solvent bonds and solute-solute bonds.

**5.** In order for a chemical change to occur, particles must be separated and rearranged. Dissolving the particles in a solvent partly accomplishes this.

**6.** When hydrochloric acid is dissolved in water, it dissociates completely; most molecular compounds do not. Hydrochloric acid is a polar molecule, so there are dipole-dipole interactions between hydrochloric acid and water. The separation in charge creates a pathway for the flow of a current.

**7.** Dissolve a small amount of each of the solids in 50 mL of distilled water. Use a conductivity apparatus to test the solutions for conductivity. The sugar solution will not conduct because sugar is a molecular compound. The salt solution will conduct because salt is an ionic compound.

## 5.2 Solubility

**Student Textbook pages 176–183**

### Section Outcomes

In this section, students will:
- define solubility and the factors that affect it
- explain a saturated solution in terms of equilibrium (equal rates of dissolving and crystallization)
- perform an investigation to determine the solubility of a solute in a saturated solution

### Key Terms

solubility
saturated
unsaturated
equilibrium

## Chemistry Background

- Students should be able to qualitatively and quantitatively differentiate saturated, unsaturated, and supersaturated solutions at a given temperature.
- A solubility table for ionic compounds at 25 °C (298.15 K) is given in Appendix G Table G.9 of the student textbook. This table is useful for predicting if an ionic compound is

soluble in water (concentration of 0.1 mol/L or greater) or if it has low solubility (concentration less than 0.1 mol/L).

- For students to classify a solution as saturated, unsaturated, or supersaturated, they need to know how soluble the solute is at a specified temperature. Students should be able to predict that solubility changes when the temperature of the solvent is increased. For solids, increasing the water temperature generally increases the solubility, but for gases it results in a decrease in solubility. Thus, the solubility of gases is generally less than that of solids or liquids (less than 0.1 mol/L) in water, and a gas is still considered soluble at less than 0.1mol/L.
- Students are not expected to predict the solubility of most molecular compounds in water.
- Macroscopic properties such as colour and evidence of undissolved solute can be used to describe solutions as saturated or unsaturated.
- By the end of this section, students should recognize that dissociation and crystallization equations represent a dynamic equilibrium that exists in saturated solutions at a particular temperature. For example:

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

  Crystals — Ions in solution
- Students should be able to use laboratory data to generate solubility-temperature curves.
- The kinetic energies of the particles in matter determine temperature. As the average motion of the particles increases, so too does the temperature. Gaseous solutes lose kinetic energy when they dissolve in water. For example: $NH_3(g) \leftrightarrow NH_3(aq)$ + energy. When energy is added the temperature increases and the equilibrium shifts, resulting in a decrease in the amount of gas dissolved. Pressure is another factor that affects gas solute solubility.
- The temperature-solubility relationship allows students to understand thermal pollution for solid and gas solutes.

## Teaching Strategies

- Figure 5.9 (student textbook page 173) can be used to help students visualize a saturated solution. Ask students why there is visible solute at the bottom of some of the beakers. This question makes students read the caption for the figure carefully and better appreciate terminology such as saturated vs. unsaturated.
- Discuss Figure 5.11 (student textbook page 177) by having the students answer the question and defend their answers. Crystallization and dissolving are opposite processes and occur simultaneously in saturated solutions.
- Using **BLM 5.2.3 (OH) The Effect of Temperature on the Solubility of Solids**, students can see the difference in solubility with temperature, and among a number of solutes.
- Reinforce the concept of slightly soluble and sparingly soluble using conductivity. Even sparingly soluble ionic compounds will produce slightly conductive solutions.
- To reinforce the differences in the effect of temperature on the solubility of solids and gases, have students dissolve as much sugar as they can in a cup of hot water and in a cup of cold water, then taste the difference. Bring Figure 5.16 to life by opening two bottles of a soft drink, one at room temperature and the other cold from refrigeration. If they are opened under a beaker filled with water, the undissolved gas may be collected and the volumes compared.
- Two overhead masters have been prepared for this section. You will find them with the Chapter 5 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  **Number (Type) Title**

  5.2.1 (OH) Dissolving and Crystallizing in a Saturated Solution

  5.2.3 (OH) The Effect of Temperature on the Solubility of Solids

## Answers to Questions for Comprehension

**Student Textbook page 177**

**Q9. (a)** 188 g

**(b)** unsaturated

**(c)** 44 g

**(d)** 104 g

**Student Textbook page 179**

**Q10. (a)** At equilibrium, the rate of the forward reaction or process must equal the rate of the reverse reaction or process in a closed system.

**(b)** In a saturated solution, the solid solute dissolves at the same rate as the aqueous solute precipitates.

**Q11. (a)** $NaCl(s) \rightarrow Na^{+}(aq) + Cl^{-}(aq)$

**(b)** $CaCl_2(s) \rightarrow Ca^{2+}(aq) + 2Cl^{-}(aq)$

**(c)** $(NH_4)_2CO_3(s) \leftrightarrow 2NH_4^{+}(aq) + CO_3^{2-}(aq)$

**(d)** $Mg_3(PO_4)_2(s) \leftrightarrow 3Mg^{2+}(aq) + 2PO_4^{3-}(aq)$

## Investigation 5.B: Plotting Solubility Curves

**Student Textbook pages 180–181**

### Purpose

To determine the temperature at which a certain amount of potassium nitrate is soluble in water using individual and class data.

### Outcomes

- 20–C1.1s
- 20–C1.2s
- 20–C1.4s

## Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Ensure all materials are available. |
| 1 day before | ■ Collect materials and distilled water.<br>■ Assemble stoppers with thermometers. Photocopy **BLM 5.2.2 (HAND) Investigation 5.B: Plotting Solubility Curves.** |

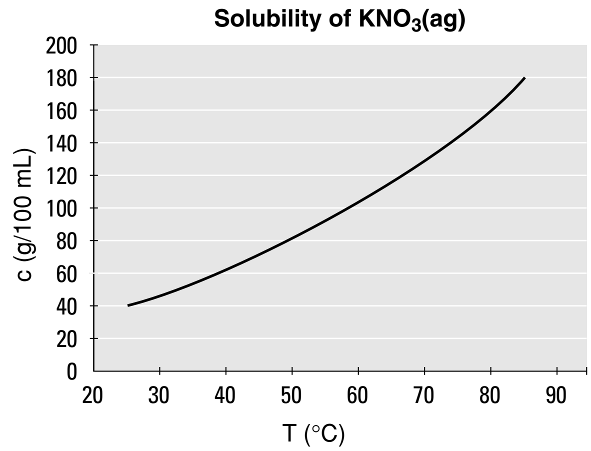
| Materials |
|---|
| ■ graduated pipette<br>■ balance<br>■ scoopula®<br>■ 100 mL beaker<br>■ 400 mL beakers (2)<br>■ stirring rod<br>■ pipette bulb<br>■ two-holed stopper to fit the test tube with a thermometer inside<br>■ large test tube<br>■ hot plate or Bunsen burner<br>■ $KNO_3$(s) (15.0 g per group)<br>■ distilled water |

## Time Required

60 minutes

## Helpful Hints

- The potassium nitrate may be recrystallized and reused. Have students reheat their solutions until all of the solute is dissolved, then collect the solutions in a common container.
- Discuss student results after recording them on the board or overhead. Results that are much higher or lower than other groups using the same volume should be eliminated before plotting the graph.
- If potassium nitrate is unavailable, use ammonium chloride or potassium chlorate. Do not use sodium chloride as its solubility does not change appreciably with an increase in temperature.
- Use **BLM 5.2.2 (HAND) Investigation 5.B: Plotting Solubility Curves** and **BLM 5.2.2A (ANS) Investigation 5.B: Plotting Solubility Curves Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** The students will find that the solubility of potassium nitrate increases with temperature. Sample data are plotted at the top of the next column.




At 40 °C, you would expect the solubility to be about 60 g/100mL.
At 60 °C, you would expect the solubility to be about 100 g/100mL.
At 20 °C, you would expect the solubility to be about 36 g/100mL.
At 80 °C, you would expect the solubility to be about 160 g/100mL.

## Safety Precautions

- Remind students to handle hot plates with care. Do not move until cool enough to handle.
- Ensure students know how to use pipettes and the correct number of values to record for their calculations. Incorrect technique can result in broken or chipped glassware. Ensure that students do not "mouth" pipette any solutions in the laboratory.

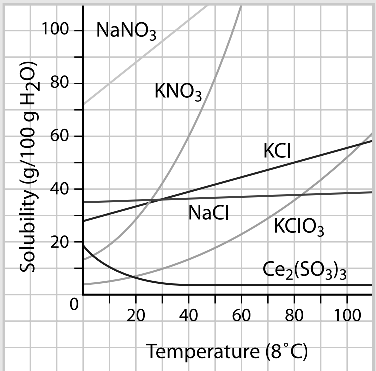
## Student Hypothesis

Students will likely predict that an increase in temperature results in an increase in solubility of substances in water. They base this hypothesis on previous experience. Students' data should resemble that for solubility of $KNO_3$ on student textbook page 183.

## Answers to Analysis Questions

1. Solubility will vary from 5 g/100 mL at 20 °C to 160 g/100 mL at 80 °C. Students should use the formula provided in order to make valid comparisons.
2. Solubility should increase with temperature if students were careful in gathering data and in doing the calculation in question 1.

**3., 4.** Students' data should resemble that for solubility of $KNO_3$ on student textbook page 183.




## Answer to Conclusion Question

**5. (a)** Discuss any discrepancies in the shape of the graph and reasons for the differences.

**(b)** Temperature increases the rate of solubility appreciably.

**(c)** Students should answer the question using values obtained, by their group and by the class, in the investigation. They could comment on how their data compared to those of their classmates.

## Answers to Applications Questions

**(Based on the graph from page 183)**

**6. (a)** At 60 °C, 110 g of $KNO_3$ will dissolve in 100 g of water.

**(b)** At 40 °C, 60 g of $KNO_3$ will dissolve in 100 g of water.

**7. (a)** At 80 °C, 155–160 g of $KNO_3$ will dissolve in 100 g of water.

**(b)** At 20 °C, 30 g of $KNO_3$ will dissolve in 100 g of water.

## Assessment Options

- Collect and assess student answers to Analysis, Conclusion, and Application Questions.
- Use Assessment Checklist 3 Performance Task Self-Assessment (see Appendix A).
- Use Assessment Checklist 4 Performance Task Group Assessment (see Appendix A).

## Chemistry File: Web Link

**Student Textbook page 182**

Coal burning has led to metals in the sediment and high levels of mercury in some of the fish in Wabamun Lake. Power plants also lead to thermal pollution in lakes.

## Section 5.2 Review Answers

**Student Textbook page 183**

**1. (a)** Solubility is the amount of substance that dissolves in a given quantity of solvent at a given temperature to give a saturated solution.

**(b)** An unsaturated solution is a solution that is not in equilibrium and in which more of the solute can dissolve.

**(c)** A saturated solution is in equilibrium with respect to a dissolved substance, and no more solute can be dissolved at a given temperature.

**2. (a)** This solution would be considered unsaturated because the mass of solute, 20.0 g/100 mL, is lower than the given solubility.

**(b)** This is a supersaturated solution because it has a higher concentration than the solubility at this temperature.

**3. (a)** $LiCl(s) \leftrightarrow Li^+(aq) + Cl^-(aq)$

**(b)** $NH_4F(s) \leftrightarrow NH^{4+}(aq) + F^-(aq)$

**(c)** $Na_2S(s) \leftrightarrow 2Na^+(aq) + S^{2-}(aq)$

**(d)** $(NH_4)_2SO_4(s) \leftrightarrow 2NH_4^+(aq) + SO_4^{2-}(aq)$

**4. (a)** Saturated solution

**(b)** 40.0 g – 34.7 g = 5.3 g undissolved solute

**(c)** $KCl(s) \leftrightarrow K^+(aq) + Cl^-(aq)$

**5.** More solute can dissolve in the warmer thermal springs than in the cooler mountain springs.

**6.** The presence of the undissolved solute guarantees that the maximum amount of dissolved solute remains in solution as individual particles move from a dissolved to undissolved state at equilibrium.

**7. (a)** $Ce_2(SO_3)_3$ **(b)** $Ce_2(SO_3)_3$ **(c)** NaCl

**(d)** approximately 85 °C **(e)** approximately 10.8 g

## 5.3 The Concentration of Solutions

**Student Textbook pages 184–196**

## Section Outcomes

In this section, students will:

- express concentration in a variety of ways, including:
  - percent by mass (percent *m*/*m*)
  - parts per million (ppm)
  - moles per litre of solution (mol/L)
- calculate the concentration of solutions in mol/L
- determine mass or volume from concentrations in mol/L
- calculate ion concentration from empirical data and dissociation equations
- design a procedure to determine the concentration of a solution containing a solid solute
- use experimental data to determine the concentration of a solution

## Key Terms

concentration
concentrated
dilute
percent by mass
parts per million
parts per billion
molar concentration

## Chemistry Background

- Concentration can be expressed in a variety of ways, including percent by mass, parts per million or per billion, and moles per litre of solution. Students should already be familiar with unit conversions such as millilitres to litres and grams to kilograms, and recognize the need to include all units for calculations and measurements. Numerical answers should be rounded to the correct number of significant digits at the final calculation step. Refer to Appendix for rules for rounding measured and exact values.
- The correct manipulation of formula variables and the use of dimensional analysis are necessary for accurate scientific communication.
- Students should be able to use dissociation equations to determine the molar ratio of different ions present in a solution and to calculate their concentration. Ion concentrations can be determined from the solution concentration and mole ratio. For example:
  $1\ Na_2S(aq) \rightarrow 2\ Na^+(aq) + 1\ S^{2-}(aq)$ yields molar ratio 1:2:1. So for $[Na_2S(aq)] = 1.0$ mol/L, there are 2.0 mol/L of $Na^+(aq)$ ions and 1.0 mol/L of $S^{2-}(aq)$ ions.
- Students should know the formula $n = \frac{m}{M}$ for determining the moles of a substance, and how to manipulate the formula to solve for any of the three variables. The new formula at this level is for molar concentration, $C = \frac{n}{V}$. Students should be able to write formulas for ionic compounds, determine their molar mass, and determine either the volume of solution, the mass of solute, or the molar concentration of the solution by manipulating the two formulas. Students should also be able to use empirical data to determine solution concentration.
- Students should know the formula $n = \frac{m}{M}$ for determining the moles of a substance, and how to manipulate the formula to solve for any of the three variables. The new formula at this level is for molar concentration, $C = \frac{n}{V}$. Students should be able to write formulas for ionic compounds, determine their molar mass, and determine either the volume of solution, the mass of solute, or the molar concentration of the solution by manipulating the two formulas. Students should also be able to use empirical data to determine solution concentration.
- The determination of safe limits of particular solutes is concentration-dependent. Given safe limits, students should be able to use concentration as part of a risk-benefit analysis.

## Teaching Strategies

- Labels on commercial products can be used to brainstorm scientific communication of solutes present in solutions. Do they follow SI and/or IUPAC conventions? Students need to recognize that not all labelling is the same. Useful examples include: bottled water, vinegar (a diluted acid), hydrogen peroxide (sold in various concentrations from 1% *w/v* as a disinfectant to 30% to lift hair colour), cough medications, and so on. Students should know from *Science 10* that weight is gravity dependent. Thus for chemistry, % *m/m* is used rather than % *w/w* or % *w/v*.
- Have students research the Alberta legal alcohol limit for operating a vehicle (0.08%). What does this number mean? How was it arrived at? This value is a concentration that could be converted to mol/L, ppm, or % *m/m* as Section 5.3 is taught. This topic usually gets students interested and could support SADD (Students Against Drunk Driving) awareness.
- Parts per million is a difficult concentration to visualize. You can make a glass jar of a million rice grains. Have the students decide how to use mass to estimate a million grains. Place the estimated million grains in a jar, remove one grain, colour it with a marker and return it to the jar. You now have a 1 ppm mixture. (Depending on the size of the rice, this could be more than 12 L of rice, if done by volume.)
- Use **BLM 5.3.2 (AST) Calculations Involving Percent by Mass, Parts per Million, and Parts Per Billion, BLM 5.3.3 (AST) Calculating Molar Concentration, BLM 5.3.4 (OH) Molar Concentration of Ions in Solution, BLM 5.3.5 (AST) Calculating the Molar Concentration of Ions in Solution, BLM 5.3.6 (AST) Calculating Mass and Volume from Concentration, BLM 5.3.7 (AST) Mixed Concentration Problems, and BLM 5.4.1 (AST) Dilution Calculations** to help students practice calculating and converting units of concentration. There are also answer files for each of these BLMs.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 5 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
  **Number (Type) Title**
  5.3.2 (AST) Calculations Involving Percent by Mass, Parts per Million, and Parts Per Billion
  5.3.2A (ANS) Calculations Involving Percent by Mass, Parts per Million, and Parts Per Billion Answer Key
  5.3.3 (AST) Calculating Molar Concentration
  5.3.3A (ANS) Calculating Molar Concentration Answer Key
  5.3.4 (OH) Molar Concentration of Ions in Solution
  5.3.5 (AST) Calculating the Molar Concentration of Ions in Solution
  5.3.5A (ANS) Calculating the Molar Concentration of Ions in Solution Answer Key
  5.3.6 (AST) Calculating Mass and Volume from Concentration
  5.3.6A (ANS) Calculating Mass and Volume from Concentration Answer Key

5.3.7 (AST) Mixed Concentration Problems
5.3.7A (ANS) Mixed Concentration Problems Answer Key

## Thought Lab 5.1: Expressing Concentration

**Student Textbook page 185**

### Purpose

Students will be exposed to different styles of calculating concentration in various commercial and industrial products. They will also compare the availability and amount of active and possibly toxic material present in these products, as well as at manufacturing and waste sites.

### Outcomes

- 20–C1.1s
- 20–C1.5sts
- 20–C1.4s

### Helpful Hints

- Use **BLM 5.3.1 (HAND) Thought Lab 5.1: Expressing Concentration** and **BLM 5.3.1A (ANS) Thought Lab 5.1: Expressing Concentration Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

### Answers to Analysis Questions

**1. (a)** Common ways of expressing concentration include parts per million (ppm) or per billion (ppb), percent by weight-volume (% *w/v*), percent by volume (% *v/v*), percent by mass (% *m/m*), and molar concentration (mol/L).

