Chapter 2

Earth as a System

Chapter Outline

Why It Matters

Earth's supply of matter is finite and cycles continuously among Earth's four major reservoir systems. Energy, on the other hand, must be supplied constantly to maintain this cycling and support life processes.

Inquiry Lab

15 min

Observing Water's Changes

Fill a **jar** with **room-temperature water** until it is nearly full. Place the **lid** upside down on top of the jar. Stack as many **ice cubes** as you can on top of the lid. Make and record observations for about 10 min.

Questions to Get You Started

1. What are the three states of water and all other kinds of matter?
2. Which states did you observe changing from one state to another?
3. How might this setup be used as a model for the water cycle?

READING TOOLBOX

These reading tools will help you learn the material in this chapter.

Generalizations

Characteristics of Earth Generalizations are statements that apply to a large group of things (or people). Generalizations may be signaled by words, such as *most, mostly,* or *generally*, and by phrases, such as *in general* or *for the most part*. Many generalizations, however, are not signaled by any words or phrases.

> **Example of a generalization:**
> Earth is made mostly of rock.

This statement is a generalization because

- it applies to most—but not all—of Earth's matter
- water (which covers Earth's surface) and air (which surrounds Earth's surface) are exceptions.

Your Turn Record two statements in Section 2 or 3 that are generalizations. Give one or two reasons why each is a generalization.

Fact, Hypothesis, or Theory?

Scientific Laws A scientific law describes or summarizes a pattern in nature. Scientific theories are sometimes confused with scientific laws, but they are not the same thing. Theories explain. Laws describe. The following statements apply to scientific laws:

- They describe patterns in nature.
- They are different from theories.
- They have been confirmed by experiments, or they have been observed so often that they are assumed to be true.

Your Turn As you read Section 2, record the name of each law that is discussed. Also record the pattern that the law describes or summarizes. Include an example of a situation to which the law applies to help you remember it.

Note Taking

Outlining Outlining the content of a section or chapter is a simple and effective way to take notes. To make an outline, follow the steps below.

1. List each main idea or topic, such as a section title, after a Roman numeral.
2. Add major points that give you important information about the idea or topic. List these points after capitalized letters.
3. Add subpoints that describe or explain the major points. List these subpoints after numerals.
4. Add supporting details for each subpoint. List these details after lowercase letters.

Your Turn Use outlining to take notes for Section 1. The example below, for part of Section 1, can help you get started.

I. Earth's Gravity
A. Gravity: force of attraction between all matter
1. Law of Gravitation: The force of attraction depends on masses of objects and distance between objects.

For more information on how to use these and other tools, see **Appendix A.**

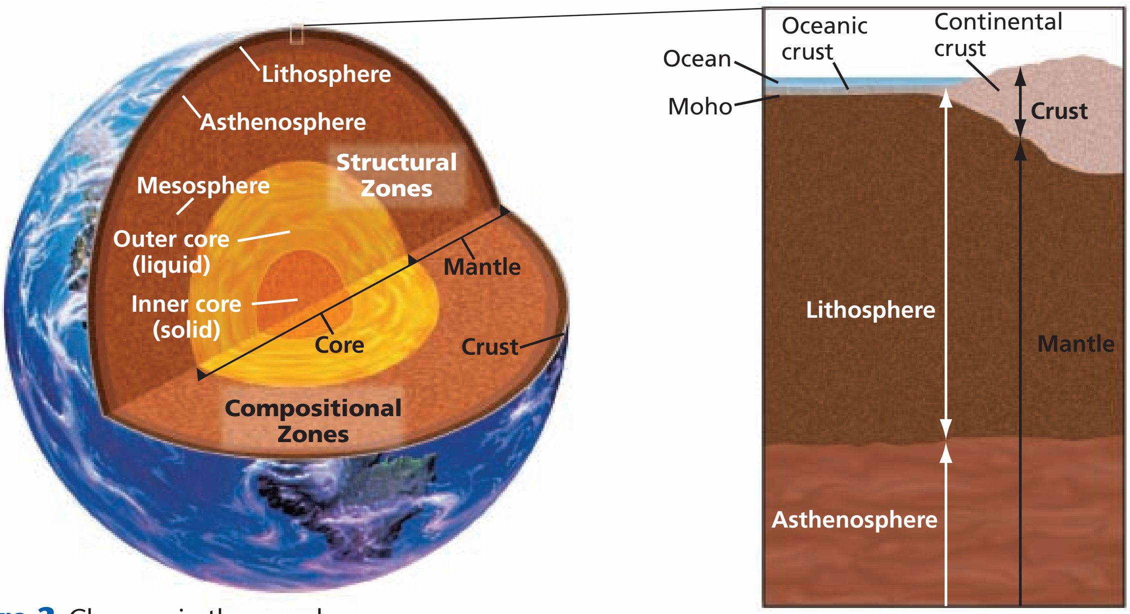

Figure 2 Changes in the speed and direction of seismic waves were used to determine the locations and properties of Earth's interior zones.

Math Skills

Speeding Waves Earth's layers are of the following average thicknesses: crust, 35 km; mantle, 2,900 km; outer core, 2,250 km; and inner core, 1,228 km. Estimate how long a seismic wave would take to reach Earth's center if the wave's average rate of travel was 8 km/s through the crust, 12 km/s through the mantle, 9.5 km/s through the outer core, and 10.5 km/s through the inner core.

crust the thin and solid outermost layer of the Earth above the mantle

mantle in Earth science, the layer of rock between Earth's crust and core

core the central part of the Earth below the mantle

Earth's Interior

Direct observation of Earth's interior has been limited to the upper few kilometers that can be reached by drilling. So, scientists rely on indirect methods to study Earth at greater depths. For example, scientists have made important discoveries about Earth's interior through studies of seismic waves. *Seismic waves* are vibrations that travel through Earth. Earthquakes and explosions near Earth's surface produce seismic waves. By studying these waves as they travel through Earth, scientists have determined that Earth is made up of three major compositional zones and five major structural zones, as shown in **Figure 2.**

Compositional Zones of Earth's Interior

The thin, solid, outermost zone of Earth is called the **crust.** The crust makes up only 1% of Earth's mass. The crust beneath the oceans is called *oceanic crust*. Oceanic crust is only 5 to 10 km thick. The part of the crust that makes up the continents is called *continental crust*. The continental crust varies in thickness and is generally between 15 and 80 km thick. Continental crust is thickest beneath high mountain ranges.

The lower boundary of the crust, which was named for its discoverer, is called the *Mohorovičić* (MOH hoh ROH vuh CHICH) *discontinuity*, or *Moho*. The **mantle,** the layer that underlies the crust, is denser than the crust. The mantle is nearly 2,900 km thick and makes up almost two-thirds of Earth's mass.

The center of Earth is a sphere whose radius is about 3,500 km. Scientists think that this center sphere, called the **core,** is composed mainly of iron and nickel.

Reading Check **Explain why scientists have to rely on indirect observations to study Earth's interior.** (See Appendix G for answers to Reading Checks.)

Structural Zones of Earth's Interior

The three compositional zones of Earth's interior are divided into five structural zones. The uppermost part of the mantle is cool and brittle. This part of the mantle and the crust above it make up the **lithosphere,** a rigid layer 15 to 300 km thick. Below the lithosphere is a less rigid layer, known as the **asthenosphere.** The asthenosphere is about 200 to 250 km thick. Because of enormous heat and pressure, the solid rock of the asthenosphere has the ability to flow. This ability to flow is called *plasticity*. Below the asthenosphere is a layer of solid mantle rock called the **mesosphere.**

At a depth of about 2,900 km lies the boundary between the mantle and the *outer core*. Scientists think that the outer core is a dense liquid. The inner core begins at a depth of 5,150 km. The inner core is a dense, rigid solid. The inner and outer core together make up nearly one-third of Earth's mass.

lithosphere the solid, outer layer of Earth that consists of the crust and the rigid upper part of the mantle

asthenosphere the solid, plastic layer of the mantle beneath the lithosphere; made of mantle rock that flows very slowly, which allows tectonic plates to move on top of it

mesosphere literally, the "middle sphere"; the strong, lower part of the mantle between the asthenosphere and the outer core

Earth as a Magnet

Earth has two magnetic poles. The lines of force of Earth's magnetic field extend between the North geomagnetic pole and the South geomagnetic pole. Earth's magnetic field, shown in **Figure 3,** extends beyond the atmosphere and affects a region of space called the *magnetosphere*.

The source of Earth's magnetic field may be the liquid iron in Earth's outer core. Scientists hypothesize that motions within the core produce electric currents that in turn create Earth's magnetic field. However, recent research indicates that the magnetic field may have another source. Scientists have learned that the sun and moon also have magnetic fields. Because the sun contains little iron and the moon does not have a liquid outer core, discovering the sources of the magnetic fields of the sun and moon may help identify the source of Earth's magnetic field.

READING TOOLBOX

Generalizations

Find at least two generalizations in Section 1. Record them in a list, and underline any words or phrases that signal the generalizations. As you read the rest of the chapter, find other generalizations and add them to your list.

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Topic: Zones of Earth
Code: **HQX1684**

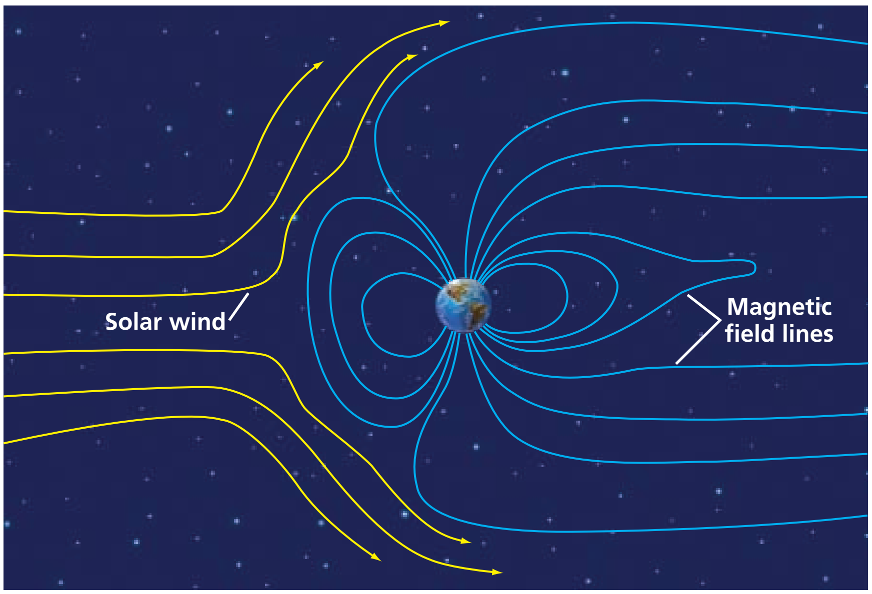

Figure 3 The magnetic field lines around Earth show the shape of Earth's magnetosphere. Earth's magnetosphere is compressed and shaped by solar wind, which is the flow of charged particles from the sun.

