23.2 Solar Energy and the Atmosphere

Section Objectives

- **Explain how radiant energy reaches the earth.**
- **Describe how visible light and infrared energy warm the earth.**
- **Summarize the processes of radiation, conduction, and convection.**

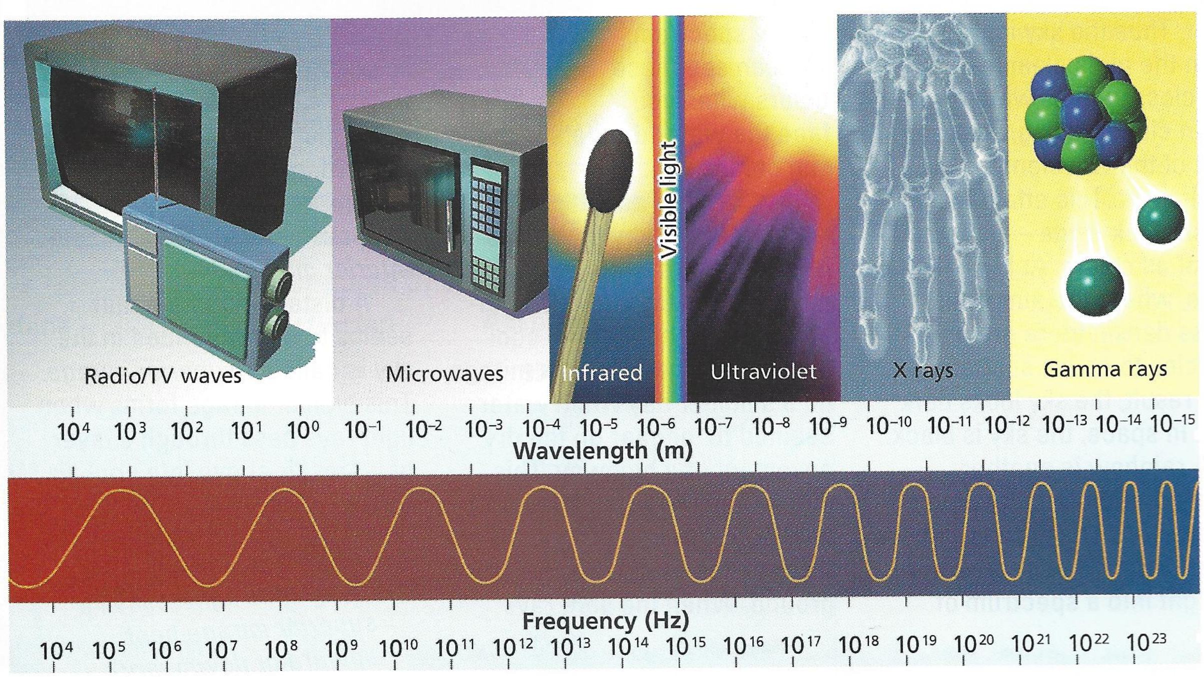
The earth's atmosphere is heated in several ways by the transfer of energy from the sun. Some of the heat in the atmosphere comes from the rays of the sun as they are absorbed by some gases in the atmosphere. Some heat enters the atmosphere indirectly as ocean and land surfaces absorb solar energy and then give it off as heat.

Radiation

All of the energy that the earth receives from the sun travels through space between the earth and the sun as *radiation*. Radiation includes all forms of energy that travel through space as waves. Light is the form of radiation that can be seen with our eyes. However, there are many other forms of radiation that we cannot see, such as X rays and radio waves.

Radiation travels through space in the form of waves at a very high speed—300,000 km/s. The distance from one wave crest to the next is called the *wavelength* of a wave. The various types of radiation differ in the length of their waves, as shown in Figure 23–8. Visible light, for example, consists of waves with various wavelengths that you see as different colors. Wavelengths shorter than those of visible light include ultraviolet rays, X rays, and gamma rays. Longer wavelengths include *infrared* (IN-fruh-RED) *waves* and radio waves. The waves that make up all forms of radiation are called *electromagnetic waves*. The complete range of wavelengths makes up the **electromagnetic spectrum.**

Figure 23–8. This illustration shows the electromagnetic spectrum from long radio waves to short gamma rays.

