UNIT 4 CHEMISTRY IN THE ENVIRONMENT

4.1 EXTENSION EXERCISE

(Pages 199–200)

CASE STUDY: IS LAKE ERIE SAVED?—EXTRA CHALLENGE

Questions

1. Indicators that a freshwater source is undergoing significant environmental degradation include excess nutrients in the water, eutrophication, decreased levels of oxygen in the water, change in the colour of the water, deaths of organisms such as fish and plants, and rotting algae washing up on shore.
2. (a) Phosphate pollution from fertilizers and wastewater enters the lake from industrial discharges, municipal sewage, and agricultural runoff.
   (b) The construction of additional sewage treatment plants would stop phosphate pollution from fertilizers and wastewater entering the lake from municipal sewage, but would not stop phosphates from industrial discharges or agricultural runoff, which are sources of water pollution that enter the lake without being treated at treatment plants.
3. (a) Zebra mussels are native to the Caspian Sea region of Asia. Scientists believe that mussels arrived in the Great Lakes from ballast water in a transatlantic freighter. The ballast water, taken on in a freshwater European port, was discharged into Lake St. Clair. Since 1988, when zebra mussels were first discovered, they have spread rapidly to all of the Great Lakes. Zebra mussels often attach to boats and boat trailers, and, thus are inadvertently moved from one water body to another by people.
   (b) Zebra mussels are filter feeders and, thus, feed by processing every particle in the water and either eating it, or wrapping it in mucus and spitting it out. One zebra mussel can filter 1 L of water a day. This feeding ability of the zebra mussels, along with their high population densities, clears the water. In Lake Erie, water clarity has increased from 15 cm to 10 m in some areas because of zebra mussels.
   (c) Zebra mussels have different effects on various fish populations. Since zebra mussels clear the water, the resulting brighter light levels in the water cause the growth of aquatic plants that are beneficial to such fish as the northern pike, smallmouth bass, and yellow perch. Many fish, such as lake sturgeon, yellow perch, freshwater drum, black carp, catfish, and sunfish, feed on zebra mussels. The zebra mussels are affecting the food sources of other fish. Whitefish feed on tiny crustaceans, known as Diporeia, whose populations are declining. Diporeia compete with the zebra mussel for algae. Other fish, such as sculpin, smelt, and chub are also being affected by the decline in Diporeia.
4. Many municipalities in Ontario obtain their water from the Great Lakes. In fact, one out of every three Canadians depends on the Great Lakes for water. If serious pollution issues were identified in the Great Lakes, the quality of the drinking water for many municipalities would be affected.

   The Great Lakes contain 25% of the world's fresh water in lakes. Recall from **Table 1** in Section 4.1 of the Student Text that freshwater lakes only contain 0.007% of the world's water (or 0.26% of the total fresh water). Pollution of this important freshwater resource has serious implications for the world.

4.2 EXTENSION EXERCISE

(Page 203)

ACTIVITY: VARIATIONS IN DISSOLVED OXYGEN LEVELS—EXTRA CHALLENGE

Analysis

(a) The dissolved oxygen concentrations measured in December (11.0 ppm) are higher than the levels measured in June (9.8 ppm). The reason for the difference is that more oxygen dissolves in water at a low temperature than in water at a higher temperature.

(b) The dissolved oxygen concentrations are similar in March and November because the average water temperature is the same during both months.

(c) The dissolved oxygen level is inversely related to the water temperature. As the water temperature increases (as in June–September), the average dissolved oxygen is low (9.8–9.2 ppm). When the water temperature is low (as in November–March), the average dissolved oxygen is high (11.0–12.7 ppm).

(d) The average dissolved oxygen level for in August 2001 is 9.2 ppm while the level in August 2002 is 9.6 ppm. The difference is related to the water temperature. The average water temperature in August 2001 is 20°C, while the temperature in August 2002 is 18°C. Since the water temperature in August 2002 is lower than the temperature in August 2001, the level of dissolved oxygen in the water is higher in August 2002.

4.3 EXTENSION EXERCISE

(Pages 204–206)

CASE STUDY: DRINKING WATER MADE SAFE—EXTRA CHALLENGE

Questions

1. Chlorine is added to water to kill microorganisms and to react with most organic molecules present in the water. The destruction of disease-causing organisms is the most important step in the water treatment process. Untreated water may contain microorganisms, which may have adverse effects on human health.
2. Aluminum sulfate, $Al_2(SO_4)_3$, and slaked lime, $Ca(OH)_2$, are added to remove suspended particles from the water. The slaked lime reacts with water to make the solution slightly basic, causing gelatinous aluminum hydroxide to precipitate out of the water. As the precipitate settles to the bottom, it takes suspended solids and bacteria with it. The overall equation is

   $Al_2(SO_4)_{3(s)} + 6\ H_2O_{(l)} \rightarrow 2\ Al(OH)_{3(s)} + 3\ H_2O_{(l)} + 3\ SO_{3(g)}$
3. (a) The soda-lime process (the addition of sodium hydrogen carbonate and calcium hydroxide) removes calcium and magnesium ions from hard water:

   $$Ca(OH)_{2(s)} \rightarrow Ca^{2+}_{(aq)} + 2\ OH^-_{(aq)}$$

   $$2\ OH^-_{(aq)} + 2\ HCO^-_{3(aq)} \rightarrow 2\ CO^{2-}_{3(aq)} + 2\ H_2O_{(l)}$$

   $$CO^{2-}_{3(aq)} + Ca^{2+}_{(aq)} \rightarrow CaCO_{3(s)}$$

   $$CO^{2-}_{3(aq)} + Mg^{2+}_{(aq)} \rightarrow MgCO_{3(s)}$$

   (b) Although it seems odd to add calcium hydroxide to hard water, the chemistry shows that more calcium ions, $Ca^{2+}_{(aq)}$, are taken from the water than are added to the water. The hydroxide ion, $OH^-_{(aq)}$, transforms the hydrogen carbonate ion, $HCO^-_{3(aq)}$, into the carbonate ion, $CO^{2-}_{3(aq)}$. The carbonate ion then precipitates not only the calcium ion from the calcium hydroxide, but also the calcium ions present in the hard water. From the equations in (a), you can see that 1 mol $Ca(OH)_{2(s)}$ produces 2 mol $OH^-_{(aq)}$, which leads to 2 mol $CO^{2-}_{3(aq)}$. Each mole of $CO^{2-}_{3(aq)}$ precipitates 2 mol $Ca^{2+}_{(aq)}$.
4. (a) Concerns about adding fluoride to drinking water include claims that the addition of fluoride can cause serious health problems in some people, and questions about the effectiveness of fluoridation in reducing cavities and preventing tooth decay. Human right activists question whether imposed medication of the public violates the right of individual choice.

   (b) The results of studies investigating the effectiveness of fluoridation are questioned because factors that affect tooth decay, such as diet, personal dental hygiene, dental care, and heredity, are difficult to control.

5. **Table 3** shows a comparison of the water cycle with the water purification process in a municipal water treatment facility.

Table 3 A Comparison of Water Purification Processes

Step	Municipal treatment facility	Water cycle
collection	• water is pumped in from intake pipes deep in surface water or from a well • large objects and debris are removed	• water collects as surface water from precipitation
flocculation	• suspended particles are removed from the water after various chemicals are added	• distillation of water occurs during evaporation
filtration	• water is filtered through sand to remove all remaining fine solids	• sedimentation of solid particles occurs in slow-moving streams and rivers
disinfection	• during disinfection, chlorine is added to kill microorganisms in the water	• rain water contains only traces of impurities, along with gases dissolved from the air
aeration	• oxygen is bubbled through water	• aeration of ground water occurs as it trickles through rocks, allows volatile impurities to be released into the air
softening	• water is softened	• rain water contains no hard water minerals
ammoniation	• ammonia is added to stabilize the chlorine so that it remains dissolved in the treated water	• water is filtered through sand and rocks; after a complex series of reactions, organic materials are converted into harmless substances

4.3 EXTENSION EXERCISE

(Page 207)

EXPLORE AN ISSUE: IS MUNICIPAL WATER SAFE TO DRINK?—EXTRA CHALLENGE

Understanding the Issue

1. The problems that contributed to the Walkerton tragedy are sub-standard wells, insufficient water sampling and analysis, poor state of water treatment equipment, improper qualification procedures for water treatment plant operators, and improper reporting procedures between testing facilities and the government agency responsible for water quality.
2. The purpose of the Ontario Safe Drinking Water Act, 2002 is to protect human health through the control and regulation of drinking water systems and drinking water testing. Some of the standards set out in the Act include: inspections of municipal water systems, announced or unannounced, will be conducted annually; a legal requirement that systems with significant deficiencies be inspected at least once per year; all inspections must be thorough and effective; all water system operators must become certified through examination within two years and be periodically recertified; MOE should inspect municipal water systems regularly; setting drinking water quality standards should be based on a precautionary approach.

TAKE A STAND: INVESTIGATING WATER TREATMENT IN YOUR COMMUNITY

(a) Student answers will vary depending on the community. The Ontario Safe Drinking Water Act, 2002 is available on the Ontario Ministry of the Environment's web site: http://192.75.156.68/DBLaws/Statutes/English/02s32_e.htm

(b) Student answers will vary. Current practices or processes that have been adjusted to meet the new standards and that contribute to safe, clean water will depend on the community.

4.3 EXTENSION EXERCISE

(Pages 208–209)

EXPLORE AN ISSUE: TAP WATER OR BOTTLED WATER?—EXTRA CHALLENGE

Understanding the Issue

1. Student answers may vary. Bottled water is always safer to drink than tap water because there have been no reported incidences of unsafe bottled water in Canada. Bottled water is not safer than tap water since standards are less rigorous for bottled water than they are for tap water. Also, bottled water contributes to pollution in the manufacture and disposal of plastic bottles.
2. The issue of the disposal of empty bottled water containers should be a factor in the decision to use bottled water. Although many communities have recycling programs that accept plastic water bottles, these recycling programs are voluntary. Plastic bottles take up space in landfill sites and are nonbiodegradable. Irresponsible campers and hikers may litter the landscape with plastic bottles. Education programs that promote the reuse and recycling of plastic bottles are very important.
3. (a) In Canada, bottled water is considered to be a food and is regulated under Division 12 of the Food and Drug Regulations, Food and Drugs Act (updated in May 2003).
   (b) Health Canada is developing stricter regulations and guidelines to prevent bacterial and chemical contamination of bottled water. In collaboration with the Canadian Food Inspection Agency, Health Canada is reviewing product standards and labelling. Health Canada is also considering introducing additional sampling plans and microbial limits for bottled water at the source and at various stages in the bottling process.