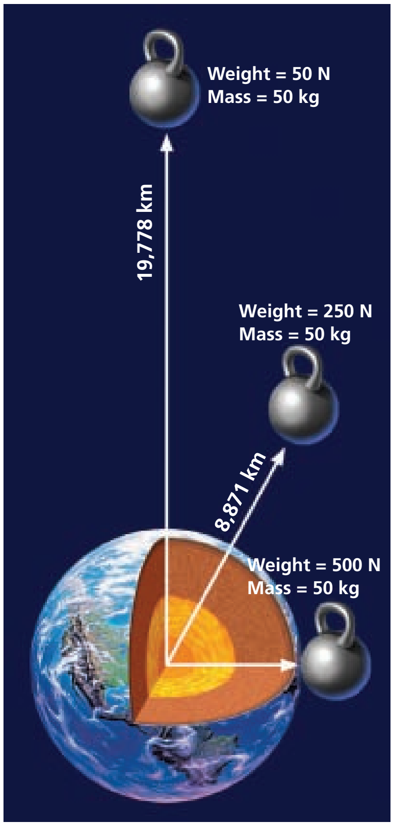

Figure 4 As the distance between an object and Earth's center changes, weight changes but mass remains constant.

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Earth's Gravity

Earth, like all objects in the universe, is affected by gravity. *Gravity* is the force of attraction that exists between all matter in the universe. The 17th-century scientist Isaac Newton was the first to explain the phenomenon of gravity. Newton described the effects of gravity in his *law of gravitation*. According to the law of gravitation, the force of attraction between any two objects depends on the masses of the objects and the distance between the objects. The larger the masses of two objects and the closer together that the two objects are, the greater the force of gravity between the objects will be.

Weight and Mass

Earth exerts a gravitational force that pulls objects toward the center of Earth. Weight is a measure of the strength of the pull of gravity on an object. The newton (N) is the SI unit used to measure weight. On Earth's surface, a kilogram of mass weighs about 10 N. The mass of an object does not change with location, but the weight of the object does. An object's weight depends on its mass and its distance from Earth's center. According to the law of gravitation, the force of gravity decreases as the distance from Earth's center increases, as shown in **Figure 4.**

Weight and Location

Weight varies according to location on Earth's surface. As you may recall, Earth spins on its axis, and this motion causes Earth to bulge near the equator. Therefore, the distance between Earth's surface and its center is greater at the equator than at the poles. This difference in distance means that your weight at the equator would be about 0.3% less than your weight at the North Pole.

Section 1 Review

Key Ideas

1. **Describe** the size and shape of Earth.
2. **Describe** two characteristics that make Earth unique in our solar system.
3. **Summarize** how scientists learn about Earth's interior.
4. **Compare** Earth's compositional layers with its structural layers.
5. **Identify** the possible source of Earth's magnetic field.
6. **Summarize** Newton's law of gravitation.

Critical Thinking

7. **Making Inferences** What does the difference between your weight at the equator and your weight at the poles suggest about Earth's shape?
8. **Making Comparisons** How does the asthenosphere differ from the mesosphere?
9. **Analyzing Ideas** Why would you weigh less on a high mountain peak than you would at sea level?

Concept Mapping

10. Use the following terms to create a concept map: *crust, mantle, core, lithosphere, asthenosphere, mesosphere, inner core,* and *outer core.*

ENVIRONMENTAL CONNECTION

SECTION 2

Energy in the Earth System

Key Ideas	Key Terms	Why It Matters
❯ Compare an open system with a closed system. ❯ List the characteristics of Earth's four major spheres. ❯ Identify the two main sources of energy in the Earth system. ❯ Identify four processes in which matter and energy cycle on Earth.	**system** **atmosphere** **hydrosphere** **geosphere** **biosphere**	Viewing Earth as a system helps scientists study ways that matter and energy interact to create and support Earth's life forms and living conditions.

Traditionally, different fields of Earth science have been studied separately. Geologists studied Earth's rocks and interior, oceanographers studied the oceans, and meteorologists studied the atmosphere. But now, some scientists are combining knowledge of several fields of Earth science in order to study Earth as a system.

Earth-System Science

An organized group of related objects or components that interact to create a whole is a **system.** Systems vary in size from subatomic to the size of the universe. All systems have boundaries, and many systems have matter and energy that flow through them. Even though each system can be described separately, all systems are linked. A large and complex system, such as the Earth system, operates as a result of the combination of smaller, interrelated systems, as shown in **Figure 1.**

system a set of particles or interacting components considered to be a distinct physical entity for the purpose of study

The operation of the Earth system is a result of interaction between the two most basic components of the universe: matter and energy. *Matter* is anything that has mass and takes up space. Matter can be atoms or molecules, such as oxygen atoms or water molecules, and matter can be larger objects, such as rocks, living organisms, or planets. *Energy* is defined as the ability to do work. Energy can be transferred in a variety of forms, including heat, light, vibrations, or electromagnetic waves. A system can be described by the way that matter and energy are transferred within the system or to and from other systems. Transfers of matter and energy are commonly accompanied by changes in the physical or chemical properties of the matter.

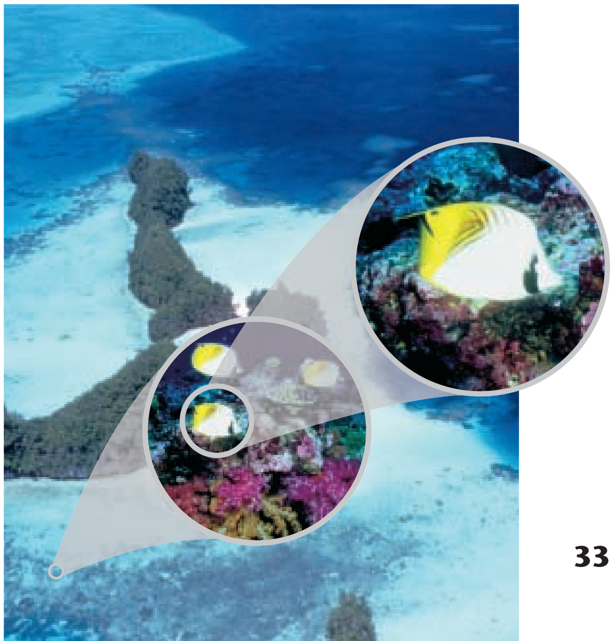
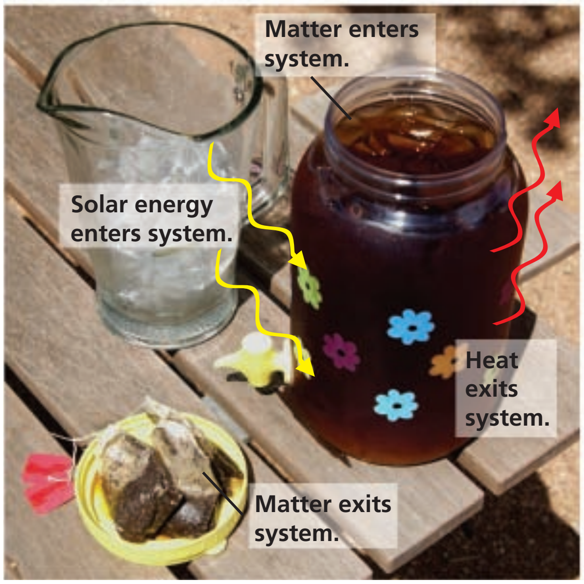


Figure 1 This threadfin butterflyfish is part of a system that includes other living organisms, such as coral. Together, the organisms are part of a larger system, a coral reef system in Micronesia.



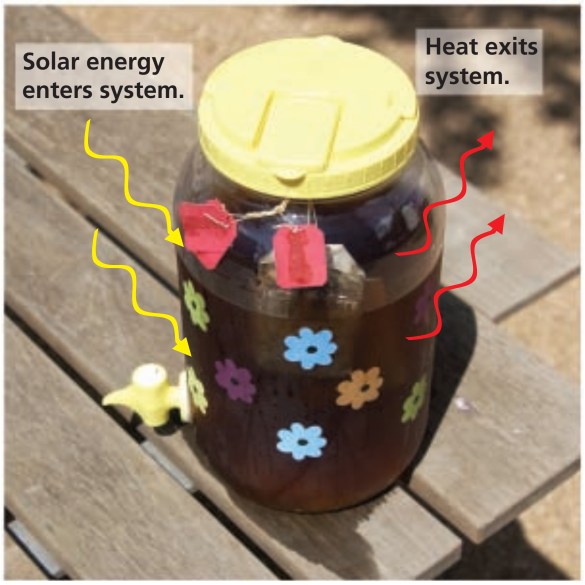


Figure 2 Energy is exchanged in both the open system (left) and the closed system (right). In the open system, matter is also exchanged.

Open Systems

An *open system* is a system in which both energy and matter are exchanged with the surroundings. The open jar in **Figure 2** is an open system. A lake is also an open system. Water molecules enter a lake through rainfall and streams. Water exits a lake through streams, evaporation, and absorption by the ground. Sunlight and air exchange heat with the lake. Wind's energy is transferred to the lake as waves.