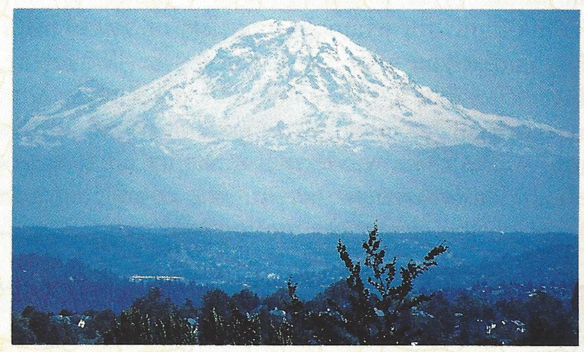


Almost all the energy reaching the earth from the sun is in the form of electromagnetic waves. A small amount of solar energy is carried to the earth by atomic particles emitted by the sun. Before the sun's radiation reaches the solid part of the earth, it passes through the earth's atmosphere. The atmosphere affects this radiation in several ways. First the molecules of nitrogen and oxygen in the upper atmosphere absorb the short wavelengths of X rays, gamma rays, and ultraviolet rays. This absorption occurs in the mesosphere and thermosphere. As solar energy is absorbed, molecules and atoms of nitrogen and oxygen lose electrons and become positively charged ions. In the stratosphere, ultraviolet rays are absorbed and act upon oxygen molecules to form ozone.

Thus, almost all of the shorter wavelengths are absorbed in the upper atmosphere. The small amount of ultraviolet radiation that does reach the earth's surface causes sunburn on skin that is exposed

EARTHBEAT

Visible Light and the Atmosphere



The atmosphere has a number of effects on the light that you see. The wavelengths of visible light that are most readily scattered by the fine dust in the air are the shorter ones. You see these wavelengths as blue and violet. Thus the sky looks blue when the air is clear. Larger particles, such as water droplets in clouds or fog, scatter most of the wavelengths of visible light. This effect makes the sky look white—a combination of all colors. At high altitudes, where the atmosphere is less dense, there are few particles to cause scattering. As a result, the sky looks dark blue. In space, the sky is black.

A rainbow is another example of the effects of the atmosphere on light. A rainbow is caused by the separation of sunlight into a spectrum of colors by raindrops. Refraction, or bending, of light rays in the raindrops separate white light into the entire visible spectrum. You can see these colors when you face the water droplets with the sun behind you.

A mirage is an optical illusion created by the atmosphere. Light rays are refracted as they pass through a boundary between hot air and cool air. You may have seen a mirage on a summer day when water seemed to appear on the dry pavement of a highway. This mirage occurs when a layer of cool air reflects the sky onto a layer of hot air close to the ground. When the light rays enter the hot air, they are bent upward, causing the sky to appear as a pool of water on the pavement. This is called an *inferior mirage.*

A distant mountain that seems to be suspended in the sky is called a *superior mirage.* This type of mirage forms when light rays pass through a layer of warm air above into cool air below.

Are the light rays in a superior mirage bent upward or downward?

to direct sunlight too long. Most of the solar rays that reach the lower atmosphere have longer wavelengths—those of visible and infrared waves. Most incoming infrared radiation is absorbed by carbon dioxide, water vapor, and other complex molecules in the troposphere. Only small amounts of visible light waves are absorbed as they pass through the atmosphere.

