Section 3
The Cycling of Energy

Key Concept Various heat-exchange systems work in the Earth system and affect phenomena on Earth's surface.

What You Will Learn
- Heat flow is the transfer of energy from a warmer object to a cooler object.
- Energy from the sun, the major source of energy for phenomena on Earth's surface, is transmitted to Earth by radiation.
- Heat from Earth's interior reaches the surface mostly by convection.

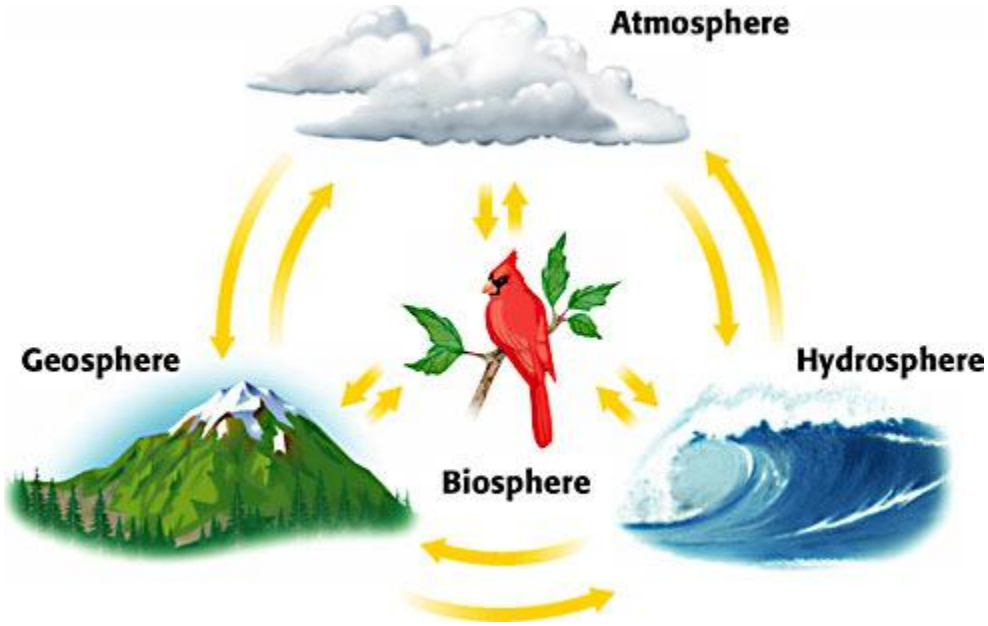
Why It Matters
The movement of energy through Earth's systems is a major factor in most of Earth's processes.

You are on a camping trip with your family. It is a warm, sunny day. But you see clouds forming in the sky. Suddenly, a strong wind starts to blow, and the air feels cooler. Soon, you hear thunder, and a downpour of rain follows. Why did the weather change so quickly? The answer involves the movement of energy through Earth's atmosphere.

The Flow of Energy
Energy can be carried from one place to another by heat flow, by waves, or by moving objects. **Heat flow** is the transfer of energy from a warmer object to a cooler object. Waves—such as water waves, light waves, and sound waves—transfer energy through vibrations. Waves move energy, but they do not move matter from one place to another. Objects carry energy while they are moving. As they move, the objects pass the energy to objects that they touch.

Energy moves through Earth's systems, as **Figure 1** shows. The sun is the major source of energy for the Earth system. Heat from Earth's interior also supplies energy, but the amount of energy is much smaller. Energy from the sun and from Earth's interior moves through the geosphere, hydrosphere, biosphere, and atmosphere. The processes that move the energy are radiation, convection, and conduction.

Figure 1 Energy Transfer through Earth's Systems



Standards Check List two sources from which Earth receives its energy.

Radiation

We live almost 150 million kilometers from the sun. But the sun is the source of 99% of the energy on Earth. Energy from the sun is transmitted through space by radiation.

The Electromagnetic Spectrum

You can see the visible light that the sun radiates. But the sun also radiates other forms of energy that you cannot see. All energy from the sun travels in waves. These waves are called *electromagnetic radiation.* Electromagnetic radiation includes a wide range of wavelengths, which are collectively referred to as the **electromagnetic spectrum.** As **Figure 2** shows, wavelengths range from long, such as the wavelengths of radio waves, to short, such as the wavelengths of gamma rays.