Closed Systems

A *closed system* is a system in which energy, but not matter, is exchanged with the surroundings. The sealed jar in **Figure 2** is a closed system. Energy in the form of light and heat can be exchanged through the jar's sides. But because the jar is sealed, matter cannot exit or enter the system. Most aquariums are open systems because oxygen and food must be added to them, but some are closed systems. Closed-system aquariums contain a variety of organisms: plants, which produce oxygen, and aquatic animals, some of which are food for others. Some of the animals feed on the plants. Animal wastes and organic matter nourish the plants. Only sunlight enters from the surroundings.

The Earth System

Technically, all systems that make up the Earth system are open. But the Earth system is almost a closed system because matter exchange is limited. Energy enters the system in the form of sunlight and is released into space as heat. Only a small amount of dust and rock from space enters the system, and only a fraction of the hydrogen atoms in the atmosphere escape into space.

Reading Check **What types of matter and energy are exchanged between Earth and space?**

Earth's Four Spheres

Matter on Earth is in solid, liquid, and gaseous states. The Earth system is composed of four "spheres" that are storehouses of all of the planet's matter. These four spheres are shown in **Figure 3.**

The Atmosphere

The blanket of gases that surrounds Earth's surface is called the **atmosphere.** The atmosphere provides the air that you breathe and shields Earth from the sun's harmful radiation. Earth's atmosphere is made up of 78% nitrogen and 21% oxygen. The remaining 1% includes other gases, such as argon, carbon dioxide, and helium.

atmosphere a mixture of gases that surrounds a planet, moon, or other celestial body

hydrosphere the portion of the Earth that is water

geosphere the mostly solid, rocky part of the Earth; extends from the center of the core to the surface of the crust

biosphere the part of Earth where life exists; includes all of the living organisms on Earth

The Hydrosphere

Water covers much of Earth's surface, and 97% of this water is contained in the salty oceans. The remaining 3% is fresh water. Fresh water can be found in lakes, rivers, and streams, frozen in glaciers and the polar ice sheets, and underground in soil and bedrock. All of Earth's water makes up the **hydrosphere.**

The Geosphere

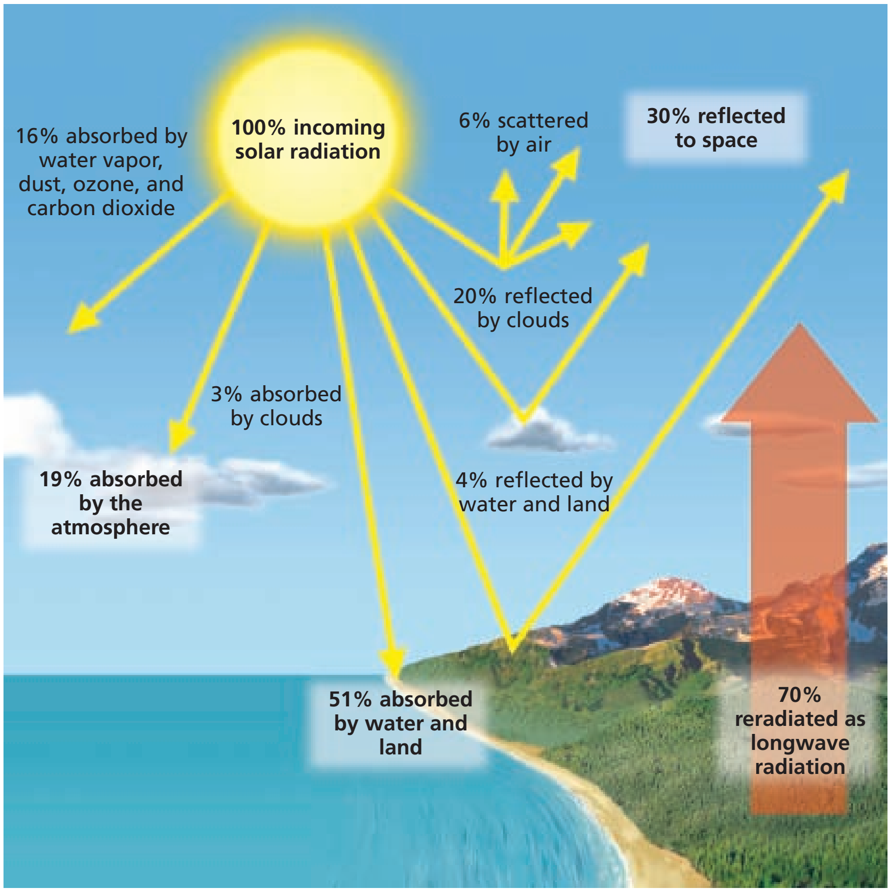
The mostly solid part of Earth is known as the **geosphere.** This sphere includes all of the rock and soil on the surface of the continents and on the ocean floor. The geosphere also includes the solid and molten interior of Earth, which makes up the largest volume of matter on Earth. Natural processes, such as volcanism, bring matter from deep inside Earth's interior to the surface. Other processes move surface matter back into Earth's interior.

The Biosphere

Another one of the four subdivisions of the Earth system is the biosphere. The **biosphere** is composed of all of the forms of life in the geosphere, in the hydrosphere, and in the atmosphere. The biosphere also contains any organic matter that has not decomposed. Once organic matter has completely decomposed, it becomes a part of the other three spheres. The biosphere extends from the deepest parts of the ocean to the atmosphere a few kilometers above Earth's surface.

Figure 3 The Earth system is composed of the atmosphere, hydrosphere, geosphere, and biosphere. ***Can you identify elements of the four spheres in this photo?***

Figure 4 Incoming solar energy is balanced by solar energy reflected or reradiated by several of Earth's systems.



Earth's Energy Budget

Exchanges and flow of energy on Earth happen in predictable ways. According to the *first law of thermodynamics*, energy is transferred between systems, but it cannot be created or destroyed. The transfers of energy between Earth's spheres can be thought of as parts of an *energy budget*, in which additions in energy are balanced by subtractions. This concept is shown in **Figure 4,** which shows how solar energy is transferred through Earth's systems. Solar energy is absorbed and reflected in such a way that the solar energy input is balanced by the solar energy output. Like energy, matter can be transferred but cannot be created or destroyed.

The *second law of thermodynamics* states that when energy transfer takes place, matter becomes less organized with time. The overall effect of this natural law is that the universe's energy is spread out more and more uniformly over time.

Earth's four main spheres are open systems that can be thought of as huge storehouses of matter and energy. Matter and energy are constantly being exchanged between the spheres. This constant exchange happens through chemical reactions, radioactive decay, the radiation of energy (including light and heat), and the growth and decay of organisms.

Reading Check **Define *energy budget*.**

Internal Sources of Energy

When Earth formed about 4.6 billion years ago, its interior was heated by radioactive decay and gravitational contraction. Since that time, the amount of energy as heat generated by radioactive decay has declined. But the decay of radioactive atoms still generates enough energy to keep Earth's interior hot. Earth's interior also retains much of the energy from the planet's formation.

Because Earth's interior is warmer than its surface layers, hot materials move toward the surface in a process called *convection*. As material is heated, the material's density decreases, and the hot material rises and releases energy as heat. Cooler, denser material sinks and displaces the hot material. As a result, the energy in Earth's interior is transferred through the layers of Earth and is released at Earth's surface as heat. On a large scale, this process drives the motions in the surface layers of the geosphere that create mountain ranges and ocean basins.

External Energy Sources

In order for the life-supporting processes on Earth to continue operating for billions of years, energy must be added to the Earth system. Earth's most important external energy source is the sun. Solar radiation warms Earth's atmosphere and surface. This heating causes the movement of air masses, which generates winds and ocean currents. Plants, such as the wheat shown in **Figure 5,** use solar energy to fuel their growth. Because many animals feed on plants, plants provide the energy that acts as a base for the energy flow through the biosphere. Even the chemical reactions that break down rock into soil require solar energy. Another important external source of energy is gravitational energy from the moon and sun. The pull of the sun and the moon on the oceans, combined with Earth's rotation, generates tides that cause currents and drive the mixing of ocean water.

Quick Lab — 10 min

Effects of Solar Energy

Procedure

1. Wrap one **small glass jar** with **black construction paper** so that no light can enter it. Get a **second glass jar.** Make sure that the second jar has a clean, transparent surface.
2. Use a **hammer** and **large nail** to punch a hole in each jar lid.
3. Place a **thermometer** through the hole in each jar lid. Place the lids tightly onto the jars.
4. Place the jars on the windowsill. Wait 5 min. Then, read the temperature from each jar's thermometer.

Analysis

1. Which jar had the higher temperature?
2. Which jar represents a system in which energy enters from outside the system?

Figure 5 Solar energy is changed into stored energy in the wheat kernels by chemical processes in the wheat plant. When the wheat is eaten, the stored energy is released from the wheat and used or stored by the consumer.

Cycles in the Earth System

A *reservoir* is a place where matter or energy is stored. A *cycle* is a group of processes in which matter repeatedly moves through a series of reservoirs. Many elements on Earth cycle between reservoirs. These cycles rely on energy sources to drive them. The length of time that energy or matter spends in a reservoir can vary from a few hours to several million years.

READING TOOLBOX

Outlining
Use outlining to make notes about the main ideas in Section 2. Use the red- and green-colored topic headings to help you organize your notes. Trading outlines with other students can help you learn how to improve your outlining skills.

