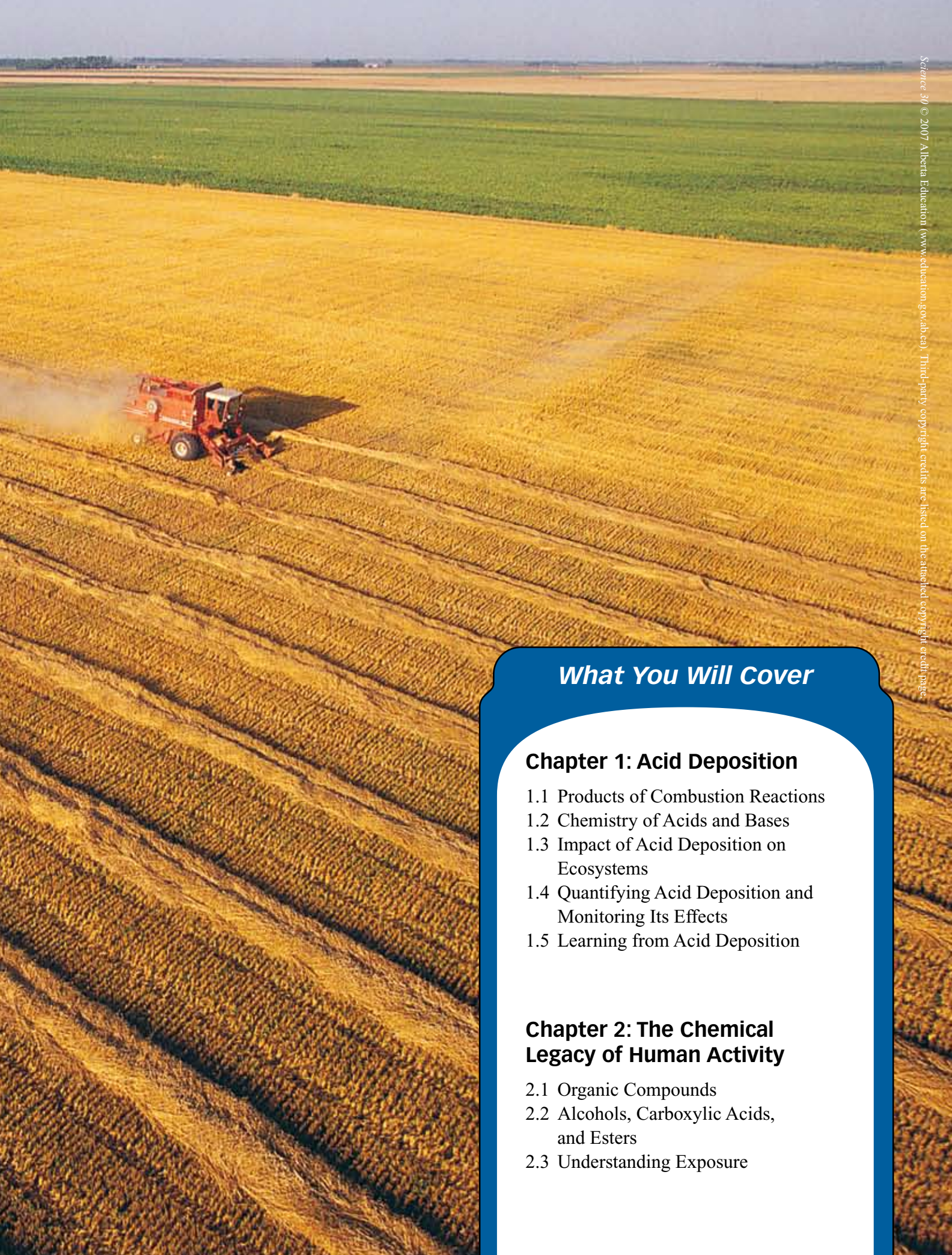
Unit B Chemistry and the Environment

The prairies during harvest are an impressive sight. After careful seeding and management of crops, farmers look forward to harvest time as the final step. As you have seen in Unit A, agriculture—although steeped in tradition—has benefited from new technologies: improved machinery for seeding and harvesting; herbicides to remove unwanted plants; and new varieties of hardier plants.

Advancements in technology provide a way to fulfill society's needs. Discoveries and developments in science and technology have changed the practices in modern-day agriculture. Recent innovations have improved the processes for refining raw materials and manufacturing consumer products.

The use of processes to manipulate raw materials is a common practice in chemistry. New combinations of atoms or the isolation of one substance from a mixture can have intended or unintended effects. The manipulation of matter, and other technologies, affects people and the environment.

In this unit you will find out about some chemical processes that are important to society. You will also learn about the environmental consequences of these processes and the actions being taken to counteract the unintended effects.



What You Will Cover

Chapter 1: Acid Deposition

1.1 Products of Combustion Reactions
1.2 Chemistry of Acids and Bases
1.3 Impact of Acid Deposition on Ecosystems
1.4 Quantifying Acid Deposition and Monitoring Its Effects
1.5 Learning from Acid Deposition

Chapter 2: The Chemical Legacy of Human Activity

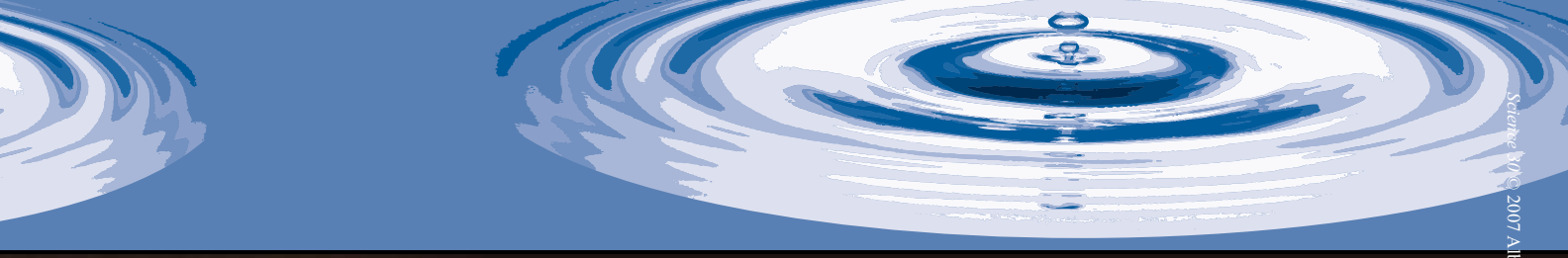
2.1 Organic Compounds
2.2 Alcohols, Carboxylic Acids, and Esters
2.3 Understanding Exposure

Chapter 1 Acid Deposition

Camping is an activity enjoyed by many people worldwide. After a full day of activities such as hiking or canoeing, there is nothing like sitting around and enjoying the light and warmth of a campfire with friends or family.

To enjoy a camping trip, you need activities and manufactured items that require the combustion of fuel. At the campsite, fuels are burned for heating, cooking, and light. To drive to the campsite, you need fuel for automobiles and camping trailers. Even the manufacturing processes for making the tent, trailer, and camping equipment requires an abundance of fuel.

Since the 1960s, scientists have been collecting evidence that some of the products of fuel combustion are negatively affecting the environment. What evidence is there? What are some of the effects on the environment? Are there ways to reverse or control these effects? These are some of the questions you will explore throughout this chapter.



Try This Activity

Detection Limits

Advances in technology have led to sophisticated and sensitive apparatus that are able to detect substances at very low concentrations. The detection of a substance is the first step toward understanding the impact of its presence within the environment.

Purpose

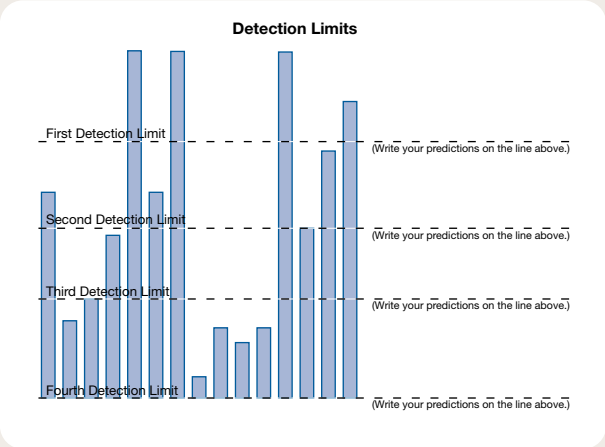
You and a partner will perform an analysis that simulates the relationship between detection limits and the amount of information available.

Procedure

Obtain the "Detection Limits" handout from the Science 30 Textbook CD. You will need one copy for each person.

step 1: You and your partner must create a sentence that contains 8 to 15 words. Do not share your sentences.

step 2: Write the words of your sentence into the top part of the bars—one word per bar—on the "Detection Limits" handout.



Science Skills

✓ Analyzing and Interpreting

step 3: Cover the handout you prepared in step 2 with cardboard or a sheet of heavy paper.

step 4: Have your partner pull the piece of cardboard down to the dotted line labelled "First Detection Limit" and read the words that are visible.

step 5: Have your partner use the visible words to predict what the sentence is. His or her prediction should be written in the space provided on the handout.

step 6: Repeat steps 4 and 5 for the remaining detection limits.

Analysis

1. Compare the predictions you made at each detection limit. At what point was your prediction reasonably close to the actual sentence? At what point was your prediction identical (or nearly identical)?
2. Assume that each bar on the page represents a different chemical substance associated with a chemical process. These may be reactants, products, or by-products of the process. Assume that the height of each bar represents the concentration of a substance. If you were studying the chemical process, at which detection limit would you want to collect information? Explain your reasoning.
3. If each bar represents a different chemical substance that could be released into the environment, identify which bars would be of greatest concern. Support your answer.

1.1 Products of Combustion Reactions

Working as a team in a local dogsled race, Kayla and her dogs challenge the cold and their physical limits. They are all working and breathing hard. With each breath Kayla and her dogs take, they must exhale the products of **cellular respiration**—a process that converts the chemical potential energy within food into a form the body's muscles can use. Energy-converting processes, like cellular respiration and the **combustion** of fuels, are important; however, they produce emissions.

In the next investigation you will look at the chemical properties of the gases produced from cellular respiration and from the combustion of a hydrocarbon.

- **cellular respiration:** the process by which cells convert the chemical energy stored in organic molecules (sugars) into energy that cells can use
- **combustion:** a chemical reaction that occurs in the presence of oxygen and results in the release of energy

Investigation

Comparing the Effects of the Products of Cellular Respiration and Combustion

Cells use molecules within food as an energy source. Cellular respiration is a process similar to the combustion of hydrocarbons in that oxygen is required, carbon dioxide and water are produced, and energy is released.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will compare the effects of the products of cellular respiration with the products of the combustion of a hydrocarbon (coal).

Part 1: Cellular Respiration

Materials

- 125-mL Erlenmeyer flask
- 75 mL of distilled water
- bromothymol blue indicator
- 100-mL graduated cylinder
- drinking straw
- eyedropper
- stopwatch

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Use the graduated cylinder to measure 75 mL of distilled water; then transfer the water to the Erlenmeyer flask.

step 2: Add four drops of bromothymol blue to the distilled water. Note the colour of the mixture.

step 3: Insert the drinking straw into the mixture in the flask, and exhale through the straw until the colour of the indicator changes to yellow. Record the time taken for the indicator to change colour.

Observations

1. Complete the following table.

Colour of Indicator Before Exhaling	Time Taken for Indicator to Turn Yellow

Analysis

2. Explain the significance of the colour change.
3. Identify the reason for the mixture to change colour. **Note:** Refer to the "Acid-Base Indicators" table on page 184.
4. Write the balanced chemical equation for the cellular respiration of glucose, $C_6H_{12}O_6(aq)$.
5. Hypothesize the effect that carbon dioxide released by many processes could have on water within the biosphere.

Part 2: Teacher Demonstration—Combustion of Coal

Materials

Your teacher will set up the materials as shown in Figure B1.1.

CAUTION!

Be careful near an exposed flame and hot objects.

Figure B1.1

Procedure for Teacher

step 1: Measure 75 mL of distilled water, and transfer it to the flask.

step 2: Add four drops of bromothymol blue to the distilled water. Note the colour of the mixture.

step 3: Place the coal in a crucible, and ignite the coal using a Bunsen burner or torch.

step 4: Once the coal is glowing and producing smoke, position the crucible below the inverted funnel.

step 5: Turn on the vacuum to draw the smoke into the flask. Record the time it takes for the indicator inside the flask to change colour.

step 6: Turn off the vacuum, and let the system sit untouched for a few minutes to allow the air pressure in the flask to return to normal. Remove the crucible, and extinguish the coal with water.

Observations

6. Complete the following table.

Colour of Indicator Before	Time Taken for Indicator to Turn Yellow

Analysis

7. Explain the significance of the colour change.
8. Suggest a reason why the water containing the bromothymol blue indicator in Parts 1 and 2 took different lengths of time to change colour.
9. Write the balanced chemical equation for the combustion of coal, C(s).
10. Identify a process or technology where coal is used.

Combustion Reactions and Their Products

Natural gas used to heat most homes contains mostly methane, $CH_4(g)$, and is an example of a **hydrocarbon** and a **fuel**. During combustion, collisions between the molecules of methane and oxygen result in the formation of new molecules.

The Combustion of Methane

Hydrogen reacts with oxygen.

Carbon reacts with oxygen.

$$\underbrace{CH_4(g)}_{\text{material being combusted}} + \underbrace{2\,O_2(g)}_{\text{combustion process requires reaction with oxgen}} \rightarrow \underbrace{CO_2(g) + 2\,H_2O(g)}_{\text{products of combustion – determined by the atoms being combusted – often are gases}}$$

Figure B1.2

The equation in Figure B1.2 shows that the products of combustion are carbon dioxide, $CO_2(g)$, and water vapour, $H_2O(g)$—oxides of carbon and hydrogen.

The products formed during a combustion reaction are directly related to the atoms present in the substance being combusted. When a hydrocarbon combusts, the products are usually carbon dioxide and water. Later, you will discover that other products can appear if other atoms appear within the fuel. During most combustion reactions, the oxides produced are released into the atmosphere. These are referred to as **emissions**.

- **hydrocarbon:** an organic compound containing only carbon and hydrogen atoms
- **fuel:** a substance that releases energy when involved in a chemical reaction (often combustion) or a nuclear reaction
- **emission:** a substance discharged into the atmosphere or into surface water

Balancing Chemical Equations

Substances do not always react with each other on a one-to-one basis. To indicate the relative proportions of each substance involved in a reaction, you need to balance the chemical equation. Matter is conserved in all chemical processes. Therefore, a balanced chemical equation has an equal number of each type of atom appearing on the reactants side and on the products side of the equation. Balance the equation using coefficients. Carefully work through Example Problem 1.1.

Example Problem 1.1

Ethane is one of the components in natural gas. Balance the following combustion equation for ethane.

$C_2H_6(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

Solution

____ $C_2H_6(g)$ + ____ $O_2(g)$ → ____ $CO_2(g)$ + ____ $H_2O(g)$

↓ Add a coefficient to balance the carbon atoms.

1 $C_2H_6(g)$ + ____ $O_2(g)$ → **2** $CO_2(g)$ + ____ $H_2O(g)$

↓ Add a coefficient to balance the hydrogen atoms.

1 $C_2H_6(g)$ + ____ $O_2(g)$ → **2** $CO_2(g)$ + **3** $H_2O(g)$

↓ Add a coefficient to balance the oxygen atoms.

1 $C_2H_6(g)$ + **3.5** $O_2(g)$ → **2** $CO_2(g)$ + **3** $H_2O(g)$

Recall that coefficients of 1 are not normally shown. Therefore, the balanced chemical equation is

$C_2H_6(g) + 3.5\,O_2(g) \rightarrow 3\,CO_2(g) + 4\,H_2O(g)$

Note: If you wish to have whole-number coefficients, multiply all coefficients in the equation by 2.

2 $C_2H_6(g)$ + **7** $O_2(g)$ → **4** $CO_2(g)$ + **6** $H_2O(g)$

Practice

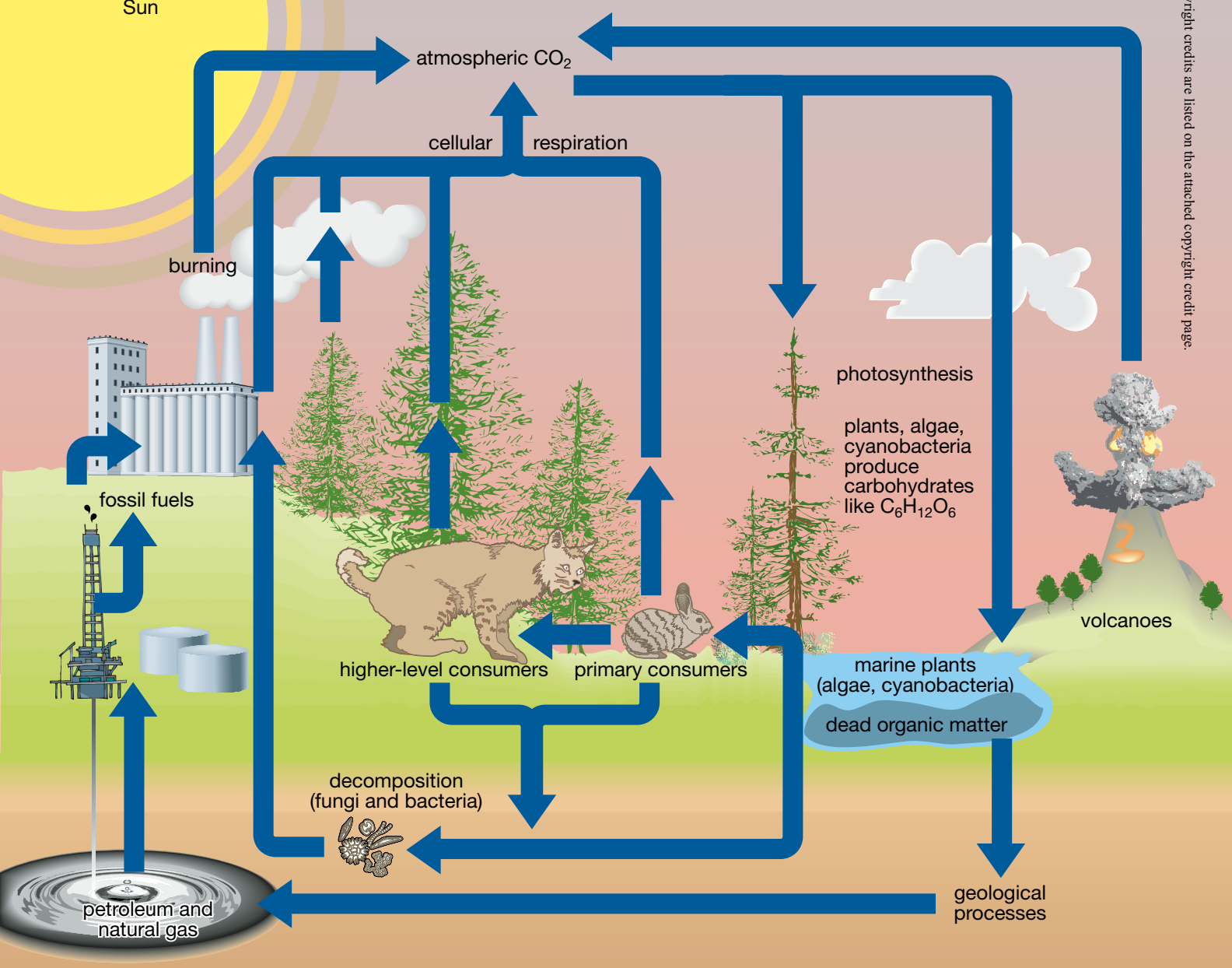
1. Balance the following combustion reactions.
   - **a.** ____ $C_5H_{12}(l)$ + ____ $O_2(g)$ → ____ $CO_2(g)$ + ____ $H_2O(g)$
   - **b.** ____ $C_4H_8(g)$ + ____ $O_2(g)$ → ____ $CO_2(g)$ + ____ $H_2O(g)$
   - **c.** ____ $C_4H_{10}(g)$ + ____ $O_2(g)$ → ____ $CO_2(g)$ + ____ $H_2O(g)$
   - **d.** combustion of octane, $C_8H_{18}(g)$

Oxides of Carbon

Burning carbon compounds, like wood and other forms of **biomass**, or burning hydrocarbon molecules, such as those present in natural gas and gasoline, results in the production of carbon dioxide. Within the biosphere, natural processes that produce carbon dioxide include the cellular respiration of organisms, forest fires, volcanic eruptions, and the weathering of some forms of rock. As a result of these natural processes, carbon dioxide is present within the collection of gases that make up Earth's atmosphere.

biomass: plant matter or agricultural waste from recently living sources used as a fuel or as an energy source

The Carbon Cycle



Recall from previous courses that carbon dioxide is an important gas with respect to life on Earth. Carbon dioxide is a component of the carbon cycle—the series of reactions of carbon-containing compounds in the biosphere. Within the carbon cycle, processes are interrelated. Cellular respiration, which produces carbon dioxide, and photosynthesis, which uses carbon dioxide, act to maintain a relatively steady amount of carbon dioxide in the atmosphere. Also, recall that carbon dioxide is a greenhouse gas, meaning that it has the ability to absorb thermal energy (heat). By absorbing thermal energy, greenhouse gases prevent the loss of thermal energy into space and, thus, have a direct impact on Earth's climate. Since the industrial revolution in the late 1800s, society has increased its reliance on combustion technologies involving fossil fuels. Higher levels of carbon dioxide emissions are believed to be a major contributor to current changes to global climate. Scientific evidence shows that as the amount of carbon dioxide in the atmosphere increases, the quantity of thermal energy retained also increases. The retention of thermal energy results in an increase in the atmospheric temperature, which, in turn, affects climate and ecosystems.

Practice

2. Refer to the diagram of the carbon cycle on page 157. Explain how the increased use of combustion processes by society and deforestation could result in a higher level of atmospheric carbon dioxide, a level that cannot be removed by natural mechanisms.
3. Use the Internet to research the terms *carbon sink* and *carbon sequestering*. Explain how carbon sinks or carbon sequestering are possible mechanisms for reducing the concentration of carbon dioxide in the atmosphere. Identify how carbon sinks or carbon sequestering would impact the carbon cycle.

Carbon Monoxide

Another oxide of carbon—carbon monoxide, CO(g)—is a common product of combustion. Carbon monoxide is produced when the quantity of oxygen is limited during the reaction process.

$$2\ CH_4(g) + 3\ O_2(g) \rightarrow 2\ CO(g) + 4\ H_2O(g)$$

↑ Carbon monoxide is a product of an incomplete combustion of a carbon compound.

Concern exists over the presence of carbon monoxide in emissions. As a result, its concentration is often measured during environmental monitoring.

Figure B1.3: Mechanics often have to work on an engine while it is operating. To prevent exposure to carbon monoxide, an exhaust vacuum is used.

Carbon monoxide is associated with inefficient combustion processes, which include automobile emissions. Carbon monoxide can pose a threat to your health. In Unit A you discovered that the circulatory system transports oxygen to cells within the body and that this is only possible by the interaction of oxygen with hemoglobin. Because of the similarities between oxygen and carbon monoxide molecules, carbon monoxide is able to compete with oxygen for binding sites on a hemoglobin molecule. When carbon monoxide is present in inhaled air, it binds to hemoglobin, preventing hemoglobin from binding to oxygen. This decreases the amount of oxygen available to the cells in your body, and can result in death. Emissions-testing programs measure the carbon monoxide concentration in vehicle exhaust. These programs can indicate whether maintenance is required to improve the efficiency of an automobile's engine.

A carbon monoxide detector, present in many homes today, provides one means of monitoring combustion processes. A furnace that has poor combustion efficiency not only produces carbon monoxide, a health threat, but also converts less of the potential energy from the fuel it uses into thermal energy. Regular inspection and maintenance ensures the proper operation of a furnace. There is a great deal of concern about maximizing the efficiency of combustion and other energy-conversion processes.

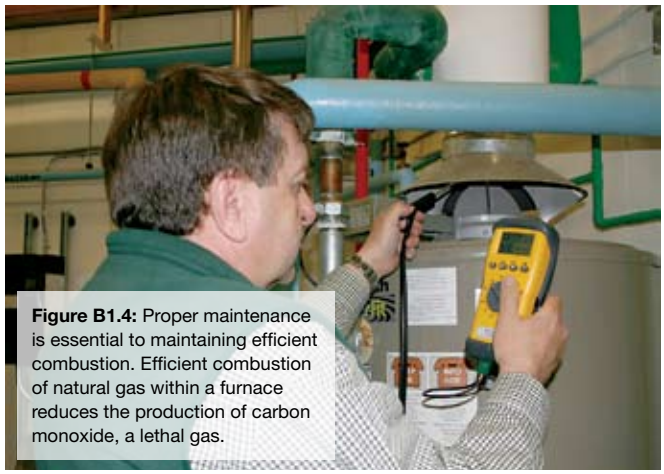


Figure B1.4: Proper maintenance is essential to maintaining efficient combustion. Efficient combustion of natural gas within a furnace reduces the production of carbon monoxide, a lethal gas.

Science Links

Monitoring the efficiency of electricity production can involve more than the detection of by-products, like carbon monoxide. Other monitoring methods involve measuring the power output of the facility. In Unit C you will read more about measuring power and how it can be used to determine the efficiency of the transfer of electrical energy through transmission lines.

DID YOU KNOW?

On average, the concentration of CO(g) in a room may be 0 to 2 parts per million (ppm). Carbon monoxide detectors emit a warning when levels reach 75 ppm to 100 ppm. Expressed as a percent, the detector is set to recognize a CO(g) concentration between 0.0075% and 0.0100%.

Practice

4. Balance the equations representing the complete and incomplete combustions of methane.

   complete combustion:
   $CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

   incomplete combustion:
   $CH_4(g) + O_2(g) \rightarrow CO(g) + H_2O(g)$

5. Use the coefficients from the balanced equations in question 4 to determine the ratio of methane to oxygen in each process. Which reaction uses more oxygen per molecule of methane? Explain how you used the ratios to determine your answer.

Oxides of Sulfur

Sulfur is an element found in small quantities within many of the natural resources burned as fuels. Coal—a fuel commonly used in the production of electricity throughout Alberta and the world—often contains sulfur in varying amounts. Other energy resources, like crude oil and tar sands, also contain sulfur.

Natural gas is another energy source that commonly contains sulfur; but it is in the form of hydrogen sulfide, $H_2S(g)$. The hydrogen sulfide present in **sour gas** is toxic to humans and forms an acidic solution if combined with water. Some sources of sour gas contain more than 30% hydrogen sulfide. Processing natural gas often involves removing the hydrogen sulfide. This is called sweetening. The sweetening process not only reduces the risk to humans in the case of an accidental gas leak, but also reduces the corrosive effects sour gas has on pipelines.

sour gas: natural gas that contains greater than 1% hydrogen sulfide

It is estimated that about 40% of the natural gas reserves in Alberta are sour. Therefore, the removal of hydrogen sulfide is a vital industrial process.

Figure B1.5: Sour gas flare

During the lifespan of a gas well, low-quality natural gas is sometimes released. This low-quality gas—often containing hydrogen sulfide—is flared. Flaring converts hydrogen sulfide into sulfur dioxide and sulfur trioxide emissions.

Flaring Process—Unbalanced Chemical Equations

$H_2S(g) + O_2(g) \rightarrow SO_2(g) + H_2O(g)$

$SO_2(g) + O_2(g) \rightarrow SO_3(g)$

The combustion of coal also results in the production of sulfur dioxide, although the amount can vary depending on the quantity of sulfur in the coal. The coal mined in Alberta contains less sulfur than the coal mined in eastern Canada. What do you think the effect would have been if sulfur-rich coal were used in the investigation on page 155?

Figure B1.6: Stockpile of sulfur from desulfurization

The yellow stockpiles seen near facilities that process natural resources (e.g., petroleum, oil sand, and very sour gas) consist of elemental sulfur—the product of desulfurization. Sulfur is commonly combined with metal atoms within metal ores. Refining metal ores involves removing sulfur by heating the ore in the presence of oxygen. In eastern Canada, particularly southern Ontario, the refining of nickel and other metals produces sulfur dioxide emissions.

Practice

6. Balance the chemical equations that occur during the flaring process.

Oxides of Nitrogen

You probably already know that Earth's atmosphere is a mixture of many gases. Nitrogen, $N_2(g)$, makes up 78.1% of Earth's atmosphere. Whenever you inhale or whenever air is drawn into an engine to combust a fuel, nitrogen is present. If the temperature of the combustion process is high enough (above 650°C), the normally unreactive nitrogen molecule is activated and will react, often producing nitrogen oxides. The oxides of nitrogen produced by combustion reactions are nitrogen monoxide, NO(g), and nitrogen dioxide, $NO_2(g)$. These are commonly referred to as NO_x compounds.

Production of NO_x Compounds

$N_2(g) + O_2(g) \rightarrow 2\ NO(g)$

$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

The most common sources of NO_x compounds are high-temperature combustion processes. These include the combustion of hydrocarbon fuels by automobiles and by furnaces used in homes and industry. Studies have shown that higher NO_x emissions occur in urban areas and that NO_x levels can fluctuate daily or monthly depending on the season.

Practice

7. Explain why NO_x emissions are higher in urban areas than in rural areas.

8. For each situation given, predict whether levels of NO_x emission will increase or decrease.

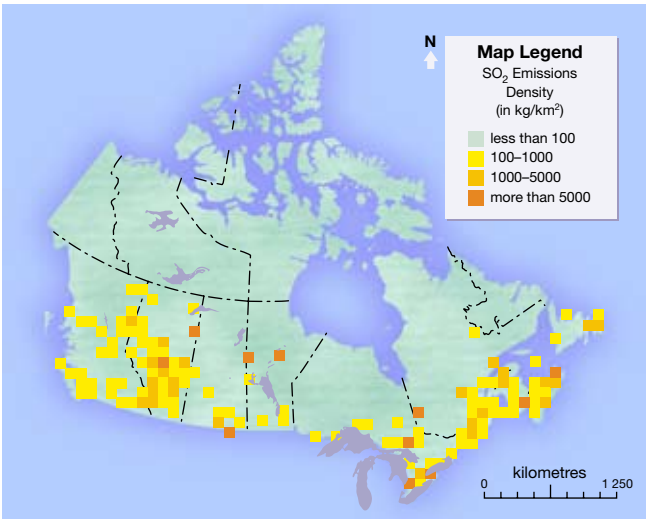
a. morning and evening rush hour

b. a cold snap in the winter

c. a heat wave in the summer months

Chemical Reactions in the Atmosphere

Sulfur Dioxide (SO_2) Emissions in Canada (2000)



Nitrogen Oxide (NO_x) Emissions in Canada (2000)

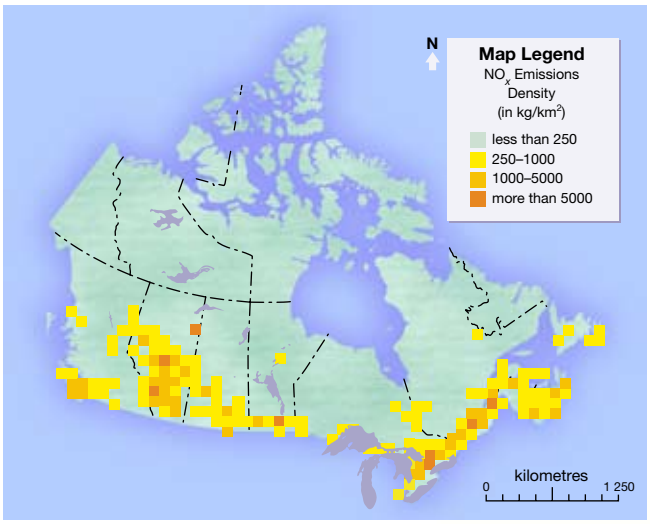


Figure B1.7: Greater emissions of SO_2 and NO_x occur near major Canadian centres.

A list of natural and human activities that produce SO_2 and NO_x is shown in the "Sources of SO_2 and NO_x" table.

SOURCES OF SO_2 AND NO_x

Sources of SO_2	Sources of NO_x
Natural	**Natural**
• hot springs • volcanic outgassing	• forest fires
Human-made	**Human-made**
emissions from • coal-fired power plants • pulp and paper mills • refining crude oil • refining oil sands • refining metals and smelting • automobiles	emissions from • fossil fuel power plants • industrial and domestic furnaces • production of fertilizers • burning of crops • automobiles

Notice that many of these emissions are the result of human activity, with the result that larger emissions occur close to major cities. As you will see in later lessons, Earth's atmosphere can provide suitable conditions for emissions—such as the oxides of carbon, sulfur, and nitrogen—to undergo additional chemical reactions. You will examine the impact that NO_x and SO_2 emissions have on the biosphere. But first, you will see how emissions are monitored in Alberta and who is involved.

Monitoring Emissions in Alberta

Alberta Environment is involved in programs that monitor and maintain the quality of Alberta's environment to protect the health of citizens and ecosystems. Desired standards for environmental quality are determined by the collection of data from scientific, societal, technical, and economic sources. Factors considered when establishing standards for environmental quality include the

- sensitivity of organisms to the presence of substances of concern
- behaviour of substances when in the atmosphere or other parts of the environment
- natural levels and fluctuations that may occur in concentration of substances
- availability of technology to control or avoid emissions
- ability to detect and monitor the presence of substances of concern

Figure B1.8: Alberta Environment's MAML (mobile air monitoring laboratory) is specially equipped to sample and monitor the air in any location throughout Alberta.

In Alberta, air quality is monitored using data collected by monitoring stations operated by industry and the provincial and federal government. Currently, you are able to use the Internet to access information about air quality throughout the province. Depending on the location of the monitoring stations in your immediate area, you may be able to view the concentrations for a variety of substances that are used to determine air quality in the area immediately near your school or home.

Alberta Environment also uses a mobile monitoring system to perform measurements of air quality. View the segment "Mobile Air Monitoring Labs (MAML)" on the Science 30 Textbook CD for additional information about the mobile monitoring system.

Metals and Metal Oxides

Metal atoms, either in their elemental form or as a compound, can also be present in emissions from processes that rely on combustion reactions. For example, coal may contain small amounts of metals, like lead or mercury. When coal is combusted, these metals may be carried great distances before depositing on the ground. Monitoring processes pay close attention to the detection and measurement of the concentrations of heavy metals, like lead and mercury, in emissions and elsewhere in the environment, especially since these metals have been known to adversely affect human health.

Particulate Matter

A higher incidence of asthma and other respiratory diseases occurs in populations of individuals exposed to higher levels of particulate matter. Particulate matter consists of solids suspended in the atmosphere that come from natural and human-made sources. Soot, smoke, and ash produced by either industrial processes or forest fires; soil particles; and pollen are examples of particulate matter that may irritate parts of the respiratory system. Cigarette smoke is an especially dangerous source of particulate matter because it contains organic compounds (e.g., benzene) that are **carcinogens**. You will learn more about organic compounds in Chapter 2 of this unit.

carcinogen: any agent that causes the likelihood of cancer to increase
Many carcinogens are also mutagens.

Utilizing Technology

Taking a Stand—Emissions Testing

Science Skills

✓ Performing and Recording
✓ Communication and Teamwork

Albertans have a high dependence on the cars and trucks they drive for pleasure or for work. In addition, Albertans enjoy their recreation vehicles (e.g., motorcycles, quads, boats, and snowmobiles). Albertans also place a high priority on their health and the health of the diverse habitats that exist throughout the province.

As you know, pollution from vehicles affects both society and the environment. Is it time to place standards on the emissions from vehicles? Currently, three Canadian provinces—British Columbia, Ontario, and New Brunswick—have emissions-testing programs for vehicles. Should Alberta be next?

Purpose

You will debate the following question:

Should Alberta have an emissions-testing program for vehicles similar to those used in British Columbia, Ontario, and New Brunswick?

Background Information

Before you begin, use the Internet to answer the following questions.

1. Why is emissions testing required in some provinces and not in others? In provinces that have emissions-testing programs, are all vehicles tested in all regions of the province?
2. Identify the reason for initiating emissions-testing programs in these provinces.
3. List the items being tested for during an emissions test.
4. What do emissions tests cost consumers in the provinces with testing programs?

Procedure

5. Prepare a position statement that clearly defines whether you support or do not support mandatory emissions testing of all vehicles in Alberta. When developing your position statement, review the list of perspectives listed on page 590. Use this list to help justify your position.
6. Prepare a rebuttal—a second statement that responds to a criticism of your position. When preparing your rebuttal, imagine you are the opponent in the debate. What part of your position statement would your opponent most likely challenge? Would it be the credibility of the information you present or the conclusions you make? Your rebuttal is your opportunity to develop a plan to further defend your position.

1.1 Summary

Combustion processes, both complete and incomplete, involve a reaction with oxygen that results in the formation of oxide compounds. Some of the oxides produced include carbon dioxide, carbon monoxide, sulfur dioxide, and NO_x compounds (e.g., nitrogen monoxide and nitrogen dioxide). Other emissions that can result from combustion processes include heavy metals and particulate matter.

Because emissions react with elements in the atmosphere that may affect humans and other organisms, monitoring programs have been implemented to measure emissions from combustion processes. These programs provide information that can be used to address issues regarding the quality of the environment.

1.1 Questions

Knowledge

1. Define each term, and describe its significance to this lesson.
   - **a.** combustion
   - **b.** oxide
   - **c.** pollution
   - **d.** greenhouse gas
   - **e.** hemoglobin
   - **f.** sour gas
   - **g.** NO_x
   - **h.** particulate matter
   - **i.** carcinogen
2. Describe, at the atomic level, what happens to the molecules in a fuel during combustion.
3. "The products of a combustion reaction are dependent on the substance being combusted." Explain the meaning of this statement, and include an example.
4. Explain why nitrogen oxides are often referred to as NO_x.
5. Natural gas is a collection of hydrocarbons. Balance the combustion reactions for three hydrocarbons often found in natural gas.
   - **a.** $\_\_ CH_4(g) + \_\_ O_2(g) \rightarrow \_\_ CO_2(g) + \_\_ H_2O(g)$
   - **b.** $\_\_ C_2H_6(g) + \_\_ O_2(g) \rightarrow \_\_ CO_2(g) + \_\_ H_2O(g)$
   - **c.** $\_\_ C_3H_8(g) + \_\_ O_2(g) \rightarrow \_\_ CO_2(g) + \_\_ H_2O(g)$

Applying Concepts

6. Gasoline is a mixture of hydrocarbons, none of which contain nitrogen. Explain how the combustion of gasoline in automobiles can be considered to be a major source of the production of NO_x compounds.
7. The Claus process can be used to remove hydrogen sulfide from sour natural gas. The Claus process occurs in two steps:

   1) Thermal Step

   $H_2S(g) + O_2(g) \rightarrow S(s) + H_2O(g)$

   $H_2S(g) + O_2(g) \rightarrow SO_2(g) + H_2O(g)$

   This step occurs in a furnace at high temperatures.

   2) Catalytic Step

   $H_2S(g) + SO_2(g) \rightarrow S(s) + H_2O(g)$

   - **a.** Balance the three reactions in the Claus process.
   - **b.** Identify one emission, other than those listed in the equations, that is produced by the Claus process.
   - **c.** Improvements to the Claus process focus on reducing emissions. One improvement requires the use of pure oxygen rather than atmospheric air in the furnace. Explain how the use of pure oxygen could result in a reduction to emissions from the Claus process.
8. Prepare a table that summarizes the similarities and differences between the properties and processes that result in the formation of the carbon, nitrogen, and sulfur oxides described in this lesson.
9. Obtain the handout "NO_x and SO_2 Emissions in Canada (2000)" from the Science 30 Textbook CD.
   - **a.** Use the information from each map to prepare a table that identifies the locations in Alberta where emissions of SO_2 and NO_x are moderate and high. Provide a reason as to why emissions are moderate to high.
   - **b.** Identify a location in Alberta with high levels of NO_x emissions and low levels of SO_2 emissions. Explain how this situation could exist.
   - **c.** Use the Internet to obtain information on other locations in Canada where SO_2 and NO_x emissions are relatively high. Add this information to your table in question 9.a.
10. In 2000, emissions of SO_2 in Canada were estimated to be 2.4×10^6 t (tonnes). Prepare a table that shows the mass of sulfur dioxide emissions from each of the sources shown in Figure B1.9.

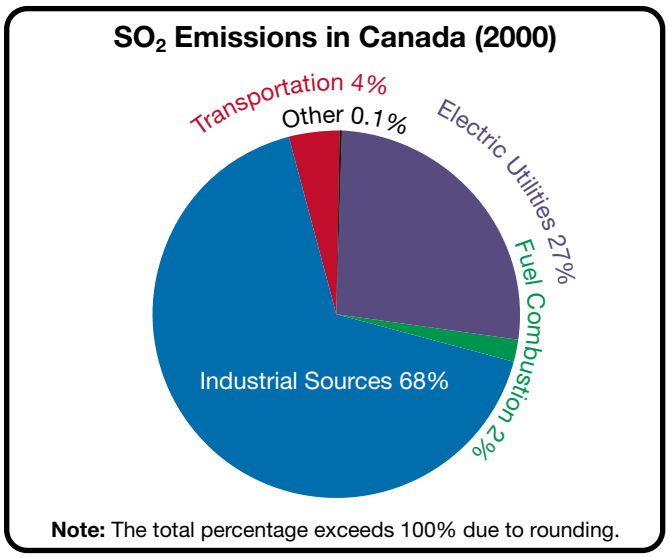


Figure B1.9

1.2 Chemistry of Acids and Bases

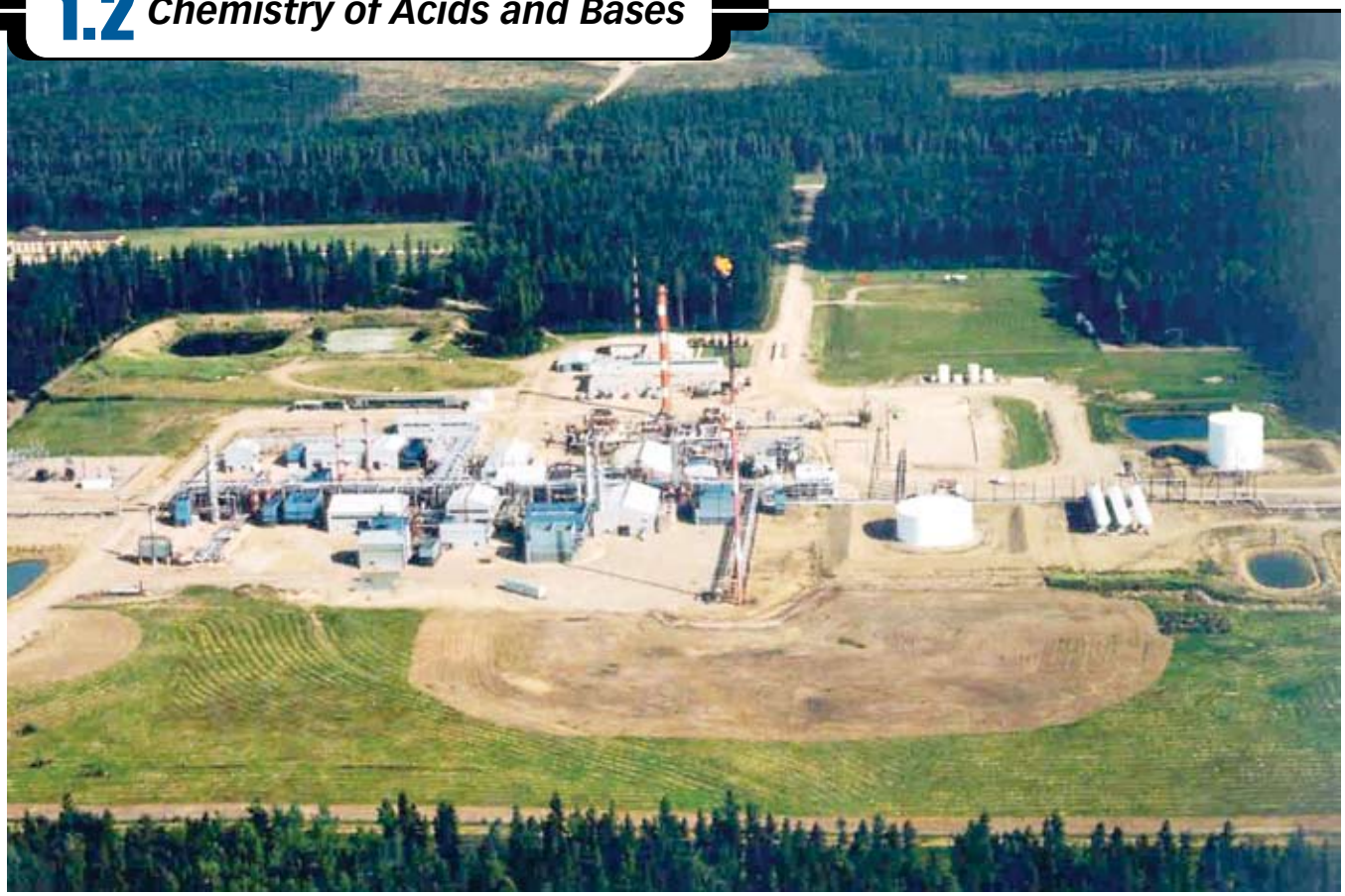


Figure B1.10

Most of the natural gas collected and processed from gas wells in Alberta contains hydrogen sulfide, $H_2S(g)$. At sour gas processing facilities (like the one shown in Figure B1.10), the hydrogen sulfide is removed and is converted into sulfur. Metal pipes, like the one shown in Figure B1.11, can be damaged by exposure to sour gas. Recall from previous science courses that the corrosion of metal objects occurs when certain substances come into contact with one another.

Workers in the oil and gas industry continually monitor the corrosion of pipes, especially where sour gas is extracted and processed. Strict safety standards are maintained to protect people and the environment from the effects of sour gas.

In this lesson you will closely study the chemical components within sour gas that enable it to affect metals and other substances. You will also see how the products of combustion reactions can further react to produce acidic solutions. You will examine how acidic solutions can affect other substances, including bases, within chemical systems. You will then discover methods to measure and describe the acidity of solutions.

Figure B1.11: A metal pipe damaged by corrosion

What Makes Sour Gas Sour?

Figure B1.12: The sour taste of many foods is distinctive and is produced by the acids naturally present within the food or by acids added during its production.

Words like *sour* are used to provide a description. Oranges, lemon juice, or perhaps your favourite candy can be described as having a sour taste. Likewise, scientists use descriptive terms to communicate the behaviour of substances they investigate. Often, these descriptions are based on observations of the matter during experimentation. Descriptions of the response of substances to tests performed during an experiment can be used to make **empirical** definitions.

As described earlier, sour gas contains hydrogen sulfide, $H_2S(g)$. Since water is often present within pipes containing sour gas, hydrogen sulfide can dissolve into water to form an **aqueous solution**, represented as $H_2S(aq)$.

- **empirical:** a result of an observation
- **aqueous solution:** a solution in which water is the solvent

Practice

9. In previous science courses you were introduced to the terms *ionic compound*, *molecular compound*, *acid*, and *base*. Match each term with one of the following definitions.

a. a compound composed of oppositely charged particles, often metal and non-metal atoms; usually forms conductive solutions, called electrolytes, when dissolved in water

b. a corrosive solution containing hydrogen in the chemical formula of the solute

c. a compound composed of two or more non-metal atoms; may dissolve in water; only some form electrolytes, but most often form non-electrolytes

d. a caustic, corrosive solution; often contains a hydroxide ion and a group 1 or 2 metal in the periodic table

10. a. In previous science courses you worked with conductivity meters and litmus paper (red and blue litmus). Familiarize yourself with how and why each of these pieces of equipment is used. Summarize your review by copying and completing the following table.

Apparatus	Used to Identify	Expected Result for a Positive Test	Expected Result for a Negative Test
conductivity meter			
red litmus paper			
blue litmus paper			

b. Describe the experimental control used with each apparatus. Include the solution tested and the expected result for the test.

Empirical Properties of Acids, Bases, and Neutral Solutions

Careful planning and attention to detail is essential when you design an experiment or investigation. Your attention to detail, such as performing the same test on experimental controls, improves the quality of the data you collect. The quality of data is determined by considering validity and reliability when designing and performing the investigation. The "Reliability and Validity" table on page 167 demonstrates some questions and actions you might take to make your experimental design and procedure reliable and valid. By paying attention to these aspects, you will become more confident in your data.

RELIABILITY AND VALIDITY

Reliability	Validity
Questions the Way Experiment Is Performed Is it possible to obtain the same result if I repeat the experiment using the same method?	**Questions the Process Used to Obtain Measurements** Does this process measure what it is supposed to?
How to Improve Reliability • Repeat tests with both positive and negative experimental controls. • Perform frequent calibration checks. • Practise techniques and use of equipment.	**How to Improve Validity** • Select equipment that is appropriate for the experiment. • Select methods that others have used successfully to perform similar tasks. • Use the equipment appropriately.

In the next investigation you will test some aqueous solutions and describe the response of each solution to the tests. Once you are finished, you should be able to identify trends within your observations and develop a set of empirical definitions for the solutions tested.

Investigation

Testing Aqueous Solutions

Purpose

You will design and perform an experiment to identify acidic, basic, neutral molecular, and neutral ionic solutions.

Science Skills

✓ Initiating and Planning
✓ Performing and Recording

Materials

- 0.100-mol/L solutions of
  - $HCl(aq)$
  - $HNO_3(aq)$
  - $H_2SO_4(aq)$
  - $H_2S(aq)$
  - $NaOH(aq)$
  - $Na_2CO_3(aq)$
  - $Na_2SO_4(aq)$
  - $NaCl(aq)$
  - $CH_3OH(aq)$
- distilled or de-ionized water
- multiwell dish (or 13 watch glasses or Petri dishes)
- blue and red litmus paper
- magnesium turnings (or iron filings)
- stirring rod
- forceps or tweezers
- MSDS (Material Safety Data Sheet) for each solution
- conductivity meter (or tester)

Procedure

step 1: Develop an experimental design that includes the following considerations:

- **Safety:** Identify solutions that contain compounds that are irritants or that may cause some other safety concern. Consult the MSDS information for each solution.
- **Manipulation of apparatus:** If necessary, seek further instruction from your teacher regarding the use of the apparatus (e.g., the conductivity meter).
- **Cleanup:** Learn the proper procedure for the disposal of the chemicals. Determine how the apparatus should be cleaned.

step 2: Have your teacher approve your procedure before you begin.

step 3: Follow your procedure, and record your results.

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Analysis

1. Identify the positive and negative controls in the investigation.
2. Identify actions taken during the investigation that improved the quality of the data collected.
3. Describe how the data collected during the investigation demonstrates reliability.
4. Describe how the tests completed during the investigation address validity.

Trends and Patterns in Data

Trends and patterns within experimental data are important. When you look at the data from the "Testing Aqueous Solutions" investigation, do you notice that some of the solutions behaved in a similar manner? Is it possible to sort the solutions using the similarities in their behaviour to certain tests?

Did you notice how many of the solutions had a similar reaction to each type of litmus paper used in the tests? The sorting of substances based on their similar behaviours to certain tests was used to create the empirical definitions you explored earlier. Refer to the "Properties of Acids, Bases, and Neutral Solutions" table.

PROPERTIES OF ACIDS, BASES, AND NEUTRAL SOLUTIONS

Solution	Properties
acid	• electrolytic (conducts a current) • corrosive • turns blue litmus red • reacts with active metals (e.g., Mg, Zn, and Fe) to produce hydrogen gas • neutralized by bases and basic solutions • tastes sour
base	• electrolytic (conducts a current) • corrosive • turns red litmus blue • feels slippery (when diluted) • neutralized by acids and acidic solutions • tastes bitter
neutral	• can be electrolytic (if solute is an ionic compound) • does not change red or blue litmus

Types of Deposition

Emissions from industrial activities can carry sulfur dioxide and other substances great distances. A major factor in determining how long emissions will stay in the atmosphere is how quickly they come into contact with other materials in the environment. Emissions that contact liquid or solid forms of water in the atmosphere can dissolve and return as **wet deposition**. Gases and particles within emissions that are absorbed by Earth's surface are called **dry deposition**. Alberta has a dry climate. It is estimated that most of the pollution from emissions in Alberta occurs in the form of dry deposition. The terms *wet* and *dry* refer to the state of the material being deposited; therefore, it is possible for dry deposition to be deposited onto any surface, including bodies of water (e.g., lakes and rivers).

- **wet deposition:** gases or particles that are removed from the atmosphere by water (liquid or solid) and deposited as precipitation
- **dry deposition:** gases or particles that are transported by winds and absorbed by Earth's surface

Practice

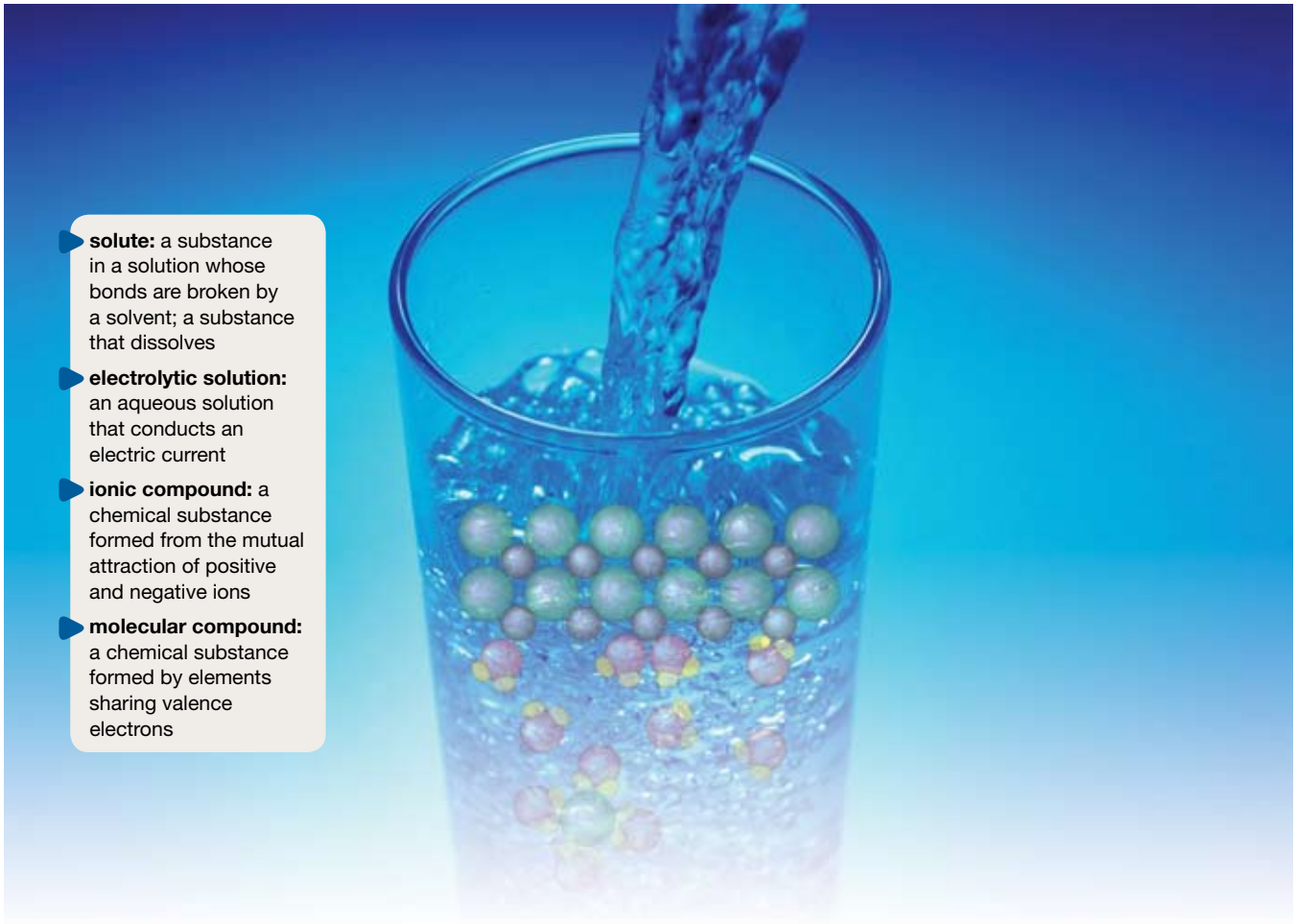
11. Copy and complete the following table to summarize the results from the "Testing Aqueous Solutions" investigation. For now, do not complete the Definition column.

Solution	Definition	Empirical Properties	Examples
acidic			
basic			
neutral			

What Makes a Solution Acidic?

Earlier, you were able to use similarities within your observations to classify a solution as being acidic, basic, or neutral. You also saw that the groupings you made coincided with the known empirical properties for acids, bases, and neutral solutions. Apart from these similarities, did you note any other similarities among the acidic solutions?

Acids are a special group of chemical compounds. Did you notice that all of the substances categorized as acids contain hydrogen and were dissolved in water? You may have also noted that all the acidic solutions tested were **electrolytic solutions**, even if their chemical formula suggests that the **solute** is a **molecular compound**. Although many acids are molecular compounds, all acids appear to behave like **ionic compounds** when dissolved in water. Acids tend to form electrolytic solutions, whereas molecular compounds form non-electrolytic solutions. As you will soon see, the microscopic changes that occur within a solution containing a dissolved acid are important when explaining the properties of acids.

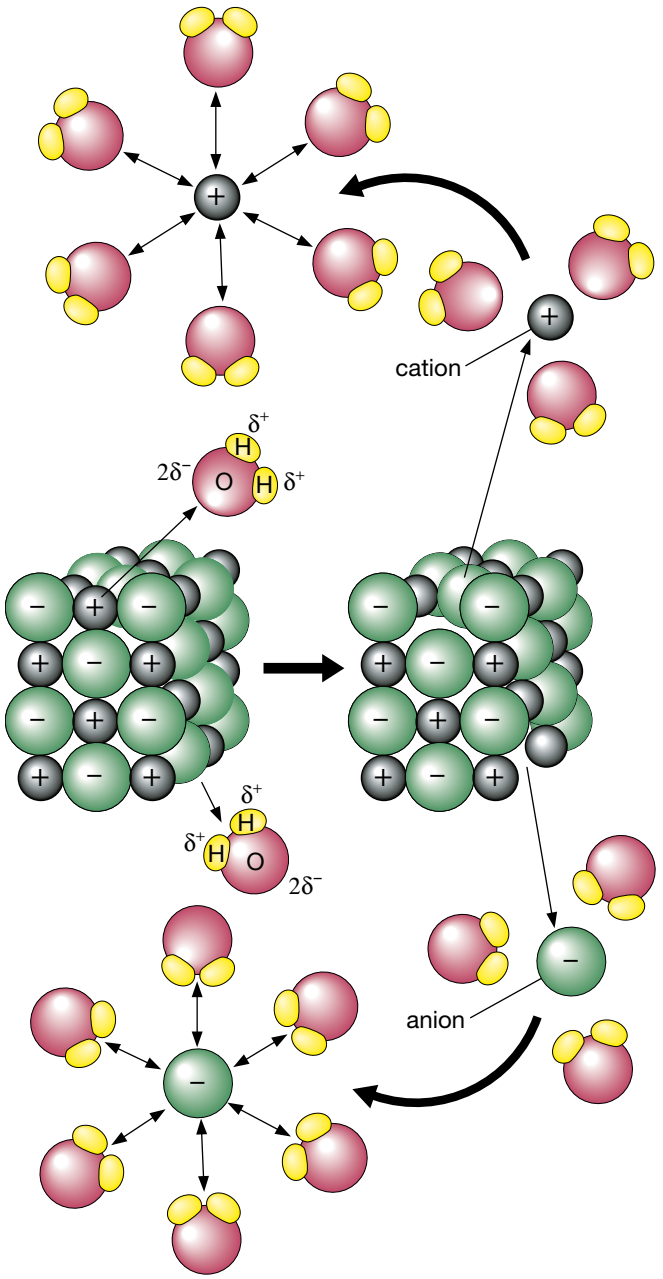


- **solute:** a substance in a solution whose bonds are broken by a solvent; a substance that dissolves
- **electrolytic solution:** an aqueous solution that conducts an electric current
- **ionic compound:** a chemical substance formed from the mutual attraction of positive and negative ions
- **molecular compound:** a chemical substance formed by elements sharing valence electrons

Acids and Bases in Solutions

Conductive solutions contain freely moving ions. In previous science courses you discovered that water molecules break the bonds between ions in an ionic solute, causing the ions to dissociate. **Dissociation** occurs due to **electrostatic attraction** between the charged ions of the solute and the charges on water molecules. Although dissociation cannot be seen, a positive conductivity test—implying that charged particles are present and are able to move within the solution being tested—is indirect evidence of this microscopic change. In 1834, an English physicist by the name of Michael Faraday was the first scientist to demonstrate that acids, bases, and salts (later determined to be composed of ionic compounds) all dissolve in water to form electrolytes.