TAKE A STAND: IS BOTTLED WATER BETTER THAN TAP WATER?

(a) According to the Food Bureau, there are 71 bottlers and 206 wholesalers and distributors nationwide that manufacture bottled water. The Canadian Bottled Water Association (CBWA), which is the trade association for the bottled water industry in Canada, has about 50 member companies that produce and distribute about 85% of the bottled water sold in Canada.

(b) According to the Food and Drugs Act, Food and Drug Regulations, Part B, Division 12 (B.12.001), mineral or spring water must be obtained from an underground source; must not contain any coliform bacteria, as determined by official method; shall not have its composition modified through the use of any chemicals, but may contain added carbon dioxide, fluoride (provided the total fluoride ion content does not exceed 1 ppm); and added ozone. The label must indicate the geographical location of the underground source from which the water is obtained; the total dissolved mineral salt content, expressed in ppm; the total fluoride ion content, expressed in ppm; and any addition of ozone. If carbon dioxide has been added to the water, the label must contain the word “carbonated” (B.12.002 and B.12.003).

No prepackaged water in sealed containers may be sold if it contains any coliform bacteria or more than 100 total aerobic bacteria per millilitre, as determined by official method; naturally occurring fluoride ion in an amount that exceeds its naturally occurring amount; or added fluoride in such an amount that the total amount exceeds 1 ppm (B.12.004).

Bottled water, other that mineral or spring water, shall be labelled “distilled" when the treatment of the water includes vaporization and condensation; "demineralized" when the treatment of the water reduces the mineral content of the water to less than 10 ppm; and "carbonated" when the water contains added carbon dioxide. The label on a sealed container of water, other than mineral or spring water, describes any treatment the water has undergone, with the exception of the addition of an ingredient declared in the list of ingredients; chlorination followed by removal of any chlorine and compounds of chlorine produced in the water; decantation; and filtration (B.12.006 and B.12.009).

The Food and Drug Act and the Food and Drugs Regulations may be found at http://www.hc-sc.gc.ca/food-aliment/friia-raaii/food_drugs-aliments_drogues/act-loi/e_index.html

(c) Student answers may vary. Sample answers are provided.

The Pros and Cons of Drinking Tap Water

Pros	Cons
• tap water is relatively inexpensive • tap water is available, accessible • tap water is safe • tap water can be portable if put into a drinking bottle	• concerns about water safety after Walkerton tragedy • not always available (in remote places) • may contain chemicals, including chlorine, that can affect taste and smell • water is not cold coming out of tap

(d) Student answers may vary. Sample answers are provided.

The Pros and Cons of Drinking Bottled Water

Pros	Cons
• convenient • portable • safe • may be better for you (no chemicals added to spring water) • may be better tasting • may be cold if kept in fridge	• relatively expensive • plastic bottle is often thrown away as waste • requires storage (if bought in bulk) • may not be clear what source of water is

(e) Student answers will vary depending on personal opinion as to whether bottled water is better than tap water.

4.4 EXTENSION EXERCISE

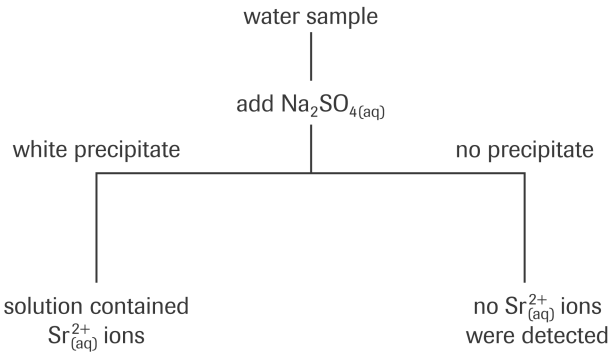
(Pages 213–214)

WATER TESTING FOR IONS—EXTRA CHALLENGE

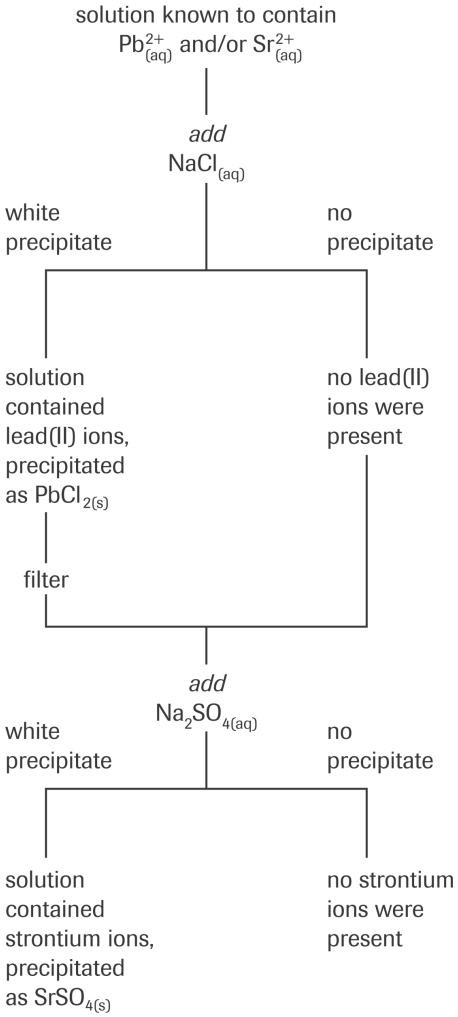
Questions

1. (a) aqueous calcium chloride + aqueous sodium carbonate → solid calcium carbonate + aqueous sodium chloride
   Calcium carbonate will form a precipitate.
   (b) aqueous barium chloride + aqueous potassium sulfate → solid barium sulfate + aqueous potassium chloride
   Barium sulfate will form a precipitate.
   (c) aqueous copper(II) nitrate + aqueous magnesium chloride → aqueous copper(II) chloride + aqueous magnesium nitrate
   No precipitate forms.
   (d) aqueous barium hydroxide + aqueous iron(III) sulfate → solid barium sulfate + solid iron(III) hydroxide
   Both barium sulfate and iron(III) hydroxide form a precipitate.
   (e) aqueous sodium acetate + aqueous calcium chloride → aqueous sodium chloride + aqueous calcium acetate
   No precipitate forms.

2. Below is a flow chart that shows how to test a water sample for strontium ions, $Sr^{2+}_{(aq)}$.



3. Below is a flow chart that shows how to test a water sample for both lead(II) ions and strontium ions.



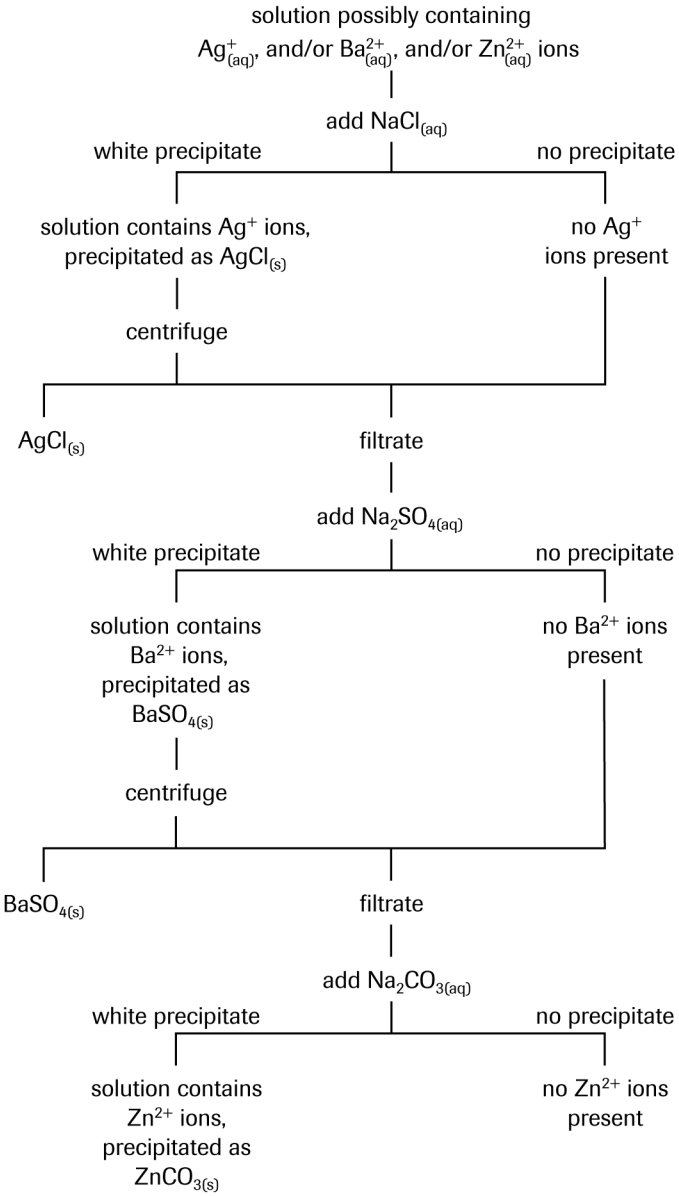
4.4 EXTENSION EXERCISE

(Pages 215–216)

INVESTIGATION: SEQUENTIAL CHEMICAL ANALYSIS IN SOLUTION—EXTRA CHALLENGE

Experimental Design

(a)



Materials

(b) Seye protection
lab apron
protective gloves
sodium chloride solution, $NaCl_{(aq)}$
sodium sulfate solution, $Na_2SO_{4(aq)}$
sodium carbonate solution, $Na_2CO_{3(aq)}$
3 eyedroppers
filter paper
funnel
ring clamp
retort stand
beaker
solution containing unidentified ions

Procedure

1. Obtain a sample solution from the teacher and place it in the test-tube rack.
2. Set up a filtration apparatus.
3. Obtain three test tubes from the teacher, each containing one of the following solutions: sodium chloride, $NaCl_{(aq)}$, sodium sulfate, $Na_2SO_{4(aq)}$, and sodium carbonate, $Na_2CO_{3(aq)}$. Place these test tubes into the test-tube rack.
4. Using an eyedropper, add a few drops of sodium chloride solution to the sample solution. Observe what happens. Record your observations. If a precipitate forms, continue adding sodium chloride solution until no more precipitate forms, then go to step 5. If no precipitate forms, go to step 7.
5. Filter the precipitate using the filtration apparatus.
6. Remove the filter paper with the precipitate from the funnel and put aside. Rinse the funnel and replace the filter paper.
7. Using a clean eyedropper, add a few drops of sodium sulfate solution to the sample solution or filtrate. Observe what happens. Record your observations. If a precipitate forms, continue adding sodium sulfate solution until no more precipitate forms, then go to step 8. If no precipitate forms, go to step 10.
8. Filter the precipitate using the filtration apparatus.
9. Remove the filter paper with the precipitate from the funnel and put aside.
10. Using a clean eyedropper, add a few drops of sodium carbonate solution to the sample solution or filtrate. Observe what happens. Record your observations.