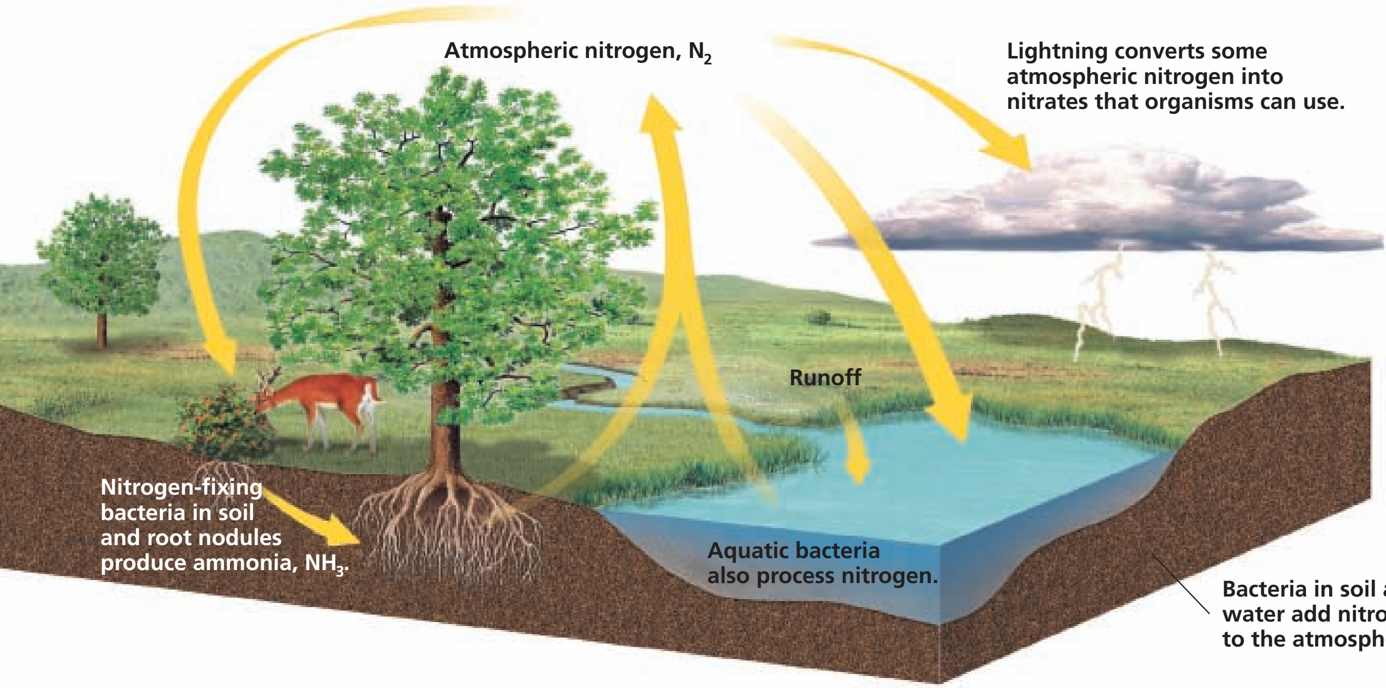
The Nitrogen Cycle

Organisms on Earth use the element nitrogen to build proteins, which are then used to build cells. Nitrogen gas makes up 78% of the atmosphere, but most organisms cannot use the atmospheric form of nitrogen. The nitrogen must be altered, or *fixed*, before organisms can use it. Nitrogen fixing is an important step in the *nitrogen cycle*, which is shown in **Figure 6.**

In the nitrogen cycle, nitrogen moves from air to soil, from soil to plants and animals, and back to air again. Nitrogen is removed from air mainly by the action of nitrogen-fixing bacteria. These bacteria live in soil and on the roots of certain plants. The bacteria chemically change nitrogen from air into nitrogen compounds, which are vital to the growth of all plants. When animals eat plants, nitrogen compounds in the plants become part of the animals' bodies. These compounds are returned to the soil by the decay of dead animals and in animals' excretions. After nitrogen compounds enter the soil, chemical processes release nitrogen back into the atmosphere. Water-dwelling plants and animals take part in a similar nitrogen cycle.

Reading Check **Identify two nitrogen reservoirs on Earth.**

Figure 6 The balance of nitrogen in the atmosphere and biosphere is maintained through the nitrogen cycle. ***What role do animals play in the nitrogen cycle?***



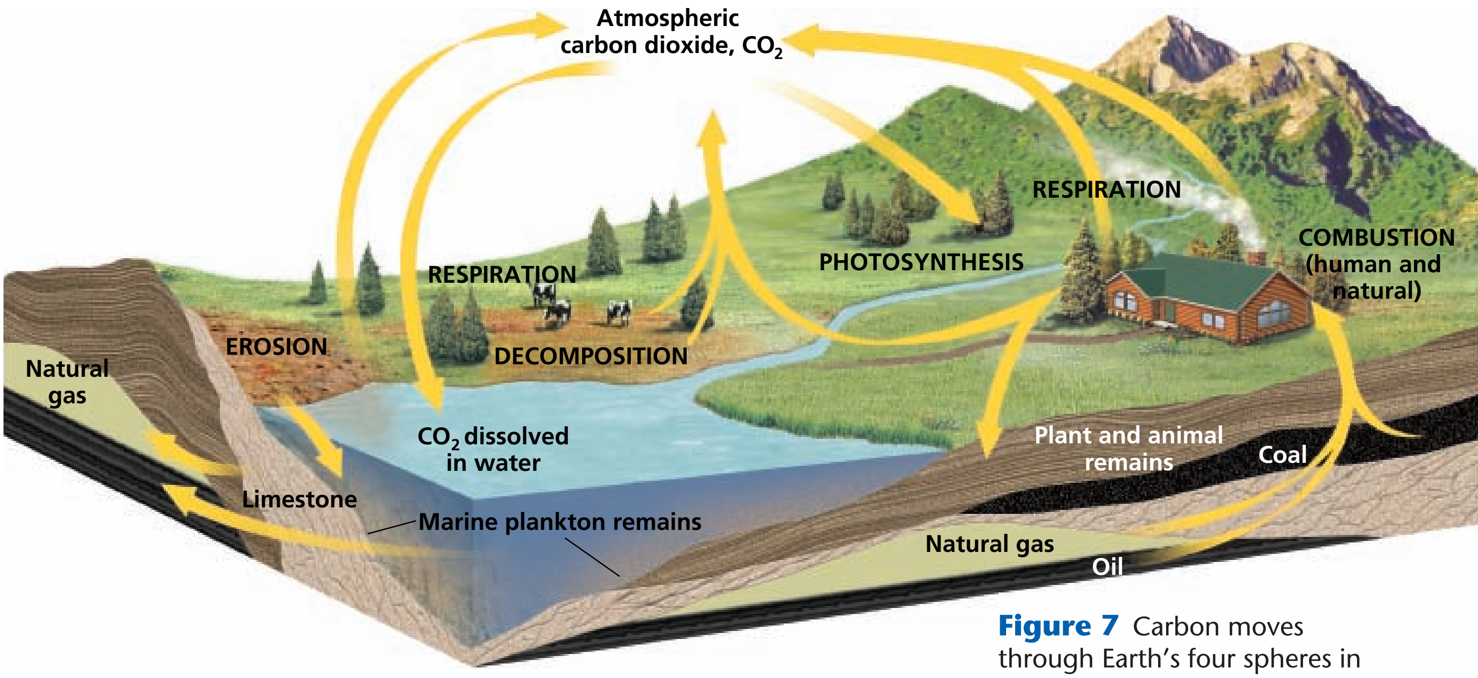


Figure 7 Carbon moves through Earth's four spheres in a combination of short-term and long-term cycles.

The Carbon Cycle

Carbon is an essential substance in the fuels used for life processes. Carbon moves through all four spheres in a process called the *carbon cycle*, as **Figure 7** shows. Part of the carbon cycle is a short-term cycle. In this short-term cycle, plants convert carbon dioxide, CO_2, from the atmosphere into carbohydrates, such as glucose, $C_6H_{12}O_6$. Then, organisms eat the plants and obtain the carbon from the carbohydrates. Next, organisms' bodies break down the carbohydrates and release some of the carbon back into the air as CO_2. Organisms also release carbon into the air through their organic wastes and by the decay of their remains, which release carbon into the air as CO_2 or as methane, CH_4.

Part of the carbon cycle is a long-term cycle in which carbon moves through Earth's four spheres over a very long time. Carbon is stored in the geosphere in buried plant or animal remains and in a type of rock called a *carbonate*, such as limestone. Carbonate forms from shells and bones of once-living organisms.

SCILINKS.
www.scilinks.org
Topic: Carbon Cycle
Code: **HQX0216**
Topic: Nitrogen Cycle
Code: **HQX1036**

The Phosphorus Cycle

The element phosphorus is part of some molecules that organisms need to build cells. During the *phosphorus cycle*, phosphorus moves through every sphere except the atmosphere, because phosphorus is rarely a gas. Phosphorus enters soil and water when rock breaks down and when phosphorus dissolves in water. Some organisms excrete their excess phosphorus in their waste, and this phosphorus may enter soil and water. Plants absorb this phosphorus through their roots. The plants then incorporate it into their tissues. Animals absorb the phosphorus when they eat the plants. When the animals die, the phosphorus returns to the environment through decomposition.

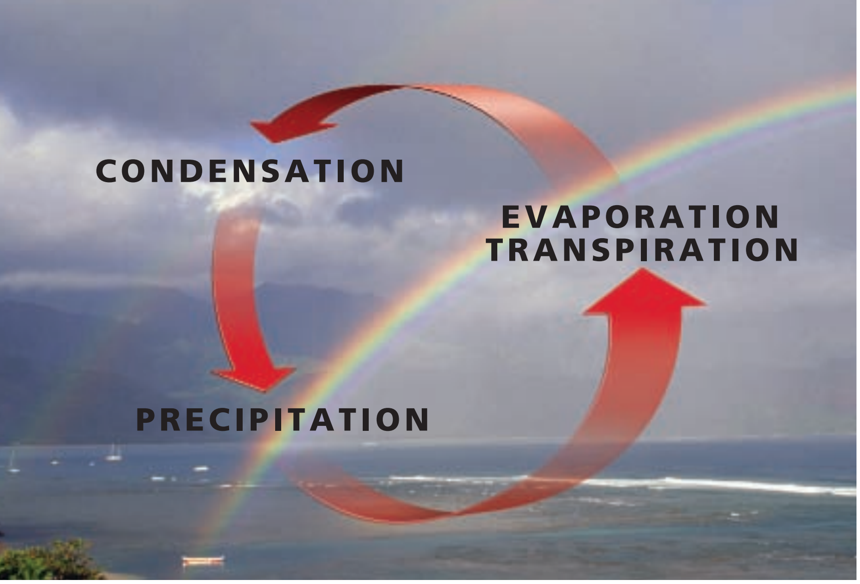


Figure 8 The water cycle is the continuous movement of water from the atmosphere to Earth's surface and back to the atmosphere.

