The concepts of heat and temperature often are confused. The phrase “in the heat of the day” is one common expression in which the word “heat” is misused to describe the concept of temperature. **Heat** is the energy transferred from one object to another because of a difference in their temperatures. **Temperature** is a measure of the average kinetic energy of the individual atoms or molecules in a substance. When energy is transferred to the gas atoms and molecules in air, those particles move faster and air temperature rises. When air transfers energy to a cooler object, its particles move slower, and air temperature drops.

**Energy Transfer as Heat**

Three mechanisms of energy transfer as heat are conduction, convection, and radiation. All three processes, illustrated in Figure 9, happen simultaneously in the atmosphere. These mechanisms operate to transfer energy between Earth’s surface (both land and water) and the atmosphere.

**Conduction** Anyone who has touched a metal spoon that was left in a hot pan has experienced the result of heat conducted through the spoon. **Conduction** is the transfer of heat through matter by molecular activity. The energy of molecules is transferred by collisions from one molecule to another. Heat flows from the higher temperature matter to the lower temperature matter.

**Convection** Warmer water expands and becomes less dense, rising through cooler water above, creating transfer of heat by circulation within a liquid.

**Radiation** The fire is the hottest thing pictured; it emits the most radiant energy.
The ability of substances to conduct heat varies greatly. Metals are good conductors, as those of us who have touched hot metal have quickly learned. Air, however, is a very poor conductor of heat. Because air is a poor conductor, conduction is important only between Earth's surface and the air directly in contact with the surface. For the atmosphere as a whole, conduction is the least important mechanism of heat transfer.

Convection

Much of the heat transfer that occurs in the atmosphere is carried on by convection. Convection is the transfer of heat by mass movement or circulation within a substance. It takes place in fluids, like the ocean and air, where the atoms and molecules are free to move about. Convection also takes place in solids, such as Earth's mantle, that behave like fluids over long periods of time.

The pan of water in Figure 9 shows circulation by convection. Radiation from the fire warms the bottom of the pan, which conducts heat to the water near the bottom of the container. As the water is heated, it expands and becomes less dense than the water above. The warmer water rises because of its buoyancy. At the same time, cooler, denser water near the top of the pan sinks to the bottom, where it becomes heated. As long as the water is heated unequally, it will continue to circulate. In much the same way, most of the heat acquired by radiation and conduction in the lowest layer of the atmosphere is transferred by convective flow.

Electromagnetic Waves

The sun is the ultimate source of energy that creates our weather. You know that the sun emits light and heat as well as the ultraviolet rays that cause a suntan. These forms of energy are only part of a large array of energy called the electromagnetic spectrum. This spectrum of electromagnetic energy is shown in Figure 10. All radiation, whether X-rays, radio waves, or heat waves, travel through the vacuum of space at 300,000 kilometers per second. They travel only slightly slower through our atmosphere.

Visual, Logical

Build Science Skills

Using Models Have students work in pairs to develop ways to model the three methods of heat transfer. Give each pair a crumpled-up piece of scrap paper and tell them it represents heat. Each student represents a molecule. Tell students to use physical movements to model each method of transfer. For example, to demonstrate conduction, students can pass the ball directly to the partner; for convection, students can carry the ball to the partner; and for radiation, students can throw the ball to the partner.

Kinesthetic, Logical

Customize for Inclusion Students

Gifted Have students create a computer graphics presentation that compares the different mechanisms of heat transfer. The presentations should include both diagrams and photographs.
Imagine what happens when you toss a pebble into a pond. Ripples are made and move away from the location where the pebble hit the water’s surface. Much like these ripples, electromagnetic waves move out from their source and come in various sizes. The most important difference among electromagnetic waves is their wavelength, or the distance from one crest to the next. Radio waves have the longest wavelengths, ranging to tens of kilometers. Gamma waves are the shortest, and are less than a billionth of a centimeter long.

Visible light is the only portion of the spectrum you can see. White light is really a mixture of colors. Each color corresponds to a specific wavelength, as shown in Figure 11. By using a prism, white light can be divided into the colors of the rainbow, from violet with the shortest wavelength—0.4 micrometer (1 micrometer is 0.0001 centimeter)—to red with the longest wavelength—0.7 micrometer.

