CHAPTER

11 Atmosphere

BIG Idea **The composition, structure, and properties of Earth's atmosphere form the basis of Earth's weather and climate.**

11.1 Atmospheric Basics

MAIN Idea Energy is transferred throughout Earth's atmosphere and surface.

11.2 Properties of the Atmosphere

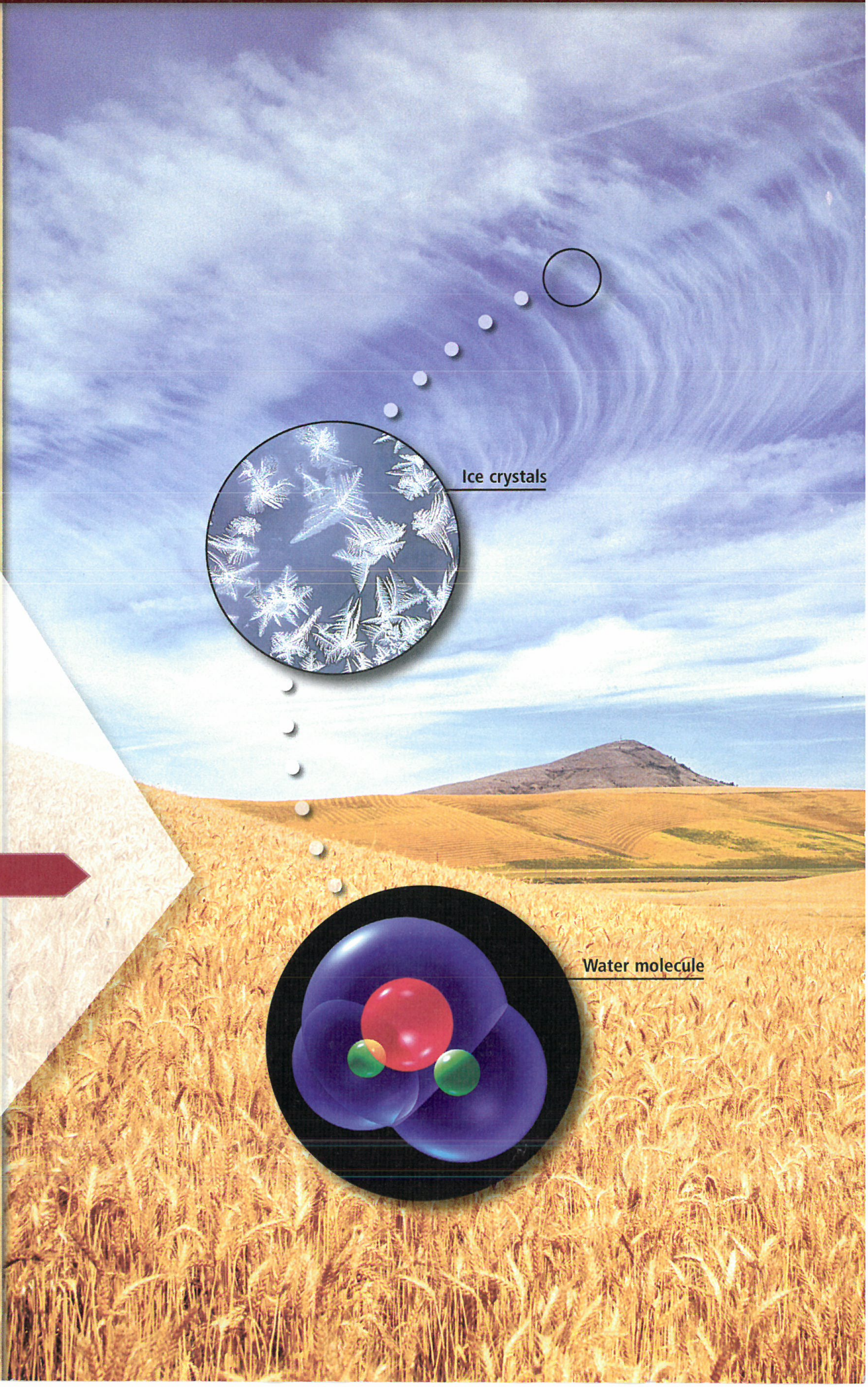
MAIN Idea Atmospheric properties, such as temperature, air pressure, and humidity describe weather conditions.