The Water Cycle

The movement of water from the atmosphere to Earth's surface and back to the atmosphere is always taking place. This continuous movement of water is called the *water cycle*, which is shown in **Figure 8.** In the water cycle, water changes from liquid water to water vapor through the energy transfers involved in evaporation and transpiration. Evaporation occurs when energy is absorbed by liquid water and the energy changes the water into water vapor. Transpiration is the release of moisture from plant leaves. During these processes, water absorbs energy and changes state. When the water loses energy, it condenses to form water droplets, such as those that form clouds. Eventually, water falls back to Earth's surface as precipitation, such as rain, snow, or hail.

Humans and the Earth System

All natural cycles can be altered by human activities. The carbon cycle is affected when humans use fossil fuels. Fossil fuels form over millions of years. Carbon dioxide is returned to the atmospheric reservoir rapidly when humans burn these fuels. Also, both the nitrogen and phosphorus cycles are affected by agriculture. Some farming techniques can strip the soil of nitrogen and phosphorus. Many farmers replace these nutrients by using fertilizers, which can upset the balance of these elements in nature.

Section 2 Review

Key Ideas

1. **Explain** how Earth can be considered a system.
2. **Compare** an open system with a closed system.
3. **List** two characteristics of each of Earth's four major spheres.
4. **Identify** the two main sources of energy in Earth's system.
5. **Identify** four processes in which matter cycles on Earth.
6. **Explain** how carbon cycles in Earth's system.
7. **Explain** how nitrogen cycles in Earth's system.

Critical Thinking

8. **Identifying Relationships** For each of Earth's four spheres, describe one way that the water cycle affects the sphere.
9. **Determining Cause and Effect** What effect, if any, would you expect a massive forest fire to have on the amount of carbon dioxide in the atmosphere? Explain your answer.
10. **Analyzing Ideas** Early Earth was constantly being bombarded by meteorites, comets, and asteroids. Was early Earth an open system or a closed system? Explain your answer.
11. **Analyzing Relationships** Explain the role of energy in the carbon cycle.

Concept Mapping

12. Use the following terms to create a concept map: *closed system, system, open system, matter, atmosphere, biosphere, energy, geosphere,* and *hydrosphere.*

ENVIRONMENTAL CONNECTION

SECTION 3
Ecology

Key Ideas	Key Terms	Why It Matters
❯ Define *ecosystem.* ❯ Identify three factors that control the balance of an ecosystem. ❯ Summarize how energy is transferred through an ecosystem. ❯ Describe one way that ecosystems respond to environmental change.	**ecosystem** **carrying capacity** **food web**	The study of ecology demonstrates, and helps us appreciate, the interconnectedness of all the Earth systems that support and sustain humans and all other living things.

One area of science in which life science and Earth science are closely linked is called *ecology*. Ecology is the study of the complex relationships between living things and their nonliving, or *abiotic,* environment. Some ecologists also investigate how communities of organisms change over time.

Ecosystems

Organisms on Earth inhabit many different environments. A community of organisms and the abiotic environment that the organisms inhabit is called an **ecosystem.** The terms *ecology* and *ecosystem* come from the Greek word *oikos*, which means "house." Each ecosystem on Earth is a distinct, self-supporting system. An ecosystem may be as large as an ocean or as small as a drop of water. The largest ecosystem is the entire biosphere.

ecosystem a community of organisms and their abiotic environment

Most of Earth's ecosystems contain a variety of plants and animals. Plants are important to an ecosystem because they use energy from the sun to produce their own food. Organisms that make their own food are called *producers*. Producers are a source of food for other organisms. *Consumers* are organisms that get their energy by eating other organisms. Consumers may get energy by eating producers or by eating other consumers, as the consumers shown in **Figure 1** are doing. Some consumers get energy by breaking down dead organisms. These consumers are called *decomposers*. To remain healthy, an ecosystem needs to have a balance of producers, consumers, and decomposers.

Figure 1 Vultures and a spotted hyena are feeding on an elephant carcass in Chobe National Park in Botswana. ***Name two consumers that are shown in this photo.***

Figure 2 The fur of this elk calf was singed in a forest fire in Yellowstone National Park.

Balancing Forces in Ecosystems

Organisms in an ecosystem use matter and energy. Because amounts of matter and energy in an ecosystem are limited, population growth within the ecosystem is limited, too. The largest population that an environment can support at any given time is called the **carrying capacity.** Carrying capacity depends on available resources. The carrying capacity of an ecosystem is also affected by how easily matter and energy are transferred between life-forms and the environment in that ecosystem. So, a given ecosystem can support only the number of organisms that allows matter and energy to be transferred efficiently through the ecosystem.

Ecological Responses to Change

Changes in any one part of an ecosystem may affect the entire system in unpredictable ways. However, in general, ecosystems react to changes in ways that maintain or restore balance in the ecosystem.

Environmental change in the form of a sudden disturbance, such as a forest fire, can greatly damage and disrupt ecosystems, as shown in **Figure 2.** But over time, organisms will migrate back into damaged areas in predictable patterns. First, grasses and fast-growing plants will start to grow. Then, shrubs and small animal species will return. Eventually, larger tree species and larger animals will return to the area. Ecosystems are resilient and tend to restore a community of organisms to a state like its original state unless the physical environment is permanently altered.

carrying capacity the largest population that an environment can support at any given time

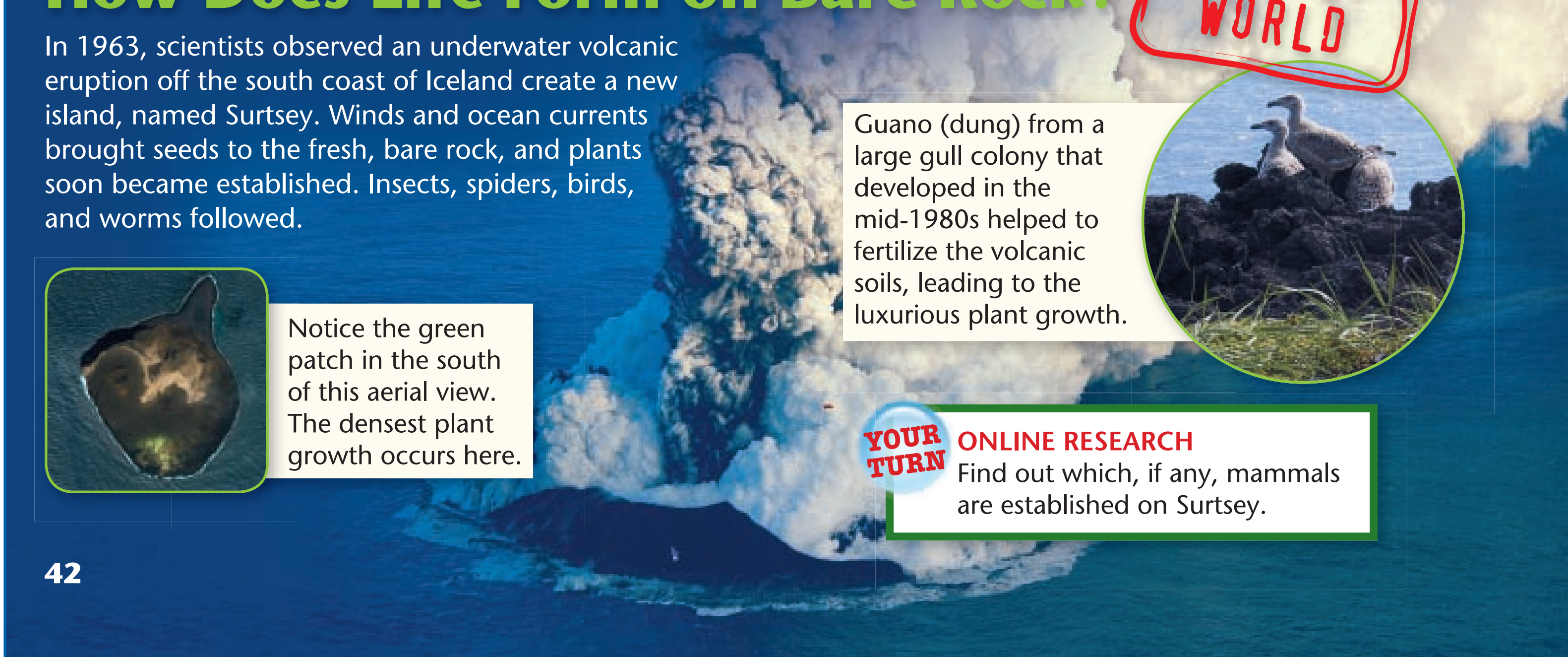
Reading Check **Explain the relationship between carrying capacity and the amount of matter and energy in an ecosystem.**

Why It Matters

How Does Life Form on Bare Rock?

REAL WORLD

In 1963, scientists observed an underwater volcanic eruption off the south coast of Iceland create a new island, named Surtsey. Winds and ocean currents brought seeds to the fresh, bare rock, and plants soon became established. Insects, spiders, birds, and worms followed.



Notice the green patch in the south of this aerial view. The densest plant growth occurs here.

Guano (dung) from a large gull colony that developed in the mid-1980s helped to fertilize the volcanic soils, leading to the luxurious plant growth.

YOUR TURN
ONLINE RESEARCH
Find out which, if any, mammals are established on Surtsey.

Energy Transfer

The ultimate source of energy for almost every ecosystem is the sun. Plants capture solar energy by a chemical process called *photosynthesis*. This captured energy then flows through ecosystems from the plants, to the animals that feed on the plants, and finally to the decomposers of animal and plant remains. Matter also cycles through an ecosystem by this process.