Scattering

Clouds, dust, and gas molecules in the atmosphere affect the path of radiation from the sun, causing scattering. Scattering means that water droplets and dust suspended in the atmosphere reflect and bend the rays. This bending sends the rays out in all directions without changing their wavelengths. In clear, cloudless air, scattering is also caused by the reflection of light off gas molecules. Scattering sends some of the radiation back into space. The remaining radiation continues downward toward the earth's surface. As a result of scattering, sunlight reaching the earth's surface comes from all directions. Scattering is what makes the sky appear blue and makes the sun appear red at sunrise and sunset. Short-wavelength rays, such as blue light, are more easily scattered than long-wavelength rays are. The sun appears red when it is low in the sky because more blue light rays are scattered by the atmosphere. Thus more of the longer-wavelength red light rays reach the earth's surface, giving the sun its red color.

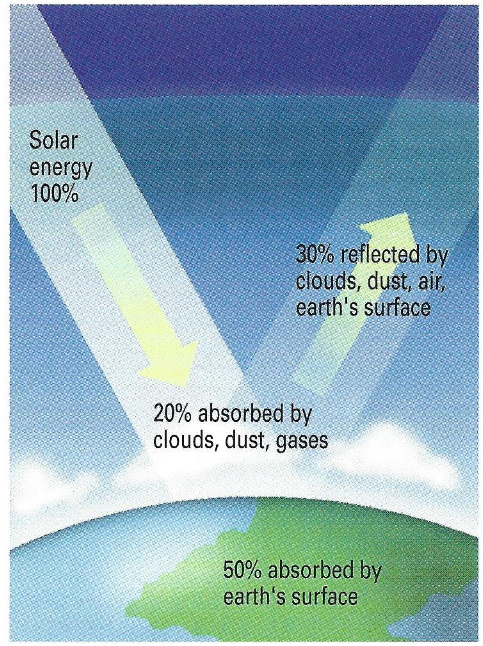


Figure 23–9. About 70% of the solar energy that reaches the earth is absorbed by the earth's land and ocean surfaces and by the atmosphere. The remainder, about 30%, is reflected back into space.

Reflection

Of the total amount of solar energy reaching the earth's atmosphere, about 20 percent is absorbed by the atmosphere. About 30 percent is scattered back into space or is reflected from clouds or the earth's surface. The remaining 50 percent is absorbed by the surface.

When solar energy reaches the earth's surface, the surface either absorbs the energy or reflects the energy. The kind of surface on which the radiation falls determines to a large extent whether absorption or reflection occurs. Table 23–1 shows the amount of incoming solar radiation absorbed and reflected by various surfaces.

Table 23–1 Reflection and Absorption

Surface	Percentage of solar radiation: Reflected	Absorbed
Soils	5–10	95–90
Desert	20–45	80–55
Grass	16–26	84–74
Forest	5–20	95–80
Snow	40–95	60–05
Water (high sun angle)	3–10	97–90
Water (low sun angle)	10–80	90–20

Because 30 percent of the total solar energy that reaches the earth's atmosphere is either reflected or scattered, the earth is said to have an average reflectivity of 0.3. The fraction of solar radiation reflected by a particular surface is called its **albedo.** The earth has an albedo of 0.3. The albedo of the moon is 0.07. What percent of the total solar energy reaching the moon is reflected?

Absorption and Infrared Energy

The solar radiation that is not reflected by the earth's surface is absorbed by the earth. Part of the absorbed radiation is composed of the infrared rays that have penetrated the atmosphere. When you feel the warmth of the sun, you are feeling infrared rays. The rocks, soil, water, and other earth materials are heated when they absorb infrared rays and visible light. The heated materials then produce their own infrared rays from the heat energy. These infrared rays have much longer wavelengths than the infrared rays that reach the earth's surface directly from the sun. The infrared rays with shorter wavelengths pass through the gases of the atmosphere. The infrared rays produced by the warmed materials of the earth's surface are mostly absorbed by water vapor and carbon dioxide in the atmosphere.

