

The Atmosphere and the Oceans

Chapter 11

Atmosphere

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

Chapter 12

Meteorology

BIG Idea Weather patterns can be observed, analyzed, and predicted.

Chapter 13

The Nature of Storms

BIG Idea The exchange of thermal energy in the atmosphere sometimes occurs with great violence that varies in form, size, and duration.

Chapter 14

Climate

BIG Idea The different climates on Earth are influenced by natural factors as well as human activities.

Chapter 15

Earth's Oceans

BIG Idea Studying oceans helps scientists learn about global climate and Earth's history.

Chapter 16

The Marine Environment

BIG Idea The marine environment is geologically diverse and contains a wealth of natural resources.

CAREERS IN EARTH SCIENCE

Marine

Scientist: This marine scientist is studying a young manatee to learn more about its interaction with the environment. Marine scientists study the ocean to classify and conserve underwater life.

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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.

11.2 Properties of the Atmosphere

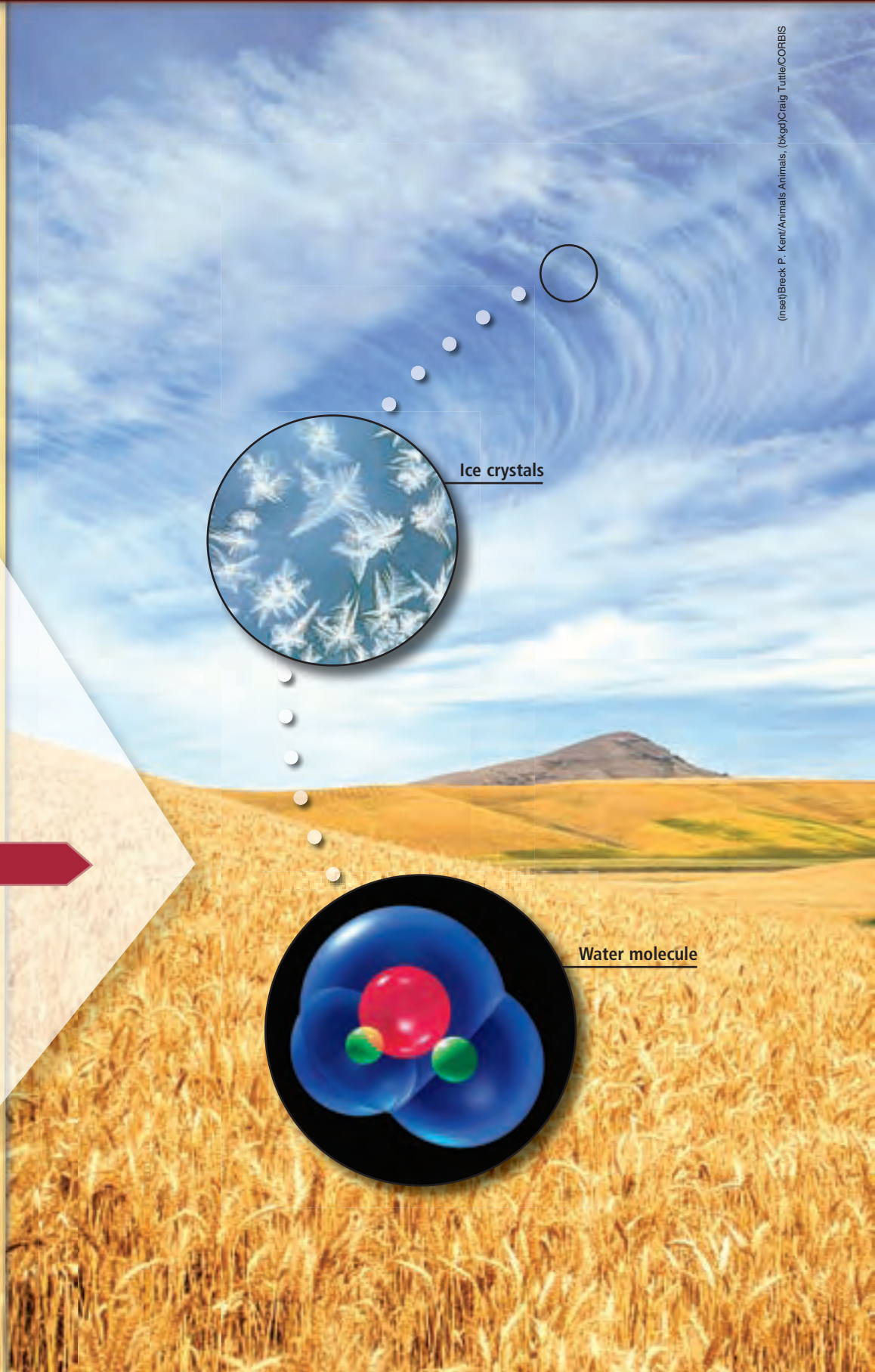
MAIN Idea Atmospheric properties, such as temperature, air pressure, and humidity describe weather conditions.

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 *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

Matt Meadows

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.

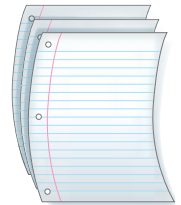
Analysis

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.

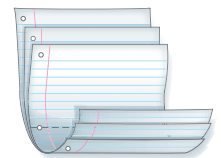
FOLDABLES™ Study Organizer

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

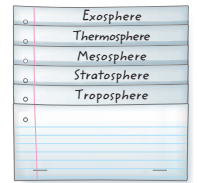
- ▶ **STEP 1** Collect three sheets of paper, and layer them about 2 cm apart vertically.



- ▶ **STEP 2** Fold up the bottom edges of the sheets to form five equal tabs. Create 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.

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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.

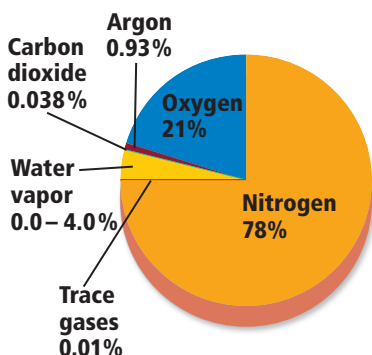
Permanent atmospheric gases About 99 percent of the atmosphere is composed of nitrogen (N_2) and oxygen (O_2). The remaining 1 percent consists of argon (Ar), carbon dioxide (CO_2), water vapor (H_2O), and other trace gases, as shown in **Figure 11.1**. The amounts of nitrogen and oxygen in the atmosphere 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



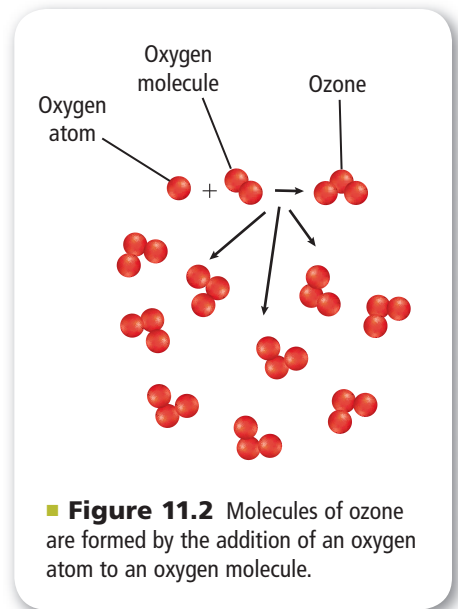
Carbon dioxide Carbon dioxide, another variable gas, currently makes up about 0.039 percent of the atmosphere. During the past 150 years, measurements have shown that the concentration of atmospheric carbon dioxide has increased from about 0.028 percent to its present value. Carbon dioxide is also cycled 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/cm³—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.



NATIONAL GEOGRAPHIC For more information on the ozone layer and the atmosphere, go to the [National Geographic Expedition](#) on page 910.