Water Molecules Dissolving an Ionic Crystal



- **dissociation:** the separation of a chemical substance into its individual ions in a solution
- **electrostatic attraction:** a force that acts to pull oppositely charged objects toward each other

Science Links

Many phenomena, including lightning, result from electrostatic attraction between oppositely charged particles. In Unit C you will study the fields that surround objects and how forces like electrostatics are the product of fields.

Conductivity tests have demonstrated that all acidic solutions also conduct an electric current, indicating that the acid molecule has formed ions. Is this observation connected to the fact that all acids contain hydrogen? Some scientific theories attempting to explain the properties and behaviours of acids have focused on the ability of acids to form hydrogen ions in water.

In 1887, a Swedish chemist named Svante Arrhenius published a theory that suggested that acids form aqueous solutions that contain hydrogen ions, $H^+(aq)$, and a negatively charged ion. His theory also proposed that bases form solutions that contain hydroxide ions, $OH^-(aq)$, and a positively charged ion. Although not defined by this theory, solutions that produced neither a hydrogen ion nor a hydroxide ion can be considered neutral electrolytic solutions.

Figure B1.13: Svante Arrhenius (1859–1927)

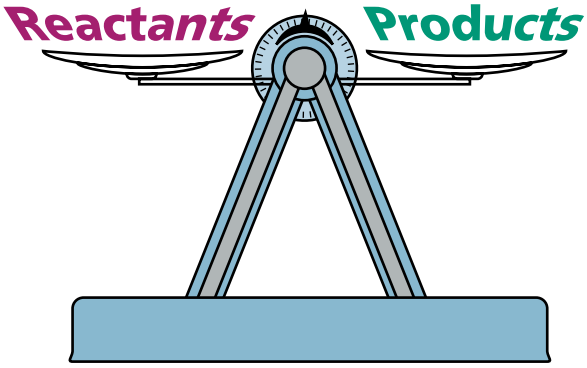
Changes to Solutes in Aqueous Solutions

Acids: e.g., hydrochloric acid
$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$

Bases: e.g., potassium hydroxide
$KOH(aq) \rightarrow K^+(aq) + OH^-(aq)$

Neutral Substances: e.g., calcium chloride
$CaCl_2(aq) \rightarrow Ca^{2+}(aq) + 2\ Cl^-(aq)$

Balancing Chemical Equations



Balancing a chemical equation using coefficients demonstrates that all the atoms on the reactants side of the equation have been accounted for on the products side. Recall that matter cannot be created nor destroyed. Coefficients represent the number of each particle involved. When properly balanced, the net charge on each side of the equation will be the same.

Balancing Equations

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

H = 1, Cl = 1
net charge = 0

H = 1, Cl = 1
net charge = 1(1+) + 1(1–)
= 0

coefficient needed to balance chloride ions

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

Ca = 1, Cl = 2
net charge = 0

Ca = 1, Cl = 2
net charge = 1(2+) + 2(1–)
= 0

Chemical equations are balanced when

- an equal number of each type of atom appears on each side of the equation
- the net charge on each side of the equation is equal

Practice

12. Write a balanced equation for the change that occurred with each substance when it was dissolved in water.

a. $HNO_3(aq)$
b. $H_2SO_4(aq)$
c. $H_2S(aq)$
d. $NaOH(aq)$
e. $Na_2CO_3(aq)$
f. $Na_2SO_4(aq)$
g. $NaCl(aq)$

13. Use the equations written in question 12 to predict whether each solution listed is acidic, basic, or neutral. List any inconsistencies.

Limitations to Arrhenius's Theory

As previously stated, when chemical substances separate into their individual ions in a solution, this is called dissociation. Dissociation equations like that for $Na_2CO_3(aq)$, may be written to explain how ionic solutions can conduct an electric current.

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

Arrhenius's theory states that the presence of hydroxide ions in the chemical formula of a solute explain its basic properties. $Na_2CO_3(aq)$, in solution, has definite basic properties. However, you can see that the above equation does not show the presence of $OH^{-}(aq)$ ions. How can these ions be responsible for basic properties? A similar problem exists for substances like $AlCl_3(aq)$, which is acidic in solution.

A second problem with Arrhenius's theory focuses on the possible existence of a free hydrogen ion moving among water molecules in a solution. Scientists questioned the possibility of free hydrogen ions existing within an aqueous solution. The simplest element is hydrogen, composed of one proton and one electron. Hydrogen atoms become positively charged when the single electron is removed. The absence of any electron, combined with the small size of hydrogen's atomic nucleus, results in the hydrogen ion having a very strong positive charge.

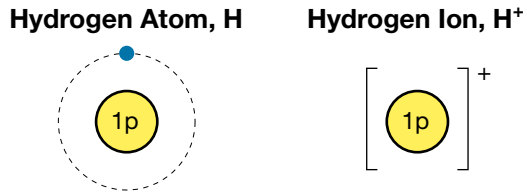


Figure B1.14: *Hydrogen ion, proton . . .* there are times when scientific terms can seem confusing. Can you explain why scientists sometimes refer to a hydrogen ion as a proton?

Many of the unique properties of a water molecule, including its ability to dissociate a solute, are explained by the **polarity** of the water molecule. Part of the polarity of the water molecule is due to exposed pairs of electrons located on the molecule's surface. Since electrons have a negative charge, the areas on the surface of a water molecule where these pairs of electrons are located will also have a partial negative charge. An electrostatic attraction between the positively charged hydrogen atom and the negatively charged areas of the water molecule provides an opportunity for these two objects to combine. The hydrogen ion becomes bound to the water molecule. The product of this reaction is the **hydronium ion**, $H_3O^+(aq)$.

polarity: the presence of different regions of charge on a molecule

hydronium ion: an ion created when a water molecule combines with a hydrogen ion; $H_3O^+(aq)$

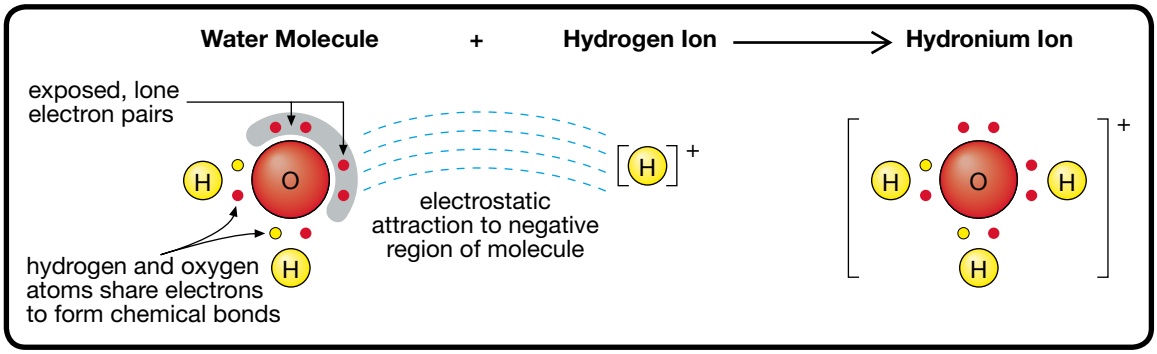


Figure B1.15: The creation of hydronium

Since the development of Arrhenius's theory, evidence has supported the existence of the hydronium ion, $H_3O^+(aq)$, within aqueous solutions. Currently, the hydronium ion is recognized as the acidic particle.

Apart from clarifying that the hydronium ion is the particle responsible for the acidity of solutions, later theories emphasized the importance of collisions between substances, including water, within a chemical system. In previous science courses, water was referred to as an excellent medium for chemical change that enables other particles to collide. Now, when you think of reactions within a solution, you may find that water is one of the reactants.

Exchange of Hydrogen Ions

You may have wondered if a collision between a hydronium ion and a water molecule could result in the transfer of the hydrogen ion to other water molecules or to other substances. The possibility of transferring hydrogen ions between substances within a solution stimulated the development of other theories to explain the behaviour of acids and bases.

In 1923, a Danish chemist—Johannes Brønsted—and an English chemist—Thomas Lowry—independently published similar theories that described an alternate way of explaining the behaviour of acids and bases. The coincidence of two scientists working in the same area of research and publishing similar theories was rare at the time. If you think this coincidence is strange, at the time Brønsted and Lowry did their work, there was no e-mail, Internet, or jet-airplane travel. Back then, the opportunities for scientists to meet and exchange ideas were greatly limited. The significance of these two researchers independently developing the same theory was great.

Figure B1.16: Johannes Brønsted (1879–1947)

Figure B1.17: Thomas Lowry (1874–1936)

Scientific ideas and discoveries undergo a process of peer review that is designed to ensure the reliability of the experimentation, the validity of the data, and its interpretation. Peer review is one way scientists can check the work of others. During peer review, scientists analyze the details of how the data was collected, the data itself, the methods used to interpret data, and the ideas and theories developed from the interpretation of the data. Often, during the peer-review process, the reviewers may suggest that further experimentation is needed to provide better support for the conclusions.

DID YOU KNOW?

In their haste to publish a scientific discovery of cold fusion, Stanley Pons and Martin Fleishman chose to share their experimental findings with the media before the peer review. They made headlines twice: once for the discovery of cold fusion—a process believed to produce energy—and the other after their work was peer reviewed and found to be invalid.

For scientists, the peer-review process is a means by which scientific knowledge is scrutinized and determined to be meaningful and valid. Before publishing their theories, Brønsted and Lowry would have had their work examined by groups of scientists. By following the peer-review process, the Brønsted-Lowry theory was quickly accepted into the scientific body of knowledge.

Writing Brønsted-Lowry Acid-Base Reactions

Unlike the theories you have seen to this point, the Brønsted-Lowry theory attempts to describe the action of acids and bases during a chemical reaction. According to this theory, a hydrogen ion is transferred from an **acid** (the donor) to a **base** (the acceptor) during acid-base reactions. The Brønsted-Lowry theory often refers to the hydrogen ion as a proton. The products of an acid-base reaction are a **conjugate acid** and a **conjugate base**.

According to the Brønsted-Lowry Acid-Base Reactions, an acid-base reaction involves the transfer of a hydrogen ion from an acid to a base. The loss or donation of a hydrogen ion by an acid converts it into a conjugate base—another form of the substance. The conjugate base form of the substance can be recognized by the loss of a hydrogen ion in its chemical formula. The gain or acceptance of a hydrogen ion by a base converts it into a conjugate acid—its alternate form that contains the transferred hydrogen ion. The chemical formulas for many acids and bases, including their conjugate forms, are shown on the "Table of Acids and Bases." This table also appears in the Science Data Booklet, called "Relative Strengths of Selected Acids and Bases for 0.10 mol/L Solution at 25°C."

TABLE OF ACIDS AND BASES

Acid Name	Acid Formula	Conjugate Base Formula
hydrochloric acid	$HCl(aq)$	$Cl^-(aq)$
sulfuric acid	$H_2SO_4(aq)$	$HSO_4^-(aq)$
nitric acid	$HNO_3(aq)$	$NO_3^-(aq)$
hydronium ion	$H_3O^+(aq)$	$H_2O(l)$
oxalic acid	$HOOCCOOH(aq)$	$HOOCCOO^-(aq)$
sulfurous acid	$H_2SO_3(aq)$	$HSO_3^-(aq)$
hydrogen sulfate ion	$HSO_4^-(aq)$	$SO_4^{2-}(aq)$
phosphoric acid	$H_3PO_4(aq)$	$H_2PO_4^-(aq)$
orange IV	$HOr(aq)$	$Or^-(aq)$
nitrous acid	$HNO_2(aq)$	$NO_2^-(aq)$
hydrofluoric acid	$HF(aq)$	$F^-(aq)$
methanoic acid	$HCOOH(aq)$	$HCOO^-(aq)$
methyl orange	$HMo(aq)$	$Mo^-(aq)$
benzoic acid	$C_6H_5COOH(aq)$	$C_6H_5COO^-(aq)$
ethanoic (acetic) acid	$CH_3COOH(aq)$	$CH_3COO^-(aq)$
carbonic acid, $CO_2(g) + H_2O(l)$	$H_2CO_3(aq)$	$HCO_3^-(aq)$
bromothymol blue	$HBb(aq)$	$Bb^-(aq)$
hydrosulfuric acid	$H_2S(aq)$	$HS^-(aq)$
phenolphthalein	$HPh(aq)$	$Ph^-(aq)$
boric acid	$H_3BO_3(aq)$	$H_2BO_3^-(aq)$
ammonium ion	$NH_4^+(aq)$	$NH_3(aq)$
hydrogen carbonate ion	$HCO_3^-(aq)$	$CO_3^{2-}(aq)$
indigo carmine	$HIc(aq)$	$Ic^-(aq)$
water (55.5 mol/L)	$H_2O(l)$	$OH^-(aq)$

- **acid:** the substance that donates or loses a hydrogen ion to another substance during a chemical reaction
- **base:** the substance that accepts or gains a hydrogen ion from another substance during a chemical reaction
- **conjugate acid:** an acid formed in an acid-base reaction when a base accepts a hydrogen ion (or proton)
- **conjugate base:** a base formed in an acid-base reaction when an acid donates a hydrogen ion (or proton)

The information in the "Table of Acids and Bases" can be used to identify the reactants and predict the products of an acid-base reaction between certain substances.

Example Problem 1.2

Sour gas contains hydrogen sulfide, $H_2S(g)$. Hydrogen sulfide can dissolve and react with water in the atmosphere. Write the chemical equation of the reaction between aqueous hydrogen sulfide and water.

Solution

step 1: Locate $H_2S(aq)$ and $H_2O(l)$ on the "Table of Acids and Bases."

TABLE OF ACIDS AND BASES

Acid Name	Acid Formula	Conjugate Base Formula
hydrochloric acid	$HCl(aq)$	$Cl^-(aq)$
sulfuric acid	$H_2SO_4(aq)$	$HSO_4^-(aq)$
nitric acid	$HNO_3(aq)$	$NO_3^-(aq)$
hydronium ion	$H_3O^+(aq)$	$H_2O(l)$
⋮	⋮	⋮
bromothymol blue	$HBb(aq)$	$Bb^-(aq)$
hydrosulfuric acid	$H_2S(aq)$	$HS^-(aq)$
phenolphthalein	$HPh(aq)$	$Ph^-(aq)$
⋮	⋮	⋮
hydrogen carbonate ion	$HCO_3^-(aq)$	$CO_3^{2-}(aq)$
indigo carmine	$HIc(aq)$	$Ic^-(aq)$
water (55.5 mol/L)	$H_2O(l)$	$OH^-(aq)$

step 2: Identify the acid and the base in the reaction. Recall that the stronger acids appear higher in the Acid Formula column and the stronger bases appear lower in the Conjugate Base Formula column.

The acid is $H_2S(aq)$ because it appears higher in the column than $H_2O(l)$. The base is $H_2O(l)$.

step 3: Write the reactants side of the chemical equation.

$$H_2S(aq) + H_2O(l) \rightarrow$$

step 4: Identify the conjugate forms of the acid and the base.

TABLE OF ACIDS AND BASES

Acid Name	Acid Formula	Conjugate Base Formula
⋮	⋮	⋮
nitric acid	$HNO_3(aq)$	$NO_3^-(aq)$
hydronium ion	$H_3O^+(aq)$	$H_2O(l)$
⋮	⋮	⋮
bromothymol blue	$HBb(aq)$	$Bb^-(aq)$
hydrosulfuric acid	$H_2S(aq)$	$HS^-(aq)$
⋮	⋮	⋮

step 5: Write the conjugate forms on the products side of the chemical equation.

acid loses a hydrogen ion to form the conjugate base

$$H_2S(aq) + H_2O(l) \rightarrow HS^-(aq) + H_3O^+(aq)$$

base gains a hydrogen ion to form the conjugate acid

Therefore, the chemical equation for the reaction of aqueous hydrogen sulfide and water is

$$H_2S(aq) + H_2O(l) \rightarrow HS^-(aq) + H_3O^+(aq)$$

The Brønsted-Lowry theory gained acceptance within the scientific community because it was able to describe a mechanism for the reaction between acids and bases in aqueous solutions. The theory also explained the production of a hydronium ion by acids when dissolved in water.

Practice

14. Write the chemical equation for the following reactions. Label the acid, the base, the conjugate acid, and the conjugate base in each reaction.

a. Dissolved nitric acid, $HNO_3(aq)$, reacts with water, $H_2O(l)$.

b. Carbonic acid in rainwater reacts with water.

Example Problem 1.3

Hydrofluoric acid, HF(aq), used to remove oxide coatings from metals prior to electroplating, can be neutralized by a reaction with the hydroxide ion, $OH^-(aq)$, of aqueous sodium hydroxide. Write the chemical equation for this neutralization reaction.

Solution

step 1: Locate HF(aq) and $OH^-(aq)$ on the "Table of Acids and Bases."

TABLE OF ACIDS AND BASES

Acid Name	Acid Formula	Conjugate Base Formula
hydrochloric acid	HCl(aq)	$Cl^-(aq)$
sulfuric acid	$H_2SO_4(aq)$	$HSO_4^-(aq)$
⋮	⋮	⋮
nitrous acid	$HNO_2(aq)$	$NO_2^-(aq)$
hydrofluoric acid	HF(aq)	$F^-(aq)$
methanoic acid	HCOOH(aq)	$HCOO^-(aq)$
⋮	⋮	⋮
hydrogen carbonate ion	$HCO_3^-(aq)$	$CO_3^{2-}(aq)$
indigo carmine	HIc(aq)	$Ic^-(aq)$
water (55.5 mol/L)	$H_2O(l)$	$OH^-(aq)$

step 2: Identify the acid and the base in the reaction.

The acid is HF(aq), and the base is $OH^-(aq)$.

step 3: Write the reactants side of the chemical equation.

$$HF(aq) + OH^-(aq) \rightarrow$$

step 4: Identify the conjugate forms of the acid and the base.

acid: $HF(aq) \rightarrow F^-(aq)$

base: $OH^-(aq) \rightarrow H_2O(l)$

step 5: Write the conjugate forms on the products side of the chemical equation.

acid loses a hydrogen ion to form the conjugate base

$$HF(aq) + OH^-(aq) \rightarrow F^-(aq) + H_2O(l)$$

base gains a hydrogen ion to form the conjugate acid

Therefore, the chemical equation for this neutralization reaction is

$$HF(aq) + OH^-(aq) \rightarrow F^-(aq) + H_2O(l)$$

Practice

15. Oxalic acid, HOOCCOOH(aq), is often used in industry to clean and sterilize containers. Write the chemical equation for the reaction of oxalic acid, HOOCCOOH(aq), and the hydroxide ion, OH^-(aq). Label the acid, the base, the conjugate acid, and the conjugate base.

Arrhenius's theory was not able to explain the basic properties of solutions like sodium carbonate, Na_2CO_3(aq). Solutions like these are not composed of hydroxide ions; however, they can produce hydroxide ions due to a reaction with water.

Example Problem 1.4

In the "Testing Aqueous Solutions" investigation, aqueous sodium carbonate, Na_2CO_3(aq), turned red litmus paper blue, indicating a basic solution. Write the chemical equation for the reaction between dissociated carbonate ions, CO_3^{2-}(aq), and water.

Solution

Locate CO_3^{2-}(aq) and H_2O(l) on the "Table of Acids and Bases," and identify the acid and the base in the reaction.

The acid is H_2O(l), and the base is CO_3^{2-}(aq).

Next, write the reactants side of the chemical equation.

$$H_2O(l) + CO_3^{2-}(aq) \rightarrow$$

Now, identify the conjugate forms of the acid and the base. Write these on the products side of the chemical equation.

acid loses a hydrogen ion to form the conjugate base

$$H_2O(l) + CO_3^{2-}(aq) \rightarrow OH^-(aq) + HCO_3^-(l)$$

base gains a hydrogen ion to form the conjugate acid

Therefore, the chemical equation for the reaction is

$$H_2O(l) + CO_3^{2-}(aq) \rightarrow OH^-(aq) + HCO_3^-(aq)$$

Note: The product OH^-(aq) is responsible for the basic properties of the solution.

Example Problem 1.4 shows that another aspect of the Brønsted-Lowry theory is its ability to describe the behaviour of water—either donating or accepting a hydrogen ion—and to explain its important role in acid-base reactions.

Practice

16. Write the chemical equation for each reaction given. Label the acid, the base, the conjugate acid, and the conjugate base in each reaction.

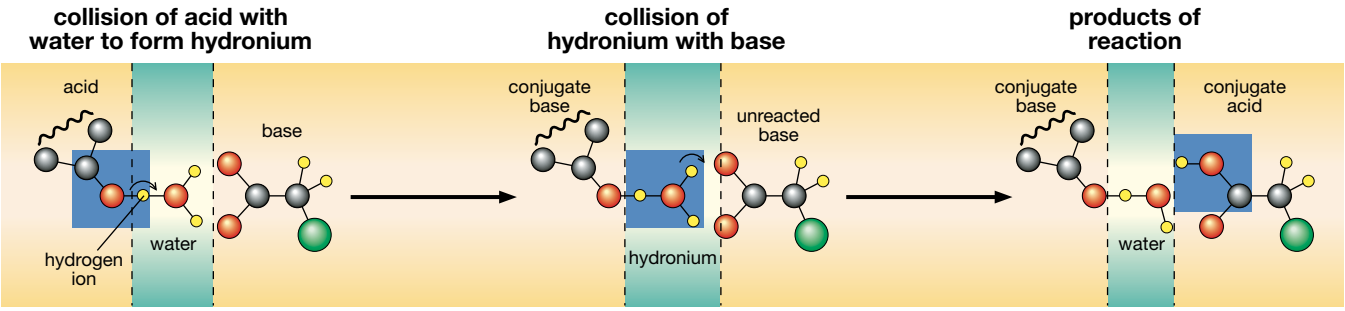
a. Sulfuric acid, H_2SO_4(aq), spilled during a lab procedure, reacts with the hydrogen carbonate ion, HCO_3^-(aq), present within an acid spill kit.

b. During the production of fertilizer, aqueous ammonia, NH_3(aq), reacts with phosphoric acid, H_3PO_4(aq).

17. Earlier, you determined that one of the empirical properties of acids and bases is that they act to neutralize each other. Using the Brønsted-Lowry theory, concisely explain how the neutralization of an acid or base occurs during an acid-base reaction.

Proton Hopping

Recent experiments to investigate the mechanism of hydrogen-ion transfer between acids and bases in aqueous solutions appear to have confirmed the description of the behaviour of acids and bases provided by the Brønsted-Lowry theory. Using lasers, a group of scientists were able to capture a series of images, like snapshots, of the motion of a chemical reaction between an acid and a base. The scientists expected to see the transfer of the hydrogen ion between the acid and the base present in the system, as would be described by a chemical equation similar to those you have written thus far. What the snapshots showed was unexpected: the acid and the base did not appear to come in contact with each other. The snapshots showed water molecules being converted into hydronium ions when they collided with the acid, followed by a collision between the hydronium and the base. This reaction resulted in the loss of a hydrogen ion to the base. The experiment demonstrated that water molecules in the system underwent many acid-base reactions, acting like a shuttle to transfer hydrogen ions between the acid and the base.



Although this research won't affect the way you write a reaction between an acid and a base, it provides a great deal of insight into the mechanism involved during a reaction. The research further supports the use of the Brønsted-Lowry theory when you write, explain, or predict reactions between acids and bases within an aqueous chemical system.

Emissions Can React

In Lesson 1.1 you saw how products from combustion reactions had an effect on bromothymol blue (an acid-base indicator). When the gases within exhaled air or gases from the combustion of coal were bubbled through the water containing bromothymol blue, a colour change occurred that indicated a change to an acidic system. How can bubbling gases through water result in a change to the acidity of the water?

PRODUCTS OF COMBUSTION REACTIONS AND THEIR SOURCES

Product of Combustion	Source
$CO(g)$, $CO_2(g)$	• carbon present in hydrocarbon fuels
$SO_2(g)$, $SO_3(g)$	• sulfur present in fuels • combustion of $H_2S(g)$, a component of sour gas
$NO(g)$, $NO_2(g)$	• air from the atmosphere that contains nitrogen

To summarize, products of combustion reactions (the substances shown in the table) are released into the atmosphere as emissions. Also, water is present in the atmosphere and on Earth's surface, and emissions are removed from the atmosphere in the form of wet or dry deposition. Even as dry deposition, these substances eventually come into contact with water. As you have seen, water can react with many substances.

Figure B1.18: Condensation that forms on the outside of a drinking glass was once water vapour present in the atmosphere. The presence of water and other substances makes the atmosphere a chemical system—a site for many chemical changes.

Most of the oxides of carbon, sulfur, and nitrogen shown in the "Products of Combustion Reactions and Their Sources" table can react with water. Refer to Figure B1.19.

Reactions of Certain Oxides with Water

Oxides of Carbon

carbon dioxide: $CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$

Oxides of Sulfur

sulfur dioxide: $SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$

sulfur trioxide: Sulfur dioxide, produced during combustion reactions, can convert into sulfur trioxide by reacting with oxygen present in the atmosphere. The sulfur trioxide then reacts with water to produce an acidic substance.

$SO_2(g) + O_2(g) \rightarrow SO_3(g)$

$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$

Note: The term SO_x is sometimes used to refer to the presence of both $SO_2(g)$ and $SO_3(g)$ in the atmosphere.

Oxides of Nitrogen

nitrogen monoxide: Nitrogen monoxide, produced by combustion reactions, can convert into nitrogen dioxide by reacting with oxygen present in the atmosphere.

$NO(g) + O_2(g) \rightarrow NO_2(g)$

It is the $NO_2(g)$ that reacts with water to produce acidic substances.

nitrogen dioxide: $NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq)$

$NO_2(g) + H_2O(l) + O_2(g) \rightarrow HNO_3(aq)$

Note: The term NO_x refers to the presence of both NO(g) and $NO_2(g)$ in the atmosphere.

Figure B1.19

Practice

18. Copy each reaction equation listed in Figure B1.19. Balance each equation.

19. Use the "Table of Acids and Bases" on page 173 to identify the names of the hydrogen-containing products in the reaction equations. Write the name for each of the products beside its chemical formula shown in the equation.

20. The products of the reactions in Figure B1.19 often remain dissolved in water that falls toward Earth as precipitation or exists in lakes and other bodies of water. Predict the effect that the products of the reactions shown in Figure B1.19 will have on the water it dissolves in. If possible, use chemical equations to support your prediction.

anthropogenic: coming from human activity

acid deposition: airborne particles containing acids or acid-forming substances contained within precipitation (wet deposition) or that absorb directly into parts of Earth's surface (dry deposition)

Acid Deposition

The chemical reactions you have studied thus far describe the origin and consequences of substances released as emissions from human activity. **Anthropogenic** emissions of carbon dioxide, $CO_2(g)$, sulfur oxides, $SO_2(g)$ and $SO_3(g)$, NO_x or nitrous oxides, NO(g) and $NO_2(g)$, originate from human-made processes that involve combustion, such as energy production and transportation. The chemical equations you have written describe how these emissions are able to react with water and form **acid deposition**. Areas exposed to wet or dry acid deposition can experience a number of effects, some of which you may be able to predict based on what you have already learned about acids from previous investigations.

Figure B1.20: Water from melting snow can contain acids that were originally deposited in either wet or dry form.

The term **acid rain** describes the excessive amount of acidity within precipitation. It surprises many people to learn that rainfall is naturally acidic. Natural processes, like cellular respiration, produce substances that can form acids. Carbon dioxide, $CO_2(g)$, for example, can react with water to form carbonic acid, $H_2CO_3(aq)$, which results in the production of hydronium ions, $H_3O^+(aq)$. The oxides of carbon, nitrogen, and sulfur are present in Earth's atmosphere as a result of natural processes and anthropogenic sources. Other natural processes that release emissions include burning biomass (forest fires), lightning, the erosion of carbonate-based rock formations, the release of volcanic gases, and the action of bacteria in marine or terrestrial habitats.

acid rain: any form of precipitation (wet deposition) containing an excess of dissolved acids; wet deposition with a pH of 5.6 or less

The amount of acid present within a solution can be measured. The method used can determine whether precipitation contains higher amounts of acids than would be expected. In many areas of the world, acid deposition is largely due to the emissions from human activities. The amount of acid deposition in a region can vary over time, even over seasons. Can you predict the effect that melting snow has on the amount of acid present in streams and bodies of water in Alberta?

Practice

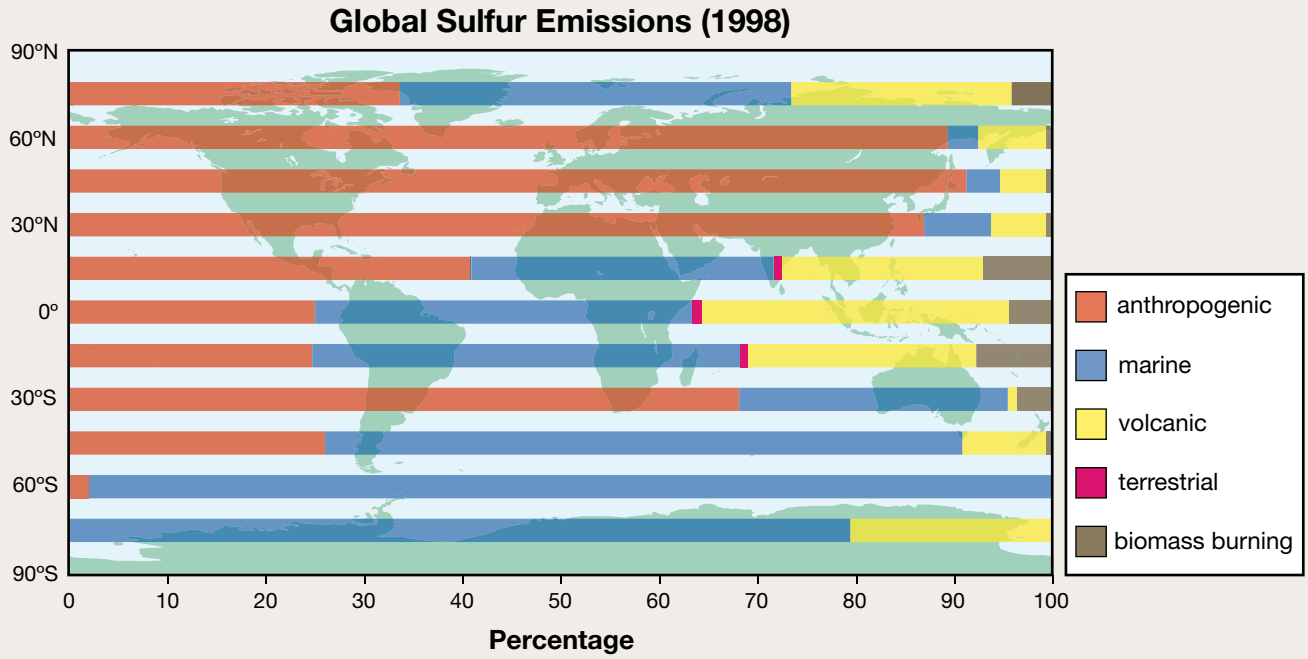
21. Analyze the graph "Global Sulfur Emissions (1998)."

a. Prepare a table that lists the following values by latitude:

- percentage of emissions from anthropogenic sources
- percentage of emissions from natural sources

b. Calculate a ratio of anthropogenic sources to natural sources for each latitude zone shown and for the world.

c. Identify areas where you suspect higher levels of acid deposition may occur.



Measuring Acids

Figure B1.21: The level of acidity in a swimming pool is checked by measuring the water's pH.

During the hot summer days, the place to be is at the local swimming pool. But before anyone can go in the water, lifeguards must take measurements of the water's acidity to ensure that it will not cause any harm. Acids are corrosive. Acidic solutions react with metals and often have warning labels to remind you of their ability to react with your skin.

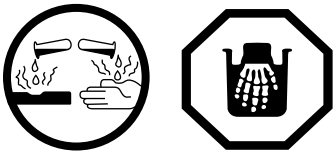


Figure B1.22: Labelling products using WHMIS symbols or HHPS (Household Hazardous Products Symbols) alert users of the possible risks and appropriate safety precautions.

pH

One way to measure the amount of acid in a solution—expressed as a concentration of hydronium ions, $H_3O^+(aq)$—is by measuring the solution's pH. Concentrated acidic solutions contain a larger number of moles of hydronium ions within each millilitre or litre of solution than dilute acidic solutions. You may have noticed that some of the labels on cleaning products containing acids or bases in your home indicate that they are "concentrated." If the same amount of concentrated cleaner and dilute cleaner were tested, the concentrated solution should remove a stain more quickly than the dilute solution because of the higher number of particles available to react with the molecules in the affected area. Recall that the presence of hydronium ions, $H_3O^+(aq)$, gives a solution its acidic properties. The concentration of hydronium ions within an acidic solution influences other aspects of the reaction involving acids, including

pH: a value that represents the concentration of dissolved hydronium ions, $H_3O^+(aq)$, within a solution

- how quickly the solution will begin to react
- how much change the acid may cause
- the amount of base required to neutralize the acid
- the amount of base or metal it will react with

In Alberta, the pH of rainfall is routinely measured at a number of locations throughout the province to provide information about acid deposition.

Calculating pH and the pH Scale

The pH scale was developed in 1909 by a Danish scientist named Soren Sörenson. He developed the scale as a means to better communicate the acidity of a solution. Scientists at that time observed that the level of acidity of a solution did not always correspond to the concentration of the acid dissolved in the solution. Not all acids react completely with water, thus producing solutions with lower concentrations of hydronium ions. Sörenson's system was designed to measure the concentration of hydronium ions present in dilute solutions, thereby providing a better description of a solution's level of acidity. A solution with a pH of 7 is considered to be neutral; a solution with a pH less than 7 is considered to be acidic; and a solution with a pH greater than 7 is considered to be basic. Figure B1.23 shows the pH scale along with examples of common substances.

pH = 0	battery acid
pH = 1	stomach acid
pH = 2	lemon juice
pH = 3	vinegar, orange juice, cola
pH = 4	tomato juice, acid rain
pH = 5	coffee (black), rain
pH = 6	urine, saliva (healthy), cow's milk
pH = 7	distilled water, human blood
pH = 8	sea water
pH = 9	baking soda
pH = 10	milk of magnesia, detergent
pH = 11	ammonia solution, household cleaners
pH = 12	hand soap
pH = 13	bleach, oven cleaner, household lye
pH = 14	liquid drain cleaner

Figure B1.23: pH scale

The exponent of the hydronium-ion concentration, when expressed in scientific notation, can be used to approximate a solution's pH. For example, a pH of 6.0 corresponds with a hydronium-ion concentration of 1×10^{-6} mol/L, which can also be expressed as 0.000 001 mol/L. A solution with a pH of 6.0 has a larger concentration of hydronium ions than a solution with a pH of 7.0, which corresponds to a hydronium-ion concentration of 1×10^{-7} mol/L or 0.000 000 1 mol/L. By dividing the hydronium-ion concentration of a solution with a pH of 6.0 by the hydronium-ion concentration of a solution with a pH of 7.0, you will see that the solution with the pH of 6.0 has ten times more hydronium ions than the solution with the pH of 7.0.

$$\frac{\text{solution with pH 6.0}}{\text{solution with pH 7.0}} = \frac{H_3O^+\text{concentration}}{H_3O^+\text{concentration}}$$
$$= \frac{1\times10^{-6}\text{ mol/L}}{1\times10^{-7}\text{ mol/L}}$$
$$= 10$$

Each whole-number division on the pH scale represents a ten-fold difference in the concentration of hydronium ions from the value above or below it. As you move down the scale toward higher pH values, the hydronium-ion concentration decreases, and vice versa as you move up the scale toward lower pH values. A change of two pH steps on the scale represents two ten-fold changes, or a 100-fold change, to the hydronium-ion concentration. If you compare the hydronium-ion concentration of a solution with a pH of 4 with that of a solution with a pH of 9, there is a 100 000-fold (10^5) difference in hydronium-ion concentration.

The pH scale was developed using dilute solutions of acids and bases. The concentration of hydronium ions within a dilute solution is small and is often expressed in scientific notation as an exponent to the base 10. Because logarithms calculate exponents, you can use the logarithm function on your calculator. Use the following equation to calculate pH.

$$pH = -\log_{10}[H_3O^+(aq)]$$

The pH of concentrated acid solutions can be below the range of the pH scale. A pH of 0 corresponds to a solution containing a hydrogen-ion concentration of 1.00 mol/L (1×10^0 mol/L). Concentrated stock acid solutions used in laboratories can have negative pH values.

Example Problem 1.5

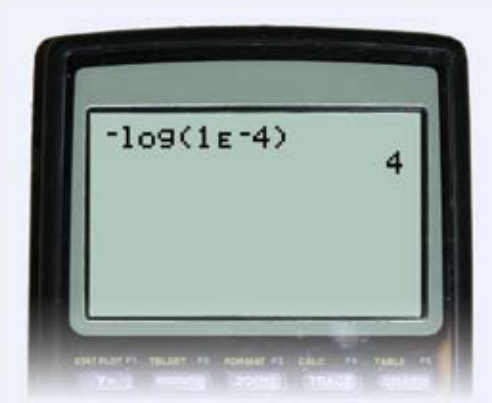
Determine the pH of a sample of rainwater that has a hydronium-ion concentration, $[H_3O^+(aq)]$, of 1.00×10^{-4} mol/L.

Solution

$$pH = -\log_{10}[H_3O^+(aq)]$$
$$= -\log_{10}(1.00 \times 10^{-4}\text{ mol/L}) \leftarrow \text{Substitute the hydronium-ion concentration.}$$
$$= 4$$

Keystrokes for Graphing Calculator

(–) LOG 1 2nd [EE] (–) 4) ENTER



The pH of the rainwater is 4.000, expressed to the appropriate number of significant digits.

Example Problem 1.6

A sample of lake water has a hydronium-ion concentration of 2.27×10^{-7} mol/L. Determine the pH of the lake water.

Solution

$$\begin{aligned} pH &= -\log_{10}[H_3O^+(aq)] \\ &= -\log_{10}(2.27 \times 10^{-7}\ \text{mol/L}) \\ &= 6.644 \quad \leftarrow \text{3 significant digits} \end{aligned}$$

The lake water has a pH of 6.644.

Significant Digits and pH Calculations

Using logarithms to represent calculations is convenient, but care must be taken to show the appropriate number of significant digits. The number to the left of the decimal point in a pH value represents the order of magnitude of the hydronium-ion concentration, reflected by the exponent of the base 10 when that concentration is written in scientific notation. The exponent provides information only about how large or small the number is, not how accurately it was measured. Accuracy of measurement is determined by examining the other numbers before and after the decimal point. Significant digits in a pH value are written using the appropriate number of digits after the decimal point.

Significant Digits and pH Values

$[H_3O^+(aq)]$ concentration = 0.000 010 mol/L

$= 1.0 \times 10^{-5}$ mol/L

2 significant digits

$pH = -\log_{10}[H_3O^+(aq)]$

$= -\log_{10}(1.0 \times 10^{-5}\ \text{mol/L})$

$= 5.00$

2 significant digits

Calculating Hydronium Ions

An algebraic relationship in mathematics, such as a formula, can be rearranged to solve for any variable in the formula. Therefore, the formula to calculate pH can be rearranged to solve for the hydronium-ion concentration when a solution's pH value is known.

$$pH = -\log_{10}[H_3O^+(aq)]$$

$$[H_3O^+(aq)] = 10^{-pH}$$

Example Problem 1.7

Calculate the hydronium-ion concentration, $[H_3O^+(aq)]$ in a shampoo with a pH of 5.72.

Solution

$$\begin{aligned} [H_3O^+(aq)] &= 10^{-pH} \\ &= 10^{-5.72} \quad \leftarrow \text{2 significant digits in pH values} \\ &= 1.905\ 460\ 718 \times 10^{-6}\ \text{mol/L} \\ &= 1.9 \times 10^{-6}\ \text{mol/L} \quad \leftarrow \text{2 signficant digits} \end{aligned}$$

Keystrokes for Graphing Calculator

Method 1: 10 [^] [(–)] 5.72 [ENTER]

Method 2: [2nd] [10^x] [(–)] 5.72 [)] [ENTER]

The shampoo has a hydronium-ion concentration of 1.9×10^{-6} mol/L.

The formula for pH and the formula for hydronium-ion concentration appear in the Science Data Booklet.

Practice

22. For each hydronium-ion concentration, calculate the pH. Classify each solution as being acidic, basic, or neutral.

a. 0.001 00 mol/L **b.** 2.00×10^{-4} mol/L
c. 1.5×10^{-6} mol/L **d.** 1.35×10^{-8} mol/L
e. 1.54×10^{-12} mol/L

23. For each pH value, calculate the hydronium-ion concentration.

a. 7.00 **b.** 2.98 **c.** 8.912 **d.** 13.1

24. Obtain the handout "pH and Hydronium-Ion Concentration" from the Science 30 Textbook CD. Complete the table by calculating values for the $[H_3O^+(aq)]$ column and the Relative Change in Hydronium-Ion Concentration with pH Value Below column. State a general trend in the last column regarding the change to hydronium-ion concentration along the pH scale.

Investigation

Measuring pH Using Indicators

Purpose

You will demonstrate the use of indicators as a means to determine the pH of a solution.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Materials

- 2 copies of the handout "Determining pH Using Indicators" from the Science 30 Textbook CD
- 1 letter-size overhead transparency sheet
- masking tape
- dropper bottles (or eyedroppers)
- solutions with pHs of 1, 3, 5, 7, 9, 11, and 13
- pH indicators
  - alizarin yellow R
  - thymol blue
  - bromothymol blue
  - bromocresol green
  - methyl orange
- water containing juice extracted from red cabbage when boiled
- unknown solutions A, B, and C

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Place one of the handouts on the surface of your work area. Cover the handout with the transparency sheet. Use masking tape to ensure the sheet lays flat and remains attached to the surface of your work area throughout the experiment.

step 2: Place one drop of the solution labelled "pH 1" into each circle in its designated column on the transparency, which is overtop the handout.

step 3: Repeat step 2 with the other pH solutions and the unknown solutions.

step 4: Carefully add a drop of alizarin yellow R indicator to the circles in the first row of the handout. When adding the indicator, ensure that the end of the bottle does not touch the drop of solution already in the circle.

step 5: Repeat step 4 using the other indicators listed in the handout.

step 6: Record the colour of the resulting mixture within each circle in a data table.

step 7: Use paper towel to absorb most of the solutions on the transparency; then rinse the transparency in the sink.

step 8: Return all apparatus to their proper location in the lab.

Observations

1. Show your results of this investigation.

Analysis

2. Use the data to estimate the pH of solutions A, B, and C. Explain how you arrived at your estimation. State a reason why using indicators results in only an estimation of the pH of the three solutions.

Use of Natural Indicators by First Nations

The name for the Blackfoot First Nation is reported to have originated from the black moccasins worn by their members when first encountered by European settlers. Research has shown that the Blackfoot used over 150 different plant species to support their traditional lifestyle. The skunkbush, as well as other prairie plants, were sources of coloured molecules that could be used to dye leather, cloth, and even the porcupine quills for ceremonial dress. The Blackfoot, as well as other First Nations, used naturally occurring acids to adjust the colour of the dyes made from the extracts of berries, leaves, or bark. They used ash from fire pits because ash combined with water forms a basic solution. Changing colour as a response to differing pH is a property of many natural substances, making them useful **indicators** of changes in the pH of a system that are often the result of an acid-base reaction.

Figure B1.24: A black dye can be prepared from the leaves of the skunkbush plant.

indicator: a substance that changes colour in response to the change in pH of a system

Using Indicators to Estimate pH

The colours shown by many indicators at various pH values are summarized in the "Acid-Base Indicators" table. The information in this table can be used to interpret and estimate the pH of a solution. This table also appears in the Science Data Booklet.

ACID-BASE INDICATORS

Indicator	Abbreviation (acid / conjugate base)	pH Range	Colour Change as pH Increases
methyl violet	$HMv(aq)/Mv^-(aq)$	0.0 – 1.6	yellow to blue
thymol blue	$H_2Tb(aq)/HTb^-(aq)$	1.2 – 2.8	red to yellow
thymol blue	$HTb^-(aq)/Tb^-(aq)$	8.0 – 9.6	yellow to blue
orange IV	$HOr(aq)/Or^-(aq)$	1.4 – 2.8	red to yellow
methyl orange	$HMo(aq)/Mo^-(aq)$	3.2 – 4.4	red to yellow
bromocresol green	$HBg(aq)/Bg^-(aq)$	3.8 – 5.4	yellow to blue
litmus	$HLt(aq)/Lt^-(aq)$	4.5 – 8.3	red to blue
methyl red	$HMr(aq)/Mr^-(aq)$	4.8 – 6.0	red to yellow
chlorophenol red	$HCh(aq)/Ch^-(aq)$	5.2 – 6.8	yellow to red
bromothymol blue	$HBb(aq)/Bb^-(aq)$	6.0 – 7.6	yellow to blue
phenol red	$HPr(aq)/Pr^-(aq)$	6.6 – 8.0	yellow to red
phenolphthalein	$HPh(aq)/Ph^-(aq)$	8.2 – 10.0	colourless to pink
thymolphthalein	$HTh(aq)/Th^-(aq)$	9.4 – 10.6	colourless to blue
alizarin yellow R	$HAy(aq)/Ay^-(aq)$	10.1 – 12.0	yellow to red
indigo carmine	$HIc(aq)/Ic^-(aq)$	11.4 – 13.0	blue to yellow
1,3,5–trinitrobenzene	$HNb(aq)/Nb(aq)$	12.0 – 14.0	colourless to orange

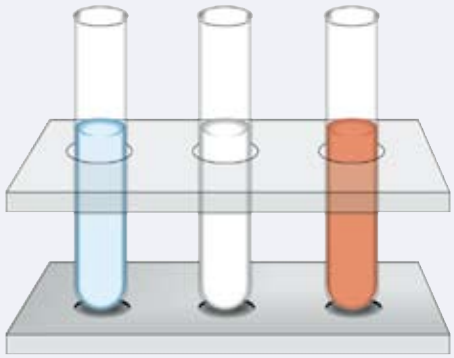
At the beginning of this unit, you observed a colour change for bromothymol blue, one of the pH indicators listed in the "Acid-Base Indicators" table. As you may recall, the colour of the indicator in the water solution within the flask was either blue or green. As gases from exhaled air and from the products of the combustion of coal were added to the respective flasks, the colour of the indicator within the water turned yellow. As can be interpreted from the "Acid-Base Indicators" table, the yellow colour observed for the flask that contained bromothymol blue indicates that the pH of the solution must have been below 6.0. Earlier in the demonstration, the blue colour indicated that the pH of the water in the flask was above 7.6. (A green colour would have indicated that the pH of the water in the flask was between 6.0 and 7.6.)

In the "Measuring pH Using Indicators" investigation, observations from more than one indicator were needed to estimate the pH of a solution to a reasonable degree of accuracy. When an observation can only estimate that a solution's pH is below 6, additional indicator data must be used to narrow the range for a more accurate estimate. Example Problem 1.8 demonstrates how data from several indicators can be used to determine the pH of a solution.

Example Problem 1.8

A solution is tested with three indicators. Here are the results.

Indicator	Colour
bromothymol blue	blue
phenolphthalein	colourless
phenol red	red



Estimate the pH of this solution.

Solution

step 1: Use the "Acid-Base Indicators" table to determine the pH range.

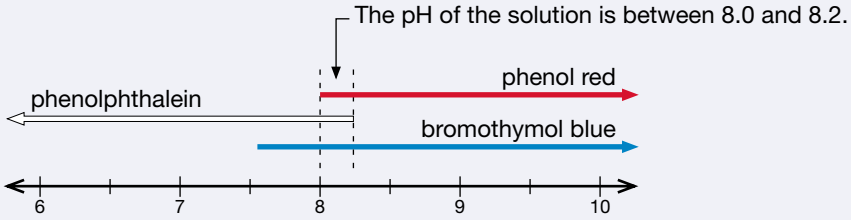
ACID-BASE INDICATORS

Indicator	Abbreviation (acid/conjugate base)	pH Range	Colour Change as pH Increases
methyl violet	HMv(aq)/Mv^-(aq)	0.0 – 1.6	yellow to blue
thymol blue	H_2Tb(aq)/HTb^-(aq)	1.2 – 2.8	red to yellow
⋮	⋮	⋮	⋮
bromothymol blue	HBb(aq)/Bb^-(aq)	6.0 – 7.6	yellow to blue
phenol red	HPr(aq)/Pr^-(aq)	6.6 – 8.0	yellow to red
phenolphthalein	HPh(aq)/Ph^-(aq)	8.2 – 10.0	colourless to pink
⋮	⋮	⋮	⋮

According to the table, the three indicators show the following:

- **bromothymol blue:** blue = above pH 7.6
- **phenolphthalein:** colourless = below pH 8.2
- **phenol red:** red = above pH 8.0

step 2: Use a number line to narrow the range of pH values.



The estimated pH of the solution is between 8.0 and 8.2.

A pH meter is used when more accurate measurements of the pH of solutions are required. A pH meter contains a probe that detects the concentration of hydronium ions in a solution. The sensitivity of the probe enables pH meters to measure values to the hundredth or thousandth of a pH unit.

Figure B1.25: pH meters are used in the laboratory and in field work to accurately measure the pH of rainwater and other solutions.

Practice

25. Describe what an indicator is and how it can determine the pH of a solution.

26. "Methyl orange is always red in an acidic solution and yellow in a basic solution." Explain whether this statement is correct or incorrect.

27. A solution is tested with three indicators. Here are the results.

Indicator	Colour
litmus	red
thymol blue	orange
orange IV	red

a. Estimate the pH of the solution.

b. Estimate the hydronium-ion concentration of the solution.

28. A few drops of bromocresol green and a few drops of thymol blue are added to the same solution with a pH of 5.6. What colour do you expect the solution to be? Concisely explain your answer.

Sources of Acid Deposition

Earlier, equations demonstrated how carbon dioxide, sulfur oxides, and nitrous oxides reacted with water to produce hydronium ions and form acidic solutions. Carbon dioxide—although produced by many combustion processes—is not considered a major source of acid deposition. Carbon dioxide is only slightly soluble in water, which limits the extent to which it can react with water. On the other hand, the oxides of nitrogen and sulfur are considerably more soluble in water and, thus, make a greater contribution to the acidification of wet and dry deposition.

1.2 Summary

In this lesson you examined the chemistry of acids and bases. You wrote chemical equations to describe the changes that occur when acids and bases react and discovered how substances released into the atmosphere can convert into acids. You discovered that chemical reactions that occur between acids and water produce hydronium ions. You also determined that the substances released as emissions can return to Earth's surface as either wet or dry deposition and that the deposition can be acidic. You then measured the pH of a solution and studied how pH relates to the concentration of hydronium ions within a solution. In the next lesson you will cover the effects of acidic deposition on the environment.

1.2 Questions

Knowledge

1. Define the following terms.
   - **a.** acid
   - **b.** base
   - **c.** dissociation
   - **d.** hydrogen ion
   - **e.** hydronium ion
   - **f.** pH scale
   - **g.** wet deposition
   - **h.** acid deposition
   - **i.** acid rain
2. Write balanced chemical equations for the reactions between the following substances. For each equation, label the acid, the base, the conjugate acid, and the conjugate base.
   - **a.** hydronium ion, $H_3O^+(aq)$, and hydroxide ion, $OH^-(aq)$
   - **b.** ethanoic acid and ammonia
3. List similarities and differences between Arrhenius's theory and the Brønsted-Lowry theory.
4. Calculate the pH values for each hydronium-ion concentration given. Identify whether the solution is acidic, basic, or neutral.
   - **a.** 0.001 25 mol/L
   - **b.** 2.3×10^{-9} mol/L
   - **c.** 4.42×10^{-13} mol/L
   - **d.** 5.6×10^{-2} mol/L
   - **e.** 8.10×10^{-8} mol/L
5. Calculate hydronium-ion concentration for each pH value given.
   - **a.** 2.14
   - **b.** 7.1
   - **c.** 9.437
   - **d.** 11.00

Applying Concepts

6. Compare and contrast the terms *proton*, *hydrogen ion*, and *hydronium ion*.
7. Antacids are usually taken to relieve heartburn. State the type of compound an antacid needs to be in order to be effective. Calcium carbonate, $CaCO_3(s)$, and aluminium hydroxide, $Al(OH)_3(s)$, are substances used in commercially available antacids. List the empirical properties common to these two antacids. Write a balanced chemical equation that represents the reaction between each of these antacids and aqueous hydronium ions that would occur in the stomach.
8. A chemical spill releases concentrated ammonia, $NH_3(aq)$, along a dangerous-goods route. The spill has been contained. Identify the general properties of the concentrated ammonia spill. If a decision is made to treat the spill to reduce the risk to people or the environment, indicate a substance that can be used. Support your answer with a balanced chemical equation.
9. A solution is yellow with thymol blue and blue with bromocresol green. Determine the colour of the solution with the following indicators.
   - **a.** methyl violet
   - **b.** indigo carmine
   - **c.** methyl orange
   - **d.** alizarin yellow R
10. "The total amount of acid being deposited in an area is equal to the amount of wet acidic deposition deposited in the area plus the amount of dry acidic deposition deposited in the area." Use the concepts you applied in this lesson to explain whether you think this statement is correct or incorrect.
11. Identify whether each example affects the validity or reliability of scientific work.
    - **a.** repeating an experiment
    - **b.** comparing your data with the data collected by other students completing the same experiment
    - **c.** two groups of scientists arriving at the same result using different methods
12. Refer to the table you prepared in Practice Problem 11 on page 169. Complete the Definition column.

1.3 Impact of Acid Deposition on Ecosystems

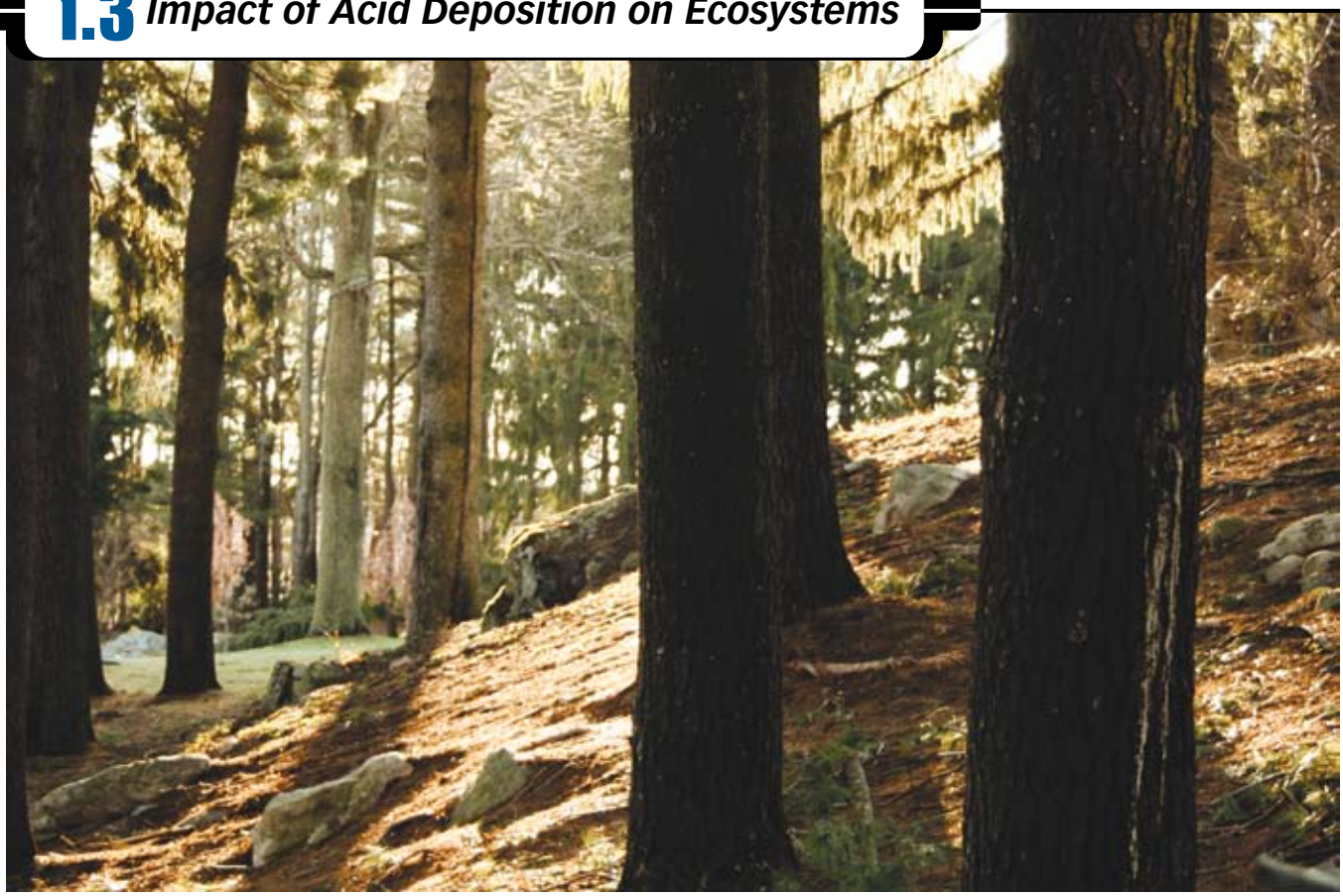


Figure B1.26: Data collection is an important process toward developing an understanding of the interactions of substances within ecosystems.

The study of environmental chemistry involves more than just the detection of substances. Scientists who study the environment conduct investigations to determine whether there is evidence of change in the environment. The area of the forest shown in Figure B1.26 has very little vegetation on the ground. Is there a connection between the dropped needles covering the forest floor and the amount of plant growth beneath these trees? Is the lack of plant growth related to the soil pH? Studies performed by environmental scientists in the field are a critical link toward understanding the changes that occur in ecosystems versus those that might be predicted.

Figure B1.27: Some mushroom species and some plant species can grow in the soil directly underneath pine trees.

Predictions currently being made by scientists rely upon the knowledge that comes from careful study of interactions within the environment. As many scientists will tell you, the complexity of interactions within an ecosystem makes the current level of understanding limited. Since the environment is the one thing that all organisms share, research is necessary to understand its ability to cope with stress from pollution.

In this lesson you will expand your knowledge of the complexity of ecosystems and the chemical interactions that can occur. Before you continue, however, do you have a hypothesis that describes the relationship between the presence of emissions in the environment and their effects? What kinds of experiments would you need to conduct to test and support your hypothesis? Do you have an idea of what you might expect to observe?

Given all that you have learned about the ability of some substances within emissions to react with water, does a relationship exist between the presence of these substances in water and the water's acidity? In a previous investigation, the emissions from burning coal acidified water. Do similar reactions occur in nature? In the next investigation you will have the opportunity to analyze data and gain further insight into this question.

Utilizing Technology

Testing a Hypothesis

Purpose

You will investigate the relationship between the presence of substances in rainwater and the pH of rainwater.

Science Skills

- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Background Information

In previous courses you described the relationship between two variables as a **direct variation**, an **inverse variation**, or having **no relationship**. In this investigation you will analyze the data collected from rainwater and determine which type of relationship is demonstrated. The data provided are from rainfall monitoring sites throughout Alberta. Included in the data are information about the quantity of rainfall, pH, total acidity of rainfall, and the nitrate and sulfate concentrations. Each of these headings is considered to be a variable—information that was measured and recorded during this study.

Pre-Lab Questions

1. Identify a relationship between two of the variables (sets of information) listed in the background information.
2. Describe the relationship—direct variation, inverse variation, or no relationship—you feel exists between the two variables defined in question 1. Explain why you chose this relationship.
3. Predict what you think the trends within the data for these two variables will show.
4. Repeat questions 1 to 3 for other combinations of variables you feel will demonstrate a direct variation, an inverse variation, or no relationship.

direct variation: a relationship between two related variables where an increase in the magnitude of one variable results in an increase in the magnitude of the related variable

inverse variation: a relationship between two related variables where an increase in the magnitude of one variable results in a decrease in the magnitude of the related variable

no relationship: a situation where no recognizable pattern is demonstrated between two variables

Materials

- computer with a spreadsheet program (e.g., Excel)
- printer

Procedure

Open the "Rainfall Data" spreadsheet on the Science 30 Textbook CD. Check with your teacher for directions about how many areas within this spreadsheet you will be analyzing. Complete the following steps for each set of data you analyze.

step 1: Identify the headings listed in the background information as they appear on the spreadsheet.

step 2: Graph two or more variables shown in the data. Use appropriate titles and axes labels. Then save your graph.

step 3: Repeat step 2 for other data you may want to investigate or for other areas your teacher instructs you to analyze. Save any additional graphs.

step 4: On each graph, use a text box to insert the hypothesis between the variables graphed.

step 5: Describe any trends on each graph. Add labels and descriptive text to your graphs that indicate these regions.

step 6: On each graph, write an explanation of how the trends or patterns demonstrated by the data support or do not support the hypothesis.

step 7: Create a new document that includes each of the graphs analyzed. At the front of this document, create a summary table that lists the variables that were compared and the relationships identified. Ensure that the order in which the graphs appear is logical and easy to reference from the summary table.

step 8: Below the summary table described in step 7, write a brief commentary indicating whether the relationships between variables you investigated were consistent with the relationships you predicted earlier. Indicate how these relationships are consistent with or differ from what you know about acid deposition.

step 9: Print a copy of the document containing the summary table, commentary on trends and relationships between variables, and the annotated graphs you prepared during your analysis.

