

Chapter 19

The Atmosphere

Chapter Outline

1 Characteristics of the Atmosphere

Composition of the Atmosphere

Atmospheric Pressure

Measuring Atmospheric Pressure

Layers of the Atmosphere

Temperature Inversions

2 Solar Energy and the Atmosphere

Radiation

The Atmosphere and Solar Radiation

Absorption and Infrared Energy

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Conduction

Convection

3 Atmospheric Circulation

The Coriolis Effect

Global Winds

Local Winds



Why It Matters

The atmosphere makes life as we know it possible on Earth. Gases, such as oxygen and carbon dioxide, which organisms need to live, are contained in the atmosphere. The atmosphere also regulates temperature on Earth and helps to protect living organisms from harmful radiation.

Inquiry Lab

 15 min

Colorful Currents



Pour **hot water** into two **beakers**, so that the beakers are three-fourths full. To one beaker, add a chunk of **dyed ice**. To the second beaker, add a **chunk of dyed ice** that contains a **short length of metal chain** or several **large paper clips** strung together. Observe the beakers. Record your observations at 0 min, 1 min, and 5 min.

Questions to Get You Started

1. What is happening in the beakers at 0 min? What is happening at 1 min and at 5 min?
2. What type of energy transfer explains the effect that you see in the first beaker? How can you tell?
3. What type of energy transfer explains the effect that you see in the second beaker? How can you tell?



Word Parts

Prefixes You can figure out the meanings of many unfamiliar science terms by looking at their word parts. For example, the word *atmosphere* is formed by combining the prefix *atmos-* with the root *sphere*. *Atmos* comes from the Greek word for “vapor” and means “air.” *Sphere* is used because the atmosphere is shaped like a sphere around Earth.

Your Turn As you read Section 1, make a table like the one started below. List the layers of the atmosphere, the prefix in the name of each layer, and your guess for the meaning of the prefix. After you have finished, look up the prefixes in a dictionary and correct your table as necessary.

Layer	Prefix	Meaning
troposphere	tropo-	
stratosphere		

Cause and Effect

Signal Words Certain words and phrases signal cause-and-effect relationships. These signal words and phrases are called *cause-and-effect markers*.

Cause markers	Effect markers
cause	therefore
affect	thus
produce	as a result of
as a result of	is an effect of
due to	results from
because	consequently

Your Turn Complete a table of cause-and-effect markers, like the one started below, as you read this chapter.

Cause	Effect	Marker(s)
convection	heating of the lower atmosphere of Earth	the result of; because

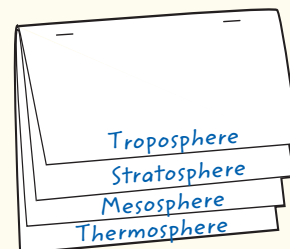
Fold Notes

Layered Book FoldNotes are a fun way to help you learn and remember ideas that you encounter as you read. You can use the flaps of the layered book to summarize information you learn into categories.

Your Turn Make a layered book, as described in **Appendix A**. Label the tabs of the layered book

“Troposphere,” “Stratosphere,”
“Mesosphere,” and “Thermosphere.”

Write notes on the appropriate layers as you read Section 1.



For more information on how to use these and other tools, see **Appendix A**.

Characteristics of the Atmosphere

Key Ideas

- Describe the composition of Earth's atmosphere.
- Explain how two types of barometers work.
- Identify the layers of the atmosphere.
- Identify two effects of air pollution.

Key Terms

atmosphere
ozone
atmospheric pressure
troposphere
stratosphere
mesosphere
thermosphere

Why It Matters

Certain characteristics of the atmosphere have a direct effect on your health and well-being. Whether it's the gases that make up air or the way that it is structured, without the atmosphere, life as we know it would be impossible.

The layer of gases that surrounds Earth is called the **atmosphere**. The atmosphere is made up of a mixture of chemical elements and compounds that is commonly called *air*. The atmosphere protects Earth's surface from the sun's radiation and helps to regulate the temperature of Earth's surface.

Composition of the Atmosphere

As the graph in **Figure 1** shows, the most abundant elements in air are the gases nitrogen, oxygen, and argon. The composition of dry air is nearly the same everywhere on Earth's surface and up to an altitude of about 80 km. The two most abundant compounds in air are the gases carbon dioxide, CO_2 , and water vapor, H_2O . In addition to containing gaseous elements and compounds, the atmosphere commonly carries various kinds of tiny solid particles, such as dust and pollen.

Nitrogen in the Atmosphere

🌿 Nitrogen makes up about 78% of Earth's atmosphere. Nitrogen in the atmosphere is maintained through a process called the *nitrogen cycle*. During the nitrogen cycle, nitrogen moves from air to the soil and then to plants and animals, and eventually returns to the air.

Nitrogen is removed from the air mainly by the action of nitrogen-fixing bacteria. These microscopic organisms live in the soil and on the roots of certain plants. The bacteria chemically change nitrogen from the air into nitrogen compounds that are vital to the growth of all plants. When animals eat plants, nitrogen compounds enter the animals' bodies. Nitrogen compounds are then returned to the soil through animal wastes or by the decay of dead organisms. Decay releases nitrogen back into the atmosphere. A similar nitrogen cycle takes place between marine organisms and ocean water.

atmosphere a mixture of gases that surrounds a planet, moon, or other celestial body

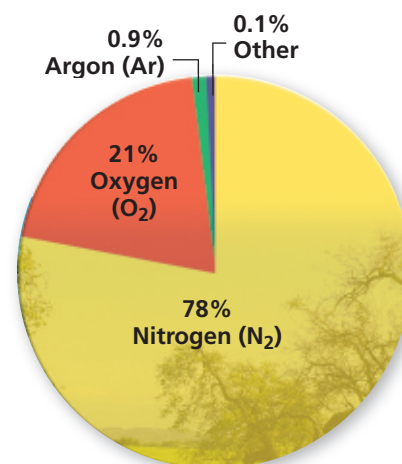
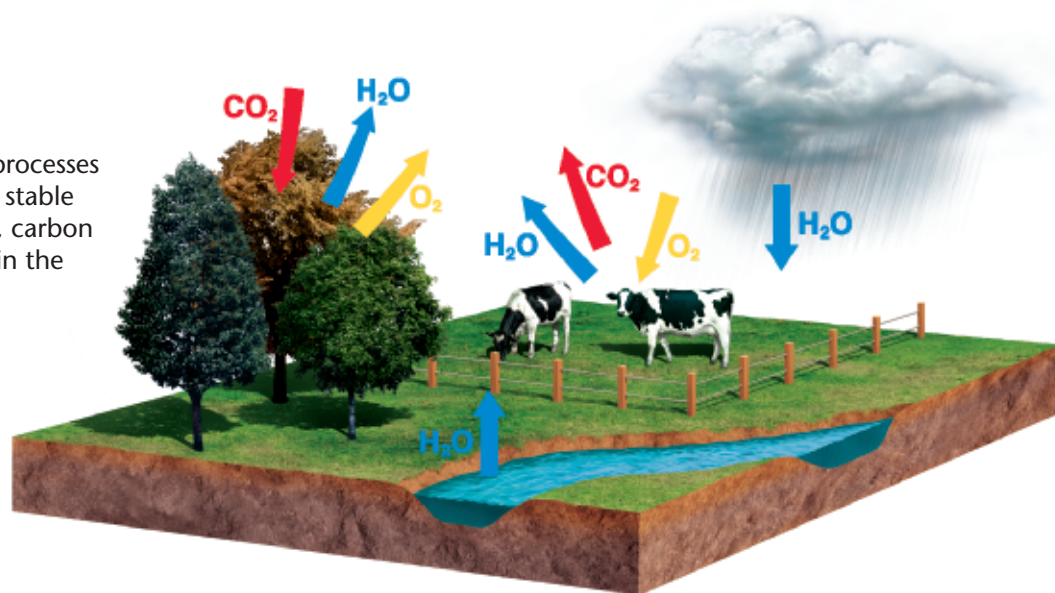


Figure 1 This pie graph shows the composition of dry air by volume at sea level.

Figure 2 Several processes interact to maintain stable amounts of oxygen, carbon dioxide, and water in the atmosphere.