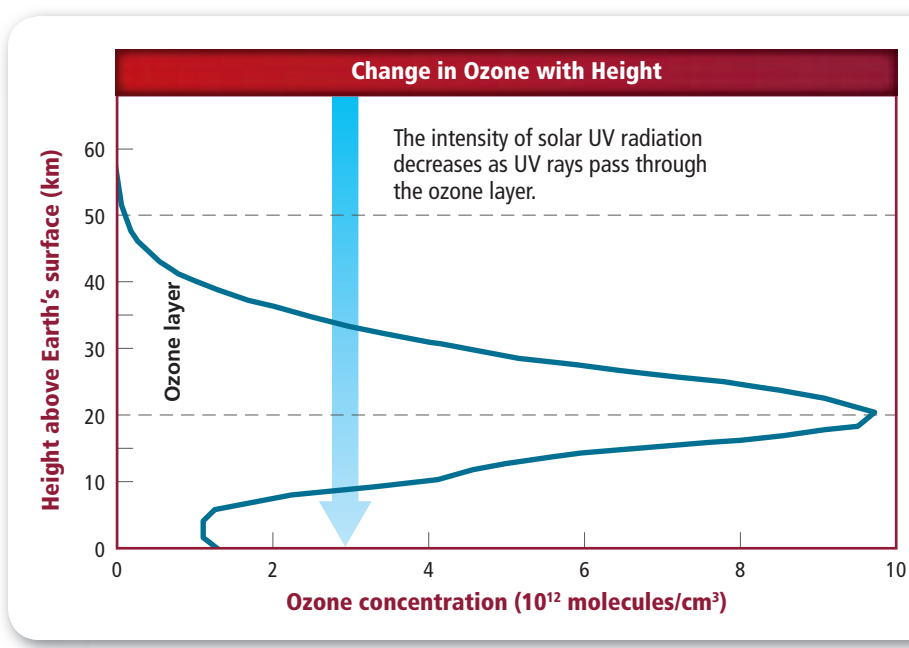


Figure 11.3 The ozone layer blocks harmful ultraviolet rays from reaching Earth's surface. Ozone concentration is highest at about 20 km above Earth's surface, in the ozone layer.

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.



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

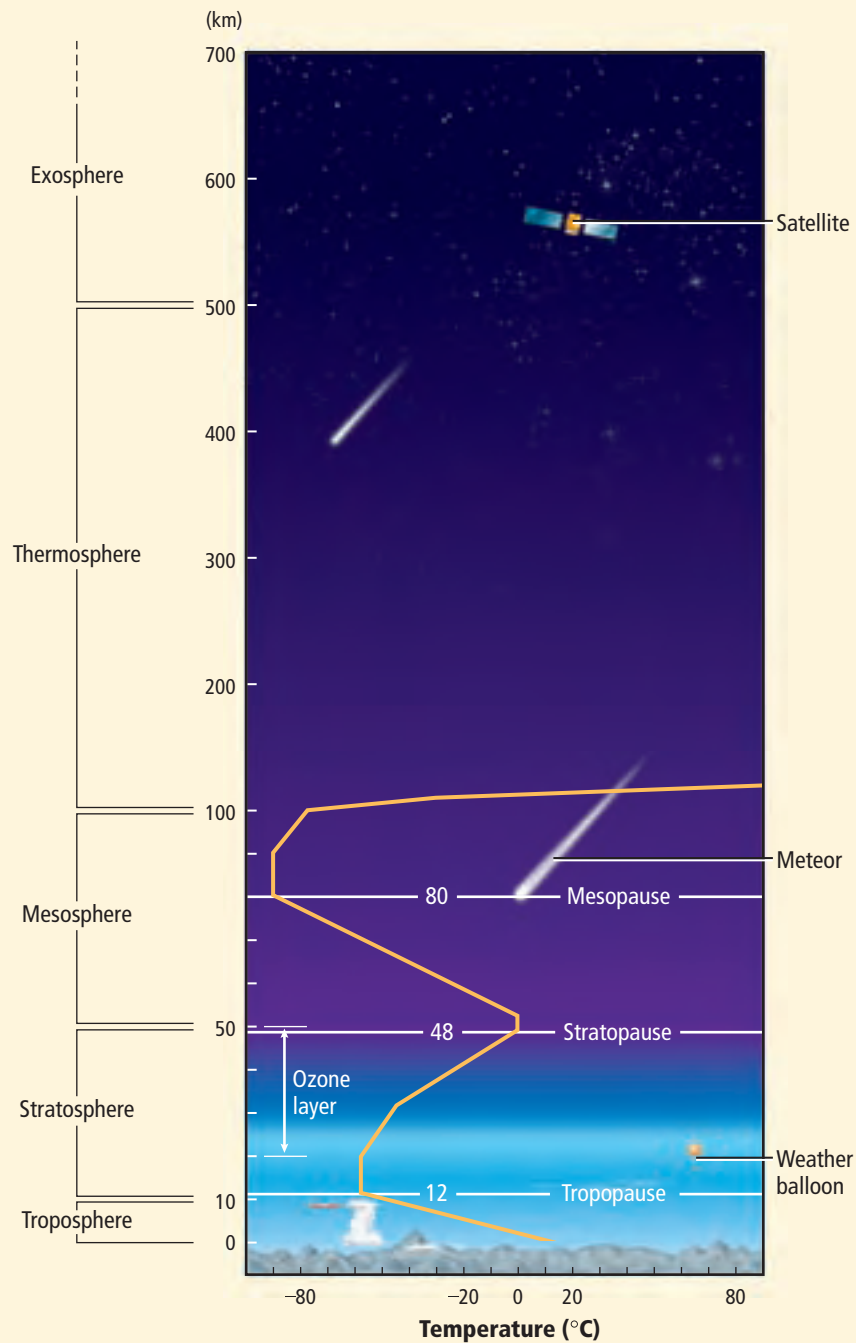
Atmospheric Layer	Components
Troposphere	layer closest to Earth's surface, ends at the tropopause
Stratosphere	layer above the troposphere, contains the ozone layer, and ends at the stratopause
Mesosphere	layer above the stratosphere, ends at the mesopause
Thermosphere	layer above the mesosphere, absorbs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

Visualizing the Layers of the Atmosphere

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.

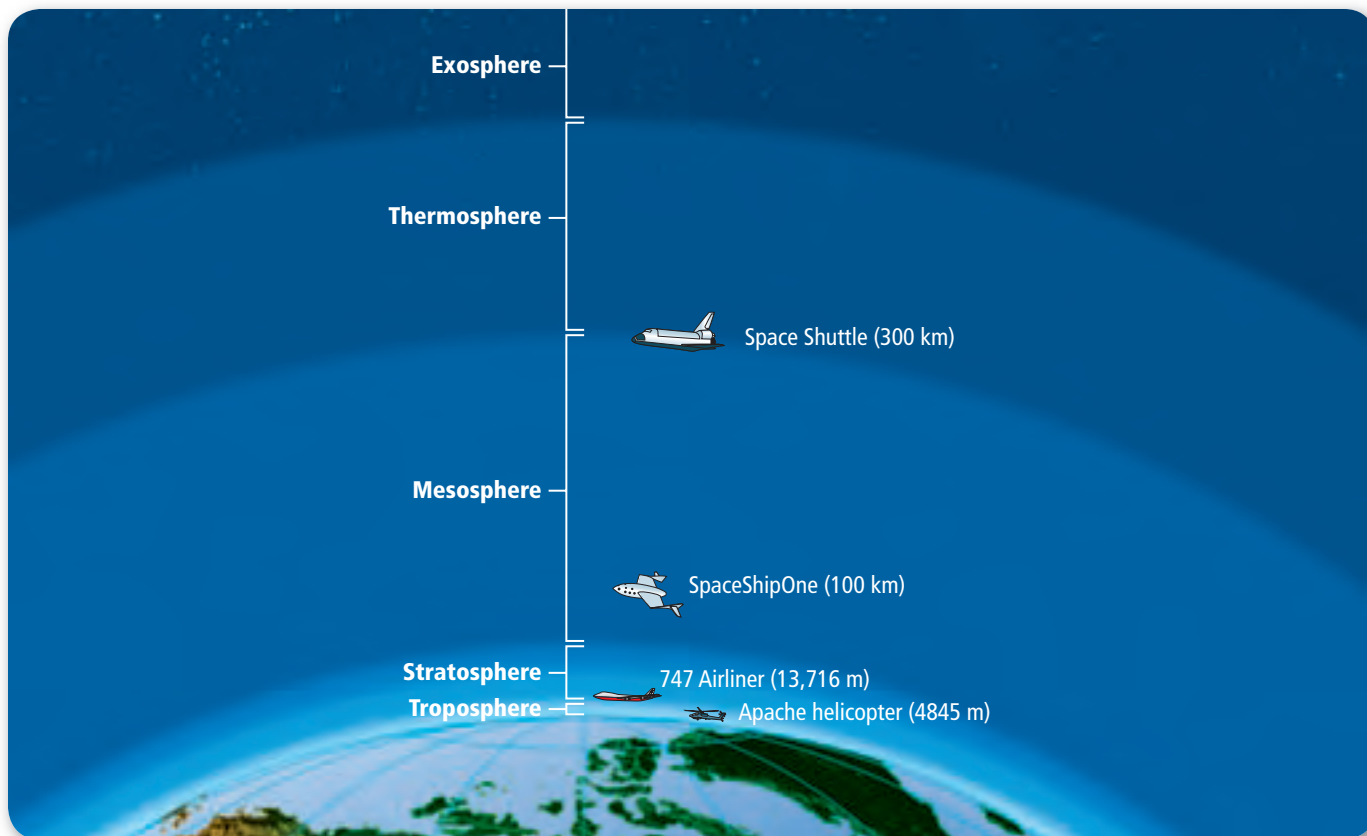
In the exosphere, gas molecules can be exchanged between the atmosphere and space.