Observations

Student answers will vary. A sample observation table is provided, assuming that all three ions were present in the sample solution.

Ion	Product
Ag^+	white precipitate
Ba^{2+}	white precipitate
Zn^{2+}	white precipitate

Analysis

(c) Student answers will vary depending on the sample they are provided with. In this example, the river-water sample contained all three ions: silver, barium, and zinc.

Evaluation

(d) The Procedure could be improved by making sure that pure solvents are used when making up the solutions, and making sure that the ions in solutions have completely precipitated before filtering the precipitate.

4.5 EXTENSION EXERCISE

(Pages 218–219)

ACTIVITY: HOME WATER PURIFICATION TECHNOLOGIES—EXTRA CHALLENGE

(a) The purification device is very efficient at removing insecticides from the influent, with efficiencies of greater than 99.6%, 98%, and 97% for aldicarb, chlordane, and methoxychlor, respectively.
(b) The purification device is 100% efficient at removing *E. coli*. The MAC level for *E. coli* is zero.
(c) The purification device is 92% efficient at removing iron from water and 94% efficient at removing lead from water. The final level of iron at 0.06 ppm is one-fifteenth the MAC level; the final level of lead at 0.005 ppm is one-half the MAC level.
(d) The trihalomethane level present in the water after treatment is 0.001 ppm, which is lower than the MAC level of 0.10 ppm by a factor of 100.
(e) Water with a hardness level of 66 mg/L would be classified as slightly hard. The device is not that effective at softening water since soft water has a hardness index of less than 50 mg/L.
(f) Student answers will depend on the community in which the student lives. The City of London was in compliance with and satisfied the requirements of the Ontario Drinking Water Standards in 2002. The report for London also listed all the contaminants present in the water and indicated whether they were within the MAC standards.

4.6 EXTENSION EXERCISE

(Pages 220–221)

CASE STUDY: SEVERN SOUND WELCOMES BACK THE WALLEYE—EXTRA CHALLENGE

Questions

1. The goals that might have been included in the RAP for Severn Sound include establishing a healthy environment, protecting the health of citizens, and sustaining communities. The objectives that might have been included in the RAP include:
   - to conserve ecologically important areas
   - to control introduction of exotic species
   - to assess and manage ecosystem health
   - to protect and promote human health
   - to reduce harmful pollutants
   - to advance sustainable use of the Great Lakes Basin

2. (a) Black crappies thrive in a nutrient-dense habitat. Algae that grow because of the high phosphate levels are ideal for black crappies. The fact that the algae use the oxygen and, therefore, leave the water with less soluble oxygen makes it hard for less hardy species to live, cutting out the competition and predators of the black crappie.
   (b) Three factors that contributed to the habitat preferred by the black crappie developing at Severn Sound are high levels of phosphates and nitrates in the water from agricultural runoff, excessive algal growth, and the depletion of oxygen from the water.
   (c) The walleye are returning to the Sound in response to the cleanup of the water. The main cause of the decline in the walleye population was related to excessive algal growth as a result of the high phosphate and nitrate levels in the water. Once the measures to decrease the phosphate levels were put into place, the algae declined. These measures included upgrading sewage treatment facilities, storm water treatment, shoreline cleanup and management, techniques to ease agricultural runoff, and public involvement and education. The Sound's algal population is now under control and the black crappie populations are declining, allowing the walleye to thrive.
3. The success of the restoration of Severn Sound rests with a group that was formed as part of the RAP, the Severn Sound Environmental Association (SSEA). The group's responsibilities include overseeing the implementation of the RAP, and monitoring the watershed to indicate any possible new problems. The group will have a say in any new projects and developments that may impact upon the Sound, and will continue to keep the public informed.

4.6 EXTENSION EXERCISE

(Page 222)

ACTIVITY: IDENTIFY AN AOC AND PROPOSE A RAP—EXTRA CHALLENGE

(a) Student answers will vary depending on the AOC selected for study. Detailed information on each of the 42 Great Lakes Remedial Action Plans may be found at http://www.on.ec.gc.ca/water/greatlakes/raps/.

Sample AOC: Metro Toronto

Toronto is located on the northeastern shore of Lake Ontario. The bay serves as a catchment area for many rivers and watersheds. As Canada's most populated city, Toronto suffers from urbanization. It was designated as an Area of Concern because of the effects on the water from sewer runoff, sewage treatment plants, storm sewers, and agricultural runoff. The bay and shoreline are contaminated with heavy metals, bacteria, and organic waste. **Table 2** illustrates the impact this contamination has had on the area.

Table 2 Metro Toronto Status

Use	Status
fish and wildlife consumption	impaired
degradation of fish and wildlife populations	impaired
deformities (tumours) of fish	under assessment
beach access (closures)	impaired
degradation of aesthetics	impaired
loss of fish and wildlife habitat	impaired

(b) Student answers will vary depending on the AOC selected for study. A RAP that meets the goals and objectives of the Great Lakes Action Plan for Metro Toronto may involve developing new sewage treatment techniques, transforming areas into wetlands, cleaning up the heavy metals, bacteria, and organic waste from the water and the shoreline areas, improving public access to waterfront areas, restoring or creating fish and wildlife habitat in the area, and providing technical aid to farms to alleviate agricultural runoff.

(c) Student answers will vary depending on the various options proposed in the RAP. Students could consider their options from the following perspectives:

- the economics of the option, including initial capital and ongoing operational costs
- public reception to the proposal, and eventual use of the restored area
- desired environmental result

Table 3 presents sample answers for the proposed RAP for Metro Toronto.

Table 3 Advantages and Disadvantages of the RAP for Metro Toronto

Option	Advantages	Disadvantages
• develop new sewage treatment techniques	• will create healthy environment • will protect health of public	• may be very costly
• transform areas into wetlands	• will conserve ecologically important areas • can assess and manage ecosystem health	• may not be acceptable to public • land is at a premium, especially for developers • wetlands may be seen as breeding grounds for mosquitoes • costs involved may be high
• clean up the heavy metals, bacteria, and organic waste from the water and the shoreline areas	• will establish a healthy environment and protect the health of citizens • will reduce harmful pollutants • will sustain communities	• costs involved may be too high • cleanup may take time • cleanup may not be possible
• improve public access to waterfront areas	• will advance sustainable use of the Great Lakes Basin	• costs involved • land use
• restore or create fish and wildlife habitat in the area	• will control introduction of exotic species • can assess and manage ecosystem health	• costs involved may be too high • public perception
• provide technical aid to farmers to alleviate agricultural runoff	• will control introduction of exotic species • can assess and manage ecosystem health	• costs involved • perception of farmers • perception of public

(d) Present research to the class.

(e) A report intended to enlist the support of the appropriate government agencies and communities in the implementation of the plan will depend on the AOC selected for study and the RAP developed by the students.

4.1–4.6 SELF QUIZ

(Page 223)

Modified True or False

1. False; Water is very good for dissolving ionic compounds.
2. False; Parts per million is a concentration unit used to express very small concentrations of ions in solution.
3. False; Drinking water contains dissolved chlorine ions to kill bacteria.
4. True
5. False; Boiling water is not an effective way to soften water.
6. False; Warm lake water will contain less dissolved oxygen than cold lake water.

Multiple Choice

7. (d)
8. (c)
9. (d)
10. (d)

11. (d)
12. (a)
13. (b)

Completion

14. melting point, boiling point, density
15. 100 ppm
16. phosphate, nitrate
17. precipitate
18. ultraviolet
19. distillation

4.7 EXTENSION EXERCISE

(Page 224)

WRITING EQUATIONS FOR ACID AND BASE SOLUTIONS, AND DETERMINING THE PH AND CONCENTRATION—ADDITIONAL PRACTICE

1. (a) $LiCl_{(s)} \rightarrow Li^+_{(aq)} + Cl^-_{(aq)}$ (dissociation)

   (b) $KOH_{(aq)} \rightarrow K^+_{(aq)} + OH^-_{(aq)}$ (dissociation)

   (c) $HI_{(aq)} \rightarrow H^+_{(aq)} + I^-_{(aq)}$ (ionization)

   (d) $NaI_{(aq)} \rightarrow Na^+_{(aq)} + I^-_{(aq)}$ (dissociation)

   (e) $H_2SO_{4(aq)} \rightarrow 2\ H^+_{(aq)} + SO^{2-}_{4(aq)}$ (ionization)

2. (a) $HBr_{(aq)} \rightarrow H^+_{(aq)} + Br^-_{(aq)}$
   1 mol $HBr_{(aq)}$ dissociates to produce 1 mol $H^+_{(aq)}$ ions and 1 mol $Br^-_{(aq)}$ ions.
   Therefore, 2.0-mol/L $HBr_{(aq)}$ dissociates to produce 2.0-mol/L $H^+_{(aq)}$ ions and 2.0-mol/L $Br^-_{(aq)}$ ions.

   (b) $LiOH_{(s)} \rightarrow Li^+_{(aq)} + OH^-_{(aq)}$
   1 mol $LiOH_{(aq)}$ dissociates to produce 1 mol $Li^+_{(aq)}$ ions and 1 mol $OH^-_{(aq)}$ ions.
   Therefore, 1.0-mol/L $LiOH_{(aq)}$ dissociates to produce 1.0-mol/L $Li^+_{(aq)}$ ions and 1.0-mol/L $OH^-_{(aq)}$ ions

   (c) $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$
   1 mol $HCl_{(aq)}$ ionizes to produce 1 mol $H^+_{(aq)}$ ions and 1 mol $Cl^-_{(aq)}$ ions.
   Therefore, 2.5-mol/L $HCl_{(aq)}$ ionizes to produce 2.5-mol/L $H^+_{(aq)}$ ions and 2.5-mol/L $Cl^-_{(aq)}$ ions.

