CHAPTER 4

Nature's Recycling Programs

Chapter Preview

Take a deep breath, and then exhale onto your hand. The breath you exhaled contains carbon in the form of carbon dioxide. The carbon you exhaled could be the same carbon that was exhaled 70 million years ago by a *Tyrannosaurus rex*, a carnivorous dinosaur. Look at the geological features in the limestone caves pictured here. Limestone is composed of calcium carbonate, a compound made of calcium, carbon, and oxygen. These caves provide an abiotic storage form for carbon.

Unlike energy's one-way flow through an ecosystem, matter flows in cycles. Energy in an ecosystem needs to be constantly replenished by the Sun, but the amount of matter in an ecosystem is limited. The chemicals that make up organisms are continuously broken into different forms, and then synthesized again into new compounds. The elements go through a cycle where compounds change from one form to another, and finally back to the original elements again. The elements can make up complex compounds in living things or salts in the ocean. In this chapter, you will learn about the cycling of matter between the biotic and abiotic components of ecosystems.

KEY IDEAS

- **Matter is classified as organic or inorganic.**
- **Nutrients cycle between biotic and abiotic components of ecosystems.**

TRY THIS: *Transpiration in Plants*

Skills Focus: observing, measuring, recording

Plants absorb water from the soil through their roots. In this activity, you will observe how plants are part of the water cycle.

Materials: balance, clear sandwich bags with twist ties, live trees or shrubs

1. Label two sandwich bags A and B. Determine and record the mass of each bag.
2. Place one bag around a leaf or group of leaves of a deciduous tree or shrub. Place the second bag around part of a branch of a coniferous tree or shrub. Use the twist ties to tie off the open end of the bags.
3. Remove the bags after 24 h. Take care not to spill any of the contents.
4. Measure and record the mass of the bags.

A. Was there a difference in the amount of water collected in the two bags?
Which bag collected the most water?

B. Suggest reasons for this difference.

C. If you had not collected the bags, what would normally happen to the water?

4.1 Cycling of Organic and Inorganic Matter

Since its formation, Earth has contained most of the matter it will ever have. The only new matter would come from meteorites that strike Earth's surface. The dynamic nature of life on Earth depends on how this matter is used and recycled between the abiotic and biotic components of the environment. To understand how matter cycles through ecosystems, you must first know the difference between organic and inorganic matter (Figure 1). **Organic** matter consists of compounds that always contain the elements carbon and hydrogen, although other elements may also be present. They are found in living organisms or the fossils of once living things. Carbohydrates, such as sugar, are examples of organic molecules. They contain carbon, hydrogen, and oxygen.

Inorganic matter describes matter that is not of biological origin; it may or may not contain carbon, and is often of mineral origin. Water and salts are examples of inorganic compounds. Although carbon dioxide contains carbon, it is classified as an inorganic compound because it does not contain hydrogen. You will learn more about the composition of these compounds in Unit B. Table 1 lists some common organic and inorganic compounds.

Table 1 Some Common Organic and Inorganic Compounds

Organic compounds	Inorganic compounds
carbohydrates	water
proteins	salts
nucleic acids (e.g., DNA)	ammonia
lipids	oxides

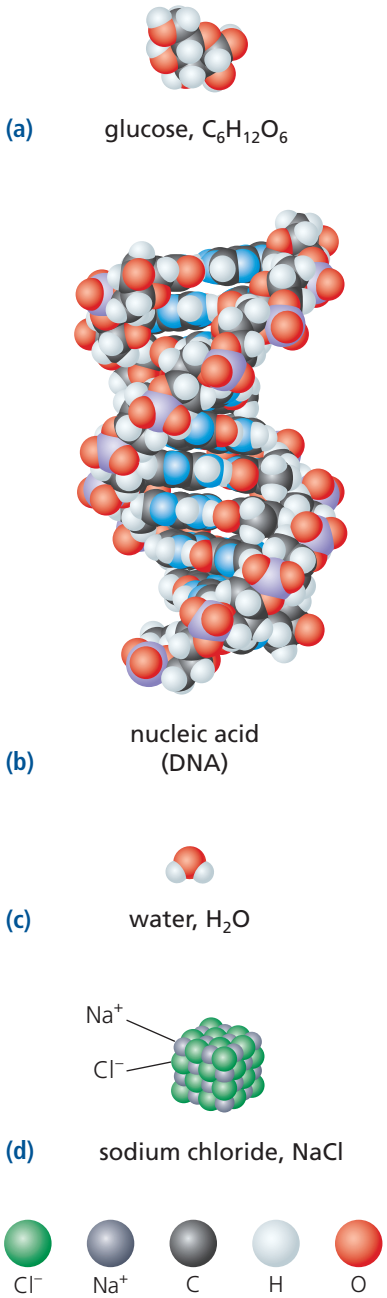

Figure 1 (a) and (b) are organic compounds, and (c) and (d) are inorganic compounds. How can you tell the difference?

Photosynthesis and Cellular Respiration

Probably the most important chemical processes on Earth are photosynthesis and cellular respiration. They are the basis for most life on Earth. **Photosynthesis** occurs when plants use the Sun's energy to convert carbon dioxide and water into carbohydrates and oxygen. The carbohydrates are used by plants to form their structures and to produce the energy required for cellular functions.

Photosynthesis makes the Sun's energy available to other organisms when these organisms consume the plant's carbohydrates as an energy source to carry out cellular respiration in their own bodies. **Cellular respiration** is the reaction between carbohydrates and oxygen that produces energy, carbon dioxide, and water. You will learn more about these two processes in the next section.

TRY THIS: *Priestley's First Experiment*

Skills Focus: observing, concluding, communicating

Joseph Priestley was an 18th-century scientist who performed experiments revealing some relationships between plants and animals. In this activity you will repeat Priestley's first experiment.

Materials: 2 safety candles in holders, matches or barbecue lighter, 2 bell jars or wide-mouthed jars, 1 mint plant, safety goggles, 1 stopwatch or a clock with a second hand

Be careful around flames. Tie back long hair. Remove loose jackets. Wear goggles. Place bell jars over flames quickly. Do not drop the bell jars.

1. Put on safety goggles. Work with a partner and light both candles. Be sure they are both secure in their holders.
2. Place the plant beside one candle.
3. Place one bell jar over the candle flame and the second jar over the candle flame and mint plant. Start the stopwatch.
4. Stop the stopwatch when the first candle flame goes out. Note the time and then start it again. Stop the stopwatch when the second candle flame goes out.

A. Which candle burned the longest?

B. What caused the candle flames to go out?

C. Which gas was used up in the burning?

D. Which gas was produced by the burning?

E. Explain why one candle burned longer than the other.

Priestley's Second Experiment

Priestley performed a second experiment using plants and mice. He created three sealed environments: one with a single mint plant; one with only a mouse; and one with a mint plant and a live mouse (Figure 2). You may have already predicted his results. After some time the plant by itself wilted. Both mice eventually died, but the one in the jar with the plant lived longer. Based on the experiments of Priestley and other scientists, it was soon discovered that plants used carbon dioxide and water to make carbohydrates and oxygen and that animals needed the oxygen the plants produced to survive.

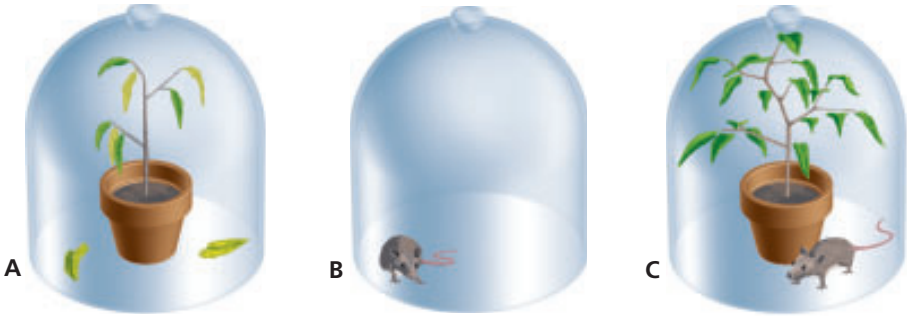

Figure 2 Priestley's second experiment. Why do you think the mouse in the jar labelled C lived longer?

LEARNING TIP
Check your understanding. Work with a partner to answer the question raised in Figure 2.

Carbon and oxygen are just two of the many nutrients required by living things. Recall that nutrients are the elements and compounds that organisms must have in order to grow and live.

4.1 CHECK YOUR Understanding

1. (a) Explain the difference between organic and inorganic compounds.
   (b) Give two examples of each.
2. Why is carbon dioxide not an organic compound?
3. Which of the following elements are contained in carbohydrates?

I	carbon
II	oxygen
III	hydrogen
IV	nitrogen

   A. I only
   B. I and II only
   C. I, II, and III only
   D. I, II, and IV only
4. Identify the following compounds as organic or inorganic:
   (a) NaCl
   (b) $C_6H_{12}O_6$
   (c) CH_4
   (d) NH_3
5. (a) Name the process that uses the Sun's energy to produce carbohydrates.
   (b) Name the process that produces energy from carbohydrates.
   (c) Explain why these two chemical processes are considered to be the most important for life on Earth.
6. (a) In Priestley's second experiment, suggest why the mint plants wilted.
   (b) Why did the mouse placed in the jar with the plant survive longer than the mouse placed in the jar by itself?
7. Using what you know about photosynthesis and cellular respiration, explain the observations in each step of Priestley's experiments. Look back to page 84 for a reminder of the experiments.
8. Name four nutrients necessary for life.
9. The fossils in Figure 3 have been preserved for millions of years. Are they examples of organic or inorganic matter? Explain your answer.