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.



Concepts in Motion To explore more about the layers of the atmosphere, visit glencoe.com.





■ **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.

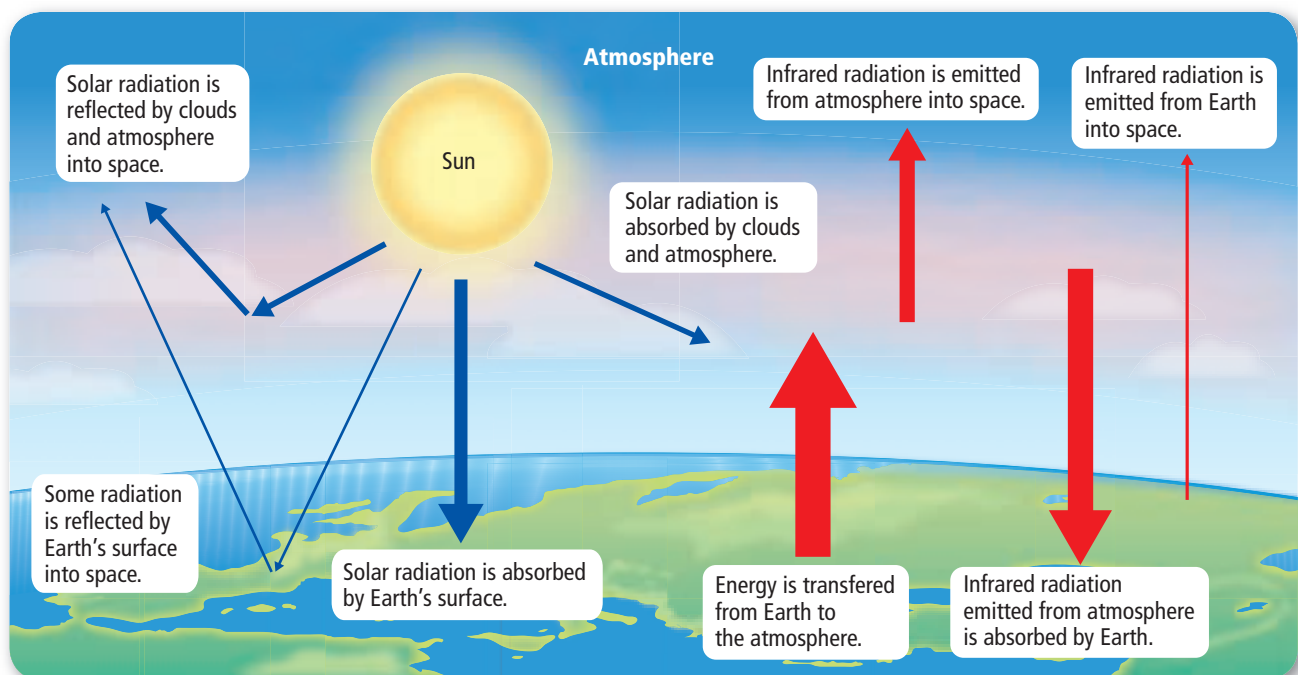
Rate of absorption The rate of absorption for any particular area varies depending on the physical characteristics of the area and the amount of solar radiation it receives. Different areas absorb energy and heat at different rates. For example, water heats and cools more slowly than land. Also, as a 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.

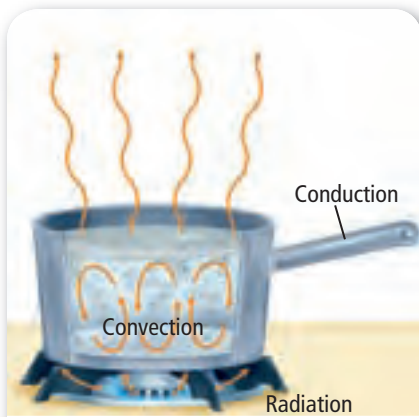


■ **Figure 11.6** A heat lamp transfers thermal energy by radiation. Here, the thermal energy helps to keep the french fries hot.

■ **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 $6.5^{\circ}\text{C}/\text{km}$. If temperature at 2.5 km altitude is 7.0°C , what is the temperature at 5.5 km altitude?

Section 11.2

Objectives

- **Identify** three properties of the atmosphere and how they interact.
- **Explain** why atmospheric properties change with changes in altitude.

Review Vocabulary

density: the mass per unit volume of a material

New Vocabulary

temperature inversion
humidity
saturation
relative humidity
dew point
latent heat

Properties of the Atmosphere

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

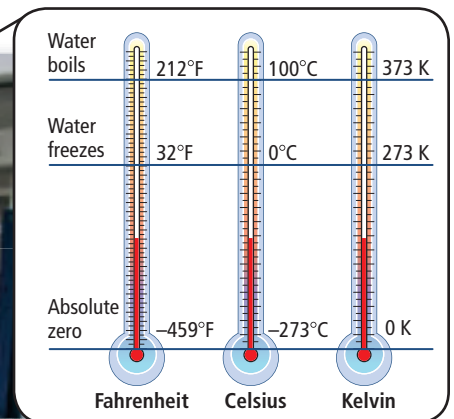
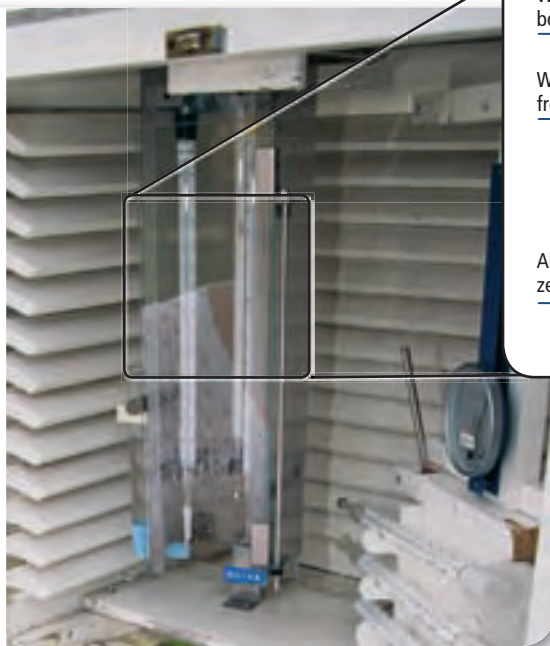
Real-World Reading Link Have you noticed the weather today? Maybe it is hot or cold, humid or dry, or even windy. These properties are always interacting and changing, and you can observe those changes every time you step outside.

Temperature

When you turn on the burner beneath a pot of water, thermal energy is transferred to the water and the temperature increases. Recall that particles in any material are in random motion. Temperature is a measure of the average kinetic energy of the particles in a material. Particles have more kinetic energy when they are moving faster, so the higher the temperature of a material, the faster the particles are moving.

Measuring temperature Temperature is usually measured using one of two common temperature scales. These scales are the Fahrenheit ($^{\circ}\text{F}$) scale, used mainly in the United States, and the Celsius ($^{\circ}\text{C}$) scale. The SI temperature scale used in science is the Kelvin (K) scale. **Figure 11.9** shows the differences among these temperature scales. The Fahrenheit and Celsius scales are based on the freezing point and boiling point of water. The zero point of the Kelvin scale is absolute zero—the lowest temperature that any substance can have.

