1.5 The Recycling of Matter

Figure D1.39: A large wildfire releases a tremendous amount of energy.

One of the most powerful forces in nature is a large wildfire. The energy released by this dramatic chemical reaction can be truly awesome. In some cases, updrafts created by the fire are so intense that cool air is sucked in from the surrounding area to create winds that can gust up to 160 km/h. These winds can sometimes develop like a tornado and are capable of hurling flaming logs great distances. In these cases, the fire is creating its own weather—this is why it's called a firestorm.

Wildfires of this magnitude are clearly seen as uncontrollable menaces that represent a significant hazard to industry, homes, public safety, and natural resources. You can see why preventing wildfires has been a top priority.

You might be surprised to know that the efforts made to prevent and suppress all wildfires—even smaller ones—may actually be putting forests more at risk for a large, massively destructive fire. Low-intensity fires reduce the accumulation of fuel, such as thick layers of pine needles, dead branches, and underbrush. An old forest that has not been subjected to a low-intensity burn is more at risk for having a catastrophic fire that burns with great intensity and spreads rapidly over a larger area.

Figure D1.40: Firefighters take a well-deserved break after battling a stubborn fire.

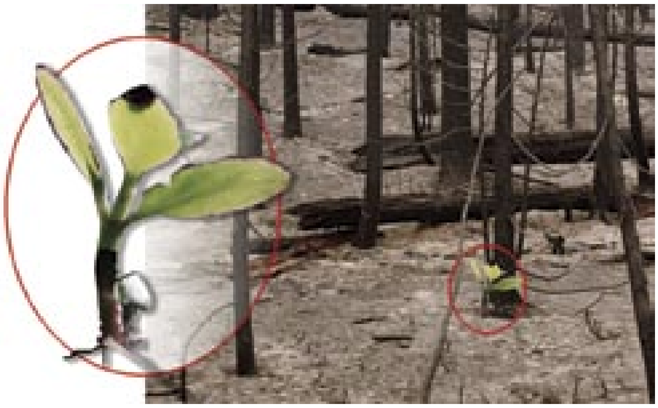


Figure D1.41: Plants emerge from the ashes of fires.

Recent studies of fire scars on trees, soil layers, and core samples from lake beds reveal that in the 10 000 years since the last Ice Age, fires have actually played an important role in boreal forest ecosystems. Ecologists agree that the boreal forest ecosystem depends upon fire to maintain a healthy and diverse habitat for a variety of plants and animals.

DID YOU KNOW?

Even though a forest fire can destroy lodgepole pine trees, only the heat from a wildfire can melt the resin that seals their pine cones shut. The parent trees may die, but within a few years the blackened landscape is dotted with lodgepole pine seedlings.

The prairie grassland ecosystem also depends upon fire. Prairie fires destroy the seedlings of trees and shrubs that would invade the prairie grasslands. And yet the fires burn only the upper portion of the grass plants, leaving the roots unharmed. Fire has a rejuvenating effect on both boreal forest and prairie grassland ecosystems because it encourages new growth and a healthy diversity in both the plant communities and the animals that depend upon plants.

How can a destructive force like a wildfire trigger a vibrant period of new growth in a diverse variety of plant species? How can the growing conditions for these pioneering plant species be enhanced by the fire? You will have an opportunity to answer these questions as you gain an understanding of the movement of matter through the trophic levels of an ecosystem.

Practice

31. A wildfire has been described as a very large and dramatic chemical reaction. What observations of a wildfire support this claim?

32. Prescribed burning is a practice in which forestry personnel deliberately set small, controlled fires under ideal weather conditions—low winds and reasonably high moisture content. This strategy attempts to mimic the historical pattern of more frequent, low-intensity burns that are an integral part of the forest ecology. Explain how this practice may actually enhance public safety and ensure the long-term health of the forest.

Energy Flows in One Direction But Matter Is Recycled

Food chains, food webs, and ecological pyramids are models that show energy moves in only one direction through the trophic levels of an ecosystem.

Energy from the Sun is stored as chemical energy in food at the first trophic level through the process of photosynthesis with producers. Then about 10% of the chemical energy is passed along to each of the higher trophic levels. About 90% of the chemical energy is used by the organisms at each level and is eventually passed into the environment as heat. Since energy is continually flowing out of the system, it must be constantly replenished in the form of energy from the Sun. Without the continual input of solar energy, the ecosystem would shut down.

Figure D1.42: Water vapour forms a cloud above a grassland ecosystem.

Matter, in the form of elements and compounds, also moves through the trophic levels and within the environment. As an example, water in the tissues of a plant can be eaten by a prairie dog and then become incorporated into its body. Some of the water may also be exhaled by the prairie dog as water vapour.

This exhaled water may add to a cloud above a grassland ecosystem and then could be carried by the wind for hundreds of kilometres to eventually fall as rain on a boreal forest ecosystem. Even though the water can move between ecosystems, it cannot leave the biosphere. It is a permanent part of the planet. Since water is neither added to nor subtracted from Spaceship Earth, and because water is needed for so many processes essential to life, water molecules must be recycled.

The Water Cycle

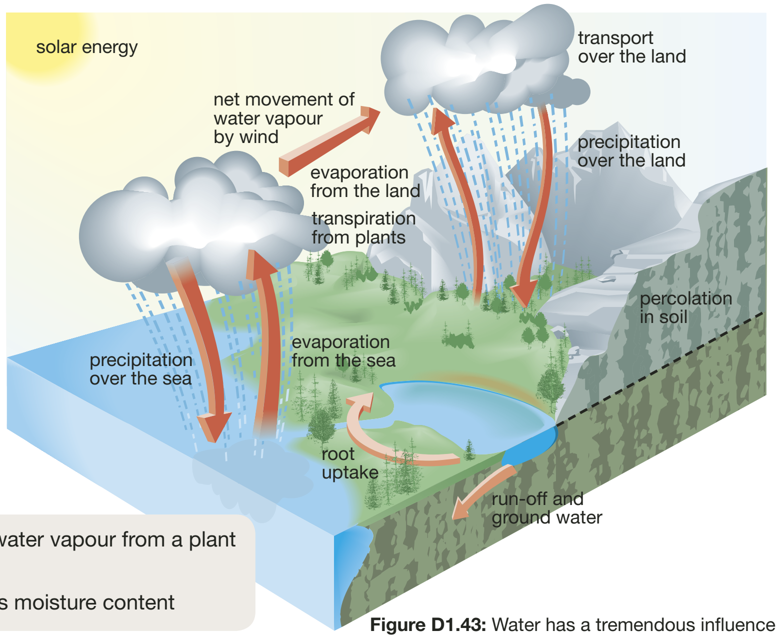


Figure D1.43: Water has a tremendous influence on ecosystems.