Figure 3

10. Complete the following:
    (a) carbon dioxide + water → carbohydrate + _____
    (b) $C_6H_{12}O_6 + O_2 \rightarrow$ _____ + water
    (c) The chemical reaction in (a) is called _____.
    (d) The chemical reaction in (b) is called _____.

4.2 The Carbon Cycle

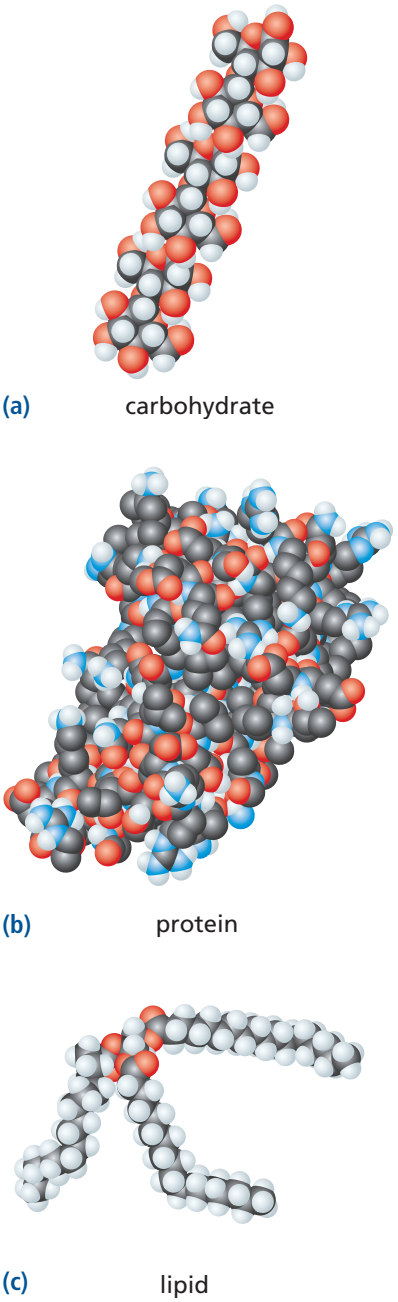

Figure 1
Important organic compounds found in food include (a) carbohydrates, (b) proteins, and (c) lipids.

Carbon is important in ecosystems because it is the key element in all living organisms. Carbon compounds are the basis for most biological molecules. The food you eat contains carbon (Figure 1). Carbohydrates are carbon compounds that organisms consume to gain useable energy. Proteins are carbon molecules that form structural parts of organisms and control body functions. Lipids also contain carbon; they serve as a long-term storage of energy and provide insulation against heat loss. Through the process of digestion, these complex organic compounds are broken down into simpler molecules that your cells use to build other complex molecules that become part of your own structure.

Sources of Carbon

Carbon is found not only in the atmosphere but also in the ocean, in Earth's crust, and in all living things. **Carbon reservoirs**, such as oceans, forests, and fossil fuels, store and release carbon slowly. Reservoirs that absorb more carbon than they release are called **carbon sinks**. These include forests and oceans. Oceans store carbon in two forms. Some of the carbon dioxide from the atmosphere becomes dissolved in the water, where it is used by aquatic producers in photosynthesis. Some carbon dioxide reacts with salt water to form calcium carbonate ($CaCO_3$) that is used to make the shells and other hard structures in marine organisms such as molluscs and corals. When these organisms die, the calcium carbonate making up their skeletons becomes part of the ocean sediments that will eventually become limestone. The limestone caves shown in the chapter preview are carbon sinks. The carbon stored here is released very slowly by weathering and erosion. The bodies of living things, trees in particular, provide a large reserve of carbon. The old growth forests in British Columbia contain trees that are hundreds of years old. As they grow, each tree converts atmospheric carbon into carbohydrates, which become a significant carbon sink. Cutting down trees does not release the carbon, but it does prevent the trees from storing any more carbon. When trees are burned, carbon is then released back to the atmosphere. Many photosynthetic organisms die and are buried before they fully decompose. These organisms can become fossils that may be compressed to form **fossil fuels** such as coal, oil, and gas. These fossil fuels are an important reservoir of carbon; however, they become a **carbon source** when, during the burning of fossil fuels, more carbon is released than is stored.

The cycling of carbon through ecosystems is called the **carbon cycle**, illustrated in Figure 2. Photosynthesis and cellular respiration are responsible for most of the carbon recycling. Each year, approximately 70 billion tonnes of carbon from inorganic compounds are recycled into organic compounds through the process of photosynthesis. The processes of

photosynthesis and cellular respiration complement each other. The products of photosynthesis are used as the reactants in cellular respiration. This ensures a balance of oxygen and carbon dioxide within the biosphere.

Photosynthesis occurs in the chloroplasts of green plants. The process uses light energy from the Sun to combine atmospheric carbon dioxide and water into glucose (a sugar), a carbohydrate.

The photosynthesis reaction is summarized in the following equation:

Reactants				*Products*		
$6CO_2$	$+ 6H_2O$	+ energy	$\rightarrow$	$C_6H_{12}O_6$	+	$6O_2$
carbon dioxide gas	+ water	+ energy	$\rightarrow$	glucose (sugar)	+	oxygen gas

The carbon in the sugar (carbohydrates) is passed along food chains and webs by consumers and decomposers. It is finally released back to the atmosphere as carbon dioxide gas through the process of cellular respiration summarized below:

Reactants				*Products*		
$C_6H_{12}O_6$	+	$6O_2$	$\rightarrow$	$6CO_2$	$+ 6 H_2O$	+ energy
glucose (sugar)	+	oxygen gas	$\rightarrow$	carbon dioxide gas	+ water	+ energy

LEARNING TIP

Diagrams show written information in a simplified way. To prepare for reading Figure 2, survey the diagram, review the labels, and then read the caption. What does the diagram show? Follow the paths of the arrows. What do the arrows tell you? Try to visualize (make a mental picture of) the carbon cycle.