■ **Figure 11.9** Temperature can be measured in degrees Fahrenheit, degrees Celsius, or in kelvin. The Kelvin scale starts at 0 K, which corresponds to -273°C and -459°F .



VOCABULARY

SCIENCE USAGE V. COMMON USAGE

Force

Science usage: an influence that might cause a body to accelerate

Common usage: violence, compulsion, or strength exerted upon or against a person or thing

Air Pressure

If you hold your hand out in front of you, Earth's atmosphere exerts a downward force on your hand due to the weight of the atmosphere above it. The force exerted on your hand divided by its area is the pressure exerted on your hand. Air pressure is the pressure exerted on a surface by the weight of the atmosphere above the surface.

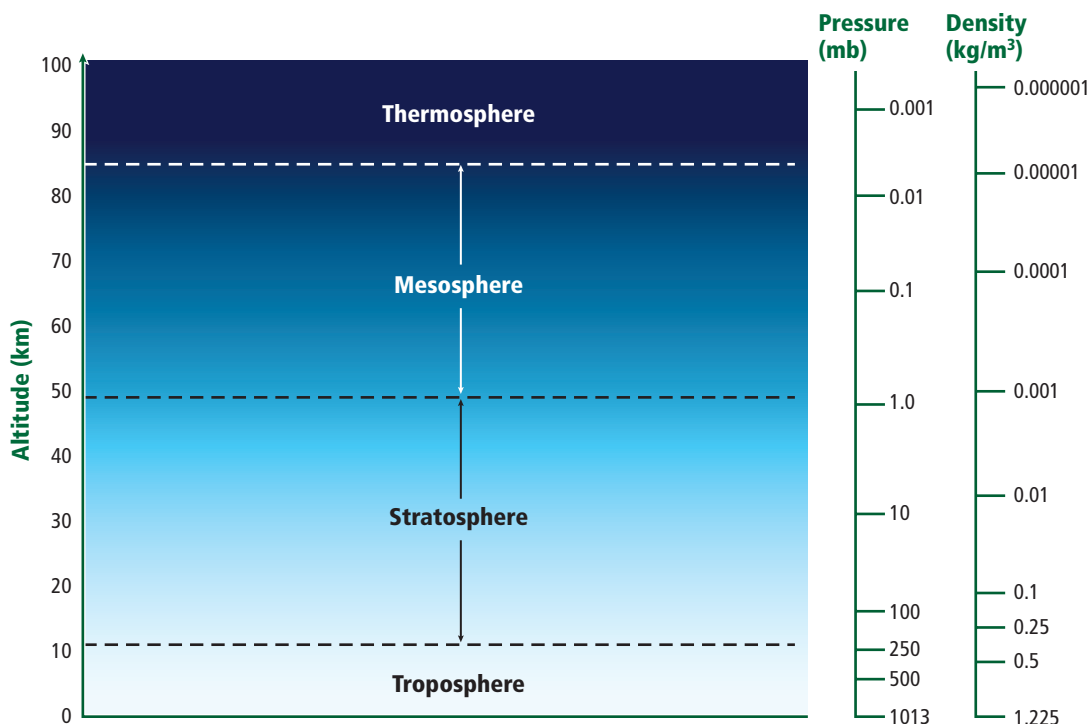
Because pressure is equal to force divided by area, the units for pressure are N/m^2 . Air pressure is often measured in units of millibars (mb), where 1 mb equals 100 N/m^2 . At sea level, the atmosphere exerts a pressure of about $100,000 \text{ N/m}^2$, or 1000 mb. As you go higher in the atmosphere, air pressure decreases as the mass of the air above you decreases. **Figure 11.10** shows how pressure in the atmosphere changes with altitude.

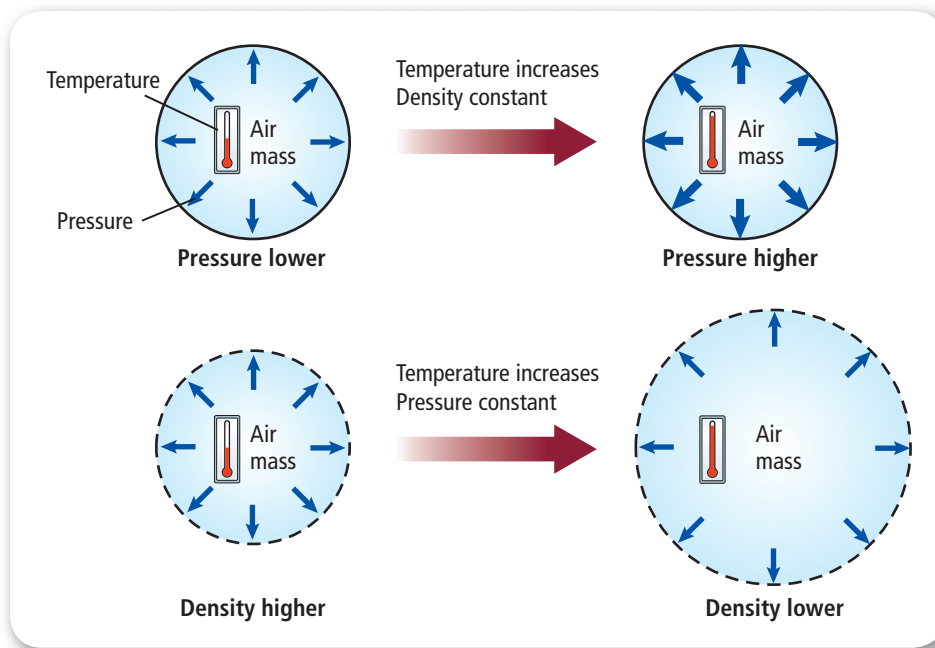


Reading Check Deduce why air pressure does not crush a human.

Density of air The density of a material is the mass of material in a unit volume, such as 1 m^3 . Atoms and molecules become farther apart in the atmosphere as altitude increases. This means that the density of air decreases with increasing altitude, as shown in **Figure 11.10**. Near sea level, the density of air is about 1.2 kg/m^3 . At the average altitude of the tropopause, or about 12 km above Earth's surface, the density of air is about 25 percent of its sea-level value. At the stratopause, or about 48 km above Earth's surface, air density has decreased to only about 0.2 percent of the air density at sea level.

■ **Figure 11.10** The density and pressure of the layers of the atmosphere decrease as altitude increases.





■ **Figure 11.11** Temperature, pressure, and density are all related to one another. If temperature increases, but density is constant, the pressure increases. If the temperature increases and the pressure is constant, the density decreases.

Pressure-temperature-density relationship In the atmosphere, the temperature, pressure, and density of air are related to each other, as shown in **Figure 11.11**. Imagine a sealed container containing only air. The pressure exerted by the air inside the container is related to the air temperature inside the container and the air density. How does the pressure change if the air temperature or density changes?

Air pressure and temperature The pressure exerted by the air in the container is due to the collisions of the gas particles in the air with the sides of the container. When these particles move faster due to an increase in temperature, they exert a greater force when they collide with the sides of the container. The air pressure inside the container increases. This means that for air with the same density, warmer air is at a higher pressure than cooler air.

Air pressure and density Imagine that the temperature of the air does not change, but that more air is pumped into the container. Now there are more gas particles in the container, and therefore, the mass of the air in the container has increased. Because the volume has not changed, the density of the air has increased. Now there are more gas particles colliding with the walls of the container, and so more force is being exerted by the particles on the walls. This means that at the same temperature, air with a higher density exerts more pressure than air with a lower density.

Temperature and density Heating a balloon causes the air inside to move faster, causing the balloon to expand and increase in volume. As a result, the air density inside the balloon decreases. The same is true for air masses in the atmosphere. At the same pressure, warmer air is less dense than cooler air.

VOCABULARY

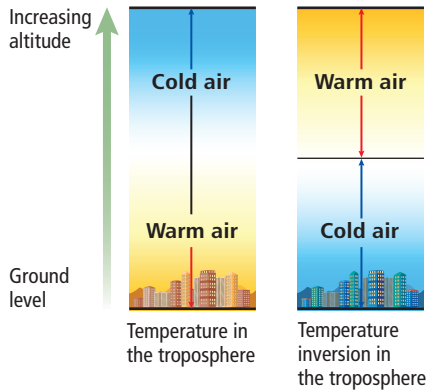
ACADEMIC VOCABULARY

Exert

to put forth (as strength)

Susan exerted a lot of energy playing basketball.