- **transpiration:** the loss of water vapour from a plant through its leaves
- **humidity:** the atmosphere's moisture content

Of all the non-living components of an ecosystem, water has the greatest influence on life found in that ecosystem. Natural processes constantly recycle water throughout the environment. The Sun's energy evaporates water from land and water surfaces, thereby adding gaseous water vapour to the atmosphere. As it cools, water vapour condenses and eventually falls as precipitation. Plants pull water from the ground and lose water from their leaves through the process of **transpiration**, which puts water vapour into the air. The addition of water vapour into the air makes local conditions more humid. **Humidity** is the moisture content of the atmosphere.

Wildfires and the Water Cycle

As the organic matter in a forest burns, hydrocarbon compounds are distilled into their constituent parts. As these materials move down into the soil, they condense on the cooler soil particles and create a waxy coating that tends to bring about a waterproof layer just under the soil surface.

The impact on the water cycle is clear—the ability of forests to absorb and hold water is reduced, not only because soil is a waterproof layer, but also because the vegetation that utilizes the water has been damaged. Heavy precipitation that happens after a forest fire has a greater portion of the water flow directed to run-off. This erodes surface soil as the water moves more directly to streams and bodies of water. Soil erosion after a wildfire is particularly noticeable on slopes. Surface vegetation begins to return within about two years of the wildfire, the waterproof soil layer begins to break down, and the soil begins to regain its ability to retain moisture.

Human Impacts on the Water Cycle

As you learned at the beginning of Chapter 1, water is a precious resource that will likely be in greater demand in years to come. Some practices considered acceptable several years ago are now being rethought. For example, households are switching to toilets that use only 6 L of water per flush instead of 18 L. If water is continually recycled, why is it important to use less? The answer to this question has to do with the fact that when humans remove fresh water from the environment, it is very difficult to return the water to the environment without a deterioration in quality. Not only does polluted water mean there is less clean water available for human use, it also means there is less clean water to support aquatic ecosystems.

Deforestation is another major way in which people affect the water cycle. Trees play a vital role in regulating both the temperature and moisture content of soil by providing shade from direct sunlight.

Practice

33. Water is often applied to lawns and gardens to keep plants healthy and green.

a. Use your knowledge of the water cycle to explain why it is more effective to water lawns in the early morning rather than the middle of the afternoon.

b. Use your knowledge of the water cycle to explain why it is better to use a soaker hose instead of a sprinkler to water trees and shrubs.

34. Recall the process known as oilfield injection discussed in Lesson 1.1.

a. In the description of oilfield injection, one of the concerns stated was that the water used in this process was permanently removed from the water cycle. Does this contradict the idea that the total amount of water on Spaceship Earth is fixed?

b. Use your knowledge of the water cycle to explain why this use of water is of great concern to environmentalists even though it represents only about 1% of fresh water used in Alberta.

35. For organisms that live in the forest floor's soil, identify at least two abiotic factors significantly affected by wildfires.

The Recycling of Other Elements and Compounds

The idea of recycling applies to other elements and compounds. The atoms of carbon, nitrogen, oxygen, and other elements that make up the bodies of living organisms are the same atoms present when life began on Earth. These materials must also be recycled. The processes involved in recycling the essential elements and compounds are referred to as **biogeochemical cycles**.

Although the word *biogeochemical* appears long, it is actually made up of three familiar parts: *bio*—referring to life + *geo*—referring to Earth + *chemical*—referring to elements and compounds. So, these cycles refer to the exchange between Earth and ecosystems of the elements essential to life.

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

photosynthesis: the process by which plants and some other organisms use light energy to convert water and carbon dioxide into oxygen and high-energy carbohydrates, such as sugars and starches

cellular respiration: the process by which cells convert the chemical energy stored in sugars into energy that the cells can use

carbon sink: a system that removes more carbon dioxide from the atmosphere than it releases into the atmosphere

peat: deep layers of mosses and plant remains unable to completely decompose due to the lack of oxygen in water-saturated soil

The Carbon Cycle

All life on Earth is based on molecules containing carbon. Atoms of carbon form the framework for proteins, carbohydrates, fats, and other molecules important to biological systems. The carbon cycle begins with producers taking in carbon dioxide from the atmosphere. During **photosynthesis**, energy from the Sun is used by producers to convert carbon dioxide gas into energy-rich molecules of glucose to be used by living organisms as a source of food and energy. The simplified overall equation for photosynthesis is