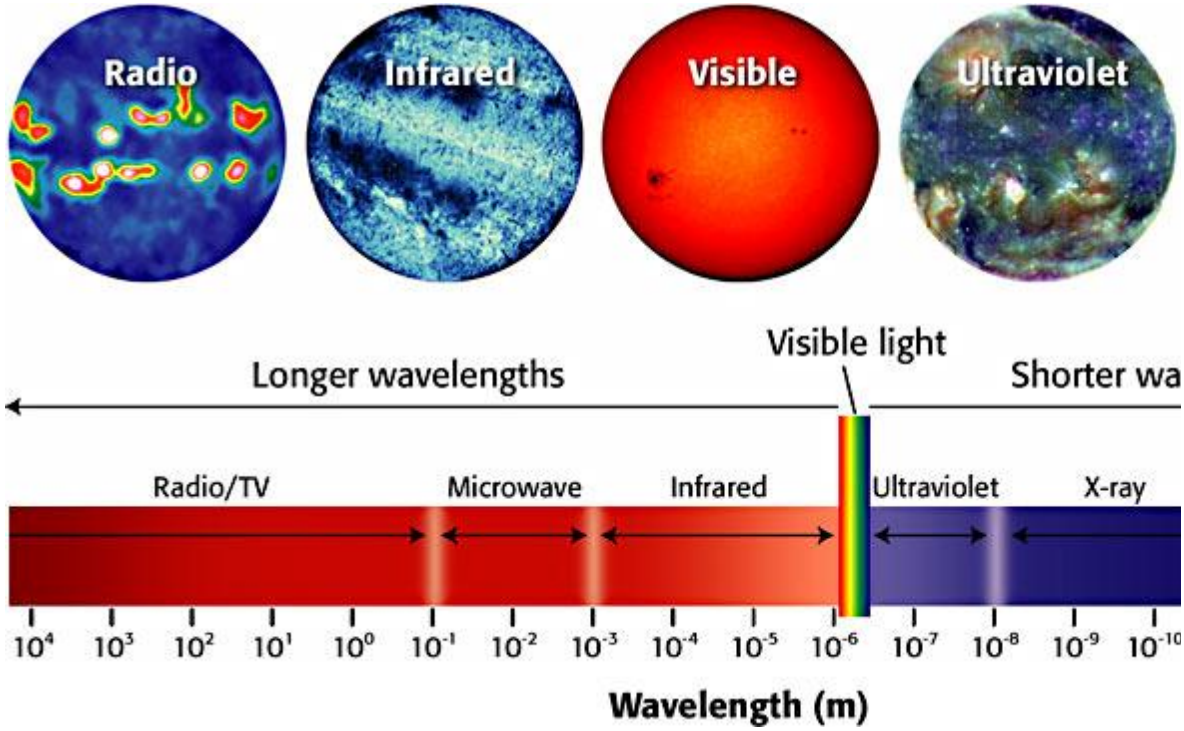


Figure 2 The wavelengths of the radiation emitted by the sun range throughout the electromagnetic spectrum. Five images of the sun are shown above. Each image shows radiation emitted at different wavelengths.

All of the energy that Earth receives from the sun moves through space as electromagnetic radiation. Wavelengths in or close to the visible range make up the largest amount of energy that is given off by the sun. Some of the energy can pass through Earth's atmosphere and reach Earth's surface.

Earth and Energy from the Sun

The Earth receives most of its energy from the sun. This energy drives the water cycle and makes life possible on Earth. The energy that Earth receives from the sun is absorbed by the atmosphere, geosphere, and hydrosphere. Then, the energy is changed into thermal energy. This thermal energy is then transferred through Earth's systems by convection and conduction.

Standards Check Explain how Earth receives energy from the sun.