**(b)** The different methods of calculating concentration have developed to take advantage of the unique properties of the types of substances used, giving clues to their manufacture, for example percent by volume for liquid-liquid solutions, percent by mass for dissolved solids. Most students will probably agree that this situation makes things harder for the general population to understand.

**2.** Students might suggest that better care ought to be taken to separate those substances that have some degree of toxic substances to prevent a dangerous buildup at landfill sites, from which these substances could subsequently be leached out into the local drinking water.

### Answers to Practice Problems 1–5

**Student Textbook page 186**

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions

**1. (a)** 20.7% **(b)** 16.61% **(c)** 15.1% **2.** 35.5% **3.** 85 g

**4.** 6.35 g **5.** 15 g

### Answers to Practice Problems 6–10

**Student Textbook page 188**

**6. (a)** 0.33 ppm **(b)** $3.3 \times 10^{2}$ ppb **(c)** $3.3 \times 10^{-5}$% (*m/m*)

**7.** 0.0700% (*m/m*) **8.** 0.040 g **9.** 1.4 ppm to 4.0 ppm

**10.** 0.0032 g

## Connections (Social and Environmental Contexts): Biomagnification and Bioaccumulation

**Student Textbook page 189**

### Teaching Strategies

- Interested students may want to perform further research on biomagnification and bioaccumulation. These topics are sometimes covered in the press. Have students clip related articles and present them to the class, or initiate a class discussion about issues related to biomagnification and bioaccumulation.

### Connections Answers

**1. (a)** 34 µg

**(b)** 525 mg

**2.** $1.82 \times 10^{15}$ ng or 1.82 t

**3.** If hydrogen sulfide in solution is reacted with solutions containing mercury, a precipitate forms that removes the mercury. The acid formed, $H^{+}$(aq), may be removed using a base.

### Answers to Practice Problems 11–16

**Student Textbook page 191**

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

**11. (a)** 1.7 mol/L **(b)** 2.41 mol/L

**12. (a)** $8.05 \times 10^{-1}$ **(b)** $1.8 \times 10^{-1}$

**13.** $7.35 \times 10^{-4}$ mol/L

**14.** $5.6 \times 10^{-6}$ mol/L

**15.** $1.05 \times 10^{-2}$

**16.** 3.1 mol/L

### Answers to Practice Problems 17–22

**Student Textbook page 193**

**17.** 0.29 mol/L

**18.** $3.2 \times 10^{-7}$ mol/L

**19.** $2 \times 10^{-6}$ mol/L

**20.** $3.45 \times 10^{-7}$ mol/L

**21.** $2.4 \times 10^{-2}$mol/L

**22.** $1.00 \times 10^{-2}$ mol/L

## Answers to Practice Problems 23–26

**Student Textbook page 194**

**23.** **(a)** 1.46 g **(b)** 135 g

**24.** **(a)** 0.16 g **(b)** $1.5 \times 10^2$ g

**25.** 7.45 g

**26.** $4.5 \times 10^2$ g

## Answers to Practice Problems 27–30

**Student Textbook page 195**

**27.** **(a)** 0.034 L **(b)** 0.052 L

**28.** **(a)** 0.0854 L **(b)** 3.1 L

**29.** 50 L

**30.** 1.0 L

## Section 5.3 Review Answers

**Student Textbook page 196**

**1.** 50% *m/m*

**2.** **(a)** 27% *m/m*

**(b)** copper

**(c)** 73% of the sample is another element

**3.** 11 g

**4.** 36 ppb

**5.** ppb = µg/l = 35 µg/0.500 L = 70 ppb

No, I would not drink the water since the concentration of selenium is above the recommended limits.

**6.** 0.101 mol/L

**7.** 0.0024 mol/L $Cu(NO_3)_2$(aq) × mol/L $Cu(NO_3)_2$(aq) = 0.45 g $Cu(NO_3)_2$ × 1 mol/187.57 g × 1/0.100 L = 0.0024 mol/L $Cu(NO_3)_2$(aq)

**8.** x mol/L KI (aq) = 2.5 g KI(s) × 1 mol/166.00 g × 1/0.375 L = 0.040 mol/L KI(aq)

**9.** $[Mg^{2+}(aq)] = 3.42 \times 10^{-8}$ mol/L

$[(PO_4)^{-}(aq)] = 2.28 \times 10^{-8}$ mol/L

**10.** 3.73 g

**11.** 0.132 L

**12.** **(a)** ppm or ppb

**(b)** mol/L

**(c)** ppm or ppb

**(d)** % *m/m*

**(e)** % *m/m*

**(f)** % *v/v*, % *m/m*

**13.** **(a)** Determine the mass of a dry beaker. Transfer the solution to the dry beaker and determine the mass of the beaker and solution. Subtract the mass of the beaker from the mass of the beaker and solution. This is the mass of the solution. Crystallize the solute dissolved in the solution by either heating it slowly to evaporate the water, or allow the water to evaporate over a number of days. Mass the beaker with the dry solute. This is the mass of solute. Determine the percent by mass by dividing the mass of the dry solute by the mass of the solution and multiply by 100 to obtain a percentage.

**(b)** To determine the molar concentration, you must know the molar mass. Either ask the teacher for the molar mass of the unknown compound, or ask the teacher for its chemical formula, and then calculate the molar mass. To determine molar concentration, use the mass of the solute divided by its molar mass to obtain the number of moles. Divide the number of moles by the volume of the solution. To obtain the volume of the solution, you can subtract the mass of the solute obtained in part a from the mass of the solution, also obtained in part a. This gives you the mass of the solvent, water. Since the density of water is 1.00 g/mL, convert the mass of the water to volume using density (1:1 ratio), and then divide by 1000 to get a volume in litres.

**14.** The concentration of a compound in solution is the number of moles of the compound per litre of solution. The concentration of an ion in solution depends on the concentration of the compound as well as the number of moles of the ion in the compound. The concentration of the potassium ion is three times that of the compound, so the formula is $K_3X$(aq), where X could be $PO_4^{3-}$(aq).

**15.** The technician must first decide what volume of solution to make. Since 5 groups of students will each be using 25 mL of the stock solution, a minimum of 5 × 25 mL = 125 mL will be used. Since small amounts of solution will remain in measuring glassware, it is necessary to make a little extra. The technician might decide to make 150 mL of the stock solution. Next the technician must calculate the mass of solute that will result in a concentration of 1.5 mol/L.

First find the number of moles needed in 150 mL to make a concentration of 1.5 mol/L.

$$n = cV$$
$$= \left(1.5\frac{\text{mol}}{\cancel{\text{L}}}\right)(0.150\,\cancel{\text{L}})$$
$$= 0.225 \text{ mol}$$

Next, find the mass of sodium sulfate that contains 0.225 mol.

$$m = nM$$
$$= (0.225\,\cancel{\text{mol}})\left(142.05\frac{\text{g}}{\cancel{\text{mol}}}\right)$$
$$= 31.96 \text{ g}$$

Use an electronic balance to tare the mass of a beaker and then add 32 g of sodium sulfate. Dissolve the sodium sulfate in approximately 60 mL of distilled water. Transfer the solution to a 150 mL volumetric flask using a funnel. Wash the beaker, stirring rod and funnel into the volumetric flask using distilled water. Mix the solution completely. Fill the volumetric flask with distilled water until the bottom of the meniscus is at the line. Make sure to view the line at eye level and do not overfill. Stopper the flask and invert to mix.

## 5.4 Preparing and Diluting Solutions

**Student Textbook pages 197–202**

### Section Outcomes

In this section, students will:

- use a balance and volumetric glassware to prepare solutions of specified concentration
- describe the procedures and calculations required for preparing and diluting solutions
- calculate concentrations and/or volumes of diluted solutions, and calculate the quantities of a diluted solution and water to use when diluting
- assess the impact of industrial effluent on water quality

### Key Terms

standard solution

### Chemistry Background

- At this stage, students will calculate the mass of solute required to make a standard solution. Students should be aware that the amount (moles) of solute sample stays constant regardless of the sample's state or whether it is dissolved in a solvent (water).
- Students will learn how to make a solution of specified concentration using volumetric glassware.
- Students differentiate between dilute and concentrated solutions and learn to determine the volume of concentrated solution required to make a specified volume of dilute solution. They use volumetric flasks and pipettes, and learn how to select the appropriate glassware.

### Teaching Strategies

- Have a collection of glassware available to demonstrate the difference in accuracy of volume measurements. Start with a large beaker containing a small volume of coloured water placed on a filter paper disc. Ask students to record the volume of the solution. Pour this solution into a smaller beaker and record the volume. Continue using a graduated cylinder and end with the use of a pipette.
- Be sure to demonstrate proper technique for the preparation of standard solution from a solid or of a dilute solution from a concentrated solution. Students need to be exposed to the safe handling and disposal of substances and use of materials. Review WHMIS labelling of substances and the value of carefully labelling all solutions used in the lab.
- Have students practice using pipettes of various sizes and styles.
- Make use of **BLM 5.4.1 (AST) Dilution Calculations, BLM 5.4.1A (ANS) Dilution Calculations Answer Key, BLM 5.4.2 (HAND) Performing a Risk-Benefit Analysis, BLM 5.4.4 (HAND) Preparing Solutions**, and **BLM 5.4.5 (HAND) Diluting Solutions** to give students practice.
- A number of handouts and a quiz have been prepared for this section. You will find them with the Chapter 5 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  **Number (Type) Title**
  5.4.1 (AST) Dilution Calculations
  5.4.1A (ANS) Dilution Calculations Answer Key
  5.4.2 (HAND) Performing a Risk-Benefit Analysis
  5.4.4 (HAND) Preparing Solutions
  5.4.5 (HAND) Diluting Solutions

### Answers to Practice Problems 31–33

**Student Textbook page 198**

For full solutions, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

**31. (a)** 0.040 L **(b)** 0.128 L

**32. (a)** 0.300 mol/L **(b)** 0.0900 mol/L **(c)** 0.00720 mol/L

**33.** 0.021 mol/L

## Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis

**Student Textbook page 199**

### Purpose

In this investigation, students research the effect of the release of chemicals into waterways (called effluent), and propose a plan to reduce the impact on the surrounding ecosystems.

### Outcomes

- 20–C1.4s
- 20–C1.3sts

### Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Book computer time.<br>■ Photocopy **BLM 5.4.3 (HAND) Investigation 5.C: Pollution of Waterway A Risk-Benefit Analysis.** |

### Time Required

- 3 classes: 1 class research time, 1 class analysis time, 1 class presentation time
- 2 classes if all work and some research is done at home

### Helpful Hints

- Ideal group size is about three students. To save time, make larger groups.
- Students may need prompting during the brainstorming session.

- If resources are scarce, or there are only a few groups, it may be necessary to assign substances to specific groups in order to prevent duplication and/or omissions. Some major pulp and paper mill pollutants are: dioxins, nitrates and other nitrogen oxides, suphur oxides, heavy metals such as mercury and cadmium.
- Review the form of a risk–benefit analysis.
- Use **BLM 5.4.3 (HAND) Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis** and **BLM 5.4.3A (ANS) Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

## Opinions and Recommendations

**6. (a)** Generally, students will find that provincial and federal governments attempt to regulate and educate industry about safety concerns. However, stronger students may criticize voluntary compliance to minimum industry guidelines and poor government funding for enforcement and inspection.

**(b)** Most students will point to the economic benefits of these industries to conclude that the benefits outweigh the risk. However, students who attempt to put a financial cost to environmental clean-up and associated health care may suggest otherwise.

**(c)** Students should discuss amount and strength of supporting details, as well as the attempt to provide clear assessment criteria.

## Assessment Options

- Assess students' participation in class discussion.
- Use Assessment Checklist 8: Oral Presentations to assess any student presentations.

# Investigation 5.D: Preparing and Diluting a Standard Solution

**Student Textbook page 200**

## Purpose

- Students practice preparing an ionic solution from solids of known concentration. Once a standard solution is prepared it will be used to make a second solution by dilution. The accuracy of the solution can be verified using colour comparisons of pre-prepared standard solutions.
- Students practice using various glassware, including pipettes and volumetric flasks, required to prepare standard solutions.

## Outcomes

- 20–1.7k
- 20–1.1k
- 20–1.3sts
- 20–C1.1s
- 20–C1.2s
- 20–C1.3s

## Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Ensure all materials are available. |
| 1 day before | ■ Collect materials and distilled water.<br>■ Prepare standard solutions of $CuSO_4.5H_2O(aq)$ in large test tubes labelled 1 to 6. Suggestion in Use<br>0.01 mol/L, 0.03 mol/L<br>0.050 mol/L, 0.08 mol/L<br>0.010 mol/L, 0.50 mol/L<br>■ Photocopy **BLMs 5.4.4 (HAND) Preparing Solutions, 5.4.5 (HAND) Diluting Solutions**, and **5.4.6 (HAND) Investigation 5.D: Preparing and Diluting a Standard Solution.** |

| Materials |
|---|
| ■ graduated pipette<br>■ balance<br>■ Scoopula®<br>■ 100 mL volumetric flask<br>■ 100 mL beaker<br>■ 250 mL beakers (2)<br>■ stirring rod<br>■ funnel<br>■ pipette bulb<br>■ large test tube<br>■ medicine dropper<br>■ light box, overhead projector, or spectrophotometer<br>■ copper (II) sulfate pentahydrate, $CuSO_4.5H_2O(s)$<br>■ distilled water<br>■ grease pen or marker<br>■ prepared standard solutions (6) |

## Time Required

45 minutes

## Helpful Tips

- With the students or as a demonstration you may wish to prepare one or more of the standard solutions that will be used for comparison purposes, so that students will be familiar with the laboratory technique. Review the calculations for the mass of solute required.
- Have students practice using pipettes with water before beginning their dilutions.
- Using tap water rather than distilled water may affect results: low solubility solutes may appear when the ionic compound

is dissolved, or there may be an undesirable side reaction that occurs. Cloudy solutions and/or different colours than anticipated are macroscopic indicators of this problem.

- Students should use clean glassware to avoid contamination. Some glassware can be wet (volumetric flask) and others need to be dry (beaker to mass the solute) when making solutions.
- Review accuracy of glassware. Ensure students select the most accurate glassware available for their solution preparations.
- When preparing the six standard sample solutions, use the exact same size and/or style of test tubes. The concentration may appear higher or lower depending on the glassware. Stopper the sample test tube solutions to avoid water loss and potential contamination.
- A conductivity apparatus or a conductivity probe may also be used to determine relative concentrations.
- Use **BLM 5.4.4 (HAND) Preparing Solutions** and **BLM 5.4.5 (HAND) Diluting Solutions** to reinforce the steps.
- Use **BLM 5.4.6 (HAND) Investigation 5.D: Preparing and Diluting a Standard Solution** and **BLM 5.4.6A (ANS) Investigation 5.D: Preparing and Diluting a Standard Solution Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** The intensity of the colour of the solutions should increase linearly with the concentration.

## Safety Precautions

- Ensure students have read and understand "Safety in Your Chemistry Laboratory and Classroom" in the student textbook.
- Dispose of all materials and any broken or chipped glassware safely in proper waste containers.

## Answers to Procedure Questions

**Part 1**

1. 12.5 g

**Part 2**

1. 10.0 mL

## Answer to Analysis Question

1. Whenever solution is transferred from one container to another, there is the risk of leaving behind some solution. Rinsing the old container and then adding the remaining solution to the new container runs the risk of diluting the solution past the desired point. It may be difficult to orient the light source so that outside light pollution is filtered out while providing sufficient light to the photometer.

## Answer to Conclusion Question

2. Depending on the concentration of known samples provided, students will use the formula

$$\text{Percent error} = \frac{\text{actual concentration} - \text{theoretical concentration}}{\text{theoretical concentration}} \times 100\%$$

## Answers to Extensions Questions

3. As the concentration of the coloured sodium chloride increases, the colour increases without increasing the toxicity of the solution.
4. The colour of the copper(II) sulfate solution undergoes a colour change at 0.100 mol/L. Students could describe procedure to dilute the solution to 0.100 mol/L and then compare the colour to a known sample.

## Assessment Options

- Collect and assess student answers to Procedure Questions.
- Use Assessment Checklist 6: Using Math in Science (see Appendix A).
- Use Assessment Checklist 5: Learning Skills (see Appendix A).

# Section 5.4 Review Answers

**Student Textbook page 202**

1. A standard solution is one of precisely known concentration.
2. Step 1: Calculate the mass of solute required, based on a known volume and concentration of solution to be prepared.

   Step 2: Using an electronic balance, obtain the required mass of solute in a beaker.

   Step 3: Dissolve the solute in approximately half the distilled water volume required in the final solution. Stir until completely dissolved.

   Step 4: Transfer the solution using a funnel into an appropriate-size volumetric flask.

   Step 5: Rinse the funnel and beaker with distilled water and pour into the volumetric flask.

   Step 6: Add distilled water to the flask up to the etched line.

   Step 7: Cap and invert to mix.
3. Step 1: Calculate the volume of concentrated reagent required.

   Step 2: Rinse the pipette with solution and discard in waste container.

   Step 3: Transfer the required volume of concentrated solution into a volumetric flask.

   Step 4: Fill the flask with distilled water to the etched line.

   Step 5: Stopper the flask and invert to mix.
4. **(a)** The solution will be less concentrated because some of the solute was not added to the volumetric flask.

   **(b)** This solution will be more concentrated than desired because less water than expected is added to the solution.

(c) Rinsing the pipette with water dilutes the standard solution that is pipetted to make the dilute solution. The final solution has a lower concentration than desired.

(d) The solution will be more concentrated because of the additional solute added.

5. (a) Beaker, graduated cylinder, pipette. The markings on each piece of glassware dictate the accuracy of the volume measurement possible.

(b) The pipette measures 10 mL of solution most precisely because it is the narrowest tube.

(c) The beaker measures 10 mL of solution least precisely because it is the widest tube.