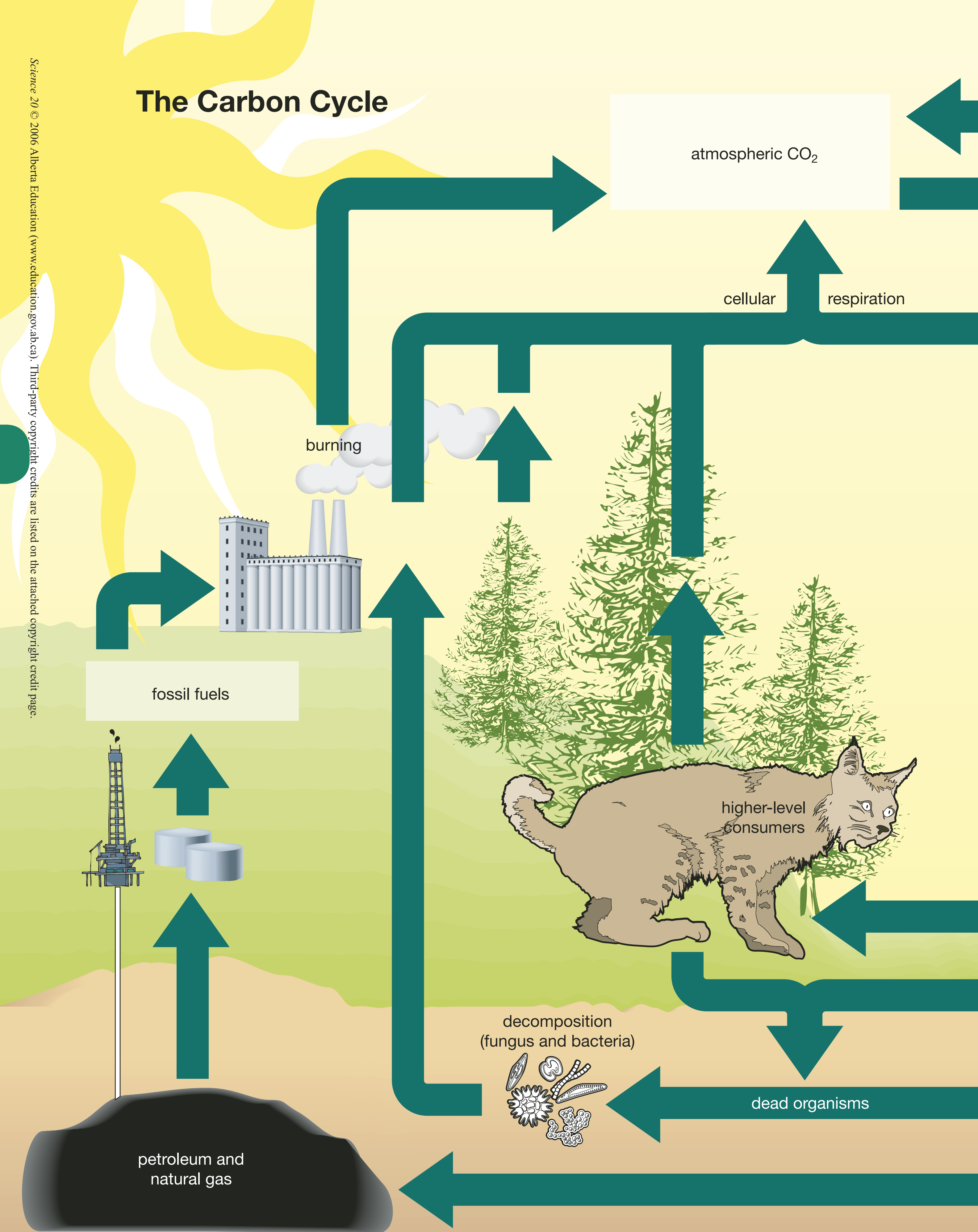
$$\text{Energy} + 6\ CO_2(g) + 6\ H_2O(g) \rightarrow C_6H_{12}O_6(aq) + 6\ O_2(g)$$

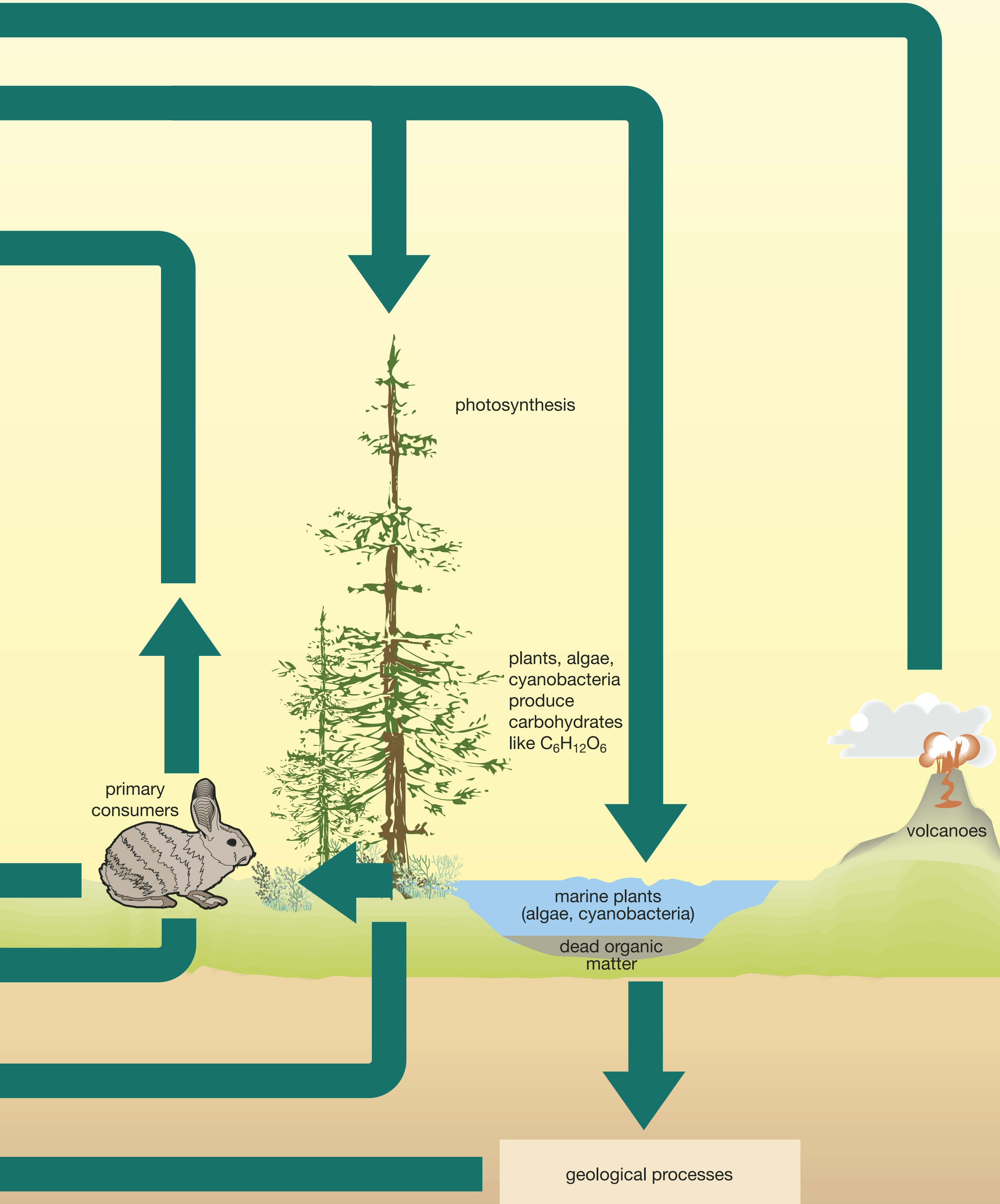
Living organisms return carbon dioxide to the atmosphere by **cellular respiration**. The simplified overall equation for cellular respiration is

$$C_6H_{12}O_6(aq) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l) + \text{Energy}$$