Wind Patterns

The "Testing a Hypothesis" investigation provided an opportunity for you to use data to test a hypothesis you developed. As you may have expected, higher levels of sulfates and nitrates in rainwater result in a higher concentration of hydronium ions in the water (direct variation) and, thus, results in a lower pH (inverse variation). These types of relationships are consistent with what is known about the effect of natural and human-made sources of emissions and their respective roles in the production of acid rain.

As mentioned earlier, many other factors can have an influence within an environmental system. One of these factors is wind. Weather in Alberta can be quite variable. There is a saying, "If you don't like the weather in Alberta, wait five minutes." One day it is excessively hot; the next day you are sure it is going to snow. In the next activity you will look at a major feature of the weather patterns across North America. As you complete this activity, remember to consider what influences weather patterns might have on acid deposition.

Utilizing Technology

Prevailing Wind Patterns

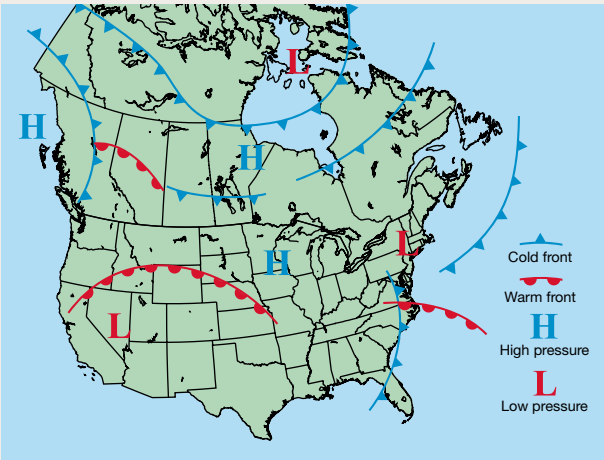


Figure B1.28: Precipitation and wind are weather patterns that influence acid deposition.

Purpose

You will examine the prevailing wind patterns in Alberta and in Canada.

Background Information

Have you completed a field study where you measured wind speed and direction? Wind is an abiotic factor of an ecosystem. Wind enables the movement of matter, whether it is water vapour in clouds, solid matter eroded by winds, or gases within atmospheric currents. The jet stream is the most influential wind current in North America. In this activity you will be asked to locate, download, and assemble information about wind patterns. The maps you create in this activity will be used in other activities within this lesson to further investigate issues related to acid deposition.

Materials

- computer with Internet connection
- handouts from the Science 30 Textbook CD
  - "Map of Canada and the US"
  - "Map of Alberta" (2 copies)

Science Skills

✓ Analyzing and Interpreting

Procedure

Part A: Map of Canada and the US

step 1: Search the Internet for images of daily, monthly, and seasonal patterns of the jet stream.

step 2: Draw a line representing an approximate average location for the jet stream across North America.

step 3: Determine the direction of the winds in areas north and south of the jet stream. Use vector arrows to indicate the direction of the winds on your map.

Part B: Map of Alberta

step 1: Search the Internet for images of daily, monthly, and seasonal wind patterns in Alberta.

step 2: Use vector arrows to indicate the direction of the winds in Alberta. **Note:** If you notice there is a change in the direction of wind patterns in the province during different seasons, use additional maps to identify these patterns. Ensure that all maps are properly labelled.

Analysis

1. Define the term *jet stream*. State the general direction of the jet stream.
2. Explain the effect the jet stream has on weather and climate in western Canada.
3. Comment on the statement, "Wind patterns in Canada and Alberta are always the same."
4. From your analysis of wind patterns, does Canada's position in the northern hemisphere ensure that air transported by currents, such as the jet stream, are relatively clean and unpolluted?

The Jet Stream and Acid Deposition

Wind patterns like the jet stream provide a way for acid deposition to be transported. As you will see later, acid deposition can be transported short and long distances. The predictability of wind patterns provides a way to trace the path of acid deposition back to its source. What happens to an ecosystem when acid deposition settles? How would it affect the plants, soil, and water it touches? Maybe the next activity will help you answer these questions.

Investigation

Acid Deposition and Its Effect on Simulated Lake Water—Demonstration

CAUTION!

This demonstration should be performed only by your teacher. Avoid exposure to sulfur dioxide. Do not handle any of the solutions used in this demonstration.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will see a demonstration of the effect of acid deposition on simulated lake water.

Materials

- 5 large graduated cylinders
- simulated lake water
- bromocresol green indicator
- calcium carbonate, $CaCO_3(s)$
- spray bottle containing water
- sulfur dioxide (prepared prior to demonstration)
- stopwatch

Experimental Design

Samples of simulated lake water will be placed into each cylinder. A small piece of calcium carbonate will be added to two of the cylinders. To test the cylinders, sulfur dioxide gas will be added. A spray bottle of water will be used with some of the cylinders to simulate precipitation. All cylinders will be monitored for changes that occur and the length of time over which the changes occur.

Data Collection

step 1: Construct a data table with the headings Cylinder, Initial Colour of Contents, $SO_2(g)$ Added, Water Spray Added, $CaCO_3(s)$ Added, and Relative Time for Colour Change.

step 2: Observe the colours of the contents of each cylinder before adding the $SO_2(g)$. Record each colour in your table.

step 3: Record which cylinders had $SO_2(g)$ added, which had $CaCO_3(s)$ added, and which received water spray.

step 4: To simulate the mixing effect made by waves and by water currents, swirl the contents of each flask once during each 10-min interval. Observe changes to colour and other aspects over the next 50 min. Record any changes that occur over each 10-min interval.

Analysis

1. Earlier, you discovered the importance of experimental controls. Identify the cylinders that were experimental controls. Briefly describe their purpose. In some experiments, only one control is used. Why are two control cylinders used in this experiment?
2. Identify the samples of simulated lake water that were exposed to wet acid deposition, that were exposed to dry acid deposition, and that were not exposed to acid deposition.
3. Describe the effect that $CaCO_3(s)$ had on the simulated lake-water samples. Support your answer using the evidence collected during the experiments and, if possible, a balanced chemical equation.
4. This demonstration was designed to simulate conditions that could occur in nature. List natural sources of $CaCO_3(s)$. Explain how $CaCO_3(s)$ could come into contact with lake water to form a chemical system.

Effects of Acid Deposition on the Environment and Ecosystems

Acid deposition can affect the pH of water. The hydronium ions formed during the chemical reaction between acids and water not only act to lower the pH of a body of water, but can react with other substances in the system. Carbonate ions, $CO_3^{2-}(aq)$, are a naturally occurring base present in many bodies of water and in the soil. In Alberta, the pH of most lakes is above 7 and can be as high as 8.3. The slightly **alkaline** pH of the lake water is due to the presence of dissociated carbonate ions that enter the water from dissolving **minerals**, such as calcium carbonate and magnesium carbonate present in limestone.

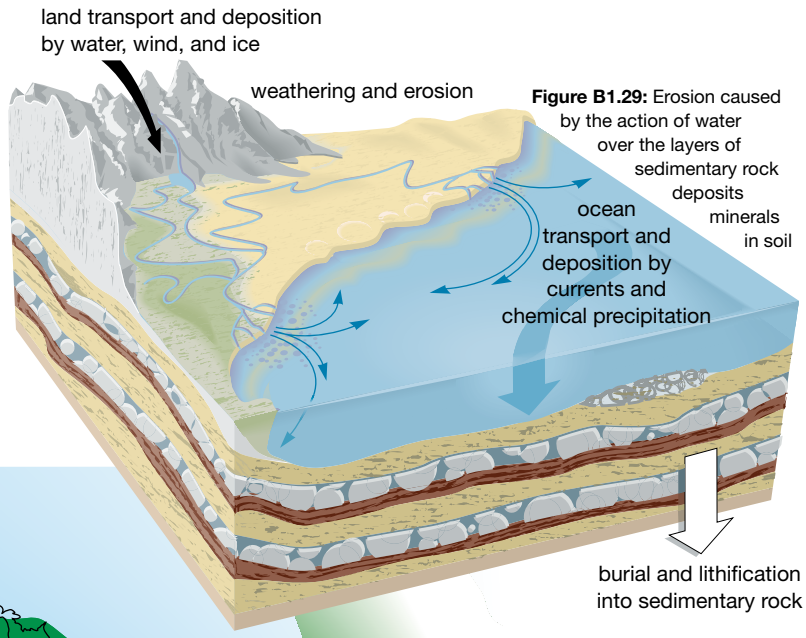


Figure B1.29: Erosion caused by the action of water over the layers of sedimentary rock deposits

- **alkaline:** having the properties of a base
- **mineral:** a solid, inorganic chemical compound produced by natural chemical processes

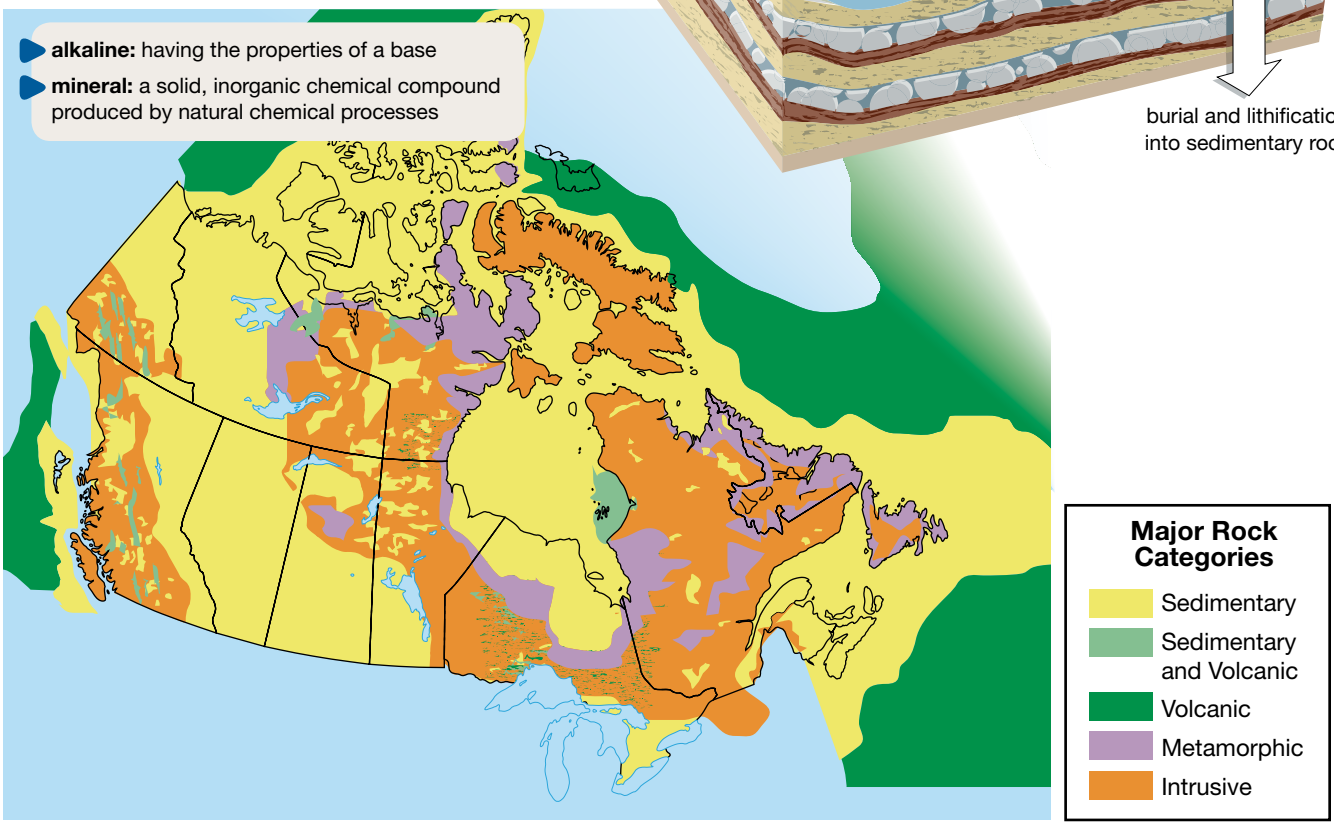


Figure B1.30: Geological events have resulted in a variety of rock types in Canada.

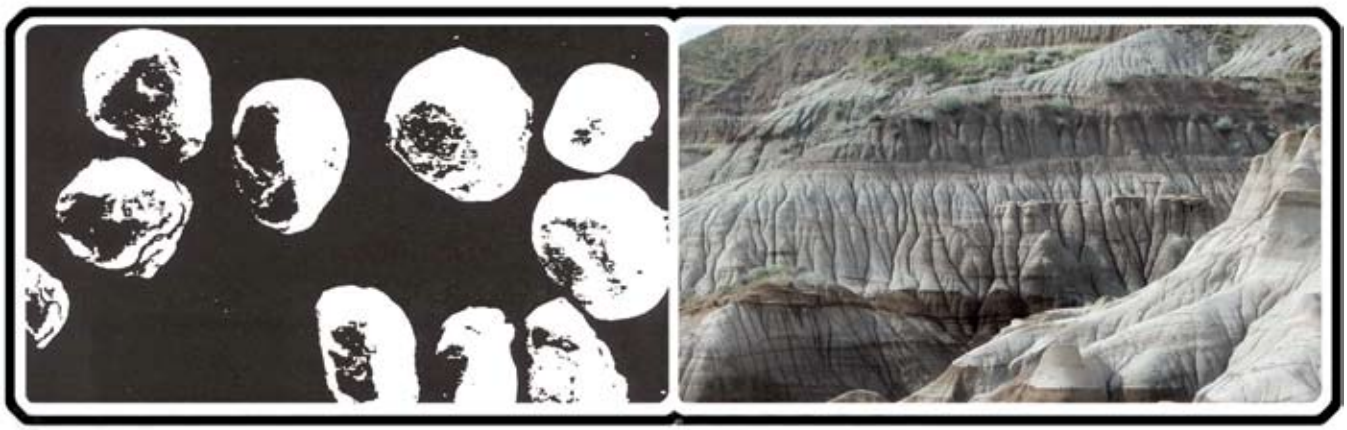
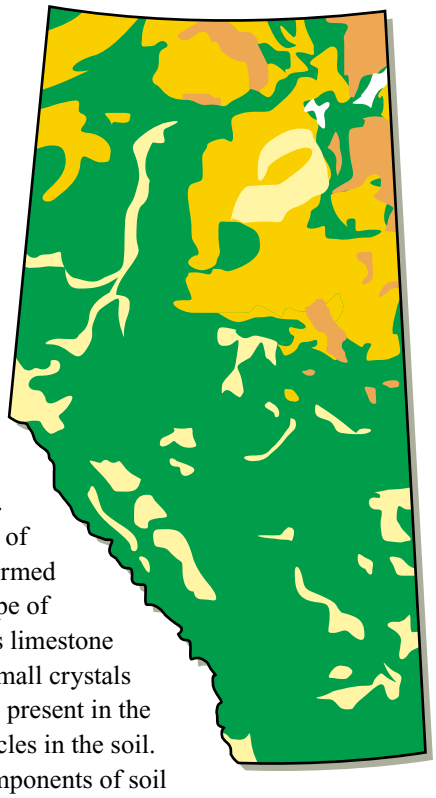


Figure B1.31: Soil contains small particles (a component of which is shown in this magnified sample) of eroded rocks from layers of exposed sedimentary rock. The chemical composition of the rock within a region influences the sensitivity of soil and lakes to acid deposition.

The area now called Alberta has undergone many geological changes. Many times throughout its history, Alberta has been covered by water. The coral reefs that developed at the bottom of these oceans were made up of calcium carbonate, $CaCO_3(s)$. Over time, the layers of calcium carbonate formed into limestone—a type of sedimentary rock. As limestone undergoes erosion, small crystals of calcium carbonate present in the limestone form particles in the soil.



The chemical components of soil have a great impact on its sensitivity to acid deposition. In the acid deposition demonstration earlier, the acid deposited into some of the cylinders containing simulated lake water was neutralized. Recall that the reaction between hydronium ions and carbonate ions involves the transfer of a hydrogen ion. The carbonate ions, acting as acceptors for hydrogen ions, convert hydronium ions into water molecules, thereby neutralizing the acid.

Reaction of Hydronium Ion and Carbonate Ion

loses a hydrogen ion

$$H_3O^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + HCO_3^-(aq)$$

acid — base — conjugate base — conjugate acid

gains a hydrogen ion

Only a small percentage of soils in Canada have a high potential for neutralizing acid deposition. Much of the soil within the province of Alberta has a high potential, mainly due to the presence of carbonate.

Practice

Obtain a copy of the handouts "Potential of Soils and Bedrock to Reduce Acidity" and "Major Rock Categories" from the Science 30 Textbook CD. Use these maps to answer questions 29 to 36. In developing your answers, consult both maps and look for similarities, differences, and correlations.

29. Do all areas of Canada have similarities in their ability to neutralize acid deposition?

30. Indicate regions in Canada that have the highest potential to reduce acid deposition.

31. Do all of the areas with the highest potential to reduce acid deposition have a similar rock type? If so, identify it.

32. Indicate regions in Canada with the least ability to reduce acid deposition.

33. Do all of the areas with the lowest potential to reduce acid deposition have similar rock types? If so, identify the types of rock found in these regions.

34. Do all regions of Alberta have equal potential to reduce acid deposition? Support your answer.

35. Predict the effect of acid deposition on the pH of soil and the pH of lake water in Canada. Do you expect the pH values to increase, decrease, or remain constant? Explain why there may be more than one answer.

36. Within the map depicting the potential of soils to reduce the acidity from the atmosphere, there is a table describing aquatic sensitivity by province. Use this information to answer questions 36.a. to 36.d. **Note:** Zooming in on this table on your computer monitor will provide a clear view of the information.

a. Identify the province with the largest percentage of lakes with a high sensitivity to acid deposition.

b. Identify the province with the lowest percentage of lakes with a high sensitivity to acid deposition.

c. Is there a correlation between the sensitivity of lakes to acid deposition and the sensitivity to soil within a province? Explain whether there is a direct variation, indirect variation, or no relationship between the sensitivity of lakes and soils to acid deposition.

d. Hypothesize a reason for the relationship you identified in question 36.c.

Buffering and Buffering Capacity

The neutralization of acid deposition by bases, such as calcium carbonate—whether present in the soil, bedrock, or lake water—prevents the accumulation of hydronium ions. An increase in the concentration of hydronium ions makes a solution more acidic and lowers the solution's pH. As you will soon see, pH is an important factor that contributes to the viability of ecosystems; and changes in pH can have drastic effects on the survival of many organisms. The neutralization of acids by bases that prevents any change to the pH of soil or lake water is called **buffering**.

As you may expect, some areas exposed to acid rain for longer periods of time eventually develop soil or surface water with lower pH values. In these situations, the accumulation of hydronium ions is due to an absence of basic substances within the soil or water. **Buffering capacity** is a measure of the amount of acid that can be neutralized by soil or surface water. In the acid deposition demonstration you observed earlier, which samples of lake water had the highest buffering capacity? If you look back at "The Potential of Soils and Bedrock to Reduce the Acidity of Atmospheric Deposition" map, can you predict which regions have higher, moderate, and lower buffering capacities?

buffering: a chemical reaction to minimize a change to the hydronium-ion concentration in soil or water

buffering capacity: the relative ability of a substance to resist change to its pH despite the addition of an acid or base

Response of Plants to pH

Plants respond to the level of acidity in a variety of ways. The area directly underneath conifers is often lacking any other plant growth. As needles fall from pine and spruce trees to the ground, acids from the needles are transferred to the soil. This results in acidification of the soil. Few species of plants can tolerate the low pH of the soil immediately underneath these trees. Similarly, crop plants used in agriculture have limited tolerance for variation in pH. Therefore, it is important for farmers to select crops best suited to the pH of the soil. Soil exposed to acid deposition or to certain crops can become acidified and, as you will learn later, must be properly managed to remain fertile.

AGRICULTURAL PLANTS AND SOIL pH FOR OPTIMAL GROWTH

Plant	Soil pH for Optimal Growth
alfalfa	6.5 to 7.0
barley	6.3 to 6.5
blueberries	4.5
canola	5.5 to 8.3
clover	5.8 to 6.2
corn	5.8 to 6.2
oats	5.8 to 6.2
pasture grass	5.5 to 6.2
sugar beets	6.5 to 8.0
potatoes	5.2 to 8.0
wheat	5.5 to 6.5

DID YOU KNOW?

The dark patches on this potato are potato scabs, the result of an infection by bacteria that live in the soil. Although the infection does not affect the taste of the potato, farmers often choose to plant potatoes in soils with a pH below 5.3 to prevent the development of potato scabs. The bacteria cannot tolerate a pH this low.

DID YOU KNOW?

Canola is a variety of the rapeseed plant. Canola was developed by selective plant breeding technologies to produce an oil with specific properties.

Plant Nutrients, Metal Leaching, and pH

Reactions between acids and minerals in the soil are important to the cycling of matter as described in **biogeochemical cycles**. In previous science courses you examined cycles that describe the conversions of carbon, oxygen, nitrogen, and water in the environment. Reactions involving other elements are of equal importance to environmental scientists. Calcium ions, $Ca^{2+}(aq)$, are one of the required nutrients for plant growth. The reaction of $CaCO_3(s)$ that neutralizes acids present in rainfall is one manner in which calcium ions—normally bound to carbonate and other ions—become available to plants.

Other nutrients are listed in Figure B1.32, along with their function. One of these functions is the production of chlorophyl—the molecule essential for photosynthesis and for influencing a plant's growth or reproduction.

biogeochemical cycle: a diagram representing the movement of elements and compounds between living and non-living components of an ecosystem

REQUIRED PLANT NUTRIENTS

Type	Element	Forms Used by Plants	Function
macronutrients (essential nutrients needed in large quantities)	calcium	Ca^{2+}	• important for root growth • component of cell walls
	magnesium	Mg^{2+}	• essential for chlorophyl formation
	nitrogen	NH_4^+, NO_3^-	• essential for proper leaf and stem growth • protein synthesis
	phosphorus	PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$	• important for germination and growth of seeds, root growth, flower, and fruit production
	potassium	K^+	• promotes quick growth and disease resistance
micronutrients (essential elements needed in small quantities)	boron	BO_3^{3-}, $B_4O_7^{2-}$	• required for transporting matter within plant and for reproduction
	chlorine	Cl^-	• may affect use and production of sugars by plant
	copper	Cu^+, Cu^{2+}	• important in plant reproduction
	iron	Fe^{2+}	• required for the production of chlorophyl and oxygen
	manganese	Mn^{2+}	• required in reactions to make sugars and chlorophyl
	molybdenum	MoO_4^{2-}	• required for reactions that convert nitrogen in the atmosphere into forms that plants can use
	zinc	Zn^{2+}	• required for protein synthesis and reactions involving sugars

Figure B1.32: Some plant nutrients may take a variety of forms; but each nutrient is involved in an important role in plant growth, function, or reproduction.

Plants absorb nutrients from the soil through their roots. Prior to planting, farmers may conduct a soil analysis to determine the mineral and nutrient content of the soil. Plants have an optimal pH for growth. In addition to pH, many plants also have specific nutrient requirements.

Figure B1.33: The yellow leaves of the soybean plant in this photo are the result of chlorosis—nutrient deficiencies in the soil.

Acid deposition can present another problem that complicates the ability to grow plants or crops. Nutrients must be in a form that allows them to be absorbed through the roots of plants.

A change in soil pH can result in the formation of insoluble forms of these nutrients, making them unattainable by roots. Chlorosis—the yellowing of plant leaves due to a lack of chlorophyl—is caused by nutrient deficiencies in soil. The yellow appearance of plant leaves is one indicator that a plant may have been exposed to acid deposition. As shown in Figure B1.34, the availability of nutrients is affected by pH. Can you identify a general trend regarding the availability of the nutrients over the pH range shown?

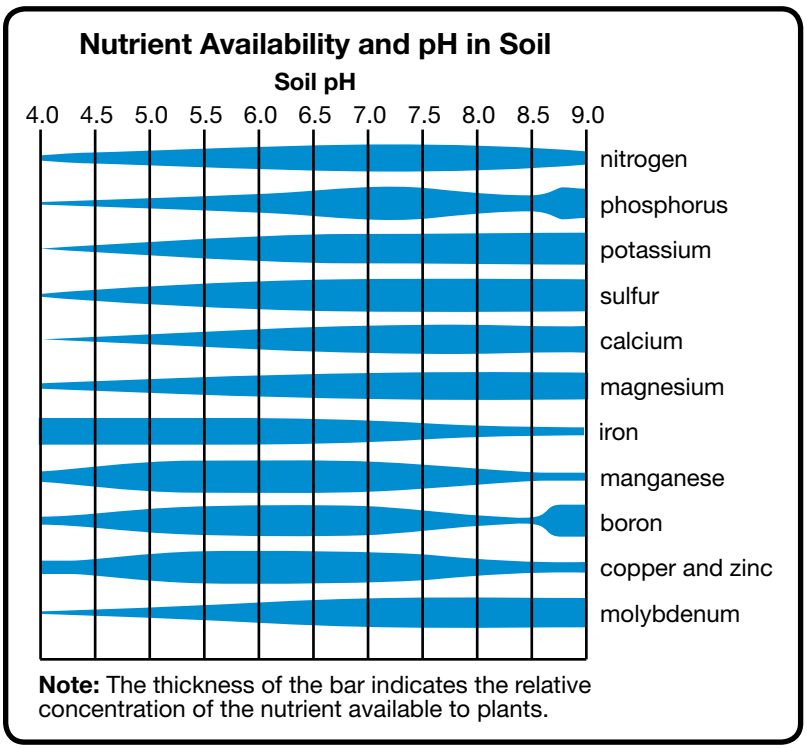


Figure B1.34: Soil pH influences the availability of nutrients. The thickness of the bars indicates where soil concentrations of each nutrient (in forms that plants can absorb) are highest and lowest.

The addition of acids to the soil can make metal ions, like Ca^{2+} and Mg^{2+}, available to plants. Hydronium ions present in soil, as a result of prolonged acid deposition, can react with other compounds in the soil. One effect of prolonged acid deposition is the **leaching** of aluminium ions, $Al^{3+}(aq)$, and mercury(II) ions, $Hg^{2+}(aq)$.

leaching: extracting a substance from a solid by dissolving it in a liquid; the removal of metal ions from topsoil that allows for their movement into lower levels of soil or into surface water

Within soil, aluminium ions are normally bound to hydroxide ions as aluminium hydroxide, $Al(OH)_3(s)$. Since aluminium hydroxide does not dissolve in water easily, very little dissociation occurs. This keeps the concentration of aluminium ions in the soil very low. When exposed to acids, the chemical reaction between aluminium hydroxide and hydronium ions allows aluminium ions to exist as dissociated ions in the soil. Unless precipitated by a reaction with another substance in the soil, the concentration of aluminium ions will accumulate over time. Higher concentrations of aluminium ions can affect plants and soil in many ways, including

- decreasing the growth of roots
- preventing the absorption of calcium
- reducing the population of soil bacteria involved in the decomposition of dead plant matter

Higher concentrations of aluminium ions in lakes and streams are toxic to fish. Exposure to aluminium ions has been known to damage the gills of older fish and increase the number of deaths of young fish.

Mercury is another metal found in soil, but in very small amounts. In acidic soils, a reaction between hydronium ions and compounds containing mercury can occur, resulting in the leaching of mercury(II) ions, $Hg^{2+}(aq)$. Once in the water or in the soil, micro-organisms convert mercury(II) ions into methyl mercury—a substance that is rapidly absorbed by other organisms. Mercury has no real function in living things and cannot be excreted. Since it is not removed, mercury tends to accumulate within cells and tissues of exposed organisms over their lifetime, often to levels that can be toxic to the organism itself and to any other organism that consumes it.

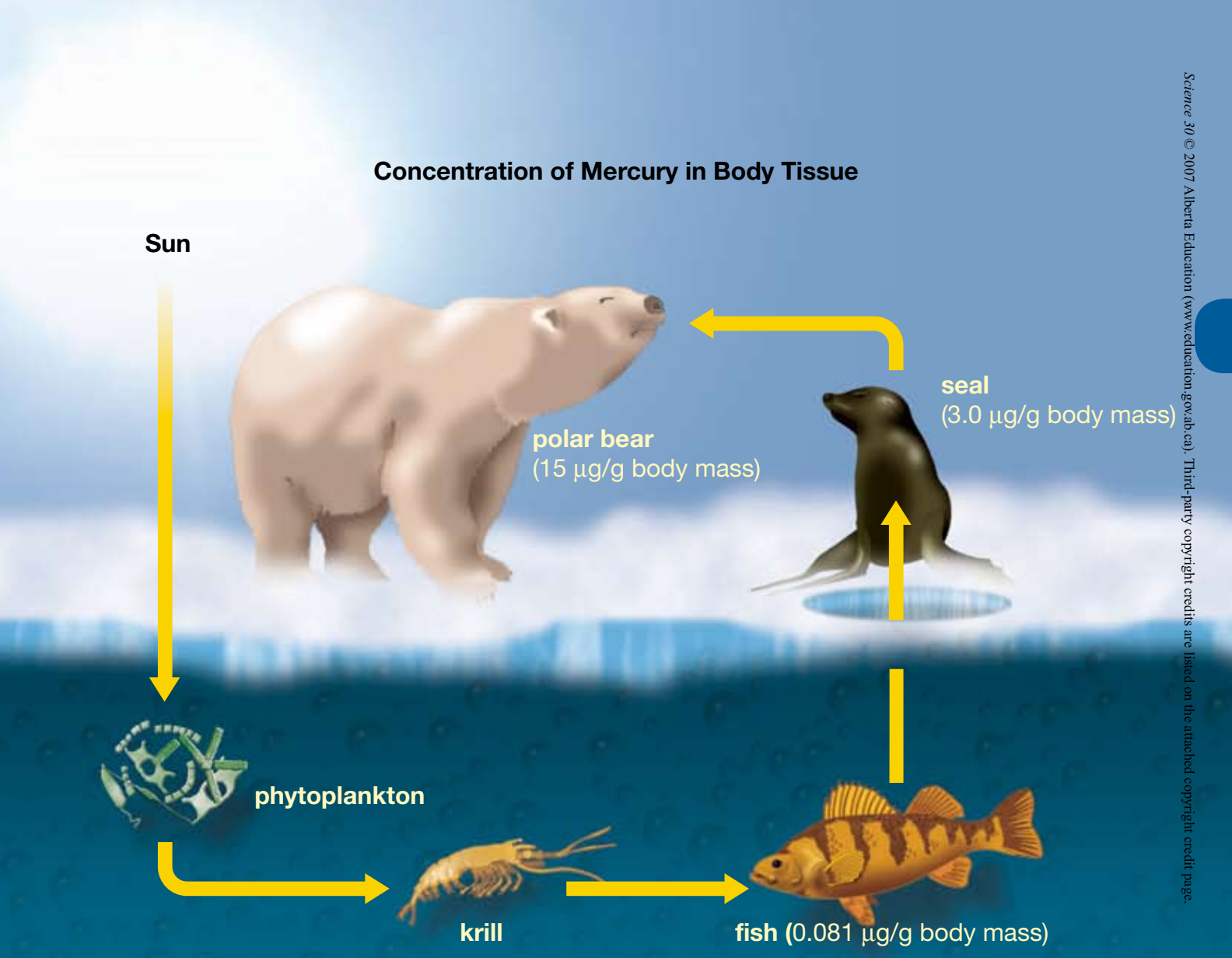


Figure B1.35: The transfer of energy within a food chain can also be used to demonstrate biomagnification of mercury.

Biomagnification can occur with a variety of substances. Regardless of the substance, bioaccumulation occurs because of the inability of an organism to use or eliminate the substance. In a situation where biomagnification occurs, the concentration of mercury within the body of each organism is higher than the concentration of mercury in its environment. Also, as you compare the concentration of mercury at each successive level of the food chain, you will see that there is a significantly higher concentration in the tissues of a predator than in its prey. Can you estimate the magnitude of the change?

Mercury poisoning occurs when the concentration of mercury within an organism reaches a toxic level. In many ecosystems, an organism suffering from mercury poisoning tends to be high up in the food chain. Where do humans fit in a food chain? Do you think information about the bioaccumulation of mercury in food chains would be useful to Aboriginal communities, many of whom have retained their traditional diets?

Acid deposition can cause other metals to have toxic effects on an ecosystem through leaching. These metals include lead, zinc, copper, cadmium, chromium, manganese, and vanadium.

biomagnification: the tendency of a pollutant to appear at higher concentrations at higher levels in a food chain

Expressing Concentration

In environmental science, the concentration of a substance is expressed in many ways. You have seen that hydrogen-ion concentration can be expressed as mol/L or as pH. Because the concentrations of substances that bioaccumulate are very low, units like μg/g of body mass, parts per million, parts per billion, and even parts per trillion are used. The formula to calculate parts per million is in the Science Data Booklet. You can adapt this formula to parts per billion by replacing 10^6 with 10^9 or to parts per trillion by replacing 10^6 with 10^{12}.

Practice

37. The plant in this photograph was grown in soil with a pH of 5.5.

a. State the name that describes the yellowing of the plant leaves.

b. Explain why the plant leaves are yellowing.

c. Indicate a possible cause for the condition of the plant.

d. Explain the relationship between soil pH and the yellowing of the plant leaves.

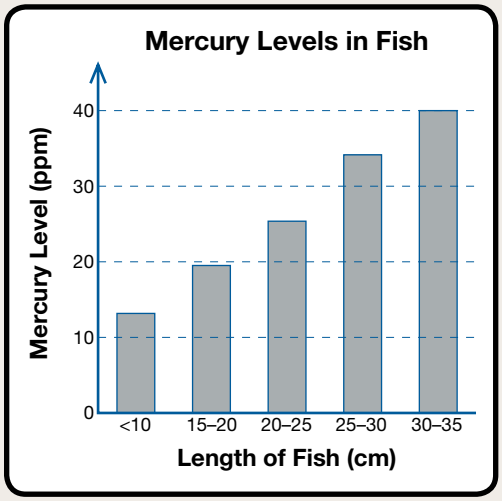
38. The term *biomagnification* refers to the progressive buildup of heavy metals (or other substances) in successive levels of a food chain. Use the concentrations of mercury in Figure B1.35 (on page 197) to calculate ratios of the concentration of mercury in a seal and a polar bear relative to their prey. Explain how the ratios you calculated demonstrate that bioaccumulation is occurring.

39. Use the information in Figure B1.35 to calculate concentration levels of mercury in other organisms in the arctic food chain.

a. Fish concentrate mercury to a level 500 times greater than the concentration of mercury in the krill they consume. Calculate the approximate concentration of mercury in krill.

b. The concentration of mercury in krill is 1000 times greater than that of phytoplankton. Calculate the concentration of mercury in phytoplankton.

40. Scientists sampled fish from one lake over a ten-year period and collected data on the concentration of mercury within the bodies of the same species of fish of various sizes. The graph given summarizes the data they collected.



The scientists who conducted the study concluded that mercury levels are higher in older fish.

a. How does the data support this conclusion?

b. Concisely explain why the older fish most likely have a higher concentration of mercury in their bodies than the younger fish.

c. Identify one experimental control used in the study. Explain the importance of this control.

Effect on Biotic Factors

In your study of ecosystems—and maybe even during a field study—you may have measured temperature, moisture content of soil, amount of sunlight, soil pH, and other **abiotic factors**. The pH of soil within an ecosystem can determine the type of plants that will grow. In turn, the types of plants present can determine the types of animals that exist within the community. Changes to the abiotic factors, especially those brought about by acid deposition, have an impact on the **biotic factors** within an ecosystem.

Recall that soil bacteria can be directly affected by acid deposition or indirectly affected by changes to the concentration of metal ions due to leaching. Besides affecting a plant's ability to produce chlorophyl, causing chlorosis, acids that directly contact plants damage the protective waxy coating on leaves. The loss of this coating permits further damage to the leaf, either by additional acid or by disease.

Aquatic organisms also demonstrate sensitivity to changes in pH. These changes are summarized in the "Sensitivity of Aquatic Organisms to pH" handout on the Science 30 Textbook CD. Because ecosystems involve complex interactions between many organisms, any change that impacts the health and survival of one organism affects the **biodiversity** of the whole ecosystem. How would you use the information in this table if you were asked to investigate whether acid deposition was affecting the area where you live? In the next investigation you will look at some locations where acid deposition has occurred and read about the effects.

- **abiotic factor:** a physical, non-living part of the environment
- **biotic factor:** a living organism in the environment
- **biodiversity:** the variety of life in all its forms, including the genetic diversity and numbers and types of organisms within an ecosystem

Utilizing Technology

Effects of Acid Deposition on Ecosystems

Purpose

You will examine information describing the effects of acid deposition on ecosystems in Montserrat and in eastern Canada.

Science Skills

✓ Analyzing and Interpreting

Procedure

The information for this activity is located on the Science 30 Textbook CD. Obtain the document "Case Study: Eastern Canada." Read the case study; and use the information, along with what you have learned in this lesson, to answer questions 1 to 3.

Analysis

1. Are the changes to the environment in eastern Canada the result of acid deposition only? Identify any other sources that may have contributed to these effects.
2. Describe the type of data used in the material you read. Was adequate information provided regarding the effects acid deposition had on these ecosystems?
3. Evaluate the descriptions provided about the changes to the environment in eastern Canada. Are the descriptions and claims consistent with what you learned about the effects of acid deposition? Identify any similarities.

Try This Activity

Assessing Factors Involved in Acid Deposition in Alberta

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Background Information

Throughout this chapter you examined activities that produce emissions related to acid deposition. The major processes that produce emissions of $SO_2(g)$ and $NO_x(g)$ in Alberta include

- the production of electricity by the combustion of coal, natural gas, or biomass
- upstream petroleum and gas production, including the processes of exploration, extracting, and processing (refining) petroleum and natural gas such as
  - sour gas flaring
  - sweetening or removal of sulfur from sour natural gas
  - removal of sulfur from crude oil
- oil sands (tar sands) production
- transportation
- use of fossil fuels as a heat source in homes or in industry (considered as stationary sources)

You also discovered that wind and quantity of precipitation can be major factors in determining where deposition of acidic particles or solutions will occur. In addition, you studied how the role that soil components, including calcium carbonate from limestone, can have in neutralizing acids. You also saw how acid deposition affects abiotic and biotic components of the environment and how this may impact the balance that exists within ecosystems.

With what you know about acid deposition, it is logical to wonder about Alberta's situation.

Purpose

You will research emissions related to acid deposition to obtain a clearer picture of the impact of acid deposition.

Procedure

Obtain the following handouts from the Science 30 Textbook CD.

- "Map of Alberta"
- "Canadian and US Crude Oil Pipelines and Refineries"
- "Gas Flaring and Venting in Alberta"
- "All Generating Stations by Fuel Used (1997)"
- "Sour Gas Facilities in Alberta"

Note: Zooming in on this data on your computer monitor will provide a clear view of this information.

step 1: Consult with your teacher regarding the magnitude of the area for which you are required to collect information. Is it only for your local area? province? country?

step 2: Gather information (from this textbook, the Internet, or other materials) about the following topics:

- potential of soils to reduce effects of or neutralize acid deposition
- direction of prevailing winds
- locations of electrical power generation facilities
- locations of gas wells, flares, and sour gas processing facilities
- locations of oil wells, flaring, and oil refining
- locations of tar sands (oil sands) processing
- amount of precipitation, both as rain and as snow
- pH of rainfall
- locations of major bodies of water (including rivers and lakes)

step 3: On a map of Alberta, record in an organized manner the information you collected. If codes, colours, or symbols are used, be sure to include a legend.

Analysis

Use the information on your map to identify locations in Alberta where you either

(1) consider acid deposition to currently be a problem

(2) predict acid deposition will be a problem in the future

Justify your answer.

1.3 Summary

In this lesson you learned about the complexity of the environment by studying the effect acid deposition has on soil and on the living components of ecosystems. You were introduced to the effects weather patterns (e.g., prevailing winds and precipitation) have on the transfer and deposition of acidic substances. You examined the chemical interactions between substances in the soil and hydronium ions and how these interactions can result in buffering or in leaching of metal ions. Leaching metals can be a problem associated with acid deposition. Leaching may result in the loss of nutrients from soil or an increase in the concentration in either the soil or water of certain metals that can be toxic. Mercury is an example of one metal that may biomagnify within a food chain when leached from soil. You then looked at examples from eastern Canada where acid deposition has occurred. Finally, you were asked to analyze a number of factors and apply your understanding to the situation in Alberta. In the next lesson you will examine the processes used to monitor and study acid deposition.

1.3 Questions

Knowledge

1. Define the following terms.

a. jet stream **b.** alkaline **c.** minerals

d. buffering **e.** buffering capacity **f.** biogeochemical cycles

g. leaching **h.** biomagnification **i.** biodiversity

2. State the type of relationship that exists between the concentration of sulfur dioxide, $SO_2(g)$, in the atmosphere and the pH of rain.

3. **a.** Name the type of rock that has a high buffering capacity.

b. Identify the chemical compound present in the rock type identified in question 3.a.

c. Write the chemical equation between the hydronium ions and the chemical substance identified in question 3.b.

4. List factors that contributed to the occurrence of acid deposition in eastern Canada.

5. Is acid deposition entirely the result of human activity? Support your answer.

Applying Concepts

6. At the start of this lesson you were asked to develop a hypothesis describing a relationship between the presence of emissions in the environment and their effects.

a. State a hypothesis that describes a relationship between the presence of emissions in the environment and their effects.

b. List experiments you need to conduct to test and support your hypothesis.

c. The people within a community who are closely connected to the local surroundings are often the first to notice environmental change. Identify a societal group you can consult with to determine whether they have noticed environmental changes.

d. Which type of information will you collect from the sources identified in question 6.c.? Explain how this information would help you understand the relationship between emissions and their effects on the environment.

7. Use your knowledge of soil pH to explain how it is possible for soil to be rich in nutrients but unable to support good plant growth.

8. In a study of soil exposed to acid rain, measurements of calcium ions and aluminium ions were taken at regular intervals. Ratios of the concentrations of calcium ions to aluminium ions are shown in the following table.

Soil Sample	Ratio $[Ca^{2+}] : [Al^{3+}]$	Comments
1 (pre-acidification)	1 : 1	concentrations of calcium ions and aluminium ions similar to control soil samples
2 (early stages of acidification)	2 : 1	signs of stress observed in some plant species
3 (late stages of acidification)	0.2 : 1	extreme stress observed in many plant species

a. Explain why the level of calcium ions present in soil changed.

b. It was hypothesized that the concentration of aluminium ions in soil would increase as the soil became acidified. Explain whether the ratios listed in the table support this statement.

9. Aluminium is often present in the soil as aluminium hydroxide, $Al(OH)_3(s)$.

a. Write the balanced chemical equation that occurs between hydroxide ions in the soil and hydronium ions in acid rain.

b. Explain how the reaction of hydroxide ions with hydronium ions could bring about the leaching of aluminium ions into stream and lake water.

10. A study investigating biomagnification sampled the different tissues of fish, seals, and polar bears in an arctic food chain.

Tissue Sample	Concentration of Mercury (μg/g body mass)		
	Fish	Seal	Polar Bear
muscle	0.079	0.25	0.07
liver	0.080	3.0	15
kidney	0.080	1.2	15

a. Explain how the data demonstrates that mercury biomagnifies within a food chain.

b. Hypothesize why differences may exist in the concentration of mercury in different tissues in some organisms.

c. Explain how the results of this study may impact the work of other scientists.

11. The accumulation of acid deposition in soil and water can result in a lowering of pH, which causes a decrease in the number of bacteria that decompose plant and animal matter in an ecosystem. Explain how a decrease in the number of bacteria that decompose plant and animal matter would negatively affect an ecosystem.

1.4 Quantifying Acid Deposition and Monitoring Its Effects

Figure B1.36: Titration is one method used to determine the amount of acid in a sample.

In Lesson 1.2 you made observations that led to developing empirical definitions of acids and bases and used indicators to estimate the pH of a solution. In Lesson 1.3 you discovered the value of using information from chemical tests as well as information about the organisms within the environment to investigate the effects of acid deposition. Earlier, you made observations that led to developing empirical definitions of acids and bases and used indicators to estimate the pH of a solution. Information about acids and acid deposition can be categorized in two ways: as **qualitative data** or **quantitative data**.

You have seen how important the ability to resist the effects of acid deposition can be. In this lesson you will examine a process that is used to determine the concentration of an acid or base in a sample. You have seen how important the ability to resist the effects of acid deposition can be. Now, you will develop a plan to measure buffering capacity.

- **qualitative data:** a description of a substance by identifying its properties, characteristics, or attributes
- **quantitative data:** a description of a substance that involves a measurement and a numerical magnitude

Practice

41. A group of environmental scientists collected the following data to assess the effects of acid deposition in a specific area:

- spots present on surfaces of leaves
- population sizes of organisms within the ecosystem
- information from hunters and inhabitants within the area
- number of plants demonstrating chlorosis
- soil pH
- concentration of $Al^{3+}(aq)$ in soil and water
- population of young fish
- observations of fish health
- list of insect populations within the area
- list of plant species within the area

Using a table, classify the information collected as being either qualitative data or quantitative data.

Traditional Ecological Knowledge

In Lesson 1.3 you analyzed changes to the environment that scientists and others who depend on the land might observe. You also noted that these observations might be interpreted as being related to the effects of acid deposition, but they are often best considered within a larger context. When studying acid deposition, scientists recognize the intricate connections within ecosystems and have come to recognize the value of **traditional ecological knowledge** possessed by some members of Canada's First Nations, Métis, and Inuit. Traditional ecological knowledge provides a holistic or "big-picture" view. This is not only about an intimate knowledge of plants, animals, and natural phenomena, it also involves an understanding of how technologies used by First Nations, Métis, and Inuit groups have impacted the environment.

traditional ecological knowledge: the accumulated observations and understanding of the people living within an area, acquired over many hundreds of years through direct contact with the environment

When investigating environmental issues, the holistic data provided through traditional ecological knowledge often complements the methods used by scientists. This combination of perspectives provides for a fuller understanding of the complex web of interactions and relationships within an ecosystem.

Try This Activity

Identifying the More Acidic Solution

Purpose

You will perform an experiment and use the data to determine which of two solutions contains the most acid.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Background Information

pH is one way to measure the acidity of a solution. One of the empirical properties of an acid is its ability to be neutralized by a base. In this activity you will use a basic solution to test the two acidic solutions you are comparing.

Materials

- commercial lemon juice
- vinegar
- 0.100-mol/L NaOH(aq)
- 3, 50-mL beakers
- 3 plastic (berol) pipettes (or medicine droppers)
- multiwell dish (or 2 watch glasses)
- phenolphthalein
- grease pencil (or waterproof marker)
- "Identifying the More Acidic Solution" handout from the Science 30 Textbook CD

Procedure

Note: When performing this procedure, make sure all the drops are as similar in size as possible. To deliver similar-sized drops, hold the pipette vertically and maintain the same pressure on the bulb.

step 1: Pour approximately 10 mL of the commercial lemon juice and vinegar into separate 50-mL beakers. Label each beaker appropriately.

step 2: Pour approximately 20 mL of the NaOH(aq) solution into the third 50-mL beaker. Label this beaker appropriately.

step 3: Depress the bulb of the first pipette, and draw some of the lemon juice solution into the pipette.

step 4: Gently squeeze the bulb of the pipette and carefully deliver 3 drops of the lemon juice into the first well of the multiwell dish (or to the first watch glass).

step 5: Add 1 drop of phenolphthalein to the commercial lemon juice in the multiwell dish (or watch glass). Record the colour of the indicator as the initial colour in "Identifying the More Acidic Solution" handout.

step 6: Depress the bulb of the second pipette, and draw some of the NaOH(aq) solution into the pipette.

step 7: Hold the pipette containing the NaOH(aq) over the well (or watch glass) containing the lemon juice.

step 8: Gently squeeze the bulb and carefully deliver drops of NaOH(aq) solution into the well until the indicator changes colour. Record the number of drops required and the final indicator colour in your table.

step 9: Repeat steps 3 to 8 using the third pipette to deliver the vinegar solution to the second well (or watch glass).

Analysis

Use the data collected to identify which of the two solutions tested—the commercial lemon juice or the vinegar—contains more acid.

Titration—Quantifying Acid in a Solution

Previously, you examined rainfall data to further examine the factors related to acid deposition. While analyzing the graphs, you may have noted that higher values for total acidity for the rainfall occurred at times when higher concentrations of sulfate ions were present. This pattern contrasts with the inverse variation that occurs when comparing the total acidity and pH. Although pH is a measure of the concentration of hydronium ions in a solution, other methods often have to be used to determine the amount of acid present.

Titration is a method of determining the quantity of acid or base present in a sample. As you know, acids can be neutralized by a reaction with a base. Also, the colour change for some indicators can be used to signify when the pH of a solution changes from acidic to basic.

titration: a technique used to determine the concentration of a substance in a solution by adding measured quantities of another substance that it is known to react with until an endpoint is reached

How is it possible to determine which solution contains more acid using such simple equipment? What is the significance of using NaOH(aq) and an indicator? Perhaps measuring the volume and proportions of each reactant involved is a key to using your observations from a titration.

From your observations, were you able to identify which solution was more concentrated in the previous activity, "Identifying the More Acidic Solution"? In fact, you counted and compared the number of drops required to bring about a colour change to the indicator. There is always a need for quantitative data (in this case, number of drops) along with qualitative data (the colour change signifying the completion of the reaction) to find an answer. Now that you have completed your first titration, it is time for you to see how this method can be used to provide precise numerical data.

Improving Precision

Figure B1.37: Carefully reading a burette improves the precision of the results of a titration.

How would you modify your procedure if you were asked to perform a titration to determine the concentration of acid in a sample of rainwater? A titration can be adapted to produce an answer with greater precision. If you choose to use equipment—such as a burette, a graduated cylinder, or a pipette—to more accurately measure the volumes of the solutions you use, you will collect data that has greater precision than the titration you just performed.

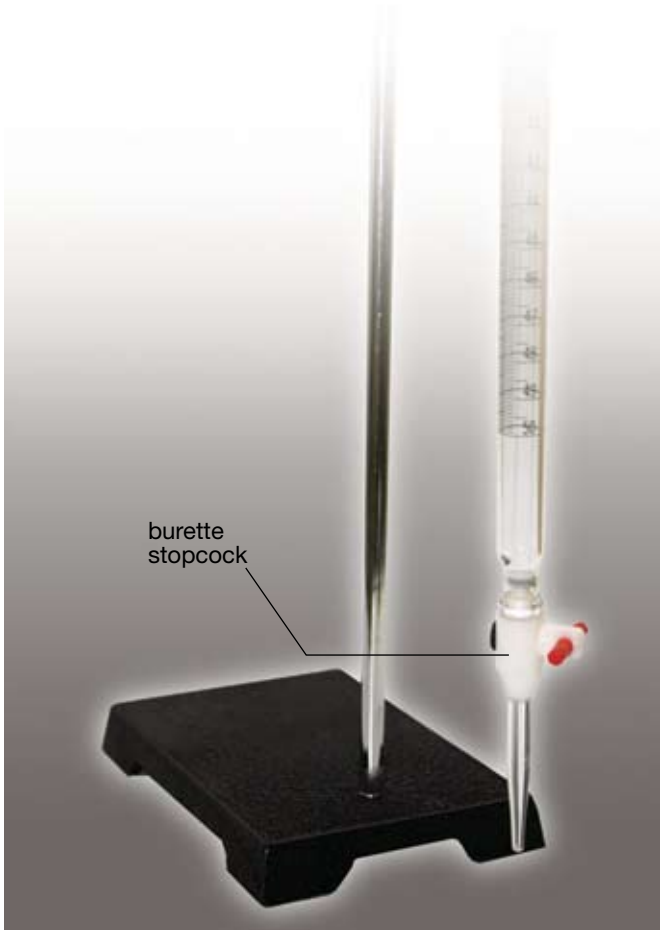
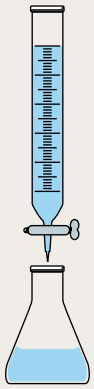


Figure B1.38: The scale along a burette is used to measure the volume of solution that flows through the stopcock during the reaction between an acid and a base.

Investigation

Titration of an Acid with a Base—Demonstration

Background Information



Your teacher will demonstrate the procedure for performing a titration. As you watch the demonstration, refer to the instructions given. You will be asked to perform titrations later in this lesson, so paying careful attention to the values you need to measure and record is essential to your ability to adapt this process.

Titrations can be performed in microscale or macroscale. This activity uses the macroscale method; however, if you wish to view the instructions describing the microscale method, they are located on the Science 30 Textbook CD.

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Materials

- bromothymol blue (or phenolphthalein)
- acid solution, containing an unknown concentration of $H_3O^+(aq)$
- 0.100-mol/L NaOH(aq)
- de-ionized or distilled water in a wash bottle
- 250-mL beaker
- 2, 50-mL beakers
- 125-mL Erlenmeyer flask
- 10-mL graduated cylinder (or 10-mL pipette and pipette bulb)
- small liquid funnel
- 50-mL burette
- burette clamp
- ring stand
- grease pencil (or waterproof marker)

Macroscale Method

step 1: Use the grease pencil to label a 50-mL beaker "Acid." Transfer approximately 40 mL of the acid solution (of unknown concentration) to this beaker.

step 2: Use the grease pencil to label another 50-mL beaker "Base Sodium Hydroxide." Transfer approximately 45 mL of the NaOH(aq) to this beaker.

step 3: Attach and secure the burette clamp half-way along the ring stand.

Science Skills

✓ Analyzing and Interpreting

step 4: Carefully wash the burette. Close the stopcock; then fill it one-third full with water from the wash bottle. Tilt the burette sideways to wash the inside walls with the water; then tilt the burette vertically and hold it over the 250 mL beaker, which will serve as the waste beaker. Open the stopcock and transfer the wash water from the burette into the waste beaker. Repeat this step one more time.

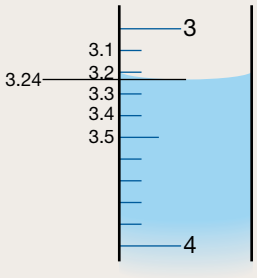
step 5: Place the burette into the burette clamp attached to the ring stand.

step 6: Close the stopcock; place the funnel into the upper end of the burette; and add approximately 15–20 mL of NaOH(aq) to the burette. Remove the funnel from the top of the burette.

step 7: Carefully remove the burette from the clamp; then tilt and wash the inside walls with the sodium hydroxide solution. Return the burette to the clamp. Position the waste beaker under the burette. Open the stopcock to drain the burette.

step 8: Close the stopcock and replace the funnel in the upper end of the burette. Add NaOH(aq) to fill the burette so that the liquid level is within the range of 0 and 5 mL.

step 9: Position the burette so that the level of the NaOH(aq) is at eye level, and measure the position of the lower surface of the meniscus. (You should be able to measure this to at least one decimal place; however, two decimal places is preferred. You might find that using a card with a dark line on it improves the visibility of the bottom of the meniscus.) Record this level in your table.



step 10: Using either a graduated cylinder or a pipette, transfer 10.0 mL of the acid solution to the 125-mL Erlenmeyer flask. Record the volume of acid sample transferred in your table.

step 11: Add 3 to 4 drops of bromothymol blue (or phenolphthalein). Record the colour of the indicator in the acid sample in your table.

step 12: Position the Erlenmeyer flask containing the acid and indicator under the burette and then open the stopcock. Add a small amount of the solution from the burette to the contents of the flask. As you add solution from the burette, swirl the contents of the flask to ensure mixing. Repeat adding small amounts of solution from the burette to the flask until the indicator changes colour. Record this colour in your table.

step 13: Once a permanent colour change has been reached, position the burette so that the level of the NaOH(aq) is at eye level. Measure the position of the lower surface of the meniscus. Record this level in your table.

step 14: Transfer the contents of the Erlenmeyer flask to the waste beaker. Rinse the flask with some water from the wash bottle. Repeat steps 8 to 13 to obtain data from two more trials.

step 15: Disassemble, wash, and return equipment to its proper location. Repeat step 4 to wash the burette.

Note: Save your data from this investigation. You will analyze it later in this lesson.

Using Titration Data

When a base is added to an acid, a neutralization reaction occurs.

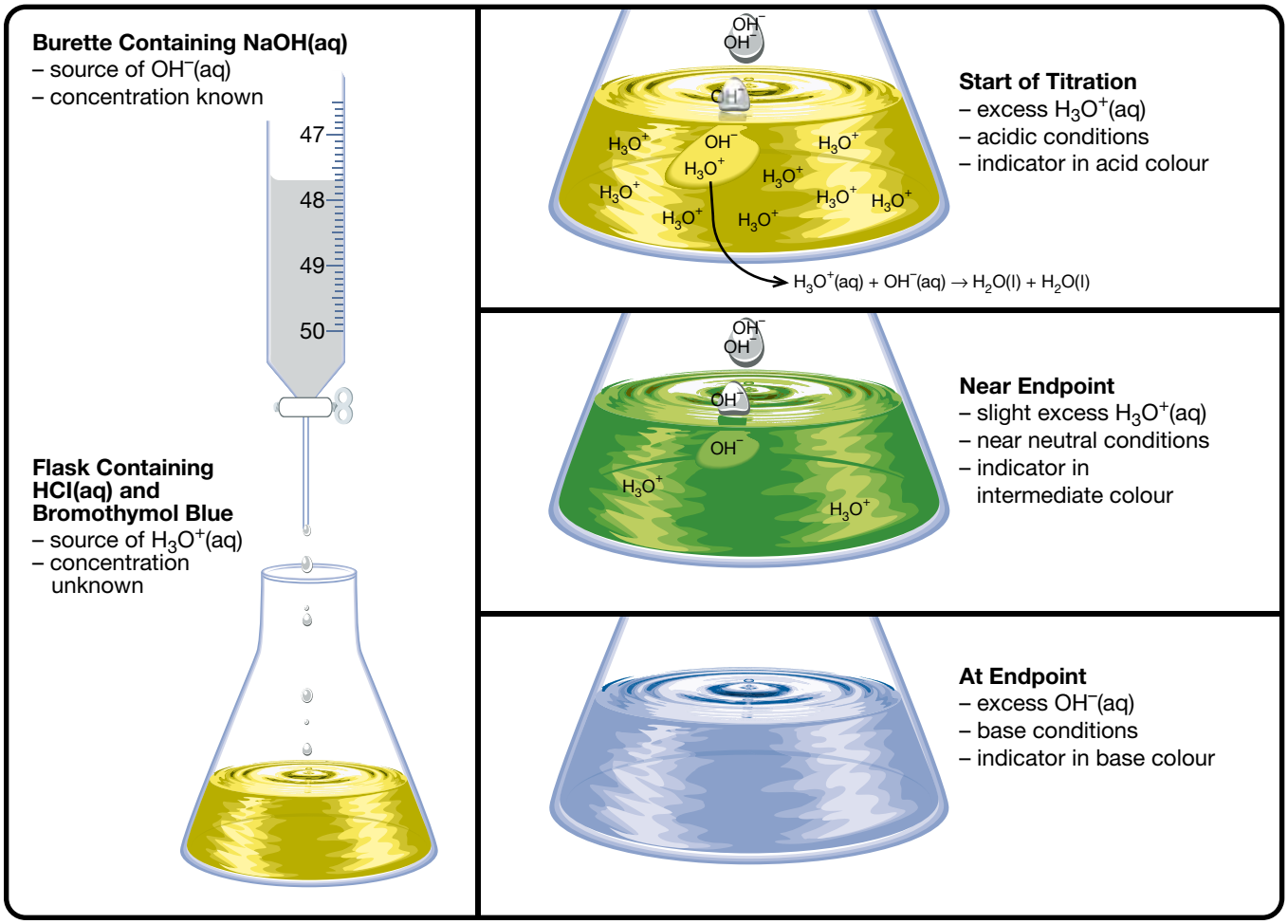


Figure B1.39: Events of titration

In Figure B1.39 on page 207, hydroxide ions within the sodium hydroxide solution were added to neutralize the hydronium ions present in the acid solution being tested. As sodium hydroxide from the burette is added, hydroxide ions enter the acid solution in the flask. A reaction between hydronium ions and hydroxide ions occurs until an excess of hydronium ions no longer exists. The decrease in the quantity of hydronium ions causes the pH of the solution in the flask to increase. The increase in pH is noticeable because of the colour change of the indicator. Once the indicator changes colour to indicate a basic condition, the endpoint of the titration has been reached and the addition of more hydroxide ions causes no further chemical change.