   (d) $KOH_{(aq)} \rightarrow K^+_{(aq)} + OH^-_{(aq)}$
   1 mol $KOH_{(aq)}$ dissociates to produce 1 mol $K^+_{(aq)}$ ions and 1 mol $OH^-_{(aq)}$ ions.
   Therefore, 0.50-mol/L $KOH_{(aq)}$ dissociates to produce 0.50-mol/L $K^+_{(aq)}$ ions and 0.5-mol/L $OH^-_{(aq)}$ ions.

   (e) $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$
   1 mol $NaOH_{(aq)}$ dissociates to produce 1 mol $Na^+_{(aq)}$ ions and 1 mol $OH^-_{(aq)}$ ions.
   Therefore, 10-mol/L $NaOH_{(aq)}$ dissociates to produce 10-mol/L $Na^+_{(aq)}$ ions and 10-mol/L $OH^-_{(aq)}$ ions.

3. (a) pH = 2
   (b) pH = 12
   (c) pH = 3
   (d) pH = 5
   (e) pH = 11

4. $[H^+] = 10^{-pH}$
   (a) $[H^+] = 10^{-8}$ mol/L
   (b) $[H^+] = 10^{-3}$ mol/L
   (c) $[H^+] = 10^{-12}$ mol/L
   (d) $[H^+] = 10^{-4}$ mol/L
   (e) $[H^+] = 10^{-5}$ mol/L

4.7 EXTENSION EXERCISE

(Page 225)

INVESTIGATION: THE ARRHENIUS THEORY—EXTRA CHALLENGE

Prediction

(a) All salts will dissolve in water to form neutral solutions.

Observations

(b) **Table 2** Type of Solution

Name of compound	Chemical formula	Nature of solution (acidic, basic, or neutral)
sodium chloride	$NaCl_{(s)}$	neutral
potassium chloride	$KCl_{(s)}$	neutral
sodium sulfate	$Na_2SO_{4(s)}$	neutral
ammonium chloride	$NH_4Cl_{(s)}$	acidic
sodium acetate	$NaC_2H_3O_{2(s)}$	basic

Analysis

(c) All salts are not neutral, as was predicted by Arrhenius. Some salts form acidic solutions, some form basic solutions, and some form neutral solutions.

(d) Although some of the salts produced solutions that were acidic or basic in nature, this does not necessarily mean that Arrhenius' theory of acids and bases is wrong. It does indicate, however, that Arrhenius' theory is limited in its ability to explain the acid/base properties of salts in aqueous solution. Arrhenius' theory may explain the behaviour of acids and bases in aqueous solutions, but not the behaviour of salts. A different theory, or a modification of Arrhenius' theory, is needed to explain the acid/base behaviour of salts in solution.

Evaluation

(e) Sources of error in this Investigation include contaminated salt solutions and difficulty matching the colour of the universal indicator paper with the standard colours given on the indicator package label. Mixing the salt solution with highly purified water and using high-quality salts could reduce errors. Using a pH meter to determine the pH of the salt solutions would also help reduce error.

(f) Most students will find that their predictions do not agree with their observations. Some salt solutions are acidic and some are basic.

Synthesis

(g) Predictions and observations for sodium dihydrogen phosphate and ammonium sulfate dissolving in water are shown in **Table 3**.

Table 3 Observations and Predictions

Salt	Prediction	Observations
sodium dihydrogen phosphate, $NaH_2PO_{4(s)}$	will form a basic solution	forms a basic solution
ammonium sulfate, $(NH_4)_2SO_{4(s)}$	will form an acidic solution	forms an acidic solution

4.8 EXTENSION EXERCISE

(Pages 228–230)

ACTIVITY: HOME HAZARDOUS PRODUCT SURVEY—EXTRA CHALLENGE

Part 1: Hazardous Household Products Survey

[Survey results will vary.] A sample survey is given in **Table 1**.

Table 1 Household Hazardous Products Data Sheet

Product	Number of items	Stored safely?(yes/no)
Paints and solvents		
furniture polish	0	
spot remover	1	yes
nail polish and nail polish remover	4	no
paint	6	yes
varnish	2	yes
paint thinner	0	
furniture stripper	1	yes
glue	6	no
Total number of paints and solvents	**20**	
Household cleaners		
drain cleaner	1	yes
oven cleaner	2	yes
floor cleaner	3	yes
disinfectant	5	no
ammonia	1	yes
scouring powder	1	yes
bleach	1	no
laundry detergent	2	yes
Total number of household cleaners	**16**	
Pesticides		
weed killer	2	yes
insecticide	4	yes
bug repellent	2	yes
flea spray or flea collar	0	
other		
Total number of pesticides	**8**	
Automotive products		
windshield washer fluid	2	yes
motor oil	0	
gasoline	1	yes

Product	Number of items	Stored safely?(yes/no)
kerosene	0	
antifreeze	1	yes
Total number of automotive products	**4**	
Other products		
air freshener	3	yes
aerosol spray	2	yes
household battery	6	no
button battery	2	no
pool chemical	4	yes
other		
Total number of other products	**17**	
Total number of hazardous products in your home	**65**	

Part 2: Finding Safer, Effective Alternatives

(a) Student answers will vary depending on the hazardous household product chosen for study. One possible product is Easy-Off® Heavy Duty oven cleaner. This product requires careful handling because of the highly corrosive nature of its components (sodium hydroxide). Gloves should be worn at all times and skin should be rinsed with water for at least 10 min if it comes into contact with the cleaner. If the cleaner is swallowed or it gets into eyes, a physician should be called immediately. The aerosol can poses an explosion risk, particularly if punctured or heated. The can should be kept away from all heat sources. Since the cleaner is used to clean an oven, used product is most likely washed down the drain into the sewer or septic system. The label encourages consumers to dispose of the empty aerosol can at an appropriate disposal or recycling facility.

(b) Safer alternatives will depend on the hazardous household product chosen. Examples of homemade oven cleaners include a 1:1 mixture of baking soda and warm water. The paste is applied to the oven and left for two hours, or overnight for tougher stains. The oven is then scrubbed clean. Another homemade cleaner is a mixture of 30 ml liquid soap and 30 ml borax in a spray bottle full of warm water. The mixture is sprayed on the oven and left for 20 min. The oven is then scrubbed clean.

(c) Risk–benefit analyses of both the alternative product and the hazardous product will vary depending on the product chosen. A risk–benefit analysis of the homemade oven cleaner made from baking soda and warm water is given below. The risk–benefit analysis of the hazardous oven cleaner is also given below.

Table 2 Risk–Benefit Analysis of Using Alternative Oven Cleaner Made from Baking Soda and Water

Risks				Benefits			
Possible result	**Cost of result (scale of 1 to 5)**	**Probability of result occurring (%)**	**Cost × probability**	**Possible result**	**Benefit of result (scale of 1 to 5)**	**Probability of result occurring (%)**	**Benefit × probability**
requires more effort to use	4	80%	320	cleans the oven effectively	5	95%	475
ingredients may not be on hand	3	60%	180	contains no harmful chemicals, thus no damage to environment	5	100%	500
may not work as well as commercial cleaner	3	50%	150	very inexpensive	5	100%	500
Total risk value			**650**	**Total benefit value**			**1475**

Table 3 Risk–Benefit Analysis of Using Hazardous Oven Cleaner

Risks				Benefits			
Possible result	**Cost of result (scale of 1 to 5)**	**Probability of result occurring (%)**	**Cost × probability**	**Possible result**	**Benefit of result (scale of 1 to 5)**	**Probability of result occurring (%)**	**Benefit × probability**
contains hazardous chemicals that pose risks to the environment	5	100%	500	very effective	5	100%	500
fairly expensive	4	75%	300	requires no mixing or preparation of ingredients	3	80%	240
Total risk value			**800**	Total benefit value			**740**

(d) Student answers will depend on the products chosen by the students. For the oven cleaner, it is clear from the risk–benefit analyses that the alternative oven cleaner provides many more benefits than the commercial oven cleaner.

4.9 ALTERNATIVE EXERCISE

(Pages 234–235)

INVESTIGATION: IS DILUTION THE SOLUTION TO POLLUTION?

Prediction

(a) The colour eventually disappears as a solution is diluted.
(b) The taste (flavour) disappears as a solution is diluted.

Observations

(c) **Table 1** Observations for the Sweetened Drink

Cup	1	2	3	4	5	6
Colour	+++++*	++++	++	+½	+½	+#
Taste (sweetness)	+++++	++++	+++	++	+	none

* indicates the most intense colour or highest sweetness
\# indicates the least intense colour or lowest sweetness

(d) **Table 2** Observations for the Unsweetened Drink

Cup	1	2	3	4	5	6
Colour	+++++*	++++	++	++	+½	+#
Taste	none	none	none	none	none	none

* indicates the most intense colour or taste
\# indicates the least intense colour or taste

Analysis

(e) Colour faded gradually for both the sweetened and the unsweetened drinks. Taste decreased gradually for the sweetened drink, but there was no change for the unsweetened drink.
(f) The colour faded from cup 2 to cup 6 for both the sweetened drink and the unsweetened drink. The taste decreased from cup 2 to cup 6 for the sweetened drink, but the taste of the unsweetened drink remained the same.
(g) Colour and flavour disappear from a solution as it is diluted.

Evaluation

(h) Sources of error in this Investigation include volume measurements, which were estimations since we relied on pen marks on the glasses to measure volume. Taste is a subjective, qualitative measurement of sweetness. An electronic instrument that measures the concentration of sugar molecules in solution would help to reduce error in the "measurement" of sweetness. A spectrophotometer may be used to measure changes in colour more accurately.
(i) Predictions were very accurate and agreed with observations.

Synthesis

(j) The contaminated water would have to be diluted approximately two more times for the colour to disappear. Taste disappeared after the fifth dilution (i.e., between cups 5 and 6).
(k) Dilution is a good solution to pollution if the pollutant does not accumulate in the bodies of living organisms. Dilution disperses pollutants and decreases their concentrations, but it does not remove pollutants from the water.
(l) Yes, pollution always remains in the water and becomes some other substance. Dilution only reduces the concentration of the pollutant in the environment.