11.3 Clouds and Precipitation

MAIN Idea Clouds vary in shape, size, height of formation, and type of precipitation.

GeoFacts

- Cirrus clouds are named for the Latin word meaning *curl of hair* because they often appear wispy and hairlike.
- High cirrus clouds are often pushed along by the jet stream and can move at speeds exceeding 160 km/h.
- Clouds can appear gray or even black if they are high enough in the atmosphere, or dense enough that light cannot penetrate them.



Start-Up Activities

LAUNCH Lab

What causes cloud formation?

Clouds form when water vapor in the air condenses into water droplets or ice. These clouds might produce rain, snow, hail, sleet, or freezing rain.

Procedure

1. Read and complete the lab safety form.
2. Pour about 125 mL of **warm water** into a **clear, plastic bowl.**
3. Loosely cover the top of the bowl with **plastic wrap.** Overlap the edges of the bowl by about 5 cm.
4. Fill a **self-sealing plastic bag** with **ice cubes,** seal it, and place it in the center of the plastic wrap on top of the bowl. Push the bag of ice down so that the plastic wrap sags in the center but does not touch the surface of the water.
5. Use **tape** to seal the plastic wrap around the bowl.
6. Observe the surface of the plastic wrap directly under the ice cubes every 10 min for 30 min, or until the ice melts.

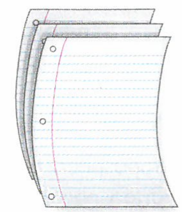
Analysis

1. **Infer** What formed on the underside of the wrap? Why did this happen?
2. **Relate** your observations to processes in the atmosphere.
3. **Predict** what would happen if you repeated this activity with hot water in the bowl.

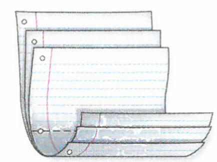
FOLDABLES™ Study Organizer

Layers of the Atmosphere Make the following Foldable to organize information about the layers of Earth's atmosphere.

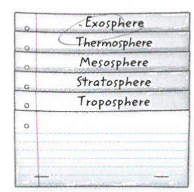
STEP 1 Collect three sheets of paper, and layer them about 2 cm apart vertically.



STEP 2 Fold up the bottom edges of the sheets to form five equal tabs. Crease the fold to hold the tabs in place.



STEP 3 Staple along the fold. Label the tabs *Exosphere, Thermosphere, Mesosphere, Stratosphere,* and *Troposphere.*



FOLDABLES **Use this Foldable with Section 11.1.** Sketch the layers on the first tab and summarize information about each layer on the appropriate tabs.

Earth Science Online

Visit glencoe.com to

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- explore Concepts In Motion animations:
  - Interactive Time Lines
  - Interactive Figures
  - Interactive Tables
- access Web Links for more information, projects, and activities;
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Section 11.1

Objectives

- **Describe** the gas and particle composition of the atmosphere.
- **Compare and contrast** the five layers of the atmosphere.
- **Identify** three ways energy is transferred in the atmosphere.

Review Vocabulary

atmosphere: the layer of gases that surrounds Earth

New Vocabulary

troposphere
stratosphere
mesosphere
thermosphere
exosphere
radiation
conduction
convection

Atmospheric Basics

MAIN Idea Energy is transferred throughout Earth's atmosphere.

Real-World Reading Link If you touch something made of metal, it will probably feel cool. Metals feel cool because they conduct thermal energy away from your hand. In a similar way, energy is transferred directly from the warmed air near Earth's surface to the air in the lowest layer of the atmosphere.

Atmospheric Composition

The ancient Greeks thought that air was one of the four fundamental elements from which all other substances were made. In fact, air is a combination of gases, such as nitrogen and oxygen, and particles, such as dust, water droplets, and ice crystals. These gases and particles form Earth's atmosphere, which surrounds Earth and extends from Earth's surface to outer space.