The movement of carbon through the carbon cycle is highly affected by carbon being stored in a variety of reservoirs, including fossil fuels, animal fossils, and the vast reserves of calcium carbonate in the world's oceans. Reservoirs of carbon are called **carbon sinks**. Boreal forest ecosystems are now recognized as significant carbon sinks not only due to the trees that live there, but also because of the accumulation of **peat** in these wetland ecosystems. Peat bogs in Alberta are called muskeg. Recent studies of peat bogs in Siberia have revealed that some of these bogs have been around since the last Ice Age, which makes them at least 10 000 years old. These studies have also determined that these peat bogs absorb huge amounts of carbon—this makes them among the world's top carbon sinks. Unfortunately, if peat bogs are drained and decomposition is allowed to occur, the carbon stored there is released as carbon dioxide and these ecosystems become a source of carbon instead of a sink.

The Carbon Cycle




photosynthesis
plants, algae, cyanobacteria produce carbohydrates like $C_6H_{12}O_6$
primary consumers
volcanoes
marine plants (algae, cyanobacteria)
dead organic matter
geological processes

Human Impact on the Carbon Cycle

Human activities that involve the burning of fossil fuels have the effect of adding to the worldwide accumulation of carbon dioxide. This amounts to reversing millions of years of photosynthesis by releasing carbon back into the atmosphere that had been stored in the remains of ancient plants—the original source of fossil fuels. In recent years, this has become a concern because increased atmospheric levels of carbon dioxide have been linked to global warming and climate change.

Deforestation also affects the carbon cycle by eliminating trees that could absorb carbon dioxide through photosynthesis. In addition, the removal of trees causes dramatic changes to the microclimate, leading to an increase in soil temperature extremes and a decrease in soil moisture. If the peat bogs begin to dry out in boreal forests, the carbon stored there starts to be released.

The Impact of Wildfires on the Carbon Cycle

It may seem obvious that wildfires will have a significant effect on the carbon cycle because a burning forest switches instantly from a carbon sink into a carbon source with the addition of carbon dioxide to the atmosphere. What is less obvious is that dried-out peat bogs are a huge fire risk because of the large amounts of fuel that have been stored in them. Fires in peat bogs have been known to burn underground for months. This comes as no surprise to geologists because ancient peat bogs are the original source of current coal deposits.

Practice

36. Explain the following statement.

> There is no need to memorize a separate chemical equation for photosynthesis and another one for cellular respiration. One equation can describe both.

37. Decomposition, combustion of fossil fuels, cellular respiration, volcanic activity, and wildfires all have something in common when it comes to the carbon cycle. Identify the common feature.

38. While driving through northern Alberta, you spend hours travelling through a large section of boreal forest consisting of muskeg and stands of spruce trees. One of your passengers comments, "It's a shame that all this land can't be put to better use." Respond to this comment by explaining the value of Alberta's boreal forests.

The Oxygen Cycle

Each breath you take involves the essential process of extracting oxygen from the atmosphere. Most living things cannot survive without a source of oxygen. Even aquatic organisms take in dissolved oxygen from the water. Why is oxygen so essential? Oxygen reacts so intensely with other elements in chemical reactions that significant amounts of energy are released. Organisms can then use the energy released in these oxidation reactions.

Given the reactive nature of oxygen, it is natural to wonder why there is any oxygen left in the atmosphere. After all, if it combines so readily with elements like iron to form oxidized mineral sediments, why hasn't it all been used up? The answer is photosynthesis. According to the fossil record, billions of years of photosynthesis by cyanobacteria living in warm, shallow seas created Earth's current oxygen-rich atmosphere. Modern plants maintain this atmosphere by adding to the reserve of atmospheric oxygen. This is balanced by cellular respiration in which energy is released from the combustion of food molecules in the presence of oxygen gas.

DID YOU KNOW?

Some athletes sleep in hypoxic tents containing only about 15% oxygen to improve their body's ability to absorb oxygen.

Connections to the Carbon Cycle

The oxygen cycle has much in common with the carbon cycle—the sinks for carbon are the sources for oxygen and vice versa. In both cases, the main processes responsible for the cycling through ecosystems are photosynthesis and cellular respiration. Despite these similarities, there are some important differences. Carbon dioxide comprises only about 0.03% of the atmosphere, whereas oxygen accounts for 21%. This means that the dynamic between carbon and oxygen is only a small part of the total oxygen system. Even though the total oxygen system also involves the cycling of other nutrients—such as sulfur, phosphorous, and nitrogen—for the sake of simplicity, only the connection to carbon is shown in this illustration. When you study the nitrogen cycle, you will see another example of a process that connects to the total oxygen system.

Human Impact on the Oxygen Cycle

Perhaps the most significant impact that people have on the oxygen cycle occurs about 10 km to 50 km above Earth's surface in a part of the atmosphere called the **ozone** layer.

ozone: a molecule comprised of three atoms of oxygen—O_3

Ozone forms when high-energy radiation from the Sun breaks apart oxygen molecules, O_2, and forms free oxygen atoms. A free oxygen atom can then react with an unbroken oxygen molecule to form ozone, O_3. Although ozone continually forms in the atmosphere, other compounds naturally present in the atmosphere destroy the ozone through chemical reactions. This balance is upset through the release of pollutants, such as chlorofluorocarbons (CFCs), that migrate to the ozone layer and cause more ozone to be broken down. The result is that the ozone layer is getting thinner. This thinning layer is a cause for concern because it shields Earth from the Sun's powerful ultraviolet radiation. This radiation is harmful to crops, to fish larvae, and to humans.