As matter cycles and energy flows through an ecosystem, chemical elements are combined and recombined. Each chemical change results in either the temporary storage of energy or the loss of energy. One way to see how energy is lost as it moves through the ecosystem is to draw an energy pyramid. Producers form the base of the pyramid. Consumers that eat producers are the next level of the pyramid. Animals that eat those consumers form the upper levels of the pyramid. As you move up the pyramid, more energy is lost at each level. Therefore, the least amount of total energy is available to organisms at the top of the pyramid.

Food Chains and Food Webs

The sequence in which organisms consume other organisms can be represented by a *food chain*. However, ecosystems are complex and generally contain more organisms than are on a single food chain. In addition, many organisms eat more than just one other species. Therefore, a **food web,** such as the one shown in **Figure 3,** is used to represent the relationships between multiple food chains. Each arrow points to the organism that eats the organism at the base of the arrow.

Quick Lab

20 min

Studying Ecosystems

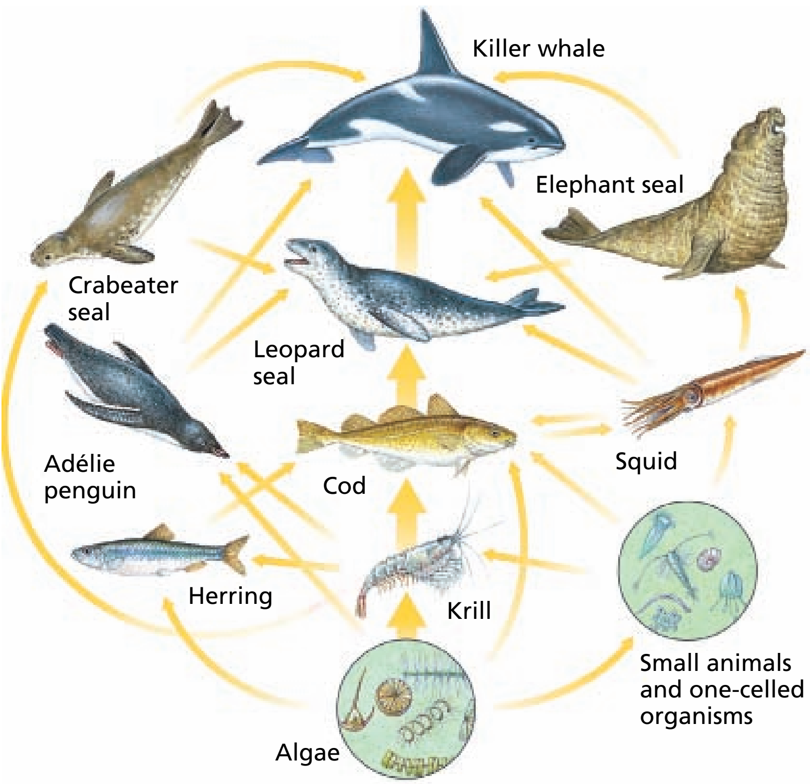
Procedure

1. Find a small natural area near your school.
2. Choose a 5 m by 5 m section of the natural area to study. This area may include the ground or vegetation such as trees or bushes.
3. Spend 10 min documenting the number and types of organisms that live in the area.

Analysis

1. How many kinds of organisms live in the area that you studied?
2. Draw a food web that describes how energy may flow through the ecosystem that you studied.

food web a diagram that shows the feeding relationships among organisms in an ecosystem



THINK central INTERACT ONLINE Keyword: HQXEASF3

Figure 3 This food web shows how, in an ocean ecosystem, the largest organisms, such as killer whales, depend on the smallest organisms, such as algae. ***Which organisms would be near the top of a food pyramid?***

Figure 4 These hikers are acting responsibly by choosing to remain on marked trails in the rain forest. In this way, they are helping prevent ecological damage to the area.

Human Stewardship of the Environment

All of Earth's systems are interconnected, and changes in one system may affect the operation of other systems. Earth's ecosystems provide a wide variety of resources on which people depend. People need water and air to survive. Changes in ecosystems can affect the ability of an area to sustain a human population. For example, the quality of the atmosphere, the productivity of soils, and the availability of natural resources can affect the availability of food.

Ecological balances can be disrupted by human activity. Populations of plants and animals can be destroyed through overconsumption of resources. When humans convert large natural areas to agricultural or urban areas, natural ecosystems are often destroyed. Another serious threat to ecosystems is pollution. *Pollution* is the contamination of the environment with harmful waste products or impurities.

When people, such as those in **Figure 4**, strive to prevent ecological damage to an area, they are trying to be responsible stewards of Earth. To help ensure the ongoing health and productivity of the Earth system, many people work to use Earth's resources wisely. By using fossil fuels, land and water resources, and other natural resources wisely, many people are helping keep Earth's ecosystems in balance.

Section 3 Review

Key Ideas

1. **Define** *ecosystem.*
2. **Explain** why the entire biosphere is an ecosystem.
3. **Identify** three factors that control the balance of an ecosystem.
4. **Summarize** how energy is transferred between the sun and consumers in an ecosystem.
5. **Describe** one way that ecosystems respond to environmental change.
6. **Compare** a food chain with a food web.
7. **Summarize** the importance of good stewardship of Earth's resources.

Critical Thinking

8. **Making Inferences** Discuss two ways that the expansion of urban areas might be harmful to nearby ecosystems.
9. **Analyzing Ideas** Why would adapting to a gradual change in environment be easier for an ecosystem than adapting to a sudden disturbance would be?
10. **Making Inferences** Why does energy flow in only one direction in a given food chain of an ecosystem?

Concept Mapping

11. Use the following terms to create a concept map: *ecology, ecosystem, producer, decomposer, carrying capacity, consumer,* and *food web.*

Why It Matters

Fish that Feed the Forest

WEIRD SCIENCE

Food webs and cycles can involve some unlikely participants. Did you know that salmon nourish the forests of North America's Pacific coast? Up to 77% of the nitrogen in coastal rain-forest trees comes from the ocean. Trees that grow close to inland salmon-spawning streams, such as Sitka spruce, grow faster than trees that do not. By understanding the links between different Earth systems, scientists have pieced together an unexpected relationship between nitrogen from the ocean, bears, salmon, and inland rain-forest trees.

Salmon spend most of their lives in the ocean. Before they die, they migrate from the ocean, up freshwater rivers and into inland streams to spawn. In the shallow waters of their spawning grounds, salmon are easy prey to predators, such as bears.

Bears often drag the salmon they catch into the forest. They often eat only their favorite parts of the fish and leave the rest to decay on the forest floor. The decaying nitrogen-rich carcasses become the fertilizer that ensures the health of the rain forest.

YOUR TURN

UNDERSTANDING CONCEPTS
How does nitrogen from the ocean end up in inland coastal trees?

CRITICAL THINKING
What could happen to the coastal rain forests if salmon populations decreased dramatically?

Testing the Conservation of Mass

What You'll Do

- **Measure** the masses of reactants and products in a chemical reaction.
- **Describe** how measuring masses of reactants and products can illustrate the law of conservation of mass.

What You'll Need

bag, plastic sandwich, zipper-type closure
baking soda (sodium bicarbonate)
balance (or scale), metric
beaker, 400 mL
cup, clear plastic, 150 mL (2)
graduated cylinder, 100 mL
paper, weighing (2 pieces)
twist tie
vinegar (acetic acid solution)
water

Safety

As matter cycles through the Earth system, the matter can undergo chemical changes that cause it to change its identity. However, although the matter may change, it is not destroyed. This principle is known as the *law of conservation of mass.* In this lab, you will cause two chemicals to react to form products that differ from the two reacting chemicals. Then, you will determine whether the amount of mass in the system (the experiment) has changed.

Procedure

1. On a blank sheet of paper, prepare a table like the one shown on the next page.
2. Place a piece of weighing paper on a balance. Place 4 to 5 g of baking soda on the paper. Carefully transfer the baking soda to a plastic cup.
3. Using a graduated cylinder, measure 50 mL of vinegar. Pour the vinegar into a second plastic cup.
4. Place both cups on the balance, and determine the combined mass of the cups, baking soda, and vinegar to the nearest 0.01 g. Record the combined mass in the first row of your table under "Initial mass."
5. Take the cups off the balance. Carefully and slowly pour the vinegar into the cup that contains the baking soda. To avoid splattering, add only a small amount of vinegar at a time. Gently swirl the cup to make sure that the reactants are well mixed.

	Initial mass (g)	Final mass (g)	Change in mass (g)
Trial 1			
Trial 2			

6. When the reaction has finished, place both cups back on the balance. Determine the combined mass to the nearest 0.01 g. Record the combined mass in the first row of your table under "Final mass."
7. Subtract final mass from initial mass, and record the difference in the first row of your table under "Change in mass."
8. Repeat step 2, but carefully transfer the baking soda to one corner of a plastic bag rather than the cup.
9. To seal the baking soda in the corner of the bag, twist the corner of the bag above the baking soda and wrap the twist tie tightly around the twisted part of the bag.
10. Add 50 mL of vinegar to the bag. Zipper-close the bag so that the vinegar cannot leak out and the bag is airtight.
11. Place the bag in the beaker, and measure the mass of the beaker, the bag, and the reactants. Record the combined mass in the second row of your table under "Initial mass."
12. Remove the twist tie from the bag, and mix the reactants.
13. When the reaction has finished, repeat steps 6 and 7 by using the beaker, bag, twist tie, and products. Record the final mass and change in mass in the table's second row.