Convection

Most energy is moved through Earth's systems by convection. Convection occurs in fluids, such as water and air. But some convection occurs in solids that can flow like putty. The uneven heating of matter drives convection. Most matter becomes less dense when heated. Hotter, less dense matter rises through surrounding matter. As the hot matter rises, it cools and becomes denser. As a result, this matter sinks back toward the heat source where it is warmed again. This movement of matter that results from differences in density is called a *convection current.*

Convection in the Ocean

Convection currents occur in the ocean because of differences in the density of ocean water. The uneven heating of ocean water causes these differences. The differences in density are also caused by differences in the salinity of ocean water. Salinity is the amount of salt in water. In the ocean, convection causes deep currents. Deep currents are streamlike movements of water far below the ocean surface. As **Figure 3** shows, deep currents flow from the North Atlantic Ocean to Antarctica. Then, they flow around Antarctica and into the Pacific Ocean. The cold bottom water then flows northward toward Alaska. This journey takes more than a thousand years.

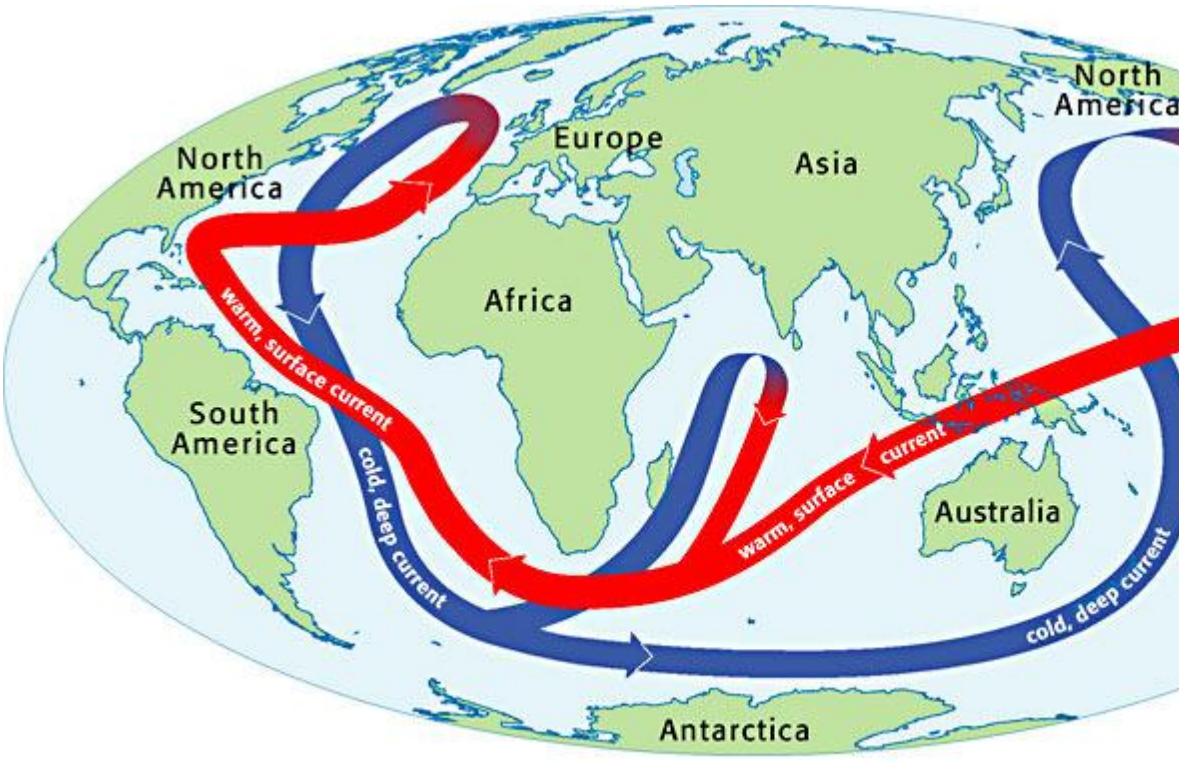


Figure 3 This map shows the directions in which ocean currents flow. Surface currents are shown in red. Deep currents are shown in blue. Together, the currents form the ocean conveyor belt.