6. It is more accurate to measure a larger volume (that is, there is less relative error in measuring 10.0 mL than 1.0 mL or 0.1 mL)

7. 0.0125 mol/L

8. 1.5 L

Transfer 350 mL of the 5.7 mol/L stock solution to a 1.5 L volumetric flask (either pouring the entire solution or transferring from a stock bottle using graduate or volumetric glassware). Rinse the transferring glassware into the volumetric flask. Fill the flask with distilled water until the bottom of the meniscus is on the etched line. Invert to mix.

9. 5.2 mL

Approximately 150 mL – 5.3 mL = 144.7 mL would have to be added.

10. (0.025 L)(1.5 mol/L) = (0.050 mol/L)V

V = 0.75 L

Therefore, approximately 750 mL – 25 mL = 725 mL of water would have to be added.

11. (475 L)(5.5 mol/L) = $(3.5 \times 10^{-7}$ mol/L)V

V= $7.46 \times 10^{9}$ L

## Chapter 5 Review Answers

**Student Textbook pages 204–205**

### Answers to Understanding Concepts Questions

1. (a) soda pop and juice

(b) hydrogen peroxide and mouthwash

(c) stainless steel sink and sterling silver jewelry

2. A solution is a mixture of two or more substances; a pure substance is made up of only one type of element or compound.

3. The turpentine is the solvent because it is present in the larger volume.

4. Electrolytes ionize in water to form individual ions, whereas non-electrolytes remain as intact molecules.

5. The dissolving process is exothermic when the energy released by the bonds forming between the solute and the solvent is greater than the energy required to separate the solid solutes and the solvent particles to make a solution. The opposite is true for the an endothermic solution.

6. Insoluble suggests that a substance does not measurably dissolve at all. All substances dissolve to some extent in water.

7. A saturated solution is in equilibrium with undissolved solute and contains the maximum amount of dissolved solute under the specific conditions. An unsaturated solution has less solute dissolved than the maximum possible. A supersaturated solution is unstable and contains a higher solute concentration than the solubility amount.

8. A saturated solution contains both the solid and the dissolved form of the solute. A brine solution can be written as a system at equilibrium.

Crystallization ↔ Dissolving

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

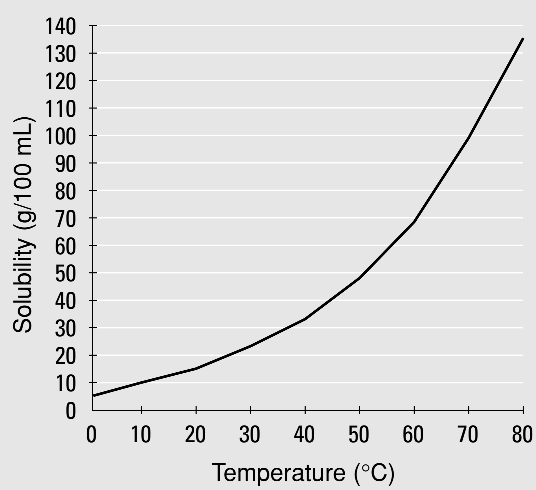
9. Liquid-in-liquid solutions are not affected appreciably by pressure and temperature. An increase in temperature increases the solubility of most solids but decreases the solubility of gases. An increase in pressure increases the solubility of gases in the solvent. The solubility of solids is not affected by pressure changes.

### Answers to Applying Concepts Questions

10. The first test a student could perform is a conductivity test, to differentiate ionic and molecular solutions. Aqueous ionic compounds are electrolytes. Molecular compounds are non-electrolytes, and distilled water is also a non-electrolyte. The remaining two liquids can be heated to boil off the solvent. The one with no solid residue is the water and the other the molecular substance.

11. Controlled variables: Mass of solute, identity of solute, glassware used
Manipulated variable: Volume of water (concentration)
Responding variable: Temperature at which crystals appear

12. (a) The curve is shown below.



(b) 86 g/100 mL (range of 82 to 88 g/100 mL is acceptable).

(c) 144 g/100 mL (range of 142–148 g/100 mL is acceptable).

(d) 77 °C (range of 75–78 °C is acceptable).

**13.** 400 g NaCL

**14.** 30 °C

## Answers to Solving Problems Questions

**15.** 5.62 g

**16.** **(a)** 25 g **(b)** 225 g **(c)** 2.5 mol/L

**17.** 1.2 mg; 1.2 ppm

**18.** $[Mg^{2+}(aq)] = 0.015$ mol/L

**19.** **(a)** 0.172 mol/L

**(b)** 0.577 mol/L

**(c)** 3.03 mol/L

**20.** **(a)** $[Mg^{2+}(aq)] = 1.53 \times 10^{-4}$ mol/L

$[OH^{-}(aq)] = 3.06 \times 10^{-4}$ mol/L

**(b)** $[Al^{3+}(aq)] = 7.4 \times 10^{-3}$ mol/L

$[NO^{3-}(aq)] = 2.2 \times 10^{-2}$ mol/L

**(c)** $[PO_4^{3-}(aq)] = 1.83 \times 10^{-3}$ mol/L

$[Na^{+}(aq)] = 5.49 \times 10^{-3}$ mol/L

**21.** $[NaCH_3COO(aq)] = 5.7$ mol/L

**22.** **(a)** 7.89 g **(b)** 83 g

**23.** **(a)** 0.23 L **(b)** 10 L

**24.** **(a)** 1.7 mol/L **(b)** 1.44 mol/L

**25.** **(a)** 0.21 L **(b)** 4.20 mL

## Answers to Making Connections Questions

**26.** The tea loses solubility with the decrease in temperature. Some of the tea has come out of solution as it cooled. The kinetic energy of the molecules has decreased.

**27.** True. Oil may sink or float on water depending on its density. Water is a polar substance and oil is non-polar. The two liquids do not form a homogeneous mixture.

**28.** Student speeches should include a number of perspectives on the issue. Scientific discussion could centre on the fact that sour gas contains sulfur, which when burned releases $H_2S(g)$ into the air. This gas combines with water vapour to form acid rain. Increasing the acidity of rain water is problematic for living things. Environmental/ecological perspectives may indicate that sulfur gases have a rotten egg smell and may cause eye irritation and respiratory problems. The cost to scrub the sulfur emissions from the plant and to the health care system are economic considerations with potential legal implications. A proposal for why the plant should or should not be built can be based on a risk–benefit analysis of potential jobs and benefits to the community vs. the potential problems.

**29.** Activities may include: laundry, showers, toilet use, swimming, juice preparation, watering plants, washing the car. Volume estimates are difficult; however, many appliance companies have energy and/or volume rating information available. Two supplies of water may make environmental sense but are difficult in terms of practicality and economics. The current situation is likely due to economics, legal issues related to misuse, and the availability of technology to make two independent water systems viable.

**30.** When the ammonium sulfate solution was sitting open, water was evaporating making the solution supersaturated. Because it was undisturbed and there were no existing crystals present to function as seeds for crystallization, no crystals formed. The motion caused by picking up the container disturbed the solution and caused crystallization to begin.

# CHAPTER 6 ACIDS AND BASES

## Curriculum Correlation

**General Outcome 2: Students will describe acid and base solutions qualitatively and quantitatively.**

| | Student Textbook | Assessment Options |
|---|---|---|
| **Outcomes for Knowledge** | | |
| **20–C2.1k** recall nomenclature of acids and bases | Reviewing Naming Rules for Acids and Bases, Section 6.1, p. 209 | Questions for Comprehension: 1, 2, Section 6.1, p. 209<br>Investigation 6.A: An Empirical Definition for Acids and Bases, Extension: 6, Section 6.1, p. 210<br>Section 6.2 Review: 2, 3, 6, p. 226<br>Chapter 6 Test |
| **20–C2.2k** recall the empirical definitions of acidic, basic and neutral solutions determined by using indicators, pH and conductivity | Empirical Definitions of Acids and Bases, Section 6.1, p. 210<br>Investigation 6.A: An Empirical Definition for Acids and Bases, Section 6.1, p. 210<br>Acids, Bases, and Conductivity, Section 6.1, p. 212 | Investigation 6.A: An Empirical Definition for Acids and Bases, Analysis: 1, Conclusion: 4, Section 6.1, p. 210<br>Chapter 6 Review: 1, 2, 7, 14, pp. 244-245<br>Chapter 6 Test<br>Unit 3 Review: 14, 15, pp. 248-251 |
| **20–C2.3k** calculate $H_3O^+(aq)$ and $OH^-(aq)$ concentrations, pH and pOH of acidic and basic solutions based on logarithmic expressions, i.e. $pH = -log[H_3O^+]$, $pOH = -log[OH^-]$ | Sample Problem: Calculating the pH of a Solution from $[H_3O^+(aq)]$, Section 6.3, p. 229<br>Sample Problem: Calculating the pH of a Solution, Section 6.3 p. 229<br>Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid, Section 6.3, p. 234<br>Sample Problem: Calculating the pOH of a Solution from $[OH^-(aq)]$, Section 6.3, p. 235<br>Sample Problem: Calculating the pOH of a Solution from Mass and Volume, Section 6.3, p. 236<br>Sample Problem: Calculating $[H_3O^+(aq)]$ from pH, Section 6.3, p. 240 | Practice Problems: 1-6, Section 6.3, p. 230<br>Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid: 2-6, Section 6.3, p. 234<br>Practice Problems: 7-12, Section 6.3, p. 237<br>Practice Problems: 13-16, Section 6.3, p. 241<br>Section 6.3 Review: 4-9, p. 242<br>Chapter 6 Review: 11-14, 19, pp. 244-245<br>Chapter 6 Test<br>Unit 3 Review: 17, pp. 248-251 |
| **20–C2.4k** use appropriate SI units to communicate the concentration of solutions and express pH and concentration answers to the correct number of significant digits, i.e., use the number of decimal places in the pH to determine the number of significant digits of the concentration | Significant Digits and pH, Section 6.3, p. 228<br>Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid, Section 6.3, p. 234 | Practice Problems: 1-6, Section 6.3, p. 230<br>Section 6.3 Review: 4-11, p. 242<br>Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid: 2-6, Section 6.3, p. 234<br>Throughout Chapter 6<br>Chapter 6 Test |
| **20–C2.5k** compare magnitude changes in pH and pOH with changes in concentration for acids and bases | Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid, Section 6.3, p. 234<br>The Relationship Between pH and pOH, Section 6.3, p. 237 | Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid: 4-6, Section 6.3, p. 234<br>Practice Problems: 13-18, Section 6.3, p. 241<br>Section 6.3 Review: 8-13, p. 242<br>Chapter 6 Review: 11-13, pp. 244-245<br>Chapter 6 Test<br>Unit 3 Review: 26, pp. 248-251 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **20–C2.6k** explain how the use of indicators, pH paper, or pH meters can be used to measure [$H_3O^+(aq)$] | Chapter 6 Launch Lab: The Colour of Your Breath, p. 207<br>Investigation 6.A: An Empirical Definition for Acids and Bases, Section 6.1, pp. 210-211<br>Indicators and Indicator Paper, Section 6.3, p. 231<br>Investigation 6.D: Determining the pH of an Unknown Solution with Indicators, Section 6.3, p. 232 | Chapter 6 Launch Lab: The Colour of Your Breath, Analysis: 1-3, p. 207<br>Investigation 6.A: An Empirical Definition for Acids and Bases, Analysis: 1, 3, Extension: 5, 6, Section 6.1, pp. 210-211<br>Investigation 6.D: Determining the pH of an Unknown Solution with Indicators: 1-3, Section 6.3, p. 232<br>Questions for Comprehension: 8-10, Section 6.3, p. 233<br>Section 6.3 Review: 3, p. 242<br>Chapter 6 Review: 8-10, 17, 18, 20, pp. 244-245<br>Chapter 6 Test<br>Unit 3 Review: 18-21, pp. 248-251 |
| **20–C2.7k** define Arrhenius (modified) acids as substances that produce $H_3O^+(aq)$ in aqueous solutions | Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases, Section 6.1, p. 214<br>A Modified Theory, Section 6.1, pp. 216-217 | Investigation 6.A: An Empirical Definition for Acids and Bases, Analysis: 1, 2, Extension: 5, 6, Section 6.1, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases: 1-4, Section 6.1, p. 214<br>Questions for Comprehension: 3, Section 6.1, p. 213<br>Section 6.1 Review: 3-5, p. 217<br>Questions for Comprehension: 5-7, Section 6.2, p. 222<br>Section 6.2 Review: 1, p. 226<br>Chapter 6 Review: 2, pp. 244-245<br>Chapter 6 Test<br>Unit 3 Review: 13, pp. 248-251 |
| **20–C2.8k** define Arrhenius (modified) bases as substances that produce $OH^-(aq)$ in aqueous solutions | Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases, Section 6.1, p. 214<br>A Modified Theory, Section 6.1, pp. 216-217 | Investigation 6.A: An Empirical Definition for Acids and Bases, Analysis: 1, 2, Extension: 5, 6, Section 6.1, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases: 1-4, Section 6.1, p. 214<br>Questions for Comprehension: 3, Section 6.1, p. 213<br>Section 6.1 Review: 3-5, p. 217<br>Questions for Comprehension: 5-7, Section 6.2, p. 222<br>Section 6.2 Review: 1, p. 226<br>Chapter 6 Review: 2, pp. 244-245<br>Chapter 6 Test<br>Unit 3 Review: 13, pp. 248-251 |
| **20–C2.9k** define neutralization as a reaction between hydronium and hydroxide ions | Neutralization, Section 6.2, p. 224 | Section 6.2 Review: 6, p. 226<br>Chapter 6 Review: 3, 20, 30, pp. 244-245<br>Chapter 6 Test |

| | Student Textbook | Assessment Options |
|---|---|---|
| **20–C2.10k** differentiate between strong acids and bases and weak acids and bases, qualitatively, on the basis of ionization and dissociation | Acids: Molecular Electrolytes, Section 5.1, p. 173<br>Strong and Weak Acids and Bases, Section 6.2, p. 218<br>Investigation 6.C: Differentiating between Weak and Strong Acids and Bases, Section 6.2, p. 221 | Section 5.1 Review: 6, p. 17<br><br>Questions for Comprehension: 5-7, Section 6.2, p. 222<br>Investigation 6.C: Differentiating between Weak and Strong Acids and Bases: 1, 2, Section 6.2, p. 221<br>Section 6.2 Review: 2-5, p. 226<br>Chapter 6 Review: 4-6, 20, 22, p. 244<br>Chapter 6 Test<br>Unit 3 Review: 15, 16, 21, 25, 49, pp. 248-251 |
| **20–C2.11k** compare the ionization of monoprotic with polyprotic acids and the dissociation/reaction with water of monoprotic with polyprotic bases, qualitatively. | Monoprotic and Polyprotic Acids, Section 6.2, pp. 222–223 | Section 6.2 Review: 2, p. 226<br>Chapter 6 Review: 5, 6, pp. 244-245<br>Chapter 6 Test |
| **Outcomes for Science, Technology and Society (Emphasis on science and technology)** | | |
| **20–C2.1sts** explain that the goal of technology is to provide solutions to practical problems by<br>■ *relating the concept of pH to solutions encountered in everyday life, e.g., pharmaceuticals, shampoo and other cleaning products, aquatic and terrestrial environments, blood/blood products* | Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189<br>Chapter 6 Launch Lab: The Colour of Your Breath, p. 207 | Connections: Biomagnification and Bioaccumulation: 3, Section 5.3, p. 189<br>Chapter 6 Launch Lab: The Colour of Your Breath, Analysis: 1-3, p. 207<br>Chapter 6 Review: 29-31, pp. 244-245<br>Unit 3 Review: 41-51, pp. 248-251 |
| **20–C2.2sts** explain that technological problems often have multiple solutions that involve different designs, materials and processes and have both intended and unintended consequences by<br>■ *providing examples of processes and products that use knowledge of acid and base chemistry, e.g., pulp and paper industry, food preparation and preservation, cleaning aids, sulfuric acid in car batteries, treating accidental acid or base spills using neutralization and dilution*<br>■ *explaining the significance of strength and concentration of solutions in everyday life, e.g., pharmaceuticals, chemical spills, transportation of dangerous goods, toxicity.* | Connections: Biomagnification and Bioaccumulation, Section 5.3, p. 189<br><br>Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Section 6.2, p. 225 | Connections: Biomagnification and Bioaccumulation: 2, Section 5.3, p. 189<br><br>Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Analysis: 1, Section 6.2, p. 225<br>Chapter 6 Review: 29-31, pp. 244-245<br>Unit 3 Review: 41-51, pp. 248-251 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **Skill Outcomes (Focus on problem solving)** | | |
| **Initiating and Planning** | | |
| **20–C2.1s** ask questions about observed relationships and plan investigations of questions, ideas, problems and issues by<br>■ designing an experiment to differentiate among acidic, basic and neutral solutions | Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210-211<br><br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases, Section 6.1, p. 214<br>Investigation 6.C: Differentiating between Weak and Strong Acids and Bases, Section 6.2, p. 221<br>Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid, Section 6.3, p. 234 | Investigation 6.A: An Empirical Definition for Acids and Bases, Analysis: 1, 2, Extension: 5, 6, Section 6.1, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases: 2-4, Section 6.1, p. 214<br><br>Investigation 6.C: Differentiating between Weak and Strong Acids and Bases: 1, 2, Section 6.2, p. 221<br>Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid: 1, 2, 4, 6, Section 6.3, p. 234 |
| ■ designing an experiment to differentiate between weak and strong acids and between weak and strong bases | Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210-211<br><br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases, p. 214<br>Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid, Section 6.3, p. 234 | Investigation 6.A: An Empirical Definition for Acids and Bases, Analysis: 1, 2, Extension: 5, 6, Section 6.1, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases: 2-4, Section 6.1, p. 214<br>Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid: 2-4, 6, Section 6.3, p. 234 |
| ■ describing procedures for safe handling, storage and disposal of materials used in the laboratory, with reference to WHMIS and consumer product labelling information. | Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases, p. 214<br>Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Section 6.2, p. 225<br>Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid, Section 6.3, p. 234 | Investigation 6.A: An Empirical Definition for Acids and Bases, pp. 210-211<br>Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases: 2-4, Section 6.1, p. 214<br>Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Analysis: 1, Section 6.2, p. 225<br>Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid: 2-6, Section 6.3, p. 234 |
| **Performing and Recording** | | |
| **20–C2.2s** conduct investigations into relationships among observable variables and use a broad range of tools and techniques to gather and record data and information by<br>■ constructing a table or graph to compare pH and hydronium ion concentration to illustrate that as the hydronium ion concentration increases, the pH decreases | Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid, Section 6.3, p. 234 | Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid: 5, Section 6.3, p. 234 |
| ■ *using a pH meter to determine acidity and/or alkalinity of a solution.* | Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid, Section 6.3, p. 234 | Investigation 6.E: The Effect of Dilution on the [$H_3O^+$(aq)] and pH of an Acid: 1-6, Section 6.3, p. 234 |
| **Analyzing and Interpreting** | | |
| **20–C2.3s** analyze data and apply mathematical and conceptual models to develop and assess possible solutions by<br>■ using indicators, determine the pH for a variety of solutions<br>■ *assessing, qualitatively, the risks and benefits of producing, using and transporting acidic and basic substances, based on WHMIS and Transportation of Dangerous Goods guidelines.* | Investigation 6.D: Determining the pH of an Unknown Solution with Indicators, Section 6.3, p. 232<br>Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Section 6.2, p. 225 | Investigation 6.D: Determining the pH of an Unknown Solution with Indicators: 1-3, Section 6.3, p. 232<br>Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Analysis: 1, Section 6.2, p. 225 |

| | Student Textbook | Assessment Options |
|---|---|---|
| **Communication and Teamwork** | | |
| **20–C2.4s** work as members of a team in addressing problems and apply the skills and conventions of science in communicating information and ideas and in assessing results by | Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Section 6.2, p. 225 | Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases, Analysis: 1, Section 6.2, p. 225 |
| ■ *collectively researching the relation between sulfuric acid and industrialization* | Connections: Drain Cleaners, Section 6.3, p. 239<br>Career Focus: Ask a Marine Conservationist, p. 246 | Connections: Drain Cleaners: 1, 2, Section 6.3, p. 239<br>Career Focus: Ask a Marine Conservationist: 1-3, p. 246 |
| ■ *assessing technologies used to reduce emissions leading to acid deposition.* | Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 2-6, Section 5.4, p. 199 | Investigation 5.C: Pollution of Waterways: A Risk-Benefit Analysis: 1-6, Section 5.4, p. 199 |

# Chapter 6

# Acids and Bases

**Student Textbook pages 206–245**

## Chapter Concepts

**Section 6.1 Theories of Acids and Bases**

- Acids and bases have been used throughout history to solve technological problems.
- Acids produce $H_3O^+(aq)$ in aqueous solutions. Bases produce $OH^-(aq)$ in aqueous solutions.