Oxygen in the Atmosphere

Oxygen makes up about 21% of Earth's atmosphere. As shown in **Figure 2**, natural processes maintain the chemical balance of oxygen in the atmosphere. Animals, bacteria, and plants remove oxygen from the air as part of their life processes. Forest fires, the burning of fuels, and the weathering of some rocks also remove oxygen from the air. These processes would quickly use up most atmospheric oxygen if various processes that add oxygen to the air did not take place.

Land and ocean plants produce large quantities of oxygen in a process called *photosynthesis*. During photosynthesis, plants use sunlight, water, and carbon dioxide to produce their food, and they release oxygen as a byproduct. The amount of oxygen produced by plants each year is about equal to the amount consumed by all animal life processes. Thus, the oxygen content of the air remains at about 21% of Earth's atmosphere.

Water Vapor in the Atmosphere

As water evaporates from oceans, lakes, streams, and soil, it enters air as the invisible gas *water vapor*. Plants and animals release water vapor during the life processes of transpiration or respiration, as shown in **Figure 2**. But as water vapor enters the atmosphere, it is removed by the processes of condensation and precipitation. The percentage of water vapor in the atmosphere varies depending on factors such as time of day, location, and season. Because the amount of water vapor in air varies, the composition of the atmosphere is usually given as that of dry air. Dry air has less than 1% water vapor. Moist air may contain as much as 4% water vapor.

Reading Check Does transpiration increase or decrease the amount of water vapor in the atmosphere? (See Appendix G for answers to Reading Checks.)

READING TOOLBOX

Signal Words

Locate the signal words that indicate cause-and-effect relationships on this page. Use a table with three columns to record the causes, the effects, and their markers.

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Topic: The Atmosphere
Code: HQX0112

Ozone in the Atmosphere

Although it is present only in small amounts, a form of oxygen called **ozone** is an important component of the atmosphere. The oxygen that we breathe, O_2 , has two atoms per molecule, but ozone, O_3 , has three atoms. Ozone in the upper atmosphere forms the *ozone layer*, which absorbs harmful ultraviolet radiation from the sun. Without the ozone layer, living organisms would be severely damaged by the sun's ultraviolet rays. Unfortunately, a number of human activities damage the ozone layer. Compounds known as *chlorofluorocarbons*, or CFCs, which were previously used in refrigerators and air conditioners, and exhaust compounds, such as nitrogen oxide, break down ozone and have caused parts of the ozone layer to weaken, as **Figure 3** shows.

Particulates in the Atmosphere

In addition to gases, the atmosphere contains various tiny solid and liquid particles, called *particulates*. Particulates can be volcanic dust, ash from fires, microscopic organisms, or mineral particles lifted from soil by winds. Pollen from plants and particles from meteors that have vaporized are also particulates. When tiny drops of ocean water are tossed into the air as sea spray, the drops evaporate. Left behind in the air are tiny crystals of salt, another type of particulate. Four common sources of particulates are shown in **Figure 4**. Large, heavy particles remain in the atmosphere only briefly, but tiny particles can remain suspended in the atmosphere for months or years. 🌿

ozone a gas molecule that is made up of three oxygen atoms

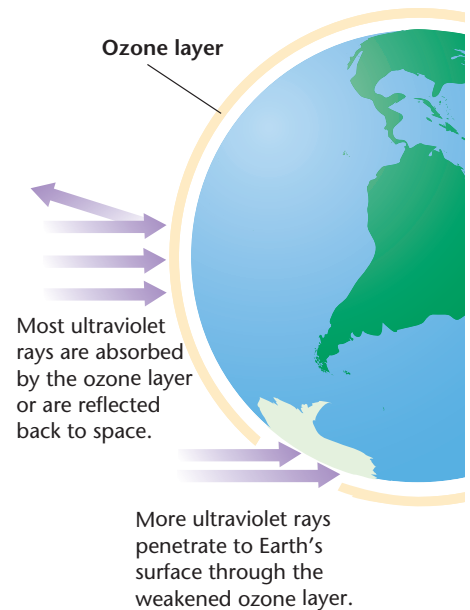


Figure 3 Harmful ultraviolet radiation can reach Earth's surface through the weakened ozone layer over Antarctica.

Figure 4 Sources of Particulates



Volcanic ash and dust can remain in the atmosphere for months.



The wind carries pollen from plant to plant.



Tornadoes and windstorms carry dirt and dust high into the atmosphere.



As seaspray evaporates, salt particles are left in the atmosphere.



Figure 5 At high altitudes, many climbers carry a supply of oxygen because the density of the atmosphere there is very low. In 2001, Eric Weihenmeyer (above) was the first blind person to reach the summit of Mount Everest.

atmospheric pressure the force per unit area that is exerted on a surface by the weight of the atmosphere

Math Skills

Force of the Air On average, a column of air 1 m^2 at its base that reaches upward from sea level has a mass of 10,300 kg and exerts a force of 101,325 N (newtons) on the ground. So, at sea level, on every square meter of Earth's surface, the atmosphere presses down with an average force of 101,325 N. What would the average force of a column of air that has a 3 m^2 base be?

Atmospheric Pressure

Gravity holds the gases of the atmosphere near Earth's surface. As a result, the air molecules are compressed together and exert force on Earth's surface. The pressure exerted on a surface by the atmosphere is called **atmospheric pressure**. Atmospheric pressure is exerted equally in all directions—up, down, and sideways.

Earth's gravity keeps 99% of the total mass of the atmosphere within 32 km of Earth's surface. The remaining 1% extends upward for hundreds of kilometers but gets increasingly thinner at high altitudes, as shown in **Figure 5**. Because there is less weight pressing down from above at higher altitudes, the air molecules are farther apart and exert less pressure on each other at higher altitudes. Thus, atmospheric pressure decreases as altitude increases.

Atmospheric pressure also changes as a result of differences in temperature and in the amount of water vapor in the air. In general, as temperature increases, atmospheric pressure at sea level decreases. The reason is that molecules move farther apart when the air is heated. So, fewer particles exert pressure on a given area, and the pressure decreases. Similarly, air that contains a lot of water vapor is less dense than drier air because water vapor molecules have less mass than nitrogen or oxygen molecules do. The lighter water vapor molecules replace an equal number of heavier oxygen and nitrogen molecules, which makes the volume of the air less dense.

Measuring Atmospheric Pressure

Meteorologists use three units for atmospheric pressure: atmospheres (atm), millimeters or inches of mercury, and millibars (mb). *Standard atmospheric pressure*, or 1 atm, is equal to 760 mm of mercury, or 1,000 mb. The average atmospheric pressure at sea level is 1 atm. Meteorologists measure atmospheric pressure by using an instrument called a *barometer*.

Mercurial Barometers

Meteorologists use two main types of barometers. One type is the *mercurial barometer*, a model of which is shown in **Figure 6**. Atmospheric pressure presses on the liquid mercury in a well at the base of the barometer. The pressure holds the mercury up to a certain height inside a tube. The height of the mercury inside the tube varies with the atmospheric pressure. The greater the atmospheric pressure is, the higher the mercury rises.

Aneroid Barometers

The type of barometer most commonly used today is called an *aneroid barometer*. Inside an aneroid barometer is a sealed metal container from which most of the air has been removed to form a partial vacuum. Changes in atmospheric pressure cause the sides of the container to bend inward or bulge out. These changes move a pointer on a scale. Aneroid barometers can be constructed to keep a continuous record of atmospheric pressure.

An aneroid barometer can also measure altitude above sea level. When used for this purpose, an aneroid barometer is called an *altimeter*. The scale on an altimeter registers altitude instead of pressure. At high altitudes, the atmosphere is less dense and has less pressure exerted on it from above than at low altitudes. So, a lowered pressure reading can be interpreted as an increased altitude reading.