As demonstrated in Figure B1.39, it is critical to note the proportion of hydroxide ions required to neutralize the hydronium ions in the solution. Previously, you studied reactions between an acid and a base that did not require coefficients larger than 1 in order to be balanced. You might like the simplicity of not having to use larger coefficients, but the ratio of one particle of acid reacting with one particle of base has even greater significance.

Chemical Reaction Between Hydronium and Hydroxide

transfers one H^+ to become

$$H_3O^+(aq) + OH^-(aq) \rightarrow H_2O(l) + H_2O(l)$$

acid | base | conjugate base | conjugate acid

accepts one H^+ to become

A balanced chemical equation is like a recipe describing how to carry out a reaction. The chemical formulas you write tell you what to use, and the coefficients that appear in front of the chemical formulas describe how much of each component to use. If you read the reaction between hydronium and hydroxide aloud, it would sound like, "One hydronium ion reacts with one hydroxide ion to produce two molecules of water." The pattern can then be expanded to any number of particles, including the number of moles. You may recall from previous science courses that the amount of particles within a chemical system is measured as moles. A mole refers to a set number of molecules or particles. *One mole* refers to the same number of particles for any substance. Using moles, you can read the statement as, "One mole of hydronium reacts with one mole of hydroxide to produce two moles of water molecules." If you were to focus on the relationship between the relative amounts of hydronium and hydroxide involved in the reaction, the same equation could be stated as, "For each mole of hydronium that reacts, one mole of hydroxide is required."

Statement of Proportions

transfers one H^+ to become

$$1\,H_3O^+(aq) + 1\,OH^-(aq) \rightarrow H_2O(l) + H_2O(l)$$

acid | base | conjugate base | conjugate acid

accepts one H^+ to become

1 particle of $H_3O^+(aq)$	reacts with	1 particle of $OH^-(aq)$
OR		
1 mol of $H_3O^+(aq)$ particles	reacts with	1 mol of $OH^-(aq)$ particles

THEREFORE

$$n_{\text{acid reacted}} = n_{\text{base reacted}}$$

The statement of proportions demonstrated by the balanced chemical equation is what makes it possible to determine the concentration of the unknown solution titrated in the "Titration of an Acid with a Base" demonstration. During the demonstration, moles of hydroxide were added until the acid was neutralized. If you can determine the number of moles of hydroxide that were added, the statement of proportions for this equation indicates that an equal number of moles of hydronium had to be neutralized by the reaction.

The molar concentration of a solution is the number of moles of dissolved solute per litre of solution.

number of moles of dissolved substance (mol)

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

molar concentration (mol/L)

total volume of solution (L)

The concentration formula can be rearranged to determine the number of moles.

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

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

$$n = CV$$

When working with solutions, it is common to know the concentration and volume of the solution you used during the process. In the case of a titration, you tend to use a **standard solution** in the burette and the graduations along the burette to determine the volume delivered during the titration. The values for the concentration of the standard solution (in the burette) and the volume of solution used to reach the endpoint are substituted into the formula to calculate the number of moles of reactant in the standard solution used to complete the reaction.

standard solution: a solution that has a known concentration

standard solution → $C = \frac{n}{V}$ ← reactant in standard solution; ← standard solution used in each titration

If the acid and the base react in a 1:1 proportion, then

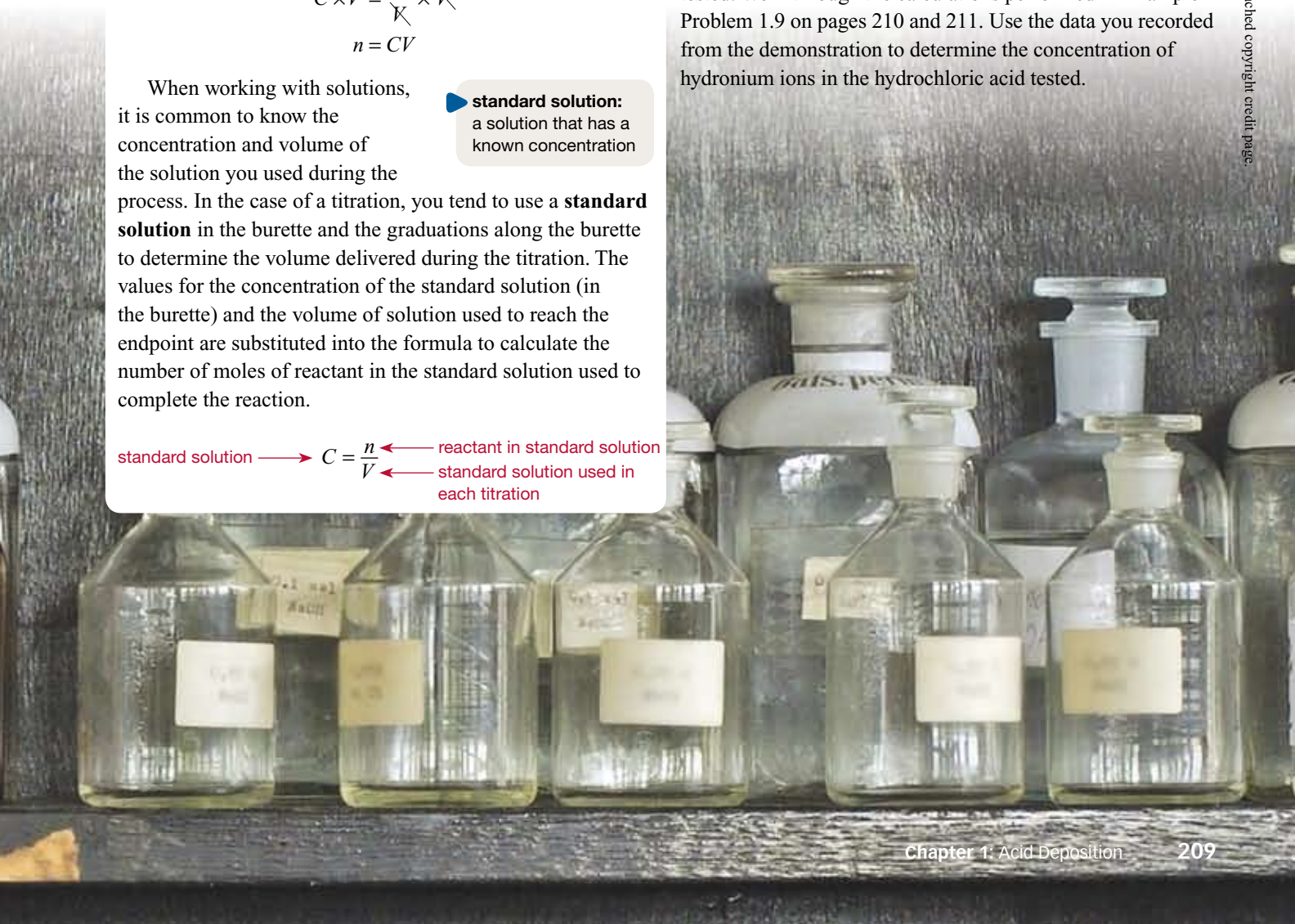
$$n_{\text{acid reacted}} = n_{\text{base reacted}}$$

This statement of proportions for an acid-base reaction, where there is a transfer of a single hydrogen ion, can be interpreted as the number of moles of reactant in the standard solution is equal to the number of moles of reactant in the test solution.

Recall that the problem identified at the start of the titration demonstration was to determine the molar concentration of the hydronium ions in the acidic solution. Up to this point, you have been able to determine the number of moles of reactant in the standard solution—hydroxide—and, thus, the number of moles of reactant in the test solution—the acid. Now, using the concentration formula, you can determine the molar concentration of the test solution. This time, use the number of moles of reactant and the volume of the test solution.

test solution → $C = \frac{n}{V}$ ← reactant in test solution; ← test solution used in each titration

The data recorded in the titration demonstration can be used to calculate the concentration of the acid in the solution tested. Work through the calculations performed in Example Problem 1.9 on pages 210 and 211. Use the data you recorded from the demonstration to determine the concentration of hydronium ions in the hydrochloric acid tested.



Example Problem 1.9

The table given shows data from the titration of four 10.0-mL samples of a solution containing hydronium ions and phenolphthalein using 0.130-mol/L sodium hydroxide solution (the standard solution).

Trial	Volume of Standard Solution (mL)			Endpoint Colour
	Final	Initial	Added	
1	13.44	1.22		dark pink
2	25.35	13.44		light pink
3	37.33	25.35		light pink
4	49.22	37.33		light pink

Calculate the concentration of the hydronium ions in the acid solution.

Solution

step 1: Complete the table.

Trial	Volume of Standard Solution (mL)			Endpoint Colour
	Final	Initial	Added	
1	13.44	1.22	12.22	dark pink
2	25.35	13.44	11.91	light pink
3	37.33	25.35	11.98	light pink
4	49.22	37.33	11.89	light pink

step 2: Select the most consistent trials, and calculate the average volume of standard solution added.

Trials 2 to 4 are the most consistent. This is shown by the similar endpoint colour and the similar volume of standard solution required (within 0.09 mL of each other). Therefore,

$$\begin{aligned} V_{\text{standard solution}} &= \frac{(11.91 + 11.98 + 11.89)\ \text{mL}}{3} \\ &= 11.926\ 666\ 67\ \text{mL} \\ &= 11.93\ \text{mL} \end{aligned}$$

step 3: Confirm proportions by writing the balanced chemical equation for the titration process.

$$H_3O^+(aq) + OH^-(aq) \rightarrow H_2O(l) + H_2O(l)$$

Therefore, for every mole of base, $OH^-(aq)$, that reacts, one mole of acid, $H_3O^+(aq)$, reacts. This means $n_{\text{base reacted}} = n_{\text{acid reacted}}$.

continued

step 4: Calculate the number of moles of acid that reacted.

$$C = 0.130 \text{ mol/L}$$

$$V = 11.926\,666\,67 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$= 0.011\,926\,666\,7 \text{ L}$$

$$n_{\text{base reacted}} = n_{\text{acid reacted}} = ?$$

$$C = \frac{n_{\text{base reacted}}}{V}$$

$$n_{\text{base reacted}} = CV$$

$$n_{\text{acid reacted}} = (0.130 \text{ mol/L})(0.011\,926\,666\,7 \text{ L})$$

$$= 0.001\,550\,466\,7 \text{ mol}$$

$$= 0.001\,55 \text{ mol}$$

step 5: Calculate the concentration of the acid solution.

$$V = 10.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$= 0.0100 \text{ L}$$

$$n_{\text{acid reacted}} = 0.001\,550\,466\,7 \text{ mol}$$

$$C = ?$$

$$C = \frac{n_{\text{acid reacted}}}{V}$$

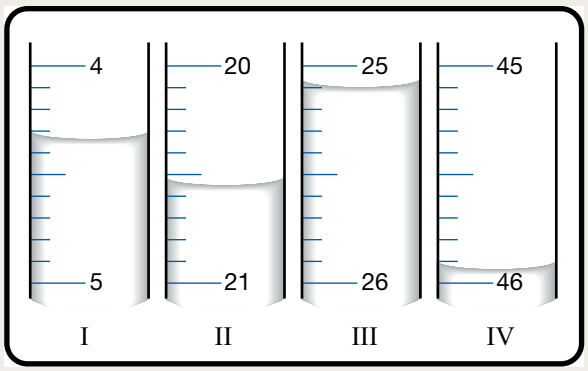
$$= \frac{0.001\,550\,466\,7 \text{ mol}}{0.0100 \text{ L}}$$

$$= 0.155 \text{ mol/L}$$

The concentration of the hydronium ions in the acid solution is 0.155 mol/L.

Practice

42. Use the following information to answer questions 42.a. to 42.c.



a. Read and record the volume in each of the four burettes.

b. If burettes I and II represent the initial and final reading for a titration respectively, calculate the volume of solution used.

c. If burettes III and IV represent the initial and final readings respectively for a second trial, comment on whether the two trials had similar results.

43. Use the following information to calculate the hydronium-ion concentration in a sample of lake water titrated using a standardized solution of sodium hydroxide.

Concentration of hydroxide ions: 0.000 125 mol/L

Initial burette reading: 2.25 mL

Final burette reading: 12.13 mL

Volume of lake water in titration: 10.00 mL

44. Waste water from a mining operation was tested using a titration with a sodium hydroxide solution containing a hydroxide-ion concentration of 0.125 mol/L. It required 44.5 mL of the sodium hydroxide solution to react with the hydronium ions in a 75.0-mL sample of the waste water.

a. Calculate the molar concentration of the hydronium ions in the waste-water sample.

b. Use the molar concentration of the hydronium ions to determine the pH of the waste-water sample.

Why Use a Titration?

For situations where the amount of substance in a solution is required, titration is the preferred method. Titrations can be performed quickly and with relatively inexpensive equipment. Because many trials are done on samples of the test solution, the results can be used to demonstrate consistent results. Consistent results improve confidence in the data and emphasize the reliability of the titration process.

Investigation

Performing a Titration

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Purpose

You will determine the concentration of acid or base in a test sample.

Background Information

The process of titration can be adapted to a variety of situations. Consult with your teacher for further instructions as to which solutions or substances you will be using in this investigation. You may wish to refer to the detailed procedure shown in the titration demonstration earlier in this lesson (pages 206 and 207) and, if necessary, adapt the procedure.

Performing and Recording

Prepare a data table to record qualitative and quantitative observations from each of the trials performed. Ensure that your data is recorded in a logical and understandable manner.

Analysis

1. Use the data you collected to complete the calculations as instructed by your teacher.

Communication and Teamwork

Obtain a copy of a data table from another group of students. Use the data to perform the calculations as instructed by your teacher. Then meet with other students to review the results of the calculations performed on your data and the data of other students.

2. Identify similarities and differences between the sets of data.
3. Comment on whether consistency is observed within the data analyzed. Identify how consistency is evident or not evident within a set of data and between the sets of data.
4. How does the consistency (or lack thereof) in the data affect your confidence in being able to state the concentration of the solution tested? Identify which aspect—reliability or validity—is addressed by consistency within and between the sets of data.

Try This Activity

Comparing Two Acids

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

Do all acids behave similarly? You will compare two acids that appear at different positions on the "Table of Acids and Bases."

Materials

- 1.00-mol/L ethanoic acid
- 1.00-mol/L hydrochloric acid
- 2, 10-mL graduated cylinders
- 2 eyedroppers
- 2, 5-cm lengths of magnesium ribbon
- 2, 50-mL beakers
- 2 test tubes (capacity around 5 mL)
- pH paper (or pH meter)
- test tube rack
- scissors
- grease pencil (or waterproof marker)
- stopwatch (or clock)
- conductivity meter
- forceps or tweezers

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Prepare a data table with two columns. Use the names of the two acid solutions listed in the materials as the headings for your table.

step 2: Use the grease pencil to label one of the test tubes "Ethanoic Acid." Place the test tube into the test tube rack.

step 3: Transfer exactly 5.00 mL of ethanoic acid to one of the graduated cylinders. Use an eyedropper to ensure the meniscus is at the 5.00-mL mark on the cylinder.

step 4: Transfer the ethanoic acid in the graduated cylinder to the "Ethanoic Acid" test tube.

step 5: Transfer enough of the ethanoic acid from the test tube to cover the bottom of one of the 50-mL beakers. Use the conductivity meter to test the solution. Record your observations in your data table. Use the acid in the beaker to measure the pH. Place one of the strips of pH paper into the remaining solution, and record the pH of the solution in a data table. (If you are using a pH meter, you may have to use a larger volume of acid in the beaker to cover the electrode at the bottom of the meter. Ensure that you rinse the electrode before testing the pH of the second solution.)

step 6: Repeat steps 2 to 5 using the hydrochloric acid solution.

step 7: Place a strip of magnesium into each of the test tubes. Record the initial response of the magnesium to the acid and the length of time until a reaction no longer occurs in each of the test tubes. Estimate the amount of magnesium remaining in each test tube.

Analysis

Use the data collected to prepare a list of similarities and differences between ethanoic acid and hydrochloric acid.

Strong and Weak Acids

The differences in the behaviour of ethanoic acid and hydrochloric acid are representative of two groupings used to classify acids. In the "Comparing Two Acids" activity, you tested two acid solutions with identical molar concentrations. Despite this similarity, can you explain why the hydrochloric acid solution had a lower pH and higher conductivity than the ethanoic acid solution? Earlier in this lesson you discovered that solutions with lower pH values, like hydrochloric acid, contain higher concentrations of hydronium ions. The higher conductivity of the hydrochloric acid solution confirmed that it contained more ions. The results from these two tests suggest that hydrochloric acid behaves differently than ethanoic acid in an aqueous solution.

Reaction of Hydrochloric Acid and Water

$$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$

acid — base — conjugate acid — conjugate base

Reaction of Ethanoic Acid and Water

$$CH_3COOH(aq) + H_2O(l) \rightarrow H_3O^+(aq) + CH_3COO^-(aq)$$

acid — base — conjugate acid — conjugate base

You might then interpret the lower conductivity and the higher pH of the ethanoic acid solution to mean that ethanoic acid produced fewer hydronium ions when it reacted with water.

Acids and bases can be categorized into two groups: strong and weak. The members of each group appear in the "Table of Acids and Bases."

TABLE OF ACIDS AND BASES

	Acid Name	Acid Formula	Conjugate Base Formula	
STRONG ACIDS	hydrochloric acid	HCl(aq)	Cl^-(aq)	
	sulfuric acid	H_2SO_4(aq)	HSO_4^-(aq)	
	nitric acid	HNO_3(aq)	NO_3^-(aq)	
	hydronium ion	H_3O^+(aq)	H_2O(l)	
WEAK ACIDS	oxalic acid	HOOCCOOH(aq)	$HOOCCOO^-$(aq)	
	sulfurous acid	H_2SO_3(aq)	HSO_3^-(aq)	
	hydrogen sulfate ion	HSO_4^-(aq)	SO_4^{2-}(aq)	
	phosphoric acid	H_3PO_4(aq)	$H_2PO_4^-$(aq)	
	orange IV	HOr(aq)	Or^-(aq)	
	nitrous acid	HNO_2(aq)	NO_2^-(aq)	
	hydrofluoric acid	HF(aq)	F^-(aq)	
	methanoic acid	HCOOH(aq)	$HCOO^-$(aq)	WEAK BASES
	methyl orange	HMo(aq)	Mo^-(aq)	
	benzoic acid	C_6H_5COOH(aq)	$C_6H_5COO^-$(aq)	
	ethanoic (acetic) acid	CH_3COOH(aq)	CH_3COO^-(aq)	
	carbonic acid, CO_2(g) + H_2O(l)	H_2CO_3(aq)	HCO_3^-(aq)	
	bromothymol blue	HBb(aq)	Bb^-(aq)	
	hydrosulfuric acid	H_2S(aq)	HS^-(aq)	
	phenolphthalein	HPh(aq)	Ph^-(aq)	
	boric acid	H_3BO_3(aq)	$H_2BO_3^-$(aq)	
	ammonium ion	NH_4^+(aq)	NH_3(aq)	
	hydrogen carbonate ion	HCO_3^-(aq)	CO_3^{2-}(aq)	
	indigo carmine	HIc(aq)	Ic^-(aq)	
	water (55.5 mol/L)	H_2O(l)	OH^-(aq)	STRONG BASE

As indicated earlier, the substances in the "Table of Acids and Bases" are arranged according to strength. It is important to note that strength refers only to the extent that an acid or base will react with water to produce hydronium ions or hydroxide ions, respectively.

As you saw, both the ethanoic acid and the hydrochloric acid tested had equal molar concentrations and both consumed the same amount of magnesium ribbon. It is important to remember that weak acids will transfer a hydrogen ion to a base similar to the way a strong acid will.

Reaction of a Weak Acid and a Base

transfers one H^+ to become

$$H_2SO_3(aq) + CO_3^{2-}(aq) \rightarrow HSO_3^-(aq) + HCO_3^-(aq)$$

sulfurous acid (weak acid) | carbonate ion (base) | conjugate base | conjugate acid

accepts one H^+ to become

The reaction between sulfurous acid and carbonate ions demonstrates that the deposition of a weak acid could react with carbonate ions—a substance found in many types of soil. From the "Comparing Two Acids" activity, you saw that a weak acid solution and a strong acid solution of identical concentration and volume produces the same overall effect. Now, recall that many acids are produced from emissions. Whether strong or weak, acids can still lower the pH of water and react with components in the soil. Can you predict the effect on chemical components of soil, like carbonate ions, when subject to long-term acid deposition?

Practice

45. List the acids produced from sulfur oxide and nitrogen oxide emissions. Use the "Table of Acids and Bases" to classify these acids as being either strong or weak.

46. Use the pH values you measured in the "Comparing Two Acids" activity to further support the notion that the two acids tested produce different concentrations of hydronium ions.

47. "Strong acids react almost completely with water to produce hydronium ions." Is this statement supported by the data you collected in the "Comparing Two Acids" activity? Support your answer.

48. Write the balanced chemical equation for the reaction between nitrous acid, $HNO_2(aq)$, and hydroxide, $OH^-(aq)$. Identify the acid, the base, the conjugate acid, and the conjugate base.

Titrations Involving Strong or Weak Acids and Bases

When you completed the "Comparing Two Acids" investigation, you may have been surprised to find that acids can vary in the extent to which they react with water. Earlier in this chapter you used pH measurements to measure acidity; but the results of the last investigation showed that pH is not the best way to determine the concentration of acid in a solution. When acid particles react directly with base particles, titration is the preferred method of determining the concentration of acid in a solution.

When designing a titration, you need to ensure that the acid will react with the base; so, when possible, a solution containing hydroxide ions (a strong base) is used. For a similar reason, solutions containing strong acids are most often used to titrate basic solutions. When selecting solutions for titration, you may want to refer to the "Table of Acids and Bases."

Regardless of the acid being titrated, the quantity (number of moles) involved in the reaction, not its strength, will determine the volume of base required. Example Problems 1.10 and 1.11, on pages 216 and 217, demonstrate calculations using data obtained from the titration of weak acids and bases. As you work through these problems, identify similarities in how these problems and the examples you completed earlier were solved.

Example Problem 1.10

A 25.00-mL sample of methanoic acid, HCOOH(aq), was titrated with a standard solution of 0.250-mol/L sodium hydroxide, NaOH(aq). If 17.5 mL of sodium hydroxide was required to react with the methanoic acid, calculate the initial concentration of the acid solution.

Solution

step 1: Write the balanced chemical equation of the reaction between the acid and the base.

transfers one H^+ to become

$$HCOOH(aq) + OH^-(aq) \rightarrow HCOO^-(aq) + H_2O(l)$$

acid | base | conjugate base | conjugate acid

transfers one H^+ to become

Note: Only $OH^-(aq)$ is written because that is how this base appears on the "Table of Acids and Bases." Since $Na^+(aq)$ is neither an acid nor a base, it is not involved in this reaction and does not need to appear in the equation.

step 2: Confirm that the acid and base react in equal proportions using the coefficients from the balanced chemical equation.

Because the acid and base react in equal proportions,

$$n_{OH^-} = n_{HCOOH}$$

step 3: Use the data to determine the initial concentration of the methanoic acid.

$$C_{OH^-} = 0.250 \text{ mol/L}$$

$$V_{OH^-} = 17.5 \cancel{\text{mL}} \times \frac{1 \text{ L}}{1000 \cancel{\text{mL}}}$$
$$= 0.0175 \text{ L}$$

$$V_{HCOOH} = 25.00 \cancel{\text{mL}} \times \frac{1 \text{ L}}{1000 \cancel{\text{mL}}}$$
$$= 0.025\,00 \text{ L}$$

$$C_{HCOOH} = ?$$

$$n_{OH^-} = n_{HCOOH}$$

$$C_{OH^-}V_{OH^-} = C_{HCOOH}V_{HCOOH}$$

$$C_{HCOOH} = \frac{C_{OH^-}V_{OH^-}}{V_{HCOOH}}$$
$$= \frac{(0.250 \text{ mol/L})(0.0175 \text{ L})}{(0.025\,00 \text{ L})}$$
$$= 0.175 \text{ mol/L}$$

The initial concentration of the methanoic acid was 0.175 mol/L.

Example Problem 1.11

Calculate the volume of a 0.150-mol/L solution containing hydrogen carbonate ions required to react with the hydronium ions present in 75.5 mL of a 0.200-mol/L hydrobromic acid solution.

Solution

Write the balanced chemical equation for this reaction, and determine the proportion of base reacted to acid reacted.

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

Therefore, $n_{HCO_3^-} = n_{H_3O^+}$.

Determine the volume of carbonate ions needed to react with the hydrobromic acid.

$$C_{H_3O^+} = 0.200 \text{ mol/L}$$

$$V_{H_3O^+} = 75.5 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}$$

$$= 0.0755 \text{ L}$$

$$C_{HCO_3^+} = 0.150 \text{ mol/L}$$

$$V_{HCO_3^-} = ?$$

$$n_{HCO_3^-} = n_{H_3O^+}$$

$$C_{HCO_3^-}V_{HCO_3^-} = C_{H_3O^+}V_{H_3O^+}$$

$$V_{HCO_3^-} = \frac{C_{H_3O^+}V_{H_3O^+}}{C_{HCO_3^-}}$$

$$= \frac{(0.200 \text{ mol/L})(0.0755 \text{ L})}{(0.150 \text{ mol/L})}$$

$$= 0.101 \text{ L or } 101 \text{ mL}$$

To neutralize the hydrobromic acid, 101 mL of the hydrogen carbonate ion solution is required.

Practice

49. In a titration, 27.3 mL of a 0.0130-mol/L potassium hydroxide solution was required to neutralize 50.0 mL of a nitric acid solution. Calculate the concentration of the nitric acid solution.

50. A student titrates a solution containing an unknown concentration of sodium hydroxide with a standard solution of hydrochloric acid. If 33.6 mL of 0.0200-mol/L hydrochloric acid is required to neutralize a 25.0-mL sample of the basic solution, calculate the concentration of the sodium hydroxide in the basic solution.

51. A technician wants to predict the volume of a 0.150-mol/L sodium hydroxide solution required to neutralize 2.00 L of a 0.100-mol/L acidic solution. Calculate the volume of sodium hydroxide solution required.

Determining Buffering Capacity

Components in the soil or water can neutralize acid added as either wet or dry deposition. As you know, soils and lake water in different parts of Canada have different chemical components and, thus, vary in their ability to neutralize acids. As a result, measuring the buffering capacity of soil or lake water provides a great deal of insight into the ability of an area to withstand the effects of acid deposition.

Buffering, as the term suggests, refers to a sample's ability to be exposed to acid or base and not change in pH. The chemical components in soil can act as buffers because substances that can act as bases or as acids are present. You have examined the importance of the carbonate ion, $CO_3^{2-}(aq)$, as a buffer in soil. Because a carbonate ion has the ability to accept a hydrogen ion from an acid, the carbonate ion reacts with the acid, keeping the pH of the soil (or of the water) constant.

Sources of Buffering

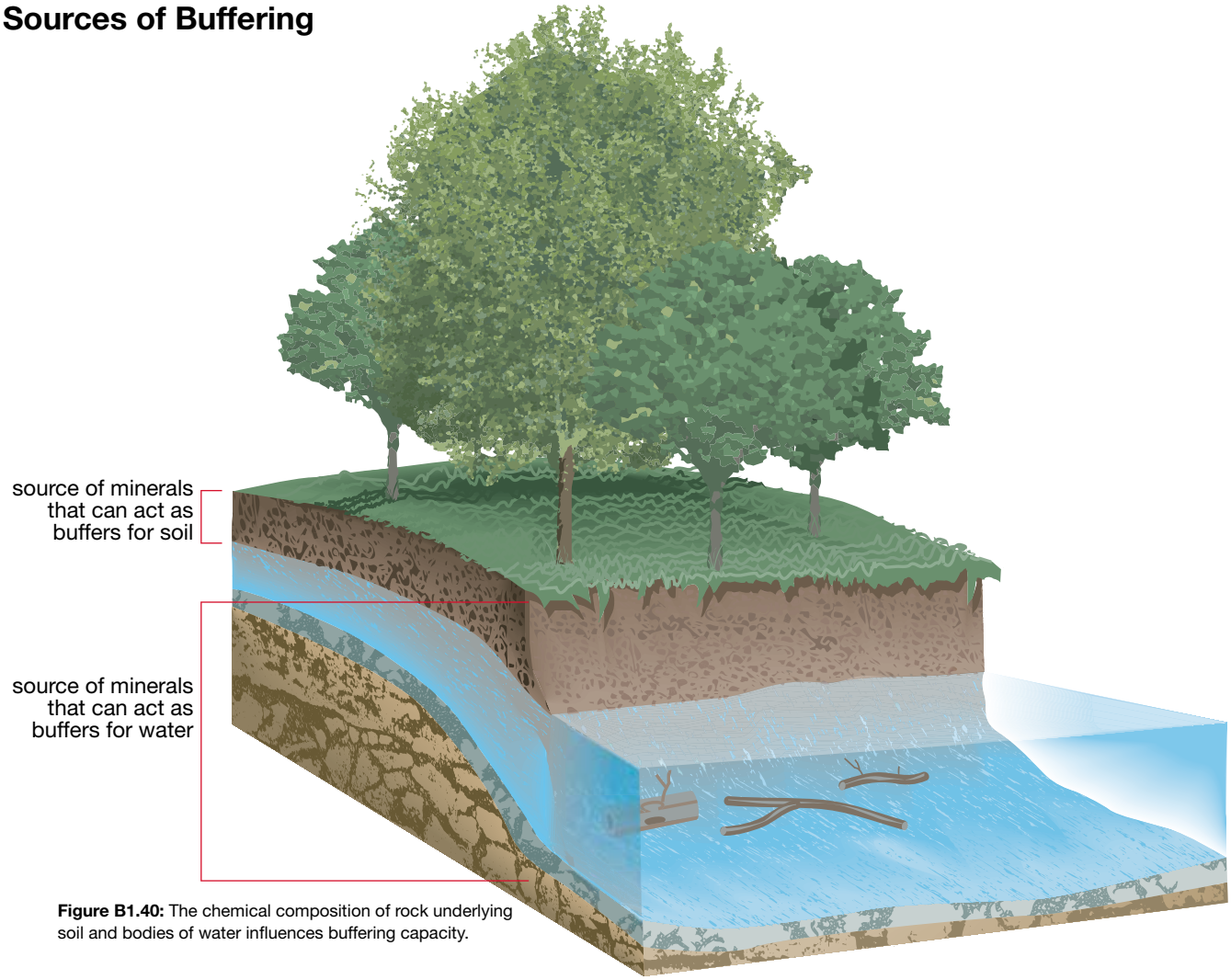
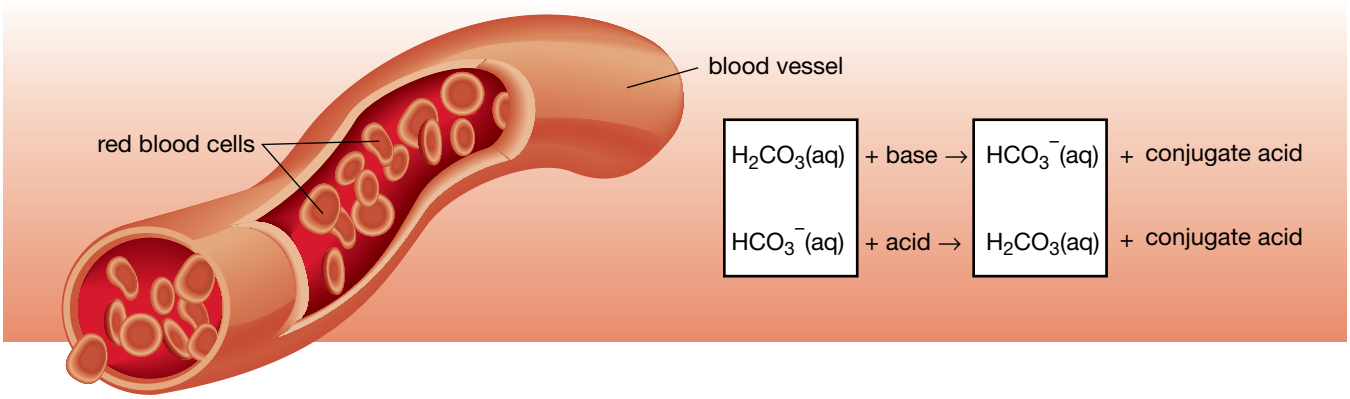


Figure B1.40: The chemical composition of rock underlying soil and bodies of water influences buffering capacity.

Buffers exist in other biological systems. Blood contains two dissolved chemical substances: carbonic acid, $H_2CO_3(aq)$, and hydrogen carbonate, $HCO_3^-(aq)$. Each of these substances has the ability to react with and counteract the presence of either excess base or excess acid, respectively, that may be present in blood. Because a change in blood pH of over 0.5 can be fatal, this buffering mechanism is important to survival. Even when you are exercising and producing lots of CO_2 and lactic acid, the hydrogen carbonate ion in the blood counteracts the effects of CO_2 and lactic acid to maintain a constant pH.

Blood Buffering



The net effect of a buffer is to maintain the pH at a relatively constant level despite the addition of an acid or base. Can buffering last forever? From earlier studies, it appears that regions of eastern Canada have low natural buffering capacity; many areas have become overwhelmed by acid deposition. Is it possible to apply what you have learned about performing a titration and using the data collected to determine a value for the buffering capacity of a sample? In the next investigation you will develop an experimental procedure to address this question.

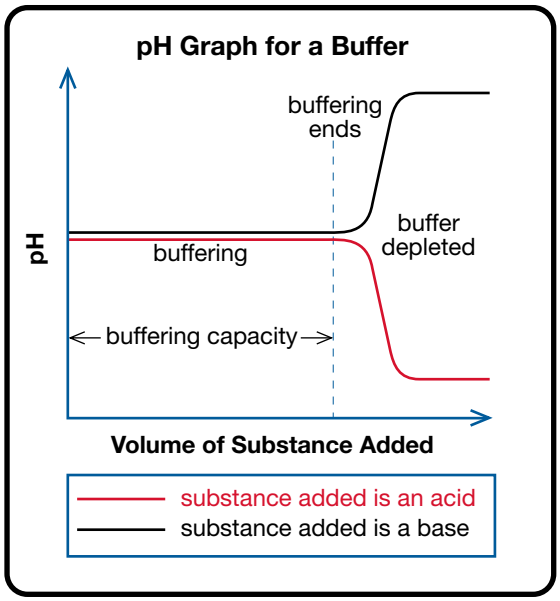


Figure B1.41: Buffers minimize the pH change for a system (e.g., soil or lake water). A sharp change to the pH of a sample being tested indicates that the acid or base being added is no longer being neutralized—the buffering capacity has been exceeded.

Investigation

Designing an Experiment to Determine Buffering Capacity

Background Information

So far in this unit you have learned about acid-base reactions, indicators, pH, titrations, and calculations involving chemical quantities of substances when dissolved in solution. You are encouraged to use your accumulated knowledge and skills to develop an experiment that could achieve the purpose of this investigation.

Science Skills

✓ Initiating and Planning

Purpose

You will develop a procedure to determine the amount (number of moles) of acid that can be buffered by a sample of lake water or by a sample of soil.

Other Ways of Monitoring Acid Deposition

In Lesson 1.1 you discovered that Alberta's Ministry of the Environment collects information about the condition of the atmosphere from a variety of monitoring stations throughout the province. In addition, a mobile monitoring station is available to travel to locations where additional testing is required. Recall that scientists examine biodiversity and changes to populations within an ecosystem as another source of information about the effects of acid deposition. You also looked at the traditional ecological knowledge of people within Canada's First Nations, Métis, and Inuit communities regarding changes that have been occurring within the environment. All of these sources provide valuable information and contribute to a better understanding of the impact human activity has on the environment.

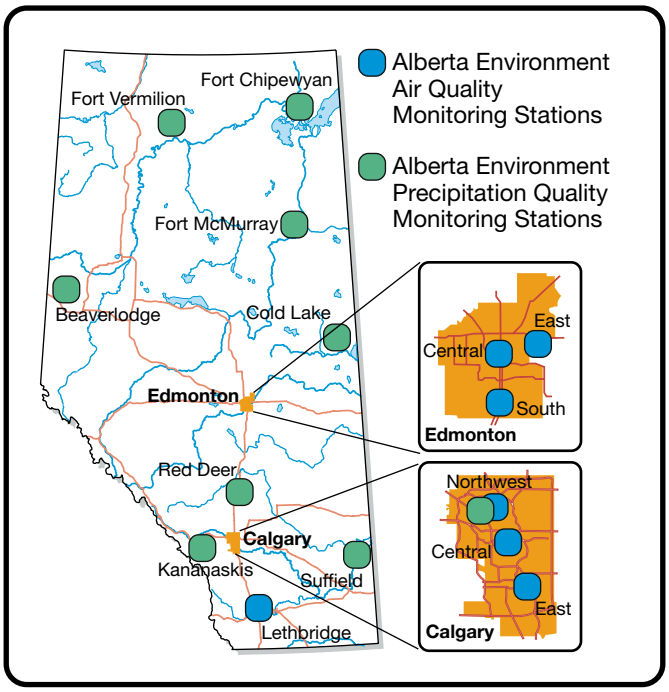


Figure B1.42: Monitoring stations throughout Alberta collect data to provide information about air quality.

Figure B1.43: This is one of many air monitoring stations around Alberta.

Utilizing Technology

Assessing an Approach to Monitor the Effects of Acid Deposition

Science Skills

✓ Analyzing and Interpreting
✓ Communication and Teamwork

Purpose

You will evaluate the experimental design of a study developed to monitor the effects of acid deposition and the recovery of an area affected by acid deposition.

Background Information

The effects of acid rain were first noticed in the Great Lakes region of eastern Canada in the 1970s. Since that time, a great deal of study has been undertaken to identify factors and patterns of emissions and how they have affected the environment. Current studies involve the long-term collection of chemical and biological data to monitor a number of lakes in the region for signs of change. You should note that many of these lakes have been affected by acidification and are being monitored for changes to determine whether water quality and ecosystems are demonstrating improvement over time.

Procedure

step 1: Prepare a table with two columns. Add the heading "Positive Aspects" to the first column and the heading "Negative Aspects" to the second column.

step 2: Obtain the document "Acid Rain Biomonitoring in Ontario's Lakes" from the Science 30 Textbook CD.

step 3: Read the plan described in the document. Then use the Internet to conduct additional research on this plan.

step 4: Consider each aspect of the plan described in the document and those identified in the additional information you collected. Determine if the aspect is positive or negative. For each entry in the table, provide a justification.

step 5: Identify any aspects that are not being investigated in the plan, and place them in the appropriate column along with your justification.

step 6: Compare your table with those of other students. Identify any similarities and differences among the aspects and any similarities and differences among the justifications.

step 7: Develop a consensus within the group, and prepare a brief visual presentation identifying important strengths and weaknesses of the approach used to monitor the effects of acid deposition.

step 8: To use reliable methods and improve the validity of research, scientists often choose to use approaches developed by previous studies when planning a new study. Make a recommendation as to whether the plan you reviewed should be used as a framework for studies to monitor the effects of acid deposition in Alberta. If possible, indicate parts of the study that need to be modified or identify any additional tests that should be performed. Explain your reasoning.

1.4 Summary

In this lesson you analyzed and performed titrations to solve problems involving quantifying acids or bases. You also learned about the importance of buffering capacity to a biological system. Titration can be used to determine a value for buffering capacity. You also determined that acids and bases can be classified as being strong or weak, based on the extent to which they react with water.

1.4 Questions

Knowledge

1. Define the following terms.
   - **a.** indicator
   - **b.** titration
   - **c.** burette
   - **d.** Erlenmeyer flask
   - **e.** endpoint
   - **f.** pH meter
2. Explain why a solution's pH cannot always be used to estimate the concentration of acid within a solution.
3. Write a list of the strong acids that appear on the "Table of Acids and Bases." Explain why strong acids are often used as standard solutions for titrations.

Applying Concepts

4. It takes 16.7 mL of 0.100-mol/L hydroxide ions to neutralize 10.0 mL of an acidic solution of unknown concentration.
   - **a.** Calculate the hydronium-ion concentration of the acid.
   - **b.** Determine the pH of the acid.
5. 60.0 mL of nitric acid with a molar concentration of 2.50 mol/L is accidentally spilled. The base, HCO_3^-(aq), from an acid-spill kit has a concentration of 0.145 mol/L. Determine the volume of base, HCO_3^-(aq), needed to treat the spill.
6. In a titration experiment, a 10.0-mL sample of vinegar, CH_3COOH(aq), is titrated with 0.108-mol/L sodium hydroxide, NaOH(aq). After three trials, it is determined that an average of 7.55 mL of NaOH(aq) is required to neutralize the solution. Determine the molar concentration of ethanoic acid in the vinegar solution.
7. Three 10.0-mL samples of hydrochloric acid with phenolphthalein were titrated with a 0.0567-mol/L solution of sodium hydroxide, NaOH(aq). The results obtained are summarized in the table.

Trial	Volume of Standard Solution (mL)			Endpoint Colour
	Final	Initial	Added	
1	13.61	1.72		light pink
2	25.68	13.67		light pink
3	37.55	25.64		light pink

   - **a.** Calculate the average volume of NaOH(aq) used.
   - **b.** Calculate the molar concentration of the hydrochloric acid tested.
8. Mikhail performed two series of titrations on 15.0-mL test samples. Here are his results.

TITRATION 1

Initial Reading (mL)	Final Reading (mL)	Difference (mL)
10.13	20.73	10.60
20.73	31.34	10.61
31.34	41.93	10.59

TITRATION 2

Initial Reading (mL)	Final Reading (mL)	Difference (mL)
10.15	19.96	9.81
19.96	30.68	10.72
30.68	41.87	11.19

   Which set of data would you be more confident with? Explain your reasons.
9. Explain at least two ways in which you can improve your titration technique to obtain more consistent results.

1.5 Learning from Acid Deposition

Figure B1.44: Sulfur stockpiles are the result of using technologies that remove sulfur from natural gas and other petroleum sources.

Thus far, you have seen that a great deal of knowledge, both chemical and general, is required to understand the issue of acid deposition. Earlier, you were asked to identify intended and unintended aspects of human activity and use of technology. When you think about preventing acid deposition, the obvious solution is to remove acid-forming substances from emissions. But what do you do with the products?

Sulfur is also stockpiled from oil sand refined near Fort McMurray. Each year, 15 million tonnes of sulfur is removed from oil sand. What is done with all that sulfur? Does sulfur removal actually help reduce acid deposition?

In this lesson you will discover how tackling the problem of acid deposition not only involves the use of technology, it also involves all parts of society: local and international governments, industries, and individuals.

Practice

52. It is estimated that up to 5% of the mass of oil sand mined is sulfur and that 15 million tonnes of sulfur each year are produced by sulfur-removal processes used in the oil sands. Estimate the mass (in tonnes) of oil sand mined yearly.

Reducing Acid Deposition

Theories about acid deposition and its effects on the environment have changed over time as new evidence has accumulated. At one time, it was believed that dispersing sulfur-dioxide emissions from the smelting of nickel higher in the atmosphere using a superstack (like the one in Figure B1.45) would decrease the occurrence of acid deposition. Unfortunately, the hypothesis was not supported when evidence of acid deposition began to appear in areas over 200 km from the smelter.

Currently, a variety of technologies are used to reduce emissions. Evidence collected from studies of lakes in Ontario and other regions affected by acid deposition have shown the following:

- Reducing emissions is necessary for areas exposed to extreme acid deposition to recover.
- Areas exposed to extreme levels of acid deposition will recover, but it is a long process.

Figure B1.45: The 380-m tall superstack in Sudbury, Ontario, was the world's tallest chimney when it was built in 1972.

Try This Activity

Catching Emissions

Science Skills

✓ Analyzing and Interpreting

Purpose

You will determine a method of catching emissions.

Materials

- long, plastic tube (e.g., golf-club tube at least 30 cm long)
- electric hair dryer (at least 1000 W)
- plastic grocery bag
- metre-stick
- Styrofoam chips (or confetti or black pepper)
- 10-cm length of transparent tape (or elastic band)

Procedure

step 1: Hold one end of the plastic tube about 3 cm above a small pile of Styrofoam chips.

step 2: Use your other hand to turn on the hair dryer, and position the airflow across the top of the tube. Operate the hair dryer for one minute.

step 3: Observe the effect the air current has on the material at the other end of the tube.

step 4: Once the minute is up, turn off the hair dryer and inspect the inside of the tube.

step 5: Wrap the plastic bag around the end of the metre-stick to make a ball small enough to fit inside the plastic tube. Use the tape to fasten the bag to the metre-stick so the plastic bag stays in place.

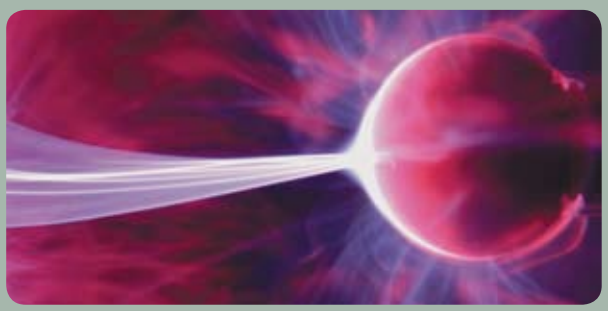
step 6: Insert the end of the metre-stick with the bag attached into the plastic tube. Move the bag back and forth along the inside of the plastic tube for 1 min.

step 7: After 1 min, remove the metre-stick (and the plastic bag) from the plastic tube and repeat steps 1 to 3.

step 8: Clean the inside of the tube as instructed by your teacher, and return all materials to their proper place.

Science Links

Transferring charges onto the surface of the plastic tube causes the charged particles drawn up the tube to be attracted to the inside walls, stopping the particles' movement. In Unit C you will learn more about electric charges and fields and how substances moving against each other often cause a transfer of electrons.



Analysis

1. Describe the effect that the air from the hair dryer had on the material at the lower end of the tube.
2. Describe the effect that moving the plastic bag through the tube had on the material located at the lower end of the tube when you repeated the procedure.
3. Provide an explanation of the results observed.

Reducing Emissions—Electrostatic Precipitation

Did you notice in the "Catching Emissions" activity that the material drawn into the tube stuck to the walls after the plastic bag was moved through the tube? What effect did transferring a charge onto the tube have on the particles drawn up the tube?

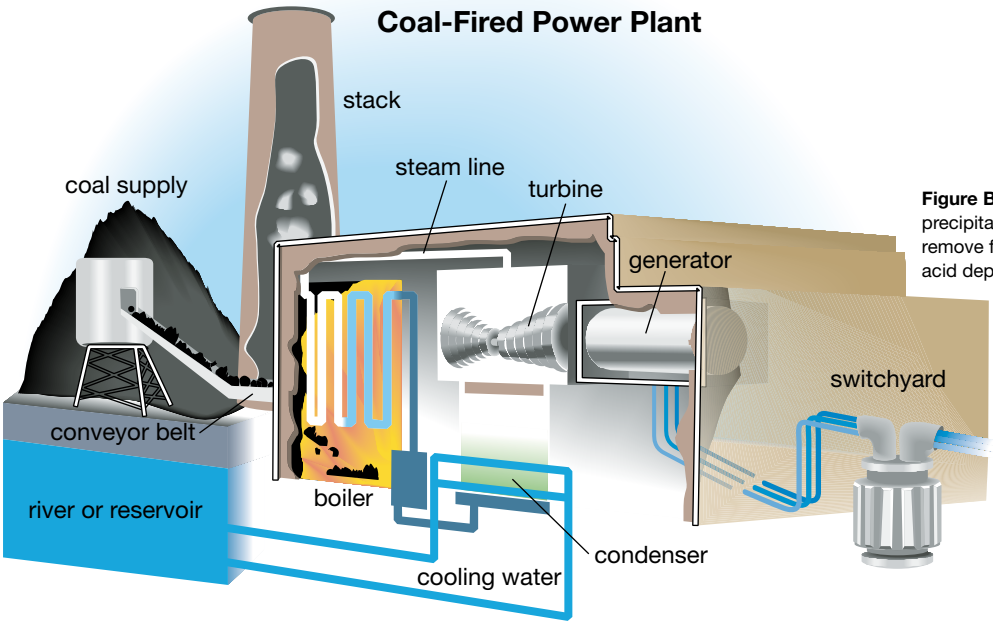


Figure B1.46: Electrostatic precipitators can be used to remove fly ash containing dry acid deposition.

The coal combusted in a coal-fired power plant contains a small volume of sand. Although the combustion reaction does not chemically change the sand, smaller particles of sand are released from the combustion chamber and leave the stack as **fly ash**. Recall that SO_2 and NO_x can be absorbed into the surface of substances, including fly ash. This makes fly ash a potential source of dry acid deposition.

In a process similar to the "Catching Emissions" activity, fly ash is removed from the gases that travel up the stack by an **electrostatic precipitator**. As the particles of ash move into the precipitator, they are exposed to two electrodes. Particles of fly ash become negatively charged as a result of their contact with the negative electrode. Once the fly ash is negatively charged, it will be attracted to and stick to the positively charged plates within the precipitator.

- **fly ash:** small particles of sand and other unburned material that remain suspended in the exhaust gases when pulverized coal is combusted
- **electrostatic precipitator:** a device that uses electric fields to collect fly ash from emissions

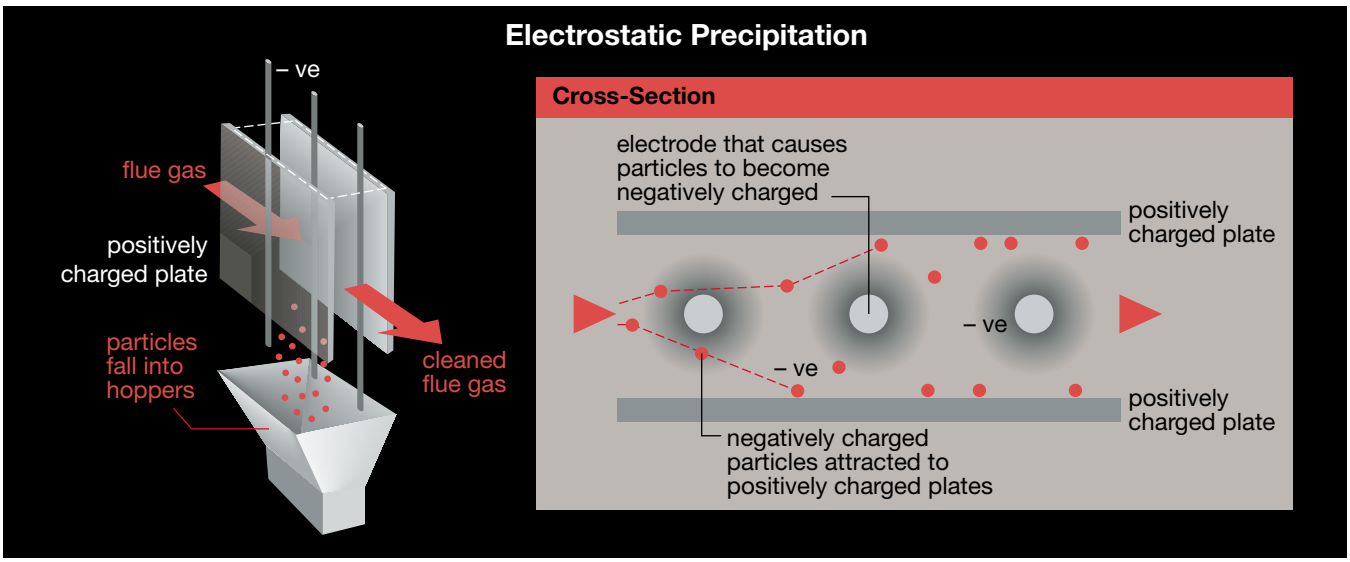


Figure B1.47: An electrostatic precipitator collects fly ash to reduce particulate emissions and acid deposition.

Electrostatic precipitators not only greatly reduce the release of dry acid deposition absorbed onto fly ash, they also reduce particulate emissions. Recently, greater attention has been paid to particulate emissions because evidence has shown that they are a cause of the increased numbers of cases of asthma and other breathing difficulties.

Reducing Emissions—Scrubbing Emissions

When the smoke from the combusted coal was bubbled into water, it rapidly changed the colour of the indicator in the water. **Scrubbing** is a process used to remove one or more gases from a mixture of gases. Scrubbers are used to remove $SO_2(g)$ produced by the combustion of coal.

What kind of substance would you place into the scrubber to remove $SO_2(g)$? Perhaps the next demonstration will help you answer this question.

scrubbing: a process used to remove one or more components from a mixture of gases by passing it through substances that absorb and separate unwanted components

Investigation

Testing Scrubbing Materials—Demonstration

Science Skills

✓ Analyzing and Interpreting

CAUTION!

The procedure should be performed by your teacher.

Purpose

You will watch a demonstration that tests the ability of substances to remove acid-forming compounds from smoke.

Materials

Set up the materials as shown in Figure B1.48.

Figure B1.48

- 0.100-mol/L NaCl(aq)
- 0.100-mol/L NaOH(aq)
- 0.100-mol/L Na_2CO_3(aq)
- 0.100-mol/L NH_3(aq)
- $CaCO_3$(s)

Procedure

Observe and compare the results for each of the trials performed with the solutions listed. Observe and compare the results of the trial using the solid substance with the results obtained from the trials using the solutions.

Analysis

1. Explain how you were able to determine whether the substance tested was able to reduce the amount of acid-forming substances in the gas.
2. Rank the substances tested in terms of their decreasing ability to remove acid-forming substances from the gas collected.
3. Using your knowledge of chemistry, explain which type of substance appeared to be best at removing acid-forming substances.
4. If the solutions represent a wet-scrubbing process and the solid represents a dry-scrubbing process, compare the efficiency of wet and dry scrubbers at removing acid-forming substances from the gas collected.
5. Do you feel the procedure in this demonstration allowed for valid comparisons to be made among the substances tested and between the use of solutions and solids as materials for scrubbing? Support your answer by citing specific examples.

Many substances are capable of scrubbing or absorbing acid-forming emissions. Did you notice in the demonstration that the best scrubbers were bases—the substances containing hydroxide ions, carbonate ions, and ammonia? All of these substances are used in industrial scrubbers because of their ability to react with acids. Calcium carbonate is a popular scrubbing compound because of its abundance and because it is a weak base. Safety concerns associated with the use of hydroxides (e.g., highly corrosive) and ammonia (e.g., strong, pungent odour) restrict the use of these substances as scrubbers.

The design of a scrubber is quite simple. Refer to Figure B1.49. Exhaust gases enter the bottom of the tower. At the top of the tower, the liquid containing the material that will absorb components from the exhaust gases is added. The gases and the scrubbing compounds meet within the tower and the reaction between the two substances completes the scrubbing process.

Cross-Section of a Scrubber

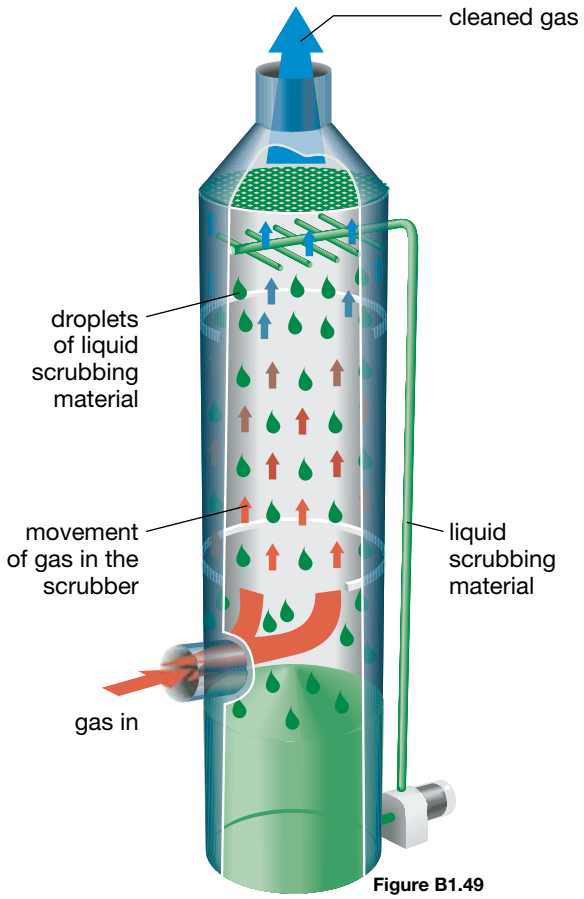


Figure B1.49

Many of the materials used in scrubbers to remove SO_2 are related. The metal-refining industry depends highly on the use of scrubbers that contain lime (calcium oxide) to remove sulfur dioxide produced during the refining of metal ores. Lime (calcium oxide) is produced by the heating of calcium carbonate. Both substances also have basic properties. Kilns, like the one pictured in Figure B1.50, are used to heat calcium carbonate to produce lime.

DID YOU KNOW?

Kilns measuring up to 200 m in length operate at temperatures above 1400°C to convert limestone into lime, which is used in the production of cement. To produce such high temperatures, a large quantity of coal or natural gas is required. The cement and other industries that utilize combustion processes use technologies, like scrubbers, to control emissions.

Figure B1.50: This kiln at Lehigh Inland Cement in Edmonton is over half the length of a football field and 4.2 m in diameter.

DID YOU KNOW?

The reaction between SO_2 and limestone in a scrubber can be used to produce calcium sulfate, $CaSO_4(s)$, commonly known as gypsum. Gypsum is used in a variety of building materials, like drywall. Many industrial processes are being designed in such a way that waste materials may be used for other processes.

Reducing Emissions—NO_x

Recall that NO_x is an abbreviation for two oxides of nitrogen: NO(g) and NO_2(g). Because of differences in the chemical properties of these two compounds, it is difficult to remove both compounds using a scrubber. A more efficient method for removing NO_x compounds from the exhaust of combustion reactions involves the use of a **catalyst**.

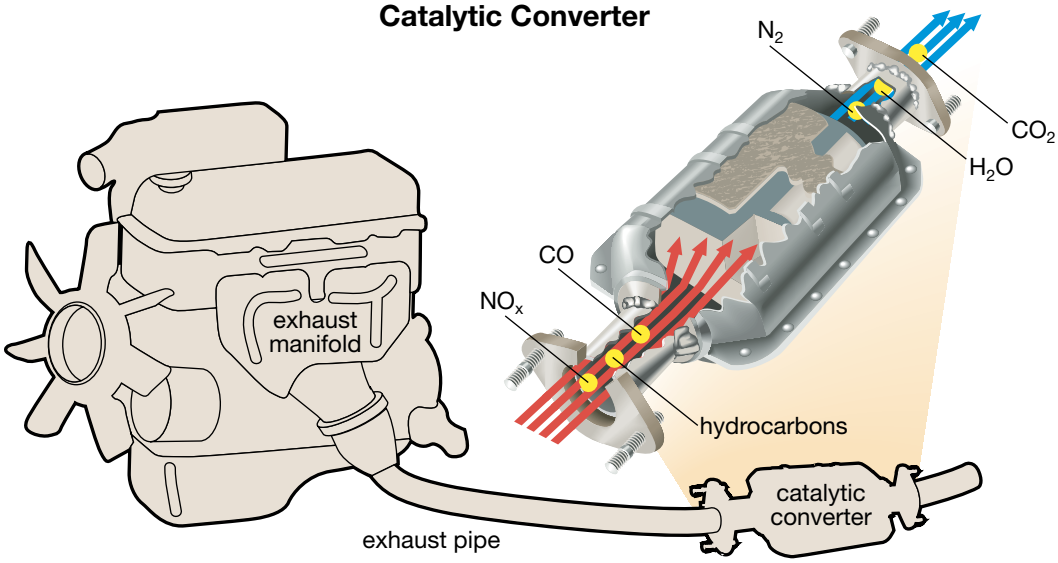
The transportation industry, including automobiles, is a major source of acid deposition because of the NO_x emissions produced by the internal combustion engine. The high temperature at which combustion occurs within an engine causes a reaction between atmospheric nitrogen and oxygen that produces NO_x.

