Section 2

Solar Energy and the Atmosphere

California Content Standards

4b Students know the fate of incoming solar radiation in terms of reflection, absorption, and photosynthesis.
4c Students know the different atmospheric gases that absorb the Earth's thermal radiation, and the mechanism and significance of the greenhouse effect.
8a Students know the thermal structure and chemical composition of the atmosphere.

Earth's atmosphere is heated by the transfer of energy from the sun. Some of the heat in the atmosphere comes from the absorption of the sun's rays by gases in the atmosphere. Some heat enters the atmosphere indirectly as ocean and land surfaces absorb solar energy and then give off that energy as heat.

OBJECTIVES

- **Explain** how radiant energy reaches Earth. 4b
- **Describe** how visible light and infrared energy warm Earth. 4c, 4b
- **Summarize** the processes of radiation, conduction, and convection. 4b, 5a

KEY TERMS

electromagnetic spectrum
albedo
greenhouse effect
conduction
convection

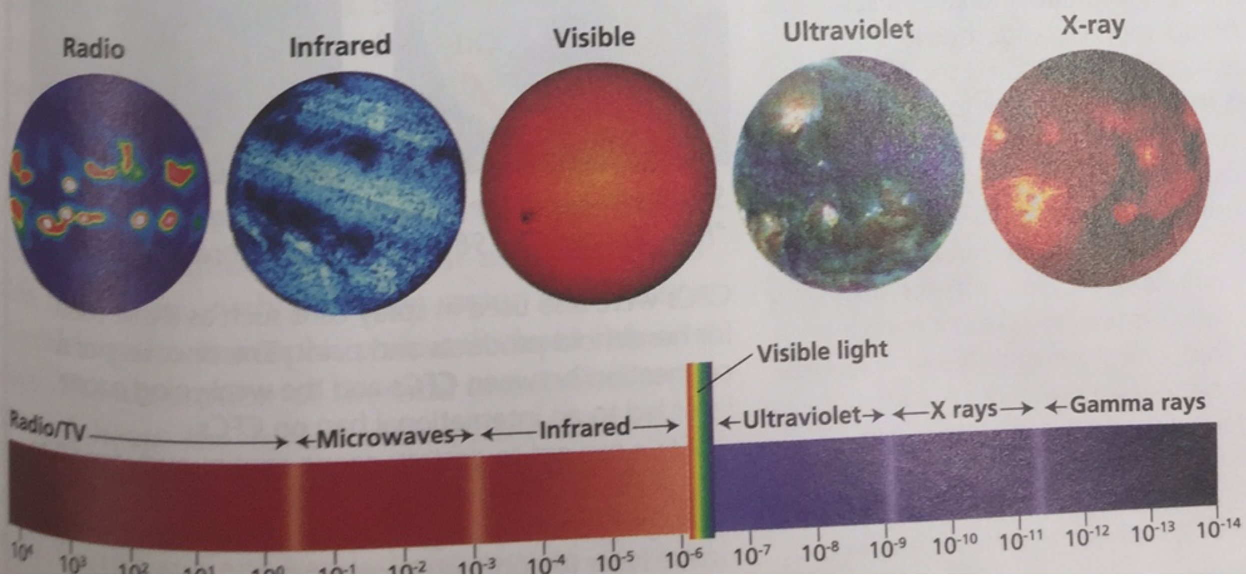
Radiation

All of the energy that Earth receives from the sun travels through space between Earth and the sun as radiation. *Radiation* includes all forms of energy that travel through space as waves. Visible light is the form of radiation that human eyes can detect. However, there are many other forms of radiation that humans cannot see, such as ultraviolet light, X rays, and radio waves.

Radiation travels through space in the form of waves at a very high speed—approximately 300,000 km/s. The distance from any point on a wave to the identical point on the next wave, for example from crest to crest, is called the *wavelength* of a wave. The various types of radiation differ in the length of their waves. Visible light, for example, consists of waves that have various wavelengths that are seen as different colors. The wavelengths of ultraviolet rays, X rays, and gamma rays are shorter than those of visible light. Infrared waves and radio waves have relatively long wavelengths. The waves that make up all forms of radiation are called *electromagnetic waves*. Almost all of the energy that reaches Earth from the sun is in the form of electromagnetic waves. The **electromagnetic spectrum,** shown at the bottom of **Figure 1,** consists of the complete range of wavelengths of electromagnetic waves.

electromagnetic spectrum all of the frequencies or wavelengths of electromagnetic radiation

Figure 1 ▶ The sun emits radiation whose wavelengths range through the electromagnetic spectrum. Five images of the sun are shown above. Each image shows radiation emitted at different wavelengths.