4.10 EXTENSION EXERCISE

(Pages 240–241)

ACTIVITY: STANDARDIZATION OF A STOCK ACID—EXTRA CHALLENGE

Observations

The level of hydrochloric acid solution in the burette for each trial is recorded in the following table. The volume of concentrated hydrochloric acid to prepare 500 mL of 0.10-mol/L solution is 4.2 mL.

Table 1 Volume of $HCl_{(aq)}$ to Titrate 10.0 mL of 0.050-mol/L $Na_2CO3_{(aq)}$

Trial	1	2	3	4	Average
Final burette reading (mL)	12.02 mL	23.45 mL	34.68 mL	45.95 mL	
Initial burette reading (mL)	0.10 mL	12.05 mL	23.40 mL	34.60 mL	
Volume of $HCl_{(aq)}$ added (mL)	11.92 mL	11.40 mL	11.28 mL	11.35 mL	11.34 mL*

* Average of Trials 2, 3, and 4

Analysis

(a) The volume of concentrated hydrochloric acid required to prepare the dilute acid used in the titration is:

$$v_i c_i = v_f c_f$$

$$v_i \times 12\,\text{mol/L} = 500\,\text{mL} \times 0.10\,\text{mol/L}$$

$$v_i = 4.2\,\text{mL}$$

Thus, the volume of concentrated hydrochloric acid is 4.2 mol/L.

(b) The results from Trials 2, 3, and 4, are used to determine the average volume of hydrochloric acid used in this titration.

$$v_{ave} = \frac{11.40\,\text{mL} + 11.28\,\text{mL} + 11.35\,\text{mL}}{3}$$

$$v_{ave} = 11.34\,\text{mL}$$

Thus, the average volume of hydrochloric acid is 11.34 mL.

(c) To determine the concentration of the hydrochloric acid:

$$n_{Na_2CO_3} = vc$$

$$= 0.0100\,\text{L} \times 0.050\,\text{mol/L}$$

$$n_{Na_2CO_3} = 0.00050\,\text{mol}$$

$$n_{HCl} = 0.00050\,\text{mol}\,Na_2CO_3 \times \frac{2\,\text{mol}\,HCl}{1\,\text{mol}\,Na_2CO_3}$$

$$n_{HCl} = 0.0010\,\text{mol}$$

$$c_{HCl} = \frac{n}{v}$$

$$= \frac{0.0010\,\text{mol}}{0.01134\,\text{L}}$$

$$c_{HCl} = 0.088\,\text{mol/L}$$

The concentration of the hydrochloric acid is 0.088 mol/L.

d)
$$\%\ \text{difference} = \frac{|0.088\,\text{mol/L} - 0.10\,\text{mol/L}|}{0.10\,\text{mol/L}} \times 100$$

$$\%\ \text{difference} = 12\%$$

This difference is significant. Hydrogen chloride gas easily escapes from the stock solution and it is quite likely that the original solution is less concentrated than 12 mol/L.

Evaluation

(e) Sources of error include measurement errors using the volumetric pipette, the delivery pipette, and the burette, uncertainty in the concentration of the sodium carbonate; and judgment of final colour change, which was not very distinct. These sources of error could be improved by using a more precise volumetric pipette, using a more precise concentration of sodium carbonate, and using a better indicator that shows a clearer change at the endpoint.

4.11 EXTENSION EXERCISE

(Page 242)

BALANCING EQUATIONS AND SOLVING TITRATION PROBLEMS—ADDITIONAL PRACTICE

1. (a) $HNO_{3(aq)} + KOH_{(aq)} \rightarrow KNO_{3(aq)} + H_2O_{(l)}$
   (b) $2\ HCl_{(aq)} + Ca(OH)_{2(aq)} \rightarrow CaCl_{2(aq)} + 2\ H_2O_{(l)}$
2. (a) 1 mol $KOH_{(aq)}$ is required to neutralize 1 mol $HNO_{3(aq)}$.
   (b) 0.5 mol $Ca(OH)_{2(aq)}$ is required to neutralize 1 mol $HCl_{(aq)}$.
3. $HNO_{3(aq)} + NaOH_{(aq)} \rightarrow NaNO_{3(aq)} + H_2O_{(l)}$

$$v_{HNO_3} = 250\ mL = 0.250\ L$$

$$v_{NaOH} = 9.30\ mL = 0.00930\ L$$

$$c_{NaOH} = 0.001\ mol/L$$

$$n_{NaOH} = v_{NaOH} c_{NaOH}$$

$$= 0.00930\ L \times 0.001\ mol/L$$

$$n_{NaOH} = 0.000\ 009\ 30\ mol$$

$$n_{HNO_3} = 0.000\ 009\ 30\ mol\ NaOH \times \frac{1\ mol\ HNO_3}{1\ mol\ NaOH}$$

$$n_{HNO_3} = 0.000\ 009\ 30 mol$$

$$c_{HNO_3} = \frac{n_{HNO_3}}{v_{HNO_3}}$$

$$= \frac{0.000\ 009\ 30\ mol}{0.250\ L}$$

$$c_{HNO_3} = 0.000\ 037\ 0\ mol/L$$

The concentration of nitric acid in the pond water sample is 0.000 037 0 mol/L.

4.11 EXTENSION EXERCISE

(Pages 243–244)

ACTIVITY: DETERMINING THE CONCENTRATION OF A BASE—EXTRA CHALLENGE

Observations

Table 2 Titration of $KHP_{(aq)}$ with $NaOH_{(aq)}$

Trial	1	2	3	Average
Mass of KHP (g)	0.342	0.355	0.360	0.352
Final burette reading (mL)	19.05	18.75	19.30	
Initial burette reading (mL)	1.70	0.55	0.09	
Volume of $NaOH_{(aq)}$ added (mL)	17.35	18.20	18.40	17.98

Analysis

(a) $$v_{ave} = \frac{17.35\ mL + 18.20\ mL + 18.40\ mL}{3}$$

$$v_{ave} = 17.98\ mL$$

The average volume of sodium hydroxide solution required to neutralize the KHP solution is 17.98 mL.

(b) (i) $KHC_8H_4O_{4(s)} \rightarrow K^+_{(aq)} + HC_8H_4O^-_{4(aq)}$

(ii) $HC_8H_4O^-_{4(aq)} \rightarrow H^+_{(aq)} + C_8H_4O^{2-}_{4(aq)}$

(c) $KHC_8H_4O_{4(aq)} + NaOH_{(aq)} \rightarrow KNaC_8H_4O_{4(aq)} + H_2O_{(l)}$

(d) To determine the concentration of sodium hydroxide:

$$n_{KHP} = \frac{m}{M}$$

$$= \frac{0.352\ g\ KHP}{204.23\ g/mol}$$

$$n_{KHP} = 0.001\,72\ mol\ KHP$$

$$n_{NaOH} = 0.001\,72\ mol\ KHP \times \frac{1\ mol\ NaOH}{1\ mol\ KHP}$$

$$n_{NaOH} = 0.001\,72\ mol\ NaOH$$

$$c_{NaOH} = \frac{n}{v}$$

$$= \frac{0.001\,72\ mol}{0.017\ 98\ L}$$

$$c_{NaOH} = 0.0957\ mol/L$$

The concentration of sodium hydroxide solution is 0.0957 mol/L.

(e) The experimental answer is slightly lower than the concentration listed on the label, by 4.3%.

$$\%\ difference = \frac{|0.0957\ mol/L - 0.10\ mol/L|}{0.10\ mol/L} \times 100$$

$$\%\ difference = 4.3\%$$

(f) A primary standard can be used in a titration procedure to accurately determine the concentration of a basic solution, assuming that the primary standard is pure and the proper procedures have been followed.

Evaluation

(g) There are several sources of uncertainty or error: possible uncertainty in the purity of the KHP; measurement uncertainties using the balance and burette; and judgment of the final pink colour in the relatively large final volume of the mixture.

A possible improvement is to prepare a standard solution of KHP and pipette samples of this solution for the titration. This method will likely be more accurate and is more efficient. Alternatively, a more precise balance (e.g., a milligram balance) would reduce the experimental error. Finally, KHP could be used to titrate other basic solutions, or a different primary standard could be used to titrate the same sodium hydroxide solution.

Synthesis

(h) One of the properties of a base is that its solutions feel slippery. Therefore, the cause is likely that some sodium hydroxide solution has been spilled. You should immediately wash your hands with lots of cold water.

(i) Phenolphthalein was used as an indicator because it changes colour at the end of the reaction between sodium hydroxide solution and KHP.

(j) No, this approach will not change the accuracy of the results, which are determined by the careful, drop-by-drop addition of titrant near the endpoint, and the repetition of this procedure to obtain three consistent results. This approach will, however, improve the efficiency of the titration process.

4.11 EXTENSION EXERCISE

(Pages 245–246)

ACTIVITY: DETERMINING THE CONCENTRATION OF AN ACID—EXTRA CHALLENGE

Observations

The concentration of sodium hydroxide solution used was 0.0957 mol/L (determined in Extension Exercise 4.11: Activity: Determining the Concentration of a Base—Extra Challenge).

Table 3 Titration of $HCl_{(aq)}$ with $NaOH_{(aq)}$

Trial	1	2	3	Average
Final burette reading (mL)	21.03	42.25	22.55	
Initial burette reading (mL)	0.13	21.03	1.20	
Volume of $NaOH_{(aq)}$ added (mL)	20.90	21.22	21.35	21.16

Analysis

(a) $NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

(b) To determine the concentration of the hydrochloric acid solution:

$$n_{NaOH} = v_{NaOH} c_{NaOH}$$

$$= 0.02116\ \text{L NaOH} \times 0.0957\ \text{mol/L NaOH}$$

$$n_{NaOH} = 0.00202\ \text{mol}$$

$$n_{HCl} = 0.00202\ \text{mol NaOH} \times \frac{1\ \text{mol HCl}}{1\ \text{mol NaOH}}$$

$$n_{HCl} = 0.00202\ \text{mol}$$

$$c_{HCl} = \frac{n_{HCl}}{v_{HCl}}$$

$$= \frac{0.00202\ \text{mol}}{0.0200\ \text{L}}$$

$$c_{HCl} = 0.101\ \text{mol/L}$$

(c) The experimental answer is 1.0% less than the concentration on the label.

$$\%\ \text{difference} = \frac{|0.101\ \text{mol/L} - 0.10\ \text{mol/L}|}{0.10\ \text{mol/L}} \times 100$$

$$\%\ \text{difference} = 1.0\%$$

(d) A sodium hydroxide solution of known concentration can be used as a standard solution in a titration procedure to determine the unknown concentration of an acidic solution.