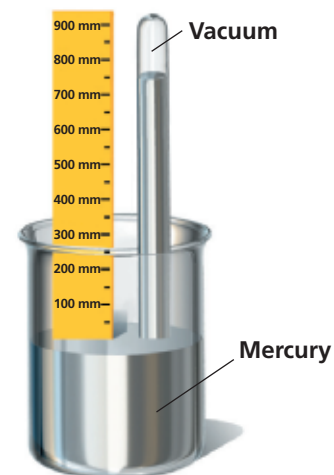


Figure 6 The height of the mercury in this mercurial barometer indicates barometric pressure. *What is the barometric pressure shown?*

Academic Vocabulary

interpret (in TUHR pruh) figure out the meaning of

 **Reading Check** What is inside an aneroid barometer?

Quick Lab Barometric Pressure




25 min
(over 5 days)

Procedure

- 1 Use a **rubber band** to secure **plastic wrap** tightly over the open end of a **coffee can**.
- 2 Use **tape** to secure one end of a **10 cm drinking straw** onto the plastic wrap near the center of the can.
- 3 Use **scissors** and a **metric ruler** to cut a piece of **cardboard** 10 cm wide. The cardboard should also be at least 13 cm taller than the can.
- 4 Fold the cardboard so that it stands upright and extends at least 3 cm above the top of the straw.
- 5 Place the cardboard near the can so that the free end of the straw just touches the front of the cardboard. Mark an X where the straw touches.
- 6 Draw three horizontal lines on the cardboard: one that is level with the X, one that is 2 cm above the X, and one that is 2 cm below the X.
- 7 Position the cardboard so that the straw touches the X. Tape the base of the cardboard in place.
- 8 Observe the level of the straw at least once per day over a 5-day period. Record any changes that you see.

Analysis

1. What factors affect how your model works? Explain.
2. What does an upward movement of the straw indicate? What does a downward movement indicate?
3. Compare your results with the barometric pressures listed in your local newspaper. What may have caused your results to differ from the newspaper's?



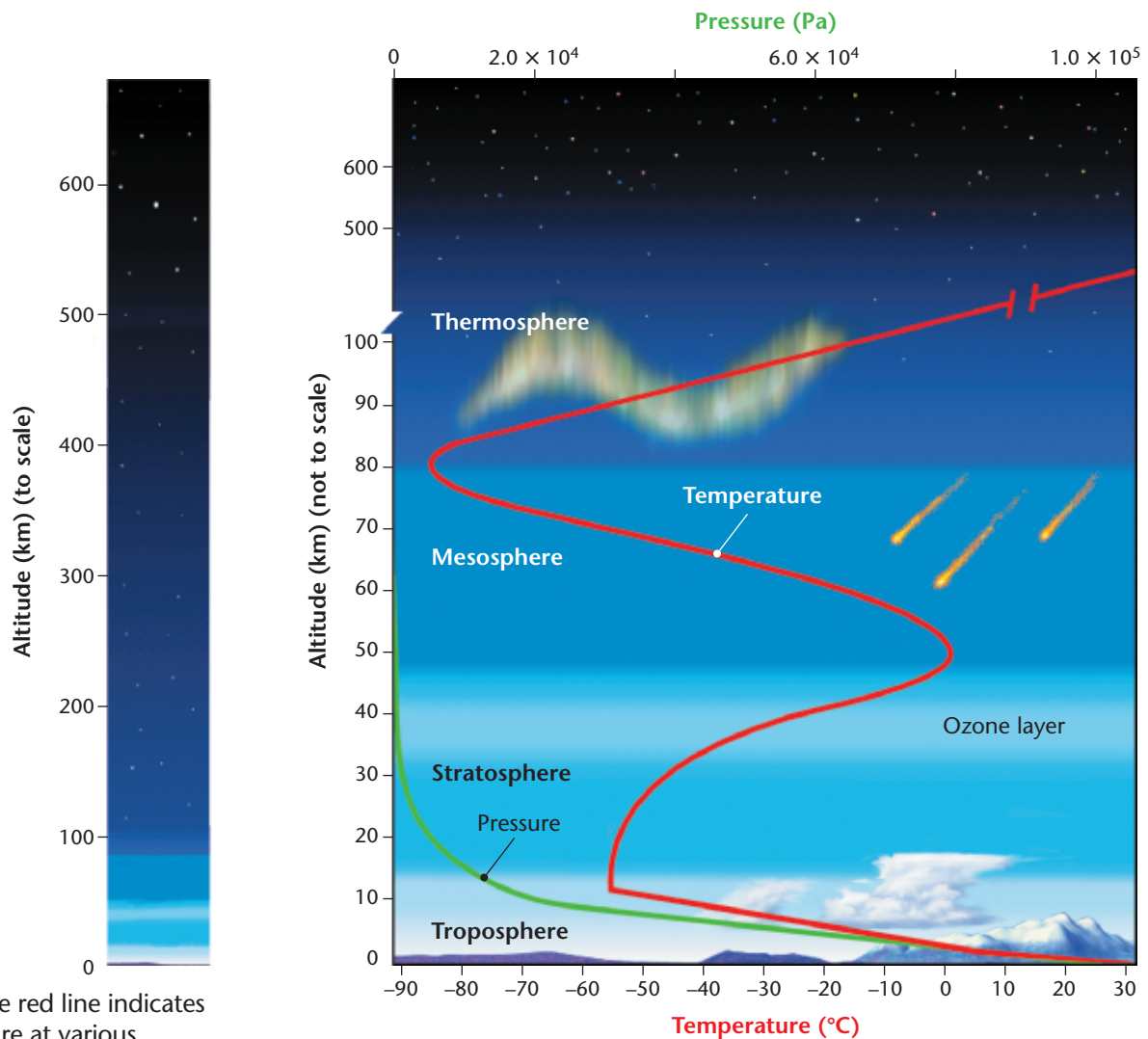


Figure 7 The red line indicates the temperature at various altitudes in the atmosphere. The green line indicates atmospheric pressure at various altitudes.

Layers of the Atmosphere

Earth's atmosphere has a distinctive pattern of temperature changes with increasing altitude, as shown in **Figure 7**. The temperature differences mainly result from how solar energy is absorbed as it moves through the atmosphere. Scientists identify four main layers of the atmosphere based on these differences.

The Troposphere

The atmospheric layer that is closest to Earth's surface and in which nearly all weather occurs is called the **troposphere**. Almost all the water vapor and carbon dioxide in the atmosphere is found in this layer. Temperature within the troposphere decreases as altitude increases because air in this layer is heated from below by thermal energy that radiates from Earth's surface. The temperature within the troposphere decreases at the average rate of 6.5°C per kilometer as the distance from Earth's surface increases. However, at an average altitude of 12 km, the temperature stops decreasing. This zone is called the *tropopause* and represents the upper boundary of the troposphere. The altitude of this boundary varies with latitude and season.

troposphere the lowest layer of the atmosphere, in which temperature drops at a constant rate as altitude increases; the part of the atmosphere where weather conditions exist

The Stratosphere

The layer of the atmosphere called the **stratosphere** extends from the tropopause to an altitude of nearly 50 km. Almost all the ozone in the atmosphere is concentrated in this layer. In the lower stratosphere, the temperature is almost -60°C . In the upper stratosphere, the temperature increases as altitude increases because air in the stratosphere is heated by absorption of solar radiation by ozone. The temperature of the air in this layer rises steadily to a temperature of about 0°C at an altitude of about 50 km above Earth's surface. This zone, called the *stratopause*, marks the upper boundary of the stratosphere.

The Mesosphere

Located above the stratopause and extending to an altitude of about 80 km is the **mesosphere**. In this layer, temperature decreases as altitude increases. The upper boundary of the mesosphere, called the *mesopause*, has an average temperature of nearly -90°C , which is the coldest temperature in the atmosphere. Above this boundary, temperatures again begin to increase.

The Thermosphere

The atmospheric layer above the mesopause is called the **thermosphere**. In the thermosphere, temperature increases steadily as altitude increases because nitrogen and oxygen atoms absorb solar radiation. Because air particles in the thermosphere are very far apart, they do not strike a thermometer often enough to produce an accurate temperature reading. Therefore, special instruments are needed. These instruments have recorded temperatures of more than $1,000^{\circ}\text{C}$ in the thermosphere.

The lower region of the thermosphere, at an altitude of 80 to 400 km, is commonly called the *ionosphere*. In the ionosphere, solar radiation that is absorbed by atmospheric gases causes the atoms of gas molecules to lose electrons and to produce ions and free electrons. Interactions between solar radiation and the ionosphere cause the phenomena known as *auroras*, which are shown in **Figure 8**.

There are not enough data about temperature changes in the thermosphere to determine its upper boundary. However, above the ionosphere is the region where Earth's atmosphere blends into the almost complete vacuum of space. This zone of indefinite altitude, called the *exosphere*, extends for thousands of kilometers above the ionosphere.