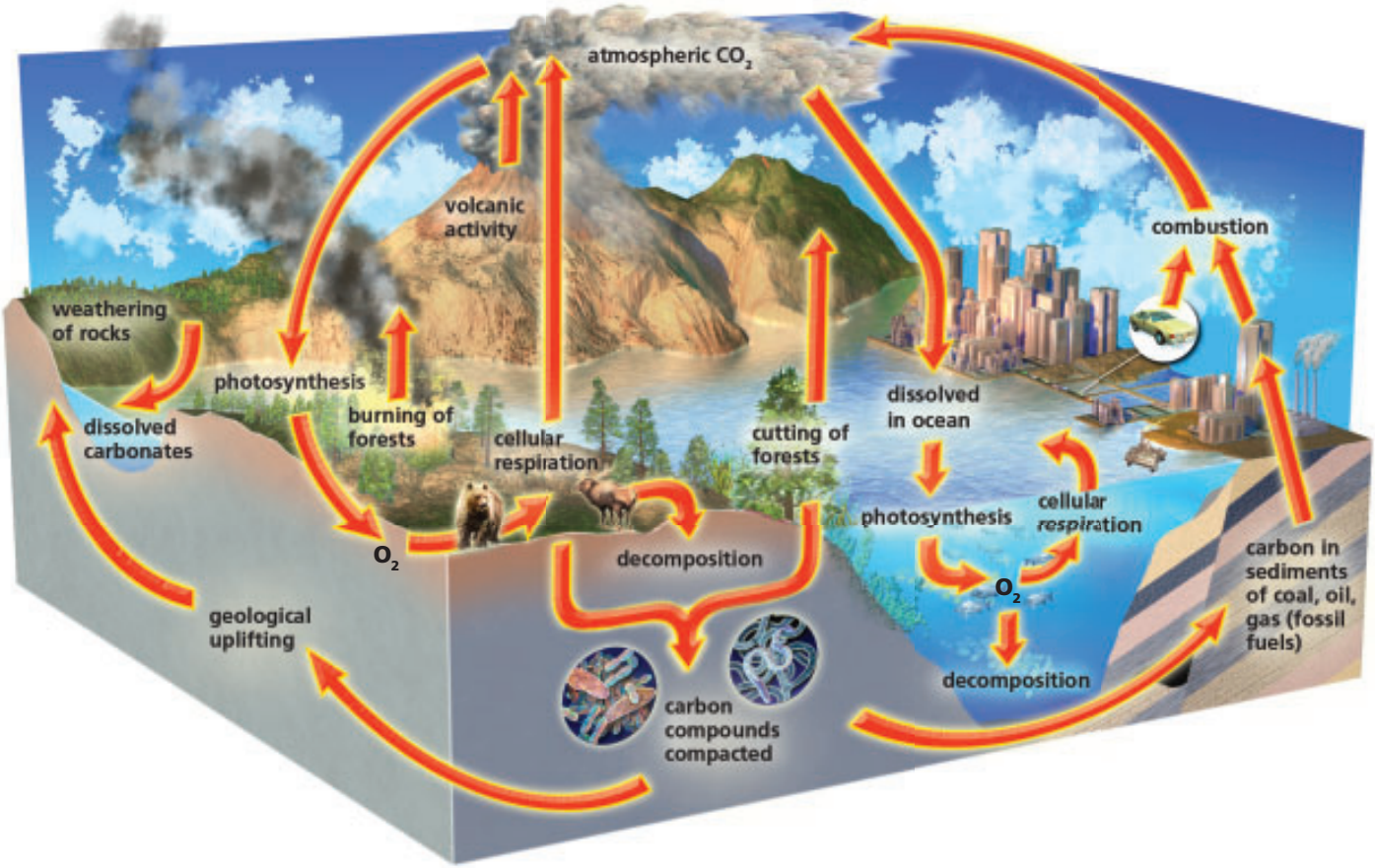

Figure 2 The carbon cycle

The carbon cycle is much more complex than the simple exchange of carbon from carbon dioxide and carbohydrates. Carbon is cycled through the biosphere in several processes other than photosynthesis and cellular respiration. For example, digestion and decomposition break down carbohydrates and return the carbon to the soil or water. Geological processes, such as volcanic activity, release carbon dioxide gas from inorganic carbon compounds such as limestone found in the crust. Erosion returns carbon compounds to the ocean where they are incorporated into ocean sediments. Human activity such as combustion or burning of fossil fuels, and cutting and burning forests, releases stored carbon into the atmosphere in the form of carbon dioxide.

To explore the carbon cycle in more detail, go to **www.science.nelson.com**

Carbon Compounds and Greenhouse Gases

Two carbon-containing compounds, carbon dioxide and methane (CH_4), are greenhouse gases. **Greenhouse gases** act like the glass of a greenhouse by trapping the heat from the Sun in the atmosphere resulting in the **greenhouse effect** (Figure 3). Without a certain amount of greenhouse gases, Earth would be too cold to sustain life as we know it. Unfortunately, too much trapped heat can cause dramatic changes to the climate. Many scientists attribute the increase in CO_2 to the steady increase in combustion of fossil fuels by humans. Also, changes in land use, such as the clearing of forests for agriculture and housing, have contributed to increased CO_2 levels by changing carbon sinks to carbon sources. Ruminant livestock, such as cows and sheep, and decomposition at landfills, produce much of the global methane emissions from human-related activities. A result of these human activities has been an increase in global temperatures. You will learn more about global climate change in Chapter 16.

STUDY TIP

Do exams make you nervous? First, define the problem. Is the problem a lack of organization and time management? Is it a lack of preparation? Or is it difficulties with note-taking and studying? Once you have defined the problem, then you can start generating solutions.

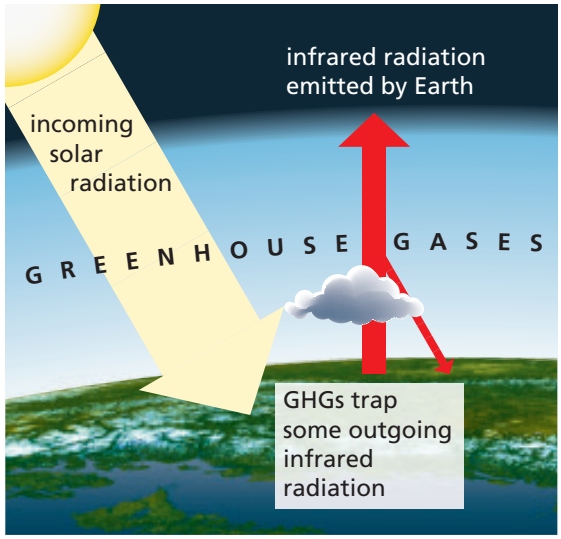

Figure 3 The greenhouse effect

TRY THIS: Carbon Dioxide and Photosynthesis

Skills Focus: predicting, recording, analyzing

In this activity, you will use plants, soda lime, and baking soda to predict and test the effects of carbon dioxide on photosynthesis.

Materials: two similarly potted plants (such as begonias), clear plastic bags, elastic bands, ruler, one small plastic container of soda lime, one small plastic container of baking soda, apron, disposable gloves, safety goggles

Wear your apron, gloves, and goggles. Avoid touching your eyes after handling soil, soda lime, or baking soda.

1. Place a plastic container of soda lime on the soil of one plant and label accordingly.
2. Place a plastic container of baking soda on the soil of another plant and label accordingly.
3. Place the plastic bags over the plants and pots and secure with the elastic bands as shown in Figure 4.
4. Predict what you will observe occurring to each plant over the next few days.
5. Observe and record your observations.

A. Describe one way that you could control this experiment.

B. Describe the growth in each pot.

C. How do your results relate to your prediction?

D. Describe the effects of carbon dioxide on photosynthesis.

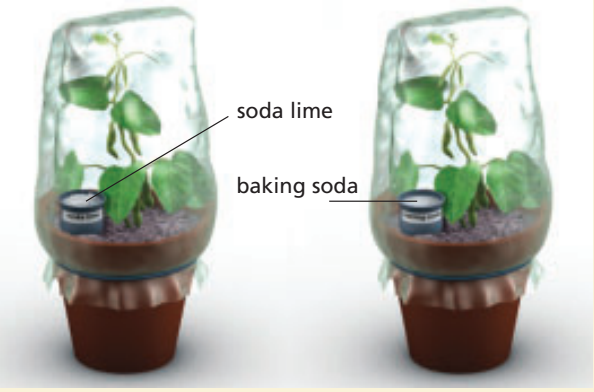

Figure 4

The Oxygen Cycle

Another vital nutrient for all organisms is oxygen. In Grade 8, you learned how the respiratory systems of humans use the oxygen from inhaled air to chemically break down food and release the energy necessary to live. Humans cannot survive very long without oxygen. After about five minutes without oxygen, human brain cells die and permanent brain damage can occur. Plants and other autotrophs also require oxygen, but they produce more than enough for their own cellular respiration and release the rest into the atmosphere or water.

The main source of oxygen is atmospheric air. Air is composed of two main gases: nitrogen (78 %) and oxygen (21 %). Other trace gases are also present (Figure 5).

Oxygen is the most abundant element in Earth's crust. It is combined with silicon along with other compounds to form silicates. Oxygen is also contained in water molecules. Oxygen gas dissolved in water is available to aquatic organisms in order for them to carry out cellular respiration. Oxygen is dissolved in water through the movement of water at the surface, for

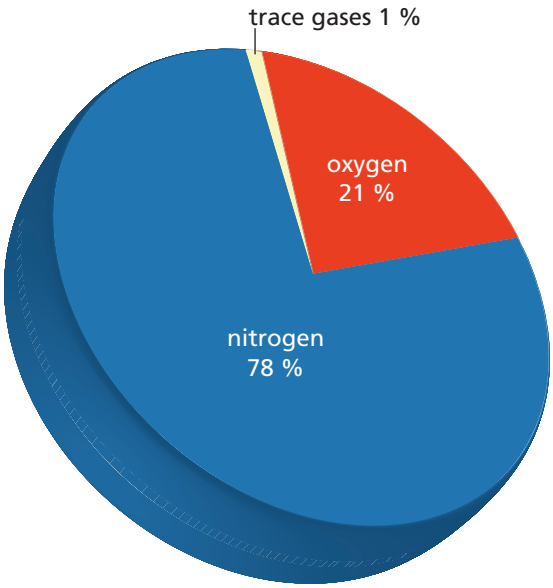

Figure 5 The composition of air

LEARNING TIP

Check your understanding. Ask yourself, "What are the most important points that I have learned about the carbon cycle?" If you have difficulty answering this question, reread the section to re-acquaint yourself with the important points.

example, when waves form (Figure 6). It is also released by aquatic plants and phytoplankton during photosynthesis. Recall from Chapter 2 that phytoplankton are photosynthetic aquatic micro-organisms that move through the water with water currents and produce much of the world's oxygen.

Figure 6 Oxygen gas is dissolved in water during movement at the surface, such as when water rushes over these rapids.

Did You KNOW?

The Night Shift

During the day when the Sun is available, plants produce 10 times more oxygen than they need. At night, however, they need to absorb oxygen from the atmosphere or water to carry out cellular respiration. This can produce low oxygen levels in some aquatic environments.

You have learned that oxygen is released into the atmosphere by plants during photosynthesis. The **oxygen cycle** describes the path of oxygen through ecosystems. It occurs in combination with the carbon cycle. Look back at Figure 2 and identify the role of oxygen within the carbon cycle. The oxygen cycle includes both photosynthesis and cellular respiration. Most organisms require oxygen to release the energy from carbohydrates, and they take in oxygen gas from the atmosphere or water. The oxygen reacts with the carbohydrates in food to produce the chemical energy necessary for life. Respiration that uses oxygen to release the energy in carbohydrates is called **aerobic respiration**.