The Impact of Wildfires on the Oxygen Cycle

Decomposers may take years to break down a tree branch into simple compounds. A wildfire can accomplish the same thing in seconds. A wildfire is a powerful example of a number of oxidation reactions that rapidly release energy. Clearly, a wildfire will remove oxygen from the atmosphere. However, a fire's most significant effect may be related to the erosion that often follows the fire—this is due to rains washing away soil no longer held in place by vegetation. Minerals that had been locked up in the earth are now exposed and can chemically react with atmospheric oxygen. The chemical weathering of these minerals further depletes atmospheric oxygen.

Practice

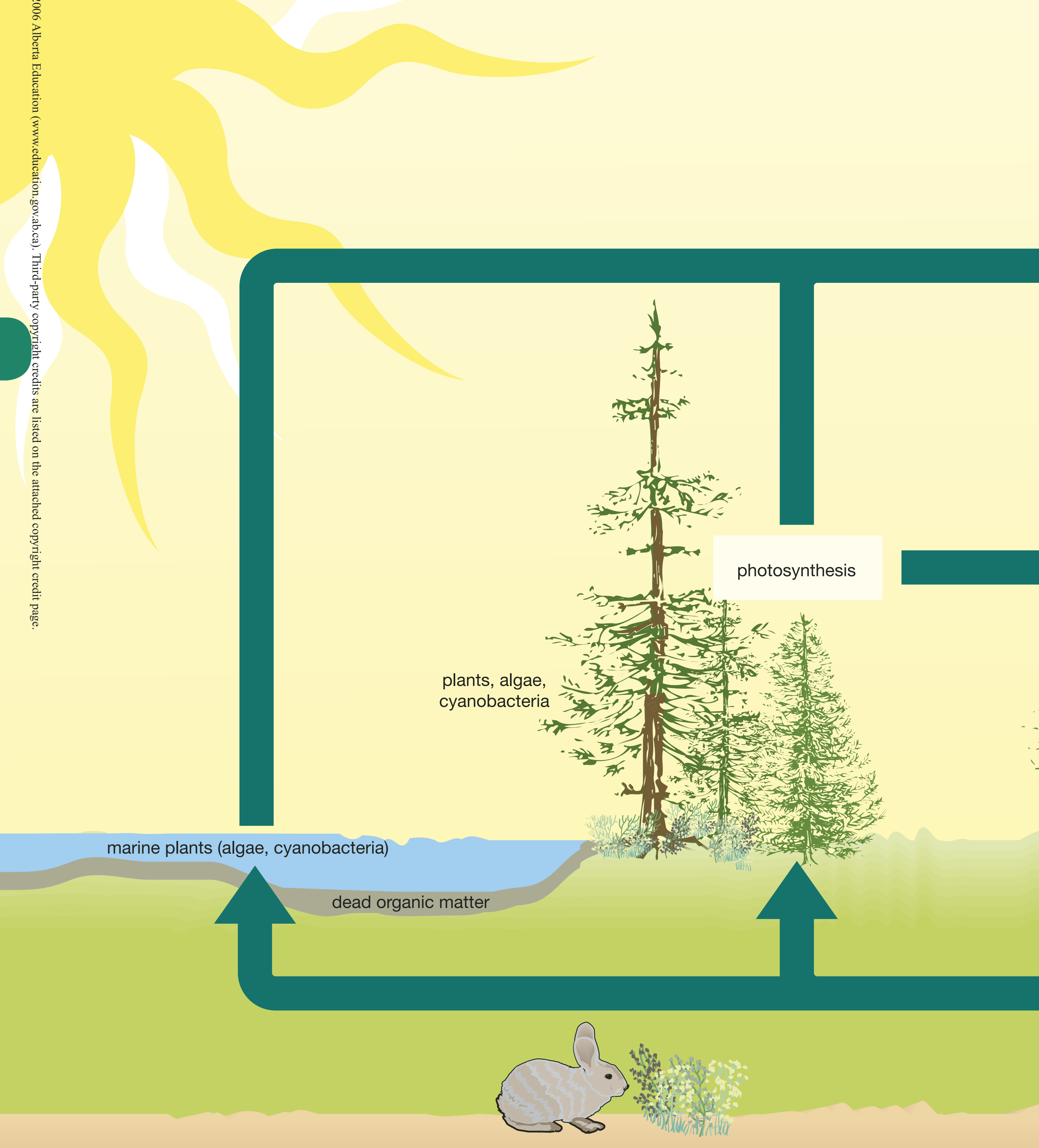
39. Sketch a unified diagram that identifies processes common to both the carbon cycle and the oxygen cycle.