The Greenhouse Effect

The absorption of long-wavelength infrared rays from the earth's surface by gas molecules in the atmosphere traps heat energy and prevents it from escaping back into space. As a result, the lower atmosphere becomes warm. The warmed lower atmosphere keeps the earth's surface much warmer than it would be if there were no atmosphere. The process by which the atmosphere absorbs radiation has been compared to a greenhouse. The glass of a greenhouse allows the short wavelengths of visible light and infrared rays from the sun to pass through to the interior. The glass also prevents the long infrared rays emitted by the warmed surfaces within the greenhouse

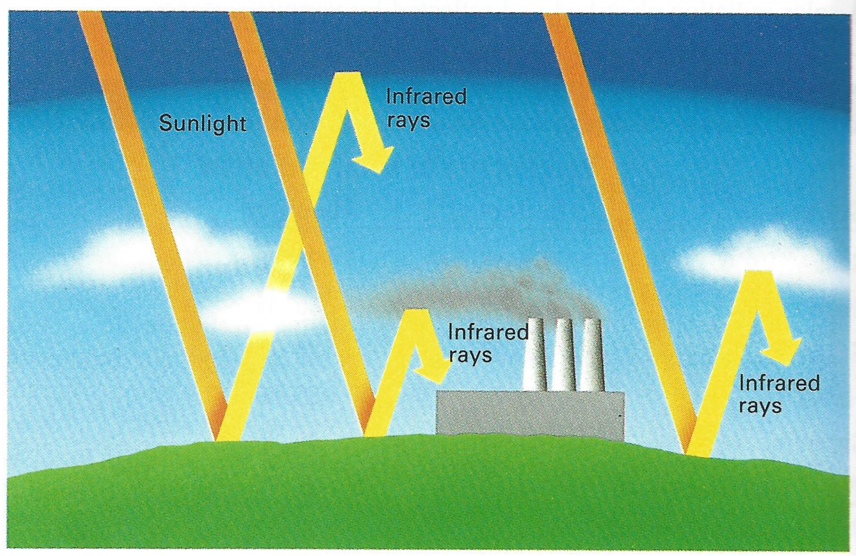


Figure 23–10. The visible and infrared rays of incoming sunlight pass through the water vapor and carbon dioxide of the atmosphere. Most of the longer infrared rays sent out by the warmed surfaces on the earth are trapped by these same substances.

from escaping to the outside. However, experiments have shown that a greenhouse is also heated because air warmed by the infrared rays is prevented from escaping. Thus, a greenhouse does not become heated in exactly the same way as does the atmosphere. Nevertheless, the process by which the atmosphere traps infrared rays over the earth's surface is called the **greenhouse effect.** By this process, the energy from the sun warms the air after having first been absorbed at the earth's surface. The atmosphere is heated mostly in the lower layer, the troposphere.

The average temperatures over all the earth's surface do not change much from year to year. Normally the amount of solar energy trapped is about equal to the amount that escapes into space. However, human activities may change this balance and cause the average temperature of the atmosphere to increase. For example, the burning of fossil fuels releases carbon dioxide into the air. Carbon dioxide absorbs infrared rays very effectively. Measurements have shown that the amount of carbon dioxide in the atmosphere has been increasing in recent years and seems likely to continue to increase in the future. Increases in the amount of carbon dioxide will intensify the greenhouse effect and may cause the earth to become warmer. Such general warming will probably cause climate changes in many parts of the world. Scientists are doing intensive research on the possible effects of global warming.

Variations in Temperature

Radiation from the sun does not heat the earth equally at all places at all times. How warm the atmosphere becomes in any region on the earth's surface depends on several factors. Latitude is the primary factor. Average temperatures are higher near the equator than near the poles. The direct rays of the sun striking near the equator are more effective in heating an area than the slanting rays striking the polar regions. Slanting rays spread their energy over a larger area than do direct rays.

Elevation is another factor in regional temperature variations. High elevations, such as mountaintops, become warm during the day, but they cool very quickly at night. The thinner air at high altitudes contains less water vapor and carbon dioxide to trap the heat. Desert temperatures usually show large changes between day and night because there is little water vapor present to hold the heat.