There are some organisms, such as certain bacteria, that do not require oxygen to release energy from carbohydrates. **Anaerobic respiration** or **fermentation** occurs in the absence of oxygen. Certain bacteria use this method and instead of carbon dioxide and water, they release compounds such as methane, ethyl alcohol, and acetic acid (the main ingredient of vinegar).

Some plants and animals that usually get energy from aerobic cellular respiration are able to use anaerobic respiration when extra energy is needed. For example, human muscle cells are able to perform anaerobic respiration, but only for short periods of time, such as during intense exercise. During the anaerobic respiration, lactic acid is released, and accumulates in the muscle cells. It is this lactic acid buildup that causes sore muscles after exercise.

Plants are critical to the production of oxygen. Early in the history of life on Earth, only photosynthetic organisms existed. They could convert the carbon dioxide in the atmosphere along with water and the Sun's energy into carbohydrates and oxygen. The excess oxygen remained in the atmosphere or the oceans. Once enough oxygen was available, animals requiring a lot of oxygen could then be supported.

4.2 CHECK YOUR Understanding

1. Identify the appropriate organic molecule that matches the following descriptions:
   (a) forms structural components of organisms
   (b) provides immediate energy
   (c) controls body functions
   (d) provides insulation against heat loss
   (e) long-term storage of energy
2. List five sources of carbon. Identify if they are biotic or abiotic.
3. What are two uses for carbon dioxide in marine organisms?
4. Why are phytoplankton so important in marine ecosystems?
5. Explain how trees provide a large reserve of carbon. Give examples of animals that also store carbon.
6. Consumers release carbon dioxide as waste during cellular respiration. Give one example of how animals use carbon dioxide.
7. Why are some fossils considered to be significant reservoirs of carbon?
8. In your own words, explain why photosynthesis and cellular respiration are considered to be complementary processes.
9. Where does photosynthesis occur in plants?
10. Give the chemical formulas of the reactants and products of photosynthesis.
11. Name and complete the following word equation:
    _____ gas + water + _____
    produces _____ + oxygen gas
12. Complete the following reactions by filling in the missing substances:
    $6CO_2$ + 6 ___ + energy → $C_6H_{12}O_6$ + ___
    Name of reaction: _____
    ___ + oxygen gas → ___ gas + water + energy
    Name of reaction: _____
13. Name five processes that release carbon dioxide.
14. Explain the importance of decomposers in the carbon cycle.
15. Draw a simple diagram of the carbon cycle, using the following terms: consumers, photosynthesis, combustion, fossil fuels, decomposers.
16. Which of the following will add oxygen to the atmosphere?
    A. planting trees
    B. cutting down trees
    C. burning fossil fuels
    D. decomposing organisms
17. Scientists are concerned about large-scale clearing and burning of forests to make way for farmland and housing. Explain how the burning of forests could change the levels of both oxygen and carbon dioxide in the atmosphere.
18. How might changes in the oxygen levels in the atmosphere affect living things?
19. Describe the two methods by which oxygen becomes dissolved in water.
20. Describe an important role that phytoplankton play in the carbon cycle.

4.3 The Nitrogen Cycle

LEARNING TIP

Section 4.3 includes many new terms. As you read each new term, ask yourself, "Do I know the meaning of this term?" If not, write the term on a study card. On the back of the card, write the definition in a form that is meaningful for you.

All organisms need nitrogen. In living things, nitrogen atoms are used to synthesize nucleic acids and amino acids (Figure 1). As you learned in Grade 9, nucleotides are the building blocks of the nucleic acids DNA and RNA. These molecules are necessary to determine the special traits of each individual organism and to pass these traits on to offspring. Amino acids are the building blocks of proteins, which are critically important structural and functional molecules in living things.

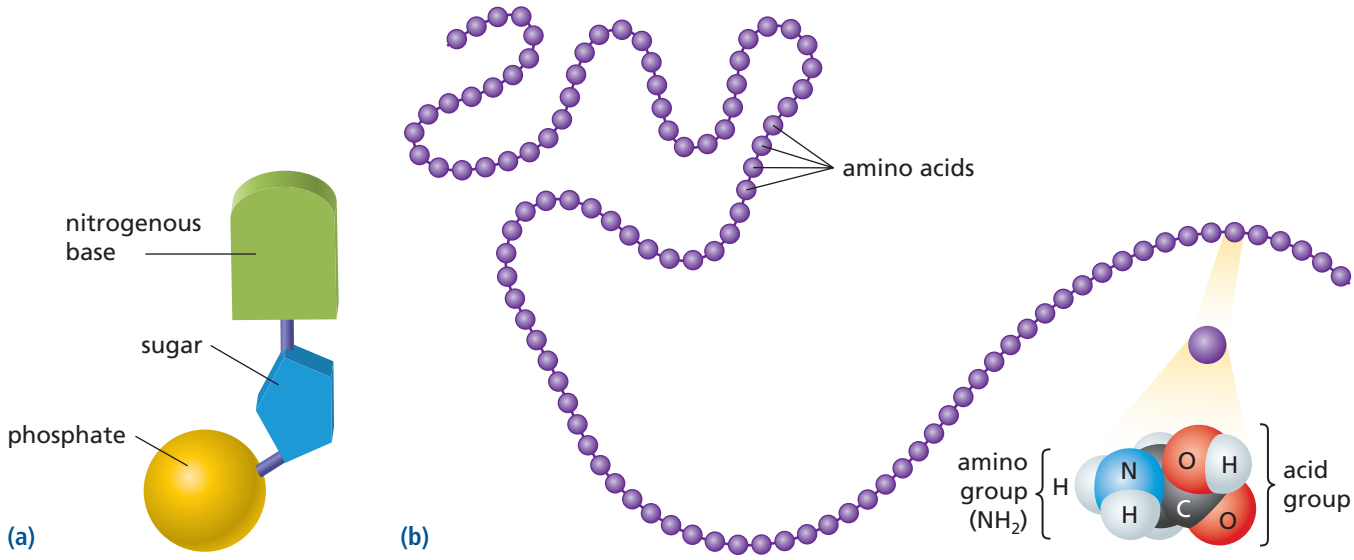

Figure 1 (a) Nucleic acids and (b) amino acids contain nitrogen.

Sources of Nitrogen

Nitrogen is the most abundant gas in the atmosphere. However, nitrogen gas (N_2) is a very stable molecule and is unavailable to most organisms because it is difficult to break the strong bonds within the nitrogen molecule. The movement of nitrogen between the abiotic and biotic components of the biosphere is called the **nitrogen cycle** (Figure 2). In order to be useful to organisms, nitrogen gas must first be converted to usable nitrogen compounds. 4A *Investigation*

4A *Investigation*

Effects of Nitrogen on Algal Growth

To perform this investigation, turn to page 101.

In this investigation, you will explore the effects of fertilizer on algal growth.

Nitrogen Fixation

The first step in the nitrogen cycle occurs when nitrogen from nitrogen gas is "fixed" or combined with hydrogen to produce ammonia (NH_3). This process is known as **nitrogen fixation**. Certain bacteria are capable of fixing nitrogen and they produce the majority of ammonia in water and soil. These nitrogen-fixing bacteria are also found in nodules on the roots of certain plants called **legumes**, which include crops such as peas, peanuts, soybeans,