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Convection in the Atmosphere

The process of convection in the atmosphere is shown in **Figure 4.** If Earth's surface is warmer than the air, conduction will heat the air touching the ground. As this air becomes warmer, it becomes less dense and rises. The warm air moves upward, away from Earth's surface. As the air rises, it cools. The air becomes denser and begins to sink back toward Earth's surface. As the cooled air sinks, it forces warm air away from Earth's surface. This cycle causes winds and moves energy through the atmosphere.

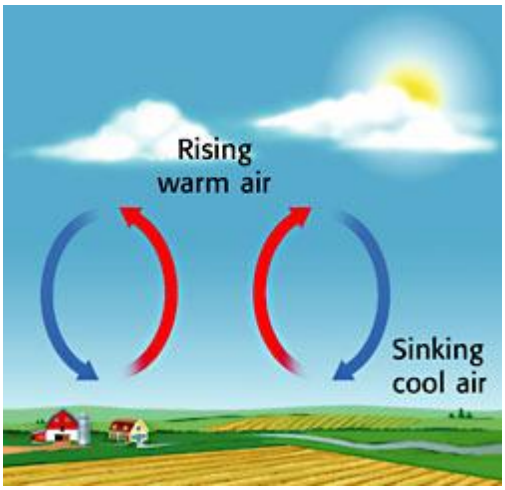

Figure 4 Convection currents in the atmosphere form when cold air sinks and forces warm air away from Earth's surface.

Convection in the Geosphere

Earth may seem solid and rigid to you. But inside Earth, solid rock is slowly moving. Energy produced deep inside Earth heats rock in the mantle. The heated rock is under high pressure. So, the rock becomes plastic without melting, which causes the rock to flow like putty. As it becomes less dense, the heated rock rises toward Earth's surface. The cooler, denser rock surrounding the heated rock sinks, as **Figure 5** shows. In this way, heat inside Earth moves toward the cooler crust. This movement of rock is a convection current. Convection currents in the mantle cause the movement of tectonic plates.