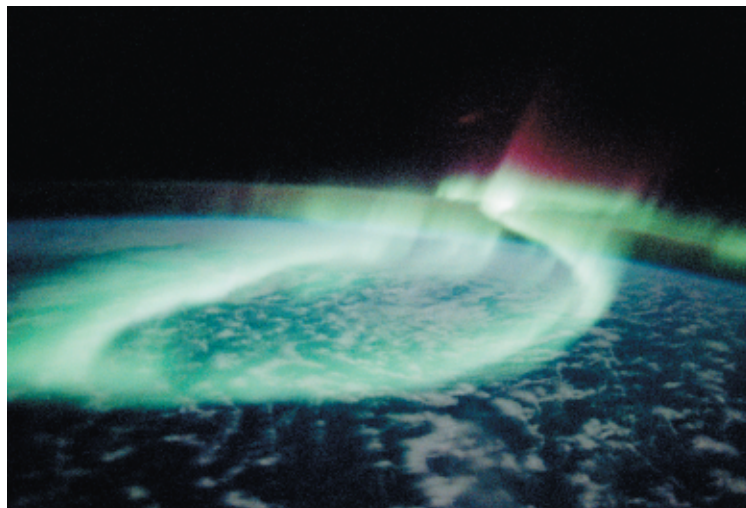
 **Reading Check** What is the lower region of the thermosphere called?

stratosphere the layer of the atmosphere that lies between the troposphere and the mesosphere and in which temperature increases as altitude increases; contains the ozone layer

mesosphere the coldest layer of the atmosphere, between the stratosphere and the thermosphere, in which temperature decreases as altitude increases

thermosphere the uppermost layer of the atmosphere, in which temperature increases as altitude increases; includes the ionosphere

Figure 8 Auroras can be seen from space as well as from the ground.





Temperature Inversions

Any substance that is in the atmosphere and that is harmful to people, animals, plants, or property is called an *air pollutant*. Today, the main source of air pollution is the burning of fossil fuels, such as coal and petroleum. As these fuels burn, they may release harmful chemical substances, such as sulfur dioxide gas, hydrocarbons, nitrogen oxides, carbon monoxide, and lead, into the air.

Certain weather conditions can make air pollution worse. One such condition is a *temperature inversion*, the layering of warm air on top of cool air. Warm air, which is less dense than cool air is, can trap cool, polluted air beneath it. In some

Figure 9 During a temperature inversion, polluted cool air becomes trapped beneath a warm-air layer.

areas, topography may make air pollution even worse by keeping the polluted inversion layer from dispersing, as **Figure 9** shows. Under conditions in which air cannot circulate up and away from an area, trapped automobile exhaust can produce *smog*, a general term for air pollution that is a combination of smoke and fog.

Air pollution can be controlled only by preventing the release of pollutants into the atmosphere. International, federal, and local laws have been passed to reduce the amount of air pollutants produced by automobiles and industry.

Section 1 Review

Key Ideas

- Describe** the composition of dry air at sea level.
- Identify** five main components of the atmosphere.
- Explain** the cause of atmospheric pressure.
- Explain** how the two types of barometers measure atmospheric pressure.
- Identify** the layer of the atmosphere in which weather occurs.
- Compare** the four main layers of the atmosphere.
- Identify** the two atmospheric layers that contain air as warm as 25°C.

Critical Thinking

- Drawing Conclusions** Why is atmospheric pressure generally lower beneath a mass of warm air than beneath a mass of cold air?

- Making Calculations** How much colder is the air at the top of Mount Everest, which is almost 9 km above sea level, than the air at the Indian coastline? (Hint: On average, the temperature in the troposphere decreases by 6.5°C per kilometer of altitude.)

- Applying Ideas** Which industrial city would have fewer air-pollution incidents related to temperature inversions: one on the Great Plains or one near the Rocky Mountains? Explain your answer.

- Applying Concepts** In 1982, Larry Walters rose to an altitude of approximately 4,900 m on a lawn chair attached to 45 helium-filled weather balloons. Give two reasons why Walters' trip was dangerous.

Concept Mapping

- Use the following terms to create a concept map: *oxygen, atmosphere, air, nitrogen, water vapor, ozone, and particulates*.

SECTION 2

Solar Energy and the Atmosphere

Key Ideas

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

Key Terms

electromagnetic spectrum
albedo
greenhouse effect
conduction
convection

Why It Matters

By understanding what happens to solar radiation in the atmosphere, scientists can learn more about how the actions of humans affect 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 this energy as heat.

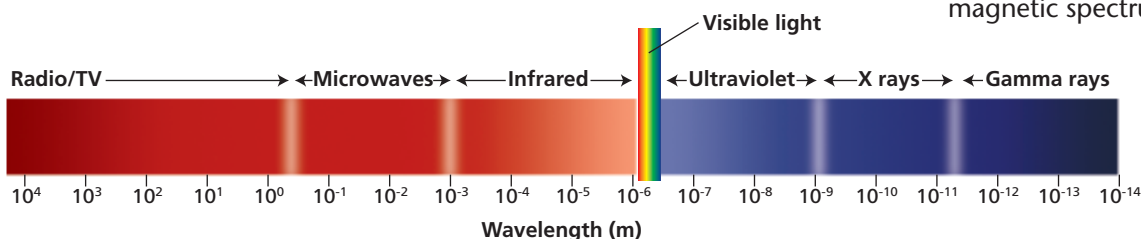
Radiation

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 with 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 the energy that reaches Earth from the sun is in the form of *electromagnetic waves*. The **electromagnetic spectrum**, shown in **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 throughout the electromagnetic spectrum.



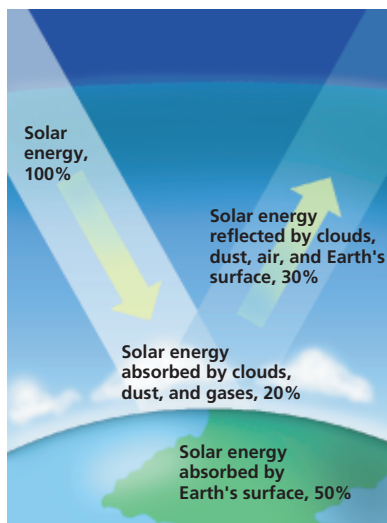


Figure 2 About 70% of the solar energy that reaches Earth is absorbed by Earth's land and ocean surfaces and by the atmosphere. The remainder is reflected back into space.

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 sunset.

Why It Matters

Gardens in the Sky

Rooftop gardens—such as this one on top of Chicago's City Hall—harness solar radiation, which helps the environment and cuts energy costs. While concrete roofs absorb only 55 to 65% of solar radiation, plants on "green roofs" absorb 75 to 95%. The plants help to decrease indoor temperatures in the summer, which means less air conditioning is needed. In addition, plants filter air pollution and muffle street noise, and provide a habitat for animals such as birds.

The layers of a rooftop garden absorb rainwater, which helps to prevent flooding of the sewage system in the city below.

EYE ON THE ENVIRONMENT

YOUR TURN

WRITING IN SCIENCE

Design a rooftop garden for a building in your area. Draw plans, and explain your design.

Table 1 Reflection and Absorption Rates of Various Materials

Percentage of Solar Radiation		
Surface	Reflected	Absorbed
Soil (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

**READING
TOOLBOX****Prefixes**

The prefix *ab-* in *absorb* means “from” while the prefix *re-* in *reflect* means “back.” Explain how these prefixes give you a clue to the direction of solar radiation when it is absorbed or reflected by different surfaces.

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 with longer wavelengths and reemit the energy at those wavelengths. Gas molecules, such as water vapor and carbon dioxide, in the atmosphere absorb the 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 to heat Earth's atmosphere is similar to the process that heats a greenhouse.



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

SCILINKS

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Topic: Greenhouse Effect
Code: HQX0694

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 the greenhouse. But the glass prevents the infrared rays that are emitted by the warmed surfaces within the greenhouse from escaping quickly. Similarly, Earth's atmosphere reduces 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**.

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, in addition to natural causes, are changing this balance and are causing 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 and 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.

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.

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 energy, 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 heat energy. 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. The reason for these moderate temperatures is that water heats up and cools down slower than land 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 has more moderate temperatures than a similar region in which the winds blow from the land.

Reading Check Why are deserts generally colder at night than other areas are?