Temperature Trends



■ **Figure 11.12** In a temperature inversion, the warm air is located on top of the cooler air.

Temperature inversion In the troposphere, air temperature decreases as height increases. However, sometimes over a localized region in the troposphere, a temperature inversion can occur. A **temperature inversion** is an increase in temperature with height in an atmospheric layer. In other words, when a temperature inversion occurs, warmer air is on top of cooler air. This is called a temperature inversion because the temperature-altitude relationship is inverted, or turned upside down, as shown in **Figure 11.12**.

Causes of temperature inversion One example of a temperature inversion on the troposphere is the rapid cooling of land on a cold, clear, winter night when the air is calm. Under these conditions, the land does not radiate thermal energy to the lower layers of the atmosphere. As a result, the lower layers of air become cooler than the air above them, so that temperature increases with height and forms a temperature inversion.

Effects of temperature inversion If the sky is very hazy, there is probably an inversion somewhere in the lower atmosphere. A temperature inversion can lead to fog or low-level clouds. Fog is a significant factor in blocking visibility in many coastal cities, such as San Francisco. In some cities, such as the one shown in **Figure 11.13**, a temperature inversion can worsen air-pollution problems. The heated air rises as long as it is warmer than the air above it and then it stops rising, acting like a lid to trap pollution under the inversion layer. Pollutants are consequently unable to be lifted from Earth's surface. Temperature inversions that remain over an industrial area for a long time usually result in episodes of severe smog—a combination of smoke and fog—that can cause respiratory problems.

■ **Figure 11.13** A temperature inversion in New York City traps air pollution above the city.

Describe the effect of temperature inversion on air quality in metropolitan areas.



Wind Imagine you are entering a large, air-conditioned building on a hot summer day. As you open the door, you feel cool air rushing past you out of the building. This sudden rush of cool air occurs because the warm air outside the building is less dense and at a lower pressure than the cooler air inside the building. When the door opens, the difference in pressure causes the cool, dense air to rush out of the building. The movement of air is commonly known as wind.

Wind and pressure differences In the example above, the air in the building moves from a region of higher density to a region of lower density. In the lower atmosphere, air also generally moves from regions of higher density to regions of lower density. These density differences are produced by the unequal heating and cooling of different regions of Earth's surface. In the atmosphere, air pressure generally increases as density increases, so regions of high and low density are also regions of high and low air pressure respectively. As a result, air moves from a region of high pressure to a region of low pressure.

Wind speed and altitude Wind speed and direction change with height in the atmosphere. Near Earth's surface, wind is constantly slowed by the friction that results from contact with surfaces including trees, buildings, and hills, as shown **Figure 11.14**. Even the surface of water affects air motion. Higher up from Earth's surface, air encounters less friction and wind speeds increase. Wind speed is usually measured in miles per hour (mph) or kilometers per hour (km/h). Ships at sea usually measure wind in knots. One knot is equal to 1.85 km/h.



■ **Figure 11.14** When wind blows over a forested area by a coast, it encounters more friction than when it blows over flatter terrain. This occurs because the wind encounters friction from the mountains, trees, and then the water, slowing the wind's speed.

Humidity

The distribution and movement of water vapor in the atmosphere play an important role in determining the weather of any region.

Humidity is the amount of water vapor in the atmosphere at a given location on Earth's surface. Two ways of expressing the water vapor content of the atmosphere are relative humidity and dew point.

Relative humidity Consider a flask containing water. Some water molecules evaporate, leaving the liquid and becoming part of the water vapor in the flask. At the same time, other water molecules condense, returning from the vapor to become part of the liquid. Just as the amount of water vapor in the flask might vary, so does the amount of water vapor in the atmosphere. Water on Earth's surface evaporates and enters the atmosphere and condenses to form clouds and precipitation.

In the example of the flask, if the rate of evaporation is greater than the rate of condensation, the amount of water vapor in the flask increases. **Saturation** occurs when the amount of water vapor in a volume of air has reached the maximum amount. Recall from Chapter 3 that a saturated solution cannot hold any more of the substance that is being added to it. When a volume of air is saturated, it cannot hold any more water.

The amount of water vapor in a volume of air relative to the amount of water vapor needed for that volume of air to reach saturation is called **relative humidity**. Relative humidity is expressed as a percentage. When a certain volume of air is saturated, its relative humidity is 100 percent. If you hear a weather forecaster say that the relative humidity is 50 percent, it means that the air contains 50 percent of the water vapor needed for the air to be saturated.

PROBLEM-SOLVING LAB

Interpret the Graph

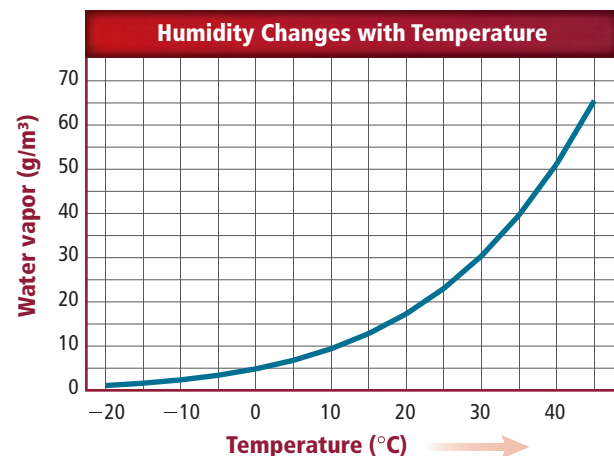
How do you calculate relative humidity?

Relative humidity is the ratio of the actual amount of water vapor in a volume of air relative to the maximum amount of water vapor needed for that volume of air to reach saturation. Use the graph at the right to answer the following questions.

Think Critically

1. **Compare** the maximum amount of water vapor 1 m^3 of air could hold at 15°C and 25°C .
2. **Calculate** the relative humidity of 1 m^3 of air containing 10 g/m^3 at 20°C .
3. **Analyze** Can relative humidity be more than 100 percent? Explain your answer.

Data and Observations



Dew point Another common way of describing the moisture content of air is the dew point. The **dew point** is the temperature to which air must be cooled at constant pressure to reach saturation. The dew point is often called the condensation temperature because it is the temperature at which water vapor in air condenses into water called dew. If the dew point is nearly the same as the air temperature, then the relative humidity is high.

Latent heat As water vapor in the air condenses, thermal energy is released. Where does this energy come from? To change liquid water to water vapor, thermal energy is added to the water by heating it. The water vapor then contains more thermal energy than the liquid water. This is the energy that is released when condensation occurs. The extra thermal energy contained in water vapor compared to liquid water is called **latent heat**.

When condensation occurs, as in **Figure 11.15**, latent heat is released and warms the air. At any given time, the amount of water vapor present in the atmosphere is a significant source of energy because it contains latent heat. When water vapor condenses, the latent heat released can provide energy to a weather system, such as a hurricane, increasing its intensity.

Condensation level An air mass can change temperature without being heated or cooled. A process in which temperature changes without the addition or removal of thermal energy from a system is called an adiabatic process. An example of an adiabatic process is the heating of air in a bicycle pump as the air is compressed. In a similar way, an air mass heats up as it sinks and cools off as it rises. Adiabatic heating occurs when air is compressed, and adiabatic cooling occurs when air expands.

MiniLab

Investigate Dew Formation

How does dew form? Dew forms when moist air near the ground cools and the water vapor in the air condenses into water droplets.

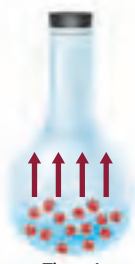
Procedure    

1. Read and complete the lab safety form.
2. Fill a **glass** about two-thirds full of **water**. Record the temperature of the room and the water.
3. Add **ice cubes** until the glass is full. Record the temperature of the water at 10-s intervals.
4. Observe the outside of the glass. Note the time and the temperature at which changes occur on the outside of the glass.
5. Repeat the investigation outside. Record the temperature of the water and the air outside.

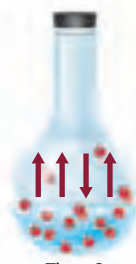
Analysis

1. **Compare and contrast** what happened to the outside of the glass when the investigation was performed in your classroom and when it was performed outside. If there was a difference, explain.
2. **Relate** your observations to the formation of dew.