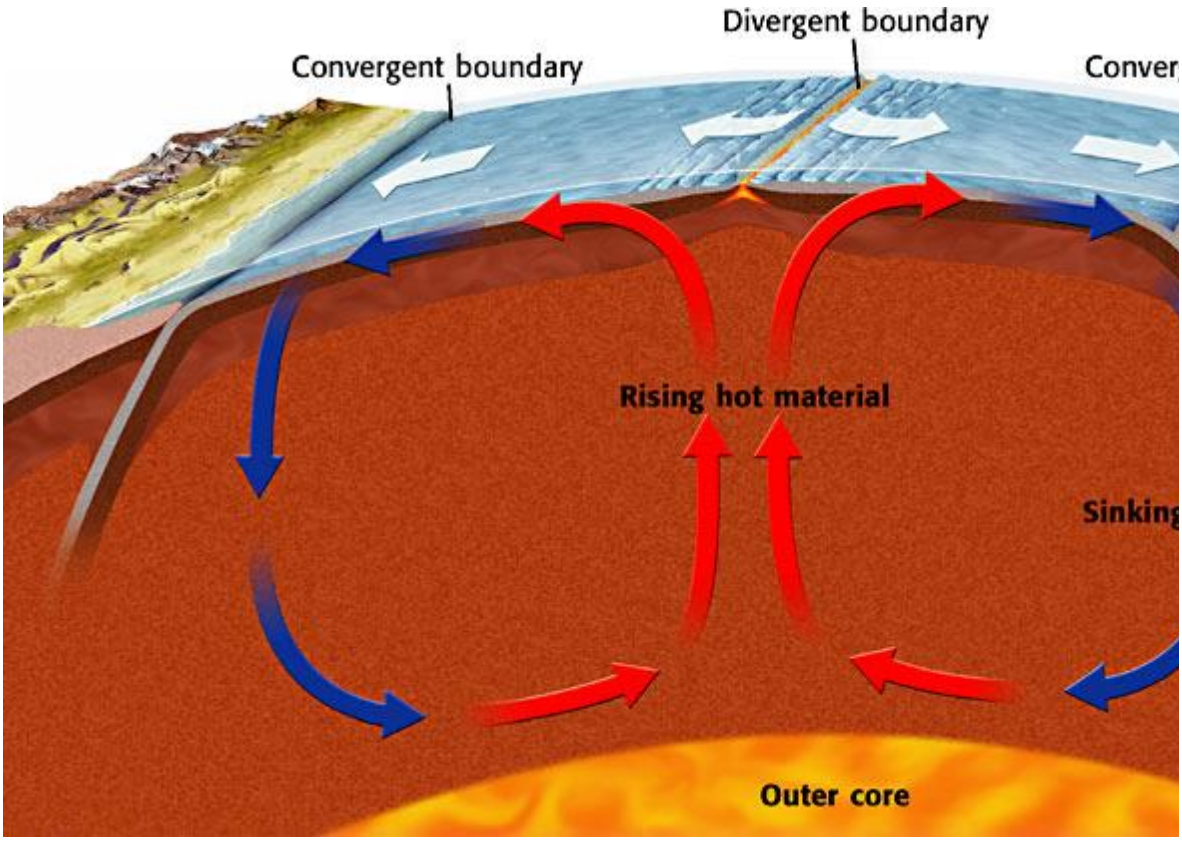

Figure 5 Convection currents in the geosphere carry heat from Earth's interior toward the surface.

Standards Check How does convection occur in the geosphere?

Conduction

Why does a spoon in a bowl of hot soup feel warm? The spoon feels warm because energy from the soup warms the spoon by

conduction. This conduction of heat occurs because the spoon's particles interact with the soup's particles.

Interaction of Particles

When objects at different temperatures touch, their particles interact with one another. Because its particles are moving faster, the warmer substance has a higher average kinetic energy. The fast-moving particles transfer energy to the particles in the cooler substance, which has a lower average kinetic energy. The transfer of energy causes the particles in the cooler substance to move faster. So, the cooler substance becomes warmer.

Conduction Between Systems

Energy can be transferred between the geosphere and the atmosphere by conduction, as **Figure 6** shows. When Earth's surface is warmer than the atmosphere, the ground will transfer energy to the atmosphere. When air comes into direct contact with the warm surface of Earth, energy is passed to the atmosphere by conduction. If the atmosphere is warmer than Earth's surface, energy flows from the atmosphere to Earth.

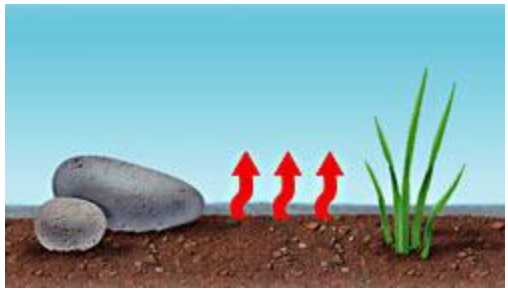

Figure 6 Conduction of heat from the geosphere to the atmosphere occurs only within a few centimeters of Earth's surface, where the air touches the ground. Transfer of heat from the geosphere to the atmosphere occurs only when the atmosphere is cooler than the geosphere, such as at night or on cold days.

How does the geosphere transfer energy to the atmosphere?

Earth's Energy Budget

Energy on Earth moves through and between four spheres. These four spheres are open systems, which means that they constantly exchange energy with one another. For example, solar radiation heats Earth's surface. And Earth's surface heats air in the lower atmosphere by conduction.

Energy is neither created nor destroyed. It is simply transferred between spheres or converted into another form of energy. You can think of the movement of energy between each of Earth's spheres as part of an energy budget. In a system, additions in energy are balanced by subtractions in energy. For example, energy that is taken away from the atmosphere may be added to the oceans or to the geosphere.

Section Summary

- Energy can be transferred from one place to another by heat flow, by waves, or by objects that are moving.
- Heat flow is the transfer of energy from a warmer object to a cooler object.
- Energy from the sun reaches Earth by radiation.
- Energy is transferred through the oceans, the atmosphere, and the geosphere by convection.
- Energy is transferred between the geosphere and the atmosphere by conduction.