Evaluation

(e) There are two sources of uncertainty or error: measurement uncertainties using the pipette and burette, and judgment of the final green colour. Adding distilled water to the flask is likely not necessary and the larger volume makes the colour change more difficult to see.

Synthesis

(f) One of the properties of a base is that its solutions feel slippery. Therefore, the cause is likely some sodium hydroxide solution that has been spilled. You should immediately wash your hands with lots of cold water.

(g) Bromothymol blue was used as an indicator because it changes colour at the end of the reaction between sodium hydroxide and hydrochloric acid.

4.12 EXTENSION EXERCISE

(Pages 248–250)

INVESTIGATION: A TECHNOLOGICAL APPROACH TO DETERMINING THE CONCENTRATION OF AN ACID SOLUTION—EXTRA CHALLENGE

Prediction

(a) The concentration of an acid solution determined in a titration using an indicator and a standard base solution would be less accurate than the concentration determined by titration with a graphing calculator and a pH probe.

Part 1: Standard Titration of Hydrochloric Acid with Sodium Hydroxide Solution

Observations

The actual concentration of standard sodium hydroxide used was 0.0957 mol/L.

Table 2 Titration of an Unknown Concentration of $HCl_{(aq)}$ with Standard $NaOH_{(aq)}$

Trial	1	2	3	Average
Final burette reading (mL)	22.05	43.45	22.35	
Initial burette reading (mL)	0.10	22.05	1.20	
Volume of $NaOH_{(aq)}$ added (mL)	21.95	21.40	21.15	21.50

Analysis

(b) The concentration of the hydrochloric acid as determined by titration with an acid–base indicator and a standard base solution is determined using the following calculations:

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$$v_{HCl} = 25.0\ mL = 0.025\ L$$

$$v_{NaOH} = 21.50\ mL = 0.02150\ L$$

$$c_{NaOH} = 0.0957\ mol/L$$

$$n_{NaOH} = v_{NaOH} c_{NaOH}$$

$$= 0.021\ 50\ \text{L NaOH} \times 0.0957\ \text{mol/L NaOH}$$

$$n_{NaOH} = 0.002\ 06\ \text{mol}$$

$$n_{HCl} = 0.002\ 06\ \text{mol NaOH} \times \frac{1\ \text{mol HCl}}{1\ \text{mol NaOH}}$$

$$n_{HCl} = 0.002\ 06\ \text{mol}$$

$$c_{HCl} = \frac{n_{HCl}}{v_{HCl}}$$

$$= \frac{0.002\ 06\ \text{mol}}{0.0250\ \text{L}}$$

$$c_{HCl} = 0.0824\ \text{mol/L}$$

The concentration of hydrochloric acid is 0.0824 mol/L.

Evaluation

(c) There are two sources of uncertainty or error: measurement uncertainties using the pipette and burette, and judgment of the final pink colour. Adding distilled water to the flask is likely not necessary and the larger volume makes the colour change more difficult to see.

Part 2: Technological Titration of Hydrochloric Acid with Sodium Hydroxide Solution

Observations

Trial	1
Final burette reading (mL)	21.90
Initial burette reading (mL)	0.040
Volume of $NaOH_{(aq)}$ added (mL)	21.86

According to the pH–Volume graph, the x value that appears at the steepest part of the graph is 15.9.

$$n_{NaOH} = v_{NaOH} c_{NaOH}$$
$$= 0.021\,86 \text{ L NaOH} \times 0.0957 \text{ mol/L NaOH}$$
$$= 0.002\,092 \text{ mol NaOH}$$
$$n_{HCl} = 0.002\,092 \text{ mol NaOH} \times \frac{1 \text{ mol HCl}}{1 \text{ mol NaOH}}$$
$$n_{HCl} = 0.002\,092 \text{ mol HCl}$$
$$c_{HCl} = \frac{n_{HCl}}{v_{HCl}}$$
$$= \frac{0.002\,092 \text{ mol HCl}}{0.021\,86 \text{ L}}$$
$$c_{HCl} = 0.09570 \text{ mol/L}$$

The volume of $NaOH_{(aq)}$ added that corresponds to this point (the greatest change in pH) is 21.86 mL.

$$v_{HCl} = 25.0 \text{ mL} = 0.025 \text{ L}$$
$$v_{NaOH} = 21.86 \text{ mL} = 0.021\,86 \text{ L}$$
$$c_{NaOH} = 0.0957 \text{ mol/L}$$

Analysis

(d) The concentration of hydrochloric acid as determined by titration with a graphing calculator, a pH probe, and a standard base solution is 0.095 70 mol/L.

(e) In this sample, the concentration of hydrochloric acid is more accurate than the concentration found using the standard titration method. Individual results will vary, however.

Evaluation

(f) Sources of uncertainty or error in this part of the investigation include accuracy in measuring with the pipette or burette. Also, the standard titration was performed three times, while the titration using the pH probe was performed only once. Therefore, the results of the technological titration could be considered suspect. To reduce uncertainty, the titration using the pH probe could be performed a couple of times.

(g) Student answers will vary depending on the results of their titrations.

(h) While both methods require accurate measuring with the pipette and burette, the technological titration allows students to see the curve as they titrate, which helps them to determine the endpoint more accurately, possibly allowing for a more accurate calculation of the concentration of the acid.

Synthesis

(i) The pH probe does not require the endpoint to be signaled by a change in the colour of an indicator, but by a sharp rise in the pH of the solution, which is detected by the instrument and displayed on a digital readout. Thus, the pH probe can titrate a coloured or colourless solution, while a standard titration (with an indicator) can only be used to titrate a colourless solution.

4.13 EXTENSION EXERCISE

(Page 252)

CASE STUDY: ACID RAIN AND HUMAN HEALTH—EXTRA CHALLENGE

Questions

1. Respiratory problems that are attributed to the inhalation of acid droplets include coughing, congestion, restriction of the airways, and increased mucus production in the lungs.
2. Symptoms that differentiated Ontario children from their Manitoba counterparts in the Health Canada study include more chest colds, coughs, allergies, stuffy noses, and lower lung function.
3. Student answers may vary. The differences in respiratory ailments between the children from the two cities are not significant enough to be linked to the differences in air quality. The study reported only a 2% difference for lung function. Although all of the symptoms are elevated differences, and, thus, may seem to be statistically significant, we are not given any other data that may account for the differences, such as other environmental factors or nutrition.
4. Additional information that would be required may include data for other symptoms, and any other environmental and health differences—are the differences related just to acid rain, or are there other factors involved?

4.13 EXTENSION EXERCISE

(Page 253)

CASE STUDY: IS THE QUEBEC SUGAR MAPLE A VICTIM OF ACID RAIN?—EXTRA CHALLENGE

Questions

1. Effects that acid deposition has on soil include removing calcium and magnesium compounds from the soil, making the soil acidic, and increasing the amount of aluminum dissolved in the soil. The soil becomes acidic because acid deposition removes calcium and magnesium compounds, which have a neutralizing effect on the soil.
2. Calcium and magnesium compounds have a neutralizing effect on the soil. When calcium and magnesium compounds are removed from the soil, the soil becomes more acidic. During neutralization, these compounds become new substances, and are no longer able to neutralize more acid rain. The removal of calcium and magnesium compounds from the soil also affects trees, which need these essential nutrients to grow.
3. (a) $2\ HNO_{3(aq)} + Ca(OH)_{2(s)} \rightarrow Ca(NO_3)_{2(aq)} + 2\ H_2O_{(l)}$

   (b) $2\ HNO_{3(aq)} + CaCO_{3(s)} \rightarrow Ca(NO_3)_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$
4. Student answers may vary. Proposed solutions to acid deposition involve decreasing the emissions of acid-forming pollutants by switching coal-burning plants to natural gas and installing sulfur dioxide scrubbers in smokestacks.
5. Sugar maple trees affected by acid precipitation become less resistant to disease. The leaves of the sugar maple trees become more permeable to the ill effects of the acid rain as their waxy protective layer is compromised. The roots of the trees also lose their amino acids and sugars as they leach out to the more acidic soil. The increased aluminum concentration around the roots inhibits the uptake of water and nutrients.

4.7–4.13 SELF QUIZ

(Pages 254–255)

Modified True or False

1. True
2. False; Weak acids are acids that partially ionize in water. A dilute solution contains a relatively small amount of solute per unit volume of solution.
3. True
4. False; The pH scale measures the hydrogen ion concentration of a solution; therefore, it can be used to determine the alkalinity of a solution.
5. False; A titration is a lab procedure that involves the carefully measured and controlled addition of a solution from a burette into a measured volume of the sample being analyzed to determine the concentration of the sample.

Multiple Choice

6. (a)
7. (b)
8. (a)
9. (d)
10. (d)
11. (b)
12. (b)
13. (b)
14. (d)

Completion

15. increases, decreases
16. pops, hydrogen
17. cloudy, carbon dioxide
18. acidic, basic
19. hydrogen, hydroxide
20. neutralization, salt, water

4.14 EXTENSION EXERCISE

(Page 256)

ACTIVITY: TEMPERATURE AND PRESSURE OF A GAS—EXTRA CHALLENGE

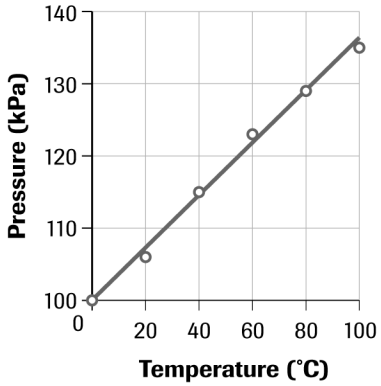
Experimental Design

(a) One possible experiment is to fill the bulb of the apparatus shown in **Figure 1** with nitrogen gas, and close the stopcock. A beaker containing enough water to submerge the entire bulb of the apparatus is heated to 20°C, 40°C, 60°C, 80°C, and 100°C. Measurements of the pressure of the nitrogen gas in the bulb are read directly from the pressure gauge attached to the bulb at each temperature.

The independent variables are the quantity (volume) of gas in the bulb and the temperature of the gas in the bulb. The dependent variable is the pressure of the gas in the bulb.