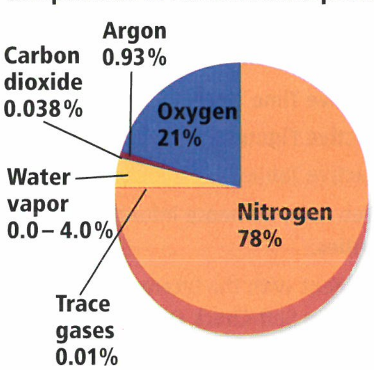
Permanent atmospheric gases About 99 percent of the atmosphere is composed of nitrogen (N_2) and oxygen (O_2). The remaining 1 percent consists of argon (Ar), carbon dioxide (CO_2), water vapor (H_2O), and other trace gases, as shown in **Figure 11.1.** The amounts of nitrogen and oxygen in the atmosphere are fairly constant over recent time. However, over Earth's history, the composition of the atmosphere has changed greatly. For example, Earth's early atmosphere probably contained mostly helium (He), hydrogen (H_2), methane (CH_4), and ammonia (NH_3). Today, oxygen and nitrogen are continually being recycled between the atmosphere, living organisms, the oceans, and Earth's crust.

Variable atmospheric gases The concentrations of some atmospheric gases are not as constant over time as the concentrations of nitrogen and oxygen. Gases such as water vapor and ozone (O_3) can vary significantly from place to place. The concentrations of some of these gases, such as water vapor and carbon dioxide, play an important role in regulating the amount of energy the atmosphere absorbs and emits back to Earth's surface.

Water vapor Water vapor is the invisible, gaseous form of water. The amount of water vapor in the atmosphere can vary greatly over time and from one place to another. At a given place and time, the concentration of water vapor can be as much as 4 percent or as little as nearly zero. The concentration varies with the seasons, with the altitude of a particular mass of air, and with the properties of the surface beneath the air. Air over deserts, for instance, contains much less water vapor than the air over oceans.

Figure 11.1 Earth's atmosphere consists mainly of nitrogen (78 percent) and oxygen (21 percent).

Composition of Earth's Atmosphere



Carbon dioxide Carbon dioxide, another variable gas, currently makes up about 0.039 percent of the atmosphere. During the past 150 years, measurements have shown that the concentration of atmospheric carbon dioxide has increased from about 0.028 percent to its present value. Carbon dioxide is also cycled between the atmosphere, the oceans, living organisms, and Earth's rocks.

The recent increase in atmospheric carbon dioxide is due primarily to the burning of fossil fuels, such as oil, coal, and natural gas. These fuels are burned to heat buildings, produce electricity, and power vehicles. Burning fossil fuels can also produce other gases, such as sulfur dioxide and nitrous oxides, that can cause various respiratory illnesses, as well as other environmental problems.

Ozone Molecules of ozone are formed by the addition of an oxygen atom to an oxygen molecule, as shown in **Figure 11.2.** Most atmospheric ozone is found in the ozone layer, 20 km to 50 km above Earth's surface, as shown in **Figure 11.3.** The maximum concentration of ozone in this layer—9.8×10^{12} molecules/cm^3—is only about 0.0012 percent of the atmosphere.

The ozone concentration in the ozone layer varies seasonally at higher latitudes, reaching a minimum in the spring. The greatest seasonal changes occur over Antarctica. During the past several decades, measured ozone levels over Antarctica in the spring have dropped significantly. This decrease is due to the presence of chemicals called chlorofluorocarbons (CFCs) that react with ozone and break it down in the atmosphere.

Atmospheric particles Earth's atmosphere also contains variable amounts of solids in the form of tiny particles, such as dust, salt, and ice. Fine particles of dust and soil are carried into the atmosphere by wind. Winds also pick up salt particles from ocean spray. Airborne microorganisms, such as fungi and bacteria, can also be found attached to microscopic dust particles in the atmosphere.

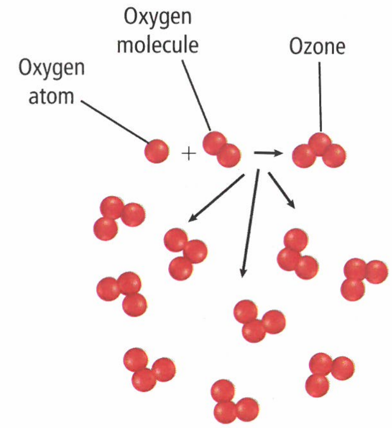


Figure 11.2 Molecules of ozone are formed by the addition of an oxygen atom to an oxygen molecule.

NATIONAL GEOGRAPHIC For more information on the ozone layer and the atmosphere, go to the **National Geographic Expedition** on page 910.