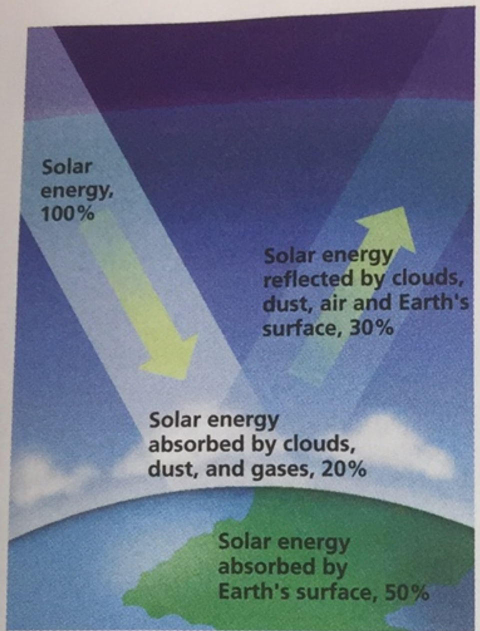


Figure 2 ▶ About 70% of the solar energy that reaches Earth is absorbed by Earth's land and ocean surfaces and by the atmosphere. The remainder is reflected back into space.

The Atmosphere and Solar Radiation

As solar radiation passes through Earth's atmosphere, the atmosphere affects the radiation in several ways. The upper atmosphere absorbs almost all radiation that has a wavelength shorter than the wavelengths of visible light. Molecules of nitrogen and oxygen in the thermosphere and mesosphere absorb the X rays, gamma rays, and ultraviolet rays. In the stratosphere, ultraviolet rays are absorbed and act upon oxygen molecules to form ozone.

Most of the solar rays that reach the lower atmosphere, such as visible and infrared waves, have longer wavelengths. Most incoming infrared radiation is absorbed by carbon dioxide, water vapor, and other complex molecules in the troposphere. As visible light waves pass through the atmosphere, only a small amount of this radiation is absorbed. **Figure 2** shows the percentage of solar energy that is reflected and absorbed by the atmosphere.

Scattering

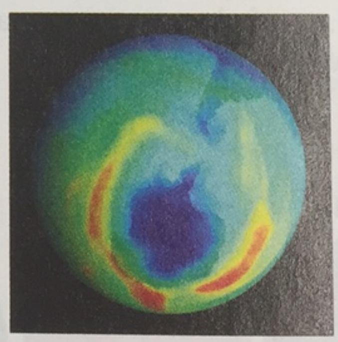
Clouds, dust, water droplets, and gas molecules in the atmosphere disrupt the paths of radiation from the sun and cause scattering. Scattering occurs when particles and gas molecules in the atmosphere reflect and bend the solar rays. This deflection causes the rays to travel out in all directions without changing their wavelengths. Scattering sends some of the radiation back into space. The remaining radiation continues toward Earth's surface. As a result of scattering, sunlight that reaches Earth's surface comes from all directions. In addition, scattering makes the sky appear blue and makes the sun appear red at sunrise and sunset.

Connection to PHYSICS

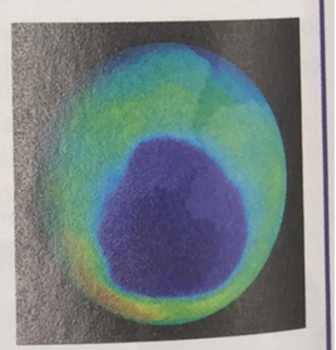
The Ozone "Hole"

Ozone, O_3, is a naturally occurring gas that is present primarily in the stratosphere. The thin layer of ozone that surrounds Earth prevents most of the sun's ultraviolet (UV) radiation from reaching Earth's surface. Overexposure to UV radiation is dangerous to living things because it damages DNA. DNA is the genetic material that carries the information for inherited characteristics. UV radiation also makes the body more susceptible to skin cancer.

The protective ozone layer is not distributed around Earth evenly. Scientists have observed that ozone concentrations vary with latitude and with the time of year. In 1985, scientists discovered that the ozone layer was unusually thin in regions over Antarctica. This "ozone hole" allows greater amounts of UV radiation to reach Earth's surface. Scientists discovered that chemicals called chlorofluorocarbons (CFCs) were causing the ozone layer to break down. CFCs were used as coolants in refrigerators and air conditioners.



Satellite image of the ozone "hole" (purple) in 1980



Satellite image of the same ozone "hole" in 2000

CFCs were also used in spray cans such as those used for household products and paint. The discovery of a connection between CFCs and the weakening ozone layer led to an international ban on CFCs.