Analysis

(b) The graph shows that, as the temperature increases, the pressure of a gas in a closed container increases proportionally.



Evaluation

(c) The observations seem reasonable because, according to the kinetic molecular theory, the particles of a gas increase in speed as they absorb thermal energy. Therefore, at higher temperatures, the particles will collide with the walls of a container more often and with more force, causing the pressure to increase.

Synthesis

(d) The temperature of the compressed air in a scuba tank increases as the tank is being filled because, as the tank is filled, gas particles collide with each other more frequently. The increased friction produces heat, and causes the temperature of the gas to increase.

(e) As you drive, friction between the road and the rubber tires increases the temperature of the tires and the temperature of the air inside the tires. The increased temperature causes the air in the tires to expand, and, therefore, causes the pressure of the air to increase.

(f) If you released air from the tires described in question (e) until the recommended air pressure is reached, the tires would deflate once you stopped driving because the temperature of the air inside the tires decreases.

4.14 EXTENSION EXERCISE

(Page 257)

INVESTIGATION: PRESSURE AND VOLUME OF A GAS—EXTRA CHALLENGE

Prediction

(a) As the pressure on a gas increases, the volume of the gas will decrease.

Experimental Design

(b) A fixed volume of a gas is placed in a closed syringe. A number of objects of equal mass (books) are placed on the platform attached to the syringe's plunger. The volume of the gas in the syringe is measured after the addition of each book.

(c) The independent variables are the quantity (volume) of gas placed in the syringe, and the mass of the books. The dependent variable is the volume of the gas in the syringe.

(d) Data are recorded in **Table 3.**

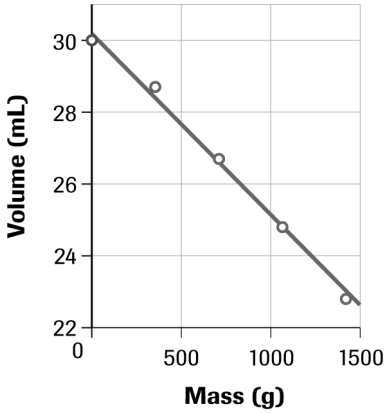
Observations

Table 3 Observations

Mass on gas in syringe (g)	Volume of gas in syringe (mL)
0	30.0
355	28.7
710	26.7
1065	24.8
1420	22.8

Analysis

(e)



(f) As the mass on the plunger increases, the volume of air inside the syringe decreases.

(g) Since the graph in (e) is a straight line sweeping downward to the right, the volume of the gas decreases as the pressure (mass of books) on it increases.

Evaluation

(h) Since the points on the graph do not form a perfectly straight line, we know that experimental errors occurred during the Procedure.

(i) Improvements that might reduce or eliminate sources of error would be to use objects having masses that are known to a high degree of certainty. Books do not all have the same mass, even if they have the same title. Also, syringes calibrated to 1/100th of a millilitre instead of 1/10th of a millilitre could be used to help reduce measurement error.

4.14 EXTENSION EXERCISE

(Page 258)

ACTIVITY: TEMPERATURE AND VOLUME OF A GAS—EXTRA CHALLENGE

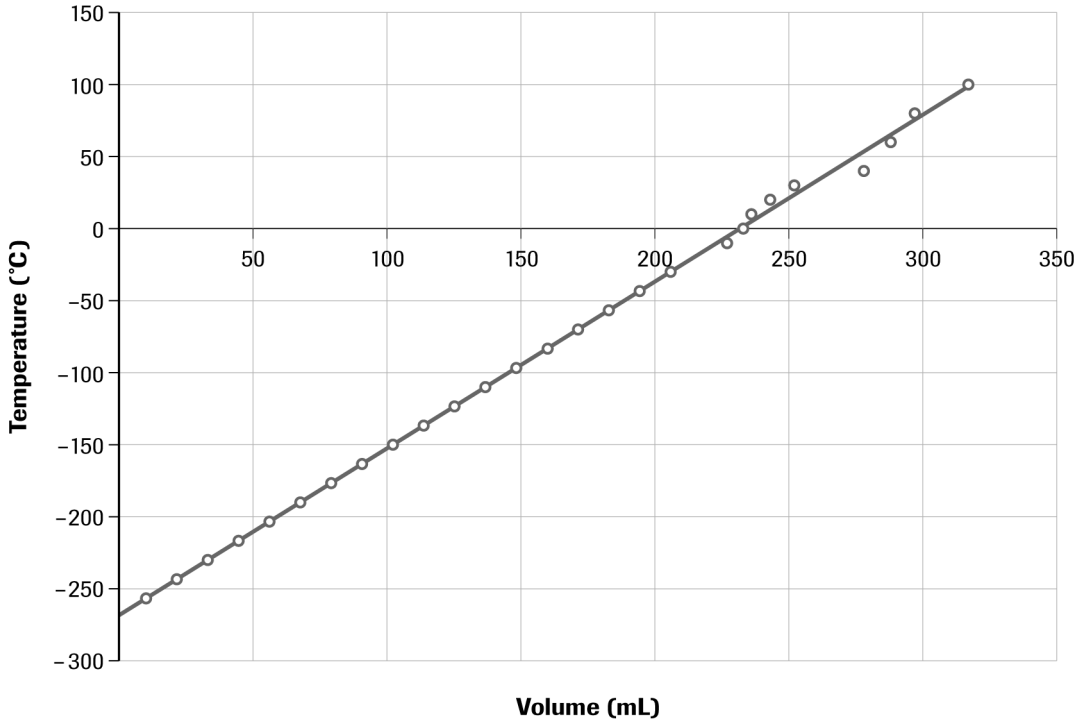
Experimental Design

(a) A volume of air (15–20 mL) is sealed in a syringe, and then placed in a water bath that is gradually heated on a hot plate. As the temperature of the water changes, the volume of air is measured.

Analysis

(b) Increasing the temperature of a gas increases the volume of a gas.

(c)



(d) When you extrapolate the volume–temperature line of best fit back to the vertical axis, the line crosses the vertical axis at approximately –273°C. This point on the graph is absolute zero (0 K).

Evaluation

(e) Possible sources of error include escaping air from the capped tip of the syringe or through the seals around the plunger. Also, the thermometer may not be giving equally accurate readings in each temperature range. Using a syringe that has been tested for leaks may help improve the results. Also, syringes calibrated to 1/100th of a millilitre instead of 1/10th of a millilitre would help reduce measurement error.

4.15 EXTENSION EXERCISE

(Pages 259–260)

EXPLORE AN ISSUE: ARE THE COSTS OF KYOTO TOO HIGH?—EXTRA CHALLENGE

Understanding the Issue

1. Automakers received an exemption from the Kyoto emission targets because the auto industry was united in its opposition to the agreement.
2. According to this article, Canada's Kyoto targets are a 6% cut in greenhouse gas emissions from 1990 levels. In today's terms, this reduction amounts to a 30% cut, or 240 megatonnes, of greenhouse gases.
3. The economic costs of Canada's participation in the Kyoto Protocol, as described in the article, include loss of 450 000 jobs over the next eight years (as predicted by the Canadian Manufacturers and Exporters Association), a loss in the GDP (gross domestic product) of $45 billion, or 3% of the total GDP, an economic recession, a doubling of electricity prices, a 60% increase in the price of natural gas, and an increase in the cost of gasoline by 50% to $1.50/L.

TAKE A STAND: THE COSTS OF KYOTO ARE TOO HIGH

(a) Statement: The costs of implementing the Kyoto Protocol far outweigh the benefits of reducing the greenhouse gas emissions that can lead to global warming.

Student answers will vary depending on the research done and the position taken. The following general information defends the statement:

- The government of Alberta and the Canadian Chamber of Commerce have predicted a $40 billion cost to meet obligations under the Kyoto Protocol.
- Energy-intensive industries in Ontario and the older smokestack industries may not be able to compete. Some companies will close plants and may reopen in countries that have not ratified the Kyoto Protocol.
- The Canadian Manufacturers and Exporters Association calculates that 450 000 manufacturing jobs will be lost over the 20-year period covered by Kyoto. The loss of those jobs means a loss in tax revenue, which means that fewer funds will be available for government services. Other businesses that depend on Canadians' spending may also fail. The trend could continue in a domino effect. Ontario, as the largest private sector employer, would be the province most affected. However, all provinces would suffer.
- Alberta and the other oil- and gas-producing provinces (British Columbia and Newfoundland) will be hard hit. A carbon tax will affect all Canadians.
- Government analysis predicts that, by 2010, Canada's economy will generate about 1.26 million new jobs, which is about 60 000 fewer jobs than we could expect if Canada had not ratified the Kyoto Protocol.
- Production costs of energy and raw materials, such as steel and aluminum, would rise slightly.

The following general information opposes the statement:

- Effects of climate change being experienced by Canadians include: more heat waves and related health problems; declining water levels in the Great Lakes; changes in fish migration; melting of the polar ice cap; insect infestations in forests; hotter summers; higher levels of smog in urban centres; and extreme weather events such as droughts, ice storms, and flooding.
- Scientists estimate that Ontario will warm an average of 2°C to 5°C within the next 75 to 100 years.
- Over the next 50 years, heat waves will increase in frequency, intensity, and duration in southern Ontario; the number of days over 30°C will rise from an average of 10 days each summer to over 30 days.
- Increased temperatures increase the risk of heat-stress-related health problems, especially in the very old, the very young, and those with chronic lung diseases, such as asthma.
- Higher temperatures would result in more "bad air days."
- A warmer climate may permit the spread of diseases, such as Lyme disease and West Nile Virus.
- A decrease in the number of extremely cold days may have an impact on cold weather mortality rates.
- Global climate models project that by 2050, Great Lake levels will be one metre lower than they are now.
- Lower water levels and flows will result in less hydropower production in Ontario, will create problems for recreational boating, and will affect the drinking water supply.
- Forests will suffer from greater stress due to drought and extreme storms, wind damage, fires, and insect outbreaks.

(b) Student answers will vary.

(c) Student answers will vary.

4.16 ALTERNATIVE EXERCISE

(Page 262)

ACTIVITY: FUEL-EFFICIENT VEHICLES

Analysis

(a) The focus of this letter is the popularity of SUVs and how this popularity is more related to advertisements than responsible environmental practices.