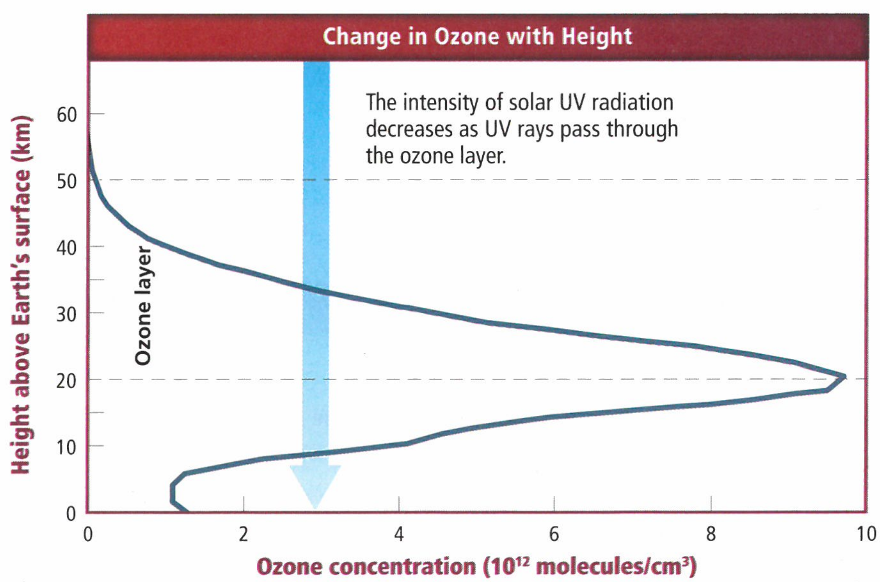


Figure 11.3 The ozone layer blocks harmful ultraviolet rays from reaching Earth's surface. Ozone concentration is highest at about 20 km above Earth's surface, in the ozone layer.

Atmospheric Layers

The atmosphere is classified into five different layers, as shown in **Table 11.1** and **Figure 11.4.** These layers are the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. Each layer differs in composition and temperature profile.

FOLDABLES
Incorporate information from this section into your Foldable.

Troposphere The layer closest to Earth's surface, the **troposphere,** contains most of the mass of the atmosphere. Weather occurs in the troposphere. In the troposphere, air temperature decreases as altitude increases. The altitude at which the temperature stops decreasing is called the tropopause. The height of the tropopause varies from about 16 km above Earth's surface in the tropics to about 9 km above it at the poles. Temperatures at the tropopause can be as low as −60°C.

Stratosphere Above the tropopause is the **stratosphere,** a layer in which the air temperature mainly increases with altitude and contains the ozone layer. In the lower stratosphere below the ozone layer, the temperature stays constant with altitude. However, starting at the bottom of the ozone layer, the temperature in the stratosphere increases as altitude increases. This heating is caused by ozone molecules, which absorb ultraviolet radiation from the Sun. At the stratopause, air temperature stops increasing with altitude. The stratopause is about 48 km above Earth's surface. About 99.9 percent of the mass of Earth's atmosphere is below the stratopause.

Mesosphere Above the stratopause is the **mesosphere,** which is about 50 km to 100 km above Earth's surface. In the mesosphere, air temperature decreases with altitude, as shown in **Figure 11.4.** This temperature decrease occurs because very little solar radiation is absorbed in this layer. The top of the mesosphere, where temperatures stop decreasing with altitude, is called the mesopause.

Thermosphere The **thermosphere** is the layer between about 100 km and 500 km above Earth's surface. In this layer, the extremely low density of air causes the temperature to rise. This will be discussed further in Section 11.2. Temperatures in this layer can be more than 1000°C. The ionosphere, which is made of electrically charged particles, is part of the thermosphere.

Concepts In Motion
Interactive Table To explore more about layers of the atmosphere, visit glencoe.com.

Table 11.1 Components of the Atmosphere

Atmospheric Layer	Components
Troposphere	layer closest to Earth's surface, ends at the tropopause
Stratosphere	layer above the troposphere, contains the ozone layer, and ends at the stratopause
Mesosphere	layer above the stratosphere, ends at the mesopause
Thermosphere	layer above the mesosphere, absorbs solar radiation
Exosphere	outermost layer of Earth's atmosphere, transitional space between Earth's atmosphere and outer space