CFCs can act to destroy ozone continuously for 60 to 120 years. So, CFCs released 30 years ago may still be destroying ozone today. It will take many years for the ozone layer to completely recover.

Table 1 ▼

Percentage of Solar Radiation		
Surface	Reflected	Absorbed
Soils (dark colored)	5–10	90–95
Desert	20–40	60–80
Grass	5–25	75–95
Forest	5–10	90–95
Snow	50–90	10–50
Water (high sun angle)	5–10	90–95
Water (low sun angle)	50–80	20–50

Table 1 ▶ Reflection and Absorption Rates of Various Materials

Reflection

When solar energy reaches Earth's surface, the surface either absorbs or reflects the energy. The amount of energy that is absorbed or reflected depends on characteristics such as the color, texture, composition, volume, mass, transparency, state of matter, and specific heat of the material on which the solar radiation falls. The intensity and amount of time that a surface material receives radiation also affects how much energy is reflected or absorbed.

The fraction of solar radiation that is reflected by a particular surface is called the **albedo.** Because 30% of the solar energy that reaches Earth's atmosphere is either reflected or scattered, Earth is said to have an albedo of 0.3. **Table 1** shows the amount of incoming solar radiation that is absorbed and reflected by various surfaces.

albedo the fraction of solar radiation that is reflected off the surface of an object

Absorption and Infrared Energy

The sun constantly emits radiation. Solar radiation that is not reflected is absorbed by rocks, soil, water, and other surface materials. When Earth's surface absorbs solar radiation, the radiation's short-wavelength infrared rays and visible light heat the surface materials. Then, the heated materials convert the energy into infrared rays of longer-wavelengths and reemit it as those waves. Gas molecules, such as water vapor and carbon dioxide, in the atmosphere absorb these infrared rays. The absorption of thermal energy from the ground heats the lower atmosphere and keeps Earth's surface much warmer than it would be if there were no atmosphere. Sometimes, warm air near Earth's surface bends light rays to produce an effect called a *mirage*, as **Figure 3** shows.

Figure 3 ▶ Hot air near the surface of this road bends light rays. ***What objects in this photo appear to be reflected?***

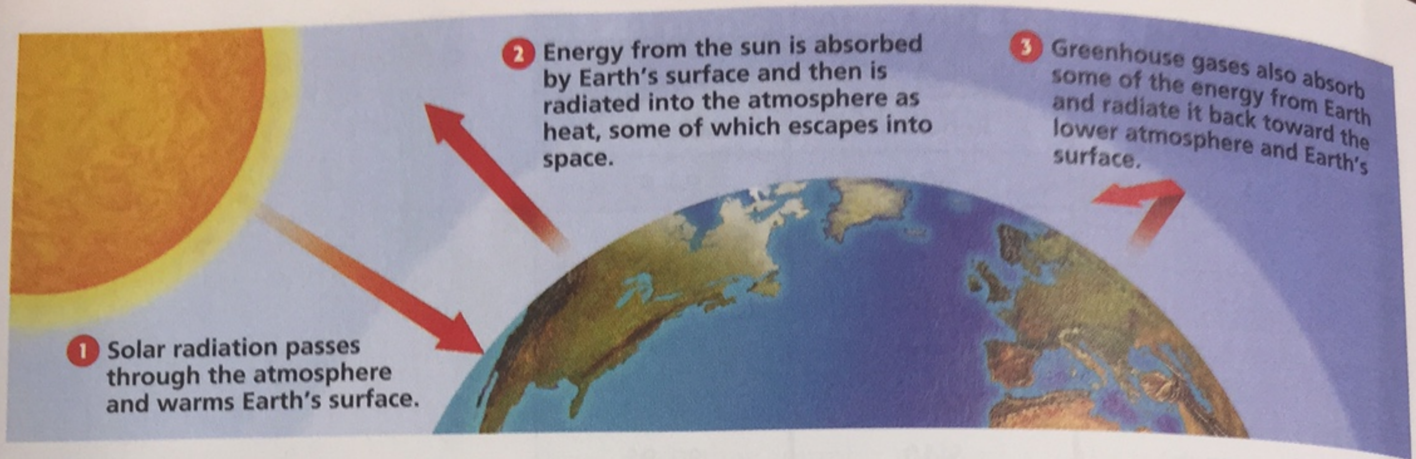


Figure 4 ▶ One process that helps heat Earth's atmosphere is similar to the process that heats a greenhouse.