The temperature of water changes less than the temperature of land when solar energy is absorbed or when heat is given off. Water thus has a moderating effect. Under similar conditions, regions close to large bodies of water generally have more moderate temperatures. In other words, they will be cooler during daytime and warmer at nighttime than inland regions with the same general weather conditions. Also, the location of an area in relation to the wind patterns makes a difference. A region that receives winds off the ocean waters has more moderate temperatures than a similar region in which the winds blow from the land.

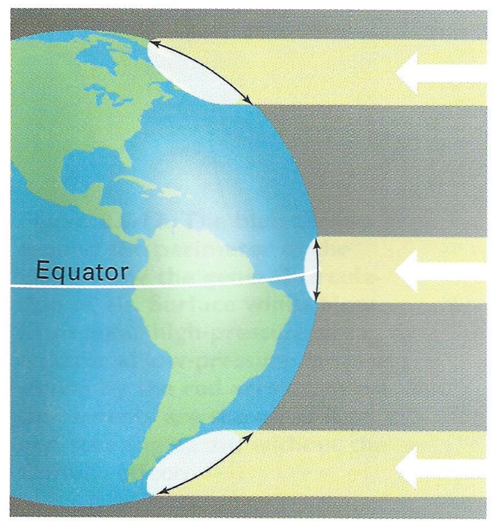


Figure 23–11. Temperatures are higher at the equator because solar energy is concentrated in a small surface area. Farther north and south, the same amount of solar energy is spread out over a larger surface area, and temperatures are lower.

> **INVESTIGATE!**
>
> *To learn more about air density and temperature, try the In-Depth Investigation on pages 476–477.*

There is also a delay in the heating of the atmosphere both seasonally and daily. The sun is highest and its rays most direct in the Northern Hemisphere on June 21. You might expect that this would be the warmest time of the year. However, it is usually late July before enough heat has been absorbed and reradiated from the ground to really heat up the atmosphere. Only then does the warm, summer weather begin. For similar reasons, the warmest hours of the day are usually about 2:00 in the afternoon, although the sun is strongest at 12:00 noon.

Conduction and Convection

While most heating of the atmosphere comes from radiation, a small amount results from **conduction** and *convection*. In conduction, the molecules in a substance move faster as they become heated. These fast-moving molecules cause other molecules to also move faster. The motion makes the substance warm. Solid substances, in which the molecules are close together, make good conductors because heat can be transferred quickly from molecule to molecule. Air is warmed when it comes in contact with anything hotter than the air itself. However, the molecules of air are far apart. As a result, air is a poor conductor of heat. Some heating of the lower part of the atmosphere takes place through conduction when air comes into contact with the warmed surface of the earth.

Convection, as you learned in Chapter 4, involves the movement of gases or liquids when they are heated unevenly. The movement of air due to convection takes place when some of the air is heated by radiation or conduction. As that air is heated by radiation or conduction, it becomes less dense and rises. Nearby cooler air, which is more dense, sinks. As it sinks, the cooler air pushes the warm air up. The cold air is, in turn, warmed, and then it rises also. This continuous cycle of cold air sinking and warm air rising helps warm the earth's surface relatively evenly. Because heated air is less dense than cool air, it exerts less pressure on the earth than the same volume of cooler air does. Consequently, the atmospheric pressure is generally lower beneath a mass of warm air than it is under cool air. As dense, cool air moves into a low-pressure region, the less dense, warmer air is pushed upward. The general movement of cool air is always toward regions of lower pressure. These pressure differences, which are the result of the unequal heating that causes convection, create winds.

Section 23.2 Review

1. What type of solar radiation causes sunburn?
2. Why is the atmospheric pressure lower beneath a mass of warm air than beneath a mass of cold air?
3. You decide not to be outside during the warmest hours of a warm summer day. When will the warmest hours probably be? How do you know?