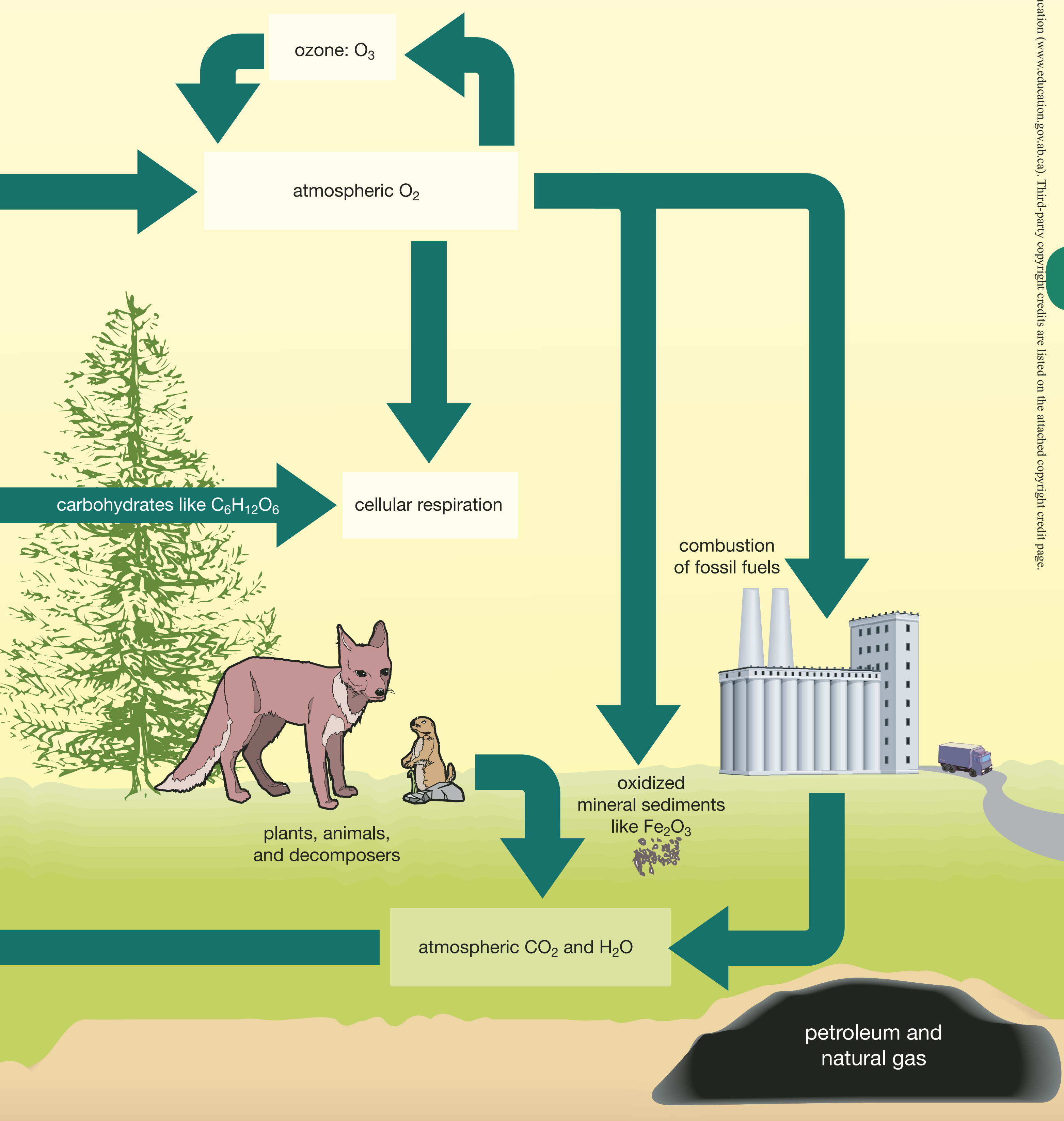
40. Identify the key forms in which carbon and oxygen will occur within both the oxygen cycle and the carbon cycle.

41. Cellular respiration is said to be an exothermic reaction because energy is released. If photosynthesis is an endothermic reaction because energy is required, identify the source of the energy for photosynthesis.

42. The fossil record suggests life did not colonize land until the atmospheric concentration of oxygen reached adequate levels. Suggest two reasons why it was essential to have the atmospheric oxygen concentration at adequate levels before life could begin on land.

The Oxygen Cycle




ozone: O3
atmospheric O2
carbohydrates like C6H12O6
cellular respiration
combustion
of fossil fuels
oxidized
mineral sediments
like Fe2O3
plants, animals,
and decomposers
atmospheric CO2 and H2O
petroleum and
natural gas

The Nitrogen Cycle

Nitrogen is critically important to life because it is a key component in biologically important molecules, such as protein and DNA. Since the atmosphere is composed of 78% nitrogen, it is reasonable to wonder why you can't get your nitrogen from breathing. After all, more than three-quarters of every breath is nitrogen! The trouble with this idea is that nitrogen gas, N_2, is non-reactive; it takes a lot of energy to break up N_2 molecules so single nitrogen atoms can be combined with other elements to form proteins. Plants and other producers have the same problem—they can't use atmospheric nitrogen either. The plants rely upon bacteria to convert nitrogen gas, N_2, into forms they can use. These other forms of nitrogen include ammonia (NH_3), nitrate ions (NO_3^-), and nitrite ions (NO_2^-). These nitrogen-containing substances are found in the waste products of many organisms and in dead and decaying organic matter.

Plants use nitrates or nitrites for their nutrients. For nitrogen gas to be used by plants, the gas has to be converted by certain types of bacteria into ammonia—this is done using a process known as **nitrogen fixation**. The bacteria involved in nitrogen fixation are found in the soil and in the nodules on the roots of plants called legumes. Other types of bacteria in the soil, known as **nitrifying bacteria**, convert ammonia into nitrates and nitrites by a process called **nitrification**. Since all cycles have to be able to return to the starting point, another soil bacteria known as **denitrifying bacteria** converts nitrates into nitrogen gas. This process is known as **denitrification**. Other non-living processes—such as lightning—may convert nitrogen gas into nitrates.