NO_x Compounds

N = O
nitrogen monoxide, NO

O = N – O
nitrogen dioxide, NO_2

Catalytic Converter



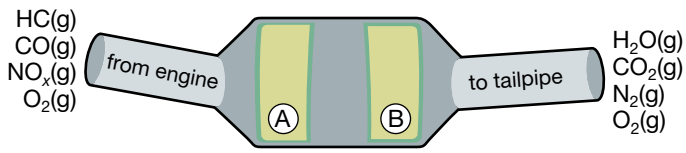
catalyst: a substance used in a chemical process that increases the speed of the reaction and is not affected by the process

catalytic converter: an emission-control device used to remove NO_x, carbon monoxide, and hydrocarbons from vehicle exhaust

One of the purposes of a **catalytic converter** is to change NO_x compounds into nitrogen. Automobile exhaust containing NO_x, carbon monoxide, and small hydrocarbon molecules undergoes reactions in the presence of the catalysts within the converter to produce N_2(g), CO_2(g), and H_2O(g). Catalytic converters were first used in automobiles in the 1970s as a pollution-control device. Further development of the technology has resulted in converters becoming more efficient in removing pollutants from exhaust. Converters are used in vehicles fuelled by gasoline, diesel, propane, and natural gas.

Large industry also uses catalysts to remove NO_x compounds from emissions.

Catalytic Converter Process



Ⓐ Reduction

NO_x, CO → N_2 + CO_2

Ⓑ Oxidation

HC, CO, O_2 → H_2O + CO_2

Figure B1.51: The reactions within a catalytic converter change NO_x and other substances of concern into less harmful substances.

Figure B1.52: Concerns regarding emissions where vehicles are used indoors have prompted the development of catalytic converters for vehicles like this forklift, which operates on propane.

DID YOU KNOW?

The actions of drivers can have a significant effect on emissions. When catalytic converters were first fitted on vehicles, concerns about the reduction in the horsepower cause many people to remove them from their vehicles. Even with more efficient models of catalytic converters, drivers cause significant levels of emissions by excessive idling, such as waiting in line at a drive-through.

Photochemical Smog

Imagine you've been sitting indoors all day. You are looking forward to getting outside and doing some sort of physical activity, whether it be playing soccer, running, or walking. But when you look out the window toward the horizon you notice a brownish haze in the sky. You may begin to wonder what that haze is and whether it is even safe to exercise outside.

The brownish haze is $NO_2(g)$ collecting in the **troposphere**. This brownish haze is often referred to as **photochemical smog**. Photochemical smog occurs most often in major cities, where higher levels of automobile exhaust and emissions of hydrocarbons and NO_x compounds occur.

Photochemical Smog Reaction 1

Within car engine: $N_2(g) + O_2(g) \rightarrow NO(g)$

In atmosphere: $2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

The brown haze, $NO_2(g)$, is the result of NO(g)—produced by the reaction of nitrogen and oxygen in vehicle engines—that is quickly converted into $NO_2(g)$ once it is released into the atmosphere. The photochemical smog reaction doesn't stop at $NO_2(g)$. Sunlight can cause a further reaction. Sunlight is composed of wavelengths of radiation with different energies. Some of these wavelengths have sufficient energy to convert $NO_2(g)$ back into NO(g) and a single oxygen atom.

Photochemical Smog Reaction 2

$$NO_2(g) \xrightarrow[\text{sunlight}]{\text{energy from}} NO(g) + \underset{\text{oxygen atom}}{O(g)}$$

Now, a single oxygen atom is highly reactive and will combine with oxygen in the troposphere to form ozone.

Photochemical Smog Reaction 3

$$O(g) + O_2(g) \rightarrow O_3(g)$$

Note: This reaction involves another substance, like $N_2(g)$, present in the atmosphere to act as a catalyst.

Normally, ozone is considered to be beneficial as a filter to protect Earth from ultraviolet radiation; but that is when it is located in the stratosphere, not the troposphere. Ozone is toxic to organisms at high concentrations. At lower concentrations, like those present in photochemical smog, it irritates your eyes, nose, and throat. Hot, windless days during summer can contribute to higher levels of ground-level ozone, causing asthma, bronchitis, coughing, respiratory infections, and decreased lung performance. On such days, smog advisories might be issued to inform you that exercising outdoors is not recommended.

Figure B1.53: Toronto (bottom) shows a thicker layer of photochemical smog than Calgary (top). The city of Calgary, along with many other highly populated urban areas is working hard to avoid the air-quality problems that the city of Toronto is experiencing.

- **troposphere:** the lowest region of the atmosphere that extends to approximately 18 km above Earth's surface; the region of the atmosphere where all weather occurs
- **photochemical smog:** a brownish-red haze produced by the reaction of sunlight and the components in automobile exhaust

DID YOU KNOW?

Information about air quality, including ozone levels, can be obtained form a variety of sources, like the television or the Internet. Alberta Environment updates air-quality information hourly and makes this information available at

http://www3.gov.ab.ca/env/air/AmbientAirMonitoring/currentairquality.html

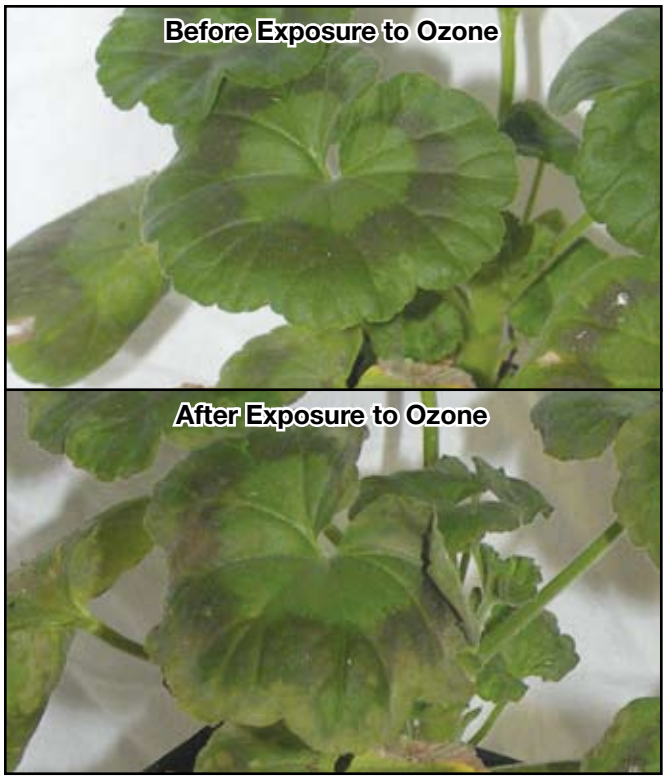


Figure B1.54: The colour change along the edge of the leaf and the spots on the leaf are indicators of damage caused by ozone.

Although ground-level ozone is invisible, you can see quite easily the evidence of its effects. Some plants are extremely sensitive to ozone concentrations in the atmosphere and are used as bio-indicators. Materials like rubber, plastics, and paint are also affected by exposure to ozone. You may recall that rubber is composed of unsaturated hydrocarbon molecules. Ozone reacts with the multiple bonds between carbon atoms in unsaturated molecules, changing the properties of the rubber and causing it to lose its elasticity.

Volatile organic compounds (VOCs), including the hydrocarbons in exhaust and other organic molecules present in the atmosphere, can react with NO_x and ground-level ozone to produce peroxyacetyl nitrate, often referred to as PAN. The presence of PAN in the air is a concern because it is a strong irritant to the respiratory system.

volatile organic compound (VOC): a hydrocarbon or other organic molecule that vapourizes and exists as a gas in the air; sources include gasoline, solvents, paints, and other petroleum-based materials that vapourize

The catalytic converter is designed to reduce—not completely remove—hydrocarbons and NO_x emissions in vehicle exhaust. Since the occurrence of photochemical smog is directly related to automobile use, many major cities have initiated programs to reduce the number of vehicles on the road during morning and evening rush hour. These programs have made an impact on the severity of photochemical smog and the frequency of smog alerts in some areas.

Practice

53. Catalysts can become "poisoned" and lose their ability to function when exposed to certain substances. The catalyst within catalytic converters can be poisoned by the presence of lead and sulfur in gasoline. List other benefits that come from the removal of lead and sulfur from gasoline.

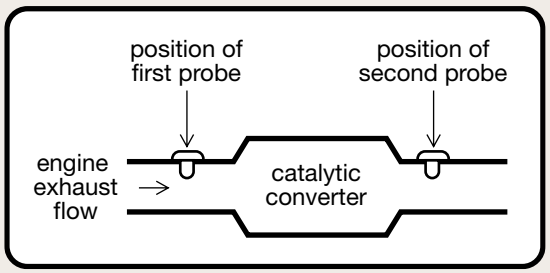
54. The pollution-reduction reaction that occurs within a catalytic converter is temperature sensitive. Better emissions reduction occurs when the catalytic converter operates at higher temperatures than at lower temperatures. Identify which driving behaviour listed below allows the catalytic converter to provide the best pollution reduction.

Driving Behaviours

- starting a car's engine 10 min before driving on a cold winter day
- waiting in the line at a drive-through with the engine running
- parking the car and turning off the engine while waiting to pick up a friend
- rapidly accelerating away from the curb after starting the vehicle

55. Explain how installing catalytic converters in vehicles that are used indoors can promote improved workplace safety.

56. During an emissions test, the function of an automobile's catalytic converter can be tested. To perform this test, probes are placed to detect the presence of substances in the vehicle's exhaust. One probe measures the amounts of substances in the exhaust before the catalytic converter, and the other probe measures the amounts of substances after the catalytic converter.



a. Identify whether the relative concentrations of CO, NO_x, and H_2O in the exhaust are high or low at the first and second probes.

b. In catalytic-converter testing, only a sensor that detects the amount of oxygen is normally used. Explain the rationale and the risks and benefits of using data regarding one substance in such a test.

Practice

57. Refer to Figure B1.55 when answering questions 57.a. to 57.d.

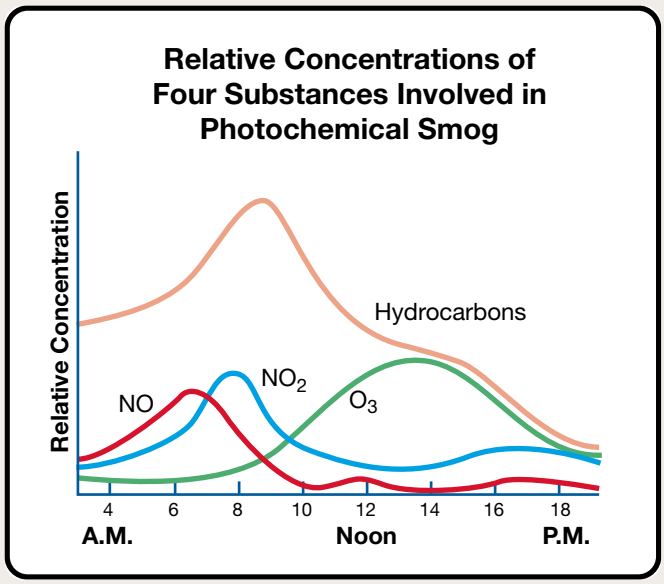


Figure B1.55

a. Explain the reason for the increase in the levels of NO and hydrocarbons early in the graph.

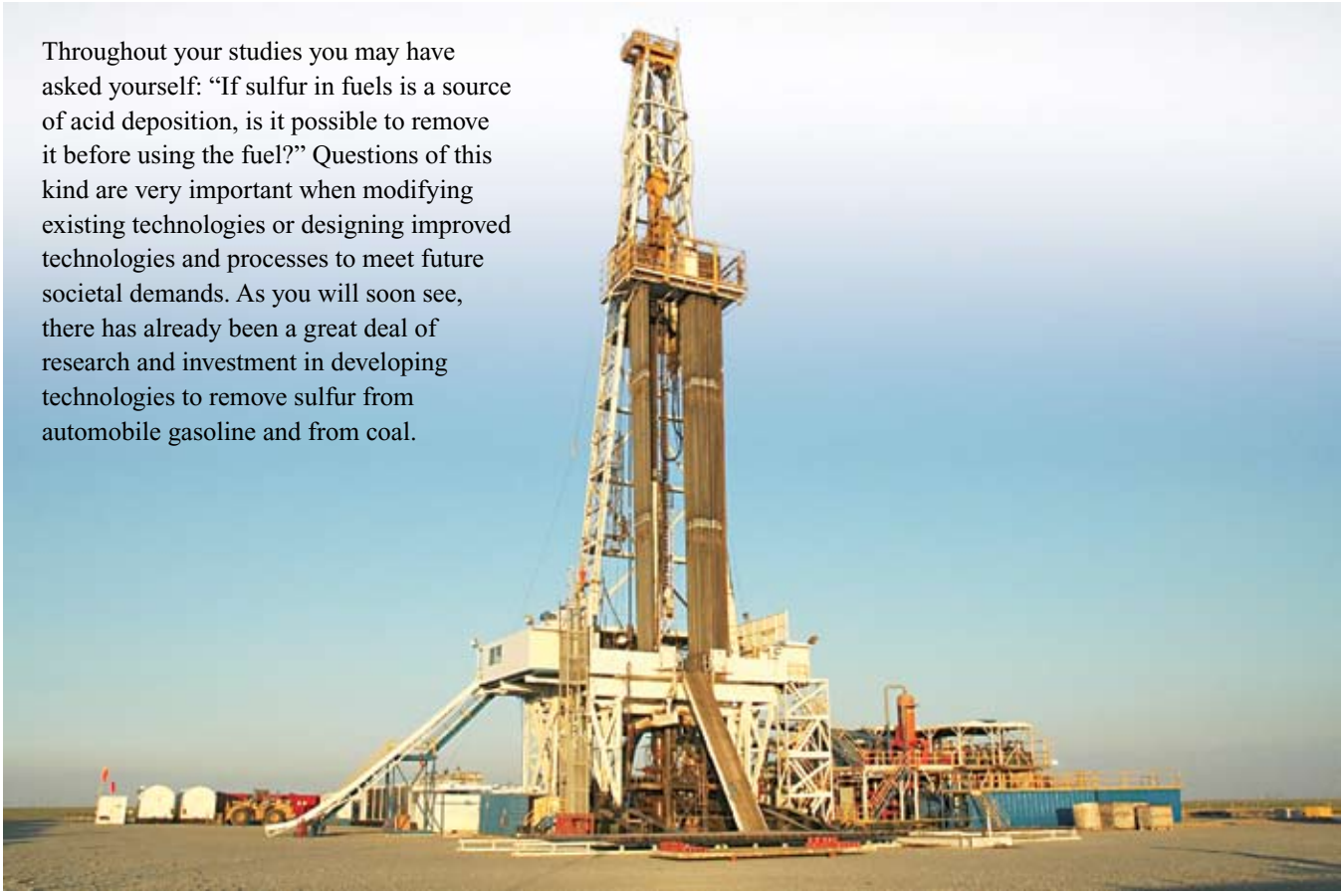
b. Explain why the highest concentration of NO_2 does not occur at the same time as the highest concentration of NO.

c. Explain why the concentration of O_3 rises in the afternoon when the concentrations of the other substances decrease.

d. Could a similar pattern of changing concentrations for these four substances occur in the late afternoon and evening after rush hour? Support your answer.

Reducing Emissions—Preventing the Production of SO_2, NO_x, and H_2S

Throughout your studies you may have asked yourself: "If sulfur in fuels is a source of acid deposition, is it possible to remove it before using the fuel?" Questions of this kind are very important when modifying existing technologies or designing improved technologies and processes to meet future societal demands. As you will soon see, there has already been a great deal of research and investment in developing technologies to remove sulfur from automobile gasoline and from coal.



Earlier, you learned about hydrogen sulfide, H_2S, that may be present in sour gas, natural gas, or petroleum deposits. Hydrogen sulfide is not only toxic, but it forms hydrosulfuric acid when dissolved in water. As you know, acids can contribute to the corrosion of metal. This creates additional problems at well sites. Many petroleum deposits begin to produce $H_2S(g)$ and, thus, become sour gas wells once they have been drilled. Research has identified that proper management of the water used at well sites can prevent wells from becoming contaminated with bacteria that converts the sulfur in the petroleum or natural gas which produces sour gas.

DID YOU KNOW?

Some species of bacteria can use the hydrocarbons in oil and natural gas as food. Oil companies support scientific research into the use of bacteria that consume petroleum and other hydrocarbons for cleanup and reclamation of sites where spills have occurred.

Emissions of NO_x can be prevented by altering conditions for combustion processes. You may recall that high temperatures within a furnace or combustion chamber of an automobile engine can provide sufficient energy for nitrogen and oxygen to combine. Two changes that have made considerable differences to NO_x emissions have been to

- use non-combustion processes where possible
- remove nitrogen from the combustion process by using oxygen instead of atmospheric air

Figure B1.56: Wind turbines are an example of a non-combustion process that can be used to produce electricity.

DID YOU KNOW?

Research enables modifications to the processes used to reduce emissions. The Claus process—invented over 100 years ago to remove sulfur from hydrogen sulfide to sweeten sour gas—has been modified many times. The SuperClaus process uses special catalysts to prevent the formation of SO_2. The Oxygen-Claus process uses pure oxygen to prevent the production of NO_x.

Recovering from Acid Deposition

Because ecosystems are so complex—involving the interaction of biotic and abiotic factors—recovery from acid deposition is expected to take a long time. Scientific data collected on lakes in Ontario that have experienced severe acidification demonstrated that the ecosystems have begun to show signs of recovery; but it is still a slow process.

liming: adding a basic compound to soil or a body of water to neutralize acid deposition

One method to assist in the recovery of lakes and/or soil that have become acidified is **liming**. Lime is calcium oxide, which is a basic compound. Other basic compounds that can be used include calcium carbonate, calcium hydroxide, and magnesium carbonate. Adding lime neutralizes the accumulated acid in the soil or water. By neutralizing the accumulated acid, liming immediately changes the pH of soil or water. Despite this immediate effect, can you think of a reason why liming is considered only a short-term solution to acidic deposition? Another problem with liming is the amount required. Calculations to determine the amount of lime to add and careful management during its application are important to ensure that an excess of the base is not added. An excess of base—and resulting alkaline pH—could create other undesirable effects.

Practice

58. Write the chemical formula for the bases used for liming.

59. Write a balanced chemical equation for the reaction describing the reaction between hydronium ions in the soil with the following bases.

a. magnesium carbonate

b. calcium hydroxide

Evaluating Needs and Technologies

Thus far, you have studied processes and actions that can be used to reduce emissions that can cause acid deposition. In the next activity you will study how many of these methods can be used together to achieve a purpose.

Utilizing Technology

Risks and Benefits of Clean-Coal Technologies

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Background Information

The vast majority of the electricity produced in Alberta comes form the combustion of coal. Alberta has extensive low-sulfur coal reserves, but coal is considered to be one of the dirtiest fuels. Currently, there is much discussion about the development of a technology to reduce emissions produced by the combustion of coal. Zero-emissions or clean-coal technologies could provide a means for ensuring future energy supplies, maintaining (or even improving) environmental standards. There would also be economic benefits from the possible sale of the technology to other countries.

Question

Will investment in developing clean-coal technology benefit all Albertans?

Purpose

You will perform a risk-benefit analysis on the development of technologies that reduce emissions.

Procedure

step 1: Read the "Reducing Emissions from Coal" handout from the Science 30 Textbook CD. This handout describes the steps involved in developing clean-coal technology.

step 2: Read the article *Clean-Coal Advocates Seek Federal Funding for $33M Pilot Project* on the Science 30 Textbook CD.

step 3: Use the Internet to research the following focus questions:

- Will coal be required as an energy source in Alberta, in Canada, and throughout the world in the future?
- What is the projected impact on the environment if coal continues to be used in the future?
- What other technologies could be used to produce electricity if coal was not to be used?
- Is it possible to develop zero-emissions coal? Where do the emissions go? Would this result in improved environmental standards?
- Does it make sense for governments to invest in the development of the technology so that Alberta can become a leader in the development of clean-coal technology?
- What would be the local, national, and international impact of being a leader in the development of this type of technology?

Analysis

1. Use the steps listed in "Decision-Making Skills and Risk-Benefit Analysis" on pages 590 and 591 to perform a risk-benefit analysis to address the question stated following the background information.
2. Prepare a brief summary outlining the results of your risk-benefit analysis and your position regarding the research question you investigated.

Thinking Smart—Not Creating New Problems

Methods to address acid deposition have often relied on using technology. Scrubbers and catalytic converters are examples of these technologies. However, as you have seen, if the processes that generate emissions continue, the technology may not be enough. Technology cannot always fix problems, but changing processes and behaviours can.

Using public transport to reduce the number of cars on the road, changing driving habits, or using vehicles and equipment that do not rely on a combustion process can reduce emissions.

Figure B1.57: Participating in a car pool reduces the number of cars on the road at rush hour and reduces emissions contributing to photochemical smog and acid deposition.

DID YOU KNOW?

Plans for development prior to the 2010 Olympic Winter Games involve the use of 20 hydrogen-fuel-cell buses to service the Whistler area. After the Olympics, these buses will join the general fleet of buses, replacing the older diesel buses. Other plans to address environmental concerns associated with the development and hosting of the Olympics involve using fuel-cell-powered vehicles and building hydrogen filling stations between the major centres of Vancouver, Victoria, and Whistler.

Many major cities are using buses that utilize fuel cells—a technology you will study more in depth in Unit D. Fuel cells convert the chemical potential energy in hydrogen into electrical energy that powers an electric motor in the bus. This technology does not involve a combustion reaction and, therefore, does not produce emissions that contribute to acid deposition. However, there are questions regarding how hydrogen is produced and whether these methods make hydrogen a clean fuel.

Earlier, you saw a picture of the blocks of sulfur generated by the sulfur-removal processes used in refining oil sand. Some of the sulfur produced is sold to the manufacturers of fertilizers, pharmaceuticals, and other products; but a large excess cannot be sold. The stockpiles of excess sulfur have the potential to create environmental problems. Temperature extremes between winter and summer in the Fort McMurray area can cause the blocks of sulfur to erode and be carried by wind and deposit on surrounding soil. Deposited sulfur can be converted by bacteria in the soil into sulfuric acid. Possible negative effects such as soil acidification and possible changes to groundwater or surface water near the blocks are reduced by methods used to construct and monitor sulfur stockpiles.

Figure B1.58: Technicians use a variety of techniques, including video cameras, to determine the changes that occur to stockpiled sulfur.

Burying sulfur seems like an obvious solution to the problems caused by exposed sulfur piles, but careful study is required before burying sulfur is seriously considered as an option. Many factors, like temperature and moisture content of the ground and exposure to oxygen, can influence the growth of bacteria. Careful testing must ensure that proper conditions for storage occur. Both scientific and economic data for underground sulfur storage is being collected in order to make an informed decision regarding the use of this technology. How do you think scientific and economic data should be considered when making decisions about an environmental issue? You might want to look at the information that is available about this project and the scientific and economic data. You may also want to further discuss this issue with other students in your class.

International, National, and Individual Action

Throughout your study, you have seen that acid deposition is not only a problem in Canada. The United States and other industrialized countries have also been affected. Scientific evidence about substances that cause acidic deposition is quite clear—reducing emissions will result in a decrease in the occurrence of acid deposition and other environmental problems, like photochemical smog. Because wind currents can carry emissions across borders, international agreements between countries need to exist to protect the environment and people living in the countries affected.

Canada has participated in the development of a variety of international agreements relating to SO_2 and NO_x emissions. These include the

- 1985 United Nations Economic Commission for Europe Sulfur Protocol
- 1988 United Nations Economic Commission for Europe NO_x Protocol
- 1991 Canada-US Air Quality Agreement
- 1994 United Nations Economic Commission for Europe Sulfur Protocol

Since 1980, SO_2 emissions in Canada have been reduced by almost 50%, enabling Canada to meet its commitment to these international agreements. But, as you have seen, acid deposition is still a serious problem.

At the time this textbook was published, *The Canada-Wide Acid Rain Strategy for Post-2000* was the most recent document describing plans and actions to address acid deposition.

In Alberta, the development and use of plentiful fossil fuel resources has led to an increase in SO_2 and NO_x emissions, despite the extensive use of technologies that reduce emissions. Although this strategy acknowledges the opportunities for Alberta to develop these resources, it acts as a reminder of possible harm that may come to the environment. It may be only a matter of time before Saskatchewan and other provinces downwind of Alberta begin to demonstrate negative effects from acid deposition.

The strategy also identifies actions that each individual can take to help reduce SO_2 and NO_x emissions. Some of these actions include

- conserving energy by using public transport or alternative forms of transport, using more efficient automobiles, changing driving habits, and improving the insulation in your home
- supporting the development of technologies that produce electricity through non-combustion processes
- supporting processes that use technologies that reduce emissions
- recycling paper, metals, and plastics

1.5 Summary

In this lesson you discussed technologies used to reduce SO_2 and NO_x emissions. You also examined how the development of technology may indirectly cause other problems. You also discovered that solving the problem of acid deposition is a complex process that requires reductions in emissions to provide the opportunity for recovery. Canada's participation in international agreements and its development of a national strategy to address acid deposition have provided an opportunity for industry and individuals to take action to reduce emissions.

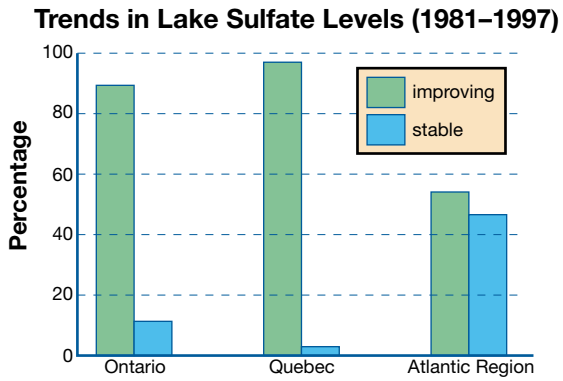
1.5 Questions

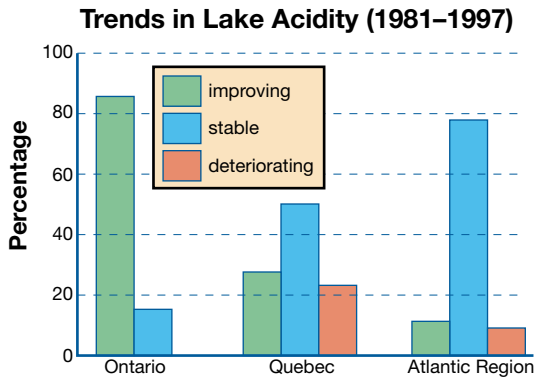
Knowledge

1. Make a list of activities that you and your family undertake that contribute to acid deposition.
2. Examine the list of personal actions that can be taken to reduce SO_2 and NO_x emissions on page 234. Explain how each of these actions could result in lower emissions.
3. Explain the conditions and substances necessary for the development of photochemical smog.
4. List the technologies that reduce SO_2 and NO_x emissions.

Applying Concepts

5. Use the following graphs to answer questions 5.a. to 5.e.





   a. Explain why sulfate levels can be used as a means to assess the level of acid deposition.
   b. During the period shown on the graphs, sulfur-reduction technologies were required to be used by industry in Canada. Identify which regions of eastern Canada appeared to benefit the most and which appeared to benefit the least from the use of these technologies. If possible, provide a possible explanation for the improvement and for the lack of improvement.
   c. What information would you want to see before making any conclusions as to whether the area was recovering?
   d. Explain what is meant by "Lake acidity is still deteriorating in some lakes" when referencing the "Trends in Lake Acidity (1981–1997)" graph.
   e. Is there a correlation between the information shown on the two graphs? Support your answer.
6. From March to May 1993, Calgary was the first Canadian city to have a voluntary emissions-testing program for vehicles. The SMOG FREE (Save Money On Gas From Reduced Exhaust Emissions) program offered free emissions tests and coupons for discounts on products, repairs, and services.
   a. List advantages and disadvantages of a program like SMOG FREE.
   b. Suggest possible reasons for the program to no longer exist.
   c. Predict whether a program like SMOG FREE would work today. Support your answer using examples.
7. Explain the benefits of being able to access current air-quality reports using the Internet or other technologies.
8. Use the Internet to determine the conditions necessary for a smog alert to be issued.
9. Is it necessary to invest funds on research and the development of technologies that reduce emissions to prevent acid deposition? Identify other ways the money could be spent.

Chapter 1 Summary

Producing electricity, driving automobiles, and other processes important to society create emissions that can have adverse effects on the environment and human health. Your study in this chapter has enabled you to identify substances contained in emissions from processes involving combustion and explain how these emissions can lead to acid deposition and other negative environmental effects. You also examined the technologies and changes to behaviour that help reduce emissions.

Studying the effects of acid deposition on the environment involves conducting experiments and collecting data about chemical and biological changes in the environment. Additional data about environmental change can be gathered by consulting those with traditional ecological knowledge. In Chapter 2 you will continue your study of organic compounds and their impact on society and their effects on the environmental.

Summarize Your Learning

This chapter focused on a variety of technologies, chemical terms, and chemical reactions and their impact on the environment. As you may recall, there are many complex relationships between these aspects. Managing the complex information you learned is much easier if you take some time to identify relationships within the information and organize it into some sort of pattern. Now that you have come to the end of this chapter, this is an appropriate time to focus on the patterns within the things you have learned.

Since the pattern has to be in a form that is meaningful to you, you have some options about how you can create this summary. Each of the following options is described in the Reference Section.

Option 1:	Option 2:	Option 3:	Option 4:	Option 5:	Option 6:
Draw a concept map or a web diagram.	Create a point-form summary.	Write a story using key terms and concepts.	Create a colourful poster.	Build a model.	Write a script for a skit (a mock news report).

Chapter 1 Review Questions

Knowledge

1. Use the following information to classify each substance listed as either acidic, basic, or neutral.

a. lake water with a pH of 7.9

b. gastric acid with a pH of 2.0

c. window cleaner with a hydronium-ion concentration of 2.23×10^{-10} mol/L

d. rust remover with a hydronium-ion concentration of 5.72×10^{-3} mol/L

2. Indicators can be used to measure the pH of a solution.

a. Explain how indicators can be used for this purpose.

b. Explain the level of precision that is attainable using indicators to measure pH.

c. Identify one technology that can be used to measure pH and provides better precision than indicators.

3. a. State the name of the theory that identifies acid-base reactions as involving the transfer of a hydrogen ion.

b. Identify which substance donates a hydrogen ion and which substance accepts a hydrogen ion during an acid-base reaction.

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Applying Concepts

4. Complete the following reactions. Label the acid, the base, the conjugate acid, and the conjugate base in each reaction.
   a. $HF(aq) + NH_3(aq) \rightarrow$
   b. $HNO_3(aq) + HCO_3^-(aq) \rightarrow$
   c. $H_3O^+(aq) + H_2BO_3^-(aq) \rightarrow$
   d. $OH^-(aq) + HCO_3^-(aq) \rightarrow$
   e. $CH_3COO^-(aq) + HS^-(aq) \rightarrow$
5. Methanoic acid is dissolved in water and produces a solution that has acidic properties.
   a. Write the balanced chemical equation for methanoic acid and water.
   b. Identify which product is responsible for the solution's acidic properties.
   c. List the properties an acidic solution would have when tested using the apparatus you used in the investigations throughout this chapter.
   d. Explain how empirical properties of acids and bases are useful when describing acids and bases.
6. Explain how rainwater can naturally have a pH of around 5.5.
7. Explain how rainwater can have a pH lower than 5.5.
8. Use the following information to complete the statement.

Solution	pH or $[H_3O^+(aq)]$
1	12.4
2	1.20×10^{-2} mol/L
3	4.5×10^{-9} mol/L
4	5.6

The four solutions in order from most acidic to least acidic are _____, _____, _____, and _____.

9. Refer to Figure B1.42 on page 219 to answer questions 9.a. to 9.e.
   a. Explain why many monitoring stations are used in Alberta.
   b. Review the locations of the precipitation-quality monitoring stations shown on the map. Identify monitoring stations that are located near activities that may have an effect on the environment.
   c. List the kinds of measurements that are made during precipitation-quality monitoring. Explain the significance of these tests.
   d. Explain how the locations of the monitoring stations provide information about acid deposition in Alberta.
   e. Explain how the monitoring stations in these locations may not provide sufficient data regarding the effects of acid deposition in Alberta.
10. Refer to the cartoon to answer questions 10.a. to 10.c.
    a. Identify the issue the cartoon is addressing.
    b. Use your scientific knowledge to explain the issue identified in the cartoon.
    c. Identify aspects of the cartoon that may be misleading.

11. "The solution to pollution is dilution." Use your knowledge of acidic deposition to build an argument that either agrees or disagrees with this statement.

12. Describe some of the long-term effects acidic deposition might have within your local area.

13. Describe actions being taken by groups within your community to study or reduce emissions that could lead to acid deposition. Describe how the groups are determining whether these actions are having any effect.

14. Explain what takes place during chemical monitoring within the environment. Explain the importance of chemical data from monitoring stations to the study of acid deposition.

15. Define *biomonitoring*. Explain how biomonitoring is done within an ecosystem. Explain the importance of biomonitoring to the study of acid deposition.

16. Define *traditional ecological knowledge*. Explain the importance of traditional ecological knowledge to the study of acid deposition.

17. A student designs an experiment to investigate the effect of acid deposition on plants. Use the following information to answer questions 17.a. to 17.f.

> **Experimental Design**
> Obtain three healthy spider plants. Each plant will be watered daily, directly onto the soil, and using equal volumes of liquid. The first plant will be watered with a solution containing sulfuric acid that has a pH of 1; the second plant will be watered with a solution of ethanoic acid with a pH of 3; and the third plant will be watered with distilled water (pH 7). The plants will be observed each day for one week for signs of damage to leaves, loss of colour, and other changes to the appearance of the plant.

a. Predict some of the changes to the plants you think you will see during the experiment.

b. If you were able to perform chemical tests on the soil during the experiment, predict any changes you might expect to occur.

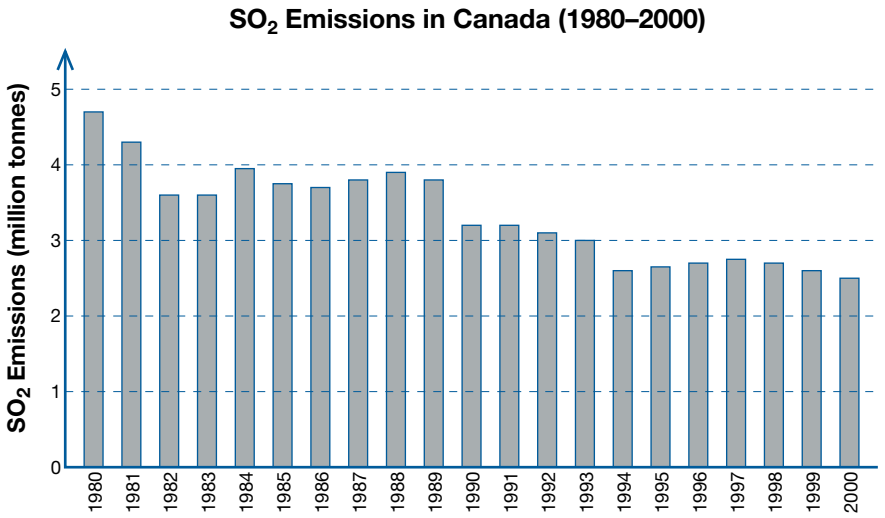
c. Predict the effect that a potting soil with a high buffering capacity could have on the results of the experiment.

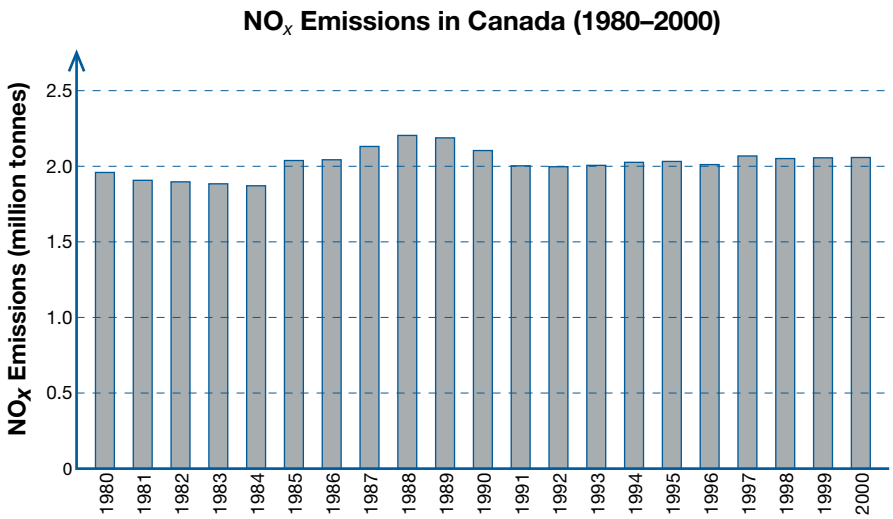
d. Identify the controlled variables in the experiment.

e. Identify the limitations of the experiment.

f. Describe any modifications to this experiment that could improve both reliability and validity.

18. Closely examine the graphs titled "SO_2 Emissions in Canada (1980–2000)" and "NO_x Emissions in Canada (1980–2000)."





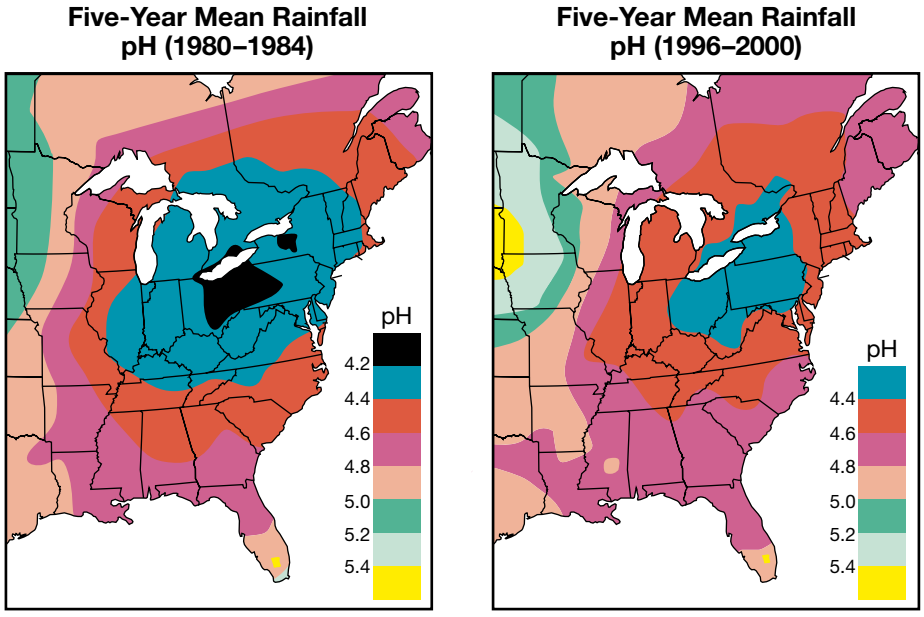
a. Determine the percentage change for each of SO_2 and NO_x from 1980 to 2000 in Canada.

b. Account for the trend shown on each of the graphs.

c. Predict the effect that the change in emissions would have on the pH of rainfall.

d. Explain why data for SO_2 and NO_x emissions from sources in the United States is important in developing a prediction regarding changes in the pH of rainfall in Canada.

e. Refer to the following maps.



Explain whether the data shown on these maps supports the predictions you made in your answer to question 18.c. What inference can you make from these maps regarding SO_2 and NO_x emissions in the United States over the time given?

f. Is it possible to use the maps depicting a five-year mean pH for rainfall to conclude that a reduction in SO_2 and NO_x emissions will reduce the severity of acid deposition? Support your answer.

Chapter 2 The Chemical Legacy of Human Activity

"A Touch of the Farm in the Heart of the City" is the slogan for the Old Strathcona Farmers' Market in Edmonton. Every Saturday, thousands of customers flock to the market to browse and buy from more than 130 vendors. Many people frequent the Farmers' Market for the crafts and the entertainment; but for the most part, people make the trip to Old Strathcona for the wide array of food available.

One type of food, in particular, that many people purchase is "certified organic" food. Many have expressed concern about "chemicals" used in the production of foods and other materials. But isn't all matter, technically, a chemical? Can chemical substances be classified as good and bad? What criteria would be used to do this?

In this unit you will consider the concerns people have about human practices and their impact on the environment. You will study substances used in agriculture, industry, and your home; and you will become aware that some of their properties may cause concern. You will also examine how science, industry, and government address concerns about the environmental impact of some human practices.

Try This Activity

Keeping Up with the News—Chemicals and the Environment

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will collect information about environmental issues and determine whether each issue is the result of a single chemical substance or a group of substances.

Background Information

The term *chemical* is often misused. As a science student, you know that all matter, including water and oxygen, are chemicals. How is this term used or misused by the media? When are "chemicals" referred to and in what way?

Instruction

step 1: Prepare a table with the following headings: Title of News Item, Source of News Item, Chemical Substance Discussed, Source of Chemical Substance, and Issue Addressed. Leave room for three additional columns that you will add later.

step 2: As you study this chapter, collect news items (e.g., newspaper clippings, magazine articles, sound bites from radio or podcasts, and video segments) that discuss "chemicals" in the environment.

step 3: As you collect items, record the information in your table.

step 4: At the end of this chapter you will be given additional instructions about organizing the news items you collect.

2.1 Organic Compounds

Successful farming relies on more than selecting an appropriate crop to match soil conditions. Over the length of a growing season, farmers manage many factors that affect the health and growth of crop plants. Farming requires careful observation of the crop during key stages in its growth. Many farmers use fertilizers, herbicides, and pesticides at certain times of the growing season in hopes of producing a large, high-quality crop.

As many people in the agriculture industry will tell you, current farming practices that include the use of organic compounds are necessary for crop production. Scientific evidence collected from water and from the tissues of animals suggests that the use of organic compounds in farming and in manufactured materials may have an impact far beyond what they were originally intended for.

In this lesson you will study some of the substances used in agriculture and around your home, along with their intended and unintended effects. You will also examine how the chemical properties of organic compounds influence their behaviour in the environment.

Figure B2.1: Fat samples taken from a polar bear can be used to detect presence of organic pollutants within arctic ecosystems.

Organic Compounds

In Science 20 you were introduced to organic chemistry—the study of compounds composed of carbon. The simplest types of organic molecules are hydrocarbons. The bonding between the carbon atoms in a hydrocarbon is significant. As demonstrated in Figure B2.2, a single, double, or even triple bond can exist between carbon atoms in a hydrocarbon.

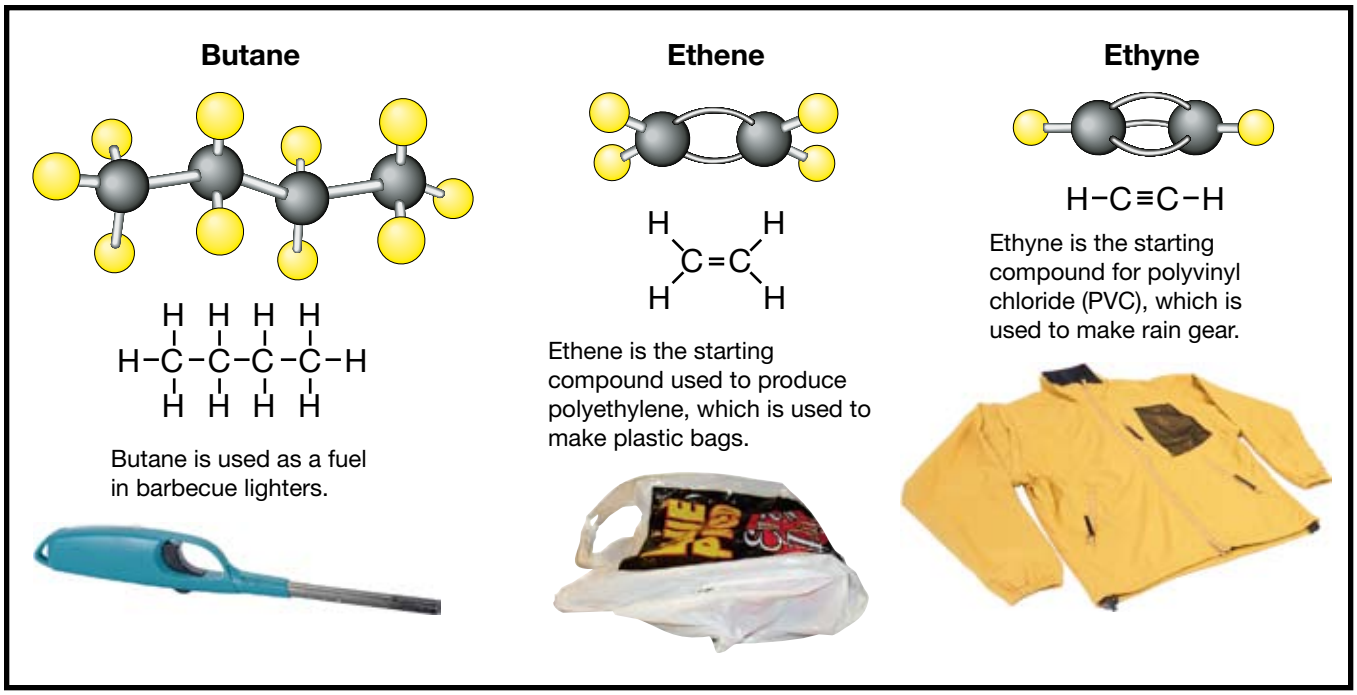


Figure B2.2: Hydrocarbons are the simplest types of organic molecules.

You may recall that hydrocarbons with multiple bonds between carbon atoms are unsaturated and have a different name than saturated hydrocarbons. You will review the naming of hydrocarbons later in this lesson; but for now, use the next activity to review some of the concepts about the shape and other features of hydrocarbons.

Try This Activity

Building Models of Hydrocarbons

Science Skills
✓ Analyzing and Interpreting

Purpose

You will construct a molecular model for each hydrocarbon listed.

Background Information

Molecular models can be used to provide accurate information about the shape of the molecule and the types of bonds between carbon atoms in a hydrocarbon molecule.

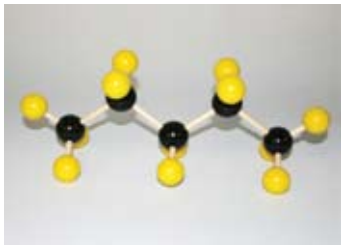
Materials

- molecular model kit

Procedure

Build a model of each compound listed in question 1. Use your model kit to determine whether there are enough hydrogen atoms in the chemical formula to fill the spaces around each carbon atom. Use an additional spring to fill open spaces between carbon atoms to symbolize double bonds where necessary. Use only single or double bonds between carbon atoms when constructing models in this activity.

1. Copy and complete the following table. For each molecule you build, record information about the molecule.

Chemical Formula	Complete Structural Diagram	Bonds Between Carbon Atoms	Saturated or Unsaturated
C_5H_{12}		all single bonds no double bonds	saturated
C_5H_{10}			
C_5H_8			
C_6H_{14}			
C_6H_{12}			
C_6H_{10}			
C_6H_8			
C_6H_6			
C_6H_6 (circular)			
C_7H_8 (circular)			
C_8H_{10} (circular)			

Analysis

2. In Science 20 you learned that the general structure for hydrocarbon molecules was linear. Is this a correct description of the general shape for all hydrocarbons? Describe other arrangements that are possible.
3. If you reduce the number of hydrogens, describe the effect on the arrangement of carbons within a hydrocarbon.
4. Is it possible to have a saturated hydrocarbon that does not possess the maximum number of hydrogen atoms?

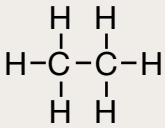
Naming System for Hydrocarbons

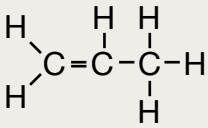
If you compare the molecules you constructed with those built by other students, you may notice that there are many possible correct formations. In order to communicate the precise arrangement of the atoms within organic molecules, a systematic naming system is used. Recall that the longest continuous chain of carbon atoms is considered to be the backbone for most organic molecules and features prominently in the name.

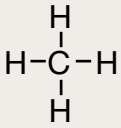
To review the systematic names for linear and branched hydrocarbon molecules, refer to the "Naming Hydrocarbons—Flowchart" handout from the Science 30 Textbook CD.

Practice

1. Write the systematic names for the following hydrocarbon compounds.

   a. 

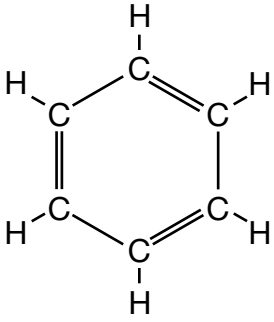
   b. 

   c. 

2. Draw the structural diagram for each compound given.
   a. 2,2-dimethylpropane
   b. 2-methylprop-1-ene

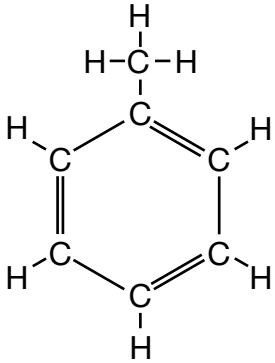
Hydrocarbons can come in many arrangements, including cyclic shapes. One arrangement for the carbon atoms is a hexagon, and one type of hexagonal hydrocarbon structure is a **benzene ring**. Benzene, C_6H_6, and other molecules containing this ring structure are a group of compounds that share similar physical and chemical properties that make them unique organic compounds. This structure can also be referred to as an **aromatic ring** or **phenyl ring**. Aromatic compounds, biphenyls, or benzene-based compounds that you may hear about in the news are all substances that contain this hexagonal structure.

Benzene



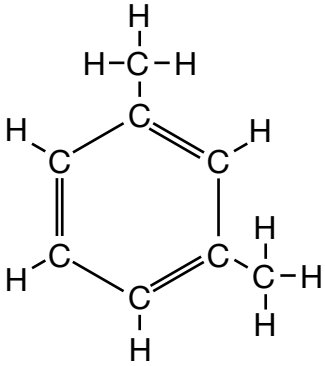
- found in gasoline
- used to make polystyrene

Toluene



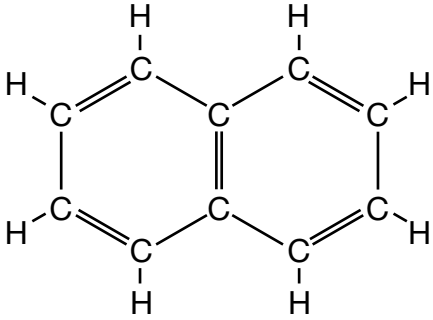
- found in high-octane gasoline
- used in glues for plastic

Xylene



- found in high-octane gasoline
- used in rubber cement

Napthalene



- found in water
- used as moth repellent and fungicide

benzene ring: the hexagonal-ring-shaped chemical structure formed by six carbon atoms and six hydrogen atoms or other atoms

aromatic ring: another name for a benzene ring

phenyl ring: another name for a benzene ring

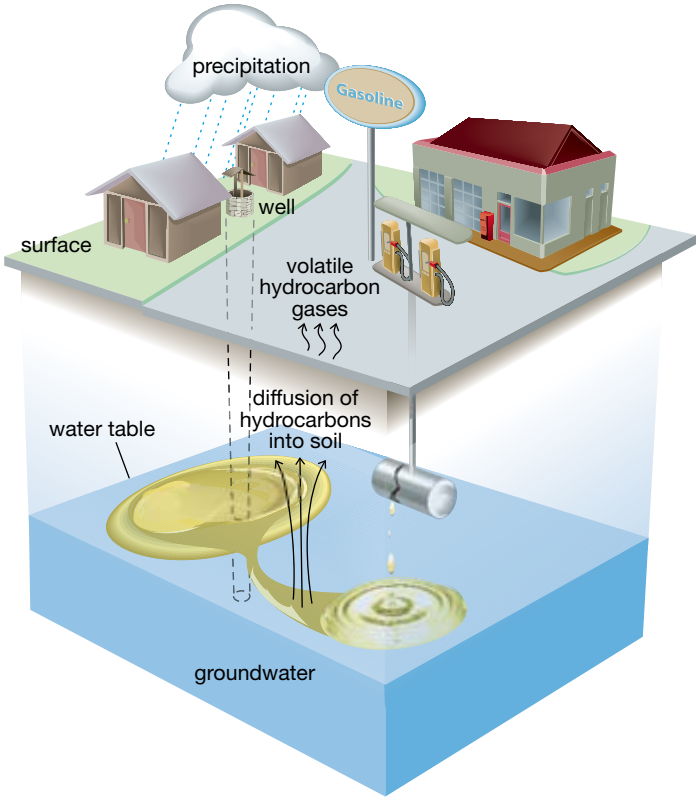
Benzene and Its Consequences

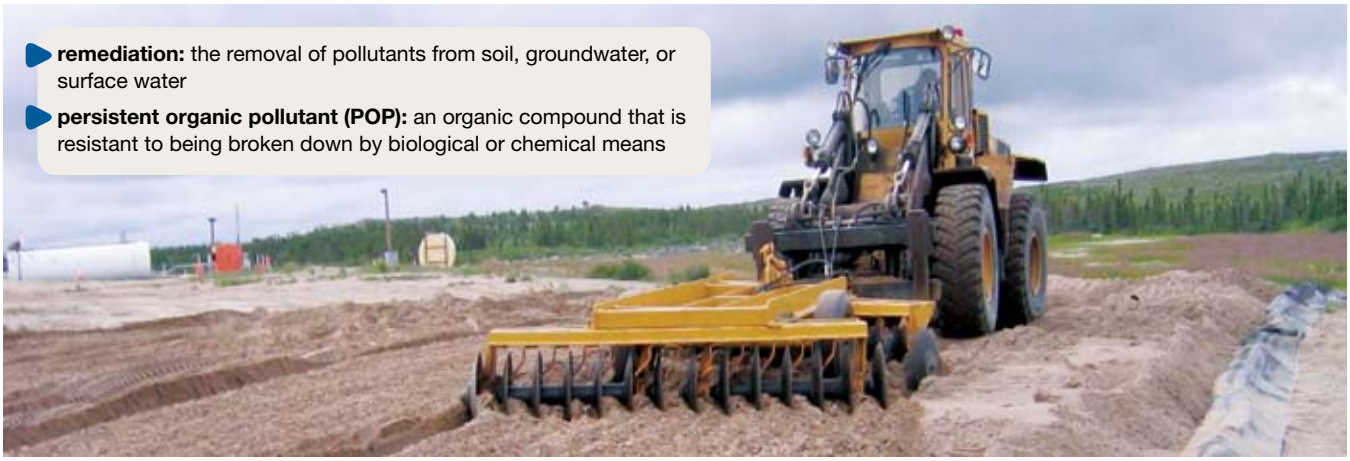
Aromatic compounds are naturally occurring compounds, present in natural resources like petroleum and coal. The gasoline or diesel fuel used in automobiles is a mixture of many hydrocarbons, including aromatic compounds. At one time, benzene and related aromatic compounds made up a large percentage of the hydrocarbons in gasoline. When scientific evidence first suggested that benzene was a carcinogen, action was taken by government and industry to reduce the concentration of benzene in gasoline. Legislation in Canada restricts the percentage of benzene permitted in gasoline.

Cleaning up gasoline that has leaked from an underground storage tank or cleaning up a fuel spill requires the removal of the contaminated soil from the site for treatment. Even though the densities of hydrocarbons are less than the density of water, some compounds in petroleum and gasoline are soluble in water. At spill sites there is often concern about the leaching of benzene and other aromatic hydrocarbons into sources of drinking water. This leaching can contaminate well water and ground water, threatening the health of animals and humans. Water-quality tests performed on well water and other sources of drinking water can identify whether any hydrocarbons are present (e.g., benzene).

The contaminated soil removed from a service station must be treated by a process called **remediation**. Remediation involves the removal or breakdown of hydrocarbons in the spilled gasoline. During remediation, linear hydrocarbons tend to be quickly broken down by the action of bacteria in the soil. Unfortunately, the remediation of molecules containing benzene rings is not as quickly achieved. As you learned earlier, the chemical stability of the benzene rings makes it more difficult for bacteria or chemical processes to break them down. The chemical stability of benzene-based molecules has resulted in their classification as persistent organic molecules, or **persistent organic pollutants** (POPs).

Figure B2.3: Service stations sometimes have to replace their underground fuel tanks with new tanks to keep hydrocarbons in gasoline from leaching into soil because of corroded containers.





remediation: the removal of pollutants from soil, groundwater, or surface water

persistent organic pollutant (POP): an organic compound that is resistant to being broken down by biological or chemical means

You may recall that the presence of double bonds can influence a molecule's shape and chemical reactivity. If the benzene ring consists of three double bonds, you would expect that aromatic compounds would be very reactive, like unsaturated hydrocarbons. Despite the prediction that three double bonds are present in a benzene molecule, substances containing benzene rings are very stable unlike saturated hydrocarbons. Analysis of the structure of the benzene ring demonstrates that bonds between carbon atoms that form the ring are not similar to the double bonds between the carbon atoms in other hydrocarbons. Aromatic compounds have a reactivity similar to compounds with single bonds, but do not have a structure like those with single bonds.

Structural Diagrams of Benzene C_6H_6

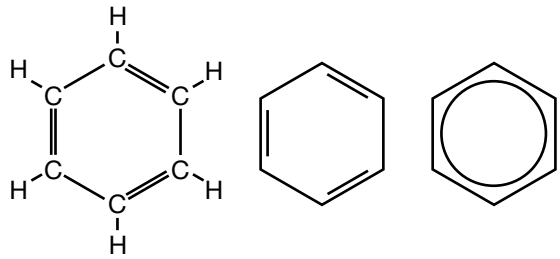


Figure B2.4: Aromatic rings are represented using alternating single and double bonds or using a circle inside the ring to represent resonance.

Carbons in a benzene ring demonstrate a unique bonding arrangement called **resonance**. Within an aromatic ring, extra electrons become shared by all the carbon atoms. A circle placed inside the hexagon in the structural diagram indicates this special bonding in the benzene ring. This unique bonding is believed to be responsible for the high degree of chemical stability and the flat shape of the benzene ring structure.

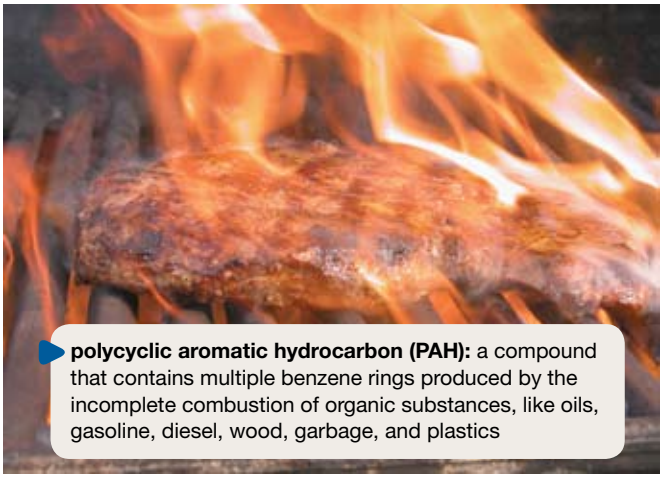
resonance: a concept used to describe the true structure for certain compounds that cannot be accurately represented using any one type of bonding structure

Figure B2.5: The purple and pink rings above and below this model for benzene represent the bonding of the six carbon atoms in the ring to the extra electrons.

The temperature at which combustion occurs in motor vehicles is not sufficient to break apart the aromatic compounds in the fuel. Concern about the presence of benzene in tailpipe emissions was a major factor in the development of legislation to reduce the concentration of aromatic hydrocarbons in gasoline.

Practice

3. Draw three diagrams used to represent a benzene ring.
4. Write two names, other than benzene, that describe the chemical structures in question 3.



polycyclic aromatic hydrocarbon (PAH): a compound that contains multiple benzene rings produced by the incomplete combustion of organic substances, like oils, gasoline, diesel, wood, garbage, and plastics

Figure B2.6: High grill temperatures and flames are used to charbroil foods.

Many people love the taste of charbroiled foods, but the incomplete combustion of oils from the food can produce **polycyclic aromatic hydrocarbons** (**PAHs**). Like the particles that form the charred layer on a steak, PAHs are particulate emissions contained in motor vehicle exhaust or the smoke from forest fires. Recent research has indicated that polycyclic aromatic hydrocarbons, like benzopyrene, have the ability to interact with deoxyribonucleic acid (DNA) and form structures that may result in mutations. Because emissions from diesel automobiles are a major source of PAH emissions, many major cities are investigating means to reduce particulate emissions from diesel engines, including those in cars, buses, and trucks. When you cook food using a barbecue, you may want to use a low-temperature grill to reduce flare-ups and the PAHs present in your food.