**Section 6.2 Strong and Weak Acids and Bases**

- Acid or base properties are determined by both the concentration and the identity of the acid or base.
- The relative strength of acids and bases can be explained by the degree of ionization or dissociation.
- Some acid molecules have more than one hydrogen atom that can ionize and react with water.

**Section 6.3 Acids, Bases, and pH**

- Indicators enable you to estimate the hydronium ion concentration in a solution; pH meters enable you to precisely measure the hydronium ion concentration in a solution.
- $H_3O^+(aq)$ and $OH^-(aq)$ concentrations, and pH and pOH of acid and base solutions can be calculated based on logarithmic expressions.

## Common Misconceptions

- Students often believe that concentrated acids are much more dangerous than concentrated bases. Most students have some knowledge of the dangers of concentrated acids but are not aware that concentrated, strong bases are equally hazardous. Most bowl and drain cleaners are concentrated bases that are good at dissolving organic material. These common household materials can be very dangerous if not handled properly.
- Another common misconception occurs when students think that a higher pH value means more acidic—reinforce the opposite.
- The term "neutralization reaction" invites a number of misconceptions, because students may interpret the result as a neutral solution, with pH = 7. Point out that an acid-base reaction involves hydronium and hydroxide ions reacting to form water. Only if the amount of $H_3O^+(aq)$ and $OH^-(aq)$ reacting is equal will the solution have pH = 7. Many acid-base reactions result in a solution with pH other than 7 at equivalence due to the hydrolysis of one or both ions present.
- Students often want to write one-line ionization and dissociation reactions for polyprotic acids in which the acid loses all possible hydrogen ions. Remind students that this process is stepwise. For example, $H_2SO_4(aq)$ reacts 100% with water to form $HSO_4^-(aq)$. A small proportion of $HSO_4^-(aq)$ ions then react with water to form $SO_4^{2-}(aq)$. Understanding that these steps constitute two separate reactions is important in Chemistry 30, when students will learn that each reaction has a different equilibrium constant.

## Helpful Resources

### Books and Journal Articles

- Adcock, Jamie L.J., "Teaching Brønsted–Lowry Acid–Base Theory in a Direct Comprehensive Way," *Journal of Chemical Education*, 2001, 78, p. 1495.
- Carlton, Terry S., "Why and How to Teach Acid–Base Reactions Without Equilibrium," *Journal of Chemical Education*, 1997, 74, p. 939.
- Plumsky, Roger, "A pHorseshoe," *Journal of Chemical Education,* 1999, 76, p. 935.
- Silverstein, Todd P., "Weak Versus Strong Acids and Bases: The Football Analogy," *Journal of Chemical Education*, 2000, 77, p. 849.

### Web Sites

Web links related to properties and theories of acids and bases, calculating pH, and using pH meters, papers, and indicators, as well as other topics related to acids and bases, can be found at **www.albertachemistry.ca**. Go to the Online Learning Centre and log on to the Instructor Edition. Choose Teacher Web Links.

### List of BLMs

Blackline masters (BLMs) have been prepared to support the material in this chapter. The BLMs are either for assessment (AST); use as overheads (OH); use as handouts (HAND), in particular to support activities; or to supply answers (ANS) for assessment or handouts. The BLMs are in digital form, stored on the CD-ROM that accompanies this Teacher's Resource or on the web site at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

**Number (Type) Title**

6.0.1 (HAND) Launch Lab: The Colour of Your Breath
6.0.1A (ANS) Launch Lab: The Colour of Your Breath Answer Key

6.1.1 (OH) Common Products Containing Acids or Bases
6.1.2 (AST) Naming Acids and Bases Review Quiz
6.1.2A (ANS) Naming Acids and Bases Review Quiz Answer Key
6.1.3 (OH) Properties of Acids and Bases
6.1.4 (AST) Identifying Acids and Bases
6.1.4A (ANS) Identifying Acids and Bases Answer Key
6.1.5 (HAND) Investigation 6.A: An Empirical Definition for Acids and Bases
6.1.5A (ANS) Investigation 6.A: An Empirical Definition for Acids and Bases Answer Key
6.1.6 (HAND) Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases

6.1.6A (ANS) Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases Answer Key
6.1.7 (OH) Hydronium Ions in Solution

6.2.1 (OH) Strong Acids
6.2.2 (OH) Weak Acids
6.2.3 (OH) Strong Bases and Weak Bases
6.2.4 (AST) Properties of Strong and Weak Acids and Bases
6.2.4A (ANS) Properties of Strong and Weak Acids and Bases Answer Key
6.2.5 (HAND) Investigation 6.C: Differentiating between Weak and Strong Acids and Bases
6.2.5A (ANS) Investigation 6.C: Differentiating between Weak and Strong Acids and Bases Answer Key
6.2.6 (OH) Acids and Bases in Industry
6.2.7 (HAND) Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases
6.2.7A (ANS) Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases Answer Key

6.3.1 (OH) Ion Concentration in Water
6.3.2 (AST) Calculating Concentrations of Acids and Bases
6.3.2A (ANS) Calculating Concentrations of Acids and Bases Answer Key
6.3.3 (OH) The pH Scale
6.3.4 (AST) Calculating pH
6.3.4A (ANS) Calculating pH Answer Key
6.3.5 (OH) Common Acid-Base Indicators
6.3.6 (AST) Acid-Base Indicators
6.3.6A (ANS) Acid-Base Indicators Answer Key
6.3.7 (HAND) Investigation 6.D: Determining the pH of an Unknown Solution with Indicators
6.3.7A (ANS) Investigation 6.D: Determining the pH of an Unknown Solution with Indicators Answer Key
6.3.8 (AST) Calculating pH After Dilution
6.3.8A (ANS) Calculating pH After Dilution Answer Key
6.3.9 (HAND) Investigation 6.E: The Effect of Dilution on the [$H_30$+(aq)] and pH of an Acid
6.3.9A (ANS) Investigation 6.E: The Effect of Dilution on the [H30+(aq)] and pH of an Acid Answer Key
6.3.10 (AST) Calculating pOH and Changing from pH to pOH
6.3.10A (ANS) Calculating pOH and Changing from pH to pOH Answer Key
6.3.11 (OH) Understanding pH and pOH
6.3.12 (AST) Calculating Concentration from pH and pOH
6.3.12A (ANS) Calculating Concentration from pH and pOH Answer Key
6.3.13 (AST) Putting it all Together: Dilutions as Advanced Acid-Base Calculations
6.3.13A (ANS) Putting it all Together Answer Key
6.3.14 (AST) Acid-Base Review
6.3.14A (ANS) Acid-Base Review Answer Key

6.4.1 (AST) Chapter 6 Test
6.4.1A (ANS) Chapter 6 Test Answer Key

## Using the Chapter 6 Opener

**Student Textbook pages 206–207**

### Teaching Strategies

- Have students brainstorm safety precautions to take with acids and bases. Interestingly, hydrofluoric acid is the most dangerous of all acids, but not due to corrosiveness. The fluoride ion is small enough to penetrate membranes and enter the bloodstream. It reacts with calcium and other minerals in the body, and even a relatively small spill on the skin can cause death if it is not quickly neutralized.
- Brainstorm with students to see what other acids and bases they may be familiar with. To get students thinking about applications, challenge them to state the problem that each acid or base solves; for example, "How can I make a product that soothes heartburn caused by acid reflux?" A pharmaceutical solution could be "Formulate an antacid tablet containing a base that neutralizes the acid."
- The diagnostic solutions investigation from *ScienceFocus 10* (McGraw-Hill Ryerson) provides a quick template for a review activity. Students can design and execute a flow chart to identify an unknown solution from the list provided. This will re-familiarize them with some of the equipment they will be using throughout the chapter, such as conductivity meters, litmus paper, and pH meters, and with terms such as electrolyte and non-electrolyte.
- Students can take pH paper home and measure the pH of various foodstuffs. Alternately, a demonstration of a titration involving a strong acid and a weak base, or vice versa, with cabbage juice as an indicator, will provide a good range of colours, which students can then measure using a pH meter.

## Launch Lab — The Colour of Your Breath

**Student Textbook page 207**

### Purpose

Using a straw, students will blow into indicator solution and observe the results. This activity should help students recall what they know about acid–base reactions and indicators.

### Outcomes

- 20–C2.6k
- 20–C2.1sts

### Advance Preparation

| When to Begin | What to Do |
|---|---|
| Beginning of semester | ■ Ensure indicators, sodium hydroxide, and straws are available. |

| When to Begin | What to Do |
| --- | --- |
| 1 day before | ■ Collect apparatus.<br>■ Prepare small samples of indicator.<br>■ Prepare 0.10 M (mol/L) solution of sodium hydroxide.<br>■ Photocopy **BLM 6.0.1 (HAND) Launch Lab: The Colour of Your Breath.** |

| Materials |
| --- |
| ■ 250 mL Erlenmeyer flask<br>■ 100 mL graduated cylinder<br>■ stopwatch or clock with second hand<br>■ tap water<br>■ bromothymol blue indicator, one per group<br>■ 0.10 mol/L NaOH(aq) in a dropper bottle, one per group<br>■ straws, one per person |

## Time Required

10–20 minutes

## Helpful Tips

- To save time, you could carry out this activity as a demonstration and have students answer Analysis questions as a discussion.
- If appropriate for your class, add a silly twist and tell the students that the solution will turn yellow when the student who is really a Martian (or a spy, or a superhero, or whatever you like) blows into it. Then have students come up to the front of the class one at a time and take turns blowing into the solution. (Be sure to use a fresh straw for each student.)
- Use **BLM 6.0.1 (HAND) Launch Lab: The Colour of Your Breath** and **BLM 6.0.1A (ANS) Launch Lab: The Colour of Your Breath Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** Bromothymol blue is an indicator that is blue in basic solutions. Adding the sodium hydroxide to the tap water thus causes the bromothymol blue to turn blue. When you blow into the solution, the carbon dioxide in your breath reacts with the water to form carbonic acid. The acid neutralizes the sodium hydroxide and then makes the solution acidic and the colour changes to yellow. If you hold your breath for 30 s before blowing, your breath should have a larger amount of carbon dioxide and is should take less time to acidify the solution.

## Safety Precautions

- Ensure students have read and understood "Safety in Your Chemistry Lab and Classroom" on pages xii–xv on the student textbook.
- Bromothymol blue is harmful if swallowed. It may cause irritation to skin, eyes, and respiratory tract.
- Sodium hydroxide is corrosive. If spilled on skin, immediately rinse with plenty of cold water. Make sure the eye wash station has been tested recently and any eye wash bottles are filled.
- Remind students not to dip the straws into the sodium hydroxide solutions, and to be very careful not to draw any liquid up into the straw.
- Dispose of all materials safely in proper waste containers.

## Answers to Analysis Questions

1. Students should recognize that their breath produces an acidic substance when they blow into the aqueous solution. In fact, the acidity is caused by the reaction of carbon dioxide with water to form aqueous hydrogen carbonate, or carbonic acid:
   $$CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq)$$
   Students should recognize NaOH(aq) as a base from *Science 10*. Since the original solution was basic, students should recognize that a neutralization reaction is taking place. Once the carbonic acid has neutralized all the sodium hydroxide, additional breaths acidify the solution further.
2. Students should notice that it takes less time for the colour change to occur if they hold their breath before blowing into the straw. Holding the breath increases the concentration of $CO_2(g)$ in the exhalation.
3. The time it takes students to acidify the solutions will probably vary, but the overall observations should be the same: the basic solution is blue, but turns green and then yellow with increased breaths.

## Assessment Options

- Assess students' participation in the class discussion surrounding this activity.
- Have students write down what they already know, and some questions they have, about acids and bases. Assess based on completeness and thoughtfulness (not correctness) of responses.
- Collect and assess answers to Analysis questions.

## 6.1 Theories of Acids and Bases

**Student Textbook pages 208–217**

## Section Outcomes

Students will:

- recall nomenclature of acids and bases
- design a procedure to determine the properties of acids and bases
- describe acids and bases empirically, using indicators, pH, and conductivity
- define Arrhenius (modified) acids as substances that produce $H_3O^+(aq)$ in aqueous solution
- define Arrhenius (modified) bases as substances that produce $OH^-(aq)$ in aqueous solution

### Key Terms

neutral solution
Arrhenius theory of acids and bases
Arrhenius acid
Arrhenius base
ionize
dissociate
hydronium ion, $H_3O^+(aq)$
modified Arrhenius theory of acids and bases
modified Arrhenius acid
modified Arrhenius base

## Chemistry Background

- Students review the properties of acids and bases. From *Science 10*, students already know how acids and bases affect indicators such as litmus and phenolphthalein. They know that acids and bases are electrolytes. They should also know that the pH of a base is greater than 7, and the pH of an acid is less than 7, although they will not really know what pH means. (They will find out in Section 6.3.)
- The term "pH" is derived from the German phrase "potenz [power of] Hydrogen." This is slightly counterintuitive as high-pH solutions are *less* likely to donate hydrogen ions, but this is explained (in Section 6.3) by the minus sign in the formula for pH.
- Writing reaction equations for acids and bases is also reviewed. Students should be able to identify that a neutralization reaction involves a reaction between an acid and a base, with products being a salt and water. In every neutralization reaction, $H_3O^+(aq)$ and $OH^-(aq)$ ions react to produce $H_2O(\ell)$.
- New to students will be the theoretical explanation of the properties of acids and bases. According to Arrhenius, acids are substances that ionize in water to form $H^+(aq)$, and bases are substances that dissociate in water to form $OH^-(aq)$.
- One weakness of the Arrhenius theory is that X-ray crystallography evidence shows that the hydrogen ion, a lone proton, does not exist independently in water. Instead, it becomes partially hydrated to several water molecules. However, for simplicity, scientists consider that in water, a hydrogen ion bonds to one water molecule, forming the ion hydronium, $H_3O^+(aq)$.
- A second weakness of the Arrhenius theory is its inability to explain the basicity of ammonia, $NH_3(aq)$. A modified theory takes into account that molecular bases such as ammonia *react* with water to form hydroxide ions.
- In *Chemistry 30*, students will learn that there are substances that show acidic and basic characteristics that cannot be explained by the modified Arrhenius theory of acids and bases. For example, the modified Arrhenius theory applies only to aqueous solutions.

## Teaching Strategies

- Use the subsection Acids and Bases: Problem Solvers (page 208 of the student texbook) to have students brainstorm ways in which they use acids and bases in their daily lives.
- An analogy can help students understand what happens when an acid ionizes. Describe a hydrogen ion as a football or baseball that can be passed back and forth. Challenge students to create a story, puppet show, or cartoon to explain the Arrhenius theory and its limitations.
- Remind students that the formulas for organic acids often show the acidic hydrogen at one end of the compound. For example, acetic acid, $CH_3COOH(aq)$, has only one hydrogen atom that can ionize: the "end hydrogen" that is part of the hydroxyl (COOH) group. The three hydrogen atoms that are part of the methyl ($CH_3$) group do not participate in acid–base reactions.
- Ensure students know how to use the terms "ionization" and "dissociation" correctly. Ionic compounds dissociate into ions in aqueous solutions. Molecular compounds such as acids ionize in aqueous solutions.
- Provide **BLM 6.1.4 (AST) Identifying Acids and Bases,** in which students identify acids and bases by analyzing properties. Students also get practice in writing dissociation, ionization, and neutralization equations.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 6 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.
  **Number (Type) Title**
  6.1.1 (OH) Common Products Containing Acids or Bases
  6.1.2 (AST) Naming Acids and Bases Review Quiz
  6.1.2A (ANS) Naming Acids and Bases Review Quiz Answer Key
  6.1.3 (OH) Properties of Acids and Bases
  6.1.4 (AST) Identifying Acids and Bases
  6.1.4A (ANS) Identifying Acids and Bases Answer Key
  6.1.7 (OH) Hydronium Ions in Solution

## Answers to Questions for Comprehension

**Student Textbook page 209**

**Q1. (a)** hydrofluoric acid

**(b)** hydrothiocyanic acid

**(c)** carbonic acid

**(d)** nitrous acid

**(e)** sulfuric acid

**(f)** persulfuric acid

**Q2. (a)** HI(aq)

**(b)** HBr(aq)

**(c)** $H_2Cr_2O_7$(aq)

**(d)** $HMnO_4$(aq)

**(e)** $H_2CO$(aq)

**(f)** $HNO_3$(aq)

## Chemistry File: Web Link

**Student Textbook page 209**

Students should follow all safety precautions when using cleaning products. Students could include both environmental and financial cost of the different products in their comparison. Students could also include an analysis of why they think many people prefer to use the commercial cleaning products over the "natural" products in their presentations.