Step 11

Analysis

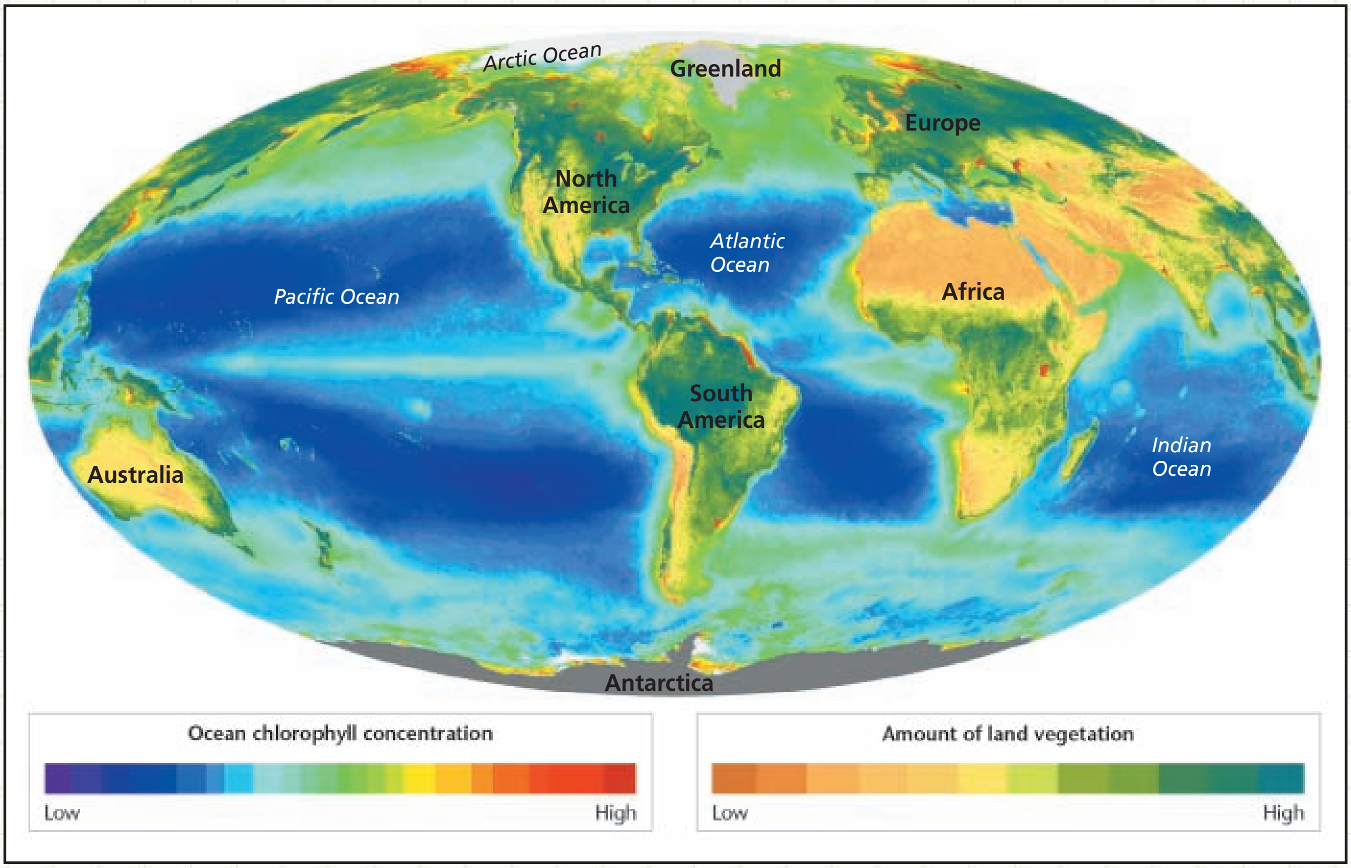
1. **Analyzing Data** Compare the change in mass that you calculated for the first trial with the change in mass that you calculated for the second trial. What evidence of the conservation of mass does the second trial show?
2. **Analyzing Results** Was the law of conservation of mass violated in the first trial? Explain your answer.
3. **Drawing Conclusions** Was the first trial an example of a closed system or an open system? Which type of system was the second trial? Explain your answer.

Extension

Designing an Experiment Brainstorm other ways to demonstrate the law of conservation of mass in a laboratory. Describe the materials that you would need, and describe any difficulties that you foresee.

MAPS in Action

Concentration of Plant Life on Earth



Map Skills Activity

This map shows the concentration of plant life on land and in the oceans. Each color in the key represents a concentration of plant life as indicated by the concentration of chlorophyll. The higher the concentration of chlorophyll is, the higher the concentration of plant life is. Use the map to answer the questions below.

1. **Using a Key** How can you distinguish between high chlorophyll concentration in the ocean and high chlorophyll concentration on land?
2. **Comparing Areas** List three areas that have very low chlorophyll concentration on land. What characteristics of these areas cause such low chlorophyll concentrations?
3. **Comparing Areas** Why do you think Antarctica, Greenland, and the Arctic Ocean lack chlorophyll?
4. **Identifying Trends** Where are the highest chlorophyll concentrations in the ocean located? Why do you think that these locations have high chlorophyll concentrations?
5. **Identifying Trends** Plants use sunlight and chlorophyll to produce energy. What can you infer about the amount of sunlight around the equator that could help explain why areas along the equator tend to have higher concentrations of chlorophyll than surrounding areas do?

Summary

THINK central SUPER SUMMARY Keyword: HQXEASS

Key Ideas | **Key Terms**

Section 1

Earth: A Unique Planet

- Earth is an oblate spheroid that has an average diameter of 12,756 km.
- The compositional layers of Earth's interior are the thin, solid outermost crust, the rocky mantle beneath the crust, and the central core. These layers are divided into five structural zones: lithosphere, asthenosphere, mesosphere, outer core, and inner core.
- Liquid iron in the outer core may be a source of Earth's magnetic field.
- Newton's law of gravitation states that the force of attraction between any two objects depends on their masses and the distance between them.

Key Terms

crust, p. 30
mantle, p. 30
core, p. 30
lithosphere, p. 31
asthenosphere, p. 31
mesosphere, p. 31

Section 2

Energy in the Earth System

- In an open system, both energy and matter enter and exit the system. In a closed system, energy enters and exits, but matter neither enters nor exits.
- The atmosphere is gaseous. The hydrosphere is mostly liquid water but may also appear in solid or vapor form. The geosphere is the solid part of Earth. The biosphere contains all the life in the other three spheres.
- The sun (external) and radioactive decay (internal) are the two main sources of energy in the Earth system.
- Matter moves through Earth systems in cycles such as the nitrogen, carbon, phosphorus, and water cycles.

Key Terms

system, p. 33
atmosphere, p. 35
hydrosphere, p. 35
geosphere, p. 35
biosphere, p. 35

Section 3

Ecology

- An ecosystem is a community of organisms and the environment that they inhabit.
- Carrying capacity, disturbance, and energy transfer are three factors that control the balance of an ecosystem.
- Energy is transferred through an ecosystem via feeding relationships.
- In general, an ecosystem responds to changes in ways that maintain or restore balance in the ecosystem.

Key Terms

ecosystem, p. 41
carrying capacity, p. 42
food web, p. 43

Chapter 2 Review

1. **Outlining** Choose one of the scientific laws in this chapter. Explain why it is an example of a scientific law rather than a scientific theory. Include an example of a scientific theory for comparison.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *system*
3. *carrying capacity*
4. *lithosphere*

For each pair of terms, explain how the meanings of the terms differ.

5. *system* and *ecosystem*
6. *biosphere* and *geosphere*
7. *hydrosphere* and *atmosphere*
8. *mantle* and *asthenosphere*
9. *energy pyramid* and *food web*

UNDERSTANDING KEY IDEAS

10. The diameter of Earth is greatest at the
    a. poles.
    b. equator.
    c. oceans.
    d. continents.
11. The element that makes up the largest percentage of the atmosphere is
    a. oxygen.
    b. nitrogen.
    c. carbon dioxide.
    d. ozone.
12. The gravitational attraction between two objects is determined by the mass of the two objects and the
    a. distance between the objects.
    b. weight of the objects.
    c. diameter of the objects.
    d. density of the objects.
13. Energy can enter the Earth system from internal sources through convection and from external sources through
    a. radioactive decay. **c.** wind energy.
    b. wave energy. **d.** solar energy.
14. Closed systems exchange energy but do *not* exchange
    a. gravity. **c.** sunlight.
    b. matter. **d.** heat.
15. Which of the following is *not* an ecosystem?
    a. a lake **c.** a tree
    b. an ocean **d.** a population
16. Which of the following processes is *not* involved in the water cycle?
    a. evaporation
    b. transpiration
    c. combustion
    d. precipitation
17. A jar with its lid on tightly is one example of a(n)
    a. open system.
    b. biosphere.
    c. closed system.
    d. ecosystem.
18. Phosphorus cycles through all spheres except the
    a. geosphere.
    b. atmosphere.
    c. biosphere.
    d. hydrosphere.

SHORT ANSWER

19. What characteristic of Earth's interior is likely to be responsible for Earth's magnetic field?
20. What is the role of decomposers in the cycling of matter in the biosphere?
21. Corrolate the three compositional zones of Earth to the five structural zones of Earth.
22. Restate the first and second laws of thermodynamics, and explain how they relate to ecosystems on Earth.
23. Describe two ways that your daily activities affect the water cycle.

24. Explain three reasons that stewardship of Earth's resources is important.

25. Describe three ways in which the atmosphere interacts with the geosphere.

26. Identify two distinguishing factors of a nearby ecosystem, and name five kinds of organisms that live in that ecosystem.

CRITICAL THINKING

27. **Analyzing Ideas** What happens to the matter and energy in fossil fuels when the fuels are burned?

28. **Making Inferences** Draw an energy pyramid that includes the organisms shown in the food web diagram in this chapter.

29. **Making Predictions** How would the removal of decomposers from Earth's biosphere affect the carbon, nitrogen, and phosphorus cycles?

30. **Analyzing Relationships** Do you think that Earth has a carrying capacity for humans? Explain your reasoning.

CONCEPT MAPPING

31. Use the following terms to create a concept map: *biosphere, magnetosphere, mantle, atmosphere, geosphere, hydrosphere, ecosystem, crust,* and *core.*

MATH SKILLS

Math Skills

32. **Making Calculations** In one year, the plants in each square meter of an ecosystem obtained 1,460 kilowatt•hours (kWh) of the sun's energy by photosynthesis. In that year, each square meter of plants stored 237 kWh. What percentage of the sun's energy did the plants use for life processes in that year?

33. **Making Calculations** The average radius of Earth is 6,371 km. If the average thickness of oceanic crust is 7.5 km and the average thickness of continental crust is 35 km, what fraction of Earth's radius is each type of crust?