Chemical Structure of Benzopyrene

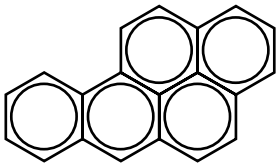


Figure B2.7: Benzopyrene is an example of a polycyclic aromatic hydrocarbon.

Practice

5. The City of Edmonton tested filters on diesel-powered buses to determine whether they were able to reduce particulate-matter emissions.

   a. Use the Internet or other sources to identify the characteristic used to classify particulate-matter emissions.

   b. Prepare a table that identifies the two groups of particulate-matter emissions and their sources. Include two examples of processes that produce each type of particulate-matter emission.

6. Obtain the handout "Diesel Particulate Filter (DPF) Demonstration" from the Science 30 Textbook CD. Read the handout, and answer the questions that follow.

   a. State the problem being investigated by this study.

   b. What do you think the term *local environmental conditions* refers to? Why is this such an important consideration?

   c. List the controlled variables used in the study.

7. Gasoline is a mixture of many hydrocarbons. A few of the many components found in gasoline are listed in a table in the "Some Components of Gasoline" handout on the Science 30 Textbook CD. Use the Internet to find the chemical formula and chemical structure for the components listed. Identify which of the substances in the list are alkanes, alkenes, aromatic compounds, hydrocarbons, and organic compounds.

DID YOU KNOW?

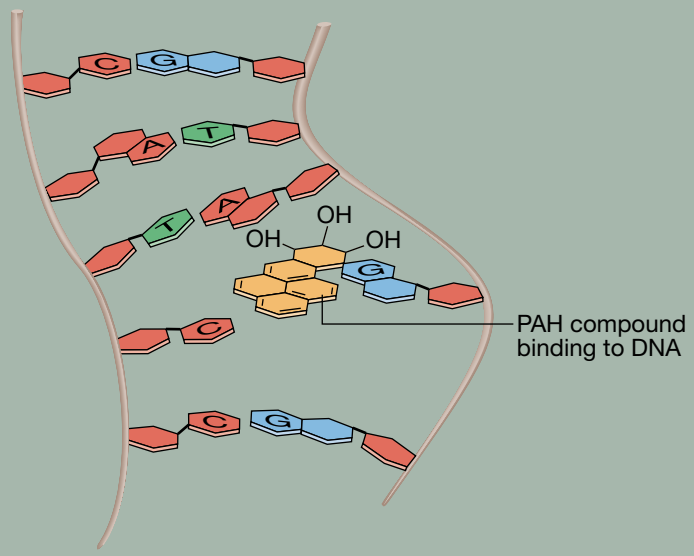
Many naturally occurring compounds, like tobacco, contain molecules with benzene rings. The low-temperature combustion of tobacco that occurs while smoking produces carcinogens that include benzene, C_6H_6, and a PAH called benzo(c)phenanthrene.

DID YOU KNOW?

You have a greater likelihood of being exposed to benzene inside your home than outdoors. Glues, paints, and solvents are common sources. Benzene is also present in tobacco smoke and vehicle exhaust.

Science Links

The three-dimensional shape of the benzene ring is similar to the shape of some parts of the DNA molecule. The ability of PAH and other molecules to form bonds to the nitrogen bases in a DNA molecule may result in the development of mutations. The structure of DNA and mutations and their effect on cells are covered in more detail in Unit A.



Science Links

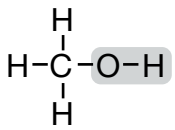
Exposure to benzene can affect the production of red and white blood cells. The role of cells within blood is covered extensively in Unit A.

Functional Groups

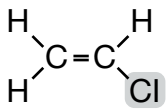
The petrochemical industry in Alberta involves other processes in addition to the extraction of oil and natural gas. Hydrocarbons, as you may recall, can be used as fuel or as a raw material for the production of plastics or other **synthetic organic molecules** (as shown in Figure B2.8).

synthetic organic molecule: a human-made compound containing carbon

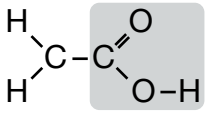
Organic Molecules Containing Functional Groups



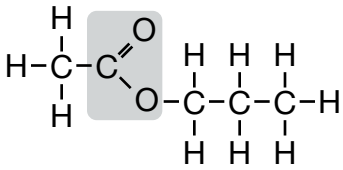
Methanol (wood alcohol)



Vinyl (used for PVC)



Ethanoic Acid (vinegar)



Propyl Ethanoate (aroma of pears)

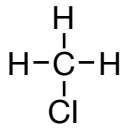
Figure B2.8

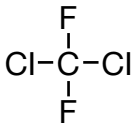
Modifications to naturally occurring hydrocarbons can involve the addition of carbon side chains or the addition of atoms other than carbon or hydrogen, creating organic molecules containing a **functional group**.

Halogenated Hydrocarbons

September 23 is an important day for environmental scientists. It's not a birthday; it is the first day of spring in the southern hemisphere. On this day, the first rays of sunlight illuminate the South Pole, which has been in total darkness throughout its winter. The end of winter is an important time for atmospheric scientists. It provides an opportunity to assess the extent of damage to the layer of ozone in the stratosphere above the South Pole.

Halogenated Hydrocarbons





Chlorofluorocarbons—commonly referred to as CFCs—were invented in the late 1920s to replace ammonia, $NH_3(g)$, sulfur dioxide, $SO_2(g)$, and other gases used in air-conditioning and refrigeration systems. Because CFCs are non-flammable and non-toxic, their use in commercial and residential refrigerators and air-conditioning systems became widespread. Although the worldwide use of CFCs in refrigeration systems and other chemical processes has had many benefits, there is evidence that their use has had harmful consequences for the ozone layer.

chlorofluorocarbon (CFC): a synthetic organic molecule in which hydrogen atoms are replaced with chlorine and fluorine atoms; also called Freon

Figure B2.9: Many CFCs, or Freons, are used in refrigeration systems.

functional group: an arrangement of single atoms or groups of atoms, other than carbon or hydrogen, attached to an organic molecule

Chlorofluorocarbons are part of a larger group of organic molecules called **halogenated hydrocarbons**. Halogenated hydrocarbons are synthetic organic compounds formed by reactions that substitute hydrogen atoms on a hydrocarbon with atoms from the halogen family of elements—chlorine, fluorine, bromine, or iodine. The term *chlorofluorocarbon* (CFC) describes the molecule as having both chlorine and fluorine atoms replacing hydrogen atoms in the chemical structure.

halogenated hydrocarbon: a hydrocarbon molecule that has one or more hydrogen atoms replaced by atoms of chlorine, fluorine, bromine, or iodine

Try This Activity

How Does a Refrigerant Work?

Purpose

You will investigate a physical change of matter and study its potential for use in a refrigeration system.

CAUTION!

Butane is flammable. Perform this activity only under the supervision of a teacher and in a room in which there are no open flames or sparks. Do not open the bags containing the butane unless you are told to do so by your teacher.

Science Skills

✓ Analyzing and Interpreting

Background Information

Butane, C_4H_{10}, has a boiling point of −0.5°C. If compressed, gaseous butane can be converted into its liquid form. In this activity you will observe the energy change that accompanies the change in state as liquid butane becomes gaseous butane.

Materials

- handouts from the Science 30 Textbook CD
  - "Schematic of a Refrigerator"
  - "MSDS: Ammonia"
  - "MSDS: Butane"
- liquid butane (Ask your teacher for this.)
- plastic, zipper-lock sandwich bag
- fume hood
- plastic drywall anchor (#4)
- scissors

Procedure

step 1: Read the entire procedure before starting the experiment. Prepare a suitable data table for recording your observations.

step 2: Read the information on the MSDS for butane. Highlight or underline sections of the MSDS that identify safety concerns regarding the use of butane.

step 3: Obtain a small sample of liquid butane in a zipper-lock sandwich bag from your teacher. Quickly observe how expanded the bag feels and how hot or cold the outside of the bag feels to the touch. Don't record your observations until you have completed step 4.

step 4: Locate where the liquid butane is in the bag. Place your fingers around the outside of the bag in an area where liquid butane is located. Observe the effect the heat from your hand has on the liquid butane and any changes to the amount the bag has expanded. Record your observation to steps 3 and 4 in the data table you prepared earlier.

step 5: Put all the equipment away, and properly dispose of the butane as instructed by your teacher.

Analysis

1. Explain how heat energy from the air surrounding the bag and your hand caused a phase change in the butane. Write the chemical reaction for this change.
2. Explain how the phase change could be used to cool the contents of food placed in a refrigerator.
3. Complete the "Schematic of a Refrigerator" handout by adding the following labels:
   - location of butane in the refrigerator system
   - states of butane at the positions A, B, and C
   - directions of the flow of thermal energy in the coils outside the refrigerator and in the coils inside the refrigerator
4. The compressor motor is an important component of a refrigerator. It forces the gaseous refrigerant to undergo a phase change back into a liquid. Identify the energy change that occurs to the compressed gas when it changes from a gas to a liquid. Explain the function for the coils outside the refrigerator.
5. Compare the safety concerns you identified for butane in step 1 of the procedure to the MSDS provided for ammonia. Based on the information, identify which substance—ammonia or butane—would make a safer refrigerant. Provide a justification for your choice. Identify any additional information you would want to have before making a final choice.

Naming Halogenated Hydrocarbons

The naming system used previously for hydrocarbons can be modified slightly to include hydrogenated hydrocarbons. Halogen atoms present in a molecule are indicated, like hydrocarbons, using the appropriate prefixes. These prefixes are listed in the "Halogen Prefixes" table. The end result will be to name the hydrocarbon part of the molecule first and, then, use prefixes to identify halogen atoms and their location.

HALOGEN PREFIXES

Halogen	Prefix
fluorine	fluoro
chlorine	chloro
iodine	iodo
bromine	bromo

To determine the systematic name for halogenated hydrocarbons, use the method for naming hydrocarbons and add the following steps.

step 1: Name the parent chain.

This is the same as naming the parent chain of a hydrocarbon.

step 2: Find all halogen atoms in the molecule.

You may find it easier if you circle these atoms.

step 3: Determine the appropriate prefixes to represent the halogens.

Each type of halogen atom is referenced using its appropriate prefix. (Refer to the "Halogen Prefixes" table.) If the same halogen atom appears in the molecule more than once, use the same prefixes that indicate the number of branches in a hydrocarbon chain (e.g., *di*- and *tri*-). For example, if two chlorine atoms are present, the prefix is *dichloro*.

step 4: Communicate where each halogen atom appears in the parent chain.

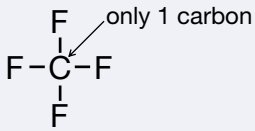
For example, 2-*fluoro* means that there is a fluorine atom on carbon 2 of the parent chain. Also, 2,2-*difluoro* means that there are two fluorine atoms on carbon 2 of the parent chain. If more than one halogen atom appears on the molecule, list them in alphabetical order.

Example Problem 2.1

One of many refrigerants developed by Thomas Midgley was CF_4. Write the systematic name for CF_4.

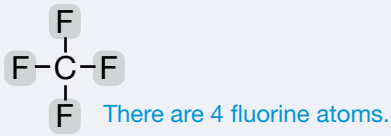
Solution

step 1: Name the parent chain.



The parent chain is methane.

step 2: Find all halogen atoms in the molecule.



step 3: Determine the appropriate prefixes to represent the halogens.

Because there are 4 fluorine atoms, the prefix is *tetrafluoro*-.

step 4: Communicate where each halogen atom appears in the parent chain.

Since there is only 1 carbon in the parent chain, there is no need to communicate where each fluorine atom appears.

Therefore, the systematic name of CF_4 is tetrafluoromethane.

Figure B2.10: Proper maintenance of an air conditioning unit involves checking the refrigerant level.

DID YOU KNOW?

Deaths attributed to leaked refrigerants led Thomas Midgley to develop CFCs. Midgley demonstrated the safety of his discovery to other scientists by inhaling a lung full of the Freon gas and then blowing out a candle flame with the exhaled gas.

Midgley—a scientist for General Motors Corporation—also worked on developing fuel additives and leaded gasoline.

Example Problem 2.2

Teflon—a polymer commonly used on frying pans and valued for its non-stickiness and ability to resist damage from high heat and other chemicals— is produced by the reaction of many molecules of 1,1,2,2-tetrafluoroethene. Draw the molecular structure of a single 1,1,2,2-tetrafluoroethene.

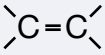
Solution

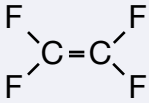
1,1,2,2-tetrafluoroethene

2 fluorine on carbon 1
2 fluorine on carbon 2

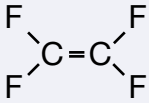
4 fluorine atoms

2 carbons, 1 double bond



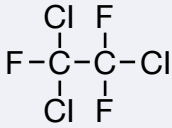


There are no empty bonds to fill with hydrogens. Therefore, the structure of 1,1,2,2-tetrafluoroethene is

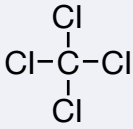


Example Problem 2.3

CFC-113 is a solvent used in the manufacture of computers and electronic components. It is also used in dry cleaning where it replaced the use of CCl_4. Write the systematic names for these two halogenated hydrocarbons.

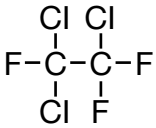
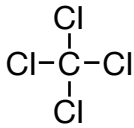


CFC-113



CCl_4

Solution

CFC-113	CCl_4
	
Determine the parent chain.	
ethane	methane
Determine the prefixes.	
trichloro- trifluoro-	tetrachloro-
Show where each halogen appears (if necessary).	
1,1,2-trichloro- 1,2,2-trifluoro-	N/A
Put it all together.	
1,1,2-trichloro-1,2,2-trifluoroethane	tetrachloromethane

Practice

8. The first CFC produced by Thomas Midgley was dichlorodifluoromethane. Draw the chemical structure for this compound.
9. Obtain the "Halogenated Hydrocarbons" handout from the Science 30 Textbook CD. On this handout, you will see some halogenated hydrocarbons listed. Complete this table.

DID YOU KNOW?

The chemical formula for a chlorofluorocarbon (CFC) or a hydrofluorocarbon (HCFC) can be determined from its number.

- Add 90 to the CFC or HCFC number, and write out the resulting number.
- The first number tells you the number of carbon atoms in the molecule.
- The second number tells you the number of hydrogen atoms in the molecule.
- The third number tells you the number of fluorine atoms in the molecule.
- The remaining bonds to the carbon atoms are filled with chlorine atoms.

Example: CFC-11

11 + 90 = 101

1 C O H 1 F

A carbon has four bonds, and only one bond is used by fluorine. Therefore, 3 chlorine atoms must be bonded to the carbon atom. The chemical formula is $CFCl_3$.

Use this method to determine the chemical formula for CFC-12, HCFC-22, HCFC-124, and HCFC-134a. Would it be possible to have a CFC-15?

Ozone and Concerns Regarding CFCs

The energy from the Sun is a collection of different forms of radiation. Some of the forms of energy in sunlight include ultraviolet and infrared radiation and visible light. Ultraviolet radiation can cause damage to living tissue because it possesses greater energy than many other forms of radiation found in sunlight. As you have learned, energy from sunlight can excite molecules and initiate chemical reactions in the atmosphere. Oxygen molecules in the **stratosphere** are exposed to ultraviolet radiation, which initiates the development of ozone, $O_3(g)$. The **ozone layer** is a portion of the stratosphere that protects Earth from exposure to excessive levels of ultraviolet radiation. The reactions involving the production and decomposition of ozone that form the ozone cycle absorb the components of ultraviolet radiation—most harmful to human skin and eyes—protecting life on Earth from its harmful effects. The importance of the ozone layer to life on Earth has made it a popular focus for scientific research.

stratosphere: the portion of the atmosphere between 10 km and 50 km above Earth's surface

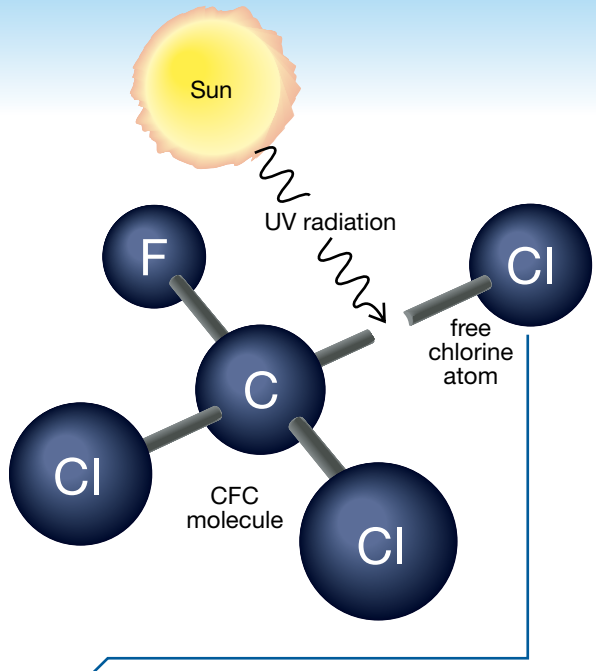
ozone layer: the portion of the stratosphere, where the highest concentrations of ozone occur

Some of the first scientific work on ozone involved identifying the ozone cycle and estimating the quantity of ozone that should be present in the ozone layer. Later—once it became possible to make measurements—it was determined that the actual amount of ozone in the stratosphere was less than the amount predicted. This observation further raised the interest of many scientists who began to work toward identifying a reason for the difference.

Although investigations had shown that some substances reacted with ozone, the demonstration that nitrogen oxides could decompose ozone attracted even more interest toward investigating the effects of human-made emissions on the ozone layer. The role of CFCs in ozone depletion became clearer when key findings from a variety of different research projects studying CFCs and the reactivity of free chlorine atoms were interpreted together.

Evidence had shown that CFCs were stable molecules in the troposphere, where they were exposed to low levels of UV radiation. Once data became available that CFC molecules were present in all levels of the atmosphere, scientists became concerned about the stability of these molecules, since they are exposed to greater levels of UV higher in the stratosphere.

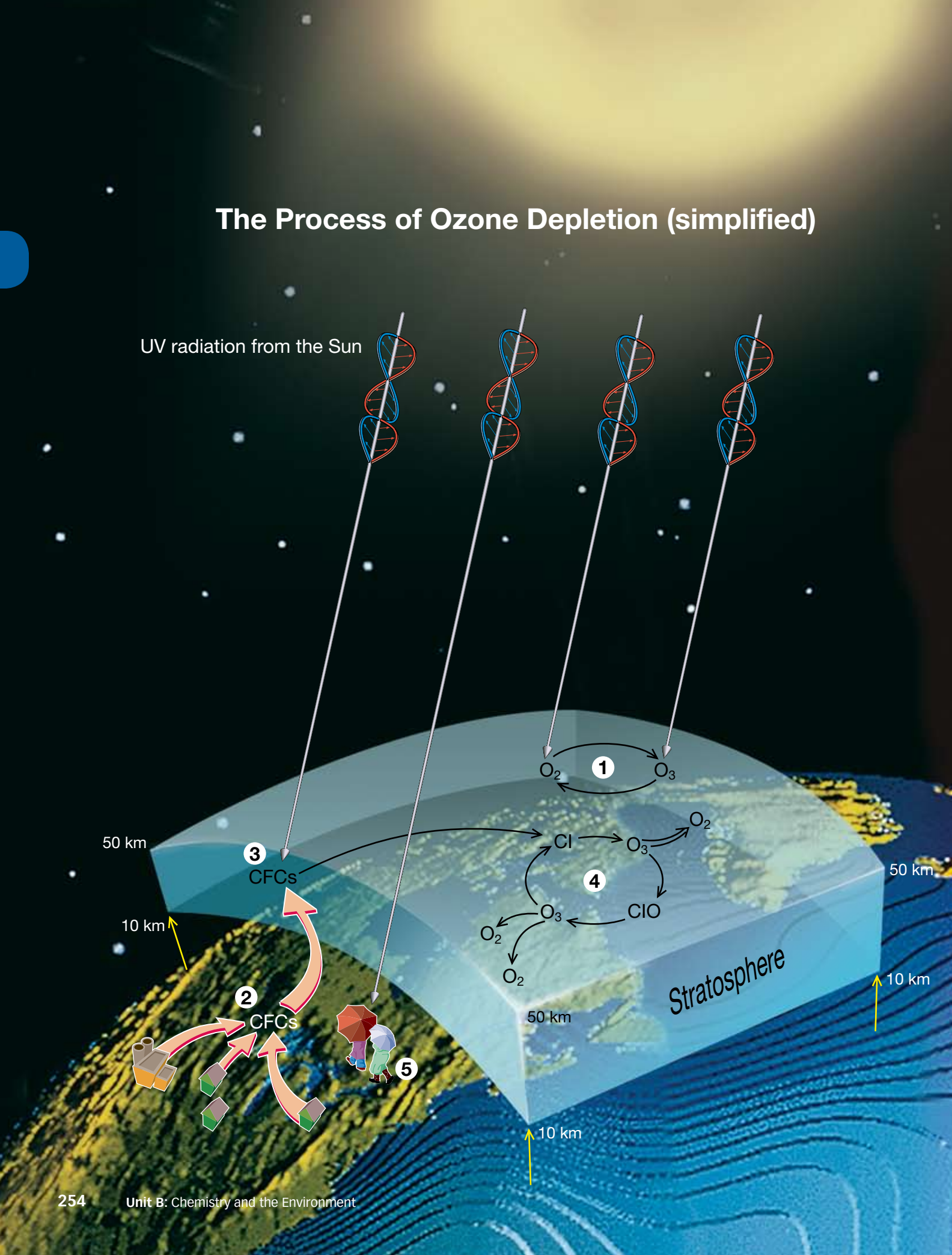
Ozone Depletion Reactions



$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$	decomposition of ozone by free chlorine atom
$O_3(g) + \xrightarrow{\text{UV radiation}} O_2(g) + O(g)$	natural decomposition of ozone (part of ozone cycle)
$O(g) + ClO(g) \rightarrow Cl(g) + O_2(g)$	reaction that re-generates the free chlorine atom

free chlorine atom able to attack more ozone

The Process of Ozone Depletion (simplified)



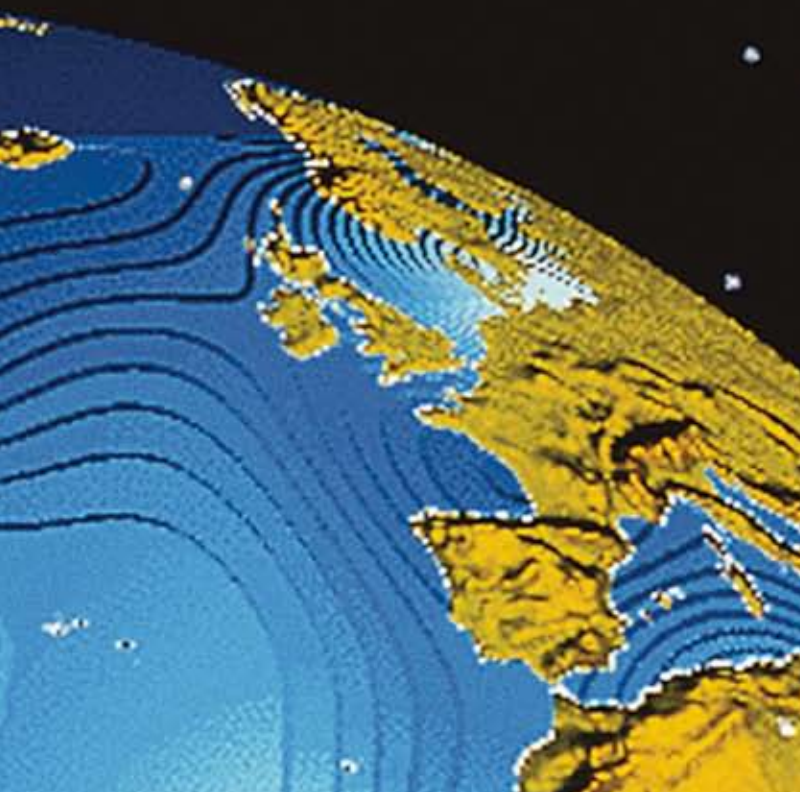
1. **Natural Ozone Cycle:** UV radiation collides with oxygen, $O_2(g)$, and ozone, $O_3(g)$, molecules. Energy from this radiation is absorbed and breaks chemical bonds, creating a cycle. The ozone cycle is the only mechanism to produce stratospheric ozone. Absorption of UV radiation by $O_2(g)$ and $O_3(g)$ prevents harmful forms of radiation from reaching Earth's surface.

2. **CFCs Released:** CFCs are stable below the stratosphere. Winds carry CFCs into the stratosphere.

3. **CFCs Broken Down:** CFCs are exposed to higher levels of UV radiation in the stratosphere. Collisions between CFCs and UV radiation produce chlorine atoms.

4. **Ozone Broken Down:** A reaction between chlorine atoms and ozone occurs. The chlorine atoms are regenerated and attack thousands of ozone molecules. The natural balance in the ozone cycle is disrupted.

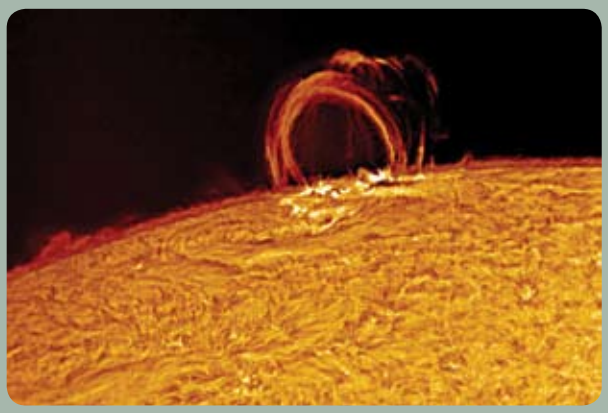
5. **Increased UV at Surface:** Harmful forms of UV can reach Earth's surface because there is less stratospheric ozone.



Results from experiments demonstrated that UV radiation caused the removal of chlorine atoms from CFC molecules in the stratosphere and that the free chlorine atoms could react to destroy ozone. CFCs that were first demonstrated by Midgley as a miracle chemical became an even greater cause for concern when additional evidence demonstrated that chlorine atoms could be regenerated by reactions occurring in the atmosphere. Regeneration provides the opportunity for a single chlorine atom to bring about the destruction of many ozone molecules.

Science Links

Ultraviolet radiation—a form of energy released by the Sun—can produce free radicals in cells, resulting in their damage. Units A and C expand on the intensity and forms of energy released by the Sun, including ultraviolet radiation and its effects on living systems.



DID YOU KNOW?

In 1995—more than 20 years after alerting the world to the impact that CFCs produced by human activity were having on the ozone layer—Paul Crutzen, Mario Molina, and F. Sherwood Rowland won the Nobel Prize in chemistry. Crutzen was acknowledged for his work on the effect of nitrogen oxides on the ozone layer, a crucial discovery that enabled Molina and Rowland to determine that CFCs also destroyed stratospheric ozone. The publication of Molina and Rowland's discovery increased society's attention to environmental issues. Government action in the late 1970s and early 1980s led to restrictions on the use of CFCs as aerosol propellants and resulted in increased attention by government, industry, and scientists toward environmental issues.

Free Radicals

The addition of UV radiation to a CFC can result in the formation of free radicals of chlorine in the atmosphere. You may have heard or read advertisements warning about the effect free radicals can have on your body. You may have heard that free radicals cause aging and can cause damage to parts of the body.

Free radicals are chemical species that have an unpaired electron in their valence shell. You may recall that substances with unpaired electrons seek out other substances they can combine with to fill their valence shell. In the body, exposure to radiation, or substances within food, may result in the production of a variety of oxygen-containing free radicals. Despite their origin, you have seen that free radicals are very reactive and bring about chemical change. Concern about free radicals in people's diet is based on evidence that they can react with lipids (a major component of the cell wall), proteins, and DNA. Damage to any of these components can affect the function of cells and may result in tissue damage.

Vitamin E (α-tocopherol)

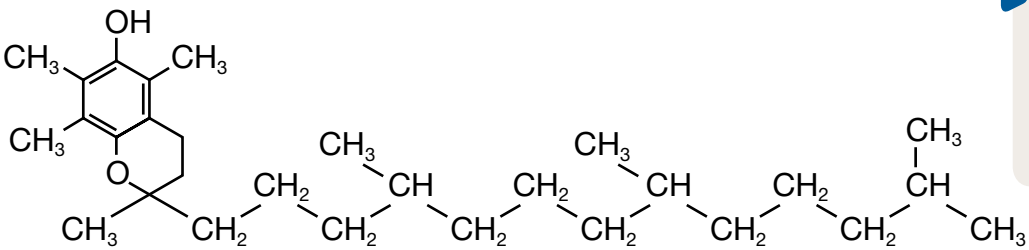


Figure B2.11: Vitamin E

antioxidant: a substance that prevents the oxidation of another substance; a substance present within the body or other materials that reacts with free radicals to protect important components

There is no way to completely avoid free radicals, but it is possible to reduce exposure through food choices containing **antioxidants**. Vitamins E and C, beta-carotene, and lycopene are well-known antioxidants. All of these antioxidants are available from vegetables. If you are concerned about the amount of antioxidants in your diet, consult Canada's Food Guide, a dietician, or other appropriate sources.

Holes in the Ozone Layer

The ozone layer over Earth varies in thickness. The thickness of the ozone layer is measured in Dobson units (DU). One Dobson unit is equivalent to a thickness of 0.01 mm of ozone gas at a standard temperature and pressure (0 ºC and 100 kPa). As you can see in Figure B2.12, some regions have significantly higher levels of ozone. Areas with low levels of ozone are called ozone holes.

Total Ozone in Dobson Units (2006/10/24)

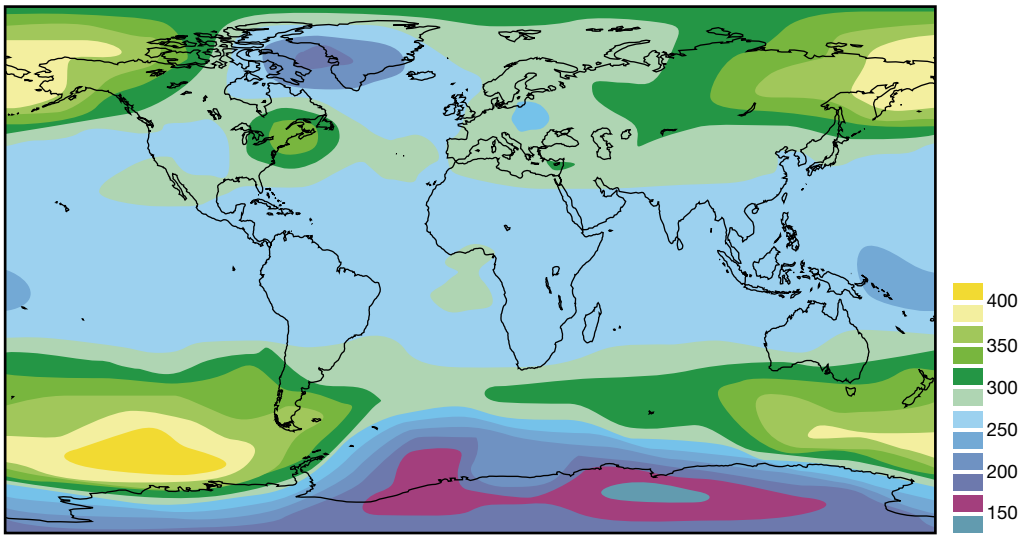


Figure B2.12

The thickness of the ozone layer can be measured daily. One of the most important evaluations of the thickness of the ozone layer occurs at the end of winter. You have learned that the reaction that produces chlorine radicals requires UV radiation. UV radiation is also required for the reaction to produce ozone. Research on the ozone layer tends to focus on the thickness of ozone over Earth's poles. Measurements taken around the end of winter for each hemisphere—September 23 for the South Pole and March 23 for the North Pole—provide scientists with the opportunity to assess the damage done to the ozone layer during the previous year and to compare the data to other years.

Practice

10. The thickness of the ozone layer at an Antarctic research station in 1956 was 321 DU. Calculate the percentage loss in ozone between 1956 and 1997, when the thickness was 139 DU.
11. In Figure B2.12, determine the locations where the thickness of the ozone layer is the lowest.
12. Use the Internet to find a recent world ozone map. Compare this map with Figure B2.13. Identify any similarities and any differences.
13. Graph the following data. Account for the fluctuation in the thickness of the ozone layer during the time for which data is shown.

AVERAGE THICKNESS OF OZONE LAYER OVER ANTARCTICA (2005–2006)

Month	Ozone Thickness (DU)
August	207
September	158
October	155
November	253
December	290
January	298
February	284
March	291
April	278

14. Predict the trend for the average monthly ozone layer thickness over the North Pole over the same time period as shown in question 13.

Monitoring Ozone

The thickness of the ozone layer is determined by data collected both from satellites and from measurements made by devices that travel into the stratosphere by weather balloon. Many satellites use spectrometers and other equipment to measure reflected UV radiation and atmospheric temperatures to determine the amount of ozone.

Balloon measurements use an ozone sonde—a device that draws in ozone as the balloon rises in the atmosphere. The concentration of ozone present at various levels in the atmosphere determines the strength for a radio signal that is sent from the sonde to a detector on the ground.

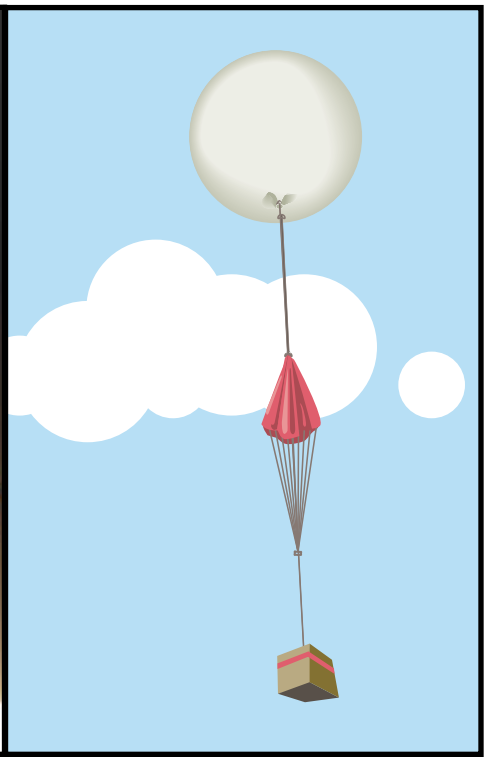


Figure B2.13: The Aura satellite, launched in 2004, is used to monitor the ozone layer.

Practice

15. Use the Internet to determine the names for the abbreviations TOMS and OMI. These devices are used in the measurement of Earth's ozone layer.
16. Measurements of Earth's ozone layer are made using satellites and balloon sondes. Because of the differences between conditions in space and on Earth, different instruments are used. Explain how the use of different instruments to study the ozone layer can improve the interpretation of the data collected.
17. Atmospheric measurements for ozone concentration are expressed as parts per million (ppm), whereas measurements for the free radical chlorine monoxide, ClO(g), are expressed as parts per billion (ppb). Explain the difference between the magnitudes of these two units for concentration. Explain how a change in the concentration of chlorine monoxide in the atmosphere could affect the concentration of ozone.

International Agreements to Protect the Ozone Layer

The scientific evidence that demonstrated the effects of CFCs and other halogenated hydrocarbons on the environment supported the need for action to protect the environment. In 1987, an international treaty called *The Montreal Protocol on Substances That Deplete the Ozone Layer* was developed. Under this agreement, countries commit to phase out the production and use of ozone-depleting substances. As of 2006, the number of countries committing to the Montreal Protocol had grown from its initial group of 40 to 190.

Figure B2.14: Montreal at night

To meet the requirements of the Montreal Protocol, governments are demanding that changes be made to previous practices. In most cases, alternatives to ozone-depleting chemicals must be found or new processes must be developed. Because chlorine atoms (radicals) released from CFCs cause damage to the ozone layer, other halogenated hydrocarbon alternatives to CFCs have been developed. HCFCs (hydrochlorofluorocarbons)—which contain fewer chlorine atoms in their chemical structures—and HFC (hydrofluorocarbons)—which do not contain any chlorine in their chemical structure—cause less damage. Target dates for the reduction of these substances and other ozone-depleting substances are shown in the table.

Ozone-Depleting Substance	Target Date for Elimination Under the Montreal Protocol
Halons	1994
CFCs, HBFCs (hydrobromofluorocarbons), tetrachloromethane	1996
bromomethane	2010
HCFCs	2030

You may wonder whether international agreements like the Montreal Protocol are successful, especially when you see the length of time required for target dates to become effective. Although the process to eliminate ozone-depleting substances appears to take a long time, many people consider the Protocol a success given the large number of countries that have committed to meeting these targets. In some cases, countries have managed to meet target dates ahead of schedule. Reasons that may account for the success of this agreement may include

- a consensus among countries regarding the scientific evidence identifying a threat to the ozone layer by CFCs and other halogenated hydrocarbons
- problem chemicals can be restricted to a few types that can be controlled or for which alternatives can be found
- changes in behaviours regarding the use of ozone-depleting substances that are not costly or do not otherwise affect countries economically

In some cases, even though scientific evidence demonstrates that a compound causes ozone depletion, it is not included in the list of substances to be phased out by the Montreal Protocol. This is because exemptions can be made for substances if there are no alternatives and their use is critical. For example, although scientific evidence has demonstrated that some halogenated hydrocarbons containing bromine have a greater capacity to deplete ozone than CFCs, these substances are not prohibited by the Protocol. Halon-1211 (also known as bromochlorofluoromethane) and Halon-1301 (or bromotrifluoromethane) have a significantly higher ability to deplete ozone when compared to CFCs. Controversy existed at the time the Protocol was drafted because these compounds were used in fire extinguishers in airplanes. Due to the unique conditions and specifications required to contain fires in this environment, few alternatives existed; so to maintain safety, the use of these compounds was allowed under even stricter control. Since then, suitable alternative fire retardants have been found.

DID YOU KNOW?

Canada, the United States, Norway, and Sweden were the first countries to restrict the use of CFCs in aerosol sprays in the late 1970s.

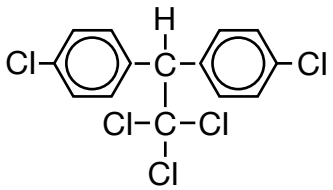
One compound for which a suitable alternative has yet to be found is bromomethane (also called methylbromide). Methylbromide is a pesticide used in agriculture to fumigate soil. A great deal of concern has been expressed by farmers, especially in the United States, that no suitable alternative exists to protect sensitive crops from pests.

In order to demonstrate agreement with the Montreal Protocol, countries applying for critical-use exemptions must justify why they need to continue to produce or import restricted substances.

Other Halogenated Compounds

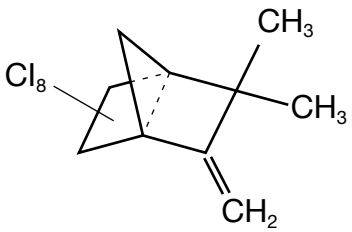
In addition to CFCs, many other synthetic halogenated organic compounds exist. Plastics, fire retardants, paints, solvents, cleaning supplies, pesticides, and herbicides are all examples of the types of products that may contain halogenated hydrocarbons.

Dichlorodiphenyltrichloroethane (DDT)



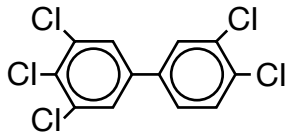
This is used for mosquito control.

Toxaphene



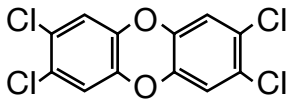
This is a pesticide. **Note:** The exact positions of the chlorine atoms are not known.

Polychlorinated Biphenyl



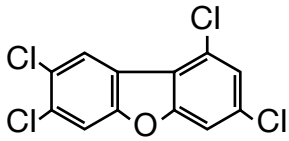
This is used in some older electric transformers.

Dioxin



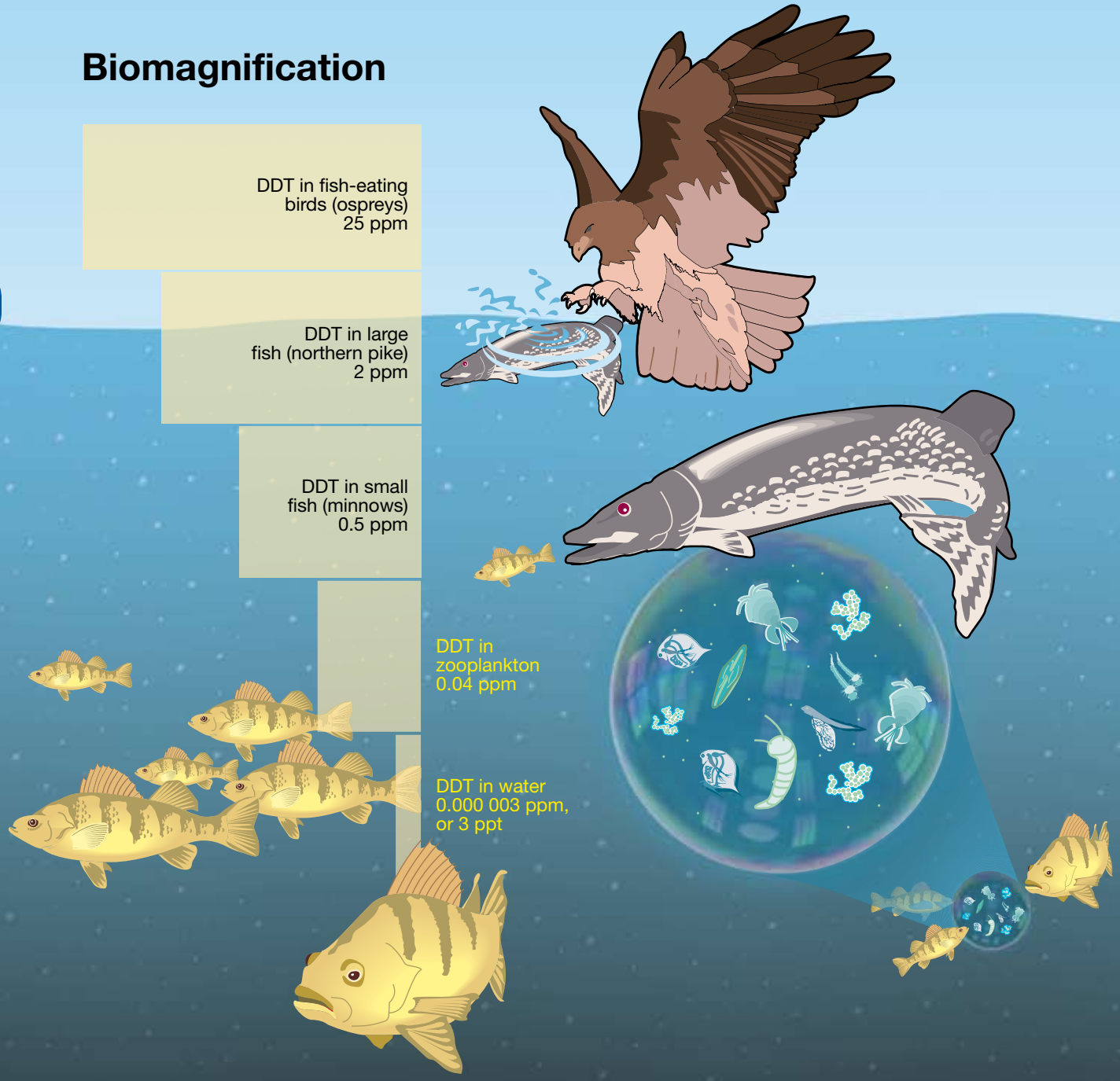
This is a by-product of some chemical processes where chlorine is used.

Furan



This is a by-product of some chemical processes where chlorine is used.

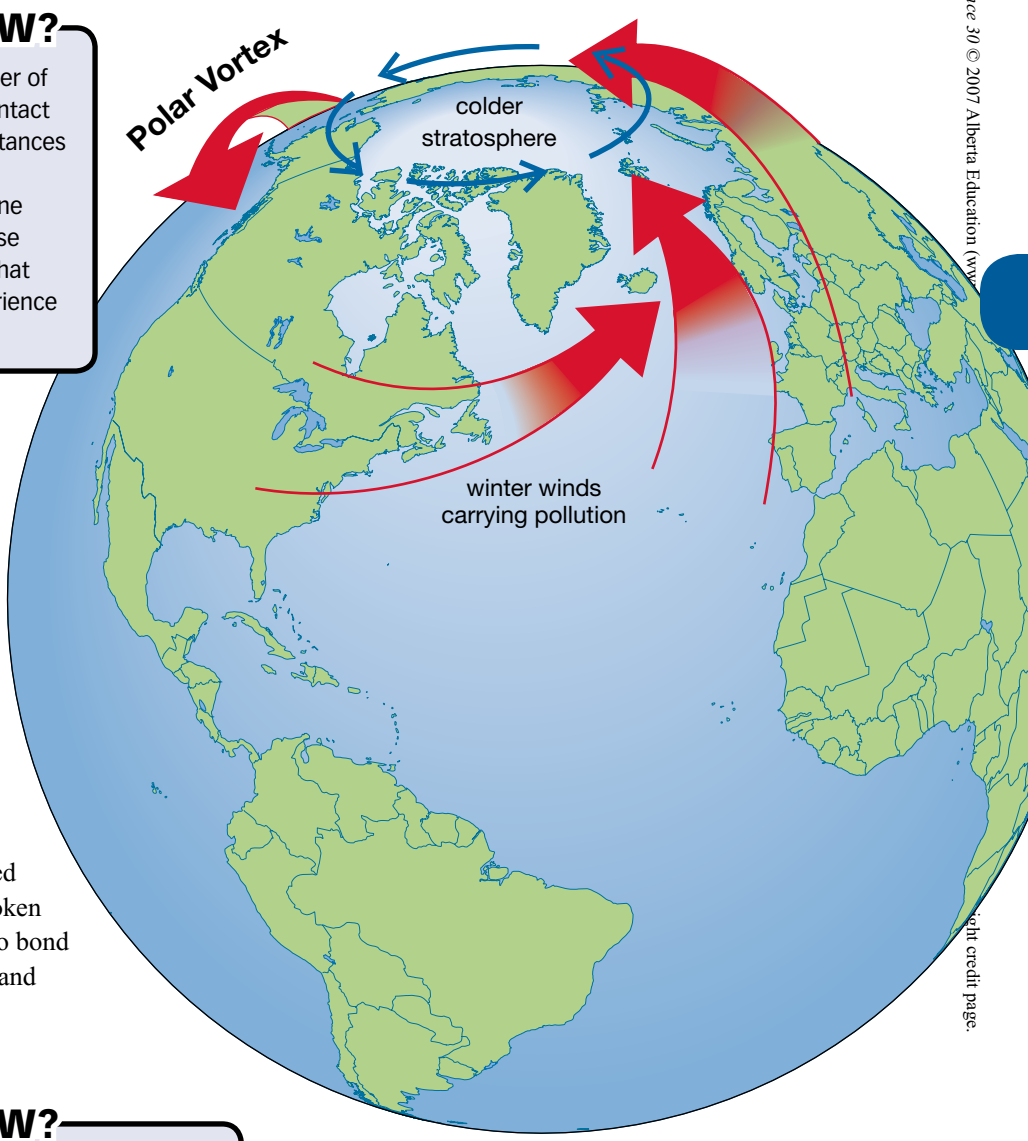
Biomagnification



The only sources of halogenated hydrocarbons are human activities, whether as an intended result or as a by-product. Some, like CFCs and polychlorinated biphenyls (PCBs), were developed for use in a variety of applications because of their chemical stability. However, this characteristic has caused them to be a problem to living organisms. Chlorinated hydrocarbon compounds, like DDT and toxaphene, have been shown to biomagnify precisely because of their tendency not to break down in food chains and affect higher-level organisms within ecosystems, like the peregine falcon, other birds of prey, and humans.

Dioxins and furans are halogenated hydrocarbons produced as a by-product of the chlorine bleaching process for wood pulp and from the low-temperature incineration of chlorinated organic compounds (e.g., plastics). Dioxins, furans, and even pesticides used thousands of kilometres away from the Arctic have been detected in the tissues of organisms in all levels of the arctic food chain, including the breast milk of Inuit women.

Focus on the Poles



DID YOU KNOW?

Because of the large number of chemical substances you come in contact with, it is difficult to identify the substances that can present the greatest risk. Epidemiology is the branch of medicine that looks at the occurrence of disease and attempts to identify similarities that may exist between people that experience certain forms of disease.

Many herbicides and pesticides contain halogen atoms. As a result, concern exists regarding the effect pesticides can have on human health. When you eat, can you be sure your food doesn't contain traces of pesticides or herbicides that may have been used in its production?

Apart from environmental persistence, halogenated hydrocarbons are a health concern because they target important parts of the body: the central nervous system, heart, liver, and kidneys. As you learned earlier, chlorine compounds can be broken down. Chlorine radicals are also able to bond to organic compounds in these tissues and cause damage.

DID YOU KNOW?

Alberta's Swan Hills Hazardous Waste Treatment Facility uses temperatures of 1200°C or higher to combust and break down the highly stable benzene ring in aromatic compounds. This facility is one of few sites in Canada capable of treating CFCs and other halogenated hydrocarbons like PCBs.

Earlier in this lesson you learned that organic compounds, like CFCs and other halogenated hydrocarbons, are detected in the tissues of arctic animals. Halogenated hydrocarbons, as you have seen, are used by industry and agriculture at lower latitudes and can be transported by prevailing wind patterns toward the polar regions.

Like all winds, the polar vortex is produced by the unequal heating of air. The winds that create the polar vortex are located higher in the atmosphere than other wind currents. Conditions exist to create a vortex at both the North Pole and South Pole. It is believed that these winds have drawn pollutants from industrialized areas toward the poles.

The collection of these compounds in the atmosphere, along with the cold temperatures that occur during winter, create polar stratospheric clouds. Much of the research on the atmosphere in the Arctic and Antarctic focuses on the chemical reactions that occur within these clouds and how these reactions affect the ozone layer and other phenomena.

2.1 Summary

In this lesson you studied the uses of hydrocarbons—aromatic compounds and halogenated hydrocarbons—by society as well as the impact these uses have had on the environment. You examined the chemical properties of these classes of compounds and you learned how the composition influences these properties. You then saw how these substances can be transported by wind currents and can be involved in reactions in the atmosphere. Their transport may have greater consequences for all parts of Earth and even the stratospheric ozone layer.

2.1 Questions

Knowledge

1. Prepare a summary table showing the different types of organic compounds that were introduced in this lesson. Use the following headings: Group Name, Example, Important Structures/Atoms, and Environmental Concerns.

Applying Concepts

2. The Montreal Protocol defines the following classes of substances.

Abbreviation	Meaning	Atoms in Molecule
CFC	chlorofluorocarbon	Cl, F, and C
HCFC	hydrochlorofluorocarbon	H, Cl, F, and C
HBFC	hydrobromofluorocarbon	H, Br, F, and C
HFC	hydrofluorocarbon	H, F, and C
HC	hydrocarbon	H and C
PFC	perfluorocarbon	F and C
Halon	N/A	Br, Cl (in some), F, H (in some), and C

   Provide two examples for each class of substances. For each example, draw a structural diagram, write its chemical formula, and determine its systematic name. (Your examples should differ in the number of carbon atoms.)

3. Describe the difference between CFCs and HCFCs.
4. Suggestions have been made to replace the use of CFCs and HCFCs with hydrocarbons, like butane, and other compounds, like ammonia. Identify risks associated with the use of these suggested alternatives.
5. Describe how the action of winds within the polar vortex could contribute to the reduction in ozone at the North Pole and South Pole.
6. 1,1,1,2,3,3,3-heptafluoropropane (FM-200) and 1,1,1,3,3,3-hexafluoropropane (HFC-236fa) are replacements for halogenated bromine compounds (Halons) used in fire extinguishers in aircraft.
   a. Draw the chemical structures for these two compounds.
   b. Identify properties of these compounds that would make them suitable alternatives to Halons.
7. Explain why free radicals are reactive substances.
8. Use the Internet to locate information and then prepare a table that lists the antioxidants identified in this lesson and the food sources that contain these substances.
9. Use the Internet to find five examples of naturally occurring and synthetic compounds that contain aromatic rings. Indicate their source or importance.
10. List concerns about aromatic compounds identified in this lesson. Explain how these concerns can be attributed to the chemical properties of the aromatic ring.

2.2 Alcohols, Carboxylic Acids, and Esters

In Lesson 2.1 you briefly studied Earth's ozone layer and its ability to absorb harmful wavelengths of ultraviolet radiation. Concerns about the thinning ozone layer and the possibility of developing skin cancer have more people thinking about using sunscreens to protect themselves from the Sun. All sunscreens contain substances that absorb UV radiation; but with so many products to choose from, which is the best choice?

You may know someone who has an allergy to a certain brand of sunscreen or even to antibiotics prescribed to fight a bacterial infection. Exposure to certain chemical substances can cause an allergic reaction. In Unit A you discovered that the body's immune system responds to antigens, the chemical substances the body identifies as foreign.

What causes substances with such different purposes to have a similar effect on the body? In this lesson you will learn more about the structure of three groups of organic compounds: alcohols, carboxylic acids, and esters. You will identify these molecules by their functional groups, and you will identify some of the chemical and physical properties demonstrated by these groups of compounds.

Alcohols

It was a nasty cold snap. In fact, it was ten straight days of temperatures below –20°C. Although you saw many stalled cars on your way to school, your family's car seemed to start just fine. It may surprise you to know that one of the reasons your family's car was able to continue to operate despite the cold conditions was the addition of a few millilitres of a certain alcohol when the car was last filled up with gasoline.

Figure B2.15: Methanol, a component of gas-line antifreeze, can be used to prevent the formation of ice in the fuel line to an automobile's engine.

Alcohols are a group of organic molecules that possess a **hydroxyl functional group**. Although the hydroxyl functional group consists of two atoms, it replaces a single hydrogen atom on a carbon atom. As you may have noticed, alcohols are also indicated by the suffix *-ol* in their names. Alcohols are one of the most important classes of organic molecules and have many uses.

hydroxyl functional group: a chemical structure found in organic molecules that consists of an oxygen atom bonded to a hydrogen atom; often represented as R–OH, where R represents a hydrocarbon or an organic molecule

SOME ALCOHOLS AND THEIR USES

Example	Use
methanol	solvents, fuels, production of pharmaceuticals, disinfectants
ethanol	solvents, fuels, alcoholic beverages, production of pharmaceuticals, disinfectants
glycol	solvents
isopropanol	disinfectants

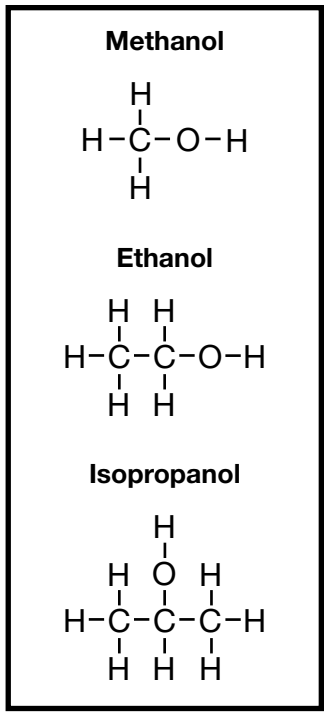


Figure B2.16

Earlier, you learned that hydrocarbons have very low solubility in water. The presence of a hydroxyl group on a hydrocarbon increases the compound's solubility in water. You also learned that the solubility of substances in water is a result of their ability to attract water molecules. In gas-line antifreeze, the polarity of the hydroxyl group of methanol acts to attract water molecules present in the fuel or within the fuel system. The attraction of the water to the methanol molecule prevents the formation of ice, which can block the fuel line.

Nomenclature of Alcohols

The systematic naming of alcohols involves the use of the suffix *-ol* to indicate the hydroxyl functional group. Other parts of the name that precede the functional group can include numbers to describe the position of the hydroxyl group and/or the prefixes and numbers used in naming the hydrocarbon portion of the molecule.

To determine the systematic name for an alcohol, use the following steps. The end result will be to name the hydrocarbon part of the molecule followed by the suffix *-ol* that identifies the hydroxyl group and its location. Alcohols, such as methanol and ethanol shown in Figure B2.16, contain a single hydroxyl functional group located on the first carbon in the parent chain. When the hydroxyl group is in this position, the number 1 is not required.

step 1: Find the hydroxyl functional group on the molecule and circle it.

step 2: Determine the parent chain of carbon atoms, starting at the end nearest the hydroxyl group.

step 3: Use the method of naming hydrocarbons to determine the initial part of the name.

For example, if the parent chain contains two carbon atoms, the initial part of the name will be *ethan-*.

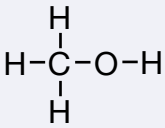
step 4: Communicate the location of the hydroxyl group on the parent chain, and add the suffix that represents the presence of a hydroxyl group.

For example, *2-ol* means the hydroxyl group is on carbon 2. Also, *1,2-diol* means there are two hydroxyl groups: one on carbon 1 and one on carbon 2 of the parent chain.

Example Problem 2.4

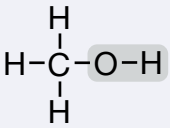
Gas-line antifreeze contains what is sometimes referred to as methyl alcohol or wood alcohol (shown on the right). Determine the systematic name of this structure.

Methyl Alcohol



Solution

step 1: Find the hydroxyl functional group on the molecule, and circle it.



There is one hydroxyl group.

step 2: Determine the parent chain of carbon atoms, starting at the end nearest the hydroxyl group.

The parent chain consists of 1 carbon.

step 3: Use the method of naming hydrocarbons to determine the initial part of the name.

Because there is only 1 carbon in the parent chain, the initial part is of the name is *methan-*.

step 4: Communicate the location of the hydroxyl group on the parent chain, and add the suffix that represents the presence of a hydroxyl group.

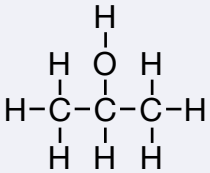
Because there is only 1 hydroxyl group and 1 carbon in the parent chain, add the suffix *-ol*.

Therefore, the systematic name of methyl alcohol, or wood alcohol, is methanol.

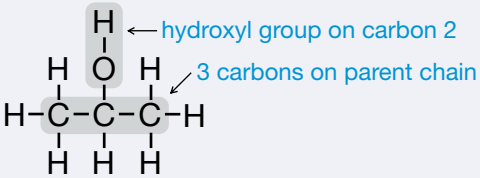
Example Problem 2.5

Isopropyl alcohol is commonly sold in stores as a disinfectant. Use the chemical structure provided to write the systematic name for isopropyl alcohol.

Isopropanol



Solution

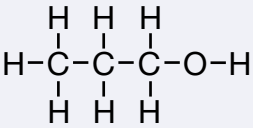


The systematic name of isopropyl alcohol is propan-2-ol.

Example Problem 2.6

Propanol, $CH_3CH_2CH_2OH$, is used as a grease remover in some cleaning products. Draw the chemical structure for propanol.

Solution

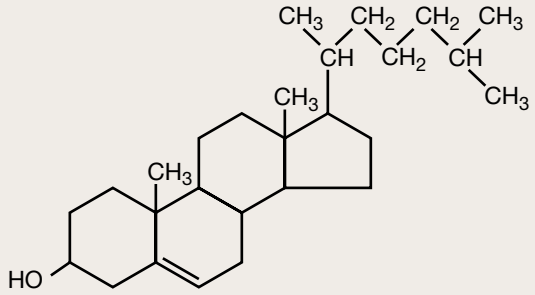


Practice

18. Draw the chemical structure and write the systematic names for two alcohol molecules each containing 3 carbon atoms, 7 hydrogen atoms, and 1 hydroxyl functional group.

19. The accumulation of cholesterol is associated with the blockage of coronary blood vessels that can result in a heart attack.

Cholesterol



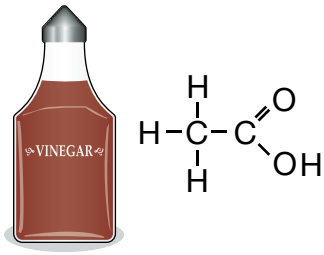
a. Identify the structure on the cholesterol molecule that is similar to alcohols.

b. Identify the portion of the name that identifies cholesterol as a molecule that possesses this functional group.

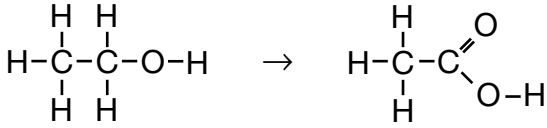
20. Ethan-1,2-diol, also known as ethylene glycol, is a solvent used in the production of paint and is a major component of automobile antifreeze. Use the systematic name to draw the chemical structure for ethylene glycol.