## Figure 6.2

**Student Textbook page 210**

The property of conductivity is based on the presence of ions in solution. Since acids, bases, and neutral ionic solutions all generate ions in solutions, conductivity does not do much to distinguish between these substances. It can be used to identify neutral molecular solutions, which do not conduct. Conductivity is also useful in distinguishing between strong and weak acids and bases, since strong acids and bases generate far more ions than weak acids and bases, and so have a much higher conductivity.

# Investigation 6.A: An Empirical Definition for Acids and Bases

**Student Textbook pages 210–211**

## Purpose

Students will observe the properties of various compounds and solutions as they undergo several simple diagnostic tests. Using these observations, they will then classify solutions as acidic, basic, or neutral.

## Outcomes

- 20–C2.6k
- 20–C2.8k
- IP–NS2
- AI–NS2
- 20–C2.1s
- ICT C6–4.2
- IP–STS3

## Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Ensure materials are available. |
| 1 day before | ■ Collect materials.<br>■ Prepare solutions.<br>■ Cut magnesium into small (2 cm) strips.<br>■ Photocopy **BLM 6.1.5 (HAND) Investigation 6.A: An Empirical Definition for Acids and Bases.** |

| Materials |
|---|
| ■ spot plate<br>■ dropper<br>■ conductivity tester<br>■ pH meter/pH paper<br>■ beakers<br>■ red and blue litmus paper<br>■ short strips of magnesium ribbon<br>■ 10 mL of each of the following solutions:<br>– hand soap (base)<br>– laundry detergent (base)<br>– glass cleaner (base)<br>– antacid (base)<br>– milk (acid)<br>– sour milk (acid)<br>– carbonated water (acid)<br>– soda pop (carbonated) (acid)<br>– soda pop (flat) (acid)<br>– apple juice (acid)<br>– vinegar (acid)<br>– baking soda (base)<br>– water and table salt solution (neutral) |

## Time Required

60 minutes

## Helpful Tips

- To save time, make larger groups or reduce the number of substances, or set up stations for students to rotate through.
- Dispense pre-cut magnesium strips to prevent waste and unsupervised use.
- Review with students the concept of an empirical definition.
- Student procedures will probably involve using litmus paper to categorize the acids and bases, and then testing properties such as conductivity, pH, and reactivity with magnesium. Alternatively, they may test all the properties

of HCl(aq) and NaOH(aq), which are a known, strong acid and base, and compare their results for those solutions to the results for the other solutions.

- Note: The water and table salt solution end up slightly acidic because of dissolved carbon dioxide if distilled water is used. Tap water can also be tested. Tap water is basic in many places in Alberta because of dissolved $CO_3^{2-}$ in the soil. Note: Not all acidic solutions will react with Mg(s) depending on their pH. If a solution is too dilute or too weak, no observable reaction will occur.
- Use **BLM 6.1.5 (HAND) Investigation 6.A: An Empirical Definition for Acids and Bases** and **BLM 6.1.5A (ANS) Investigation 6.A: An Empirical Definition for Acids and Bases Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** The students' empirical definitions of acids and bases should agree with the properties in Table 6.3 on page 210 of the textbook. Students will find that most cleaning solutions such as soap, detergent, glass cleaner, etc., are basic. Edible substances such as milk, soda pop, apple juice, and vinegar are acidic.

## Safety Precautions

- Ensure students have read and understood "Safety in Your Chemistry Lab and Classroom" on pages xii–xv in the student textbook.
- Household solutions containing acids and bases are often toxic and/or corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure the eye wash station has been tested recently and any eye wash bottles are filled.
- Dispose of all materials safely in proper waste containers.
- When using a conductivity tester with two separate electrodes, be extremely careful to keep the electrodes well separated while testing.

## Answers to Analysis Questions

**1.** Students will probably create a table similar to the one below.

| Test | Acids | Bases |
|---|---|---|
| Litmus paper | Turn blue litmus red | Turn red litmus blue |
| pH paper | pH less than 7 | pH greater than 7 |
| Electrical conductivity of solution | Conduct electricity (electrolytes) | Conduct electricity (electrolytes) |
| Reaction with magnesium | React to produce $H_2(g)$ | Do not react |

**2.** Acids and bases are both used as cleaners. Although students must not taste any substances in class, they may recognize that edible materials such as vinegar, apple juice, milk, and soft drinks are usually acidic or neutral, not basic, as basic substances taste unpleasant and bitter. Many pharmaceuticals, including antacids, are bases.

**3.** As milk sours it becomes more acidic and its pH decreases.

## Answer to Conclusion Question

**4.** An empirical definition for acids might be that acids conduct electricity, have a low pH, and react with magnesium, while a definition of bases might be that bases conduct electricity, have a high pH, and do not react with magnesium.

## Answers to Extension Questions

**5. (a)** The bubbles in carbonated soda come from the decomposition of carbonic acid into carbon dioxide and water:

$$H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(\ell)$$

In flat pop, the acid has completely decomposed and the carbon dioxide gas has mostly come out of solution. The pH of flat pop should be higher than the pH of fizzy pop.

**(b)** The presence of carbonic acid in carbonated water gives it a slightly sour taste, characteristic of all acids. In soda pop, as the carbonic acid is converted to carbon dioxide gas, going flat, the solution becomes less acidic and the taste becomes less sour and tangy, allowing the sweet, syrupy flavour from the sugars to dominate.

**6.** Answers will depend on brand of product in some cases. Basic ingredients of hand soap and laundry detergent are the most difficult to find on the Internet.

- hand soap (base): amines
- laundry detergent (base): carbonates and borates
- glass cleaner (base): ammonia, $NH_3(aq)$ (some brands)
- antacid (base): magnesium hydroxide, $Mg(OH)_2(s)$ (varies with brand and type)
- milk (acid): lactic acid, $C_3H_6O_3(aq)$
- sour milk (acid): lactic acid, $C_3H_6O_3(aq)$

- soda pop (carbonated) (acid): carbonic acid, $H_2CO_3(aq)$, phosphoric acid, $H_3PO_4(aq)$
- apple juice (acid): malic acid, $C_4H_6O_5(aq)$; ascorbic acid (vitamin C), $C_6H_8O_6(aq)$, is sometimes added
- vinegar (acid): ethanoic (acetic) acid, $CH_3COOH$
- baking soda (base): sodium hydrogen carbonate, $NaHCO_3(s)$
- water and table salt solution (neutral): sodium chloride, NaCl(s)

## Assessment Options

- Collect and assess student answers to Analysis, Conclusion, and Extension questions.
- Use Assessment Checklist 2: Laboratory Report (see Appendix A) to assess students' write-ups.

## Figure 6.4

**Student Textbook page 212**

The brighter the bulb, the higher the concentration of ions in solution. Some acids and bases ionize more than others in solution.

## Answers to Questions for Comprehension

**Student Textbook page 213**

**Q3.** Acidic solutions: **(a)**, **(f)**; basic solutions: **(b)**, **(d)**; neutral solutions: **(c)**, **(e)**

**Q4.** Acidic solutions: conductive, pH below 7, sour taste; basic solutions: conductive, pH above 7, bitter taste; neutral ionic solutions: conductive, pH of 7, salty taste; neutral molecular solutions: non-conductive, pH of 7, variable taste but generally not sour, bitter, or salty.

# Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases

**Student Textbook page 214**

## Purpose

Students design an experiment to distinguish between acids, bases, and neutral solutions. They predict results and then attempt to use the Arrhenius theory to explain their observations.

## Outcomes

- 20–C2k
- 20–C.1s
- IP-STS3
- IP–NS2
- ICT C6–4.3

## Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Ensure materials are available. |
| 2 days before | ■ Have students write procedures. |
| 1 day before | ■ Collect apparatus.<br>■ Prepare solutions.<br>■ Cut magnesium into small (2 cm) strips.<br>■ Review student procedures so proper apparatus can be supplied.<br>■ Photocopy **BLM 6.1.6 (HAND) Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases.** |

| Materials |
|---|
| ■ distilled water<br>■ pH paper/pH meter<br>■ 10 mL of the following solutions per group:<br>– 0.10 mol/L NaOH(aq)<br>– 0.10 mol/L NaCl(aq)<br>– 0.10 mol/L $C_{12}H_{22}O_{11}(aq)$<br>– 0.10 mol/L HCl(aq)<br>– 0.10 mol/L $NH_3(aq)$<br>– 0.10 mol/L $CH_3COOH(aq)$<br>– 0.10 mol/L $NaHCO_3(aq)$ |

## Time Required

30 minutes

## Helpful Tips

- To save time, make larger groups or reduce the number of substances.
- Dispense the magnesium strips to prevent students from using too much, or taking some home to be ignited in an unsupervised setting.
- Many students will want to simply use litmus paper. Limiting its role to that of a confirming test only will encourage students to think of other diagnostic tests.
- Use **BLM 6.1.6 (HAND) Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases** and **BLM 6.1.6A (ANS) Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** The students will find that HCl and $CH_3COOH$ are acidic but the pH of a 0.10 mol/L solution of HCl has a lower pH than that of the 0.10 mol/L solution of

$CH_3COOH$. The solutions of NaCl and sucrose will be neutral. The solutions of NaOH, $NH_3$, and $NaHCO_3$ will be basic but NaOH has a higher pH than do solutions of equal concentrations of $NH_3$ and $NaHCO_3$. Arrhenius theory cannot explain why $NH_3$ and $NaHCO_3$ are basic.

## Safety Precautions

- Ensure students have read and understood "Safety in Your Chemistry Lab and Classroom" on pages xii–xv in the student textbook.
- Household solutions containing acids and bases are often toxic and/or corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure the eye wash station has been tested recently and any eye wash bottles are filled.
- Dispose of all materials safely in proper waste containers.
- If using a conductivity tester with two separate electrodes, be extremely careful to keep the electrodes well separated while performing tests.

## Answer to Prediction

| Acid | Base | Neutral |
|---|---|---|
| HCl(aq) | NaOH(aq) | NaCl(aq) |
| $CH_3COOH$(aq) | $NH_3$(aq) | $C_{12}H_{22}O_{11}$(aq) |
| $NaHCO_3$(aq) | | |

Note: Students will likely predict that $NaHCO_3$(aq) is an acid, based on the Arrhenius theory, but it is actually a stronger base than acid. Many students will not predict that $NH_3$(aq) is a base, because it is not an Arrhenius base; it is a Brønsted-Lowry base.

## Answers to Analysis Questions

**1.** NaOH(aq) = sodium hydroxide

NaCl(aq) = sodium chloride

$C_{12}H_{22}O_{11}$(aq) = sucrose

HCl(aq)= hydrochloric acid

$NH_3$(aq) = ammonia

$CH_3COOH$(aq) = ethanoic or acetic acid

$NaHCO_3$(aq) = sodium hydrogen carbonate

**2.** The key to pH is not only the initial concentration of the acid or base, but also its degree of ionization. Weak acids and bases ionize only a little, giving them mild pH values, typically between 4.5 and 9.5. Approximate pH values follow:

0.10 mol/L NaOH(aq) has pH 12.5

0.10 mol/L NaCl(aq) has pH 7

This assumes that distilled water tests at a pH of 7. Dissolved carbon dioxide in the distilled water may make it test at a pH less than 7.

0.10 mol/L $C_{12}H_{22}O_{11}$(aq) has pH 7

0.10 mol/L HCl(aq) has pH 1.5

0.10 mol/L $NH_3$(aq) has pH 8.5

0.10 mol/L $CH_3COOH$(aq) has pH 4.5

0.10 mol/L $NaHCO_3$(aq) has pH 7.5

## Answer to Conclusion Question

**3. (a)** Most students will likely predict that $NaHCO_3$(aq) is acidic since it has a hydrogen to donate. However, it is easier for $HCO_3^-$(aq) to gain a hydrogen, allowing for the subsequent decomposition of the acid into water and carbon dioxide gas, than it is to lose a hydrogen and form the $CO_3^{2-}$(aq) ion:

$HCO_3^-(aq) + H_3O^+(aq) \rightarrow H_2CO_3\ (aq) + H_2O(\ell)$

$H_2CO_3\ (aq) \rightarrow H_2O(\ell) + CO_2(g)$

If students are not already aware that ammonia is a base, their results for that substance may surprise them, since the molecule does not contain a hydroxide ion that can dissociate. Some students may also expect $C_{12}H_{22}O_{11}$(aq) to be acidic since it has hydrogens in its chemical formula. Use the example of ethanoic acid to illustrate that only hydrogens listed at the beginning or the end of a compound can act as acids.

**(b)** Students should show that acids ionize to form hydrogen ions:

$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$

$CH_3COOH(aq) \rightarrow H^+(aq) + CH_3COO^-(aq)$

Note: at this stage, students should not be expected to use equilibrium arrows for ethanoic acid.

Bases dissociate or react to form hydroxide ions:

$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$

$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$

It is impossible to explain the basicity of ammonia using only the Arrhenius theory of acids and bases, because ammonia has no hydroxide ion that can dissociate.

Soluble, neutral ionic substances dissociate in water, and soluble, neutral molecular substances dissolve in water, forming neither hydrogen ions nor hydroxide ions.

$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$

$C_{12}H_{22}O_{11}(s) \rightarrow C_{12}H_{22}O_{11}(aq)$

## Answer to Extension Question

**4.** Students having difficulty can be directed to Table 6.3 (student textbook page 210). Students may attempt to use litmus paper, but this should be discouraged as it simply repeats the use of a pH meter. A conductivity test could be used to help differentiate between strong and weak acids and bases. If magnesium and/or zinc strips are available, students could look for the characteristic hydrogen bubbles from reaction with acids.

## Assessment Options

- Collect and assess student answers to Analysis questions.
- Use Assessment Checklist 1: Designing an Experiment (see Appendix A) to assess students' experimental designs.
- Use Assessment Checklist 2: Laboratory Report (see Appendix A) to assess students' write-ups.

**SUPPORTING DIVERSE STUDENT NEEDS**

To aid tactile learners and ESL students, have students use molecular model kits to build various acids and bases. Students can then use these models to carry out "reactions" forming the necessary salt and water.

## Section 6.1 Review Answers

**Student Textbook page 217**

1. **(a)** Three properties of an acid include a pH less than 7, conductivity, and a sour taste.
   **(b)** Three properties of a base include a pH greater than 7, conductivity, and a bitter taste.
2. **(a)** Acids and bases must be treated with caution because they are corrosive and often toxic. Also, many acids and bases are clear and colourless, and can therefore be easily mistaken for water.
   **(b)** Remind students to read and understand WHMIS labels and to wear safety glasses, gloves, and aprons. Ensure students know that acid should always be added to water when diluting; never water to acid. Review spill clean-up and reporting procedures. Students should know where to find eye wash stations, and should know that any acid or base spilled on skin should be immediately diluted with plenty of cool water.
3. **(a)** According to the Arrhenius theory of acids and bases, an acid is a substance that ionizes to form hydrogen ions in solution. A base dissociates to form hydroxide ions in solution.
   **(b)** The Arrhenius theory can explain the conductivity of simple acids and bases that can ionize or dissociate to form $OH^-$ or $H^+$ ions, such as HCl(aq) or NaOH(aq). The Arrhenius theory can also explain why different solutions have change in pH.
   **(c)** The Arrhenius theory cannot explain why ammonia, $NH_3$(aq), exhibits basic properties since it does not contain a hydroxide ion that can dissociate.
   **(d)** According to a modified Arrhenius theory in which water is introduced as a reactant, ammonia reacts with water to produce hydroxide ions:
   $NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$
4. **(a)** $HCl(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + Cl^-(aq)$
   **(b)** $HBr(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + Br^-(aq)$
   **(c)** $HClO_4(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + ClO_4^-(aq)$
   **(d)** $HNO_3(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + NO_3^-(aq)$
   **(e)** Step 1: $CO_2(aq) \rightarrow H_2O(\ell) \leftrightarrow H_2CO_3(aq)$
   Step 2: $H_2CO_3(aq) \rightarrow H_2O(\ell) \leftrightarrow HCO_3^-(aq) + H_3O^+(aq)$
5. **(a)** $NH_3(aq) + H_2O(\ell) \leftrightarrow NH_4^+(aq) + OH^-(aq)$
   **(b)** $NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$
   **(c)** $Ca(OH)_2(aq) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$
   **(d)** $KOH(aq) \rightarrow K^+(aq) + OH^-(aq)$
   **(e)** Step 1: $SrO_{(s)} + H_2O(\ell) \rightarrow Sr(OH)_2(aq)$
   Step 2: $Sr(OH)_2(aq) \rightarrow Sr^{2+}(aq) + 2OH^-(aq)$

## 6.2 Strong and Weak Acids and Bases

**Student Textbook pages 218–226**

### Section Outcomes

In this section, students will:

- distinguish between strong acids and bases and weak acids and bases based on ionization
- design an experiment to differentiate between weak and strong acids and between weak and strong bases
- compare the ionization of monoprotic acids with the ionization of polyprotic acids
- compare monoprotic and polyprotic bases
- define neutralization as a reaction that occurs between hydronium and hydroxide ions
- assess the risks and benefits of producing, using, and transporting acidic and basic substances

### Key Terms

strong acid
weak acid
strong base
weak base
monoprotic acids
polyprotic acids
monoprotic base
polyprotic base
salt
neutralization reaction

### Chemistry Background

- Students differentiate between strong and weak acids by comparing the extent of ionization. Strong acids ionize completely or nearly completely, while weak acids ionize to a relatively small extent. Similarly, strong bases dissociate completely. Weak bases dissociate or react with water only partially.