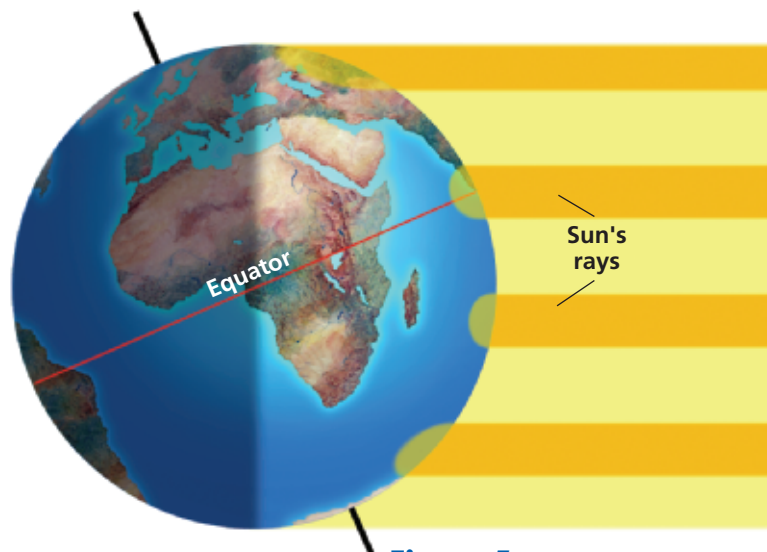


Figure 5 Temperatures are higher at the equator because solar energy is concentrated in a small area. Farther north and south, the same amount of solar energy is spread out over a larger area.

Academic Vocabulary

primary (PRI MER ee) highest in rank or importance

Quick Lab

5 min

Light and Latitude

Procedure

- 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 lab illustrate how latitude affects incoming solar radiation?

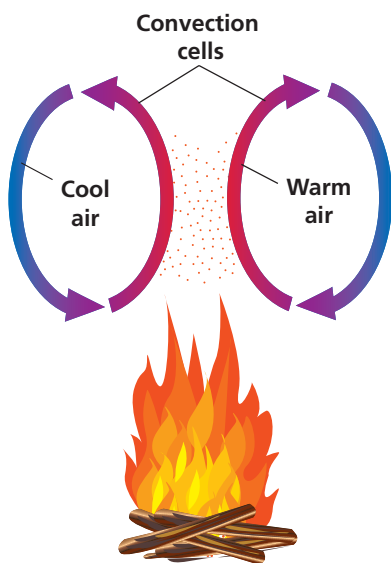


Figure 6 During convection, energy is carried away by heated air as it rises above cooler, denser air.

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

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. 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.

Section 2 Review

Key Ideas

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

Critical Thinking

- 7. Making Inferences** Why do scientists study all wavelengths of the electromagnetic spectrum?
- 8. Applying Concepts** Explain how fans in convection ovens help to cook food more evenly.
- 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?

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.*

Atmospheric Circulation

Key Ideas

- Explain the Coriolis effect.
- Describe the global patterns of air circulation, and name three global wind belts.
- Identify two factors that form local wind patterns.

Key Terms

Coriolis effect
trade winds
westerlies
polar easterlies
jet stream

Why It Matters

Understanding how wind works was important to early travelers. Such understanding has practical advantages even today.

Air near Earth's surface generally flows from the poles toward the equator. The reason for this flow is that air moves from high-pressure regions to low-pressure regions. High-pressure regions form where cold air sinks toward Earth's surface. Low-pressure regions form where warm air rises away from Earth's surface.

The Coriolis Effect

The circulation of the atmosphere and the oceans is affected by the rotation of Earth on its axis. Because each point on Earth makes one complete rotation every day, points near the equator travel farther and faster in a day than points closer to the poles do. When air moves toward the poles, it travels east faster than the land beneath it does. As a result, the air follows a curved path. The tendency of a moving object to follow a curved path rather than a straight path because of the rotation of Earth is called the **Coriolis effect**, which is shown in **Figure 1**.

The Coriolis effect deflects a moving object along a path that depends on the speed, latitude, and direction of the object. Objects are deflected to the right in the Northern Hemisphere and are deflected to the left in the Southern Hemisphere.

The faster an object travels, the greater the Coriolis effect on the object is. The Coriolis effect also noticeably changes the paths of large masses that travel long distances, such as air and ocean currents. In general, the Coriolis effect is detectable only on objects that move very fast or that travel over long distances.

Coriolis effect the curving of the path of a moving object from an otherwise straight path due to Earth's rotation

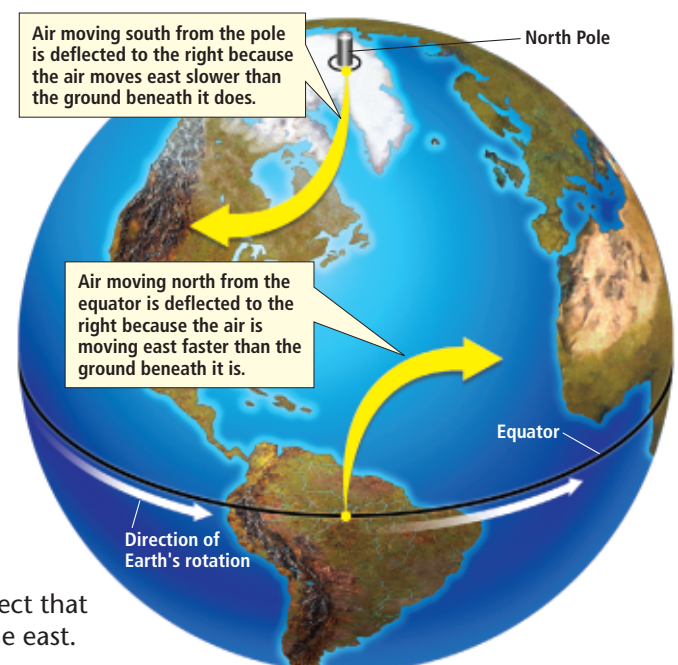
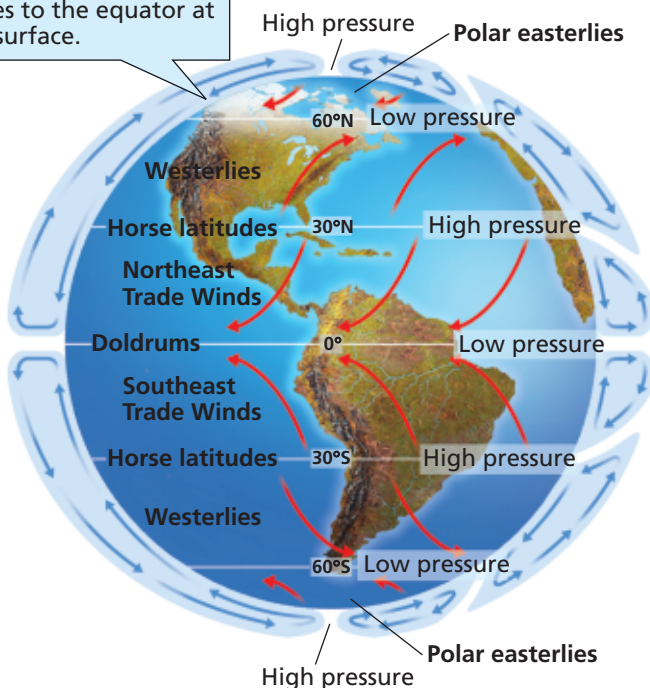


Figure 1 Because of Earth's rotation, an object that travels north from the equator will curve to the east. This curving is called the *Coriolis effect*.

Net global air flow is from the poles to the equator at Earth's surface.



Global Winds

The air that flows from the poles toward the equator does not flow in a single, straight line. Each hemisphere contains three looping patterns of flow called *convection cells*. Each convection cell correlates to an area of Earth's surface, called a *wind belt*, that is characterized by winds that flow in one main direction. These winds are called *prevailing winds*. All six wind belts are shown in **Figure 2**.

Trade Winds

In both hemispheres, the winds that flow toward the equator between 30° and 0° latitude are called **trade winds**. Like all winds, the trade winds are named according to the direction from which they flow. In the Northern Hemisphere, the trade winds flow

from the northeast and are called the *northeast trade winds*. In the Southern Hemisphere, the trade winds are called the *southeast trade winds*. These wind belts are called *trade winds* because many trading ships sailed on these winds from Europe in the 18th and 19th centuries.