**Radiation**  The third mechanism of heat transfer is radiation. As shown in Figure 9, radiation travels out in all directions from its source. **Unlike conduction and convection, which need material to travel through, radiant energy can travel through the vacuum of space.** Solar energy reaches Earth by radiation.

To understand how the atmosphere is heated, it is useful to think about four laws governing radiation.

1. **All objects, at any temperature, emit radiant energy.** Not only hot objects like the sun but also Earth—including its polar ice caps—continually emit energy.
2. **Hotter objects radiate more total energy per unit area than colder objects do.**
3. **The hottest radiating bodies produce the shortest wavelengths of maximum radiation.** For example, the sun, with a surface temperature of nearly 6000°C radiates maximum energy at 0.5 micrometers, which is in the visible range. The maximum radiation for Earth occurs at a wavelength of 10 micrometers, well within the infrared range.
4. **Objects that are good absorbers of radiation are good emitters as well.** Gases are selective absorbers and radiators. The atmosphere does not absorb certain wavelengths of radiation, but it is a good absorber of other wavelengths.

![Figure 11](image-url) Visible light consists of an array of colors commonly called the colors of the rainbow.

**Build Reading Literacy**

Refer to p. 474D, which provides the guidelines for monitoring understanding.

**Monitor Your Understanding**  Have students read the passage Radiation on pp. 484–485. When they reach the bottom of p. 485, have them stop and write down the main ideas of the passage. They should have two main groups of ideas: the different types of electromagnetic waves, and the laws that govern radiation. Have students ask themselves, “Did I have any trouble reading this passage? If so, why?” Lead a class discussion of strategies that can be used to improve understanding, such as looking up difficult words and discussing difficult concepts with a partner. Have students use these strategies as they continue reading.

**Integrate Physics**

**Rainbows**  Tell students that a rainbow occurs when white light passes through tiny drops of water in the air. Each water drop acts like a tiny prism. When light enters a drop, it slows down and refracts, or bends. Red light slows down and bends the least, whereas violet light slows down and bends the most. The light then reflects off the far inner surface of the drop and passes back through the drop, refracting again. Have students use prisms to separate light into a spectrum and project it onto a sheet of white paper.

**Logical, Verbal**

Go Online

Download a worksheet on conduction and convection for students to complete, and find additional teacher support from NSTA SciLinks.
Chapter 17

What Happens to Solar Radiation?

Use Visuals

Figure 12 Use the diagram to discuss what happens to solar radiation. Ask: What percentage of radiation is reflected from clouds? (20 percent) What percentage of radiation is lost to space by reflection and scattering? (30 percent) What types of radiation are absorbed by land and sea? (direct and diffused radiation)

Visual

Build Science Skills

Applying Concepts

Dim the room lights and shine a beam of light through the air from a large flashlight or other strong light source. Have students look at the beam and describe what they see. (tiny particles) Ask students what phenomenon allows them to see these particles. (scattering)

Logical

Reflection and Scattering Reflection occurs when light bounces off an object. The reflected radiation has the same intensity as the incident radiation. In contrast, scattering produces a larger number of weaker rays that travel in different directions. See Figure 13.

Scattering disperses light both forward and backward. However, more energy is dispersed in the forward direction. About 30 percent of the solar energy reaching the outer atmosphere is reflected back to space. This 30 percent also includes the amount of energy sent skyward by scattering. This energy is lost and does not play a role in heating Earth’s atmosphere.

Small dust particles and gas molecules in the atmosphere scatter some incoming radiation in all directions. This explains how light reaches into the area beneath a shade tree, and how a room is lit in the absence of direct sunlight. Scattering also accounts for the brightness and even the blue color of the daytime sky. In contrast, bodies like the moon and Mercury—which are without atmospheres—have dark skies and “pitch-black” shadows even during daylight hours. About half of the solar radiation that is absorbed at Earth’s surface arrives as scattered light.

What causes the blue color of the daytime sky?