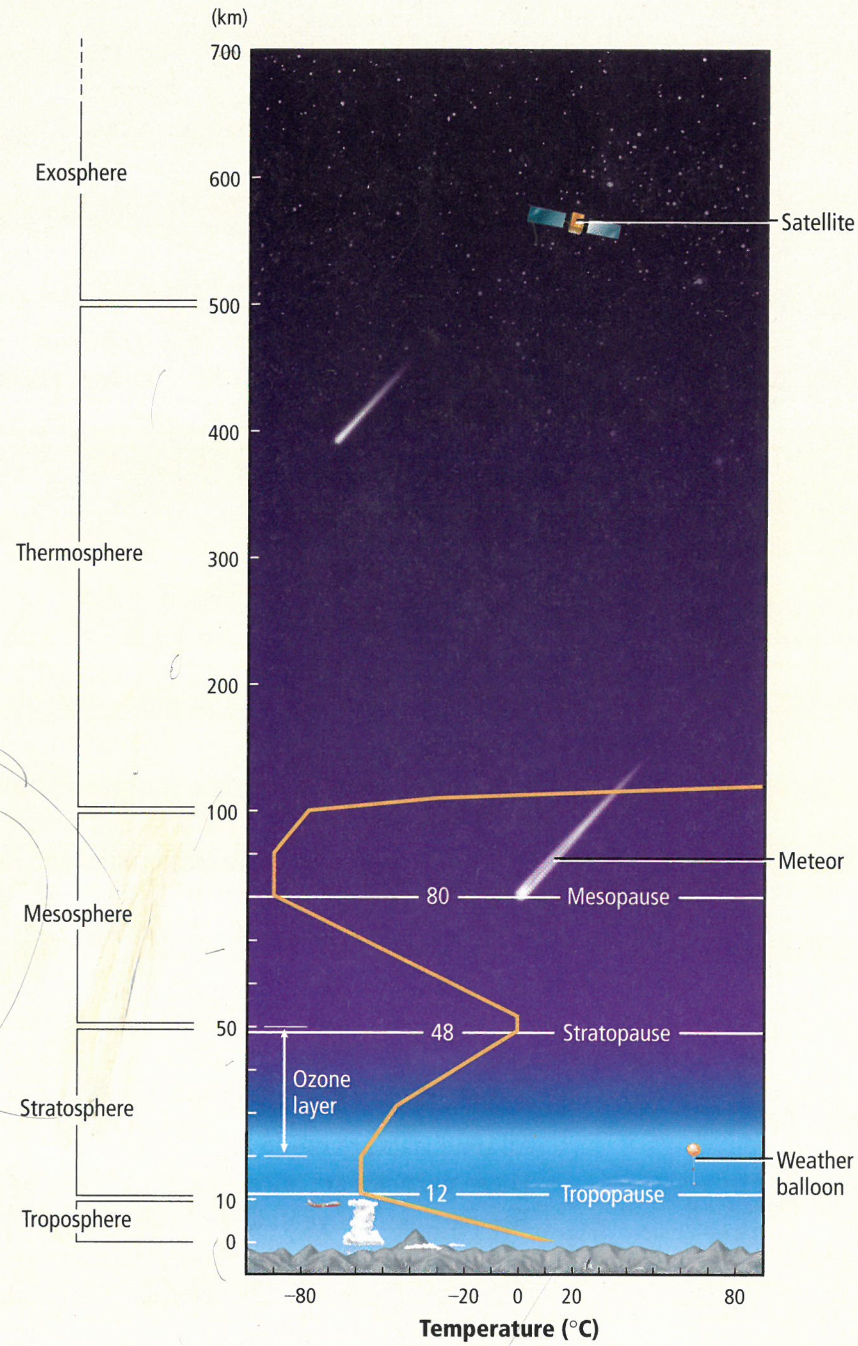
Visualizing the Layers of the Atmosphere

NATIONAL GEOGRAPHIC

Figure 11.4 Earth's atmosphere is made up of five layers. Each layer is unique in composition and temperature. As shown, air temperature changes with altitude. When you fly in a plane, you might be flying at the top of the troposphere, or you might enter into the stratosphere.

In the exosphere, gas molecules can be exchanged between the atmosphere and space.

Noctilucent clouds are shiny clouds that can be seen in the twilight in the summer around 50°–60° latitude in the northern and southern hemispheres. These are the only clouds that form in the mesosphere.