The Greenhouse Effect

One of the ways in which the gases of the atmosphere absorb and reradiate infrared rays, shown in **Figure 4**, can be compared to the process that keeps a greenhouse warm. The glass of a greenhouse allows visible light and infrared rays from the sun to pass through and warm the surfaces inside of the greenhouse. But the glass prevents the infrared rays that are emitted by the warmed surfaces within the greenhouse from escaping. Similarly, Earth's atmosphere slows the escape of energy that radiates from Earth's surface. Because this process is similar to the process that heats a greenhouse, it is called the **greenhouse effect.**

greenhouse effect the warming of the surface and lower atmosphere of Earth that occurs when carbon dioxide, water vapor, and other gases in the air absorb and reradiate infrared radiation

Human Impact on the Greenhouse Effect

Generally, the amount of solar energy that enters Earth's atmosphere is about equal to the amount that escapes into space. However, human activities may change this balance and may cause the average temperature of the atmosphere to increase. For example, measurements indicate that the amount of carbon dioxide in the atmosphere has been increasing in recent years. These increases have been attributed to the burning of more fossil fuels. These increases seem likely to continue in the future. Increases in the amount of carbon dioxide may intensify the greenhouse effect and may cause Earth to become warmer in some areas and cooler in others.

Variations in Temperature

Radiation from the sun does not heat Earth equally at all places at all times. In addition, a slight delay occurs between the absorption of energy and an increase in temperature. Earth's surface must absorb energy for a time before enough heat has been absorbed and reradiated from the ground to change the temperature of the atmosphere. For a similar reason, the warmest hours of the day are usually mid- to late afternoon even though solar radiation is most intense at noon. The temperature of the atmosphere in any region on Earth's surface depends on several factors, including latitude, surface features, and the time of year and day.

Latitude and Season

Latitude is the primary factor that affects the amount of solar energy that reaches any point on Earth's surface. Because Earth is a sphere, the sun's rays do not strike all areas at the same angle, as shown in **Figure 5.** The rays of the sun strike the ground near the equator at an angle near 90°. At the poles, the sunlight strikes the ground at a much smaller angle. When sunlight hits Earth's surface at an angle smaller than 90°, the energy is spread out over a larger area and is less intense. Thus, the energy that reaches the equator is more intense than the energy that strikes the poles, so average temperatures are higher near the equator than near the poles.

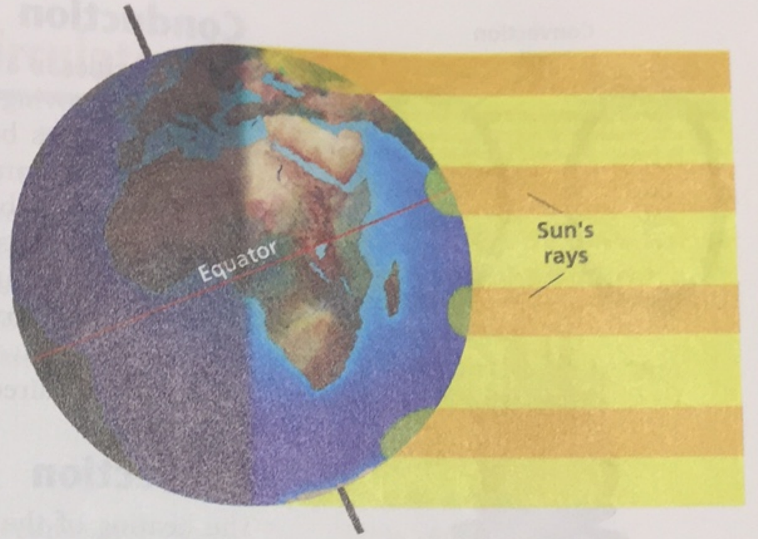


Figure 5 ▶ Temperatures are higher at the equator because solar energy is concentrated in a small area. Farther north and south, the same amount of solar energy is spread out over a larger area.

Temperature varies seasonally because of the tilt of Earth's axis. As Earth revolves around the sun once each year, the portion of Earth's surface that receives the most intense sunlight changes. For part of the year, the Northern Hemisphere is tilted toward the sun and receives more direct sunlight. During this time of year, temperatures are at their highest. For the other part of the year, the Southern Hemisphere is tilted toward the sun. During this time, the Northern Hemisphere receives less direct sunlight, and the temperatures there are at their lowest.

Water in the Air and on the Surface

Because water vapor stores heat, the amount of water in the air affects the temperature of a region. The thinner air at high elevations contains less water vapor and carbon dioxide to absorb the heat. As a result, those areas become warm during the day but cool very quickly at night. Similarly, desert temperatures may vary widely between day and night because little water vapor is present to hold the heat of the day.