- There are only six strong acids, $HClO_4(aq)$, $HI(aq)$, $HBr(aq)$, $HCl(aq)$, $HNO_3(aq)$, and $H_2SO_4(aq)$. Only Group 1 and 2 hydroxides, excluding beryllium, are the only strong bases. $NH_3$, a weak base, ionizes about 1%.
- Students will also learn about monoprotic, diprotic, and polyprotic acids and bases. A monoprotic substance such as $HCl(aq)$ can gain or lose only one hydrogen atom, whereas a polyprotic substance such as $H_2SO_4(aq)$ (diprotic) or $PO_4^{3-}(aq)$ can gain or lose more than one hydrogen atom.

## Teaching Strategies

- Conductivity is a good way to compare degree of ionization. Demonstrate the different conductivities of strong and weak acids and bases with the same concentration.
- The formulation of pharmaceuticals is an application of neutralization reactions. Many naturally occurring alkaloids and drugs are amines. Examples include caffeine, quinine, and amphetamines. Low-molar-mass amines often have an unpleasant "fishy" odour, and compounds with higher mass tend to have low solubility in water. Because amines are weak bases, they will react with an acid to form a salt; usually, hydrochloric acid is used. Compared with the corresponding amine, amine hydrochloride salts are less volatile and so have less odour, are more stable, and usually are more soluble in water. Bring in some examples to show students: Triaminic® cough syrup and Benadryl® are common examples of over-the-counter medications that use this simple chemistry.
- The double-headed equilibrium arrow ↔ in an equation signifies that the reaction proceeds in both directions. In the case of a weak acid or base, the equilibrium favours the reactants, not the products. For example, in the case of ammonia in water, both of the following reactions take place:

  $$NH_3(aq) + H_2O(\ell) \rightarrow OH^-(aq) + NH_4^+(aq)$$

  $$OH^-(aq) + NH_{4^+}(aq) \rightarrow NH_3(aq) + H_2O(\ell)$$

  At STP, the second reaction is favoured; therefore, the percentage of ammonia molecules that have reacted to form ions at any one time is very small (about 1%).
- Use **BLM 6.2.1 (OH) Strong Acids, BLM 6.2.2 (OH) Weak Acids, BLM 6.2.3 (OH) Strong Bases and Weak Bases, BLM 6.2.4 (AST) Properties of Strong and Weak Acids and Bases, BLM 6.2.4A (ANS) Properties of Strong and Weak Acids and Bases Answer Key,** and **BLM 6.2.6 (OH) Acids and Bases in Industry** to help students recognize strong and weak acids and bases, and write ionization and dissociation equations.
- A number of overhead masters and a quiz have been prepared for this section. You will find them with the Chapter 6 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  **Number (Type) Title**
  6.2.1 (OH) Strong Acids
  6.2.2 (OH) Weak Acids
  6.2.3 (OH) Strong Bases and Weak Bases
  6.2.4 (AST) Properties of Strong and Weak Acids and Bases
  6.2.4A (ANS) Properties of Strong and Weak Acids and Bases Answer Key
  6.2.6 (OH) Acids and Bases in Industry

## Investigation 6.C: Differentiating between Weak and Strong Acids and Bases

**Student Textbook page 221**

### Purpose

Students carry out a procedure to identify unknown solutions as being a strong acid, strong base, weak acid, weak base, neutral ionic solution, or molecular solution.

### Outcomes

- 20–C2.10k
- 20–C2.1s

### Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Ensure materials are available. |
| 1 day before | ■ Collect apparatus.<br>■ Prepare solutions.<br>■ Cut magnesium into small (2 cm) strips.<br>■ Photocopy **BLM 6.2.5 (HAND) Investigation 6.C: Differentiating between Weak and Strong Acids and Bases.** |

| Materials |
|---|
| ■ beakers<br>■ test tubes<br>■ dropper<br>■ conductivity tester<br>■ pH paper/pH meter<br>■ short strips of magnesium ribbon or zinc<br>■ solutions of:<br>– $C_{12}H_{22}O_{11}(aq)$ (neutral molecular)<br>– NaCl (aq) (neutral ionic)<br>– 0.10 mol/L HCl (aq) (strong acid)<br>– 0.10 mol/L NaOH (aq) (strong base)<br>– 0.10 mo/L $CH_3COOH$ (aq) (weak acid)<br>– 0.10 mol/L $NH_3(aq)$ (weak base) |

## Time Required

- 30 minutes for execution

## Helpful Tips

- Students will get a better reaction with the metal strips if they are polished first with the steel wool.
- Dispense pre-cut magnesium strips to prevent waste and unsupervised use.
- Refer students to Table 6.3 on page 210 if assistance in planning is needed.
- Note: The pH of neutral solutions may not be exactly 7 because of dissolved carbon dioxide in the distilled water.
- Use **BLM 6.2.5 (HAND) Investigation 6.C: Differentiating between Weak and Strong Acids and Bases** and **BLM 6.2.5A (ANS) Investigation 6.C: Differentiating between Weak and Strong Acids and Bases Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results***

| Solution (0.10 mol/L) | pH (approximate) | Conductivity | Reactivity with Mg |
|---|---|---|---|
| molecular | 7 | no | no |
| neutral ionic | 7 | high | no |
| strong base | 13 | high | no |
| strong acid | 1 | high | rapid |
| weak base | 9 | low | no |
| weak acid | 4 | low | slow |

## Safety Precautions

- Ensure students have read and understood "Safety in Your Chemistry Lab and Classroom" on pages xii–xv in the student textbook.
- Solutions of acids and bases may be toxic and corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure the eye wash station has been tested recently and any eye wash bottles are filled.
- Dispose of all materials safely in proper waste containers.
- If using a conductivity tester with two separate electrodes, be extremely careful to keep the electrodes well separated while performing tests.

## Answer to Analysis Question

**1.** $C_{12}H_{22}O_{11}$(aq) (neutral molecular): No conductivity, pH 7, no change to litmus paper, no reaction with metal strips.
NaCl (aq) (neutral ionic): Strong conductivity, pH 7, no change to litmus paper, no reaction with metal strips.
0.10 mol/L HCl (aq) (strong acid): Strong conductivity, pH approximately 2, turns blue litmus red, reacts vigorously with metal strips to produce hydrogen gas (bubbles).
0.10 mol/L NaOH (aq) (strong base): Strong conductivity, pH approximately 13, turns red litmus blue, no reaction with metal strips.
0.10 mol/L $CH_3COOH$ (aq) (weak acid): weak conductivity, pH approximately 4.5, turns blue litmus red, reacts slowly with metal strips to produce hydrogen gas (bubbles).
0.10 mol/L $NH_3$ (aq) (weak base): weak conductivity, pH approximately 8.5, turns red litmus blue, no reaction with metal strips.

## Answer to Conclusion Question

**2.** Strong acids: high conductivity, low pH, and vigorous reaction with magnesium or zinc.
Strong bases: high conductivity, high pH, and no reaction with magnesium or zinc.
Weak acids: low conductivity, pH slightly below 7, and slow reaction with magnesium or zinc.
Weak bases: low conductivity, pH slightly above 7, and no reaction with magnesium or zinc.
Neutral ionic solutions: high conductivity, pH of 7, and no reaction with magnesium or zinc.
Neutral molecular solutions: no conductivity, pH of 7, and no reaction with magnesium or zinc.

# Assessment Options

- Collect and assess student answers to Analysis and Conclusion questions.
- Use Assessment Checklist 2: Laboratory Report (see Appendix A) to assess students' write-ups.

## Answers to Questions for Comprehension

**Student Textbook page 222**

**Q5.** Strong acids: **(a)** and **(c)**, weak acids: **(b)** and **(d)**

**Q6.** Strong bases: **(b)** and **(d)**, weak bases: **(a)** and **(c)**

**Q7. (a)** Being a strong acid, HCl(aq) would have a higher concentration of hydronium ions.

**(b)** Being a weak acid, HF(aq) would have a lower conductivity

## Chemistry File: Try This

**Student Textbook page 223**

This activity can be used as a lead-in to Thought Lab 6.1.

Students can have some fun with their presentation. Evaluate students' research, the organization of their findings, and their creativity in presenting their findings.

# Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases

**Student Textbook page 225**

### Purpose

Students will research the industrial uses of acids and bases, noting how and with what care these substances are transported. Students will then present their findings.

### Outcomes

- 20–C2.2sts
- 20–C2.3s
- ICT F3–4.1
- AI–STS2

### Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Book computer time for research. |
| 1 day before | ■ Photocopy **BLM 6.2.7 (HAND) Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases.** |

### Time Required

- 3 class periods (1 for research, 1 to prepare presentations, 1 for presentations and discussion)

*or*

- 1 class period if students do research and prepare presentations on their own time

### Helpful Tips

- Key chemicals include sulfuric acid, ammonia, hydrogen sulfide (hydrosulfuric acid), sodium hydroxide, sodium carbonate, hydrochloric acid, ammonium nitrate, calcium carbonate, nitric acid, phosphoric acid.
- To streamline this activity, assign groups to particular compounds, or else provide a list of industries for them to explore. Petrochemical or pulp-and-paper plants, sanitation facilities, swimming pools and hockey rinks, and the food and beverage industry are good examples.
- Remind students to include detailed chemical equations to illustrate the various steps and processes.
- Use **BLM 6.2.7 (HAND) Thought Lab 6.1: Risks and Benefits of Transporting Acids and Bases** and **BLM 6.2.7A (ANS) Thought Lab: Risks and Benefits of Transporting Acids and Bases Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

### Answer to Analysis Question

**1. (a)** Discuss with students what they knew about acid–base transportation before they began their research. Where is the "hazardous goods route" through their town or city? Does it pass near their house, school, parks, or waterways? Answers may vary according to depth of research and skill of group. Generally students will find that the provincial and federal governments attempt to regulate and educate industry about safety concerns. However, stronger students may criticize voluntary compliance to minimum industry guidelines, and poor government funding for enforcement and inspection.

**(b)** Compile the list of acid–base industries uncovered by the various groups of students. How many of their families either are employed by these industries directly or use the products that they make? Now ask students to revisit the question posed in 1(b). The benefits are mainly economic, and most students will probably feel that these outweigh the environmental and safety concerns. Again, however, stronger students may suggest that Alberta may be facing many long-term problems dealing with safety and storage of harmful material, resulting from the problems in **1 (a)**.

**(c)** Answer will depend on response to **1 (a)**. Encourage students to provide specific evidence to support their ideas.

**(d)** Generally, the media only reports industrial accidents that have a human cost or interest. This means that many environmentally damaging accidents occurring on a smaller scale and/or without human injury may go unreported.

### Assessment Options

- Students may produce a poster or pamphlet that could be graded using a rubric designed by the class (peer evaluation).
- The class could perform a debate based on the information they found—should a major hazardous acid (or base) produced nearby be transported through their town?
- Students could develop a campaign to lobby for or against the construction of a plant that would produce a significantly hazardous yet profitable acid or base using the research they obtained.
- Use Assessment Checklist 4: Performance Task Group Assessment (see Appendix A) to help students assess how they worked together as a group.

**SUPPORTING DIVERSE STUDENT NEEDS**

Assign groups so as to pair up weaker students with stronger students. Likewise, assigning roles to be performed will help prevent a few students from doing all the work. Depending on the nature of your class, you can narrow down the focus of the Thought Lab to make the research easier for your students. Alternately, challenge a stronger class to demonstrate or model the industrial processes.

## Section 6.2 Review Answers

**Student Textbook page 226**

**1. (a)** The higher concentration of hydrochloric acid results in a higher hydronium ion concentration. Solutions with higher ion concentrations are better electrolytes and therefore have a higher conductivity.

**(b)** Sodium hydroxide is a strong base and dissociates completely. Ammonia is a weak base, and only a small percentage of the molecules react with water. Therefore, a 1.0 mol/L solution of sodium hydroxide contains a higher concentration of ions and a higher conductivity than a 1.0 mol/L solution of ammonia.

**2. (a)** hydrochloric acid, $HCl(aq)$

**(b)** sulfuric acid, $H_2SO_4(aq)$

**(c)** sodium hydroxide, $NaOH(aq)$

**(d)** sodium phosphate, $Na_3PO_3(aq)$

**3. (a)** acetic acid, $CH_3COOH(aq)$

**(b)** hydrochloric acid, $HCl(aq)$

**(c)** sodium hydroxide, $NaOH(aq)$

**(d)** ammonia, $NH_3(aq)$

**(e)** any Group 2 metal, such as calcium oxide, $CaO(s)$

**(f)** any of the oxides of sulfur, such as $SO_2(g)$, or of nitrogen, like $NO_2(g)$, which form sulfurous acid, $H_2SO_3(aq)$, and nitric acid, $HNO_3(aq)$, respectively

**4.** Formic acid is a weak acid.

**5.** Students should disagree with this statement. Both $H_2SO_4(aq)$ and $HCl(aq)$ are strong acids, but $H_2SO_4(aq)$ dissociates to form $HSO_4^-(aq)$, which is a weak acid. Only a small percentage of the $HSO_4^-(aq)$ ions react with water to form $SO_4^{2-}(aq)$. (They would need to react 100% for a 0.10 mol/L sulfuric acid solution to have double the hydronium ion content of a 0.10 mol/L hydrochloric acid solution.).

**6. (a)** neutralization **(b)** base **(c)** $Na_2CO_3$

**(d)** $Na_2CO_3(aq) \rightarrow Na^+ + CO_3^{2-}(aq)$

$CO_3^{2-}(aq) + H_2O(\ell) \leftrightarrow HCO_3^- + OH^-(aq)$

$HCO_3^- + H_2O(\ell) \leftrightarrow H_2CO_3^- + OH^-(aq)$

## 6.3 Acids, Bases, and pH

**Student Textbook pages 227–242**

### Section Outcomes

In this section, students will:

- calculate $H_3O^+(aq)$ and $OH^-(aq)$ concentrations, pH, and pOH based on logarithmic expressions
- compare magnitude changes in pH and pOH with changes in concentration for acids and bases
- explain how indicators, pH meters, or pH paper can be used to measure $H_3O^+$ (aq) concentration
- relate pH and hydronium ion concentration
- use indicators, pH paper, and a pH meter to determine acidity and alkalinity of a solution
- use appropriate SI units to express pH and concentration to the correct number of significant digits

### Key Terms

pH
acid–base indicator
universal indicator
pOH

### Chemistry Background

- pH is calculated using the formula $pH = -\log [H_3O^+]$. Similarly, $pOH = -\log [OH^-]$. The concentration of these ions can be found by using the inverse operations: $[H_3O^+] = 10^{-pH}$ and $[OH^-] = 10^{-pOH}$. At STP acids have a pH of below 7, bases a pH of above 7, and neutral substances a pH of 7.
- At this stage, students will calculate the pH of strong acids and bases only. Students should be aware that the pH of a strong acid will always be lower at the same concentration than the pH of a weak acid. Similarly, the pH of a strong base will always be higher than the pH of a weak base at the same concentration.
- A decrease in the value of the pH by 1 means that hydronium ion concentration increases by a factor of ten.
- Indicators are substances that change colour in solutions of different pH. Indicators themselves are usually weak acids in which the colour of the molecular substance is different from the colour of the ionized substance.
- pH meters use a hydrogen-specific electrode to measure the $[H_3O^+(aq)]$ in a solution. The first pH meters were developed for use in quality control in the citrus fruit industry.

### Teaching Strategies

- Cosmetics marketers often claim that their products are "pH balanced." What does this mean, exactly? Have students bring in samples of different soaps to compare pH. Most soaps have a pH between 9.0 and 10.0, but a few (Dove®, for example) have a pH that is around 7.0. Discuss with students the technological and economic factors at work: Is less alkaline soap less effective? Does more alkaline soap harm skin (which is naturally acidic)? Is it more expensive to manufacture a less alkaline soap? If so, why might this be the case? Is this extra expense reflected in the price of the product?

- Many dyes and pigments happen also to be indicators. One example is the goldenrod-coloured paper that you can get from some copy shops and also from educational suppliers, containing the dye C.I. Direct Yellow 4. One type of paper that contains this dye is Astrobrights® Galaxy Gold WAAB57A, from Wausau Papers. You can cut this paper into strips and use it as an inexpensive indicator paper. You can find many simple and fun demonstrations involving this paper on the Internet. For example, you can write a message on the paper using a wax candle, and then spray the paper with a dilute ammonia solution or glass cleaner. The exposed paper will turn red, revealing the message.
- A number of overhead masters and quizzes have been prepared for this section. You will find them with the Chapter 6 BLMs on the CD-ROM that accompanies this Teacher's Resource or at **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, BLMs.

  **Number (Type) Title**
  6.3.1 (OH) Ion Concentration in Water
  6.3.2 (AST) Calculating Concentrations of Acids and Bases
  6.3.2A (ANS) Calculating Concentrations of Acids and Bases Answer Key
  6.3.3 (OH) The pH Scale
  6.3.4 (AST) Calculating pH
  6.3.4A (ANS) Calculating pH Answer Key
  6.3.5 (OH) Common Acid-Base Indicators
  6.3.6 (AST) Acid-Base Indicators
  6.3.6A (ANS) Acid Base Indicators Answer Key
  6.3.8 (AST) Calculating pH After Dilution
  6.3.8A (ANS) Calculating pH After Dilution Answer Key
  6.3.10 (AST) Calculating pOH and Changing from pH to pOH
  6.3.10A (ANS) Calculating pOH and Changing from pH to pOH Answer Key
  6.3.11 (OH) Understanding pH and pOH
  6.3.12 (AST) Calculating Concentration from pH and pOH
  6.3.12A (ANS) Calculating Concentration from pH and pOH Answer Key
  6.3.13 (AST) Putting it all Together: Dilutions as Advanced Acid-Base Calculations
  6.3.13A (ANS) Putting it all Together Answer Key
  6.3.14 (AST) Acid-Base Review
  6.3.14A (ANS) Acid-Base Review Answer Key

## Answers to Practice Problems 1–6

**Student Textbook page 230**

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. **(a)** 2.57 **(b)** –0.716 **(c)** 11.082 **(d)** 4.01 **(e)** 3.792
2. 2.30 (acidic)
3. 3.54 (acidic)
4. 9.181
5. 2.201
6. 2.318

## Chemistry File: Web Link

**Student Textbook page 230**

Ask students to research other examples of logarithmic scales.