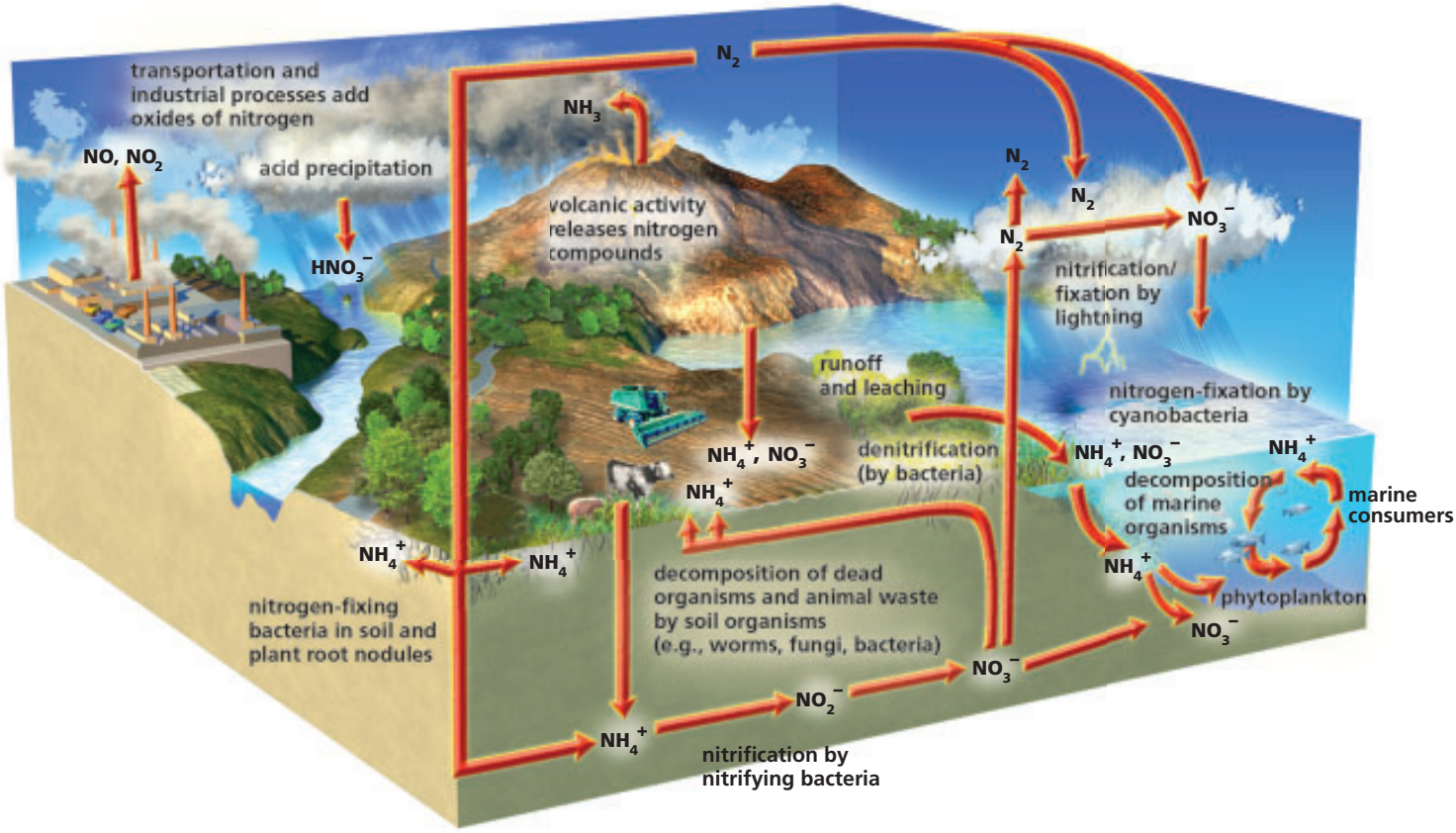

Figure 2 Nitrogen moves in a cycle through ecosystems from the environment through food chains and back into the environment.

clover, and alfalfa, and wild plants such as alders and lupins (Figure 3). The relationship between the plants and the bacteria is symbiotic and benefits both organisms, as well as other plants.

There is usually much more ammonia produced during nitrogen fixation than either the bacteria or plant requires. The excess ammonia moves into the soil, where it dissolves in water and becomes available as ammonium ions (NH_4^+). On land, certain lichens, in a symbiotic partnership between fungus and cyanobacteria, can also fix nitrogen. These cyanobacteria also carry out the process of nitrogen fixing in aquatic ecosystems by converting nitrogen into ammonia that phytoplankton and multicellular aquatic plants absorb. Non-biological nitrogen fixation by lightning and cosmic radiation also makes atmospheric nitrogen available for plants, but in much lower quantities than from biological nitrogen fixers.

Figure 3 Nodules in the roots of this pea plant contain nitrogen-fixing bacteria.

Nitrification

Most plants require a combination of ammonium ions (NH_4^+) and nitrate ions (NO_3^-) for optimal growth. **Nitrate** is a highly soluble form of nitrogen containing both nitrogen and oxygen. It is produced from ammonium by bacteria in the soil. As shown in Figure 2, the process that produces nitrate from ammonium is called **nitrification**. Nitrate is taken up by plants through their roots. Plants use the nitrate to synthesize the

Did You KNOW?

What's the Difference?

The polyatomic nitrate ion (NO_3^-) is often referred to as "nitrate" or "nitrates." Nitrite ions (NO_2^-) are often referred to as "nitrite" or "nitrites."

Figure 4 Insect-eating plants like this B.C. sundew can grow in nitrogen-poor soil.

nitrogen bases in nucleic acids (DNA and RNA), as well as the amino acids that are then assembled into proteins.

Animals obtain their nitrogen by consuming plants or by consuming other organisms that have consumed plants. The plant proteins are broken down into amino acids and reassembled into the specific proteins that the animals need. The nucleic acids are also digested into individual nitrogen bases and used to form the animal's own unique strands of DNA and RNA.

Decomposition and Denitrification

As you learned in Chapter 2, when organisms die, they decompose. Nitrogen compounds in nucleic acids and proteins are broken down by decomposers such as bacteria and fungi into the simpler ammonia and nitrate. These dissolve in water in the soil or other water sources, and are once again available to be absorbed by plants.

Another group of bacteria convert ammonia and nitrate back to nitrogen gas in the process of **denitrification**. These bacteria are anaerobic and grow best in the absence of oxygen. Aerating lawns in the spring adds more oxygen to the soil, which slows the growth of these bacteria and reduces the breakdown of nitrates into nitrogen gas. This keeps the nitrates available for plants and reduces the need for fertilizer use. Bogs are environments with low levels of useful nitrogen. This is because denitrification speeds up when the soil is very acidic or waterlogged and is therefore low in oxygen. Bogs only support certain types of plants that can tolerate low nitrogen levels. Unique to this environment are carnivorous plants such as pitcher plants and sundews (Figure 4). These plants actually trap insects and obtain part of their nitrogen by digesting them.

TRY THIS: Upsetting the Balance

Skills Focus: creating models, observing, recording

Materials: 2 1 L wide-mouth jars, pond water, 2 strands (10–15 cm) of aquatic plant (e.g., *Elodea*), 6 pond snails, 5 mL lawn fertilizer (10–20–10)

Fertilizers are toxic. Your teacher will give you specific information about the fertilizer that you are using. Clean any spills, especially on skin or clothing, with water. Wash your hands after the activity.

1. Label one jar "control" and the other "experimental."
2. Fill both jars with pond water.
3. Add one strand of aquatic plant and three snails to each jar.
4. Add 5 mL of fertilizer to the experimental jar.
5. Put both jars on the windowsill or in a bright location.
6. Record observations each day for 2 weeks.

A. Identify the roles of the aquatic plant and the snails in your ecosystem.

B. What other organisms may be present in your ecosystems?

C. Describe the purpose of the control jar.

D. Explain the changes you observed.

E. Explain how sewage entering a lake could have an effect on the plant growth in the lake.

4.3 CHECK YOUR Understanding

1. Name three compounds that contain nitrogen.
2. Nitrogen gas is the most abundant gas in the atmosphere. Explain why it is not useful to most organisms in its atmospheric state.
3. What are nitrogen-fixing bacteria? Where are they found?
4. Name the nitrogen molecule that results from nitrogen fixation. Write its formula.
5. Explain the symbiotic relationship between nitrogen-fixing bacteria and the plants they inhabit.
6. List four plants that carry out nitrogen fixation.
7. Name the following nitrogen polyatomic ions or compounds.
   (a) NO_3^-
   (b) NO_2^-
   (c) N_2
   (d) NH_3
   (e) NH_4^+
8. How do most plants get their nitrogen? How do animals get nitrogen? Explain the difference.
9. What do plants do with nitrogen?
10. Explain the difference between nitrogen fixation and nitrification.
11. Name two ways that nitrification occurs.
12. Plant and animal proteins are not all the same. Explain how animals can get the proteins they need by consuming plants.
13. An experiment was performed on bacteria living in the roots of certain plants. The results showed that during the nitrogen cycle, the bacteria
    A. denitrify nitrogen compounds.
    B. convert nitrogen gas into ammonia.
    C. convert nitrogen gas into plant proteins.
    D. convert nitrogen compounds into nitrogen gas.
14. What adaptations do plants that live in low nitrogen habitats, such as the tundra ecosystem in Figure 5, possess?

Figure 5

15. Farmers sometimes alternate crops that require large amounts of nitrogen, such as corn, with alfalfa that usually is less valuable in the market than corn. Explain why farmers would plant a crop that provides less economic value.
16. Draw a simple diagram of the nitrogen cycle using the following terms: nitrogen fixation, nitrification, decomposition, and denitrification.
17. For each description, indicate whether the process is nitrification, denitrification, or nitrogen fixation.
    (a) occurs as material decomposes
    (b) can be caused by lightning
    (c) increases levels of nitrate in soil
    (d) involves root nodules of legumes
    (e) occurs as bacteria convert ammonium ions to nitrate ions
    (f) occurs as bacteria convert nitrogen gas to ammonium ions
    (g) increases levels of atmospheric nitrogen

4.4 Explore an Issue

DECISION MAKING SKILLS

- ○ Defining the Issue
- ● Researching
- ● Identifying Alternatives
- ● Analyzing the Issue
- ● Defending a Decision
- ● Communicating
- ● Evaluating

Sustainable Agriculture

Over the past 60 years, numerous technologies have allowed for a dramatic increase in world food production. These include improvements in equipment for farming and fishing, genetically engineered high-yield and disease-resistant crops, and chemical pesticides and fertilizers to enhance crop yield. While these technologies have been effective in increasing the amount of food produced, they have also had significant impacts on the environment.

The Issue: The Impact of Agricultural Practices

The current use of fertilizers is not healthy for the environment. Long-term effects of using fertilizers are known to damage ecosystems, including those that are located some distance from where the fertilizers were applied. On the other hand, the advantage of this agricultural practice is that fertilizers increase crop yields and are cost efficient. However, sustainable agriculture must produce enough crops for the world's increasing population, as well as produce crops without causing permanent damage to the environment. As a result, the agriculture industry is being challenged to develop and use alternatives that will not interfere with the natural cycling of Earth's matter.