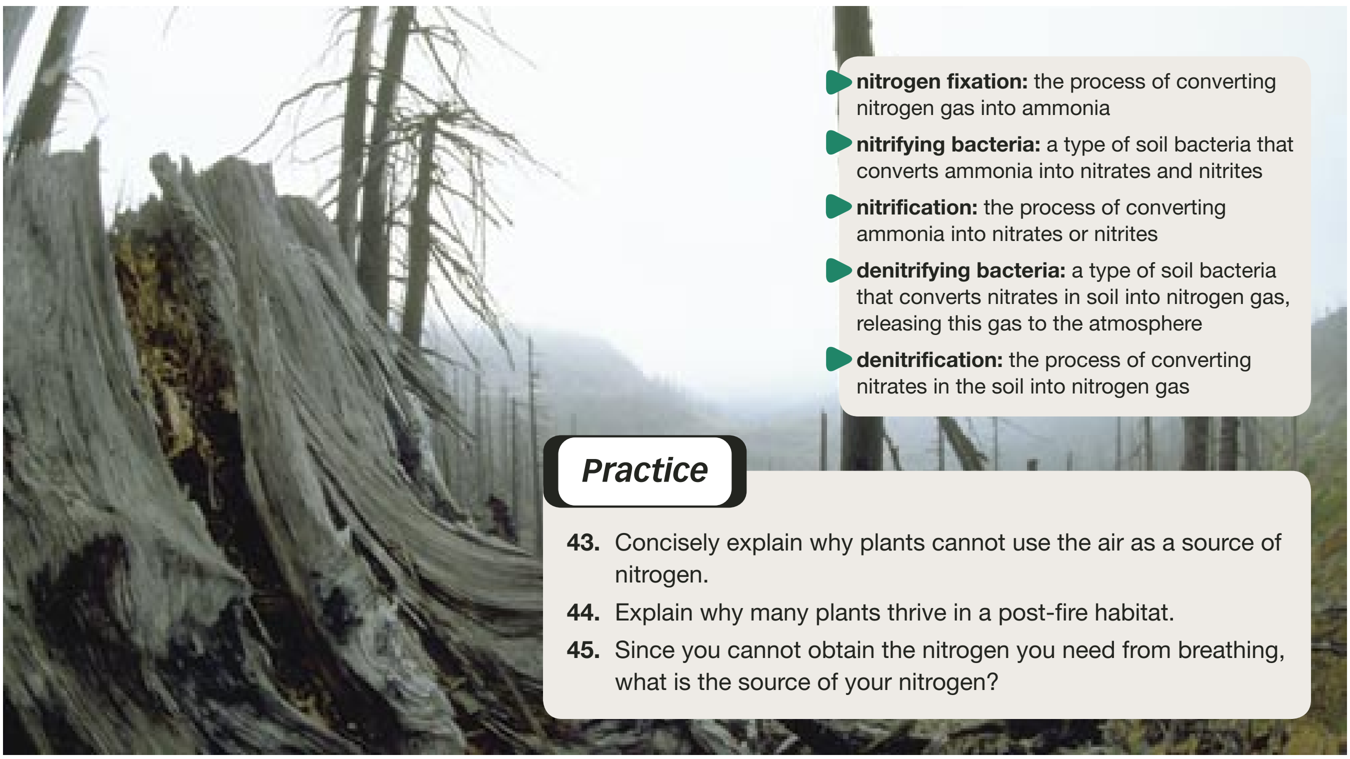
The Human Impact on the Nitrogen Cycle

Human activities primarily affect the nitrogen cycle by adding large amounts of nitrogen compounds to the water or air. Excessive fertilizers applied to crops may run off into nearby rivers or streams and result in harmful algal blooms. People also affect the nitrogen cycle through emissions from smokestacks and automobile exhaust pipes. The high temperatures of combustion produce compounds of nitrogen and oxygen (oxides of nitrogen) that may combine with rainwater to form acid rain.

The Impact of Wildfires on the Nitrogen Cycle

A wildfire breaks down organic molecules containing nitrogen into simpler forms like nitrates, ammonia, and ammonium compounds. In this respect, a wildfire has an effect similar to the work of microbes in the soil. However, a wildfire's extreme heat also means that a portion of nitrogen stored in the organic compounds of the burning vegetation is returned to the atmosphere. In spite of these losses, nitrogen-containing substances like ammonium compounds and nitrates are more abundant in the soil after a fire. A fire will also have a spinoff effect of making the soil warmer and less acidic, which creates a more favourable habitat for the many soil microbes responsible for fixing nitrogen.

An outcome of the greater availability of nitrogen in soil is demonstrated by the vibrant growth of plants in the first year after a fire. Wildflowers, especially lupins, thrive in post-fire habitats because they have nodules that contain nitrogen-fixing bacteria in their roots. These flowers take advantage of the improved soil conditions.



nitrogen fixation: the process of converting nitrogen gas into ammonia

nitrifying bacteria: a type of soil bacteria that converts ammonia into nitrates and nitrites

nitrification: the process of converting ammonia into nitrates or nitrites

denitrifying bacteria: a type of soil bacteria that converts nitrates in soil into nitrogen gas, releasing this gas to the atmosphere

denitrification: the process of converting nitrates in the soil into nitrogen gas