Land areas close to large bodies of water generally have more moderate temperatures. In other words, these areas will be cooler during the day and warmer at night than inland regions that have the same general weather conditions are. The reason for these moderate temperatures is that water heats up and cools down faster than air does, so the temperature of water changes less than the temperature of land does.

The wind patterns in an area also affect temperature. A region that receives winds off the ocean waters has more moderate temperatures than does a similar region in which the winds blow from the land.

Reading Check **Why are deserts generally colder at night than other areas are? (See the Appendix for answers to Reading Checks.)**

QuickLAB 5 min

Light and Latitude

Procedure IE.1d, IE.1g

1. Hold a **flashlight** so that the beam shines directly down on a **white piece of paper.** Use a **pencil** to trace the outline of the beam of light.
2. Move the flashlight so that the light shines on the paper at an angle. Trace the outline of the beam of light.

Analysis

1. How does the area of the direct beam differ from the area of the angled beam?
2. How does this exercise illustrate how latitude affects incoming solar radiation?

d) air pollution

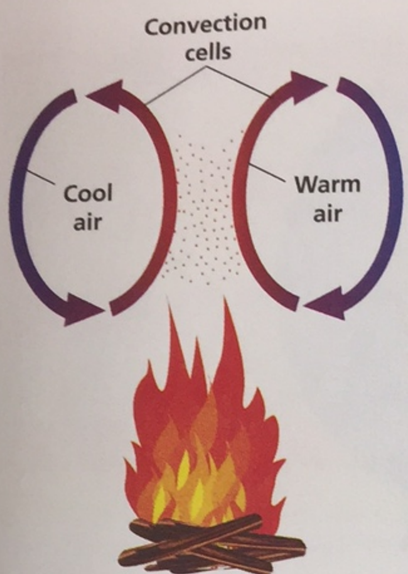


Figure 6 ▶ During convection, energy is carried away by heated air as it rises above cooler, denser air.

Conduction

The molecules in a substance move faster as they become heated. These fast-moving molecules cause other molecules to move faster. Collisions between the particles result in the transfer of energy, which warms the substance. The transfer of energy as heat from one substance to another by direct contact is called **conduction**. Solid substances, in which the molecules are close together, make relatively good conductors. Because the molecules of air are far apart, air is a poor conductor. Thus, conduction heats only the lowest few centimeters of the atmosphere, where air comes into direct contact with the warmed surface of Earth.

Convection

The heating of the lower atmosphere is primarily the result of the distribution of heat through the troposphere by convection. **Convection** is the process by which air, or other matter, rises or sinks because of differences in temperature. Convection occurs when gases or liquids are heated unevenly. As air is heated by radiation or conduction, it becomes less dense and is pushed up by nearby cooler air. In turn, this cooler air becomes warmer, and the cycle repeats, as shown in **Figure 6.**

The continuous cycle in which cold air sinks and warm air rises warms Earth's atmosphere evenly. Because warm air is less dense than cool air is, warm air exerts less pressure than the same volume of cooler air does. So, the atmospheric pressure is lower beneath a mass of warm air. As dense, cool air moves into a low-pressure region, the less dense, warmer air is pushed upward. These pressure differences, which are the result of the unequal heating that causes convection, create winds.

conduction the transfer of energy as heat through a material

convection the movement of matter due to differences in density that are caused by temperature variations; can result in the transfer of energy as heat

Section 2 Review

1. **Explain** how radiant energy reaches Earth. 4b
2. **List and describe** the types of electromagnetic waves. 4b
3. **Describe** how gases and particles in the atmosphere interact with light rays. 4b, 4c
4. **Describe** how visible light and infrared energy warm Earth. 4b, 4c
5. **Explain** how variations in the intensity of sunlight can cause temperature differences on Earth's surface. 4b
6. **Summarize** the processes of conduction and convection. 4b, 5a

CRITICAL THINKING

7. **Making Inferences** Why do scientists study all wavelengths of the electromagnetic spectrum? IE.1d
8. **Applying Concepts** Explain how fans in convection ovens help cook food more evenly. 4b, IE.1d
9. **Applying Conclusions** You decide not to be outside during the hottest hours of a summer day. When will the hottest hours probably be? How do you know? 4b, IE.1d

CONCEPT MAPPING

10. Use the following terms to create a concept map: *electromagnetic waves, infrared waves, greenhouse effect, ultraviolet waves, visible light, scattering,* and *absorption.* 4b, 4c