Statement

Agriculture in British Columbia should apply only sustainable, environmentally friendly fertilizers for its agricultural crops.

Background to the Issue

The present methods used to grow food to meet the needs of the world's population include the use of chemical fertilizers. Fertilizers are added to the soil when naturally occurring nutrients have become depleted because the same crops are harvested on the same fields from year to year. Chemical fertilizers replace nutrients such as nitrogen, phosphorus, and potassium (Figure 1). Unfortunately, these added chemicals disrupt the normal cycling of matter in ecosystems. The main problem is the contamination of soil and water. Nitrogen from fertilizers is converted to nitrates in the soil and can leach into ground water, affecting drinking water supplies and bodies of water far from the fields. Chemical fertilizers also add phosphorus to the soil. When the phosphorus leaches into the ground water and gets transported to other bodies of water, it promotes increased algal growth. When the algae die, populations of decomposers increase, depleting the

Did You KNOW?

Adding to the Cycle

N–P–K fertilizers are composed of combinations of nitrogen, phosphorus, potassium, and other minor nutrients, all necessary for healthy plant growth. For example, a 10–15–10 fertilizer contains 10 % nitrogen, 15 % phosphorus (as P_2O_5), and 10 % potassium (as K_2O). The other 65 % is filler that may or may not contain other nutrients. A 10 kg bag of 10–15–10 fertilizer would have 1.0 kg of nitrogen, 1.5 kg of P_2O_5, and 1.0 kg of K_2O.

Figure 1 Many of the world's crops are produced with the help of chemical fertilizers.

oxygen in the water and causing problems for other aquatic organisms, such as fish and amphibians (Figure 2).

Clearly, there are both advantages and disadvantages of using chemical fertilizers. Table 1 outlines some of these.

Table 1 Advantages and Disadvantages of Chemical Fertilizers

Advantages	Disadvantages
increases crop yields	no organic material is added to the soil
lowers production costs	only three essential nutrients are added to the soil
makes nutrients immediately available to plants	makes nutrients available for only a short period of time and leaches into soil and ground water
makes farming profitable	uses large amounts of energy for production
	releases nitrous oxide, a damaging greenhouse gas

Figure 2 When algae decompose in fresh water, the oxygen in the water is used up and other aquatic organisms may die from lack of oxygen.

What Can Be Done?

There is no doubt that current agricultural practices are damaging the environment. However, the world's population is growing and enough food must be produced to avoid widespread starvation. A balance must be found between permanently damaging the environment and not producing enough food to feed the growing population.

There are some alternatives to chemical fertilizers, including the use of organic fertilizers such as compost and manure. Other techniques, such as crop rotation, can be used to increase sustainable agriculture, but they require more time and money. This is important because agricultural practices must be profitable in order to be sustainable. Research is focusing on other alternatives to increase yields.

Make a Decision

1. In groups, research the issue to learn more about perspectives on current sustainable agriculture practices and the use of chemical fertilizers. Consider the present and future environmental benefits of these practices, as well as impacts on the economy.

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2. Discuss which perspectives are the most important. Explain or justify your position using your research to support your decision. Do the benefits of your position outweigh the risks, or vice versa?
3. Decide whether you agree or disagree with the statement.

LEARNING TIP

When taking a position on an issue, it is helpful to step into the person's shoes and imagine what it is like to be him or her.

Communicate Your Position

4. Prepare a presentation that summarizes your position on the issue. Prepare your presentation as either a debate or a position paper. Be sure to support your position with evidence. Be prepared to answer questions to support your position.

4.5 The Phosphorus Cycle

To learn more about the phospholipid bilayer in cell membranes, go to **www.science.nelson.com**

Phosphorus is an important element in several biological molecules. For example, the nucleic acids, DNA and RNA, have backbones of sugar and phosphates. Animals incorporate phosphates into their shells, bones, and teeth. As well, all cells are surrounded by a selectively permeable membrane made of phospholipids (Figure 1). Phospholipids are made of fat molecules with a phosphate group attached. Energy in all organisms is stored in a molecule called adenosine triphosphate (ATP) that includes three phosphate groups (Figure 2).

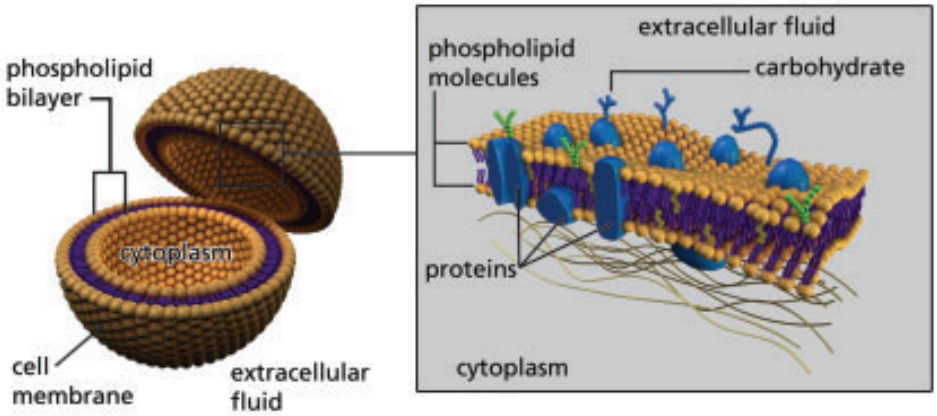


Figure 1 Cell membranes are composed of two layers of phospholipids, along with proteins and carbohydrates.

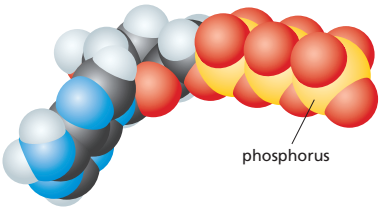


Figure 2 ATP (adenosine triphosphate) contains phosphorus. Energy is released when the bonds between the phosphate (PO_4) groups are broken.

Sources of Phosphorus

Unlike carbon, oxygen, and nitrogen, phosphorus does not have a gaseous atmospheric form. The **phosphorus cycle** describes the path of phosphorus through ecosystems (Figure 3). All phosphorus originates from the weathering of sedimentary and metamorphic bedrock in Earth's crust. **Phosphate ions** (PO_4^{3-}) are soluble in water and can be dissolved out of rock into soil or water environments through the process of weathering. Producers absorb the phosphate ions from the soil, making them available to other organisms in the food chain.

Dissolved phosphates are also carried to the ocean from the land via rivers and runoff. Algae and other aquatic plants absorb these phosphates before they become trapped in sediments. Animals eat the plants and use the phosphates to grow shells, bones, and teeth, as well as the biological molecules described above. The cycle continues in two directions.

LEARNING TIP

Scanning allows you to locate a single word, fact, or name in the text or figure. Use this strategy when you are looking for a fact or information to respond to a specific question or to write details about something.

The Short and the Long Phosphorus Cycle

A relatively short cycle occurs when organisms die and decompose. The phosphates are released by decomposers, become dissolved in water, and are made available to producers. A longer cycle occurs when animals die and the