Carboxylic Acids

For many people, vinegar is a welcome ingredient when cooking or seasoning food. From your studies earlier, it may not surprise you that the sour taste of vinegar is due to the presence of an acid. Whether your favourite vinegar is balsamic, malt, or white, the tangy taste is due to the presence of ethanoic acid. Ethanoic acid is produced naturally by the conversion of ethanol by certain kinds of bacteria. Ethanol-containing substances, like wine and cider, have been used for centuries to make many kinds of vinegars.



The Conversion of an Alcohol to a Carboxylic Acid



Ethanol → **Ethanoic Acid**

Figure B2.17: The functional groups for the reactant and product show that oxygen has a significant role in this reaction.

Carboxyl Functional Group

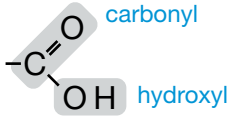


Figure B2.18: The carboxyl functional group is the combination of two functional groups: a carbonyl functional group and a hydroxyl functional group.

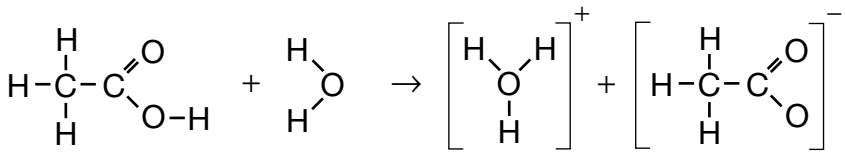
The **carboxyl functional group** contains two oxygen atoms joined to the same carbon atom. By examining Figure B2.18, you will notice that the carbon atom in the carboxyl group is attached to a single oxygen atom by a double bond; this is the **carbonyl functional group**. This same carbon is also attached to the oxygen of a hydroxyl group. All carboxylic acids contain this combination of functional groups, often represented as R-COOH and with the suffix *-oic acid* in their names.

- **carboxyl functional group:** the organic chemical structure composed of a carbonyl functional group and a hydroxyl functional group chemically joined to the same carbon atom
- **carbonyl functional group:** the functional group formed by the joining of an oxygen atom to a carbon atom by a double bond

In Chapter 1 you examined the empirical properties of acids and discovered that acids undergo a reaction with water that produces hydronium ions. Carboxylic acids demonstrate the same empirical properties as other acids. Hydronium ions are produced by the reaction between the hydrogen located on the hydroxyl group and water.

Ethanoic Acid Reacting with Water

$$\underset{\text{acid}}{CH_3COOH(aq)} + \underset{\text{base}}{H_2O(l)} \rightarrow \underset{\text{conjugate acid}}{H_3O^+(aq)} + \underset{\text{conjugate base}}{CH_3COO^-(aq)}$$



In an earlier investigation, you tested the conductivity and pH of ethanoic acid and hydrochloric acid solutions with identical concentration. It was discovered that the ethanoic acid solution had a lower conductivity and a higher pH compared to the hydrochloric acid solution. This is because organic acids do not react completely with water and, thus, are categorized as weak acids.

Lactic acid is the common name for a carboxylic acid produced by the body during physical exertion. Strenuous exercise usually results in the accumulation of lactic acid inside muscle cells. The fatigue you experience while exercising is often due to the accumulation of hydronium ions—resulting in a small change in the pH within your muscles—produced by the reaction of lactic acid with water. If lactic acid were a strong acid, a greater change in pH would occur within your muscle cells.

How does the body respond to changes in pH within its cells? As you know, humans, as well as all organisms, do not respond well to large changes in pH. Cells, as well as the blood, contain substances to neutralize excess hydronium ions. Hydrogen phosphate ions and dihydrogen phosphate ions present in muscle cells act as a buffering system to maintain a relatively constant pH within muscle cells even during physical exertion.

Practice

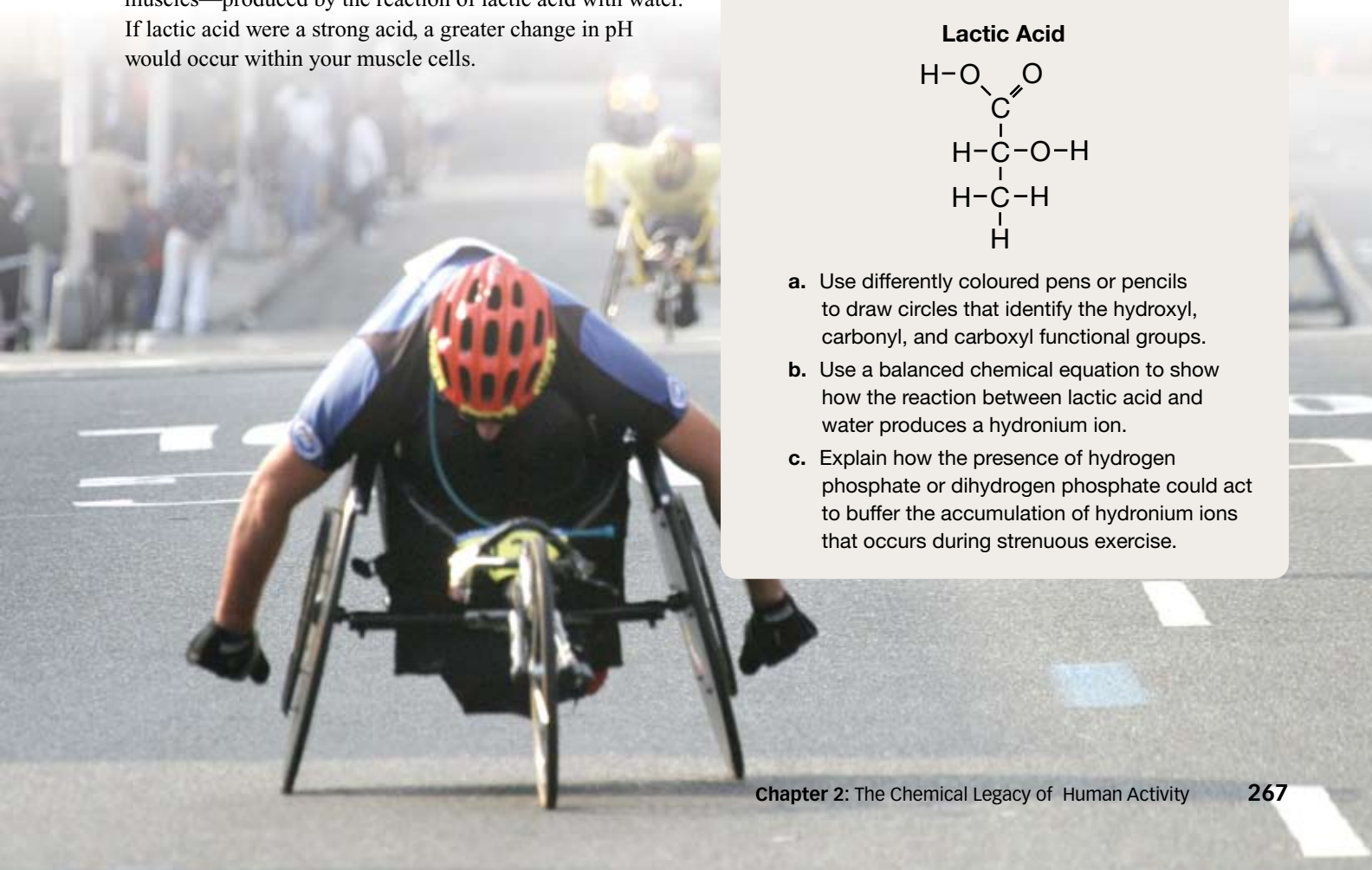
21. Copy the structure of lactic acid into your notebook.

Lactic Acid

a. Use differently coloured pens or pencils to draw circles that identify the hydroxyl, carbonyl, and carboxyl functional groups.

b. Use a balanced chemical equation to show how the reaction between lactic acid and water produces a hydronium ion.

c. Explain how the presence of hydrogen phosphate or dihydrogen phosphate could act to buffer the accumulation of hydronium ions that occurs during strenuous exercise.



Some Chemical Structures That Cause Allergic Reactions

Previously, you learned that some people have concerns about the substances present in sunscreens. PABA, short for para-aminobenzoic acid, is a molecule formed by the attachment of two functional groups—one being a carboxyl group—to a benzene molecule. The chemically stable benzene ring is able to absorb UV radiation, serving to protect skin layers beneath the sunscreen. Unfortunately for some people, exposure to PABA causes an allergic reaction. People with sensitivity to PABA tend to be sensitive to other medicines. Some sunburn and sore-throat medications, along with certain antibiotics, can be broken down by the body to produce PABA or a chemical structure very similar to PABA. The body's contact with these compounds triggers the immune system to respond.

For people who are highly sensitive to an antigen, there is a risk that exposure could cause an **anaphylactic reaction**. For some people, the choice of products they use is very important.

anaphylactic reaction: a life-threatening, severe reaction of the immune system to an antigen that results in severe swelling and may affect the muscles involved in breathing

Figure B2.19: People with extreme sensitivity to certain chemical compounds often wear jewellery that informs medical personnel of their allergy.

DID YOU KNOW?

Rashes, itchy skin, or hives can be an indication that your body is having a mild allergic reaction. Swelling and difficulty breathing are often signs of severe allergic reactions and, thus, require immediate medical attention.

Naming Carboxylic Acids

Writing systematic names for carboxylic acids involves similar steps to those used to name alcohols. The end result will be to name the hydrocarbon part of the molecule followed by the suffix *-oic acid*, which identifies the carboxyl group.

Example Problem 2.7

Propanoic acid is used to prevent some foods from spoiling.

a. Use the systematic name to draw the chemical structure for propanoic acid.

b. State whether it is possible to have the carboxyl functional group on the second carbon in the parent chain of propanoic acid.

Solution

a. **propanoic acid**

A B

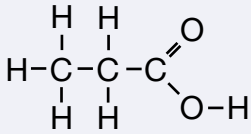
C

A indicates that there are 3 carbons in the parent chain

B indicates that the compound is a carboxylic acid—contains a carboxyl functional group

C no number indicates that the carboxyl group is attached to the first carbon

Therefore, the chemical structure is



b. The carboxyl functional group requires three bonds. A carbon atom within a chain has only two bonds available, since two of the four bonds are needed for the adjacent carbon atoms. Therefore, it is not possible for a carboxyl functional group to appear in the middle of the parent chain.

Practice

22. Prepare a table that lists the chemical structures and the systematic names for the carboxylic acids that contain one, two, and three carbons, respectively.

Household Cleaning Products

Many people use vinegar for purposes other than food preparation. Many properties of acids make them ideal for a variety of purposes, but can they be used as cleaning products in your home? In the next activity you will examine the cleaning products used in your home and consider the risks and benefits of using vinegar for cleaning.

Utilizing Technology

Risks and Benefits of Household Cleaning Products

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Purpose

You will identify issues associated with the use of common household cleaning products and to evaluate the use of alternative products.

Background Information

Regular household cleaning often involves the use of many products. Apart from the instructions for using the product and the safety information listed on the label, most people are unaware of possible risks associated with **direct exposure** to these products. Concerns also exist regarding whether the substances in household cleaning products are **biodegradable** or whether they will have negative, unexpected effects on the environment.

Problem

Is vinegar a safe and suitable replacement for many liquid household cleaners?

Procedure

step 1: Prepare a list of the liquid cleaning products used during a routine cleaning of your home and the homes of other people in your class. Identify the intended use for each product (glass cleaner, disinfectant, stain remover, etc.). Also, identify the size of the container and the cost of each cleaning product.

step 2: Use the product label, the Internet, and/or other sources of information to identify risks associated with the use of the cleaning products listed. Collect information about the

- safety concerns regarding the storage of the product
- safety concerns when using the product
- harmful effects to humans or pets from direct exposure to the product
- information about the product's biodegradability

step 3: Use the Internet to prepare a list of where vinegar can be used as an appropriate cleaner. Also, indicate situations where it is not recommended to use vinegar as a cleaner.

step 4: Use the product label and/or the Internet to collect information about risks associated with the use of vinegar.

step 5: Determine the quantity of each substance used during a regular household cleaning session. Add this information to the list prepared in step 1.

step 6: If possible, perform an experiment to determine whether vinegar is a suitable replacement for a cleaning product used in your home.

direct exposure: contact with a chemical substance that occurs while using it or by being present in an area where it has been used

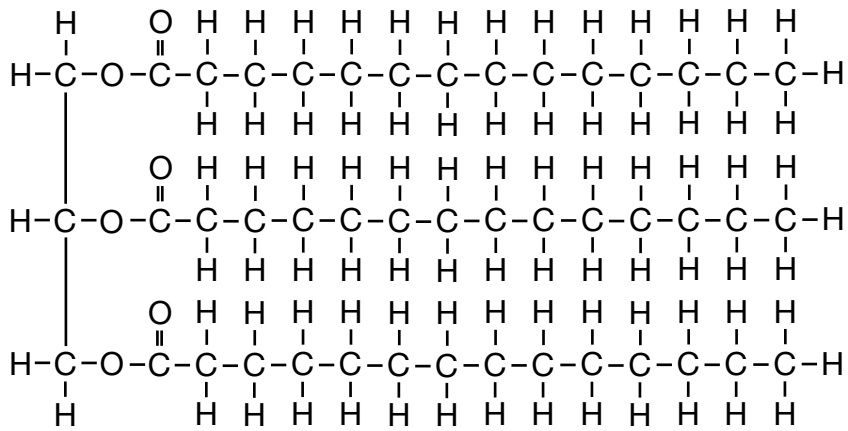
biodegradable: ability to be broken down by natural mechanisms

Analysis

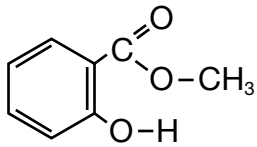
1. Identify cleaning products that could be replaced by using vinegar.
2. Calculate a price per millilitre for each liquid cleaning product used during the regular household cleaning session. Calculate the total cost for all the liquid cleaning products used in the cleaning session. You may find it helpful to use a spreadsheet or graphing calculator to calculate and display this information in a table.
3. Use the information you collected to estimate the quantity of vinegar required to complete the cleaning session. Use resources available to you to determine the cost of using vinegar to complete the routine cleaning session.
4. Prepare a risk-benefit analysis of using vinegar as a replacement for the liquid cleaners.
5. Evaluate the list of risks and benefits you prepared and develop a response to the problem stated at the start of this activity. Use one or more of the following perspectives in supporting your answer: scientific (or technological), ecological, and economic.

Esters

Fat Molecule



Methyl Salicylate



Esters are organic compounds formed by the chemical reaction of a carboxylic acid with an alcohol. Esters may be naturally occurring or synthetic products. In previous science courses you may have heard about fatty acids and fats. Fats and oils are examples of naturally occurring esters produced by your body. The synthesis of fats involves chemically joining three carboxylic acid molecules, called fatty acids, to the hydroxyl groups on a glycerol molecule.

The food and cosmetics industry dedicates a great deal of time to identifying naturally occurring esters and developing synthetic methods to produce these molecules to enhance their taste or aroma.

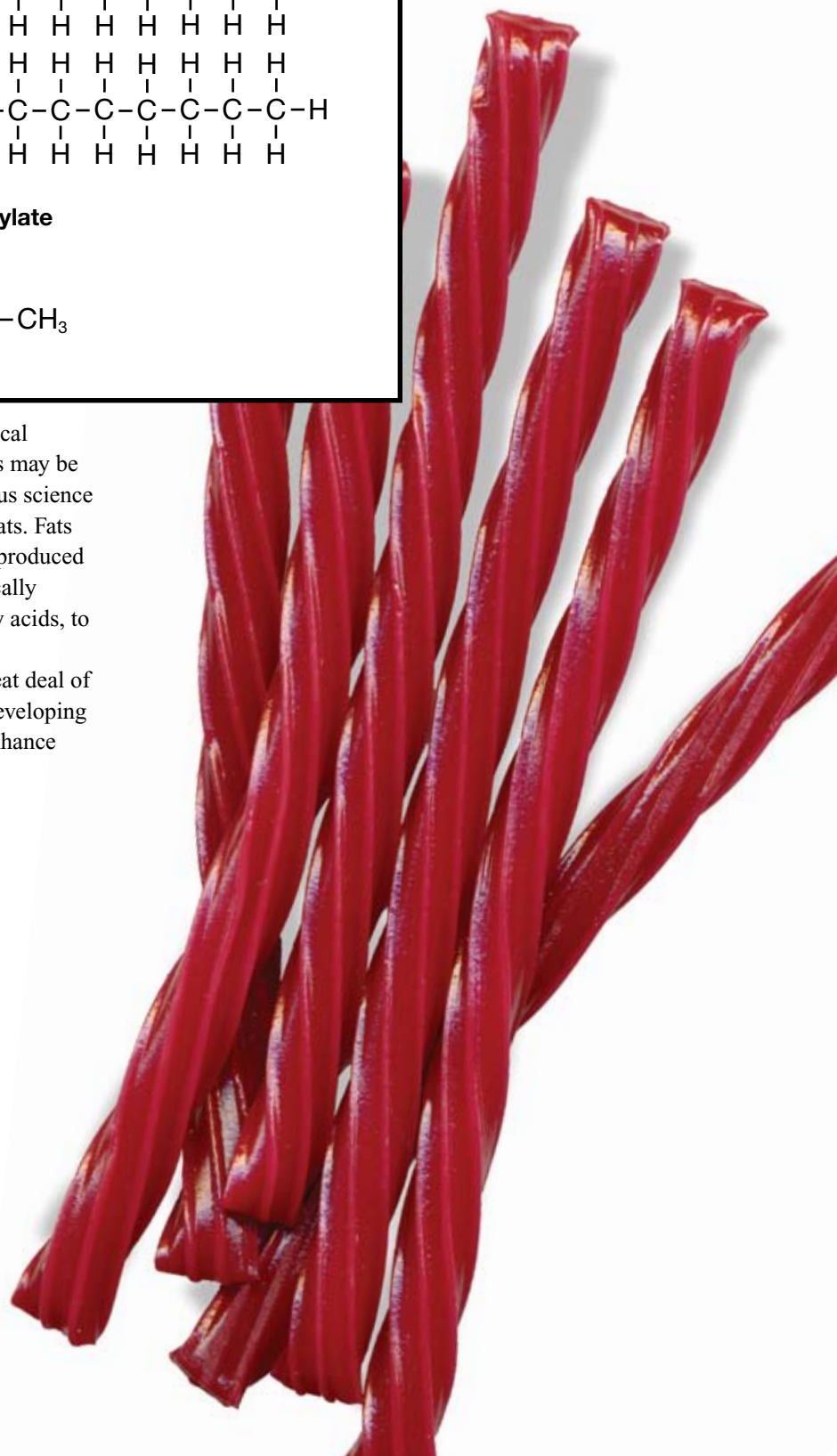
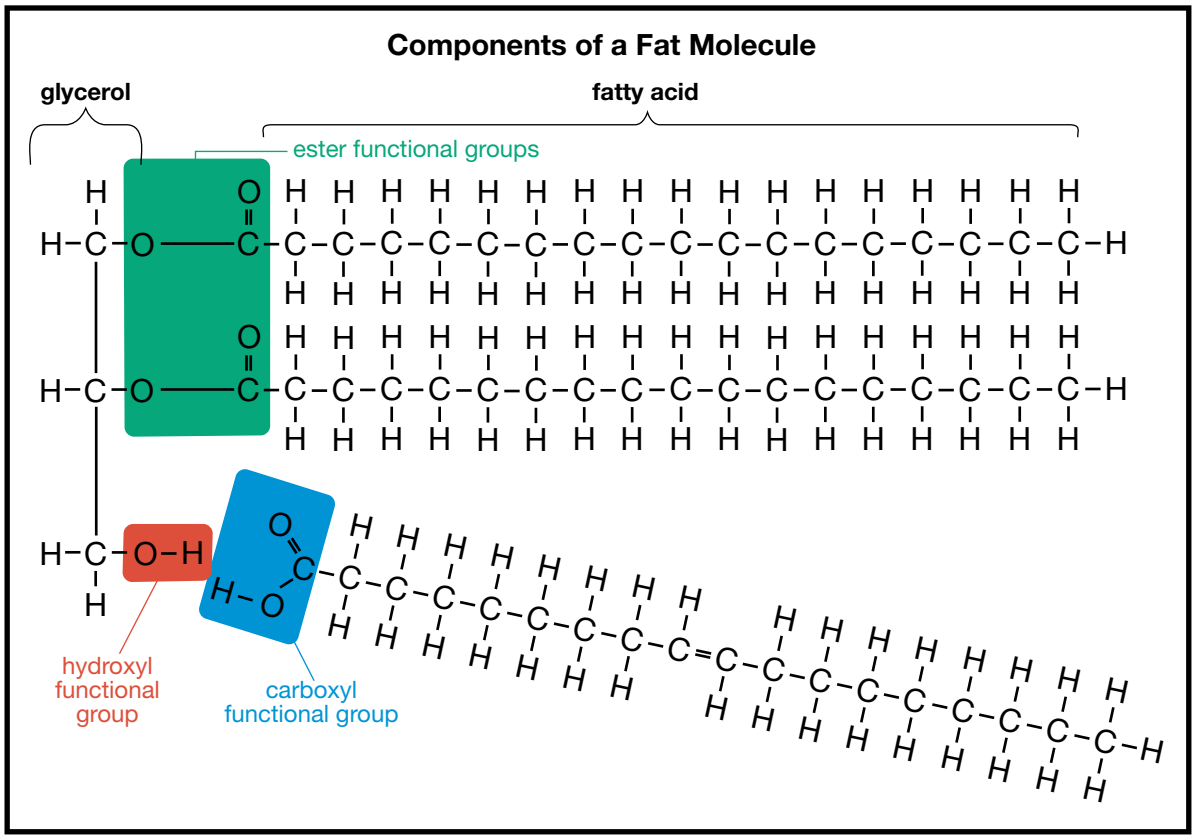
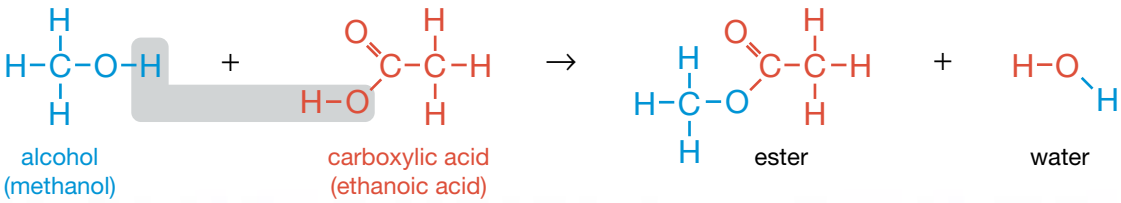


Figure B2.20: Esters are used to provide a desired flavour or odour to a food product like red licorice.

Structure and Formation of Esters



Esters contain a functional group that is a combination of the functional groups of a carboxylic acid and an alcohol. The reaction that forms an ester also forms a second product: a water molecule. The elimination of the water molecule is necessary to enable the chemical joining of the carboxylic acid to the alcohol.



The reaction that synthesizes an ester occurs between the functional groups, leaving the parent chain of both reactants unaffected. Since the other parts of the reactant molecules are unaffected, the components of an ester can be identified and a systematic process can be used to name esters.

Naming Esters

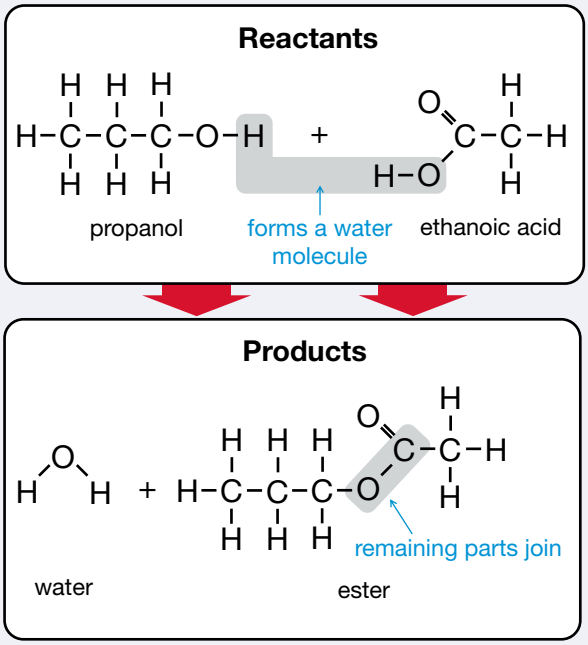
As you have seen, naming other organic compounds with functional groups containing oxygen involves the use of a suffix that identifies the functional group. For esters, the suffix is *-oate*. The remainder of the name identifies the alcohol and the carboxylic acid used in its synthesis.

Naming an ester involves either knowing both the alcohol and carboxylic acid used in its synthesis or analyzing its chemical structure to determine these components.

Example Problem 2.8

A chemical reaction occurs between propanol and ethanoic acid. Use a structural diagram to show the reactants and products for this reaction.

Solution



To determine the systematic name for an ester from a structural diagram, use the following steps:

step 1: Find the ester functional group, and draw a box around it. Then circle each chain of carbon atoms that extend from the functional group.

step 2: Locate the chain of carbon atoms that is attached to the functional group by a single bond to an oxygen atom.

This is the part of the molecule derived from an alcohol.

step 3: Identify the number of carbons in this chain.

If the chain contains one carbon, the prefix *methyl* is used.

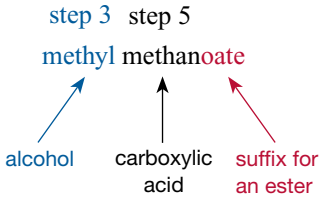
step 4: Count the number of carbon atoms in the chain, starting with the carbon that contains a double bond to an oxygen atom.

This is the portion of the ester that is derived from a carboxylic acid.

step 5: Identify the number of carbons in this chain.

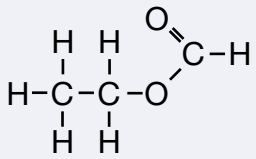
For example if the chain contains one carbon, *methan-* is used in this part.

step 6: List the parts identified in steps 3 and 5, followed by the suffix *-oate*.



Example Problem 2.9

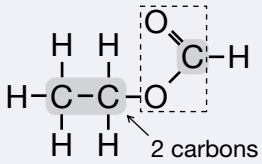
The ester depicted here produces an aroma similar to that of raspberries. Write the systematic name for this ester.



Solution

Follow the steps of systematically naming an ester. First, isolate the three parts of the ester; then identify the alcohol part of the name (steps 1 to 3).

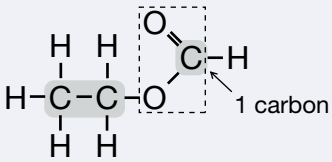
Steps 1 to 3



Since there are 2 carbons in the alcohol part, the first part of the name of this ester is *ethyl*.

Now, identify the carboxylic acid part of the name (steps 4 and 5).

Steps 4 and 5



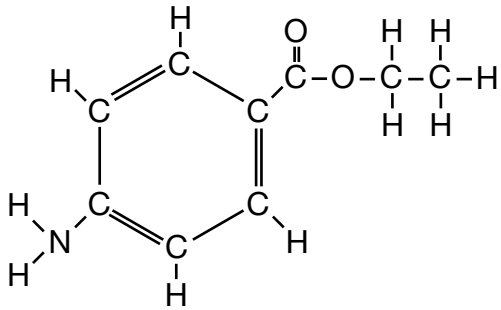
Since there is only 1 carbon in the carboxylic acid part, the middle part of the name of this ester is *methan-*.

Therefore, when you add the suffix *-oate* (step 6) for an ester, the systematic name of this ester is ethyl methanoate.

Practice

23. Benzocaine is an organic compound that is able to dull the sensation of pain by acting on parts of the nervous system. Benzocaine is used in a variety of products, including lotions and ointments used to treat mouth sores, insect bites, and sunburns.

Benzocaine



a. Copy the structure of benzocaine into your notebook, and draw a box around the ester functional group.

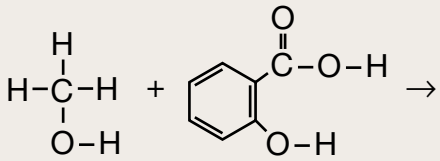
b. Circle and label the part of the benzocaine molecule that is derived from an alcohol and the part that is derived from a carboxylic acid.

c. State the name of the alcohol used in the production of benzocaine.

d. Explain why people who have allergies to sunscreens containing PABA may also demonstrate a sensitivity to benzocaine.

24. Draw the structural diagrams for the products of the following reactions. Where possible, write the names for the chemical substances involved.

a.



methanol salicylic acid

b. $CH_3CH_2OH(l) + HCOOH(l) \rightarrow$

c. ethanol + ethanoic acid →

DID YOU KNOW?

Acetylcholine—an important molecule in the action of nerves—is an ester. The ester group of an acetylcholine molecule is continually broken apart and reformed as nerve cells function to recycle this important molecule.

Investigation

Making Esters

Purpose

You will prepare a synthetic, organic compound—an ester.

Science Skills

✓ Performing and Recording

Pre-Lab Activity

Obtain the handout "Making Esters" from the Science 30 Textbook CD, and closely study the table to see which scents are produced from the reaction of the carboxylic acid and the alcohol. Also, obtain from your teacher a list of the alcohols and carboxylic acids available to you for this investigation.

1. Write the reactions and expected results for three esters that can be synthesized using the alcohols and carboxylic acids available to you. Determine the systematic name for each ester. Show your reactions to your teacher.

Materials

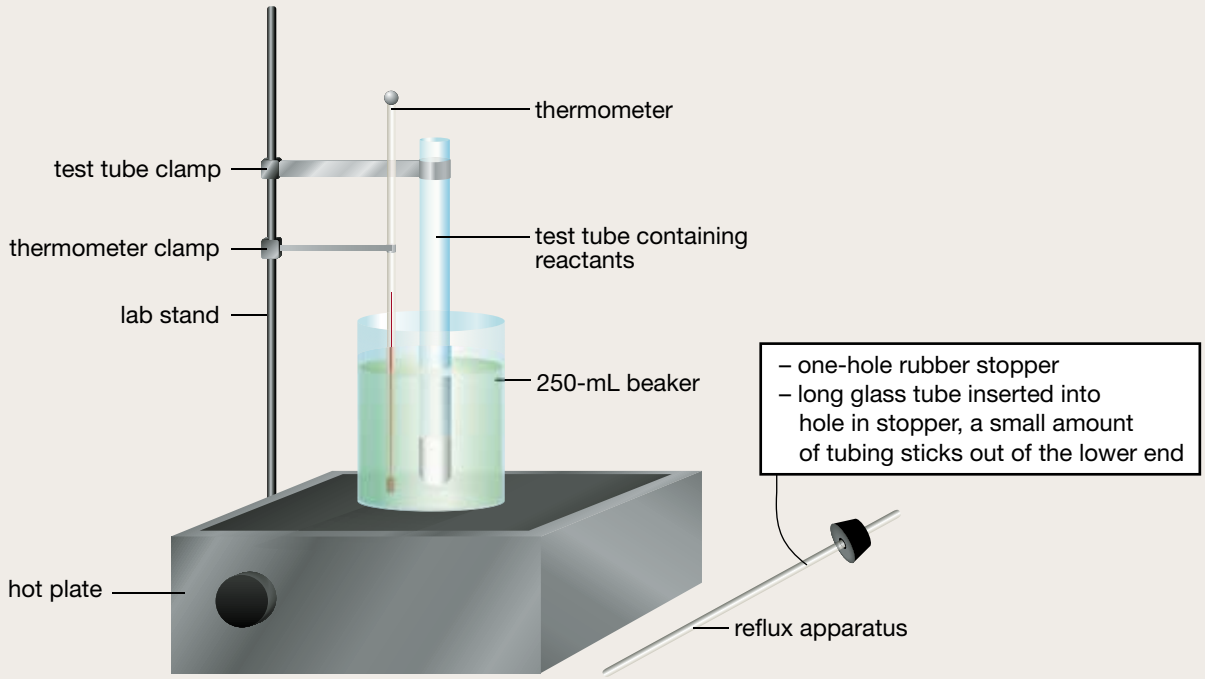
- tap water
- 25 mm × 250 mm test tubes (or larger) (1 for each reaction)
- 2, 250-mL beakers
- 3, 10-mL graduated cylinders
- weighing boat
- lab stand
- test tube clamp (or utility clamp)
- reflux apparatus (one-hole stopper with inserted glass tubing)
- alcohols and carboxylic acids made available by your teacher
- dropper bottle containing concentrated sulfuric acid (handled only by your teacher)
- hot plate
- thermometer
- thermometer clamp
- laboratory tongs
- laboratory scoop
- electronic balance
- a vial of salicylic acid
- evaporating dish (1 per reaction)
- test tube rack
- tray or large beaker containing ice

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity. Sulfuric acid is corrosive; use extreme caution.

Procedure

step 1: Assemble a water bath by placing a 250-mL beaker, half-filled with tap water, onto the hot plate. Place the water bath close to the lab stand. Attach the thermometer clamp to the lab stand and position the thermometer inside the clamp in such a way that it measures the temperature of the water inside the water bath. Attach the test tube clamp to the lab stand.



step 2: Transfer approximately 4 mL of the carboxylic acid you have chosen and approximately 5 mL of the alcohol you have selected into separate graduate cylinders. **Note:** If you use salicylic acid, measure approximately 2 g of the salicylic acid crystals into a weighing boat.

step 3: Transfer the contents from the graduated cylinders to the test tube. Fasten the test tube to the test tube clamp attached to the lab stand in such a way that the reactants in the test tube are below the surface of the water bath.

step 4: Use a clean graduated cylinder to measure 2 mL of concentrated sulfuric acid. Add this to the contents of the test tube.

step 5: Attach the reflux apparatus to the test tube. Turn on the hot plate, and begin heating the water bath. Monitor the temperature of the water bath during the experiment to maintain the temperature of the water bath between 70°C and 80°C. Allow the contents of the test tube to heat for 15 min.

step 6: Remove the test tube from the water bath, and allow the contents to cool for 5 min; then place the test tube into a second water bath containing cold or ice water water for 5 min.

step 7: Pour the cooled contents into an evaporating dish. Gently waft the vapour from the dish containing the synthesized ester toward you. Record the odour detected in the appropriate place in your table.

step 8: Repeat steps 2 to 7 for your two other esters.

step 9: Follow your teacher's instructions regarding the disposal of liquid waste. **Be careful not to spill or splash the esters. These mixtures may contain unreacted sulfuric acid.**

step 10: Disassemble, wash (if needed), and return the equipment to its appropriate place.

Analysis

2. Compare the observed odours with the scents listed in the "Making Esters" handout. Were you able to create the ester you intended to synthesize? Use the evidence from the experiment to support your answer.
3. Compare your results with those of other students in your class. Were some esters more difficult to make than others?
4. Is the creation of an ester a fast or slow reaction? Give a reason for your answer.
5. Is this method to create esters reliable and valid?

Polyesters

Enjoying the outdoors may require more than just sunscreen. The pieces of equipment used by wakeboarders, for example, are composed of many different kinds of **plastics**. Most plastics in manufactured materials are **polymers**. One common type of plastic is **polyester**. It is created from the reaction of many alcohols and carboxylic acids, forming long chains or filaments. These filaments are used to make such things as towropes, straps for personal flotation devices (PFDs), and some of the everyday T-shirts in your dresser.

- **plastic:** material that can be shaped or moulded with or without the application of heat
- **polymer:** a large molecule formed by the chemical joining of many smaller molecules
- **polyester:** a polymer containing many ester functional groups

To form the long chains of ester bonds, both the carboxylic acid and alcohol must have two functional groups. For these molecules, chemical reactions occur at both functional groups. This enables the molecule to grow in both directions, producing a filament. Bonding that occurs within and between filaments is responsible for the strength of the plastic, making polyesters like Dacron a useful material in many applications.

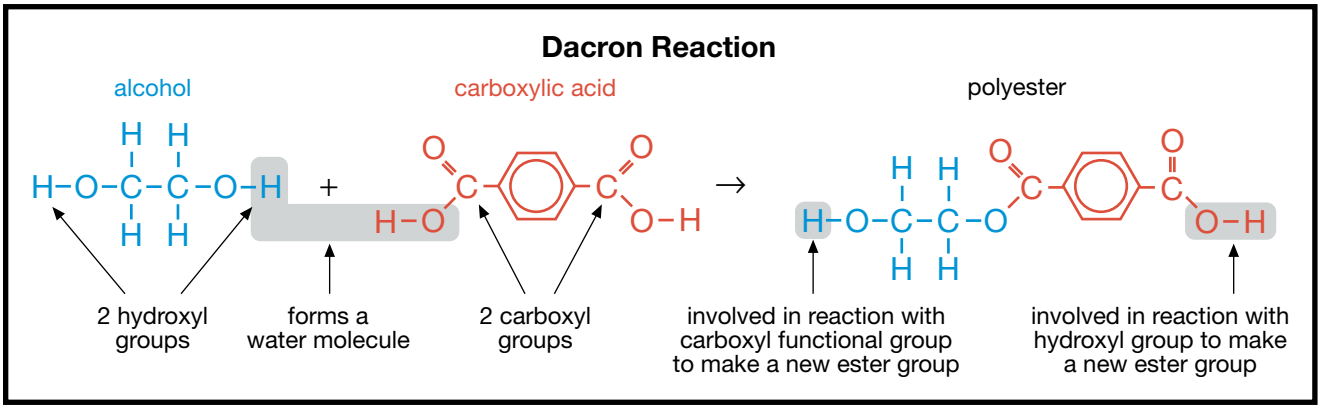


Figure B2.21: A common polyester, called Dacron, is formed by the reaction of an acid and an alcohol, each with two functional groups.

Bioplastics

A major problem with the use of plastics is that they are not biodegradable. Although recycling is one way of reducing the amount of waste sent to landfills, many plastics used today that make their way to landfills will not break down.

bioplastic: an organic polymer produced by plants or bacteria that can be used in place of synthetic polymers to form materials

Bioplastics are a group of compounds that can be used to produce a wide range of materials and have the added advantage of being completely biodegradable. Plastic cups, cutlery, plates, and store bags may be formed from a variety of naturally produced compounds. Bioplastics are produced by extracting a polyester compound from the tissues of plants (such as corn, soy, and even hemp) or from the cells of certain bacteria. The naturally occurring compounds used as bioplastics can be decomposed by bacteria within the soil, often within a few months if properly disposed. Bioplastics are being considered for use in materials like dissolvable sutures and other medical applications.

Utilizing Technology

Bioplastics

Question

How do products made from bioplastics compare to the same products made from synthetic plastics?

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Researching the Issue

Use the Internet to prepare a list of different types of bioplastics. For each type of bioplastic, list products that are made from that bioplastic.

Choose one product made from bioplastic, and design a series of experiments that will compare the properties of the product formed from the bioplastic to the same product formed from a synthetic plastic. Show your teacher the designs for the experiments you wish to conduct. If possible, perform the experiments. Use the data collected from your experiments and the results from your research to demonstrate the uses of materials composed from bioplastics.

2.2 Summary

In this lesson you studied organic compounds that have functional groups containing oxygen atoms. Alcohols, carboxylic acids, and esters represent three important groups of compounds that can be identified by the suffixes in their respective systematic names. Compounds within these groups have significance in biological systems and are often used in all aspects of people's lives, including food, building materials, and manufactured products.

2.2 Questions

Knowledge

1. Complete the following table.

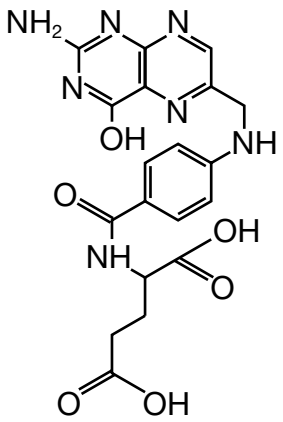
Type of Organic Compound	Drawing of Functional Group	Name of Functional Group	Suffix Used During Naming
alcohol			
carboxylic acid			
ester			

2. Prepare a list of some of the common uses for alcohols, carboxylic acids, and esters.
3. State the empirical properties shared by all acids, including carboxylic acids.

Applying Concepts

4. Folic acid is one of the B vitamins essential to human health. People must obtain folic acid through their diet. Bacteria are able to produce folic acid when provided PABA (para-aminobenzoic acid).

Folic Acid

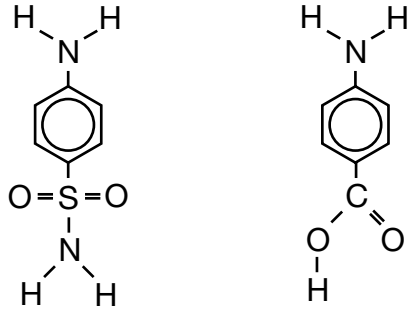


a. Identify the hydroxyl functional groups present in the structure of folic acid.

b. Identify the carboxyl functional groups present in the structure of folic acid.

5. Sulfanilamide is an antibiotic used to treat bacterial infections. Doctors must check their records to ensure that patients do not have an allergy to PABA before prescribing sulfanilamide.

Sulfanilamide **PABA**



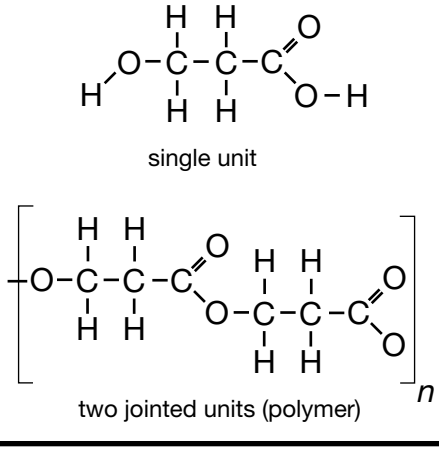
a. Identify similarities between the chemical structures of sulfanilamide and PABA.

b. Explain the significance of any similarities in structure between these two compounds and its importance to a patient's treatment.

c. Explain why it is important for doctors to know about a patient's sensitivity to PABA, or other compounds, when prescribing drugs.

6. The chemical structures for a type of bioplastic are shown here. The first structure represents a single unit, and the other represents two joined units that form part of the polymer. Use these diagrams to answer the following questions.

Chemical Structures in a Bioplastic



a. Copy the chemical structure for the single unit into your notebook. Circle each functional group, and identify the name.

b. Identify the type of functional group in the polymer.

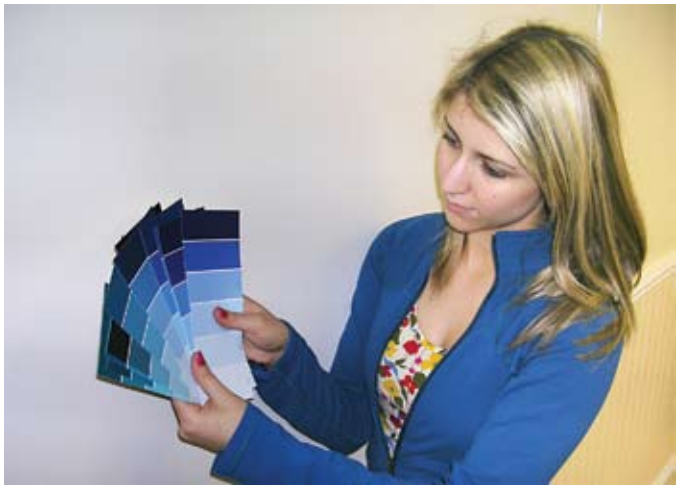
c. Use structural diagrams to explain how the polymer can be formed from the combination of two single-unit molecules.

d. Use structural diagrams to show the polymer formed from the combination of four single-unit molecules.

e. Write the balanced chemical equation for the process explained in question 6.d.

2.3 Understanding Exposure

Congratulations, you've landed a great summer job! Not only will you be able to work outside, you might even get the opportunity to play lots of golf as well. Maintaining the condition of the fairways, greens, and other parts of a golf course is a complex job that requires the superintendent and crew to utilize a variety of chemical substances, including fertilizers, herbicides, insecticides, and pesticides. As part of the grounds crew, you will be required to handle and use many of these substances. Which substance should you be concerned about the most? What actions can you take to reduce your concerns?



In this lesson you will learn more about some of the substances that are present in your environment. Considering that you spend a great deal of time both indoors and outdoors, the choices you make about the substances you use in your daily activities and how you handle them influence what you will be exposed to.

- **off-gassing:** the release of volatile organic compounds from building materials
- **indoor air quality:** an evaluation of the air within a room or structure

Painting is probably one of the many tasks you will be asked to complete, whether at home or while on the job. Imagine you were given permission to decorate your room in any style you choose. Think of all the choices! Renovating a room, an apartment, or a house involves many decisions. Not only are there colours to consider, there are so many different materials from which to choose. The smell of fresh paint is very distinct; it is also an indication of the presence of volatile organic compounds (VOCs) released by the paint through a process called **off-gassing**. Flooring, along with other materials used in decorating, can release VOCs through off-gassing as well. Because of the amount of time people spend inside, **indoor air quality** and exposure to VOCs from off-gassing is a concern for many people.

Science Links

In addition to VOCs, the air inside a room may contain mould, carbon monoxide, ozone, and even pesticides. People with asthma and allergies are especially sensitive to the air quality and substances present. Dust, mould, and insects in a room can trigger allergic reactions. To prevent the accumulation of allergens, smooth, washable surfaces are recommended along with frequent cleaning of floors, walls, and shelves. Have you included information about any substances you are allergic to or perhaps that you have asthma in your personal health file you started in Unit A?

Concerns Regarding Off-Gassing

One way to prevent off-gassing is to use products that do not contain volatile organic compounds (VOCs). Paint and related products that do not contain VOCs—like ethan-1,2-diol (ethylene glycol) or 1,2-dichloroethane (a halogenated hydrocarbon)—are available from many manufacturers.

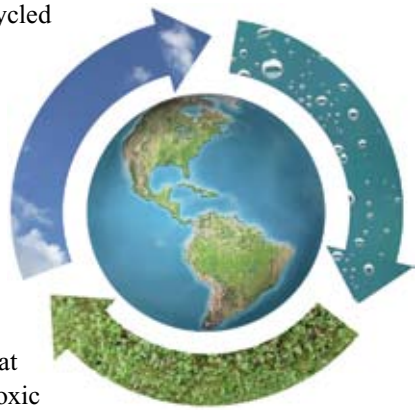
As paints or solvents dry, the compounds identified as VOCs evaporate and mix into the air in the room, where it can be inhaled. People who spend many hours indoors—in hospitals, day-care facilities, and schools—tend to have a higher level of exposure to VOCs. Reduced-odour paint provides one alternative that reduces exposure. People who work or live in newly-painted rooms experience only a short-term exposure. On the other hand, painters, who work with paint daily, experience long-term exposure. In addition to carefully choosing paint, simple practices like wearing gloves and clothing to protect skin from direct contact can also help reduce exposure.

Figure B2.22: Odourless paint and paint supplies do not contain VOCs.

Building Materials Can Limit Environmental Impact

Figure B2.23: Labels often provide instructions on how to access additional information about a product, including its effect on indoor air quality.

In addition to paint, other building materials like lumber, flooring, and floor and wall covering materials can be manufactured from recycled materials or from materials developed that use alternative technologies. Labels can indicate that a product has met national standards. When buying building materials and other products that are environmentally friendly, you are supporting companies that use processes that reduce the amount of material sent to landfills and use alternatives to toxic chemicals. Because of your decision, you may find yourself walking on a carpet containing plastic recycled from pop bottles, hanging a picture on a wall built from wood produced by a quick-growing variety of tree that absorbs carbon dioxide from the atmosphere at a high rate, or using wood that was not treated with toxic substances. Information about most building products is available on the Internet or at stores that stock the product.



In the next activity you will consider materials you could use for redecorating your room.

Practice

25. Draw the chemical structure of the VOC 1,2-dichloroethane. Identify one environmental concern associated with halogenated hydrocarbons.

26. Explain how removing halogenated hydrocarbons from paint could address the environmental problem identified in question 25.

Science Links

Safety gear, like protective suits, gloves, and masks to filter inhaled air, prevents exposure to chemicals used in automobile paint. Short- or long-term exposure to certain substances may affect the body. Similarities exist between exposure to radiation and to certain chemicals. For more information about sources of radiation you may be exposed to, go to Unit C.

Utilizing Technology

Risk-Benefit Analysis of Renovation Materials

Background Information

In this activity you will plan a renovation for a room in your home. A risk-benefit analysis involves considering many factors before you start the project. You will conduct research on some options that exist for the materials you plan to use to complete the renovation. You will also evaluate your renovation plan by considering technological, ecological, and economic factors.

Purpose

You will investigate and evaluate the use of products that decrease the release of synthetic organic compounds into the environment.

Procedure

step 1: Sketch the room you intend to renovate. In your sketch, include measurements of the dimensions of the room as well as the number and size of windows and doors.

step 2: List the materials required to complete the renovation you proposed. You may wish to use a spreadsheet to organize the information you collect in the steps that follow. Consult your teacher as to how extensive your renovation plan can be (e.g., paint, draperies, flooring, and mouldings).

step 3: Use the room measurements and, if necessary, the Internet to research information about the amount of each material listed in step 2. For example, some websites can estimate the amount of paint required. Record the amount of each material required in your spreadsheet.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

step 4: Use the Internet to research an environmentally friendly paint or an alternative to painting. Identify characteristics that enable these products to be designated as "environmentally friendly."

step 5: Visit some local businesses that sell the materials you need to complete your plan. Identify the products you would like to use. List the technological, economic, and ecological aspects of the product in your spreadsheet. These aspects may include ingredients or substances used in its construction, durability, performance, texture, look, limitations, and cost.

step 6: Collect information about environmentally friendly alternatives to the products you have chosen in step 5. Collect information about the environmentally friendly products for your spreadsheet that will allow for a comparison. Use the information in your spreadsheet to compare the products.

Analysis

1. Calculate the cost for completing the renovation project using environmentally friendly materials and the other alternative products.
2. Compare the environmentally friendly materials with the other alternative products in terms of technological, economic, and ecological factors.
3. Finalize your renovation plan, and list the products you would use. Defend your choices.

Targeting Toxic Chemicals

pesticide: a substance used to kill fungi, insects, animals, or plants considered as pests

Choices about products other than paint can influence which chemicals you are exposed to. In Lesson 2.2 you evaluated the use of vinegar as a cleaning product. Are there other substances you are exposed to?

At a golf course, or possibly at home, one or more forms of **pesticide** are used. The term *pesticide* is a very general one, since so many different types of pests exist. The "Pesticides" table lists some of the pesticides used by homeowners.

PESTICIDES

Type	Purpose	Types of Organic Compounds
insecticide	to remove insects that may cause damage or disease in domestic locations, agriculture, and forestry	halogenated hydrocarbons and various organic compounds
herbicide	to remove unwanted plants that compete for nutrients and sunlight, affecting the growth of desired plants	various organic compounds
fungicide	to protect crop plants and animals from fungi that can cause disease; can also be used to prevent the growth of moulds in food or within homes	phenols

DID YOU KNOW?

Other types of pesticides commonly used include acaricides (kill mites and ticks), rodenticides (kill small mammals like mice and gophers), algicides (kill algae in ponds or swimming pools), and disinfectants (kill micro-organisms).

Utilizing Technology

Constructing a Database of Pesticides Used in the Home

Science Skills

✓ Communication and Teamwork

Purpose

You will prepare a database of pesticides used around your home.

Procedure

Search your home, garage, or other buildings for household and garden products used to remove pests. Prepare a database of the products you find. Include the following information about each product in your database:

- product name
- intended use
- type of pesticide (herbicide, insecticide, etc.)
- name of ingredient used as killing agent in product

Check your database by searching for a name of a compound within it or by sorting the information alphabetically by product name.

Analysis

1. Identify a purpose for the database of pesticides in your home.
2. Identify additional information you would add to the database along with a justification.

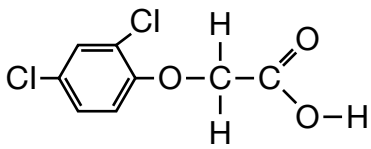
Considerations When Using Pesticides—Specificity

Chemical technologies, like pesticides, act as tools to achieve a desired purpose. On a golf course, farm, or in your yard or garden, herbicides may be used to control the growth of weeds. Careful selection of a substance that is appropriate for a pest involves knowing the pesticide's **target specificity**.

When the correct tool is selected for a job, there is a better chance of success. As you may have noticed from the database you constructed in the preceding activity, you probably have a variety of products in your home, each designed to control a specific type of pest. Some pesticides have high target specificity and are designed to act on a small range or even just one type of insect or plant. A **broad-spectrum pesticide** is a product that has low target specificity and will act more generally, affecting many species. Can you identify the pesticides in your database that have high target specificities? Can you identify those that can act on a broad spectrum?

An example of a highly selective herbicide is 2,4-D, which is short for (2,4-dichlorophenoxyethanoic acid). This herbicide is one of the more popular herbicides used in Alberta. Similarities between the chemical structure of 2,4-D and hormones that control the growth of the plant allow the herbicide to be taken to the stem and root tips, where it interferes with the plant's growth. Dandelions, clover, thistle, and other broad-leaved plants are most affected by 2,4-D, whereas narrow-leaved grasses and crop plants (e.g., wheat) are less affected.

2,4-D



Prior to using a pesticide, it is important to consult information about the **toxicity** of the product. This information may not always be available on the product label, but it can be obtained using the Internet or from the site of purchase.

- **target specificity:** the range of organism(s) affected by a pesticide
- **broad-spectrum pesticide:** a chemical substance that can control the population of a large variety of organisms
- **toxicity:** the ability of a substance to cause damage to living tissue, impair the function of a body system, or cause death when ingested, inhaled, or absorbed through the skin

LD_{50} and LC_{50}

Tests to determine toxicity of a pesticide focus on more than the target species. The most common ways to express information about the toxicity are **LD_{50}** and **LC_{50}**. These values state concentrations at which a significant killing effect on an organism is observed. LD_{50} values are often expressed in milligrams of chemical substance per kilogram of animal tested. A substance with an LD_{50} value below 43 mg/kg is considered to be highly toxic. Since pesticides often end up in bodies of water (lakes, pools, etc.), LC_{50} is often used to express the concentrations at which toxic effects on aquatic organisms occur. Products with low LD_{50} values for the target organism are popular choices for use in pest control because, in theory, smaller amounts of pesticide will be required to control the pests. Broad-spectrum pesticides should also have low LD_{50} values, but this will often be for a variety or pests.

- **LD_{50}:** the dosage of a chemical substance, given all at once, that kills half (50%) the population tested within a specified time
- **LC_{50}:** the concentration of a chemical substance in air or water that kills half (50%) the population tested within a specified time

Regardless of target specificity, pesticides should not affect non-target organisms. When looking at toxicity data, you may note that LD_{50} values are stated for many non-target organisms, often at different stages in their lifecycle. Prior to licensing a product, the Government of Canada requires that sufficient testing be completed to ensure that a pesticide will have minimal impact on non-target organisms at various levels in the food chain. It is important to note LD_{50} values for mammals that are tested because this data may provide information about what concentrations may be toxic to humans.

SOME LD_{50} AND LC_{50} DATA FOR 2,4-D

Organism	LD_{50} or LC_{50}
Daphnia (aquatic invertebrate)	25 mg/L
rainbow trout	358 mg/L
frog	359 mg/L
earthworm	350 mg/kg soil
quail	668 mg/kg
mallard duck	2000 mg/kg
mouse	370 mg/kg
rat	375–666 mg/kg

DID YOU KNOW?

Estimates on the financial impact of pesticide use suggest that for every dollar spent on pesticides, there is a return of $4 due to greater productivity.

Practice

27. Describe an advantage and disadvantage of using the following.

a. a pesticide that can kill only one type of insect

b. a pesticide that can kill many types of insects

28. Scientists testing 2,4-D and an ester of 2,4-D compared LC_{50} values.

LC_{50} VALUES FOR 2,4-D AND 2,4-D ESTER

Organism		LC_{50}	
		2,4-D	2,4-D Ester
chinook salmon	3 months to 1 year old	1.250 mg/L	0.246 mg/L
rainbow trout	3 to 5 days old	0.642 mg/L	0.329 mg/L
	3 months to 1 year old	1.555 mg/L	0.342 mg/L

a. Use the information in the table to identify the substance that has the greater toxicity.

b. State reasons why experiments are performed to determine the LD_{50} and LC_{50} values for a variety of organisms.

c. Use a structural diagram of 2,4-D to indicate how it could be modified into an ester.

29. Explain whether LD_{50} and LC_{50} test the effects of short-term or long-term exposure to a substance.

Considerations When Using Pesticides—Combined Effects

When looking at the labels of pesticides found in your home, you may have noticed that the products are often a mixture of compounds and may include trace amounts of by-products. Toxicity data is not routinely collected for commercial products; therefore, there are concerns regarding the effects that combinations of organic compounds used in pesticides may have on the environment and on humans.

Studies testing the toxicity of commercial pesticides suggest that surfactants and other compounds in the products alter the level of toxicity.

DID YOU KNOW?

Absorption of some pesticides through the skin is higher when sunscreens are worn. Despite this information, the use of sunscreens is encouraged.

Considerations When Using Pesticides—Drift, Grasshopper Effect, and Persistence

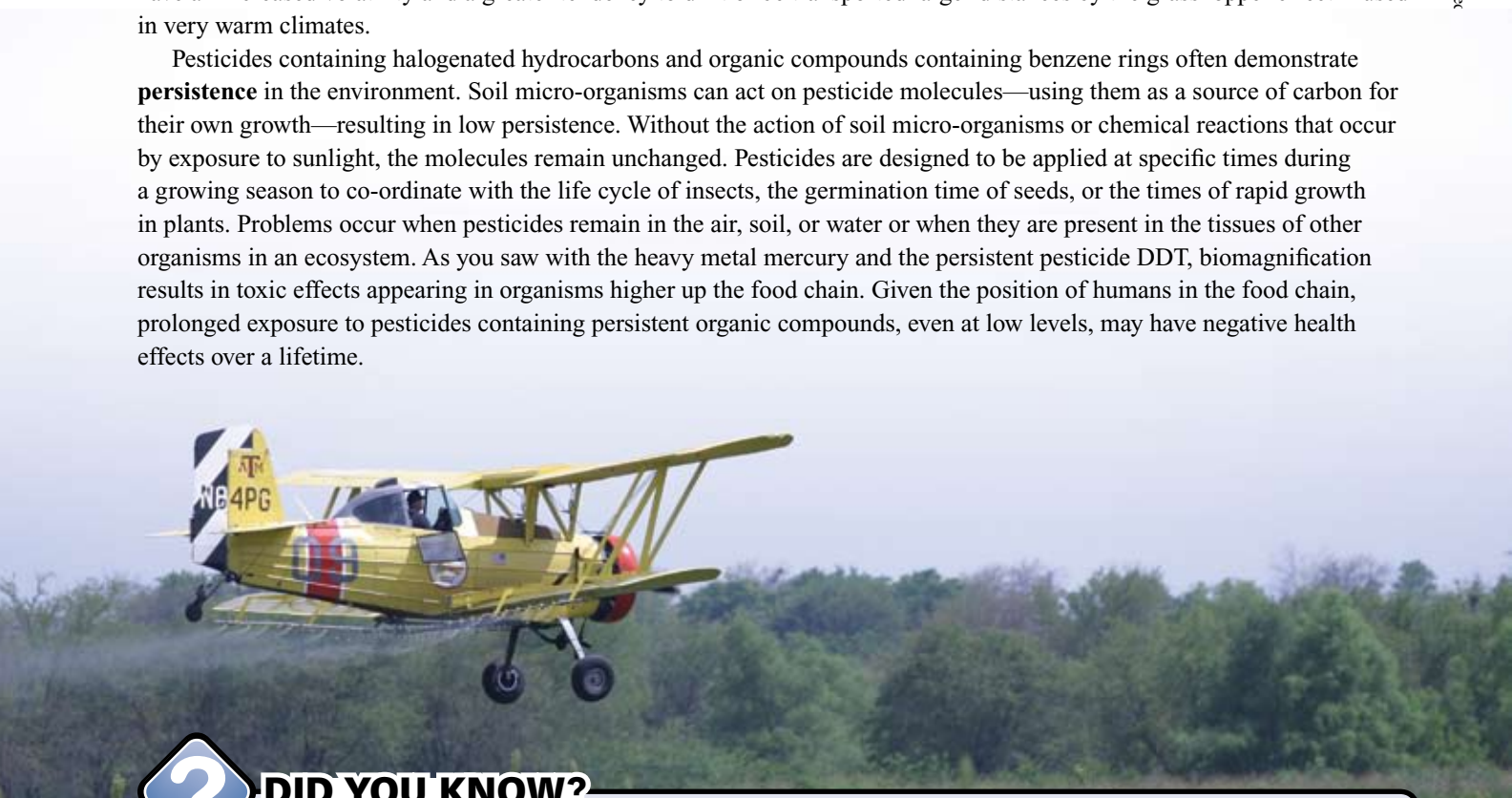
Spraying is one way to ensure direct contact between the pest and the pesticide; but weather and even the properties of the pesticide can affect contact. Spraying on a windy day can cause herbicides or insecticides to **drift** onto neighbouring crops or bodies of water. As you discovered earlier in this unit, the solubility of organic compounds in water can result in aquatic invertebrates, amphibians, fish, and other species in these ecosystems becoming exposed to the pesticide. Also, a rainfall after spraying may result in pesticides being transported into the soil with rainwater or into bodies of water in runoff.