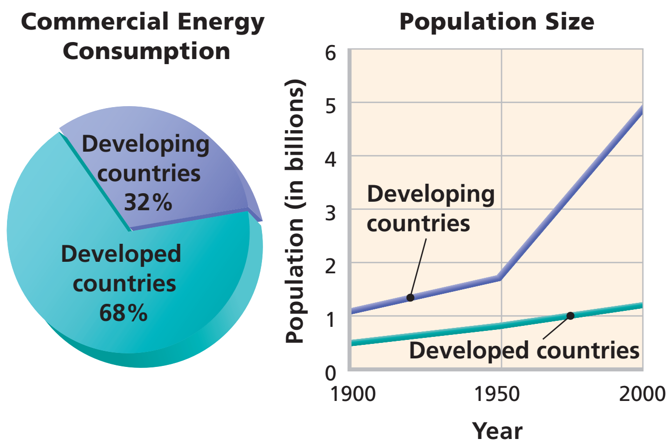
WRITING SKILLS

34. **Creative Writing** If you noticed that pollution was harming a nearby lake, how would you convince your community of the need to take action to solve the problem? Describe three research tools you would use to find materials that support your opinion.

35. **Communicating Main Ideas** Explain why closed systems typically do not exist on Earth. Suggest two examples of a closed system created by humans.

INTERPRETING GRAPHICS

The graphs below show the difference in energy consumption and population size in developed and developing countries. Use the graphs to answer the questions that follow.



36. Describe the differences in energy consumption and population growth between developed and the developing countries.

37. Do you think that the percentage of commercial energy consumed by developing countries will increase or decrease? Explain your answer.

38. Why is information on energy consumption represented in a pie graph, while population size is shown in a line graph?

Standardized Test Prep

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

1. The crust and the rigid upper part of the mantle are found in what part of the Earth?
   - **A.** the asthenosphere
   - **B.** the lithosphere
   - **C.** the mesosphere
   - **D.** the stratosphere
2. Because phosphorus rarely occurs as a gas, the phosphorus cycle mainly occurs between the
   - **F.** biosphere, geosphere, and hydrosphere.
   - **G.** biosphere, geosphere, and atmosphere.
   - **H.** geosphere, hydrosphere, and atmosphere.
   - **I.** biosphere, hydrosphere, and atmosphere.
3. How are scientists able to study the composition and size of the interior layers of Earth?
   - **A.** by direct observation
   - **B.** by analyzing surface rock samples
   - **C.** by using seismic waves
   - **D.** by deep-drilling into the interior layers
4. Which of the following methods of internal energy transfer drives volcanic activity on Earth's surface?
   - **F.** radioactive decay
   - **G.** convection
   - **H.** kinetic transfer
   - **I.** conduction
5. Earth's primary external energy source is
   - **A.** cosmic radiation.
   - **B.** the moon.
   - **C.** distant stars.
   - **D.** the sun.

Directions (6–7): For each question, write a short response.

6. What do decomposers break down to obtain energy?
7. What scientific principle states that energy can be transferred but that it cannot be created or destroyed?

Reading Skills

Directions (8–9): Read the passage below. Then, answer the questions.

Acid Rain

Acid rain is rain, snow, fog, dew, or sleet that has a pH that is lower than the pH of normal precipitation. Acid rain occurs primarily as a result of the combustion of fossil fuels—a process that produces, as byproducts, oxides of nitrogen and sulfur dioxide. When combined with water in the atmosphere, these compounds form nitric acid and sulfuric acid. When it falls to Earth, acid rain has profound effects. It harms forests by damaging tree leaves and bark, which leaves them vulnerable to weather, disease, and parasites. Similarly, it damages crops. And it damages aquatic ecosystems by causing the death of all but the hardiest species. Because of the extensive damage that acid rain causes, the U.S. Environmental Protection Agency limits the amount of sulfur dioxide and nitrogen oxides that can be emitted by factories, power plants, and motor vehicles.

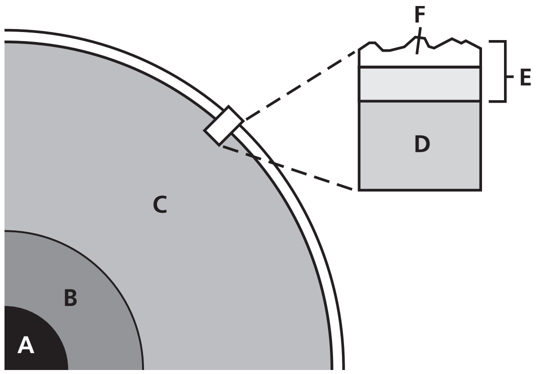
8. According to the passage, which of the following contributes to the problem of acid rain?
   - **F.** the use of fossil fuels in power plants and motor vehicles
   - **G.** parasites and diseases that harm tree leaves and bark
   - **H.** the release of nitrogen into the atmosphere by aquatic ecosystems
   - **I.** damaged crops that release too many gases into the atmosphere
9. Which of the following statements can be inferred from the information in the passage?
   - **A.** Acid rain is a natural problem that will correct itself if given enough time.
   - **B.** Ecosystems damaged by acid rain adapt so that they will not be damaged in the future.
   - **C.** Human activities are largely to blame for the problem of acid rain.
   - **D.** Acid rain is a local phenomenon and only damages plants and animals near power plants or roadways.

Interpreting Graphics

Directions (10–12): For each question below, record the correct answer on a separate sheet of paper.

The diagram below shows the interior layers of Earth. The layers in the diagram are representative of arrangement and are not drawn to scale. Use this diagram to answer question 10.

Structure of the Earth

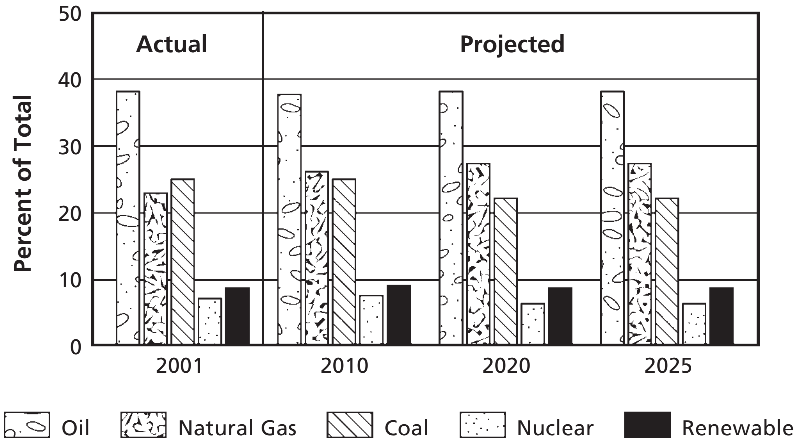


10. Which letter represents the layer of Earth known as the lithosphere?

F. layer E
G. layer D
H. layer C
I. layer A

Use the graph below, which shows predicted worldwide energy consumption by fuel type between the years 2001 and 2025, to answer questions 11 and 12.

Worldwide Energy Consumption By Source



11. Which of the following sources of energy is predicted to see the greatest increase in usage between 2001 and 2025?

A. oil
B. natural gas
C. coal
D. renewable

12. What trends in energy consumption by fuel type will change over the 25 years shown on the graph above? What trends will stay the same?

Test Tip

If time permits, take short mental breaks during the test to improve your concentration.

SECTION 1

Earth: A Unique Planet

Key Ideas	Key Terms	Why It Matters
❯ Describe the size and shape of Earth. ❯ Describe the compositional and structural layers of Earth's interior. ❯ Identify the possible source of Earth's magnetic field. ❯ Summarize Newton's law of gravitation.	**crust** **mantle** **core** **lithosphere** **asthenosphere** **mesosphere**	Understanding Earth's structure and composition helps us not only study other bodies in the universe, but also appreciate the features that make our own planet unique.

Earth is unique for several reasons. It is the only known planet in the solar system that has liquid water on its surface and an atmosphere that contains a large proportion of oxygen. Earth is also the only planet—in our solar system or in any other solar system—that is known to support life. Scientists study the characteristics of Earth that make life possible in order to know what life-supporting conditions to look for on other planets.

Earth Basics

Earth is the third planet from the sun in our solar system. Earth formed about 4.6 billion years ago and is made mostly of rock. Approximately 71% of Earth's surface is covered by a relatively thin layer of salt water called the *global ocean*.

As viewed from space, Earth is a blue sphere covered with white clouds. Earth appears to be a perfect sphere but is actually an *oblate spheroid*, or slightly flattened sphere, as **Figure 1** shows. The spinning of Earth on its axis makes the polar regions flatten and the equatorial zone bulge. Earth's circumference from pole to pole is 40,007 km. Its equatorial circumference is 40,074 km.

Earth's surface is relatively smooth. That is, distances between surface high points and low points are small when compared with Earth's size. The difference between the height of the tallest mountain and the depth of the deepest ocean trench is about 20 km. This distance is small compared with Earth's average diameter of 12,756 km.

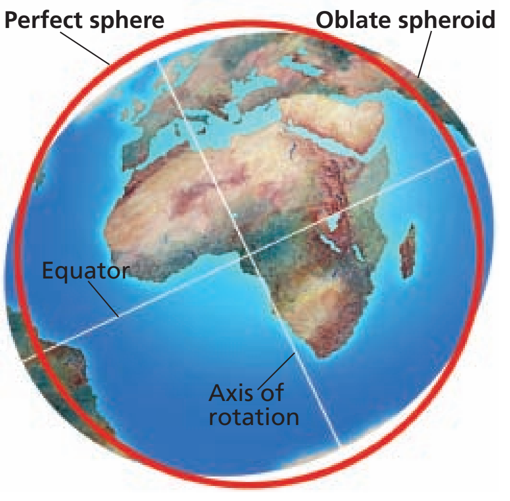


Figure 1 Although from afar Earth looks like a sphere (left), it is an oblate spheroid. In this illustration, Earth's shape has been exaggerated to show that Earth bulges at the equator.