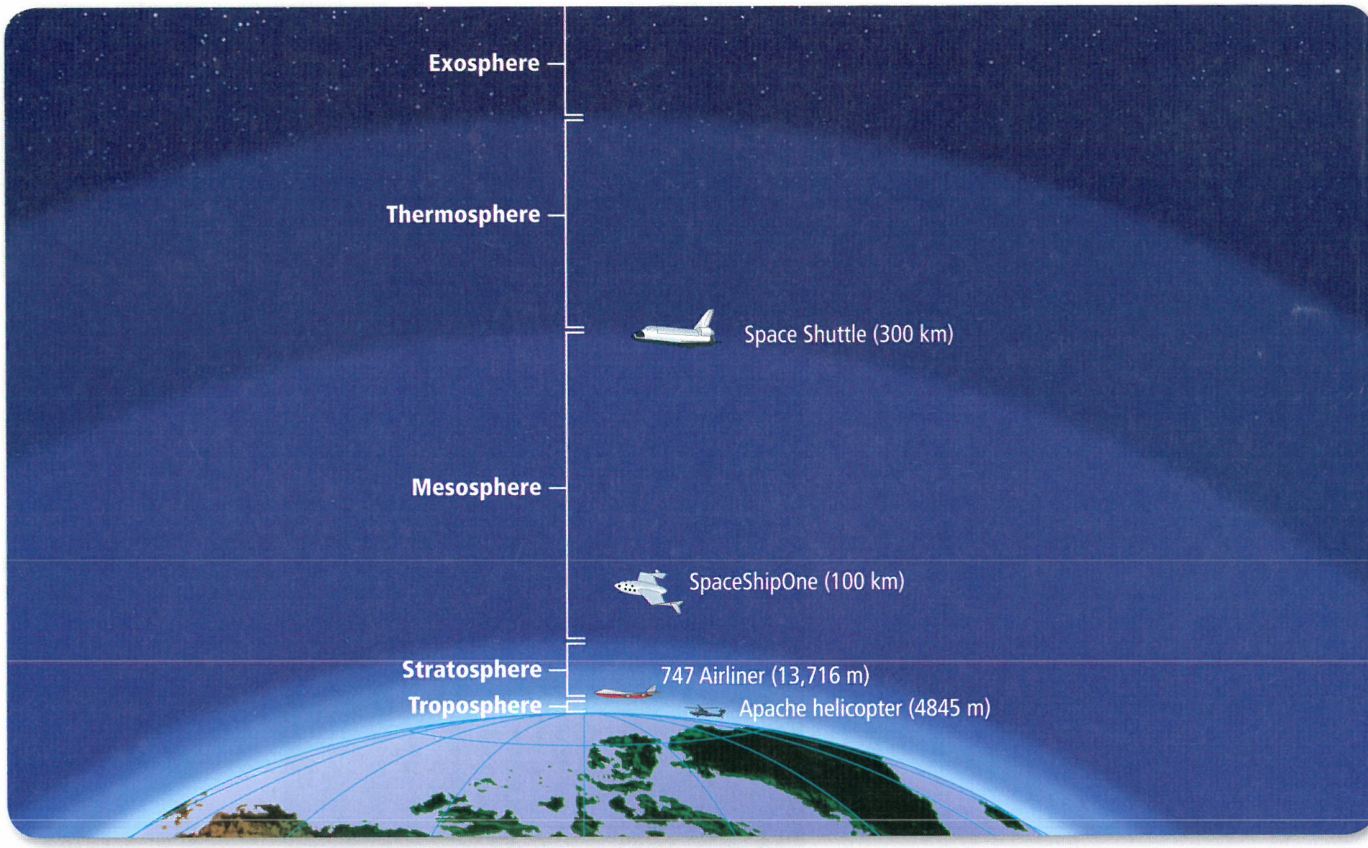


Figure 11.5 Different spacecraft can traverse the various layers of the atmosphere. **Compare** *the number of atmospheric layers each spacecraft can reach in its flight path.*

Exosphere The **exosphere** is the outermost layer of Earth's atmosphere, as shown in **Figure 11.5.** The exosphere extends from about 500 km to more than 10,000 km above Earth's surface. There is no clear boundary at the top of the exosphere. Instead, the exosphere can be thought of as the transitional region between Earth's atmosphere and outer space. The number of atoms and molecules in the exosphere becomes very small as altitude increases.

In the exosphere, atoms and molecules are so far apart that they rarely collide with each other. In this layer, some atoms and molecules are moving fast enough that they are able to escape into outer space.

Reading Check **Summarize** how temperature varies with altitude in the four lowest layers of the atmosphere.