Westerlies

Between 30° and 60° latitude, air moving toward the poles is deflected by the Coriolis effect. This flow creates the **westerlies**, which exist in another wind belt in each hemisphere. In the Northern Hemisphere, the westerlies are southwest winds. In the Southern Hemisphere, they are northwest winds. The westerlies blow throughout the contiguous United States.

Reading Check Name two ways in which the trade winds of the Northern Hemisphere differ from the westerlies of the Northern Hemisphere.

Polar Easterlies

Toward the poles, or poleward, of the westerlies—at about 60° latitude—is a zone of low pressure. This zone of low pressure separates the westerlies from a third wind belt in each hemisphere. Over the polar regions themselves, descending cold air creates areas of high pressure. Surface winds created by the polar high pressure are deflected by the Coriolis effect and become the **polar easterlies**. The polar easterlies are strongest where they flow off Antarctica. Where the polar easterlies meet warm air from the westerlies, a stormy region known as a *front* forms.

Figure 2 Each hemisphere has three wind belts. Wind belts are the result of pressure differences at the equator, the subtropics, the subpolar regions, and the poles. Winds in the belts curve because of the Coriolis effect.

Do winds in the Northern Hemisphere curve clockwise or counterclockwise?

trade winds prevailing winds that blow from east to west from 30° latitude to the equator in both hemispheres

westerlies prevailing winds that blow from west to east between 30° and 60° latitude in both hemispheres

polar easterlies prevailing winds that blow from east to west between 60° and 90° latitude in both hemispheres

The Doldrums and Horse Latitudes

As **Figure 2** shows, the trade wind systems of the Northern Hemisphere and Southern Hemisphere meet at the equator in a narrow zone called the *doldrums*. In this warm zone, most air movement is upward and surface winds are weak and variable. As the air approaches 30° latitude, it descends and a high-pressure zone forms. These subtropical high-pressure zones are called the *horse latitudes*. Here, too, surface winds are weak and variable.

Wind and Pressure Shifts

As the sun's rays shift 23.5° northward and southward during the changing seasons of the year, the positions of the pressure belts and wind belts shift in response. Although the area that receives direct sunlight can shift by up to 47°, the average shift for the pressure belts and wind belts is only about 10° of latitude. However, even this small change causes some areas of Earth's surface to be in different wind belts during different times of the year. In southern Florida, for example, westerlies prevail in the winter, but trade winds dominate in the summer.

Jet Streams

Narrow bands of high-speed winds that blow in the upper troposphere and lower stratosphere are **jet streams**. These winds exist in the Northern Hemisphere and Southern Hemisphere.

One type of jet stream is a polar jet stream. Polar jet streams form as a result of density differences between cold polar air and the warmer air of the middle latitudes. These bands of winds, which are about 100 km wide and 2 to 3 km thick, are located at altitudes of 10 to 15 km. Polar jet streams can reach speeds of over 400 km/h and can affect airline routes and the paths of storms.

Another type of jet stream is a subtropical jet stream. In the subtropical regions, very warm equatorial air meets the cooler air of the middle latitudes, and *subtropical jet streams* form. Unlike polar jet streams, subtropical jet streams do not change much in speed or position. A subtropical jet stream is shown in **Figure 3**.

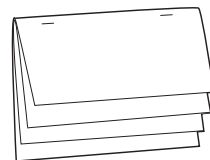


Figure 3 Clouds indicate the path of a jet stream traveling high over Egypt.

READING TOOLBOX

Layered Book

Make a layered book FoldNote, and label the tabs "Trade Winds," "Westerlies," "Polar Easterlies," and "Doldrums and Horse Latitudes." Write notes on the appropriate layers as you read this section.



jet stream a narrow band of strong winds that blow in the upper troposphere



Figure 4 Sea breezes keep these kites aloft during the afternoon.

Academic Vocabulary

influence (IN floo uhns) the effect of one thing on another

Local Winds

Winds also exist on a scale that is much smaller than a global scale. Movements of air are influenced by local conditions, and local temperature variations commonly cause local winds. Local winds are not part of the global wind belts. Winds that blow at speeds of less than 50 km/h are called *breezes*.

Land and Sea Breezes

Equal areas of land and water may receive the same amount of energy from the sun. However, land surfaces heat up faster than water surfaces do. Therefore, during daylight hours, a sharp temperature difference develops between a body of water

and the land along the water's edge. This temperature difference is apparent in the air above the land and water. The warm air above the land rises, creating low pressure. Then, cool air from above the water moves in to replace the warm air. A cool wind moving from water to land, called a *sea breeze*, generally forms in the afternoon, as shown in **Figure 4**. Overnight, the land cools more rapidly than the water does, and the sea breeze is replaced by a *land breeze*. A land breeze flows from the cool land toward the warmer water.

Mountain and Valley Breezes

During the daylight hours in mountainous regions, a gentle valley breeze blows upslope. This *valley breeze* forms when warm air from the valleys moves upslope. At night, the mountains cool more quickly than the valleys do, and cool air descends from the mountain peaks to create a *mountain breeze*. Areas near mountains may experience a warm afternoon that turns into a cold evening soon after sunset. This evening cooling happens because cold air flows down mountain slopes and settles in valleys.

Section 3 Review

Key Ideas

1. **Describe** the pattern of air circulation between an area of low pressure and an area of high pressure.
2. **Explain** how the Coriolis effect affects wind flow.
3. **Name and describe** Earth's three global wind belts.
4. **Summarize** the importance of jet streams.
5. **Identify** two factors that create local wind patterns.

Critical Thinking

6. **Applying Concepts** Determine whether wind moving south from the equator will curve eastward or westward because of the Coriolis effect.

7. **Inferring Relationships** Which has a lower pressure: the air in your lungs as you inhale or the air outside your body? Explain.

8. **Applying Ideas** While visiting the Oregon coast, you decide to hike toward the ocean, but you are not sure of the direction. The time is 4:00 P.M. How might the breeze help you find your way?

Concept Mapping

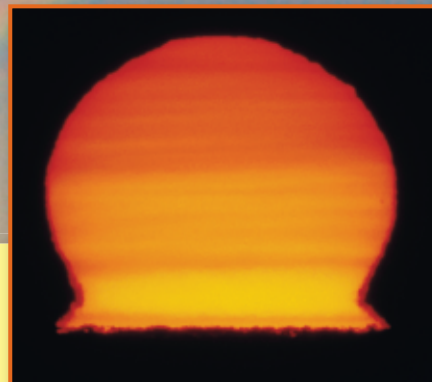
9. Use the following terms to create a concept map: *wind*, *sea breeze*, *global winds*, *trade winds*, *westerlies*, *local winds*, *polar easterlies*, *land breeze*, *mountain breeze*, and *valley breeze*.

Chasing Rainbows and Sundogs

WEIRD
SCIENCE

The interplay of sunlight or moonlight and airborne water droplets, ice crystals, or particulates can create amazing, short-lived effects known collectively as atmospheric optics. Long before computer programs could manipulate images to produce new and surprising versions of reality, atmospheric optics were producing astounding light effects in the sky. Rainbows are the most well-known of these effects. Rainbows are formed when the sun's rays are refracted as they pass through spherical raindrops, causing the white light to split into the colors of the visible spectrum.

Sunset mirages are caused when the rays of the setting sun are refracted through layers of air that are different temperatures.



Crepuscular rays are rays of sunlight that stream through gaps between clouds and alternate with shadowy areas. They are formed when sunlight is partially blocked by clouds, mountains, or anything else that casts a shadow, and then scattered as it hits airborne particulates, water droplets, or ice crystals.



Circumzenithal arcs, which appear as upside-down rainbows, are formed by the refraction of sunlight through horizontally oriented ice crystals. Sunlight enters the top face of an ice crystal and exits through a vertical side face.



Sundogs (also called *parhelia*) are two bright spots that appear on either side of the sun just after sunrise or just before sunset. They are formed when hexagonal, horizontally oriented ice crystals refract sunlight.

YOUR
TURN

UNDERSTANDING CONCEPTS

Compare and contrast rainbows and circumzenithal arcs.

ONLINE RESEARCH

Find and describe another example of an atmospheric optic. What causes it to form?

What You'll Do

- **Determine** which material would keep the inside of a house the coolest.
- **Explain** which properties of this material determine whether it is a conductor or an insulator.