(b) Student answers may vary. General information that can be used to defend a position includes:

- CO_2 emissions from vehicles are responsible for 20% of the total amount of CO_2 released into the atmosphere.
- The Sierra Club calculates that driving an SUV for one year is equivalent to the energy wasted by leaving your refrigerator door open for six years, keeping a light in your house on for 30 years, and leaving your TV on for 28 years.
- Almost half of the cars sold today are considered to be light trucks.

- Most SUVs are purchased by people who do not use the vehicle for off-road activities.
- Many SUVs are more energy efficient than many older vehicles.

(c) Letters to the editor will depend on the position the student expressed in (b).

4.16 ALTERNATIVE EXERCISE

(Page 263)

ACTIVITY: TAKING CHARGE AND MAKING PERSONAL DECISIONS

Analysis

(a) Student answers will vary. Consider using the car less often, taking public transit, car-pooling, walking, or cycling. Other ideas may be found on the Environment Canada Web site for Climate Change: http://www.climatechange.gc.ca

4.16 ALTERNATIVE EXERCISE

(Page 264)

EXPLORE AN ISSUE: THE NATURE CHALLENGE

Understanding the Issue

1. The first three challenges of the Nature Challenge are to reduce the amount of energy you use by 10% this year, to buy local foods (avoid imported foods if possible), and to eat one vegetarian meal once a week.
2. The creators of the Nature Challenge propose that the solution to environmental problems involves making simple changes to our lifestyles.

TAKE A STAND: IS THE NATURE CHALLENGE A VIABLE SOLUTION?

(a) Each recommendation is presented below.

Nature Challenge Recommendations

1. Reduce home heating and electricity use by 10% this year. Energy produced by the combustion of coal or natural gas produces greenhouse gases. Using less energy means less greenhouse gases are produced.
2. Choose an energy-efficient home and appliances. Check to see if homes meet R-2000 standards and appliances are Energy Star approved. This recommendation involves improving the energy efficiency of homes and appliances. For example, using a new clothes drier avoids putting 3800 kg of carbon dioxide in the atmosphere. Using less energy means that less greenhouse gases are produced.
3. Replace chemical pesticides on your lawn, garden, and houseplants with nontoxic alternatives. By using native plants in gardens, you'll reduce the need for fertilizers, pesticides, and extra water. Fertilizers and pesticides contribute to water pollution.
4. Choose at least one day a week to eat meat-free meals. By eating one meat-free meal one day a week, you conserve valuable water, energy, and land. Changing your diet to reduce meat, and including more fruits, vegetables, and grains also improves your health and helps the environment.
5. Prepare your meals with food from local farmers and producers for one month this year. Buying locally produced food supports Canadian farmers and reduces pollution associated with transportation. The closer consumers are to food producers, the greater is the reduction in greenhouse gas emissions and other pollutants associated with transportation.
6. Check the Canadian Government's Auto Smart ratings before purchasing a car to make sure that the car is efficient and low polluting. Select the type and size of car that meets your daily needs. Larger vehicles waste gas and produce more greenhouse gases. Smaller, more fuel-efficient cars save money on gas. For every 1 L of gasoline saved, the amount of carbon dioxide entering the atmosphere is reduced by 2.4 kg.

7. Walk, bike, carpool, or use transit to get to one of your regular destinations each week. A typical family of four in suburban Ontario travels 25 000 km annually. If the family reduces its car travel by 25%, each person would reduce greenhouse gas emissions by 437 kg, or 17%.
8. Live within a 30 min bike, walk, or transit ride from daily destinations. Living close to work, school, and shopping reduces the amount of car travel and, thus, pollutant gases produced.
9. Support alternatives to the car. Contact local government to improve public transit and bike paths. Streets should be safe for pedestrians, cyclists, and cars.
10. Learn more about conserving nature and share that knowledge with family and friends. Knowledgeable people are more aware and more vocal. Encourage government to integrate environmental conservation into public policies and to become more ecologically responsible.
    (b) Student answers will vary depending on group discussions.
    (c) Letters will vary depending on the stand taken by each student.

4.14–4.16 SELF QUIZ

(Page 265)

Modified True or False

1. False; At constant temperature, the pressure exerted by a gas sample is inversely proportional to its volume.
2. True
3. True
4. False; Under the Kyoto Protocol, Canada must reduce its emissions of greenhouse gases.
5. True

Multiple Choice

6. (d)
7. (d)
8. (a)
9. (b)
10. (a)

4.17 EXTENSION EXERCISE

(Page 266)

ACTIVITY: INDOOR AIR QUALITY TECHNOLOGY—EXTRA CHALLENGE

Analysis

(a) Student answers may vary. Some possible answers are presented in **Table 1**.

Table 1 Sources of Indoor Air Pollutants

Pollutant	Sources	Remedy
VOCs	• paints, aerosols • cleaners • new carpet • pressed wood products	• increase ventilation when using products that emit volatile organic compound • provide adequate outdoor air ventilation
fine particles	• dust • animal dander • fibres	• vacuum carpets and upholstered furniture regularly
carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2)	• cigarette or cigar smoking • improperly vented fireplaces, furnaces, wood or coal stoves, gas water heaters and gas clothes dryers; and unvented or otherwise improperly used kerosene or gas space heaters	• install and use exhaust fans over gas cooking stoves and ranges • annually inspect central air systems, including furnaces, flues, and chimneys, and promptly repair cracks or damaged parts • follow all service and maintenance procedures
molds and mildew	• improperly maintained humidifiers • water-damaged carpets and building materials • improperly ventilated bathrooms	• install and use exhaust fans that are vented to the outdoors in kitchens and bathrooms, and vent clothes dryers outdoors • ventilate the attic and crawl spaces to prevent moisture build-up • keep humidity levels in bathrooms below 50%

(b) Student answers may vary. Various ways to help purify the air in your home are described in **Table 2**.

Table 2 Methods of Indoor Air Purification

Ways to purify indoor air	Pollutants removed
eliminating or controlling the sources of pollution	• VOCs • cigarette smoke • asbestos • emissions from gas stoves and fireplaces
increasing ventilation	• VOCs • water vapour and molds • emissions from gas stoves and fireplaces
installing air cleaning devices	• particles • not designed to remove gaseous pollutants
keeping plants in the home	• carbon dioxide • the ability of plants to control indoor air pollution is not well established

(c) A general look at various types of air cleaners is presented in **Table 3**.

Table 3 Types of Air Cleaners

Air Cleaner	How it works
hepa filter	High-efficiency particulate (hepa) air filters are designed to remove 99.97% of all airborne pollutants >0.3 microns from the air that passes through the filter. Pollutants include tobacco smoke, dust, and pollen.
ulpa filter	These ultra-hepa filters are designed to trap 99.999% of all airborne pollutants <0.3 microns from the air that passes through the filter. Pollutants include tobacco smoke, household dust, and pollen.
electrostatic units	Electrostatic units have a static charge on the filter, which allows airborne particles to "stick" to the filter. They attract dust, pollen, smoke, and other particles.
ozone air cleaner	These cleaners use ozone to reduce airborne pollutants.
ion generator	Ion generators emit a small charge to the air stream, which causes particles to adhere to the filter by a magnetic-like attraction.
hybrid device	Hybrid devices contain a mechanical filter combined with an electrostatic unit or an ion generator.

UNIT 4 SELF QUIZ

(Pages 267–269)

Multiple Choice

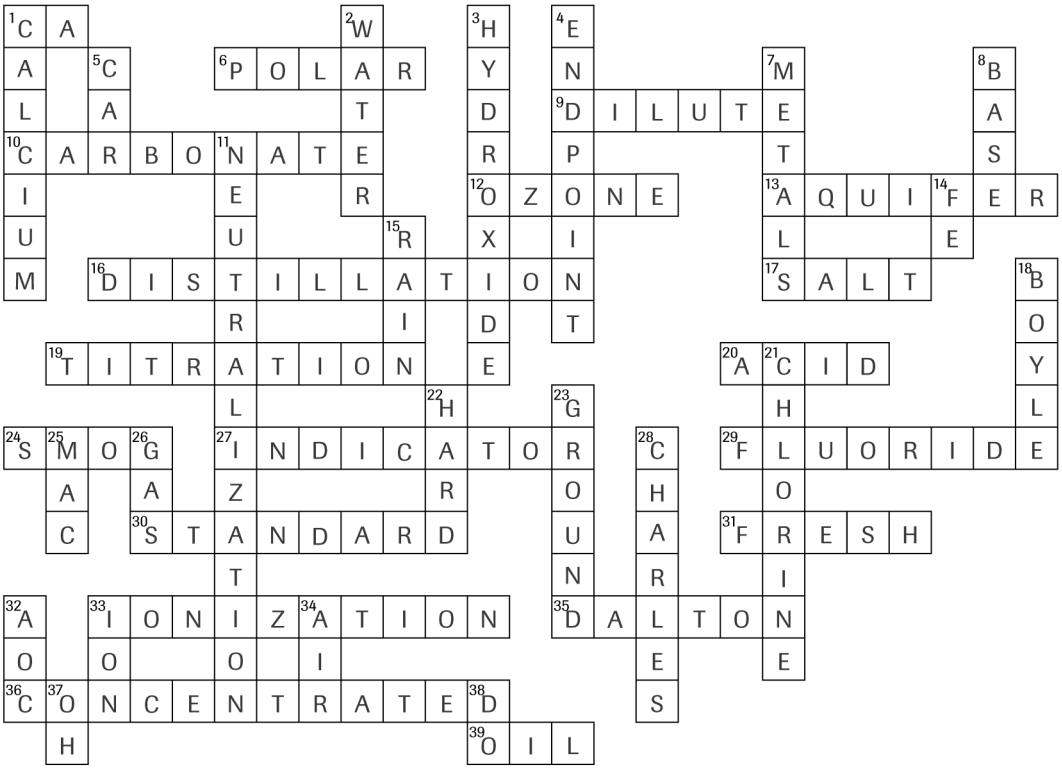
1. (a)
2. (a)
3. (d)
4. (b)
5. (c)
6. (a)
7. (a)
8. (d)

Matching

9. D
10. E
11. I
12. B
13. H
14. G
15. C
16. F
17. A

Completion

18.



19. deteriorate
20. global warming
21. Air Quality Index
22. Smog
23. 10^{-5} mol/L, 10^{-3} mol/L, 100
24. carbon diosxide, water vapour, methane, CFCs