## Figure 6.18

**Student Textbook page 231**

Most of the indicators change colour over a small pH range. Universal indicator changes colours many times over the entire pH range.

## Figure 6.19

**Student Textbook page 231**

The pH's of the solutions are A: 1; B: 5; C: 9.

## Chemistry File: Try This

**Student Textbook page 231**

This is a simple procedure that students could try at home.

# Investigation 6.D: Determining the pH of an Unknown Solution with Indicators

**Student Textbook page 232**

## Purpose

Students practice using indicators to determine pH.

## Outcomes

- 20–C2.6k
- 20–C2.3s
- PR–NS2
- AI–NS2
- AI–NS6
- ICT C6–4.1

## Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Order indicators, acids, and bases. |
| 1 day before | ■ Collect apparatus.<br>■ Prepare small samples of indicators, acids, and bases.<br>■ Photocopy **BLM 6.3.7 (HAND) Investigation 6.D: Determining the pH of an Unknown Solution with Indicators.** |

| Materials |
|---|
| ■ spot plates or small test tubes<br>■ eyedroppers<br>■ methyl orange<br>■ methyl red<br>■ bromothymol blue<br>■ phenolphthalein<br>■ 10 mL of the following solutions per group:<br>– 0.1 mol/L hydrochloric acid<br>– 0.1 mol/L sodium hydroxide<br>– 0.1 mol/L sodium carbonate<br>– 0.01 mol/L acetic acid |

## Time Required

15–25 minutes

## Helpful Tips

- Clearly label all eyedroppers to prevent cross-contamination.
- Discuss Figure 6.18 (student textbook p. 231) as a way to introduce this investigation. This photograph shows that indicators do not just show whether a substance is acidic or basic; they allow you to estimate a substance's pH when used in combination with one another.
- Use **BLM 6.3.7 (HAND) Investigation 6.D: Determining the pH of an Unknown Solution with Indicators** and **BLM 6.3.7A (ANS) Investigation 6.D: Determining the pH of an Unknown Solution with Indicators Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.

## Safety Precautions

- Ensure students have read and understood "Safety in Your Chemistry Lab and Classroom" on pages xii–xv in the student textbook.
- Solutions of acids and bases may be toxic and corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure the eye wash station has been tested recently and any eye wash bottles are filled.
- Dispose of all materials safely in proper waste containers.

## Answer to Procedure Questions

**3, 4.**

| Unknown solution | Methyl orange | Methyl red | Bromo-thymol blue | Phenolph-thalein |
|---|---|---|---|---|
| Hydro-chloric acid | Red | Red | Yellow | Colourless |
| Acetic acid | Orange | Red | Yellow | Colourless |
| Sodium carbonate | Yellow | Yellow | Blue | Colourless |
| Sodium hydroxide | Yellow | Yellow | Blue | Pink |

## Answer to Analysis Question

**1.** Student answers ought to fall within the following range: HCl(aq): 3.2 or lower; $CH_3COOH$(aq): 3.2–4.4; $Na_2CO_3$(aq): 7.6–8.2; NaOH(aq): 10.0 or higher

## Answer to Conclusion Question

**2.** Approximate pHs are HCl(aq): 1.0; $CH_3COOH$(aq): 3.4; $Na_2CO_3$(aq): 7.4; NaOH(aq): 13. The pH meter is likely to be more accurate because it gives a precise measurement, whereas the indicator allows only for an estimate.

## Answer to Extension Question

**3.** If a pH meter is available, it is the easiest and most practical, although also the most expensive. If one is not available, then cabbage juice is the most practical since it is easy to make and provides fairly accurate coverage over a wide range of pH values.

## Other Assessment Options

- Collect and assess answers to Analysis question.
- Have students distinguish among three unknowns using indicators.
- Use Assessment Checklist 2: Laboratory Report (see Appendix A) to assess students' write-ups.

## Answers to Questions for Comprehension

**Student Textbook page 233**

**Q8.** The substance has a pH of between 2.8 and 4.8.

**Q9.** The solution should turn yellow.

**Q10.** Indigo carmine is blue at a pH of 11.4 and turns yellow at a pH of 13.0. At a pH of 12.0 indigo carmine should start to appear a blue–green colour and be completely green at 12.2. At a pH of around 12.5 indigo carmine ought to appear green–yellow in colour.

## Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid

**Student Textbook page 234**

### Purpose

After calculating the theoretical pH of a diluted acid, students will use a pH meter to record the actual pH and then compare results.

### Outcomes

- 20–C2.3k
- 20–C2.4k
- 20–C2.5k
- 20–C2.1s
- 20–C2.2s
- ICT P2–4.1
- IP–NS2
- ICT C6–4.3
- PR–NS4
- ICT P2–4.2
- PR–NS3

### Advance Preparation

| When to Begin | What to Do |
|---|---|
| 2–3 weeks before | ■ Ensure all materials are available. |
| 1 day before | ■ Collect apparatus and distilled water.<br>■ Prepare solution of 0.10 mol/L hydrochloric acid.<br>■ Photocopy **BLM 6.3.9 (HAND) Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid.** |

| Materials |
|---|
| ■ 0.10 mol/L hydrochloric acid<br>■ distilled water<br>■ universal indicator paper (pH paper)<br>■ 10 mL graduated cylinders (2) (or graduated pipette)<br>■ 100 mL beaker<br>■ stirring rod<br>■ pH meter (optional) |

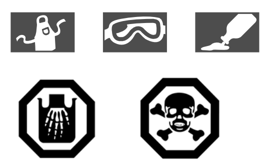
### Time Required

25–40 minutes

### Helpful Tips

- You can modify this lab to make use of any concentration of HCl(aq) if students measure the pH first, calculate backwards to the concentration of the $H^+$, and then predict the concentration of the solute after dilution.
- You may wish to pre-cut your pH paper into small strips to prevent wastage.
- It is preferable that students use pipettes and volumetric flasks for the dilutions, if this equipment is available.
- Have students practice using the pipettes before beginning their dilutions.
- Using tap water instead of distilled water may affect results, as the pH of tap water can be slightly acidic.
- Use **BLM 6.3.9 (HAND) Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid** and **BLM 6.3.9A (ANS) Investigation 6.E: The Effect of Dilution on the $[H_3O^+(aq)]$ and pH of an Acid Answer Key** to support this activity. Remove sections as appropriate to meet the needs of the students in your class.
- ***Expected Results*** There will be an increase of approximately 1 with each 10 fold dilution of the hydrochloric acid until reaching pH 7. It will remain at pH 7, the pH of water as the dilution continues.

### Safety Precautions



- Ensure students have read and understood "Safety in Your Chemistry Lab and Classroom" on pages xii–xv in the student textbook.
- Hydrochloric acid is corrosive. Wash any spills on skin or clothing with plenty of cool water. Make sure the eye wash station has been tested recently and any eye wash bottles are filled.
- Dispose of all materials safely in proper waste containers.

### Answers to Prediction

**(a)** $[H_3O^+(aq)] = [HCl(aq)] = 0.10$ mol/L

$pH = -\log[H_3O^+(aq)] = -\log(0.10) = 1.00$

**(b)** $[H_3O^+(aq)] = 0.010$ mol/L

$pH = -\log[H_3O^+(aq)] = -\log(0.010) = 2.00$

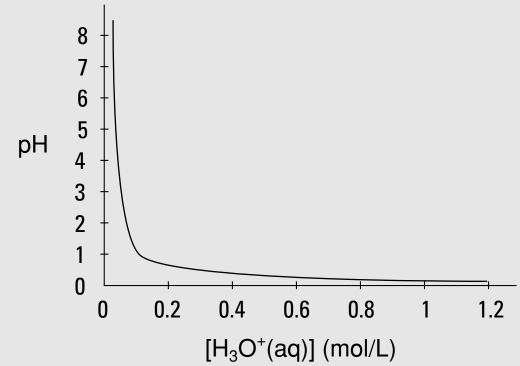
**(c)** Based on similar calculations, students will likely predict pH = 3.00, 4.00, 5.00, 6.00, 7.00, 8.00 for the next six dilutions. (Note the pH = 8.00 prediction—students will not, of course, observe this pH. With continued dilutions the pH remains at 7.00, the pH of water.)

## Answers to Procedure

| $[HCl_{(aq)}]$ (mol/L) | Calculated $[H_3O^{+}_{(aq)}]$ (mol/L) | Predicted pH | pH measured with universal indicator (accuracy may vary by paper) | pH measured with pH meter |
|---|---|---|---|---|
| $1.0 \times 10^{-1}$ | $1.0 \times 10^{-1}$ | 1.00 | 1–2 (red) | 1.0 |
| $1.0 \times 10^{-2}$ | $1.0 \times 10^{-2}$ | 2.00 | 1–2 (red) | 2.0 |
| $1.0 \times 10^{-3}$ | $1.0 \times 10^{-3}$ | 3.00 | 3–4 (orange) | 3.0 |
| $1.0 \times 10^{-4}$ | $1.0 \times 10^{-4}$ | 4.00 | 3–4 (orange) | 4.0 |
| $1.0 \times 10^{-5}$ | $1.0 \times 10^{-5}$ | 5.00 | 5–6 (yellow) | 5.0 |
| $1.0 \times 10^{-6}$ | $1.0 \times 10^{-6}$ | 6.00 | 5–6 (yellow) | 6.0 |
| $1.0 \times 10^{-7}$ | $1.0 \times 10^{-7}$ | 7.00 | 7 (yellow–green) | 7.0 |
| $1.0 \times 10^{-8}$ | $1.0 \times 10^{-8}$ (actually $1.0 \times 10^{-7}$) | 8.00 (actually 7.00) | 7 (yellow–green) | 7.0 |
| $1.0 \times 10^{-9}$ | $1.0 \times 10^{-9}$ (actually $1.0 \times 10^{-7}$) | 9.00 (actually 7.00) | 7 (yellow–green) | 7.0 |

## Answers to Analysis Questions

1. Provided that it is calibrated properly and well maintained, the pH meter is more precise and possibly more accurate. The pH meter allows for determining pH with several significant digits. Determining the colour of pH paper is subjective and can be affected by lighting and other factors such as colour blindness.
2. Most pH paper has a scale with only whole numbers, which means the pH value reported is only approximate. Digital pH meters read to the precision listed by the manufacturer. If students have values that are significantly different it may indicate problems following the calculations. Slight variations may be due to an improperly calibrated pH meter, poor dilution technique, or contamination of the acid or water.
3. This question allows you to address a common misconception. Most, if not all, students will perform the calculations for $[H_3O^+(aq)]$ and predict the pH without realizing they are predicting that by continuous dilution, an acid may be diluted to become basic and vice versa. These two solutions ought to have had a pH of around 7.00, since the hydrochloric acid is so dilute that the prime contributor of hydronium ions is the autoionization of the water itself.
4. A ten-fold dilution of hydrochloric acid results in the increase of pH by 1.0, until the pH reaches 7.0, at which point the pH does not change further by dilution because $[H_3O^+(aq)]$ remains constant.
5. The graph should resemble the one below.




## Answer to Conclusions Question

6. When the $[H_3O^+(aq)]$ of a solution decreases by a factor of 10, pH increases by 1.0.

## Assessment Options

- Collect and assess answers to Analysis, Conclusion, and Extension questions.
- Use Assessment Checklist 2: Laboratory Report (see Appendix A) to assess students' write-ups.

**SUPPORTING DIVERSE STUDENT NEEDS**

Students with any type of colour blindness may find it a challenge to work with indicators. Allow these students to work with pH meters or at least ensure they are working with a partner who can help them. You may want to challenge these students to experiment with the "olfactory indicators" described in the Chemistry File: Try This on page 231 of the student textbook.

## Answers to Practice Problems 7–12

**Student Textbook page 237**

For full solutions, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

7. **(a)** 2.21 **(b)** –0.597 **(c)** 10.3 **(d)** 2.62 **(e)** 0.279 **(f)** 1.94
8. 5.70 (basic)
9. 3.60 (basic)
10. 2.460
11. 10.02
12. 3.564

### Chemistry File: Web Link

**Student Textbook page 238**

This makes a good group project. Each group could report on the effects of acid precipitation in a different area or ecosystem in Canada.

## Connection (Science and Technology): Drain Cleaners

**Student Textbook page 239**

### Teaching Strategies

- Have students write short "educational" ads that market their drain cleaner. The ads should include the chemistry of how the cleaners work.

### Connections Answers

1. Most people likely refer to claims made in advertisements about the effectiveness of products. Encourage students to research these claims and make them the basis for question 2.
2. Students will need to be aware of the standard safety concerns when using acids and bases. Since reactions between acids and bases can generate heat and cause splashing, students need to wear goggles and gloves. An additional safety concern is that a few of these reactions generate gases and so any container that the students are using to test their products on will require some sort of opening of sufficient size to allow the rapid release of these gases in order to prevent explosion. Finally, some of the gases produced may be toxic and so this reaction should be done in a fume hood.
For more information consult the following web sites:
www.meridianeng.com/draincle.html
www.Care2.com/channels/solutions/home/210

### Answers to Practice Problems 13–18

**Student Textbook page 241**

For full solutions, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

**13. (a)** $1 \times 10^{-4}$ mol/L (acidic)
**(b)** $1.7 \times 10^{-9}$ mol/L (basic)
**(c)** $3.78 \times 10^{-6}$ mol/L (basic)
**(d)** $4.5 \times 10^{-12}$ mol/L (acidic)
**14.** $1.6 \times 10^{-5}$ mol/L
**15.** $6.2 \times 10^{-5}$ mol/L
**16.** $1.5 \times 10^{-3}$ mol/L
**17.** 1.3 g NaOH(s)
**18.** $1.2 \times 10^{-2}$ g HCl(g)

## Section 6.3 Review Answers

**Student Textbook page 242**

1. The pH system is a relatively easy way to discuss hydronium ion concentration without needing to use very small numbers and the accompanying negative exponents.
2. From least acidic to most acidic: egg white, camembert cheese, beets, yogurt, sauerkraut.

**3. (a)** 4.4–4.8 **(b)** 7.6 **(c)** 0.8
**4. (a)** pH = 7.40, base **(b)** pH = 1.40, acid
**5. (a)** pOH = 10.51, acid **(b)** pOH = 6.410, base
**6.** pH = 0.725
**7.** pH = 12.495
**8. (a)** $[H_3O^+(aq)] = 1.7 \times 10^{-3}$ mol/L
**(b)** $[H_3O^+(aq)] = 2.70 \times 10^{-4}$ mol/L
**9. (a)** $[OH^-(aq)] = 1.1 \times 10^{-4}$ mol/L
**(b)** $[OH^-(aq)] = 8 \times 10^{-5}$ mol/L
**10.** $[HNO_3(aq)] = 5.4 \times 10^{-3}$ mol/L
**11.** $4.4 \times 10^{-3}$ g KOH(s)
**12., 13.** ICT may vary

| Range of acidity and basicity | $[H_3O^+(aq)]$ (mol/L) | pH (= –log $H_3O^+(aq)$] | $[OH^-(aq)]$ (mol/L) | pOH (=14 – pH) |
|---|---|---|---|---|
| very acidic | 1.0 | 0 | 0.000 000 000 000 01 | 14 |
| | 0.1 | 1 | 0.000 000 000 000 1 | 13 |
| | 0.01 | 2 | 0.000 000 000 001 | 12 |
| | 0.001 | 3 | 0.000 000 000 01 | 11 |
| | 0.000 1 | 4 | 0.000 000 000 1 | 10 |
| | 0.000 01 | 5 | 0.000 000 001 | 9 |
| | 0.000 001 | 6 | 0.000 000 01 | 8 |
| neutral | 0.000 000 1 | 7 | 0.000 000 1 | 7 |
| | 0.000 000 01 | 8 | 0.000 001 | 6 |
| | 0.000 000 001 | 9 | 0.000 01 | 5 |
| | 0.000 000 000 1 | 10 | 0.0001 | 4 |
| | 0.000 000 000 01 | 11 | 0.001 | 3 |

| Range of acidity and basicity | $[H_3O^+(aq)]$ (mol/L) | pH (= –log $H_3O^+(aq)$] | $[OH^-(aq)]$ (mol/L) | pOH (=14 – pH) |
|---|---|---|---|---|
| | 0.000 000 000 001 | 12 | 0.01 | 2 |
| | 0.000 000 000 000 1 | 13 | 0.1 | 1 |
| very basic | 0.000 000 000 000 01 | 14 | 1 | 0 |

## Chapter 6 Review Answers

**Student Textbook pages 244–245**

### Answers to Understanding Concepts Questions

**1.** Acids: low pH, conductivity, sour taste
Bases: high pH, conductivity, bitter taste

**2. (a)** According to the modified Arrhenius theory an acid must be capable of producing hydronium ions in solution, usually through the loss of hydrogen atoms. A base must be capable of producing hydroxide ions.

**(b)** The presence of hydronium or hydroxide ions makes the solutions conductive.

**(c)** An acid loses hydrogen atoms to water, forming hydronium ions.

**(d)** A base forms hydroxide ions in water.

**(e)** Strong acids and bases dissociate completely into hydronium and hydroxide ions, whereas weak acids and bases only produce small amounts of these ions.

**(f)** The pH of a solution is dependent on the concentration of hydronium ions.

**(g)** The pOH of a solution is dependent on the concentration of hydroxide ions.

**3.** $NaOH(aq) + HNO_3(aq) \rightarrow H_2O(\ell) + NaNO_3(aq)$

**4. (a)** weak acid **(b)** weak acid
**(c)** strong base **(d)** weak base

**5.** Diprotic means that the acid has two hydrogen ions (or protons) that it can donate in solution.

**6.** $H_2SO_4(aq)$ is a strong acid as it dissociates 100%.
$HSO_4^-(aq)$ dissociates less than 50% and is a weak acid.

**7. (a)** basic **(b)** neutral **(c)** acidic

**8.** An acid–base indicator is a substance that changes colour with a change in pH.

**9.** Universal indicator undergoes many different colour changes with small changes in pH, whereas bromothymol blue only undergoes two, yellow to blue, with the solution turning green in between endpoints.