Energy Transfer in the Atmosphere

All materials are made of particles, such as atoms and molecules. These particles are always moving, even if the object is not moving. The particles move in all directions with various speeds—a type of motion called random motion. A moving object has a form of energy called kinetic energy. As a result, the particles moving in random motion have kinetic energy. The total energy of the particles in an object due to their random motion is called thermal energy.

Heat is the transfer of thermal energy from a region of higher temperature to a region of lower temperature. In the atmosphere, thermal energy can be transferred by radiation, conduction, and convection.

Radiation Light from the Sun heats some portions of Earth's surface at all times, just as the heat lamp in **Figure 11.6** uses the process of radiation to warm food. **Radiation** is the transfer of thermal energy by electromagnetic waves. The heat lamp emits visible light and infrared waves that travel from the lamp and are absorbed by the food. The thermal energy carried by these waves causes the temperature of the food to increase. In the same way, thermal energy is transferred from the Sun to Earth by radiation. The solar energy that reaches Earth is absorbed and reflected by Earth's atmosphere and Earth's surface.

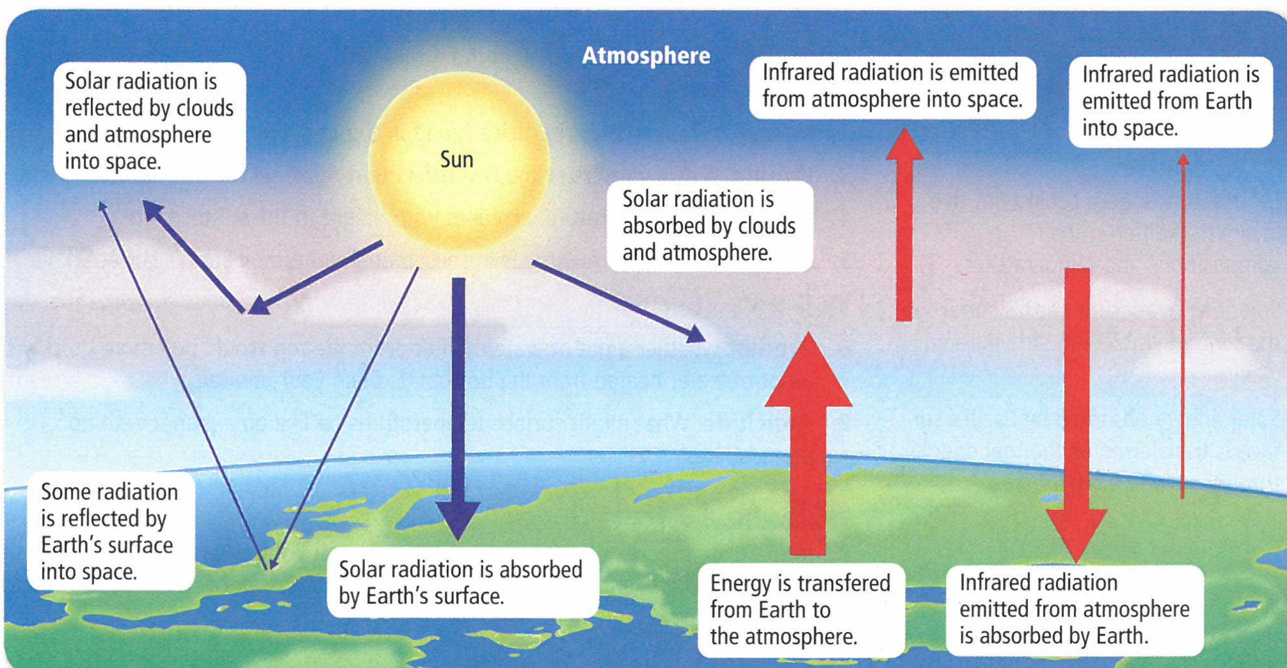
Absorption and reflection Most of the solar energy that reaches Earth is in the form of visible light waves and infrared waves. Almost all of the visible light waves pass through the atmosphere and strike Earth's surface. Most of these waves are absorbed by Earth's surface. As the surface absorbs these visible light waves, it also emits infrared waves. The atmosphere absorbs some infrared waves from the Sun and emits infrared waves with different wavelengths, as shown in **Figure 11.7.**