The volatility of many organic compounds may result in pesticides travelling in wind currents from the site where they were applied. Pesticides detected in the Arctic are believed to have been transported by the **grasshopper effect**.

- **drift:** the transfer of a pesticide by wind or air currents from the location where it is sprayed
- **grasshopper effect:** the transport of pesticides that results from their evaporation in warmer climates and condensation and deposition in colder climates
- **persistence:** the resistance of a chemical substance being broken down by biological or chemical means

Modifications, such as synthesizing esters of 2,4-D, change the volatility of a compound and the performance of the pesticide. As you might predict after completing the "Making Esters" investigation in Lesson 2.2, an ester of 2,4-D would have an increased volatility and a greater tendency to drift or be transported larger distances by the grasshopper effect if used in very warm climates.

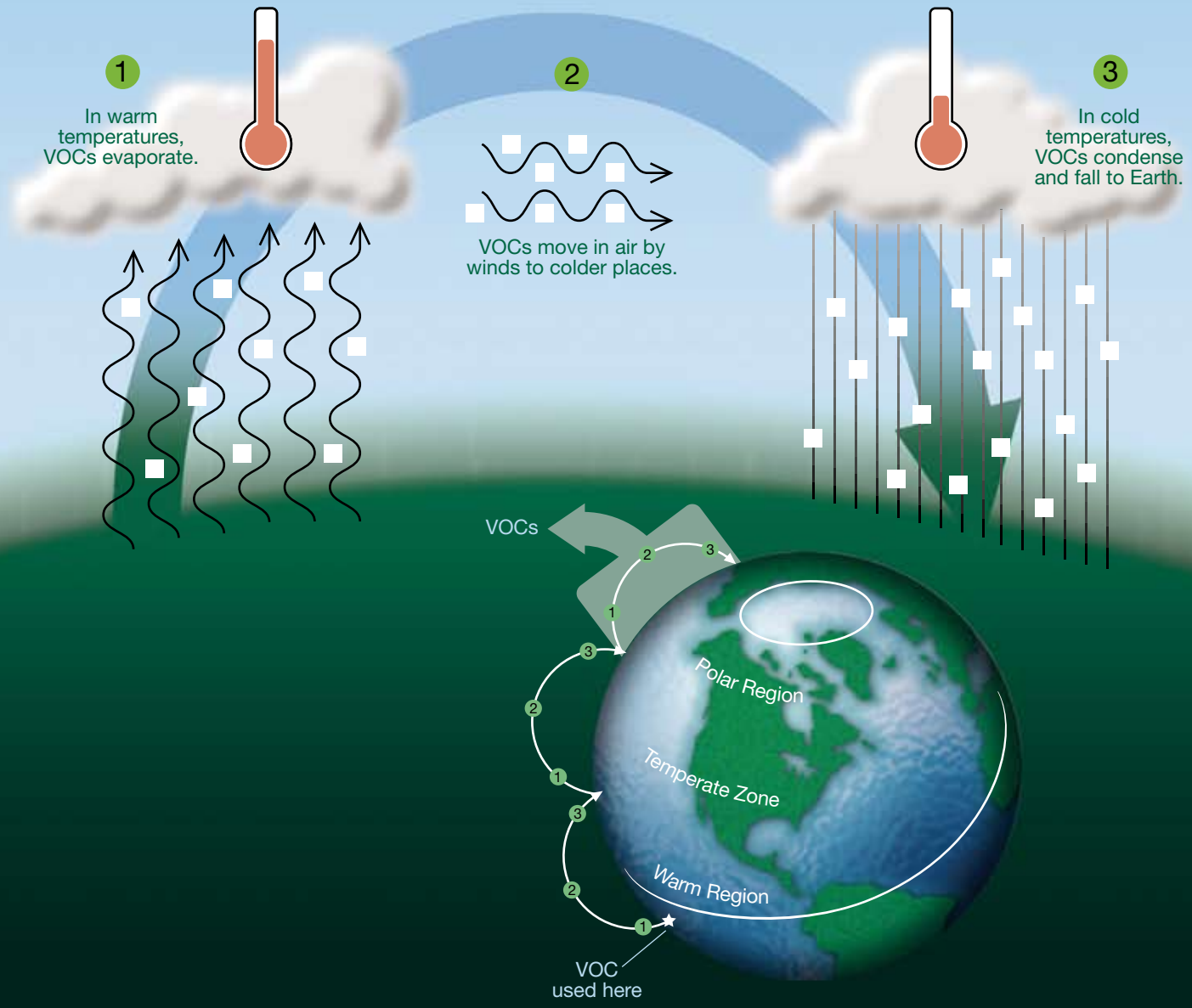
Pesticides containing halogenated hydrocarbons and organic compounds containing benzene rings often demonstrate **persistence** in the environment. Soil micro-organisms can act on pesticide molecules—using them as a source of carbon for their own growth—resulting in low persistence. Without the action of soil micro-organisms or chemical reactions that occur by exposure to sunlight, the molecules remain unchanged. Pesticides are designed to be applied at specific times during a growing season to co-ordinate with the life cycle of insects, the germination time of seeds, or the times of rapid growth in plants. Problems occur when pesticides remain in the air, soil, or water or when they are present in the tissues of other organisms in an ecosystem. As you saw with the heavy metal mercury and the persistent pesticide DDT, biomagnification results in toxic effects appearing in organisms higher up the food chain. Given the position of humans in the food chain, prolonged exposure to pesticides containing persistent organic compounds, even at low levels, may have negative health effects over a lifetime.



DID YOU KNOW?

Inhalation is a major route by which pesticides can enter your body. Directions for use for many pesticide products suggest that the area be avoided immediately after spraying to allow the substance to settle.

The Grasshopper Effect



Try This Activity

Hypothesizing Patterns for Water Quality

Science Skills

✓ Initiating and Planning

Background Information

Tests performed on water samples include the detection of organic compounds. Assume you are working for Alberta Environment and plan to conduct a study that monitors the frequency at which different pesticide compounds are found in surface waters throughout the province. Surface water may be located in a variety of forms:

- lakes
- rivers
- creeks
- wetlands
- irrigation canals and drains
- urban creeks

Purpose

You will formulate a hypothesis about pesticide use over a year in Alberta and describe how such a study can be conducted.

Questions

1. Prepare a table that lists the forms of surface water from which you collect water samples. In the table, indicate whether the pesticides originate from agricultural, industrial, and/or domestic use.
2. Obtain the handout "Predicting Pesticide Use" from the Science 30 Textbook CD. Sketch a line that describes the expected trend for pesticide concentration in all water samples collected each month during a one-year study. Provide an explanation for the pattern, including any peaks or troughs that may be shown.
3. Sketch a second line that identifies the expected trend for the number of different pesticides that would be detected each month during a one-year study. Provide an explanation for the pattern, including any peaks or troughs that may be shown.

Figure B2.24: A location on the Bow River in winter and summer.

Fertilizers and Organic Matter—Effect on Water Quality

In parts of this unit you studied the effects on water quality of acid deposition and persistent organic compounds. The leaching of metal ions and persistent organic compounds used as pesticides are not the only substances that can affect the quality of surface water sources. Contaminating bodies of water with **fertilizers** or **organic matter** can also negatively impact aquatic ecosystems.

- **fertilizer:** a substance containing one or more nutrients required by plants
- **organic matter:** waste or decaying material from plants or animals

Figure B2.25: Tests are conducted to determine water quality.

Have you ever had a day at a lake affected by the presence of a thick layer of algae growing over its surface? An **algal bloom** can be a common occurrence in many prairie lakes. Rapid growth of algae is the result of high nutrient content in the lake's water. Many prairie lakes are considered to be **eutrophic**. They can be considered examples of well-developed ecosystems in which a rapid conversion of nutrients occurs.

Domestic and agricultural fertilizers commonly contain nitrogen and phosphorous—essential plant nutrients. As stated earlier, leaching is a common mechanism for removing substances that were sprayed onto a crop.

Figure B2.26: Irrigation canal amid fields of crops

The leaching of fertilizers and organic matter rich in nitrogen and phosphorous from fields into surface water adds additional nutrients. A rapid growth of algae and other plants is a natural response to this abundance of nutrients.

Toxins produced by species of blue-green algae that are present within an algal bloom can affect the health of humans and livestock. Symptoms of exposure to these toxins include skin irritation, rashes, sore eyes, swollen lips, and allergic reactions similar to hay fever. In some cases, severe illness and death of livestock has occurred from the consumption of water containing these toxins.

The decomposition of algae from an algal bloom can produce a dramatic change to the quantity of oxygen dissolved within a body of water. During winter months, the layer of ice over the surface prevents the absorption of oxygen from the atmosphere. Many processes occurring within the lake require oxygen. In addition to the oxygen needed for the respiration of fish and other organisms, oxygen is required for the decomposition of organic matter. In the winter following an algal bloom, additional oxygen is used by micro-organisms involved in the decomposition process. **Winterkill** occurs when the concentration of dissolved oxygen falls below the levels necessary to support fish species within the lake.

A **biochemical (biological) oxygen demand** (**BOD**) test is a measure of the effects of organic matter and other substances present within a water sample will have on dissolved-oxygen concentration. This test consists of comparing the dissolved-oxygen concentrations of a sealed water sample at the beginning and end of the test period (often five days). A decrease in the concentration of dissolved oxygen within the sample occurs when micro-organisms decompose organic matter. Water samples containing higher levels of organic matter (high BOD) tend to demonstrate a large reduction in dissolved-oxygen concentration.

Water contaminated by organic matter from human or animal waste may have a high BOD or may serve as a source of nitrogen and phosphorous that promote algal blooms. Despite these possibilities, the greatest concern regarding the release of **sewage** directly into water systems is the possible exposure to disease-causing viruses and bacteria. The World Health Organization estimates that water-borne diseases are the leading cause of death in the world. Contaminated water containing a strain of the bacterium *E. coli* (*Escherichia coli*) produces a toxin that severely affects humans.

Higher nutrient levels and the presence of bacteria from human and animal waste in Alberta lakes and waterways have resulted in a greater concern about water quality. Individual homes, settlements, and municipalities with insufficient water-treatment systems are required to boil their water before use to remove harmful bacteria. Some First Nations settlements in Alberta concerned about the use of chlorine as a disinfectant to treat water are investigating the use of chemical-free water-treatment systems.

- **algal bloom:** a rapid increase in the population of algae
- **eutrophic:** of a body of water having excessive plant growth due to a rich supply of nutrients
- **toxin:** a substance that can have harmful effects
- **winterkill:** the death of water organisms caused by the depletion of oxygen in an ice-covered body of water
- **biochemical (biological) oxygen demand (BOD):** a measure of the amount of oxygen required for the decomposition of organic matter
- **sewage:** waste matter often carried in sewers

DID YOU KNOW?

The deaths of seven people in Walkerton, Ontario, was caused by the ingestion of water contaminated with bacteria from cattle manure.

Practice

30. Use the following information to complete questions 30.a. and 30.b.

	Dissolved-Oxygen Concentration (mg/L)		
	Sample A	Sample B	Sample C
Start	10	9	5
End	8	2	2

a. Use the values for dissolved oxygen to rank the water samples from lowest to highest with respect to BOD.

b. Match each water sample with one of the possible sources listed in the table.

Possible Source	Sample
raw sewage	
river water upstream of major city	
river water downstream of major city	

Considerations When Using Pesticides—Resistance

Rodent pests, like gophers and prairie dogs, can cause considerable damage to a golf course. Some farmers are concerned about their farm animals getting injured by stepping in holes made by rodents. Many people, at some point or another, have worried about being exposed to a virus carried by mice (e.g., hantavirus). There are many reasons for people to use pesticides well beyond those associated with maintaining high crop productivity. However, this broad use of pesticides can result in the development of **resistant populations**.

resistant population: a group of organisms not affected by a pesticide

Recall from Unit A that genetic principles, including mutation, create variation within a population. Variation can result in some members of the population possessing resistance to a pesticide. After application, only resistant individuals remain in the population and are able to thrive as a result of reduced competition. Since genetic traits are inherited by offspring, the population of resistant organisms increases. You may also recall that breeding between resistant and non-resistant pest populations tends to result in offspring that are resistant, further reducing the effect of existing pesticides.

It may seem like a contradiction, but pest-management practices designed to kill higher percentages of the pest population often result in the fastest development of resistant pest populations.

Warfarin is a chemical compound that acts as an anticoagulant—preventing the action of platelets, which are responsible for the clotting of blood. Warfarin was first used in the 1950s to control rodent populations. Currently, warfarin and a variety of related compounds, called first-generation anticoagulants, are ineffective on many rodents because of the development of resistance to these chemical compounds. Effective rodent control in many situations now requires the use of second-generation anticoagulants.

The development of pesticide-resistant populations may be the result of poor pest-management practices, including relying too heavily on one product. By alternating the type of pesticide used or using alternative procedures, you increase the ability to control pests resistant to one pesticide.

Figure B2.27: Traps and pesticide-laden seeds are both effective methods of controlling mice.

Have you ever noticed signs of mice present in your garage or in your home? If so, you have a variety of choices. First, you need to determine whether they are a pest and whether they present any reason for concern. For some people, co-existing with mice presents no real problem. For others, minimizing contact may be a priority. A variety of alternatives to control mice exist, but which would you choose? If the problem is due to only a small number of mice, then trapping or the short-term use of a poison may be all that is required. Removing the pesticide once there are no further signs of mice reduces the risk of selecting individuals in the population that may be resistant and the risk of accidental exposure to pets. If the level of infestation is more severe or the mice do not seem to be affected by the methods you have used, a pest-control specialist may need to be consulted.

Practice

31. Explain how leaving pesticide-laden seeds or other poisons in traps for an extended period of time might increase the possibility of developing resistance to a pesticide within a population of pests.

32. Use the Internet to add information about the target specificity, LD_{50}, persistence, and development of resistance to the pesticides listed in the database you developed earlier in this lesson.

Chemical Inventory—Toxic Substances List

Earlier, you completed an activity and prepared a database of pesticides used in your home. Your database provides information about the substances used and other information, like safety and instructions for proper use. Lists like this are important resources for information about substances people are exposed to.

Federal, provincial, and municipal levels of government in Canada are involved in the management of chemical substances. These substances may be used in consumer products, by industry, or in the maintenance of parks and recreation areas. Currently, federal legislation restricts the use of more than 1000 chemical compounds, with an additional 23 000 compounds that have been assessed for their impact on humans and the environment.

DID YOU KNOW?

To view the Toxic Substances List and to see how dangerous substances have been classified, visit the following website:

http://www.ec.gc.ca/CEPARegistry/subs_

Substances appearing on the Toxic Substances List have been organized using the following categories:

- Persistent Substances
- Bioaccumulative Substances
- Inherently Toxic to the Environment

Two additional categories in this database are used to identify health concerns for humans from exposure to substances. These categories are

- Greatest Potential for Exposure
  - indicates how often a substance is used and the possibility for exposure
- Inherently Toxic to Humans
  - substances known or suspected of having harmful effects on humans

DID YOU KNOW?

It is estimated that $300 million will be required to complete the research needed to update the Toxic Substances List.

Practice

33. Evaluate the categories used in the Toxic Substances List by indicating both good and bad points about the categories.

34. DDT is a substance on the Toxic Substances List and is not permitted for use in Canada. Use the Internet to identify the evidence used to place DDT on the list. Use this evidence to determine under which categories DDT would appear.

Utilizing Technology

Updating Canada's Toxic Substances List—Debate

Chemical technologies often result in the production of new chemical compounds. Over time, additional information about exposure to and the environmental effects of existing substances can be collected and evaluated. An update to the Toxic Substances List would involve the use of funds collected from taxes to allow for the required testing of new and existing substances.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Question

Should government funds be spent to update Canada's Toxic Substances List?

Procedure

step 1: Read each of the following articles from the Science 30 textbook CD:

- *List of Toxic Chemicals Tests Tories on Environment*
- *Gov't Targets Toxic Chemicals*
- *Scientists Call for Tougher Rules on Toxic Chemicals*

step 2: Identify which stakeholders are represented by the information presented in the articles. Identify other stakeholders who may be affected by this issue. These may include other levels of government, industry, agriculture, or the public. Use the Internet to collect information that represents the position of the other stakeholders about this topic.

step 3: Choose a debate position—either for or against—to the question stated.

step 4: If necessary, conduct additional research the aspects or impact of the Toxic Substances List. Determine how this information could be used to support your position in a debate.

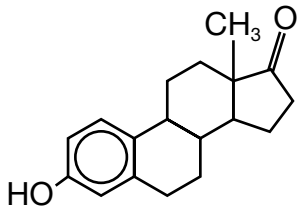
step 5: Use information collected during your research to state and defend your position in a debate on this issue.

Using Chemical Knowledge to Understand the Effect of Exposure

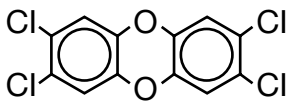
Substances can be added to the Toxic Substances List after they have been used in commercial products or chemical processes, provided that sufficient scientific evidence demonstrating harmful effects has been collected. Earlier in this unit you discovered that CFCs and benzene are examples of compounds that were restricted once evidence about their harmful effects on the environment and to humans had been demonstrated. Reasons for studying environmental chemistry include gaining a better understanding of chemical interactions in the environment and becoming better able to predict and prevent adverse effects from the chemical substances used by society.

One way to predict possible environmental effects is to group substances by similarities in chemical structure. You have already learned that a common problem associated with halogenated hydrocarbons and synthetic organic compounds containing benzene rings is their persistence in the environment.

Estrogen and Estrogen-Mimicking Compounds

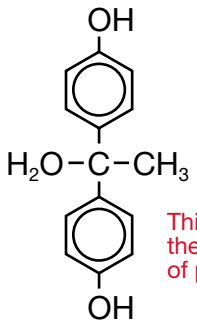


estrogen
(female sex hormone)



This dioxin is a by-product of processes where chlorine is used.

2,3,7,8-tetrachlorodibenzodioxin
(2,3,7,8-TCDD)



This is used in the manufacturing of plastics.

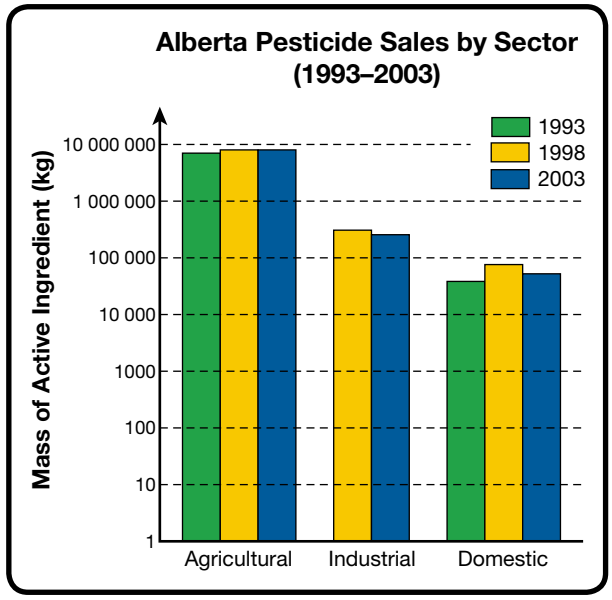
bisphenol-A

By-products of 2,4-D production can include chlorinated dioxin compounds. Although these compounds are found at levels that are barely detectable, chlorinated dioxins are associated with a number of adverse health effects in humans, such as decreased immune-system function, interference with hormonal systems, and linkages to some forms of cancer. Similarities between the chemical structure and shape of the female sex hormone estrogen and synthetic organic compounds, like dioxin, are believed to allow dioxins to stimulate cells in a manner similar to that of estrogen. Estrogen-mimicking compounds, like bisphenol-A (used in the manufacture of plastics), is suspected of influencing the development of sexual characteristics in males and females in various organisms. Synthetic organic compounds that influence the levels of sex hormones can effect reproductive cycles, fertility, and behaviour in a variety of organisms. These observations have increased interest focused on identifying and studying endocrine-disrupting compounds present in the environment.

When Does Exposure Happen?

You can reduce your exposure to organic chemicals in pesticides by wearing coveralls and gloves and following the procedures described for safe handling and use of the pesticide. Recall that the volatility and solubility of organic compounds results in their transfer into air and water.

All species are exposed to a variety of synthetic organic compounds in air, water, soil, and food. Many scientific studies have resulted from concerns about human health and focused on "how much" and "for how long." Some studies have demonstrated a connection between high levels of exposure or prolonged exposure and certain diseases. To maintain good health, humans have a responsibility to make wise decisions about materials they use and their effect on themselves and on the environment.



You have learned the importance of organic compounds in society. The use of pesticides—whether used in agriculture, industry, or your home—indicates that they are an important class of synthetic organic compounds. As the "Alberta Pesticide Sales by Sector (1993–2003)" graph indicates, pesticide use in Alberta has changed very little over the ten-year period. The pattern of use and reliance on pesticides by society results in continual exposure to these compounds.

Tests on samples of drinking water in Alberta found trace levels of pesticides in more than 25% of the water supplied by water-treatment facilities. Recall that estrogen-mimicking compounds can also be present in other sources of drinking water. The presence of these compounds in water sources demonstrates the inability of water-treatment processes to remove them. Acceptable levels for organic compounds, including pesticides in drinking water, have been established, and routine testing of source water and drinking water is important to minimize exposure. Routine sampling and testing can also be used to identify sources of pollution.

Exposure can be the result of practices people follow. What do you do with the clothes you wear after handling pesticides? Is it possible to be exposed to substances used in your yard or garden when you are inside your home? Whether working on the golf course or at home, you need to be conscious of the safety instructions provided with each product. These instructions were developed in accordance with the properties of the particular organic compounds.

Simple actions—like washing your hands and clothes—in addition to following safety precautions reduce exposure.

DID YOU KNOW?

Some pesticides and other organic compounds can be present on the foods you eat. Washing fruits and vegetables with water containing a mild detergent before use can help remove residues from some products.

Practice

35. Refer to the "Alberta Pesticides Sales by Sector (1993–2003)" graph on page 292.

a. Determine the mass of active ingredient of pesticides used by agriculture and domestic users in 2003.

b. Calculate the factor difference between the mass used by agriculture as compared to the mass for domestic use.

c. Comment on the labelling of the vertical axis for this graph.

Reducing Exposure—Actions Making a Difference

DID YOU KNOW?

Skin rashes can be a result of exposure to pesticides. Pesticides absorbed into the fabric of hats, coveralls, and other clothes concentrate over time and become a source of exposure when worn again.

One change people can make to reduce exposure to pesticides is to carefully consider not only the choice of products available, but why a pesticide is being used, and whether it is controlling the pest population. This may require consulting experts at garden centres or other knowledgeable people. Selecting the right product not only results in efficiently controlling pests, but has additional benefits, like minimizing the amount used, thereby reducing your personal exposure.

In your garden and flower beds, you may choose to control pests using alternative strategies. Selecting plants that demonstrate resistance to pests or selecting plants that require less chemicals to support their growth are two such strategies. Alternatively, routinely caring for plants by removing weeds and insect eggs as they appear can directly control many pests and reduce the need to use pesticides.

Integrated pest management is a comprehensive approach to controlling pests that involves all available strategies including

- using natural predators, parasites, and biological agents for controlling target pests
- using crop varieties resistant to pests
- carefully managing habitat using strategies like flooding or burning to deter the growth of pests
- carefully monitoring crop condition and number of pests
- using pesticides only when necessary

Canola farmers in Alberta might be quite familiar with the bertha armyworm. The larva of this insect is responsible for damage to canola and other crops. Adapting an integrated pest-management strategy to control bertha armyworms involves the practices listed in the "Controlling Bertha Armyworms" table.

CONTROLLING BERTHA ARMYWORMS

Practice	Effect on Bertha Armyworm
tilling (ploughing fields after harvest) and removing stubble from fields	• prevents accumulation of snow • exposes insect eggs to lower temperatures during winter • decreases protection for newly hatched larva
biological control strategies (e.g., introducing viruses and other insects)	• reduces bertha armyworm population by causing disease (virus) or weakening the organism (parasitic wasps)
planting alternative crops	• reduces available food for armyworms, thus reducing their population
using selective pesticides (if needed)	• kills insect population

It should be noted that the information about controlling bertha armyworms encourages farmers to evaluate the extent of infestation of their crops and its economic effect before spraying. As you have been encouraged to do throughout this course, identifying risks and benefits from ecological, economic, as well as other perspectives is an important part of decision making.

Science Links

Crops that produce the Bt toxin are examples of transgenic organisms. A process used to move genes from one organism into another and how genetic resistance can develop is explained in Unit A.

Some strategies for pest reduction focus on the use of naturally occurring compounds. The toxin produced by the soil bacteria *Bacillus thuringiensis* (Bt) can kill certain insect species. Since the toxin is harmless to humans, spraying the toxin on infested crops provides temporary control of some pests. To permit pest control during the entire life of corn and some other crop plants, the gene responsible for toxin production was used to produce genetically modified varieties of crop plants. As you might expect, resistance to Bt toxin has already begun to develop in some species of insects.

Practice

36. Explain why observation is an important aspect of pest-control strategies.

37. Identify which strategies listed at the top of the page could act to reduce the use of synthetic organic compounds in pest management.

38. Briefly explain a process by which a resistant insect population to Bt toxin could develop.

39. Match the practices used to control bertha armyworms to the strategies identified as part of integrated pest management.

Proper disposal of unused products and their containers, regardless of the quantity, can prevent the transfer of pesticides and other organic compounds into the soil and water sources. Many cities have special waste-handling facilities that permit the separation of materials containing persistent organic substances, like paint and pesticides. Taking the time to identify and transport materials to a handling facility prevents toxic materials from ending up in your household garbage where it might negatively affect the environment.

Figure B2.28: A waste-handling facility in Edmonton

Practice

Some roads are designated routes for the transport of dangerous goods.

40. Identify a roadway in your local area that is designated as a dangerous goods route. Use a map or describe the location of this route within your local area. List the risks and benefits with the route chosen.

Try This Activity

Current Opinions on the Use of 2,4-D

Background Information

2,4-D was first introduced as a herbicide in 1944. Although a great deal of testing and scientific data exists about its properties and behaviour in the environment, controversy exists over its use. Recently, the use of 2,4-D was brought into question and investigated by federal, provincial, and municipal governments in Canada.

Science Skills

- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Problem

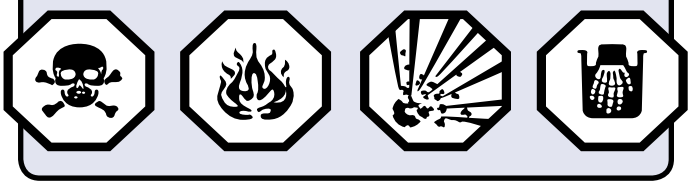
What is the current position of your local municipality regarding the use of herbicides containing 2,4-D? What scientific authority is used to support the decision regarding the level of use of 2,4-D by the municipality?

Procedure

Investigate the questions stated in the problem by accessing relevant and reliable sources of information that exist within and outside your community. Prepare a presentation that summarizes the results from your investigation and makes explicit reference to scientific data and the sources of information collected.

DID YOU KNOW?

Waste-handling facilities can accept containers of unidentified chemicals. Unknown and highly toxic materials may be transported to the Swan Hills Waste Treatment Centre for processing.



At the beginning of your study in this unit, you completed the "Detection Limits" activity. In this activity you considered how important it is to be able to detect chemicals present in the environment. Given what you have learned about the concerns regarding exposure to persistent organic compounds, the detection of chemical substances, even at low concentrations, is important for certain compounds.

Many environmental samples are analyzed using a gas chromatograph mass spectrometer (GCMS). In the next activity you will investigate how this device operates and how it is used by scientists studying the environmental impact of organic compounds.

Utilizing Technology

Detecting Organic Compounds Using a GCMS

Science Skills

✓ Analyzing and Interpreting

Background Information

Throughout this unit, you have become aware that many of the substances in air, water, soil, and animal tissues may be present in very small concentrations. The gas chromatograph mass spectrometer (GCMS) is an important apparatus used in the study of environmental science. This device detects and identifies substances present in quantities as low as a picogram.

Purpose

You will analyze data collected using a GCMS and determine if bioremediation of a crude oil component has occurred.

Procedure

step 1: Obtain the handouts "GCMS—Diagram" and "GCMS—Data" from the Science 30 Textbook CD.

step 2: Use the Internet to find a diagram or animation of the parts of a GCMS and their functions.

step 3: Label the parts of the GCMS and their functions on your copy of the diagram.

step 4: View the applet "Using the GCMS and Bioremediation" from the Science 30 Textbook CD.

Analysis

1. Compare the mass of 1 pg (picogram) to 1 mg.
2. Use the diagram of the GCMS to identify where the separation of compounds occurs.
3. Explain how the GCMS provides information on the quantity of each compound in a sample.
4. Refer to the "GCMS—Data" handout. Did the bacterial culture in the flask affect the dibenzothiophene present in the sample? Explain how you used the GCMS spectra to support your answer.

DID YOU KNOW?

The detection of caffeine in surface water samples is an indicator of pollution from human sewage. The water qualities of popular lakes are often monitored for caffeine and other indicators of pollution from human sources.

POPs in the Arctic

In this chapter you learned about mechanisms like the grasshopper effect and the polar vortex that have drawn molecules identified as persistent organic pollutants (POPs) toward the Arctic. Given the climate, the potential for the breakdown of these molecules by bioremediation is very low. Scientists examining the tissues of organisms in arctic food chains have identified bioaccumulation of persistent compounds. In addition to the work done by scientists, observations made by the Inuit, including changes to the numbers of offspring and breeding behaviours of animals, suggest that something present in the environment might be having an effect. The contributions of the traditional ecological knowledge of the Inuit and the data collected by scientists may provide an opportunity for a deeper understanding of the changes occurring.

Utilizing Technology

Investigating the Effects of POPs in the Arctic

Background Information

Observing how the issue of climate change is being addressed by the Inuit community and scientists provides an opportunity to determine how other environmental issues could be studied in a way that involves the communities affected. At the end of this activity, you should be able to

- describe information that could be classified as traditional ecological knowledge
- explain how the consideration of traditional ecological knowledge could contribute to greater scientific understanding

Purpose

You will write a research proposal that describes how you would investigate the impact of persistent organic pollutants in the arctic ecosystem.

Preparation

You may find that as you watch the video, important information appears quickly. Before you watch the video, think of strategies you may need to use so you can identify, extract, and, if necessary, go back and find important information. Before you view the video, read the Analysis questions. Prepare a table to record information as you view the video.

Procedure

View the video "Sila Alangotok—Inuit Observations on Climate Change" from the Science 30 Textbook CD. View the video once in its entirety; then, review specific sections as needed. Use the information from the video to answer the Analysis questions.

Analysis

1. Prepare a list of several changes to the environment that have been observed by the residents of Banks Island.
2. What research question were the scientists investigating?
3. Why did the scientists ask the people of Banks Island to describe their observations?
4. Using examples, describe how the observations of the residents of Banks Island demonstrate a holistic view of ecosystems.
5. Are the residents of Banks Island asked to express opinions or describe observations? Support your answer.

Science Skills

- ✓ Initiating and Planning
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

6. Do you feel the contribution of the residents of Banks Island is being respected? Support your answer.
7. Review the parts of a scientific study.

   Parts of a Scientific Study

   (1) collection of background information
   (2) development of a hypothesis
   (3) development of a problem statement
   (4) development of a design for experimental work
   (5) collection of data
   (6) analysis of data
   (7) interpretation of data
   (8) sharing of conclusions

   Identify the parts of a scientific study where the contribution of traditional ecological knowledge may benefit the scientific process. Provide support for your answers.
8. How does the oral tradition of First Nations impact the ability to access traditional ecological knowledge?
9. Describe possible benefits that could come from consulting Aboriginal populations in this study or in other studies.
10. Describe possible risks that could come from consulting Aboriginal populations in this study or in other studies.
11. Identify the main concern about climate change expressed by the residents of Banks Island.

Communication and Teamwork

12. Write a research proposal that describes how you would investigate the impact of persistent organic compounds in the arctic ecosystem. In your proposal, accurately define what you wish to study and how you intend to study it. List and justify the experiments and other investigations you intend to carry out. Indicate the equipment necessary for your study and explain why it must be used. If possible, justify the use of traditional ecological knowledge by describing how you will collect this type of data and why this type of information would be useful to the goals of your study.

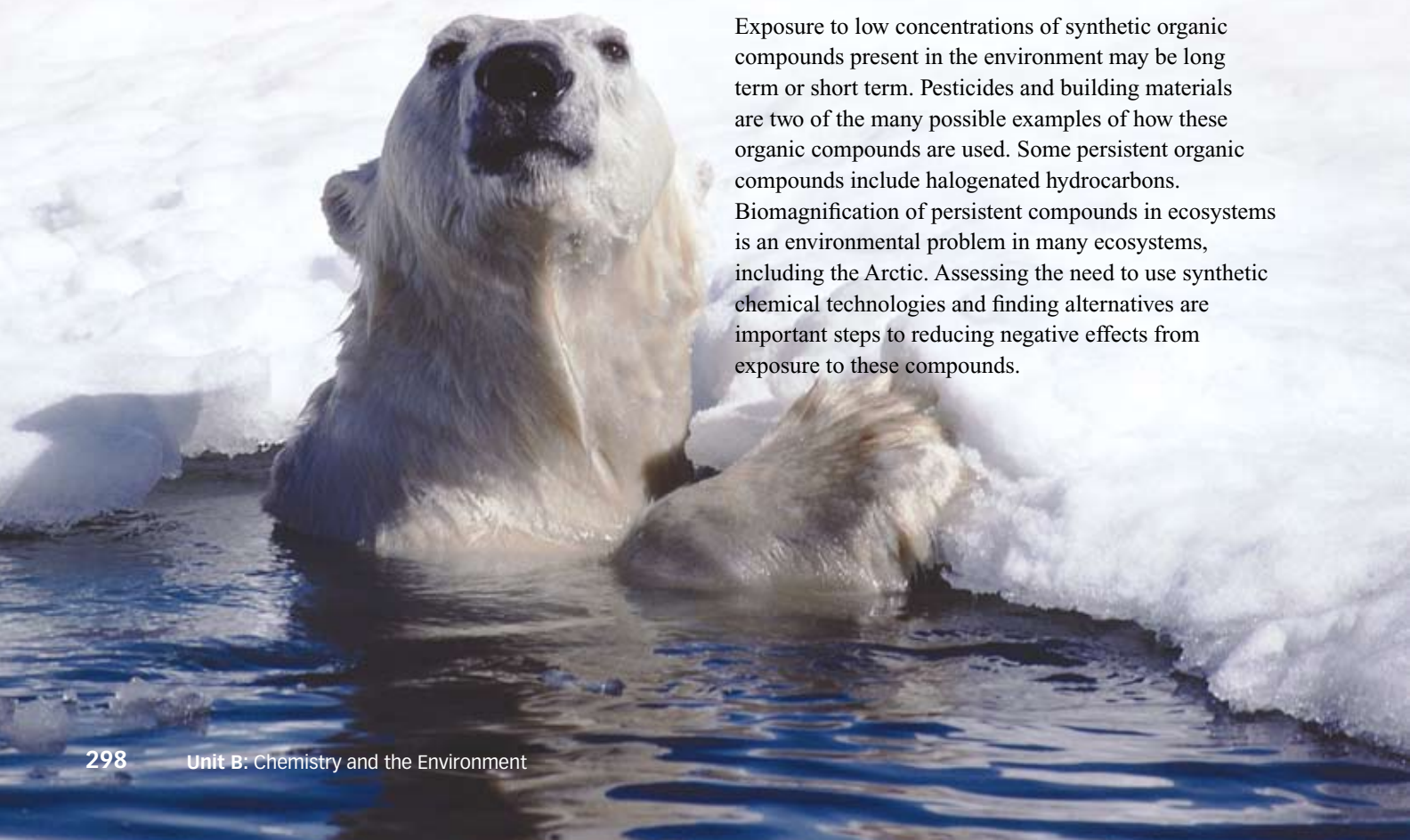
The Dirty Dozen

The "dirty dozen" are twelve persistent organic pollutants (POPs) that were identified by the Stockholm Convention—the first international agreement on POPs held in 2001. Due to the polar vortex, many of the substances in the "dirty dozen" have migrated from lower latitudes to the Arctic and have been detected within arctic food chains.

THE DIRTY DOZEN

Chemical Substance	Purpose
Aldrin	pesticide
Endrin	pesticide
Dieldrin	pesticide
hexachlorobenzene (HCH)	pesticide
Chlordane	pesticide
Heptachlor	pesticide
Mirex	pesticide
Toxaphene	pesticide
DDT	pesticide
PCBs	industrial processes
Dioxins	industrial processes
Furans	industrial processes

2.3 Summary



Exposure to low concentrations of synthetic organic compounds present in the environment may be long term or short term. Pesticides and building materials are two of the many possible examples of how these organic compounds are used. Some persistent organic compounds include halogenated hydrocarbons. Biomagnification of persistent compounds in ecosystems is an environmental problem in many ecosystems, including the Arctic. Assessing the need to use synthetic chemical technologies and finding alternatives are important steps to reducing negative effects from exposure to these compounds.

2.3 Questions

Knowledge

1. State one type of substance released during off-gassing.
2. Define *toxicity*.
3. Describe a benefit of having data from LD_{50} or LC_{50} tests.
4. List a source and two health effects that result from exposure to dioxins.
5. Identify the group of organic molecules to which dioxins and furans belong.

Applying Concepts

6. Explain the rationale for testing the LD_{50} for a pesticide in many organisms that form a food chain within an ecosystem.
7. Write the chemical structures that correspond to the red, blue, and green parts of the systematic name for the herbicide 2,4-D.

   2,4-dichlorophenoxyethanoic acid

8. Predict the effect the following weather conditions would have on the concentration of a pesticide in air, surface water, and soil in the area in which it is sprayed.
   a. a rain shower that occurs within an hour after spraying the pesticide
   b. spraying occurs on a hot day
9. Explain, in terms of reducing personal exposure to pesticides, why it is important to consult with local experts before use and to observe the effect of a pesticide after its use.
10. Review the principles of organic farming practices.

    Principles of Organic Farming Practice

    - Protect the environment, minimize soil degradation and erosion, decrease pollution, optimize biological productivity, and promote a sound state of health.
    - Maintain long-term soil fertility by optimizing conditions for biological activity within the soil.
    - Maintain biological diversity within the system.
    - Provide attentive care that promotes the health and meets the behavioural needs of livestock.
    - Prepare organic products, emphasizing careful processing and handling methods in order to maintain the organic integrity and vital qualities of the products at all stages of production.

    Identify how the use of synthetic compounds as pesticides or as fertilizers is not consistent with the practices listed.

11. Explain a situation in which you would choose to use chemical pesticides as part of an integrated pest-management strategy.
12. Describe how the development of a Bt genetically modified crop plant may lead to the development of insect populations resistant to the Bt toxin.

Chapter 2 Summary

In this chapter you studied different classes of organic compounds, including their use and impact on the environment. You identified and named halogenated hydrocarbons, alcohols, carboxylic acids, and ester compounds. You also examined the structure and properties of benzene rings and the importance of aromatic and polycyclic aromatic compounds.

Organic molecules were developed for many purposes. Throughout the chapter you were introduced to the uses of different types of organic molecules and, in some cases, their unexpected effects. Some by-products of organic reactions, including dioxins and furans, are examples of harmful persistent organic compounds that can cause mutations and even cancer.

Exposure to pesticides and other substances can have negative health effects; but actions taken by individuals and by society can reduce the presence of these substances in the environment. You also examined techniques for conducting studies and you became aware of the importance that detecting organic compounds in the environment has in studying their effects.

Summarize Your Learning

In this chapter you covered a number of chemical terms, types of organic compounds, chemical reactions, and a great deal about the impact that the development and use of chemical compounds has had on the environment. You may have collected news articles about chemical issues and the environment. You will have a much easier time recalling the application of the information you learned if you take some time to organize it into a pattern. Now that you have come to the end of this chapter, this is an appropriate time to focus on the patterns in the things you have learned.

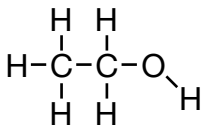
Since the pattern has to be in a meaningful form to you, there are some options about how you can create this summary. Each of the following options is described in "Summarize Your Learning Activities" in the Reference Section.

Option 1: Draw a concept map or a web diagram.	**Option 2:** Create a point-form summary.	**Option 3:** Write a story using key terms and concepts.	**Option 4:** Create a colourful poster.	**Option 5:** Build a model.	**Option 6:** Write a script for a skit (a mock news report).

Chapter 2 Review Questions

Knowledge

1. State the suffix used when naming organic compounds with each of the following functional groups: hydroxyl, carboxyl, and ester.
2. State the reactants necessary to synthesize an ester.
3. Match each name with the chemical structures given.

I.


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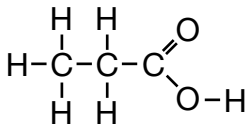

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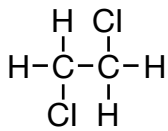

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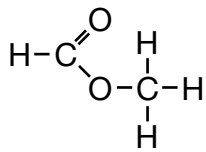
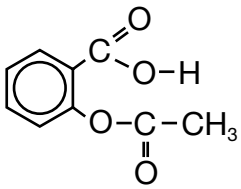


   a. 1,2-dichloroethane
   b. methyl methanoate
   c. ethanol
   d. propanoic acid

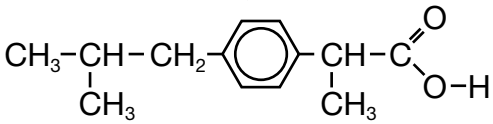
4. Use the list of chemical structures to identify parts of each molecule given. **Hint:** More than one structure may be identified in each molecule.

   Chemical Structures
   - **i.** benzene ring
   - **ii.** hydroxyl functional group
   - **iii.** carboxyl functional group
   - **iv.** ester functional group
   - **v.** halogen atom

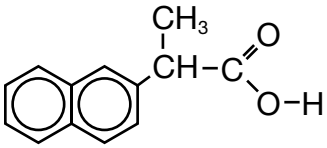
   a. **Acetylsalicylic Acid (ASA)**
   (anti-inflammatory drug)



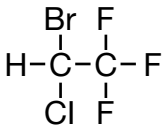
   b. **Ibuprofen**
   (anti-inflammatory drug)



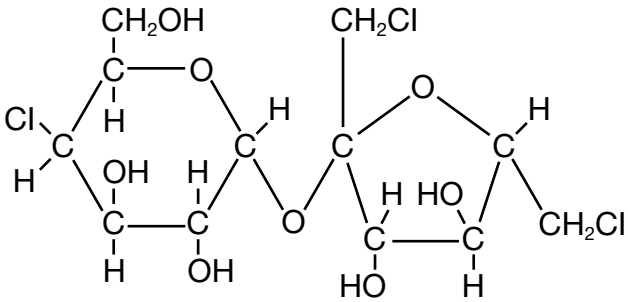
   c. **Naproxen**
   (anti-inflammatory drug)



   d. **Halothane**
   (anaesthetic gas)



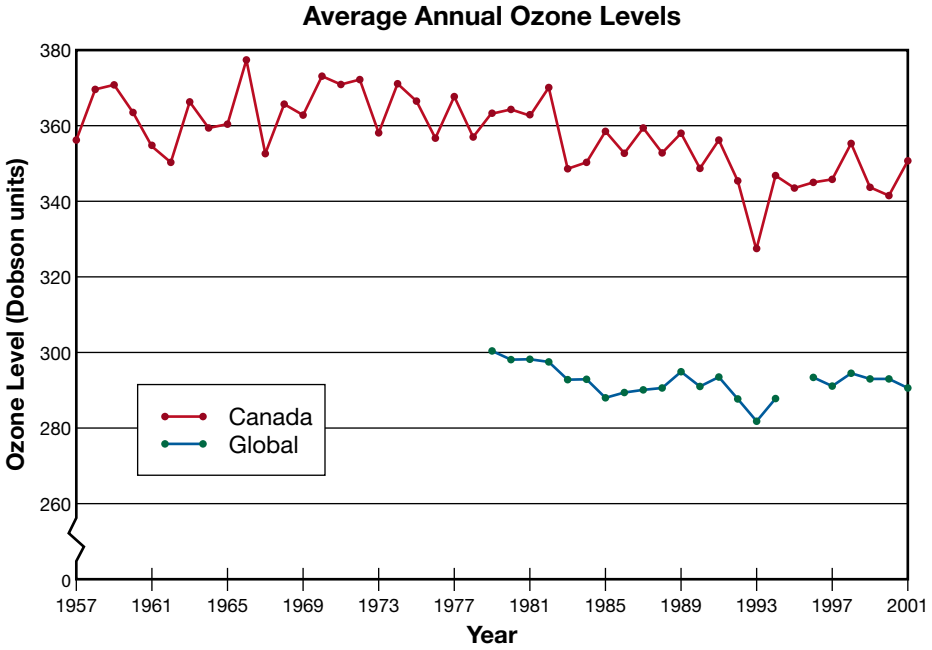
   e. **Sucralose**
   (artificial sweetener)



5. State a technology or application for each type of organic compound given.
   a. halogenated hydrocarbon
   b. alcohol
   c. carboxylic acid
   d. ester
6. Define *persistence*. State two examples of organic compounds considered to be persistent substances.

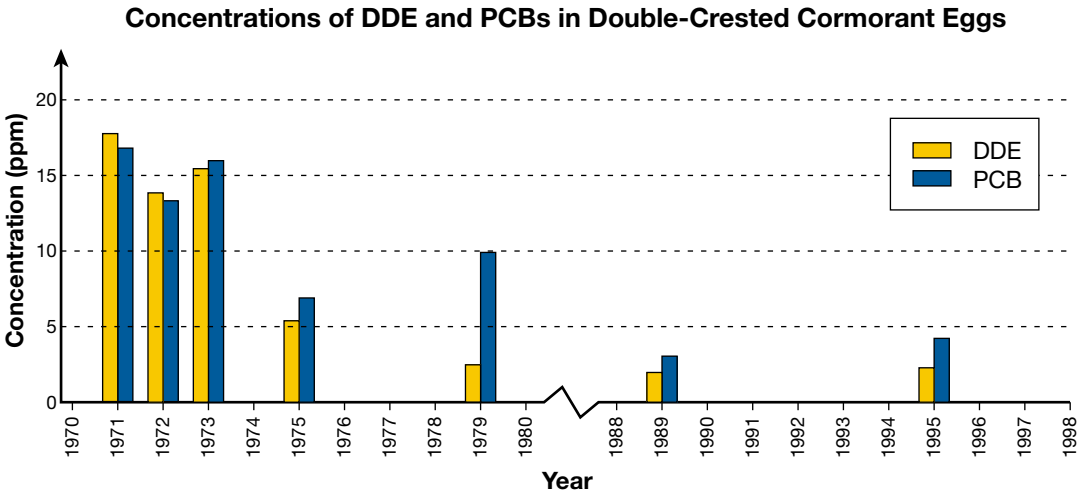
Applying Concepts

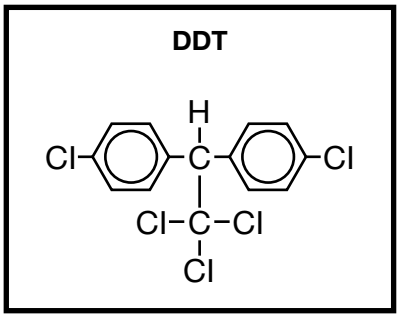
7. List similarities and differences between the hydroxyl, carboxylic acid, and ester functional groups.
8. Describe the effect that the leaching of fertilizers used in agriculture can have on a body of water.
9. List some products that contain volatile organic compounds (VOCs). Explain how exposures to VOCs occur in outdoor and indoor settings. State health risks associated with VOCs.
10. Explain how bioremediation can be used to remove organic compounds from soil and water.
11. List some water-borne diseases. Describe processes that can reduce the incidence of water-borne diseases.
12. Define *BOD*. What does a water sample with a high BOD indicate? Explain why surface water with a high BOD is undesirable.
13. Why do chlorinated hydrocarbons remain in the soil and water for such a long time?
14. List the advantages and disadvantages of using chemical pesticides.
15. Use the following graph to answer questions 15.a. to 15.d.

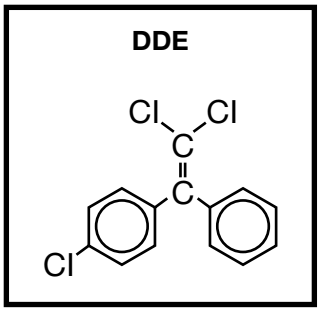


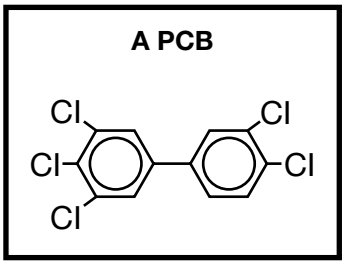
   a. Determine the year in which the largest drop in stratospheric ozone occurs.
   b. Explain why stratospheric ozone concentration is not expected to increase in the near future.
   c. List the consequences of ozone depletion.
   d. Identify regions of Earth where ozone depletion is greatest. Explain why some regions of Earth experience greater ozone depletion than others.

16. A long-term study investigating synthetic organic compounds in the environment was conducted using the eggs of cormorants, a fish-eating bird, in an area surrounding a major lake. The concentration of DDE (the main breakdown product of the pesticide DDT) and PCBs are shown in the following graph.









a. Identify parts of the chemical structure of DDT and PCBs that suggest that these compounds might be persistent in the environment.

b. DDE present in organisms comes from the body's action to absorb DDT. DDE has been shown to have toxic effects on the immune and nervous systems and the thickness of eggshells in birds. Evaluate this information, and justify whether it is appropriate to show DDE concentrations on the graph and to use these levels to make conclusions about the presence of DDT in the environment.

c. Explain how the data shown in the graph demonstrate that DDT—an insecticide banned in Canada since 1974—and PCBs—industrial chemicals that have been highly restricted since 1977—are persistent organic compounds.

d. Describe sources of persistent organic pollutants in the environment.

Unit B Conclusion

Human activity has made an impact on the environment. In this unit you learned about the impact of many important parts of Alberta's economy, including electricity generation, oil and natural gas production, agriculture, and the production and use of consumer products involving organic compounds. You also examined the processes involved in the production of acid deposition, ground-level ozone, volatile organic compounds, and persistent organic pollutants. From your study, you should be able to identify concerns associated with the presence of these substances in the environment and with the technologies and changes that serve to reduce their production.

Exposure to certain chemical compounds can have negative effects on human health, causing mutations to DNA—a topic developed in Unit A. Radiation, described in Unit C, that reaches Earth's surface due to damage to the ozone layer as a result of the release of chlorofluorocarbons can also cause mutations.

Studying the environmental effects caused by substances released into the environment is essential to preventing further harm in the future.

Career Profile

Executive—Oil and Gas Resource Development

"Since we are made from the same source and elements, humans should feel a greater connection to the environment," states Elmer Ghostkeeper. Wisdom, defined by Elmer, is the combination of the experience, knowledge, spirit, mind, and emotion a human being can serve as a guide when considering activities that might effect the environment.

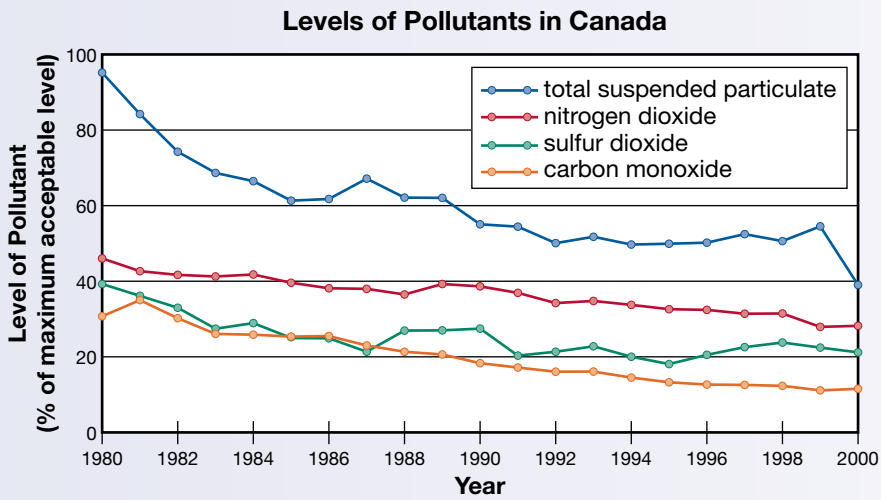
As president of Métis Moccasin Resources Inc.—a majority Métis-owned oil and natural gas company—Elmer urges the use of practices that attempt to minimize negative environmental impacts to the parts of the ecosystem we can see and to those parts that we cannot see. Consideration of possible "invisible" effects includes changes to the composition of soil, air, and water. Practices that result in the pollution of "air, water, and soil demonstrate disrespect for the environment and ourselves," states Elmer when referring to many current practices that reduce environmental quality and the need humans have for fresh air and water.

Making connections has been an important part of Elmer's life. As Regional Manager for Aboriginal Health Services for the Capital Health Aboriginal Wellness program, he helped patients connect and partner Aboriginal healing practices with the use of insulin. For Elmer, connections also played an important role in his learning, proudly stating that he still keeps in touch with his grade 7 and 8 teacher. As a learner, Elmer feels that interactions with fellow students and teachers build knowledge and provide the opportunity for additional experiences that attach additional meaning to knowledge, which develops wisdom.

As an instructor of anthropology at Portage College in Lac La Biche, Elmer encourages his students to think about the benefit of what they are being asked to learn. This often requires them to consider how the material is connected to other knowledge and how thinking about connections serves to develop a greater level of understanding. In his published works, Elmer has demonstrated how Aboriginal wisdom and Western scientific knowledge can connect to form a partnership that will benefit both cultures. Elmer has a passion for learning and is planning to further his research into the greater significance of water to other Aboriginal and world cultures.

Unit B Review Questions

1. Distinguish between the terms *acid deposition* and *acid rain*.
2. In general terms, describe the stages of change that occur within a body of water that has been exposed to acid deposition over a long period of time.
3. Use the following graph to answer questions 3.a. to 3.d.



   a. State possible sources for each air pollutant shown.
   b. Describe the environmental impact or the effect on human health that results from each pollutant shown.
   c. State one technology used to reduce the level of each pollutant shown.
   d. The graph shows an overall reduction in emissions for all substances in Canada. Suggest reasons why Alberta may not follow this trend.
4. Identify some contaminants that can affect the quality of surface water, and state the source of each contaminant identified.
5. Buffering and bioremediation are examples of processes that minimize negative impacts on ecosystems.
   a. Identify the substances that each process acts upon to minimize environmental impact.
   b. Explain how buffering and bioremediation act to minimize the negative impact on an ecosystem.
   c. Identify situations where these processes are unable to minimize negative environmental effects.
6. List some chemical impurities present in rainwater. Describe the effect that these impurities can have on the properties of rainwater.
7. List the empirical properties of acidic, basic, and neutral solutions.
8. Explain the behaviour of acids and bases during a chemical reaction.
9. List two ways a body of water can become acidic.
10. Why is water that is exposed to acid deposition especially toxic to fish?
11. Electrostatic precipitators, scrubbers, and increasing the efficiency of processes are examples of technologies used to reduce acid deposition. Describe how each of these technologies acts to decrease emissions that cause acid deposition.
12. Identify the chemical component present in rock that neutralizes acid deposition. State the name of the mineral present in rocks that reacts with the acidic components of wet or dry deposition.
13. Use a balanced chemical equation to demonstrate the neutralization of a hydronium ion, $H_3O^+(aq)$, by the component identified in question 12.

14. Describe an experiment in which three acid-base indicators are used to confirm that the pH of a sample of rainwater is between 5.5 and 6.0. State possible indicators and expected results from the test.

15. Explain the relationship between a solution's pH and the hydronium-ion concentration within the solution.

16. Explain how liming can restore the pH of a lake that has become acidified.

17. Describe an experiment that could be performed that will approximate the amount of liming compound needed to restore the pH of a lake.

18. Justify the need for performing the experiment described in question 17 by indicating the consequences if too little or too much liming compound is used.

19. Complete the following table.

$[H_3O^+(aq)]$ (mol/L)	pH	Acidic, Basic, or Neutral
1.00×10^{-5}		
	8.23	
2.5×10^{-11}		
	2.250	

20. A sample of industrial effluent was titrated against 0.0500-mol/L NaOH(aq). Calculate the molar concentration of hydronium ions in a 10.0-mL sample of effluent if 27.3 mL of NaOH(aq) were required to complete the titration.

21. Describe the similarities and differences between strong and weak acids.

22. Use the following information to answer questions 22.a. to 22.c.

LD_{50} VALUES FOR SOME SYNTHETIC ORGANIC COMPOUNDS

Substance	LD_{50} for Rats (mg/kg)
TCDD (a dioxin)	0.01
Aldicarb (insecticide)	0.8
strychnine (rodenticide)	30
2,4-D (herbicide)	370

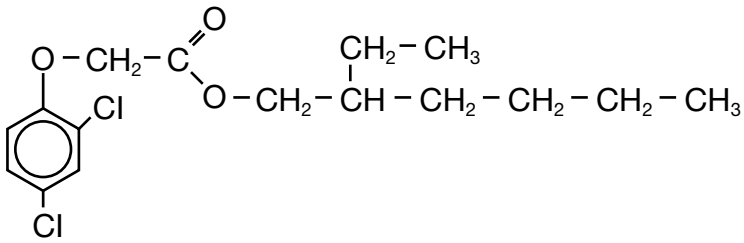
a. Rank the substances from most toxic to rats to least toxic to rats.

b. Explain the significance of the position of strychnine, a substance found in rat poison, in your ranking.

c. Suggest a reason why other compounds in the list are not used as rat poison.

23. Write the chemical structures that correspond to the coloured parts of the systematic name for the herbicide mcPA, 2-methyl-4-**chloro**phen**oxy**ethan**oic acid**

24.



The chemical structure given is often referred to as an ester of 2,4-D.

a. Circle the ester functional group in the molecule.

b. Identify the part of the molecule that corresponds to the alcohol used in the synthesis of this compound.

25. Explain how dumping sewage into a river increases the BOD (biochemical or biological oxygen demand) of the river water. Identify negative consequences that arise from dumping sewage into surface water.

26. Eutrophication—the stimulation of the growth of algae by nutrients in a body of water—can be a problem in some lakes.

a. Identify the nutrients most likely to stimulate the growth of algae.

b. Identify sources for these nutrients that come from agriculture or other human activities.

c. Describe a negative consequence of eutrophication.

d. Describe an experiment, or series of experiments, that could be used to collect data to demonstrate that eutrophication is occurring in a body of water. In your description, indicate tests that could be performed and the type of data that would need to be collected.

27. Identify substances that are by-products of processes that use chlorine. Describe the general attributes and properties of these by-products with respect to their behaviour in the environment.

28. Photochemical reactions can have significant effects on the environment.

a. Define *photochemical reactio*n.

b. Identify **two** examples of photochemical reactions. State the effect that light has in the reaction and the consequence of each reaction to the atmosphere.

c. Identify a component of solar radiation that can be involved in a photochemical reaction.

29. Explain the chemical term *radical*. In general terms, describe **two** examples of chemical reactions that involve radicals. **Note:** Chemical reactions are not necessary.

30. State some risks associated with using underground tanks for storing gasoline and other hydrocarbons.

31. Define *VOC* and *POP*.

32. List technologies that can be used to reduce the presence of VOCs and POPs in consumer products and in the environment.

33. Ozone is a significant substance in the atmosphere.

a. Indicate the atmospheric layer in which ground-level ozone and the ozone layer can be found.

b. Identify sources of ground-level ozone.

c. Explain how the location of ozone in the atmosphere can influence its interpretation as good or bad.

34. Identify major sources of hydrocarbons in polluted air.

35. Explain the rationale behind reducing sulfur in gasoline and diesel fuel.