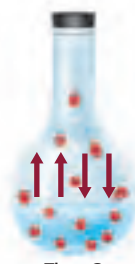
Evaporation-Condensation Equilibrium



Time 1
25°C
Water molecules
begin to evaporate.



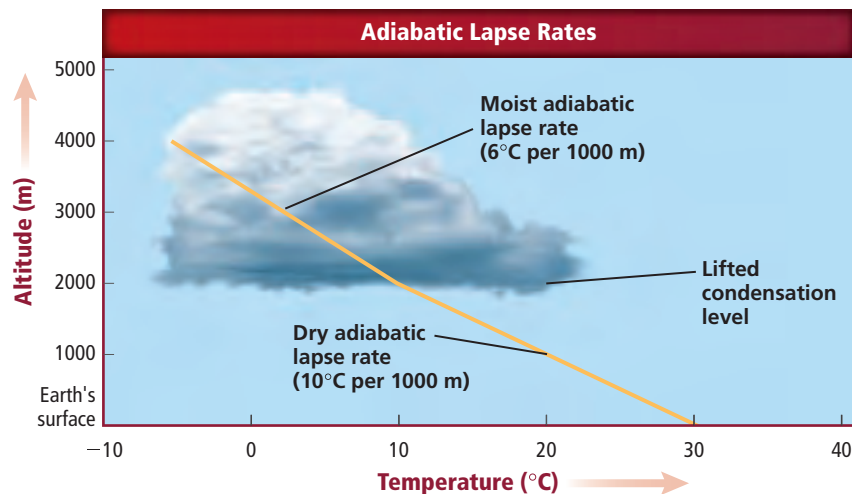
Time 2
25°C
Evaporation continues,
and condensation begins.



Time 3
25°C
Rate of evaporation equals
rate of condensation
or saturation.

■ **Figure 11.15** During evaporation, water molecules escape from the surface of the liquid and enter the air as water vapor. During condensation, water molecules return to the liquid state. At equilibrium, evaporation and condensation continue, but the amount of water in the air and amount of water in the liquid form remain constant.

■ **Figure 11.16** Condensation occurs at the lifted condensation level (LCL). Air above the LCL is saturated and thus cools more slowly than air below the LCL.
Explain why air above the LCL cools more slowly than air below the LCL.



A rising mass of air cools because the air pressure around it decreases as it rises, causing the air mass to expand. A rising air mass that does not exchange thermal energy with its surroundings will cool by about 10°C for every 1000 m it rises. This is called the dry adiabatic lapse rate—the rate at which unsaturated air will cool as it rises if no thermal energy is added or removed. If the air mass continues to rise, eventually it will cool to its condensation temperature. The height at which condensation occurs is called the lifted condensation level (LCL).

The rate at which saturated air cools is called the moist adiabatic lapse rate. This rate ranges from about 4°C/1000 m in very warm air to almost 9°C/1000 m in very cold air. This rate is slower than the dry adiabatic rate because water vapor in the air is condensing as the air rises and is releasing latent heat, as shown in **Figure 11.16**.

Section 11.2 Assessment

Section Summary

- ▶ At the same pressure, warmer air is less dense than cooler air.
- ▶ Air moves from regions of high pressure to regions of low pressure.
- ▶ The dew point of air depends on the amount of water vapor the air contains.
- ▶ Latent heat is released when water vapor condenses and when water freezes.

Understand Main Ideas

1. **MAIN Idea** Identify three properties of the atmosphere and describe how they vary with height in the atmosphere.
2. **Explain** what occurs during a temperature inversion.
3. **Describe** how the motion of particles in a material changes when the temperature of the material increases.

Think Critically

4. **Predict** how the relative humidity and dew point change in a rising mass of air.
5. **Design** an experiment that shows how average wind speeds change over different types of surfaces.

MATH in Earth Science

6. If the average thickness of the troposphere is 11 km, what would be the temperature difference between the top and bottom of the troposphere if the temperature decrease is the same as the dry adiabatic lapse rate?

Section 11.3

Objectives

- **Explain** the difference between stable and unstable air.
- **Compare and contrast** low, middle, high, and vertical development clouds.
- **Explain** how precipitation forms.

Review Vocabulary

condensation: process in which water vapor changes to a liquid

New Vocabulary

condensation nucleus
orographic lifting
cumulus
stratus
cirrus
precipitation
coalescence

Clouds and Precipitation

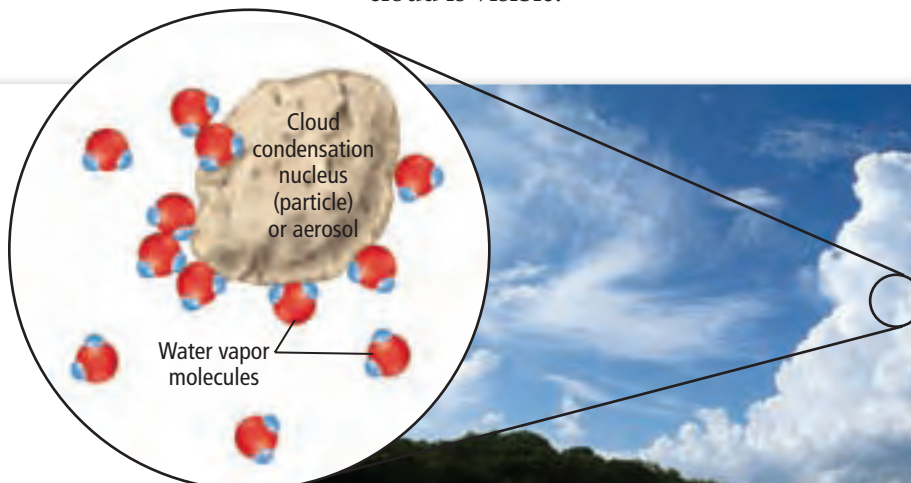
MAIN Idea Clouds vary in shape, size, height of formation, and type of precipitation.

Real-World Reading Link If you look up at the sky, you might notice differences among the clouds from day to day and hour to hour. Some clouds signal fair weather and others signal violent storms.

Cloud Formation

A cloud can form when a rising air mass cools. Recall that Earth's surface heats and cools by different amounts in different places. This uneven heating and cooling of the surface causes air masses near the surface to warm and cool. As an air mass is heated, it becomes less dense than the cooler air around it. This causes the warmer air mass to be pushed upward by the denser, cooler air.

However, as the warm air mass rises, it expands and cools adiabatically. The cooling of an air mass as it rises can cause water vapor in the air mass to condense. Recall that the lifted condensation level is the height at which condensation of water vapor occurs in an air mass. When a rising air mass reaches the lifted condensation level, water vapor condenses around condensation nuclei, as shown in **Figure 11.17**. A **condensation nucleus** is a small particle in the atmosphere around which water droplets can form. These particles are usually less than about 0.001 mm in diameter and can be made of ice, salt, dust, and other materials. The droplets that form can be liquid water or ice, depending on the surrounding temperature. When the number of these droplets is large enough, a cloud is visible.



■ **Figure 11.17** Clouds form when a mass of rising air becomes saturated and water collects on condensation nuclei.

CAREERS IN EARTH SCIENCE

Weather Observer A weather observer collects information for meteorologists about weather and sea conditions using weather equipment, radar scans, and satellite photographs. An education that includes biology, Earth science, environmental science, and geology is useful for a weather observer. To learn more about Earth science careers, visit glencoe.com.

Atmospheric stability As an air mass rises, it cools. However, the air mass will continue to rise as long as it is warmer than the surrounding air. Under some conditions, an air mass that has started to rise sinks back to its original position. When this happens, the air is considered stable because it resists rising. The stability of air masses determines the type of clouds that form and the associated weather patterns.