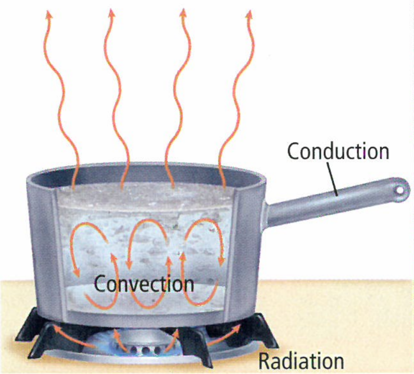
About 30 percent of solar radiation is reflected into space by Earth's surface, the atmosphere, or clouds. Another 20 percent is absorbed by the atmosphere and clouds. About 50 percent of solar radiation is absorbed directly or indirectly by Earth's surface and keeps Earth's surface warm.

Rate of absorption The rate of absorption for any particular area varies depending on the physical characteristics of the area and the amount of solar radiation it receives. Different areas absorb energy and heat at different rates. For example, water heats and cools more slowly than land. Also, as a general rule, darker objects absorb energy faster than light-colored objects. For instance, a black asphalt driveway heats faster on a sunny day than a light-colored concrete driveway.

Figure 11.6 A heat lamp transfers thermal energy by radiation. Here, the thermal energy helps to keep the french fries hot.

Figure 11.7 Incoming solar radiation is either reflected back into space or absorbed by Earth's atmosphere or its surface.
Trace *the pathways by which solar radiation is absorbed and reflected.*





■ **Figure 11.8** Thermal energy is transferred to the burner from the heat source by radiation. The burner transfers the energy to the atoms in the bottom of the pan, which collide with neighboring atoms. As these collisions occur, thermal energy is transferred by conduction to other parts of the pan, including the handle.

Concepts In Motion

Interactive Figure To see an animation of conduction, convection, and radiation, visit glencoe.com.

Conduction Another process of energy transfer can occur when two objects at different temperatures are in contact. **Conduction** is the transfer of thermal energy between objects when their atoms or molecules collide, as shown in **Figure 11.8.** Conduction can occur more easily in solids and liquids, where particles are close together, than in gases, where particles are farther apart. Because air is a mixture of gases, it is a poor conductor of thermal energy. In the atmosphere, conduction occurs between Earth's surface and the lowest part of the atmosphere.

Convection Throughout much of the atmosphere, thermal energy is transferred by a process called convection. The process of convection occurs mainly in liquids and gases. **Convection** is the transfer of thermal energy by the movement of heated material from one place to another. **Figure 11.8** illustrates the process of convection in a pan of water. As water at the bottom of the pan is heated, it expands and becomes less dense than the water around it. Because it is less dense, it is forced upward. As it rises, it transfers thermal energy to the cooler water around it, and cools. It then becomes denser than the water around it and sinks to the bottom of the pan, where it is reheated.

A similar process occurs in the atmosphere. Parcels of air near Earth's surface are heated, become less dense than the surrounding air, and rise. As the warm air rises, it cools and its density increases. When it cools below the temperature of the surrounding air, the air parcel becomes denser than the air around it and sinks. As it sinks, it warms again, and the process repeats. Convection currents, as these movements of air are called, are the main mechanism for energy transfer in the atmosphere.

Section 11.1 Assessment

Section Summary

- Earth's atmosphere is composed of several gases, primarily nitrogen and oxygen, and also contains small particles.
- Earth's atmosphere consists of five layers that differ in their compositions and temperatures.
- Solar energy reaches Earth's surface in the form of visible light and infrared waves.
- Solar energy absorbed by Earth's surface is transferred as thermal energy throughout the atmosphere.

Understand Main Ideas

1. **MAIN Idea** **Rank** the gases in the atmosphere in order from most abundant to least abundant.
2. **Name** the four types of particles found in the atmosphere.
3. **Compare and contrast** the five layers that make up the atmosphere.
4. **Explain** why temperature increases with height in the stratosphere.
5. **Compare** how solar energy is absorbed and emitted by Earth's surface.

Think Critically

6. **Predict** whether a pot of water heated from the top would boil more quickly than a pot of water heated from the bottom. Explain your answer.
7. **Conclude** What might surface temperatures be like on a planet with no atmosphere?

MATH in Earth Science

8. In the troposphere, temperature decreases with height at an average rate of 6.5°C/km. If temperature at 2.5 km altitude is 7.0°C, what is the temperature at 5.5 km altitude?

Earth Science Online Self-Check Quiz glencoe.com