Facts and Figures

The fraction of the total radiation that is reflected by a surface is called its albedo. The albedo for Earth as a whole (the planetary albedo) is 30 percent. The albedo varies considerably from place to place and time to time in the same location. Albedo can vary with amount of cloud cover and particles in the air, as well as the nature of the surface and the angle of the sun’s rays. A lower sun angle means that the rays pass through more of the atmosphere, and more solar radiation is lost. Albedo can be as low as 5 percent for a forest and as high as 90 percent for fresh snow.
Absorption  About 50 percent of the solar energy that strikes the top of the atmosphere reaches Earth's surface and is absorbed, as shown in Figure 12. Most of this energy is then reradiated skyward. Because Earth has a much lower surface temperature than the sun, the radiation that it emits has longer wavelengths than solar radiation does.

The atmosphere efficiently absorbs the longer wavelengths emitted by Earth. Water vapor and carbon dioxide are the major absorbing gases. When a gas molecule absorbs light waves, this energy is transformed into molecular motion that can be detected as a rise in temperature. Gases in the atmosphere eventually radiate some of this energy away. Some energy travels skyward, where it may be reabsorbed by other gas molecules. The remainder travels Earthward and is again absorbed by Earth. In this way, Earth’s surface is continually being supplied with heat from the atmosphere as well as from the sun.

Without these absorbing gases in our atmosphere, Earth would not be a suitable habitat for humans and other life forms. This important phenomenon has been termed the greenhouse effect because it was once thought that greenhouses were heated in a similar manner. A more important factor in keeping a greenhouse warm is the fact that the greenhouse itself prevents the mixing of air inside with cooler air outside. Nevertheless, the term greenhouse effect is still used.

**Q & A**

**Q** Isn’t the greenhouse effect responsible for global warming?

**A** It is important to note that the greenhouse effect and global warming are not the same thing. Without the greenhouse effect, Earth would be uninhabitable. We do have mounting evidence that human activity (particularly the release of carbon dioxide into the atmosphere) is responsible for a rise in global temperatures. Thus, human activities seem to be enhancing an otherwise natural process (the greenhouse effect) to increase Earth’s temperature. Nevertheless, to equate the greenhouse effect, which makes life possible, with undesirable changes to our atmosphere caused by human activity is incorrect.

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**Section 17.2 Assessment**

### Reviewing Concepts

1. How are heat and temperature related?
2. List and describe the three major mechanisms of heat transfer in the atmosphere.
3. How is the atmosphere affected by:
   - convection?
   - conduction?
   - radiation?
4. Describe what happens to solar radiation when it strikes an object.
5. Contrast reflection and scattering.

### Critical Thinking

6. Applying Concepts Dark objects tend to absorb more radiation than light-colored objects. Explain whether dark objects or light objects on Earth's surface would be better radiators of heat.

### Writing in Science

**Descriptive Paragraph** Write a paragraph that describes the four laws governing radiation discussed in this chapter. Make sure to use your own words. Use examples to reinforce concepts wherever possible.

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**Section 17.2 Assessment**

1. Both heat and temperature arise from thermal vibrations in atoms and molecules. Heat is energy transferred between objects (matter) that are at different temperatures. Temperature is the average kinetic energy of individual atoms and molecules in the substance.
3. Convection: Much of the heat transfer in the atmosphere is carried by convection. Most of the heat acquired by radiation and conduction in the lowest layer of the atmosphere is transferred by convective flow;
   - Conduction: Air is a poor conductor of heat, so conduction is most important between Earth’s surface and the air directly in contact with the surface. Conduction is the least important mechanism of heat transfer in the atmosphere;
   - Radiation: Solar energy reaches Earth by radiation. The radiation can be absorbed, transmitted, or reflected. The radiant energy that is absorbed is converted to heat and causes an increase in temperature.
4. When solar radiation strikes an object, it can absorb, reflect, or scatter the radiation.
5. Reflection: radiation bouncing off an object at the same angle and intensity as the incident radiation. Scattering: radiation bouncing off in all directions with intensities that are weaker than the incident radiation.
6. Because good absorbers also tend to be good radiators of heat, dark-colored objects are expected to be better radiators than light-colored objects.