**10.** Universal indicator relies on colour changes, which are a subjective measurement since they can change in intensity or under different lighting. Moreover, people tend to classify shades of colours differently. Colour-blind people have problems distinguishing between different colours. A pH meter displays a calculated pH value, making it more accurate.

**11. (a)** pH = 2.900, acid **(b)** pH = 5.450, acid
**(c)** pH = 12.010, base

**12. (a)** pOH = 6.100, base **(b)** pOH = 6.631, base
**(c)** pOH = 9.290, acid

**13. (a)** $[H_3O^+(aq)] = 1.1 \times 10^{-5}$
**(b)** $[H_3O^+(aq)] = 3 \times 10^{-11}$
**(c)** $[H_3O^+(aq)] = 1.7 \times 10^{-11}$
**(d)** $[H_3O^+(aq)] = 1 \times 10^{-12}$
**(e)** $[OH^-(aq)] = 2.8 \times 10^{-13}$
**(f)** $[OH^-(aq)] = 6 \times 10^{-3}$
**(g)** $[OH^-(aq)] = 2 \times 10^{-7}$
**(h)** $[OH^-(aq)] = 2 \times 10^{-3}$

### Answers to Applying Concepts Questions

**14.** The hydrochloric acid has the lowest pH as it is a strong acid, while the acetic acid has the next lowest since it is only a weak acid. The ammonia solution is a weak base and so has the highest pH.

**15.** The low pOH of codeine indicates it has a high concentration of $OH^-(aq)$ ions, making it a base.

**16.** Diluting an acid tenfold raises the pH by a value of 1. Diluting one hundredfold raises it by 2. As you continue to dilute the acid, its pH will steadily approach 7. With further dilution the acid's pH will remain at 7, since the autoionization of water dominates.

**17. (a)** 5.4–6.0 **(b)** 8.0–8.2 **(c)** 10–11.4

**18. (a)** yellow **(b)** yellow–green **(c)** yellow

**19.** The cheese is not safe to eat, since its pH of 7 is too high.

**20.** Students ought to design a procedure to test pH and conductivity. The strong acid, strong base, and neutral ionic solutions should have a high conductivity. The weak acids and bases should have a low conductivity, while the neutral molecular solution should have no conductivity. The neutral solutions should have a pH of 7, the strong acid should have a low pH, while the weak acid should be just below 7. The strong base should have a high pH and the weak base should have a pH just above 7.

**21.** When dealing with pH, or any logarithm, significant digits are counted after the decimal. For example, a pH value of 7.5 has only one decimal digit, while a pH value of 9.43 has two.

**22.** This answer depends on the concentration of the two substances. At equal or similar concentrations, since the strong acid dissociates 100%, it generates far more hydronium ions than the weak acid, giving it a far greater reactability, or strength. The weak acid would have to be significantly more concentrated than the strong acid to have the same strength.

**23.** Since the hydrochloric acid dissociates 100% as a strong acid, it will generate 1.0 mol/L of hydronium ion. Acetic acid is a weak acid and will generate approximately 0.01 mol/L of hydronium ion. While both of these solutions will react with magnesium, producing hydrogen gas as bubbles, the rate of bubbling will be much greater with the hydrochloric acid.

### Answers to Solving Problems Questions

**24.** pH = 4.046

**25.** pH = 10.281

**26.** 0.091 g $HI(\ell)$

**27.** $4 \times 10^{-3}$g $HNO_3(\ell)$

**28.** 9 g $KOH(\ell)$

### Answers to Making Connections Questions

**29.** Limestone contains calcium carbonate, $CaCO_3(s)$, which must be a base since it protects lakes from changes in pH due to acid rain. Although calcium carbonate does not contain the hydroxide ion, $OH^-(aq)$, it reacts with water to produce hydroxide ions. This base will neutralize the acid in acid rain, protecting the lake.

**30.** **(a)** $CO_2(aq) + H_2O(\ell) \rightarrow H_2CO_3(aq)$

**(b)** Carbonic acid is a relatively weak acid and the acids that make up acid rain are stronger.

**(c)** Most acid rain comes from industrial pollutants, more abundant in Eastern Canada.

**(d)** During combustion of coal, sulfur reacts with oxygen to form (principally) sulfur dioxide, $SO_2(g)$. This in turn dissolves in and reacts with water in the atmosphere to form dilute sulfurous acid:

$SO_2(aq) + H_2O(\ell) \rightarrow H_2SO_3(aq)$

**(e)** Scrubbers work by neutralizing the sulfur dioxide gas with calcium oxide:

$SO_2(g) + CaO(s) \rightarrow CaSO3(s)$

The calcium sulfite is water-soluble and can be washed away.

**(f)** Answers may include: using alternative forms of transit to cars, driving a car with greater fuel economy (e.g., not an SUV or truck), economizing use of electricity (generated mostly by burning fossil fuels), reusing and recycling paper.

**31.** The formation of carbonic acid from respiration causes the bromothymol blue to turn yellow.

## Career Focus: Ask a Marine Conservationist

**Student Textbook pages 246–247**

### Purpose

Students are exposed to the roles that acid and bases play in the deterioration and restoration of artifacts such as the *Vasa*, a 1000-year-old sunken ship, through an interview with a leading expert.

### Teaching Strategies

At the end of the Career Focus, students are introduced to three other areas of conservation. Students could be given research assignments to find out more about specific conservation cases. Depending on the skill level of students, they could visit university or government web sites and attempt to track down scientists actively involved in these conservation efforts and interview them via email.

### Answers to Go Further Questions

1. The primary difference between the *Mary Rose* and the *Vasa* is that the *Mary Rose* was buried under a large amount of clay. While the clay helped to preserve the *Mary Rose*, it created a tremendous technical challenge in excavating the ship.
2. The majority of acid rain is caused by SOx and NOx gases dissolved in water. These gases are often released by industrial manufacturing processes. Substances made out of calcium carbonate (limestone) have proven to be the most resistant to acid rain because they function as a buffer, helping to neutralize the acid rain.
3. Three preservation techniques used to halt acid rain damage are coating substances in special acid-rain-resistant paint, "liming" or introduction of calcium carbonate to bodies of water, and the reduction of emissions containing sulfur and nitrogen oxides.

## Unit 3 Review Answers

**Student Textbook pages 248–252**

### Answers to Understanding Concepts Questions

1. A homogeneous mixture contains two or more substances mixed together in such a way that the two substances cannot be distinguished, e.g., sugar in water. A heterogeneous mixture meanwhile contains two substances that can be distinguished, e.g., carbonated water, in which the bubbles of carbon dioxide are visible.
2. Solute is broken down into smaller particles (endothermic). Intermolecular bonds of solute and of solvent are broken (endothermic). Intermolecular bonds formed between solute and solvent (exothermic). The amount of energy released in this last step generally

determines whether the process will be endothermic or exothermic.

3. Moles per litre (mol/L): used when describing concentration of acids and industrial products. Percent by weight (w/w) or percent by mass (m/m): for commercial products such as hydrogen peroxide. Percent by volume (V/V): for consumer products such as alcohol. There is also percent by mass/volume (m/V). Pollutants are often cited in terms of parts per million (ppm) or even parts per billion (ppb).

4. Since a saturated solution contains the highest ratio of solute to solvent possible for a given mixture, it will always be "concentrated."

5. Solubility is defined as the amount of a substance (solute) that can be dissolved in another (solvent). It will vary according to the chemical nature of the solutes and solvents, as well as with the temperature and pressure.

6. 4 g Fe(aq)

7. $1 \times 10^{-5}$ g $P_4$(aq); $4 \times 10^{-7}$ mol/L $P_4$

8. The table sugar has considerably fewer moles present. So the salt solution is more concentrated.

9. **(a)** $[NH_4^+] = 4.12$ mol/L, $[Cl^-] = 4.12$ mol/L
   **(b)** $[Ba^{2+}] = 0.275$ mol/L, $[OH^-] = 0.550$ mol/L
   **(c)** $[NH_4^+] = 1.629$ mol/L, $[PO4^-] = 0.543$ mol/L

10. **(a)** $c_2 = 0.250$ mol/L HCl(aq)
    **(b)** $c_2 = 0.21$ mol/L $NaNO_3$(aq)
    **(c)** $c_2 = 0.577$ mol/L $(NH4)_3PO_3$(aq)

11. Scale build-up is typically caused by $CaCO_3$(s) deposits. The chemical reaction is:

    $2CH_3COOH(aq) + CaCO_3(s) \rightarrow Ca(CH_3COO)_2(aq) + H_2O(l) + CO_2\ (g)$

    Students could expect to see the carbon dioxide bubbles, and possibly an increase in temperature could be observed.

12. The acid in the lemon juice is more concentrated by a factor of 1000.

13. Providing that you knew electrolytes to be ions in aqueous solution, you could infer that acids and bases are electrolytes, since the Arrhenius theory refers to the creation of hydrogen and hydroxide ions in solution.

14. Water has a pH of 7 since it has equal amounts of hydronium and hydroxide ions present.

15. **(a)** Strong acids and bases dissociate into ions 100%, whereas weak acids and bases do not. Strong base = NaOH(aq), strong acid = HCl(aq), weak base = $NH_3$(aq), weak acid = HF(aq).
    **(b)** The terms concentrated and dilute refer to the amount of moles of acid or base initially present in solution, not the concentration of the ions after dissociation has occurred.

16. **(a)** The 0.10 mol/L solution would generate more hydronium ions per litre than the 0.010 mol/L solution. The 0.010 mol/L solution would therefore have a higher (weaker) pH.
    **(b)** The base generates hydroxide ions that reduce the concentration of hydronium ions, giving it a higher pH.
    **(c)** The solution with a pOH of 7 has a greater concentration of hydroxide ions than the solution with a pOH of 8. Since hydroxide ions reduce the concentration of hydronium ions, the solution with a pOH of 7 would have a higher pH. Or, use the fact that pOH = 14 – pH.
    **(d)** The weak acid ionizes less than the strong acid, producing fewer hydronium ions per litre, giving it a higher pH.
    **(e)** The strong base dissociates 100% into hydroxide ions, giving it a lower pOH and therefore a higher pH.
    **(f)** $H_2SO_4$(aq) is a strong acid and so would have a lower pH than $HSO_4^-$(aq).

17. **(a)** pH = –0.36
    **(b)** pH = 3.845
    **(c)** pH = 1.7

## Answers to Applying Concepts Questions

18. Begin with a conductivity test to divide solutions into three categories: strong electrolytes, weak electrolytes, and non-electrolytes. This would identify the $C_{12}H_{22}O_{11}$(aq) since it is the only non-electrolyte. The dilute (0.010 mol/L) NaOH(aq) solution ought to be less conductive than the more concentrated one, but more conductive than the weak base. Next, a litmus paper test can divide the strong conductors into acids, bases, and neutral ionic solutions (HCl(aq), 0.1 mol/L NaOH(aq), and NaCl(aq), respectively). A similar (but more sensitive) test on the weak electrolytes would also divide them into the weak acid, $CH_3COOH$(aq), and the weak base, $Na_3PO_4$(aq).

19. **(a)** bromocresol green: blue, orange IV: yellow, phenolphthalein: colourless
    **(b)** pH ≈ 10

20. The pH of the stream could vary for the following reasons: temperature affects solubility of acid rain carrying solutes, industrial activity varies throughout the year, wind patterns shift the dispersal of pollutants.

21. Procedures should be similar to that of question 18, but could also include vigorous reaction with magnesium or zinc strips.

22. When a saturated solution is at equilibrium a certain number of particles are in the solid state, while a certain number have been dissolved. Over time, individual particles change from being solid to dissolved and back again, but the aggregate numbers of particles in each state

do not change. The drawing should highlight the cyclical nature of this process.

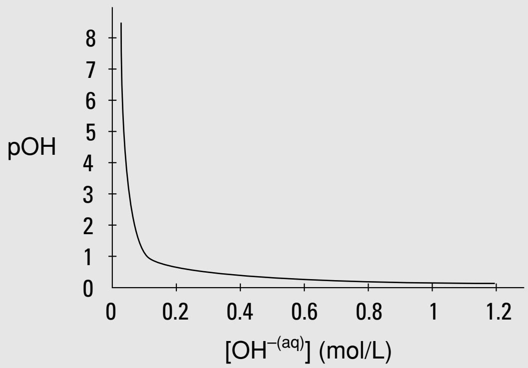
**23.** Student posters should depict appropriate glasswork, WHMIS symbols, and laboratory equipment, and should be easily read from distance of ZM.

**24.** See answer to question 3.

**25.** **(a)** The acetic acid is a weak acid and dissociates so little that it produces only as many hydronium ions per litre as the considerably less concentrated strong acid of HCl(aq).

**(b)** Students will be tempted to suggest that since the acids have the same pH, they are equally "strong." Encourage students to use a different term, such as "potency," leaving "strong" to describe acids that dissociate 100%.

**26.**




**27.** Answers will vary, but students could point out benefits such as the various industrial, commercial, and medical roles acids and bases play, while contrasting this with the role of these chemicals in pollution, acid rain, and the weapons industry.

**28.** **(a)** [KCl(aq)] = 37 g/100 mL

**(b)** [$NH_4$Cl(aq)] = 70 g/100 mL

**(c)** [$NH_4$Cl(aq)] is highest for temperatures of 20°C or higher.

**(d)** [$NH_4$Cl(aq)] is the most affected by temperature.

**29.** Dissolve 91.6 g of ammonium chloride in 200 mL of water. The solution should appear clear. To ensure that all of the ammonium chloride dissolves, the water should be heated to slightly above the desired temperature. Once the solution starts to cool off, a precipitate of ammonium chloride should start to form.

## Answers to Solving Problems Questions

**30.** [$(NH_4)_3PO_4$ (aq)] = $5.03 \times 10^{-2}$ mol/L

[$NH_4^+$] = 1.51 mol/L, [$PO_4^-$] = 0.0503 mol/L

**31.** 0.250 L

**32.** $2.4 \times 10^{-3}$ L

**33.** $1.2 \times 10^2$g $CuSO_4.5H_2O$(s)

**34.** $V_1 = 0.107$ L; $V_{water} = 0.643$ L

**35.** **(a)** pH = 0.388

**(b)** pH = 1.16

**(c)** pH = 5.393

**36.** The hydronium ion concentration has been reduced to half its original concentration so the solution is slightly less acidic. The pH was increased by only 0.3 of a pH unit from 1.60 to 1.90.

**37.** From lowest to highest: HCl(aq), 0.10 mol/L HF(aq), 0.010 mol/L HF(aq), NaCl(aq), $NH_3$(aq), NaOH(aq), $Ba(OH)_2$(aq).

**38.** **(a)** pOH = 2.73

**(b)** pOH = 1.220

**(c)** pOH = 12.301

**39.** $6.4 \times 10^{-4}$ g HBr(g)

**40.** $6.4 \times 10^{-4}$ g $Sr(OH)_2$(s)

## Answers to Making Connections Questions

**41.** Since vitamin A is a fat-soluble vitamin, it needs to be digested in conjunction with fats in order to be absorbed by the body. Diets that are low in fat are at risk of causing vitamin A deficiency.

**42.** Key sources of lead poisoning in children are in older houses where it was often used in paints, radiators, duct covers, and even some pottery. Lead poisoning can increase blood pressure and cause fertility problems, nerve disorders, muscle and joint pain, irritability, and memory or concentration problems. Long-term effects may include lower IQ scores and even death.

**43.** **(a)** The presence of $HCO_3^-$(aq) ions acts as a buffer to maintain a relatively stable pH around 7. The sulfate ion is a weak base and so causes the pH to increase slightly in the Banff Upper Hot Springs, while the presence of sulfurous acid decreases the pH in Miette.

**(b)** Solubility of solids tends to increase with temperature, so the warmer months of summer ought to increase the number of dissolved solids.

**(c)** Despite a pH of below 7, swimmers need not be concerned since the pH of rainwater is around 5.5.

**44.** The main concerns are potential spills, although excess pollution from truck transports, including noise pollution, could also be issues. Generally cities try to route dangerous goods away from heavily populated areas and create noise barriers to help reduce noise pollution.

**45.** Homemade sports drinks are relatively easy to make, being a mixture of sugar, water, and salts containing sodium and potassium. Using fresh orange juice or lemon juice will provide enough sodium and potassium. Generally these drinks provide approximately 14 g of sugar, 100 mg of sodium, and 40 mg of potassium per bottle. Aside from the cost of ingredients, students should consider the time and effort required to make the drinks, as well as packaging in an appropriate travel-proof container.

**46.** In the first example, the HCl(aq) should have the higher electrical conductivity since it is a strong acid and produces more ions. In the second example, water is the primary ion contributor, so both solutions have the same conductivity.

**47.** In order to cause hydrangeas to bloom purple, aluminum sulfate is generally added to reduce the pH of the soil to around 5.2–5.5. In order for them to bloom pink, the pH needs to be raised to around 6.0–6.2 by adding phosphorus-containing fertilizers. A pH of above 6.4 can cause damage to the flowers, as they lose iron.

**48.** Most of these pollutants occur either through industrial refining processes, or through burning of impure hydrocarbons. Better methods of recapture and filtration, along with taller smokestacks to promote a wider, less concentrated dispersal, can help reduce industrial pollution. Alternative fuels and catalysts can also play a large role in reducing pollutants from hydrocarbon combustion.

**49.** **(a)** Drain and oven cleaners are often the leading source of concentrated strong acids and bases used in the home.

**(b)** In most cases, there are simpler, safer alternatives such as the one discussed in the Chapter 6 Connections (student textbook p. 242). Enzymatic cleaners can also used to clean ovens and drains.

**(c)** Enzymatic cleaners typically cost more than traditional cleaners. Advertising and lack of awareness can also be factors that discourage the use of alternatives.

**50**. Scurvy is caused by a vitamin C (ascorbic acid) deficiency. Citrus fruits such as oranges, lemons, and limes are high in vitamin C.

**51.** The people in the helicopters may be liming the lake to reduce the effects of acidification. Calcium carbonate reacts with acids in a neutralization reaction. Adding limestone to a lake can reduce the damaged caused by acid precipitation by neutralizing the lake.