What You'll Need

cardboard,
4 cm × 4 cm × 1 cm
(4 pieces)
paint, black, white, and light
blue tempera
metal, 4 cm × 4 cm × 1 cm
rubber, beige or tan,
4 cm × 4 cm × 1 cm
sandpaper,
4 cm × 4 cm × 1 cm
thermometers, Celsius (4)
watch or clock
wood, beige or tan,
4 cm × 4 cm × 1 cm

Safety



Energy Absorption and Reflection

When solar energy reaches Earth's surface, the energy is either reflected or absorbed by the material that the surface is made of. Whether the material absorbs or reflects energy, and the amount of energy that is reflected or absorbed, depends on several characteristics of the material. These characteristics include the material's composition, its color and texture, how transparent the material is, the mass and volume of the material, and the specific heat of the material. In this lab, you will study these characteristics to determine which material is best suited for use as roofing material.

Ask a Question

- 1 Which material will keep the interior of a house the coolest?

Form a Hypothesis

- 2 Identify the material that you think will keep the inside of a house the coolest. List the characteristics of this material that caused you to choose it.

Test the Hypothesis

- 3 Brainstorm with a partner or with a small group of classmates to design a procedure that will help you determine which materials absorb the most energy and which materials keep the surface below them the coolest. You do not have to test all the materials, if you can explain why you think those materials would not be the coolest. Write down your experimental procedure.
- 4 Have your teacher approve your experimental design.

Step 3



- 5 Create a table like the one shown on the right. Use this table to record the data you collect as you perform your experiment.
- 6 Following your design, measure the temperatures that the materials and the surfaces beneath them reach.

Material	Color	Surface temperature (°C)	Temperature below material (°C)
Cardboard	white		
Rubber	beige		
Sandpaper	beige		

Analyze the Results

1. **Graphing Data** Use the data you collected to create a bar graph. Label the x-axis with the materials you tested and the y-axis with a range of temperatures.
2. **Analyzing Data** Which material reached the highest temperature on its surface? Which material caused the surface below it to reach the highest temperature?
3. **Analyzing Data** Which material stayed the lowest temperature at its surface? Which material kept the temperature of the surface beneath it the lowest?
4. **Evaluating Results** Did the color of the materials affect whether they absorbed or reflected solar energy? Explain your answer.

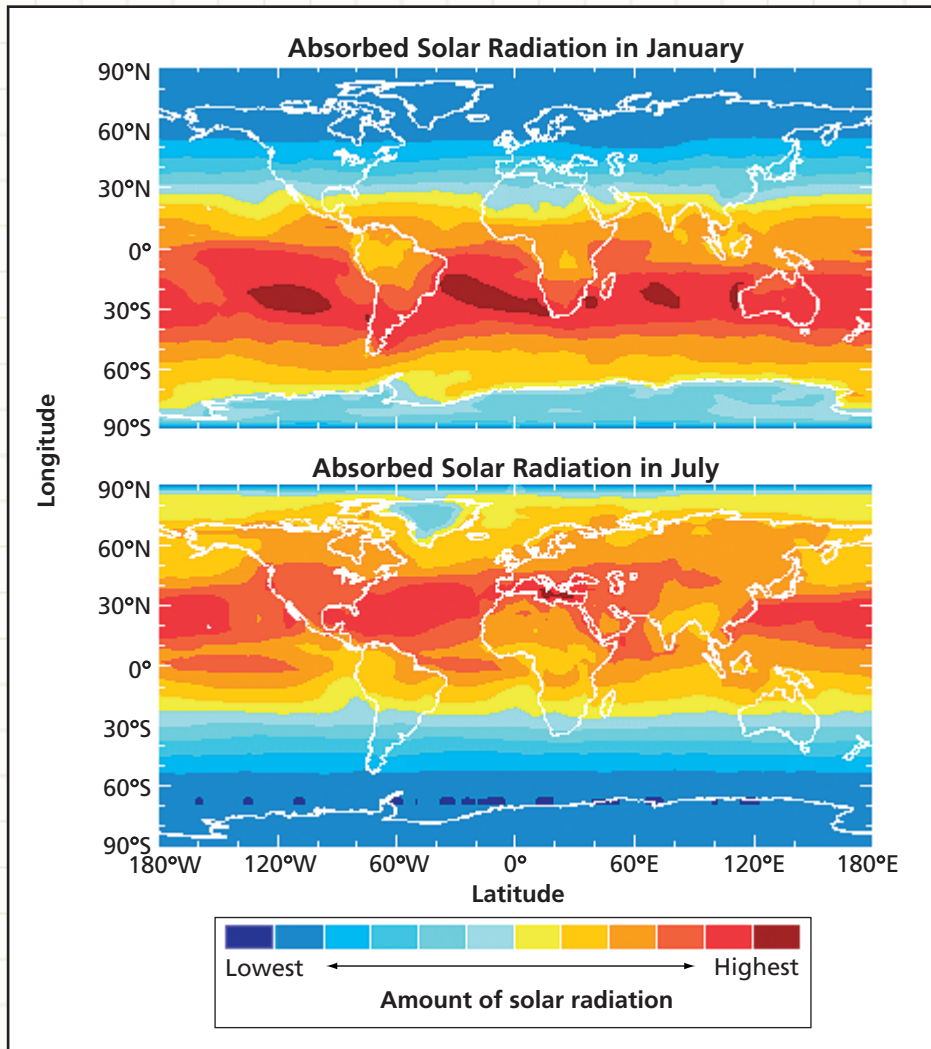
Draw Conclusions

5. **Drawing Conclusions** Based on your results, which material would you use for the roof of a house? Did your experimental results support your original hypothesis?
6. **Inferring Relationships** What properties of the material you identified in question 5 do you think make it best for this purpose? Explain your answer.
7. **Making Predictions** Do you think the material you chose would keep the inside of a house warm in colder weather? Explain your answer.
8. **Analyzing Methods** Name two changes in your experimental design that you would make if you were going to repeat the experiment. Explain why you would make each change.

Extension

Applying Ideas Use the materials you tested in the experiment to create a model of Earth's surface that represents how different parts of Earth's surface absorb or reflect solar energy. Which areas of Earth's surface absorb the least energy?

Absorbed Solar Radiation



Map Skills Activity

These maps show the total amount of solar radiation that is absorbed by Earth in January and July. Use the maps to answer the questions below.

- Using a Key** In January, which region has the highest amount of absorbed solar radiation?
- Using a Key** In July, which region has the highest amount of absorbed solar radiation?
- Comparing Areas** Which area has the greatest difference between the amount of absorbed solar radiation in January and in July: southern Australia or northeastern South America?
- Analyzing Data** At what latitudes are January's and July's amounts of absorbed solar radiation similar?
- Inferring Relationships** How do these maps explain the differences between the Northern Hemisphere's weather in January and in July?

Section 1**Characteristics of the Atmosphere**

- › Earth's atmosphere is the mixture of gases, called *air*, that surrounds Earth. Solid and liquid particles, called *particulates*, are mixed with the gases that make up air.
- › Mercury inside a mercurial barometer rises or sinks as air pressure increases or decreases. In an aneroid barometer, changes in air pressure cause a metal container inside the barometer to bend inward or bulge outward. This moves a pointer on a scale.
- › The atmosphere is divided into four main layers: the troposphere, the stratosphere, the mesosphere, and the thermosphere.
- › Air pollution can be harmful to people, animals, plants, and property.

Section 2**Solar Energy and the Atmosphere**

- › Most of the energy that reaches Earth from the sun is in the form of electromagnetic radiation.
- › Visible light and infrared rays from the sun penetrate Earth's atmosphere and heat materials on Earth's surface.
- › The upper atmosphere is heated by absorption of radiation from the sun. The lower atmosphere is heated by conduction from Earth's surface and by convection of air.

Section 3**Atmospheric Circulation**

- › The Coriolis effect is the tendency of a moving object to follow a curved path rather than a straight path because of the rotation of Earth.
- › Each hemisphere contains three convection cells that circulate air. Net global airflow near Earth's surface is from the poles toward the equator. The three global wind belts are the trade winds, the westerlies, and the polar easterlies.
- › A surface feature, such as a body of water, a mountain, or a valley, can influence local wind patterns.