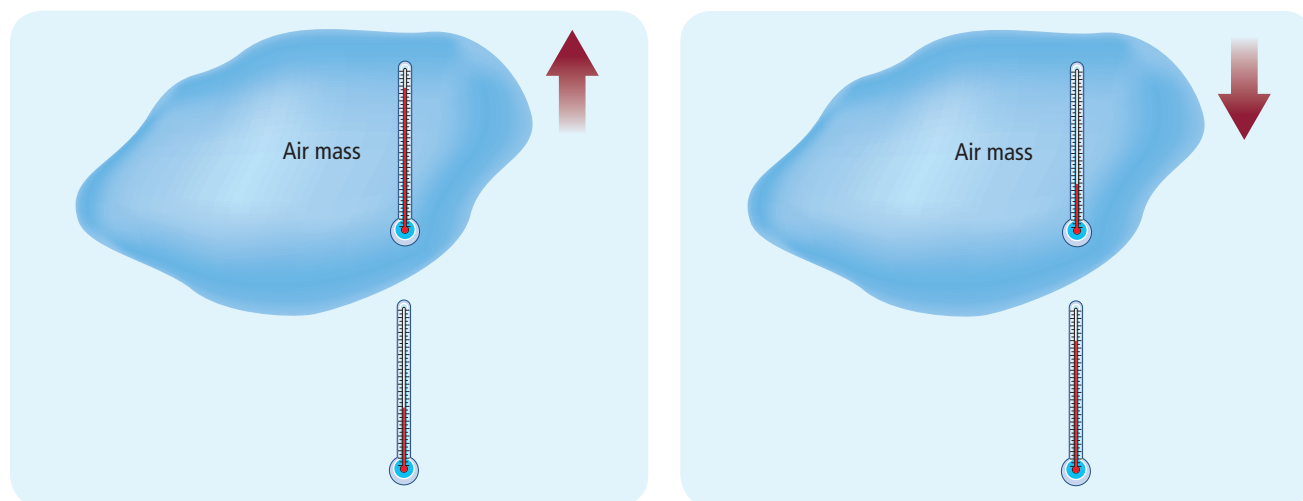
Stable air The stability of an air mass depends on how the temperature of the air mass changes relative to the atmosphere. The air temperature near Earth's surface decreases with altitude. As a result, the atmosphere becomes cooler as the air mass rises. At the same time, the rising air mass is also becoming cooler. Suppose that the temperature of the atmosphere decreases more slowly with increasing altitude than does the temperature of the rising air mass. Then the rising air mass will cool more quickly than the atmosphere. The air mass will finally reach an altitude at which it is colder than the atmosphere. It will then sink back to the altitude at which its density is the same as the atmosphere, as shown in **Figure 11.18**. Because the air mass stops rising and sinks downward, it is stable. Fair weather clouds form under stable conditions.

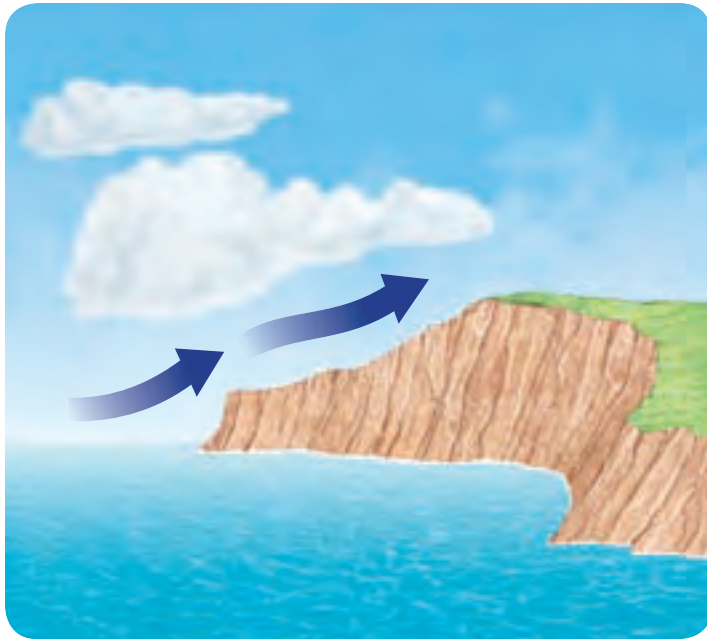


Reading Check Describe the factors that affect the stability of air.

Unstable air Suppose that the temperature of the surrounding air cools faster than the temperature of the rising air mass. Then the air mass will always be less dense than the surrounding air. As a result, the air mass will continue to rise, as shown in **Figure 11.18**. The atmosphere is then considered to be unstable. Unstable conditions can produce the type of clouds associated with thunderstorms.

■ **Figure 11.18** Stable air has a tendency to resist movement. Unstable air does not resist vertical displacement. When the temperature of a body of air is greater than the temperature of the surrounding air, the air body rises. When the temperature of the surrounding air is greater than that of the air body, it sinks.





■ **Figure 11.19** Orographic lifting occurs when warm, moist air is cooled because it is forced to rise over a mountain, or when two air bodies of different temperatures meet.

Atmospheric lifting Clouds can form when moist air rises, expands, and cools. Air rises when it is heated and becomes warmer than the surrounding air. This process is known as convective lifting. Clouds can also form when air is forced upward or lifted by mechanical processes. Two of these processes are orographic lifting and convergence.

Orographic lifting Clouds can form when air is forced to rise over elevated land or other topographic barriers. This can happen, for example, when an air mass approaches a mountain range.

Orographic lifting occurs when an air mass is forced to rise over a topographic barrier, as shown in **Figure 11.19**. The rising air mass expands and cools, with water droplets condensing when the temperature falls below the dew point. Many of the rainiest places on Earth are located on the windward sides of mountain slopes, such as the coastal side of the Sierra Nevadas. The formation of clouds and the resulting heavy precipitation along the west coast of Canada are also primarily due to orographic lifting.

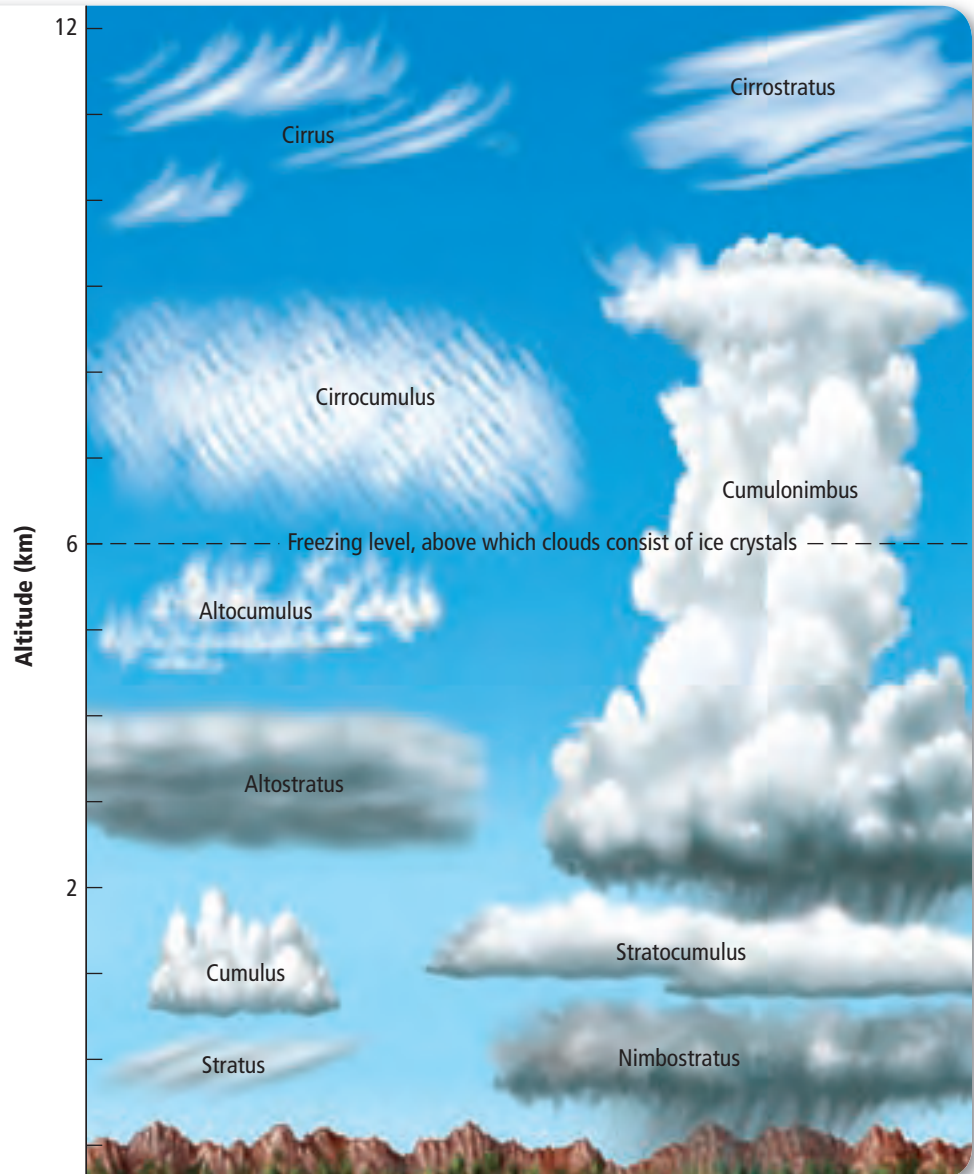
Convergence Air can be lifted by convergence, which occurs when air flows into the same area from different directions. Then some of the air is forced upward. This process is even more pronounced when air masses at different temperatures collide. When a warm air mass and a cooler air mass collide, the warmer, less-dense air is forced upward over the denser, cooler air. As the warm air rises, it cools adiabatically. If the rising air cools to the dew-point temperature, then water vapor can condense on condensation nuclei and form a cloud. This cloud formation mechanism is common at middle latitudes where severe storm systems form along the cold polar front. Convergence also occurs near the equator where the trade winds meet at the intertropical convergence zone. You will read more about these topics in Chapter 12.