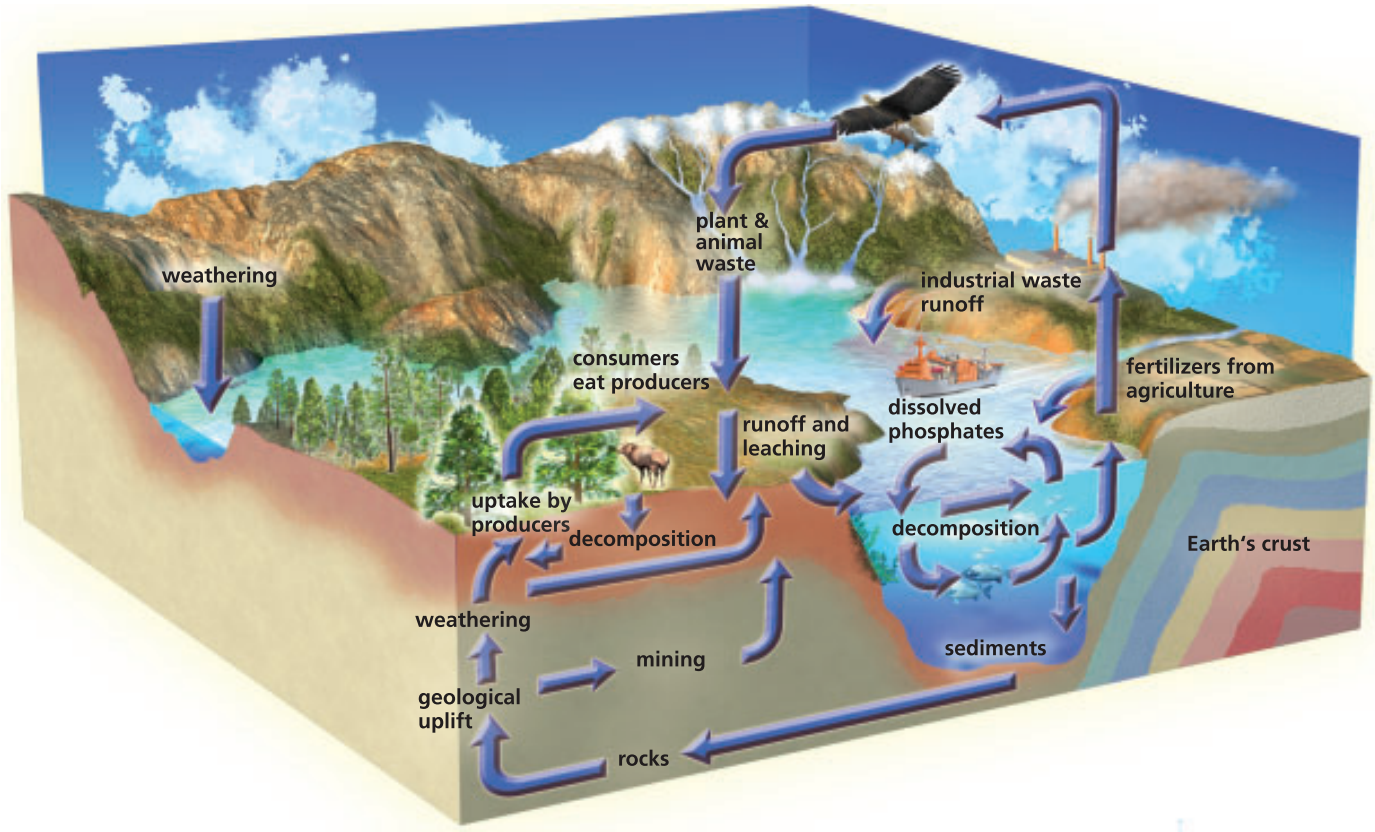


Figure 3 Phosphorus cycles both in a short time and in a longer geological time.

elements in their bodies that contain phosphates sink and are deposited on the ocean floor. Once these phospates are covered with sediments, they will eventually become rock. The phosphates remain trapped until a geological event, such as an upheaval or a geological uplift, exposes the sedimentary rock to weathering once more. This route cycles the phosphorus over geological time.

To learn more about the phosphorus cycle, view the animation found at **www.science.nelson.com**

Mycorrhizae

A symbiotic relationship exists between certain microscopic fungi and the roots of most plants. These fungi are called **mycorrhizae**; *myco* means "fungus" and *rhizae* means "roots" (Figure 4). The fungus increases the solubility of phosphate, making it more readily available for the plant. In return, the plant provides carbohydrates produced during photosynthesis for the fungus. Mycorrhizae increase the solubility of natural soil phosphates as well as the added phosphates that are present in fertilizers.

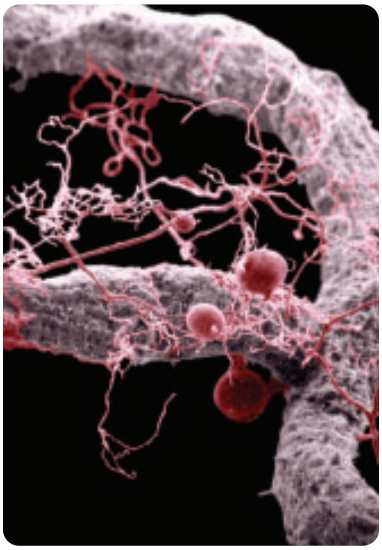


Figure 4 Symbiotic fungi living in the roots of most plants enhance the uptake of phosphates by the plants.

Humans and Phosphorus

Human activity can also add phosphorus to ecosystems. Farmers add commercially prepared fertilizers made with phosphorus as well as nitrogen and potassium to their fields. Animal manure, containing phosphorus, is also applied to enrich the soil. Outflows from human sewage treatment plants and industrial processes also add phosphates to water sources.

4.5 CHECK YOUR Understanding

1. Name three places where phosphorus is found in living things.
2. What is the original source of all phosphorus?
3. Explain the role of weathering and the rock cycle in making phosphorus available for living organisms.
4. Describe the form of phosphorus that plants can absorb.
5. Which of the following describes how phosphorus is made available to producers?
   A. weathering releases phosphorus from rocks
   B. lightning fixes phosphorus in the atmosphere
   C. respiration releases phosphorus into the atmosphere
   D. photosynthesis releases phosphorus into the atmosphere
6. How do consumers acquire their phosphorus?
7. Explain the short phosphorus cycle and the long phosphorus cycle.
8. Which of the following are true for phosphorus?

I	dissolved in water
II	present in the atmosphere
III	stored in sediments

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II, and III
9. Draw a simple diagram of the phosphorus cycle using the following terms: weathering, decomposers, ocean sediments, geological uplift.
10. How is the phosphorus cycle different from the carbon, oxygen, and nitrogen cycles?
    A. phosphorus has no atmospheric form
    B. phosphorus does not dissolve in water
    C. phosphorus does not form compounds
    D. phosphorus only forms solid compounds
11. Explain the symbiotic relationship of mycorrhizae with plants.
12. Phosphorus is sometimes called a limiting nutrient because without it, plants cannot grow properly. Explain how there could be a shortage of phosphorus in some soils.
13. Animal manure is often spread over agricultural fields before planting. Explain how this enhances crop growth.
14. The rate of phosphorus cycling is linked to the rate of decomposition. Explain this statement.
15. Which of the following processes would cause a decrease in phosphate levels of soil?
    A. decomposition of animal waste
    B. leaching of phosphate into soil
    C. formation of deep ocean sediments
    D. uptake of phosphates by terrestrial organisms
16. Which of the following processes would cause an increase in phosphate levels of soil?
    A. runoff and leaching
    B. mining of phosphates in soil
    C. growth of terrestrial vegetation
    D. application of fertilizer to farmland

4A Investigation

Effects of Nitrogen on Algal Growth

In the spring, runoff from melting snow that reaches lakes can contain nitrogen fertilizers from farms.

Question

How does fertilizer in aquatic ecosystems affect the growth of algae?

Hypothesis

Write a hypothesis that explains the effects of fertilizer on algal growth.

Prediction

Make a prediction about how nitrogen will affect the growth of algae.

Experimental Design

You will design and build two identical aquatic ecosystems. You will design an experiment to test the effects of fertilizers on algal growth.

Materials

- balance
- various containers
- pond water
- filters
- funnels
- ring stand
- beakers
- fertilizer sample
- other materials you feel necessary

Fertilizers are toxic. Your teacher will give you specific information about the fertilizers that you are using. Clean any spills, especially on skin or clothing, with water. Wash your hands after the activity.

Procedure

1. With a partner, design and draw your ecosystems and have them approved by your teacher.
2. Build your ecosystems.

INQUIRY SKILLS

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

3. Design your experiment and have it approved by your teacher.
4. Design a data table to record your results. Observe, and record your observations each day for one week.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Which ecosystem had the most algal growth? How did you determine this?

(b) What did you observe in the ecosystem with the most algal growth?

(c) Was your prediction correct? Explain.

(d) Do your results support your hypothesis?

(e) Examine the original container that the fertilizer came in. Explain what the numbers stand for.

(f) List some of the molecules in plants that contain the chemicals in the fertilizer.

Evaluation

(g) Describe possible sources of error in your investigation.

(h) How could you improve the procedures for this investigation?

(i) List the factors that affected the growth of the algae.

(j) Name the nutrients you tested.

Synthesis

(k) Explain any differences in the algal growth.

(l) What effects could increased algal growth have on aquatic ecosystems?

CHAPTER 4

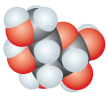
Review

Nature's Recycling Programs

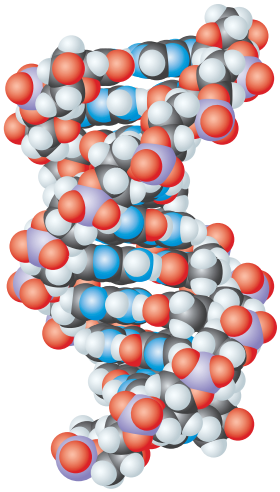
Key Ideas

Matter is classified as organic or inorganic.

- There is a finite amount of matter on Earth.
- Organic matter always contains the elements carbon and hydrogen, although other elements may also be present.
- Inorganic matter does not contain both carbon and hydrogen.