Key Terms

atmosphere, p. 513
ozone, p. 515
atmospheric pressure, p. 516
troposphere, p. 518
stratosphere, p. 519
mesosphere, p. 519
thermosphere, p. 519

electromagnetic spectrum, p. 521
albedo, p. 523
greenhouse effect, p. 524
conduction, p. 526
convection, p. 526

Coriolis effect, p. 527
trade winds, p. 528
westerlies, p. 528
polar easterlies, p. 528
jet stream, p. 529

- 1. Cause and Effect** Use cause-and-effect signal words to explain the link between Earth's tilt and the seasons.

READING TOOLBOX**USING KEY TERMS**

Use each of the following terms in a separate sentence.

2. *atmosphere*
3. *electromagnetic spectrum*
4. *Coriolis effect*

For each pair of terms, explain how the meanings of the terms differ.

5. *troposphere* and *stratosphere*
6. *mesosphere* and *thermosphere*
7. *conduction* and *convection*
8. *trade winds* and *westerlies*
9. *polar easterlies* and *westerlies*

UNDERSTANDING KEY IDEAS

10. During one part of the nitrogen cycle, nitrogen is removed from the air mainly by nitrogen-fixing
 - a. bacteria.
 - b. waves.
 - c. minerals.
 - d. crystals.
11. The atmosphere contains tiny solid particles called
 - a. gases.
 - b. particulates.
 - c. meteors.
 - d. nitrogen.
12. A barometer measures
 - a. atmospheric pressure.
 - b. wind speed.
 - c. ozone concentration.
 - d. wavelengths.
13. Almost all the water and carbon dioxide in the atmosphere is in the
 - a. exosphere.
 - b. ionosphere.
 - c. troposphere.
 - d. stratosphere.
14. The process by which the atmosphere reduces Earth's loss of heat to space is called the
 - a. greenhouse effect.
 - b. Coriolis effect.
 - c. doldrums.
 - d. convection cell.
15. Energy as heat can be transferred within the atmosphere in three ways: radiation, conduction, and
 - a. transpiration.
 - b. temperature inversion.
 - c. weathering.
 - d. convection.
16. A vertical looping pattern of airflow is known as
 - a. the Coriolis effect.
 - b. a convection cell.
 - c. a trade wind.
 - d. a westerly.
17. Wind with a speed of less than 50 km/h is called
 - a. a jet stream.
 - b. the doldrums.
 - c. a breeze.
 - d. a trade wind.
18. Which of the following layers of the atmosphere is closest to the ground?
 - a. troposphere
 - b. thermosphere
 - c. mesosphere
 - d. exosphere
19. Which of the following layers of the atmosphere is closest to space?
 - a. troposphere
 - b. ionosphere
 - c. mesosphere
 - d. exosphere

SHORT ANSWER

20. List the three main elemental gases that compose the atmosphere.
21. What is atmospheric pressure, and how is it measured?
22. List and describe the four main layers of the atmosphere.

23. What happens to visible light that enters Earth's atmosphere?
24. How is heat energy transferred by Earth's atmosphere?
25. How does latitude affect the temperature of a region?
26. Explain how the greenhouse effect helps to warm the atmosphere.
27. What causes the Coriolis effect?
28. Name and describe the three main wind belts in both hemispheres.
29. How do surface features influence local wind patterns?

CRITICAL THINKING

30. **Making Inferences** If a breeze is blowing from the ocean to the land on the coast of Maine, about what time of day is it? Explain your answer.
31. **Evaluating Ideas** What effect might jet streams have on airplane travel?
32. **Inferring Relationships** Most aerosol sprays that contain CFCs have been banned in the United States. Which of the four layers of the atmosphere does this ban help to protect? Explain your answer.
33. **Evaluating Information** You hear a report about Earth's weather. The reporter says that visible light rays coming from Earth's surface heat the atmosphere in a way similar to the way a greenhouse is heated. Explain why the reporter's statement is incorrect.

CONCEPT MAPPING

34. Use the following terms to create a concept map: *atmosphere, troposphere, stratosphere, temperature, mesosphere, thermosphere, atmospheric pressure, altitude, and exosphere.*

MATH SKILLS

Math Skills

35. **Applying Quantities** The albedo of the moon is 0.07. What percentage of the total solar radiation that reaches the moon is reflected?

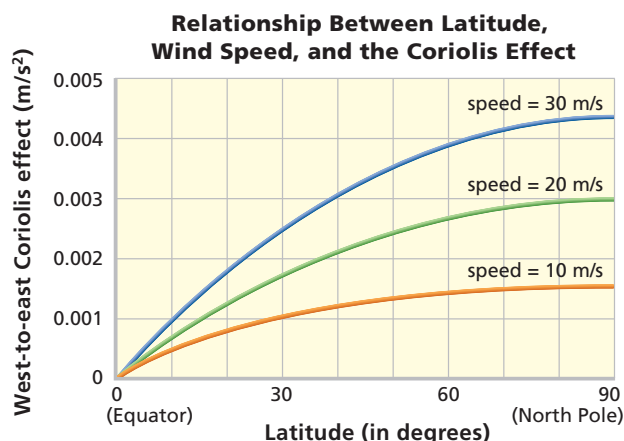
36. **Making Calculations** Maximum local wind speeds for each of the last seven days were 12 km/h, 20 km/h, 11 km/h, 6 km/h, 8 km/h, 19 km/h, and 17 km/h. What was the average maximum wind speed?

WRITING SKILLS

37. **Writing from Research** Research the debate about global warming. Write one paragraph about evidence that supports global warming and one paragraph about evidence that does not support global warming.

INTERPRETING GRAPHICS

The graph below shows how the Coriolis effect changes as latitude and wind speed change. Use this graph to answer the questions that follow.



38. At what wind speed is the Coriolis effect the greatest?
39. At what latitude is the Coriolis effect the smallest?
40. At 90° latitude, is there a direct relationship between the Coriolis effect and wind speed?

Understanding Concepts

Directions (1–4): For each question, write on a separate sheet of paper the letter of the correct answer.

- Which of the following processes is the source of the oxygen gas found in Earth's atmosphere?
 - oxidation
 - combustion
 - respiration
 - photosynthesis
- Which of the following statements best describes the relationship of atmospheric pressure to altitude?
 - The atmospheric pressure increases as the altitude increases.
 - The atmospheric pressure increases as the altitude decreases.
 - The atmospheric pressure varies unpredictably at different altitudes.
 - The atmospheric pressure is constant at all altitudes.
- Approximately how much of the solar energy that reaches Earth is absorbed by the atmosphere, land surfaces, and ocean?
 - 30%
 - 50%
 - 70%
 - 100%
- In the Northern Hemisphere, how does the Coriolis effect cause winds moving toward the North Pole to be deflected?
 - Winds are deflected to the right.
 - Winds are deflected to the left.
 - Winds are deflected in unpredictable patterns.
 - Winds are not deflected by the Coriolis effect.

Directions (5–6): For each question, write a short response.

- What is the most abundant gas in Earth's atmosphere?
- In which atmospheric layer do interactions between gas molecules and solar radiation produce the aurora borealis?

Reading Skills

Directions (7–9): Read the passage below. Then, answer the questions.

The Snow Eater

The chinook, or “snow eater,” is a dry wind that blows down the eastern side of the Rocky Mountains from New Mexico to Canada. Chinooks have the ability to melt large amounts of snow very quickly. Chinooks form when moist air is forced over a mountain range. The air cools as it rises. As the air cools, it releases moisture in the form of rain or snow, which nourishes the local flora. As the dry air flows over the mountaintop, it descends, compressing and heating the air below. The warm, dry wind that results can melt half of a meter of snow in just a few hours.

The temperature change caused when a chinook rushes down a mountainside can be dramatic. On January 22, 1943, in Spearfish, South Dakota, the temperature at 7:30 A.M. was -4°F . But only two minutes later, a chinook caused the temperature to soar to 45°F .

- Why are the chinook winds of the Rocky Mountains called “snow eaters”?
 - Chinook winds pick up snow and carry it to new locations.
 - Chinook winds drop all their snow on the western side of the mountains.
 - Chinook winds cause the temperature to decrease, which causes snow to accumulate.
 - Chinook winds cause the temperature to increase rapidly, which causes snow to melt.
- Which of the following statements can be inferred from the information in the passage?
 - Chinook winds are a relatively new phenomenon related to global warming.
 - Chinook winds occur during the winter.
 - The only type of wind that blows down from mountaintops are chinook winds.
 - When they blow up the western side of the Rocky Mountains, chinook winds are very hot.
- How do chinook winds affect weather on the eastern side of the Rocky Mountains?