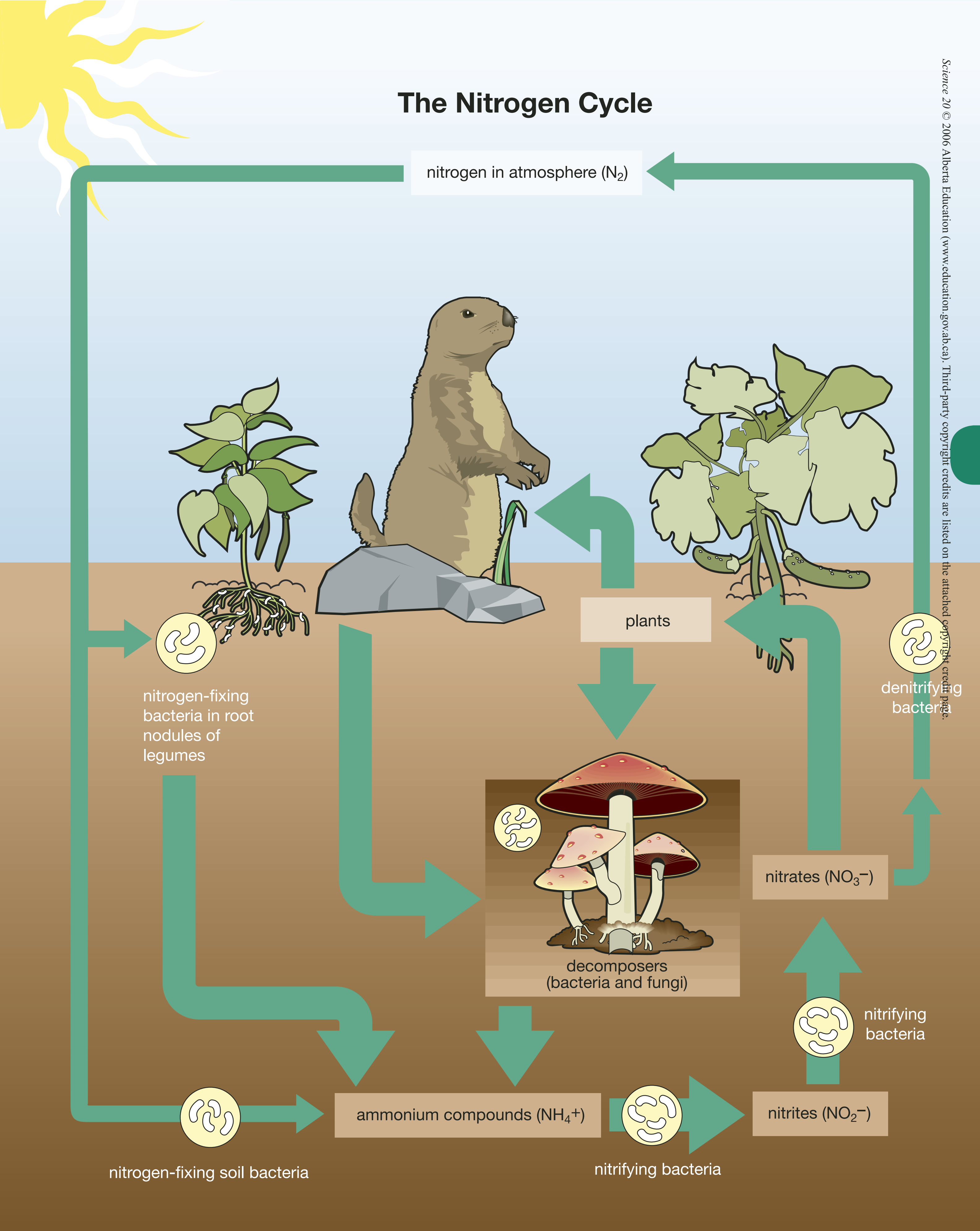
Practice

43. Concisely explain why plants cannot use the air as a source of nitrogen.

44. Explain why many plants thrive in a post-fire habitat.

45. Since you cannot obtain the nitrogen you need from breathing, what is the source of your nitrogen?

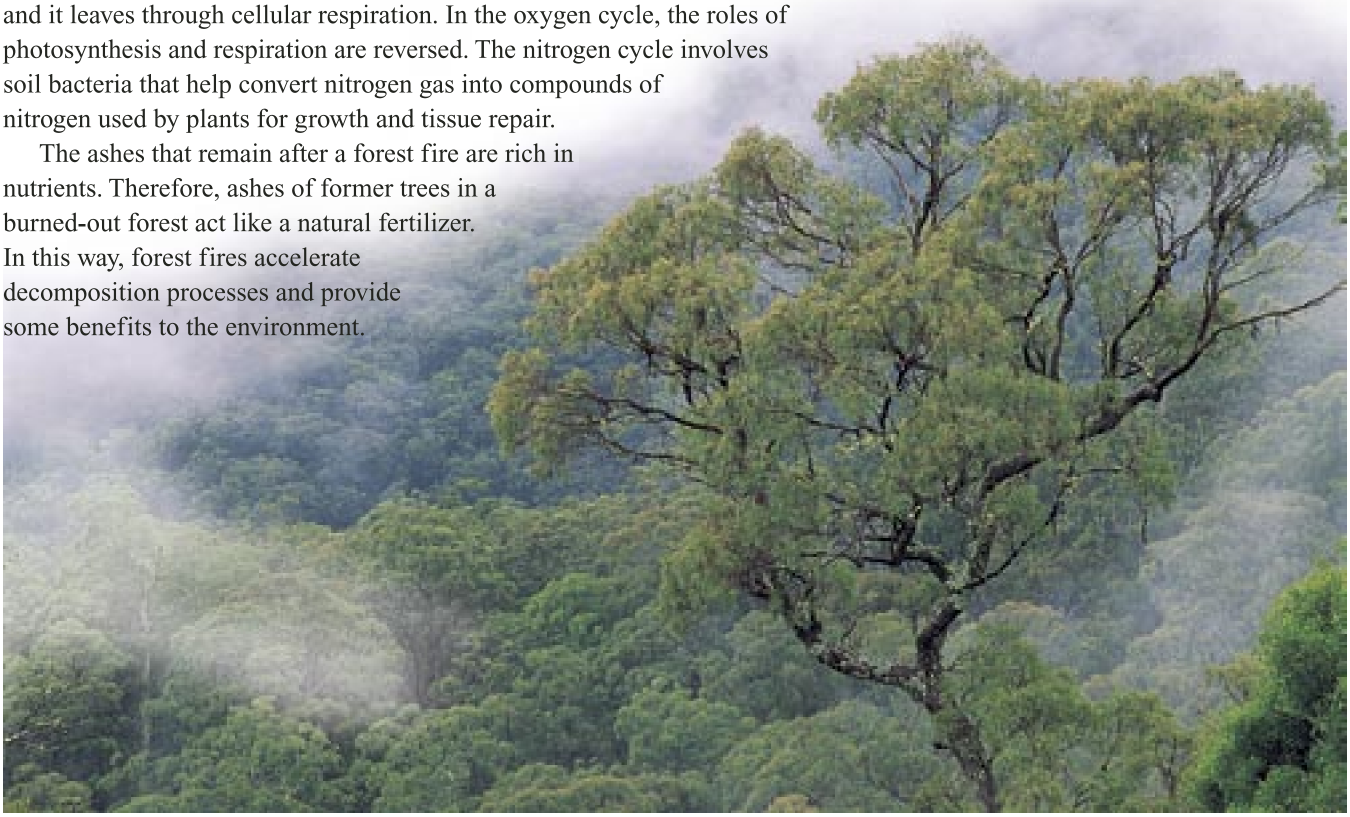
The Nitrogen Cycle



1.5 Summary

Biogeochemical cycles involve the movement of chemical elements among both the living and the non-living components of Earth. Water in the water cycle falls as precipitation and either evaporates from bodies of water, is stored in ground water, or cycles through plants and then evaporates. Carbon enters the living portion of the carbon cycle through photosynthesis, and it leaves through cellular respiration. In the oxygen cycle, the roles of photosynthesis and respiration are reversed. The nitrogen cycle involves soil bacteria that help convert nitrogen gas into compounds of nitrogen used by plants for growth and tissue repair.

The ashes that remain after a forest fire are rich in nutrients. Therefore, ashes of former trees in a burned-out forest act like a natural fertilizer. In this way, forest fires accelerate decomposition processes and provide some benefits to the environment.



1.5 Questions

Knowledge

1. Define the following terms.

- **a.** transpiration
- **b.** nitrogen fixation
- **c.** nitrification
- **d.** denitrification
- **e.** nitrifying bacteria
- **f.** denitrifying bacteria

2. What is a biogeochemical cycle? Provide several examples.

3. Describe the relationship between the carbon cycle and the oxygen cycle.

Applying Concepts

4. If approximately 78% of Earth's atmosphere is composed of nitrogen, explain how there is a shortage of nitrogen in some soils.

5. Explain the advantage of alternating wheat crops with legume crops within the same field.

6. Sewage often contains high concentrations of nitrates that could be harmful if released directly into the environment. Explain the role that denitrifying bacteria could play in sewage treatment plants.

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Legend: t = top, m = middle, b = bottom, l = left, r = right

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