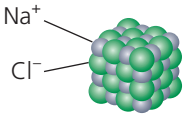


glucose, $C_6H_{12}O_6$



nucleic acid (DNA)

water, H_2O



sodium chloride, NaCl

Table 1 Some Common Organic and Inorganic Compounds

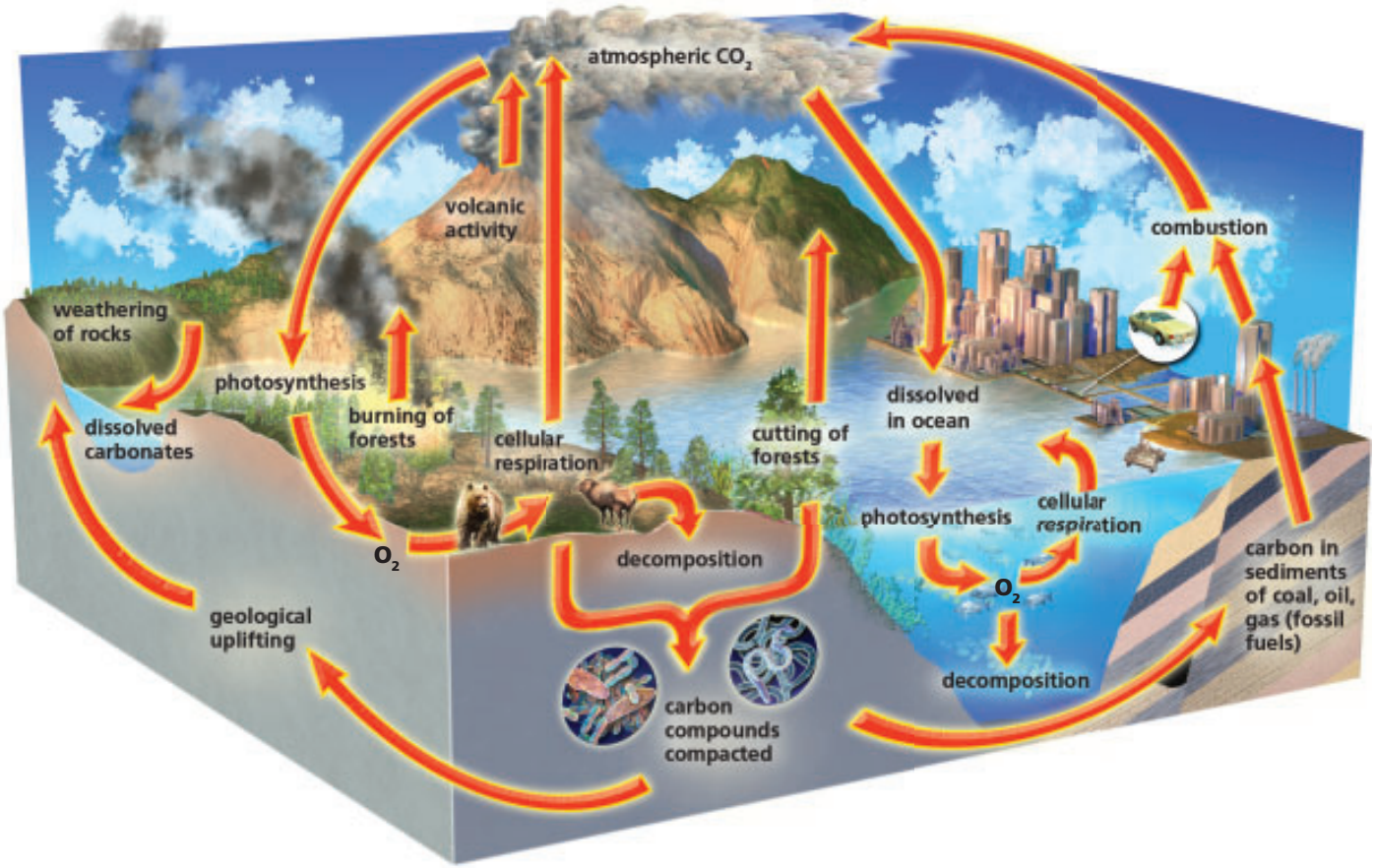
Organic compounds	Inorganic compounds
carbohydrates	water
proteins	salts
nucleic acids (e.g., DNA)	ammonia
lipids	oxides

Vocabulary

organic, p. 83
inorganic, p. 83
photosynthesis, p. 83
cellular respiration, p. 83
carbon reservoir, p. 86
carbon sink, p. 86
fossil fuel, p. 86
carbon source, p. 86
carbon cycle, p. 86
greenhouse gases, p. 88
greenhouse effect, p. 88
oxygen cycle, p. 90
aerobic respiration, p. 90
anaerobic respiration, p. 90
fermentation, p. 90
nitrogen cycle, p. 92
nitrogen fixation, p. 92
legume, p. 92
nitrate, p. 93
nitrification, p. 93
denitrification, p. 94
phosphorus cycle, p. 98
phosphate ion, p. 98
mycorrhizae, p. 99

Nutrients cycle between biotic and abiotic components of ecosystems.

- All organisms contain the nutrients carbon, oxygen, nitrogen, and phosphorus.
- The carbon cycle and the oxygen cycle are connected through the processes of photosynthesis and cellular respiration.
- The nitrogen cycle moves from nitrogen fixation to nitrification to denitrification.
- Phosphorus does not have an atmospheric form. The phosphorus cycle begins with phosphorus released from rocks.



Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.

K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K **1.** Which of the following groups include only organic compounds?

A. CH_4, CO_2, NH_3, H_20
B. CO_2, H_2O, $C_2H_4O_2$, $C_3H_6O_3$
C. CO_2, $C_6H_{12}O_6$, $C_2H_4O_2$, CH_4
D. $C_6H_{12}O_6$, CH_4, $C_3H_8O_3$, $C_9H_{18}O_2$

2. Draw a two-column table and classify these substances as organic or inorganic.

(a) sugar
(b) water
(c) gasoline
(d) ammonia
(e) carbon dioxide
(f) protein

3. List the reactants of photosynthesis.

4. List the reactants of cellular respiration.

5. For each of the following nutrients, list two compounds or polyatomic ions where each is found:

(a) carbon
(b) oxygen
(c) nitrogen
(d) phosphorus

6. What are fossil fuels? Explain how they are formed.

7. Explain how carbonates form in the ocean.

8. How do oceans act as carbon reservoirs?

9. Describe the role that bacteria play in the nitrogen cycle.

10. Explain how lightning can make nitrogen available to organisms.

11. Describe how the phosphorus cycle is different from the carbon, oxygen, and nitrogen cycles.

12. What is the main source of phosphorus?

13. Explain how the phosphorus in animals re-enters the phosphorus cycle.

K **14.** Which of the following contain phosphorus?

I	Carbohydrates
II	ATP
III	Cell membranes

A. I only
B. I and II only
C. II and III only
D. I, II, and III

Use What You've Learned

U **15.** Which of the following processes and events may release carbon into the atmosphere?

A. photosynthesis, cellular respiration, nitrogen fixing
B. volcanic eruptions, cellular respiration, forest fires
C. nitrification, burning of fossil fuels, greenhouse effect
D. forest fires, photosynthesis, decomposition of dead organisms

16. How are digestion and decomposition similar? How are they different?

17. Forests are often described as carbon sinks or reservoirs. Explain what this means.

18. Explain the importance of decomposers in the carbon and oxygen cycles.

U **19.** Which of the following groups of molecules all contain nitrogen?

A. carbohydrates, carbonates, nitrates, gasoline
B. proteins, enzymes, hormones, carbohydrates
C. nucleic acids, proteins, ammonia, amino acids
D. nucleic acids, amino acids, carbohydrates, carbon dioxide

20. Space probes sent to the Moon and Mars collected soil samples that were examined for organic compounds. Why would scientists want to know if organic substances were present in these soil samples?

21. Fertilizers contain nitrates and phosphates that are both necessary for plant growth. Explain how the application of fertilizers can cause environmental problems.

Think Critically

22. Three different ecosystems—tropical rainforest, temperate rain forest, and grassland—were analyzed for their nitrate levels during the same month. The amount of nitrates in the top layer of each soil was determined. Using the same method, the masses of nitrates in living things (biomass nitrates) in each study area were also calculated. Table 1 shows the results for each ecosystem identified by a number.

Table 1

Study area	Soil nitrates	Biomass nitrates (kg/ha)	Soil temperature
1	30	90	25
2	10	175	19
3	2	270	30
tundra	?	?	?

(a) Identify each numbered ecosystem as tropical rainforest, temperate rainforest, or grassland. Give reasons to support your answers.
(b) In which ecosystem does nitrogen cycle most rapidly?
(c) Predict what data might be collected from a tundra ecosystem. Explain your prediction.

23. Earthworms are important soil invertebrates that help decomposition and improve soil quality. Ploughing fields actually reduces the population of earthworms. Use the Internet to research the role of earthworms.

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24. Table 2 shows the mass of carbon that moves through the biosphere per year.

Table 2

Carbon movement	Mass of carbon per year (10^{13} kg)
From atmosphere to oceans	107
To atmosphere from oceans	105
To atmosphere from fossil fuel burning	5
From atmosphere to plants	120
To atmosphere from net burning of plants	2
To oceans from runoff	0.4
To atmosphere from soil	60
To atmosphere from plants	60

(a) Draw a bar graph showing the factors that increase and decrease the levels of CO_2 in the atmosphere.
(b) Calculate the amount of carbon entering the atmosphere as CO_2 each year and the amount of carbon leaving the atmosphere. Is the amount of atmospheric CO_2 increasing or decreasing?
(c) How much carbon is contributed to the atmosphere by burning forests? What other factor would be affected by burning trees?
(d) Make a list of actions that would reduce the flow of carbon dioxide into the atmosphere. How would these affect your life? Which actions are possible in your lifetime?

Reflect on Your Learning

25. Matter cycles endlessly through biotic and abiotic states. Think about an ecosystem close to you. Describe what it would look like in ten years if matter did not cycle?

26. In your own words, describe the role of photosynthesis and cellular respiration in the cycling of matter. Why do you think these processes are often described as the most important processes on Earth?

Visit the Quiz Centre at
www.science.nelson.com GO