Types of Clouds

You have probably noticed that clouds have different shapes. Some clouds look like puffy cotton balls, while others have a thin, feathery appearance. These differences in cloud shape are due to differences in the processes that cause clouds to form. Cloud formation can also take place at different altitudes—sometimes even right at Earth's surface, in which case the cloud is known as fog.

Clouds are generally classified according to a system developed in 1803, and only minor changes have been made since it was first introduced. **Figure 11.20** shows the different types of clouds. This system classifies clouds by the altitudes at which they form and by their shapes. There are four classes of clouds based on the altitudes at which they form: low, middle, and high. In addition, there are clouds with vertical development. Low clouds typically form below 2000 m. Middle clouds form mainly between 2000 m and 6000 m. High clouds form above 6000 m. Unlike the other three classes of clouds, those with vertical development can form at all altitudes.


■ **Figure 11.20** Clouds form at different altitudes and in different shapes.
Compare and contrast *cirrus* and *stratus* clouds.



Low clouds Clouds can form when warm, moist air rises, expands, and cools. If conditions are stable, the air mass stops rising at the altitude where its temperature is the same as that of the surrounding air. If a cloud has formed, it will flatten out and winds will spread it horizontally into stratocumulus or layered cumulus clouds, as shown in **Figure 11.20**. **Cumulus** (KYEW myuh lus) clouds are puffy, lumpy-looking clouds that usually occur below 2000 m. Another type of cloud that forms at heights below 2000 m is a **stratus** (STRAY tus), a layered sheetlike cloud that covers much or all of the sky in a given area. Stratus clouds often form when fog lifts away from Earth's surface.

Middle clouds Altocumulus and altostratus clouds form at altitudes between 2000 m and 6000 m. They are made up of ice crystals and water droplets due to the colder temperatures generally present at these altitudes. Middle clouds are usually layered. Altocumulus clouds are white or gray in color and form large, round masses or wavy rows. Altostratus clouds have a gray appearance, and they form thin sheets of clouds. Middle clouds sometimes produce mild precipitation.

High clouds High clouds, made up of ice crystals, form at heights of 6000 m where temperatures are below freezing. Some, such as **cirrus** (SIHR us) clouds, often have a wispy, indistinct appearance. Another type of cirrus cloud, called a cirrostratus, forms as a continuous layer that can cover the sky. Cirrostratus clouds vary in thickness from almost transparent to dense enough to block out the Sun or the Moon.

 **Reading Check** Identify types of low, middle, and high clouds.

Vertical development clouds If the air that makes up a cumulus cloud is unstable, the cloud will be warmer than the surface or surrounding air and will continue to grow upward. As it rises, water vapor condenses, and the air continues to increase in temperature due to the release of latent heat. The cloud can grow through middle altitudes as a towering cumulonimbus, as shown in **Figure 11.21**, and, if conditions are right, it can reach nearly 18,000 m. Its top is then composed of ice crystals. Strong winds can spread the top of the cloud into an anvil shape. What began as a small mass of unstable moist air is now an atmospheric giant, capable of producing the torrential rains, strong winds, and hail characteristic of some thunderstorms.

■ **Figure 11.21** Cumulonimbus clouds, such as the large, puffy cloud here, are associated with thunderstorms.

Describe how a cumulonimbus cloud can form.



Precipitation

All forms of water that fall from clouds to the ground are **precipitation**. Rain, snow, sleet, and hail are the four main types of precipitation. Clouds contain water droplets that are so small that the upward movement of air in the cloud can keep the droplets from falling. In order for these droplets to become heavy enough to fall, their size must increase by 50 to 100 times.

Coalescence One way that cloud droplets can increase in size is by coalescence. In a warm cloud, coalescence is the primary process responsible for the formation of precipitation. **Coalescence** (koh uh LEH sunts) occurs when cloud droplets collide and join together to form a larger droplet. These collisions occur as larger droplets fall and collide with smaller droplets. As the process continues, the droplets eventually become too heavy to remain suspended in the cloud and fall to Earth as precipitation. Rain is precipitation that reaches Earth's surface as a liquid. Raindrops typically have diameters between 0.5 mm and 5 mm.

Snow, sleet, and hail The type of precipitation that reaches Earth depends on the vertical variation of temperature in the atmosphere. In cold clouds where the air temperature is far below freezing, ice crystals can form that finally fall to the ground as snow. Sometimes, even if ice crystals form in a cloud, they can reach the ground as rain if they fall through air warmer than 0°C and melt.

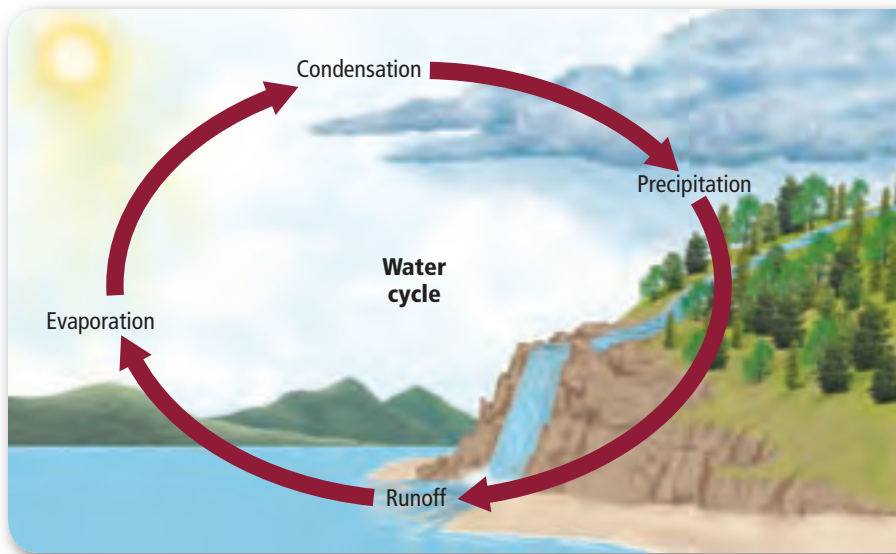
In some cases, air currents in a cloud can cause cloud droplets to move up and down through freezing and nonfreezing air, forming ice pellets that fall to the ground as sleet. Sleet can also occur when raindrops freeze as they fall through freezing air near the surface.

If the up-and-down motion in a cloud is especially strong and occurs over large stretches of the atmosphere, large ice pellets known as hail can form. **Figure 11.22** shows a sample of hail. Most hailstones are smaller in diameter than a dime, but some stones have been found to weigh more than 0.5 kg. Larger stones are often produced during severe thunderstorms.



■ **Figure 11.22** Hail is precipitation in the form of balls or lumps of ice that is produced by intense thunderstorms.

Infer How might the layers in the cross section of the hailstone form?



■ **Figure 11.23** Water moves from Earth to the atmosphere and back to Earth in the water cycle.

The water cycle More than 97 percent of Earth’s water is in the oceans. At any one time, only a small percentage of water is present in the atmosphere. Still, this water is vitally important because, as it continually moves between the atmosphere and Earth’s surface, it nourishes living things. The constant movement of water between the atmosphere and Earth’s surface is known as the water cycle.

The water cycle is summarized in **Figure 11.23**. Radiation from the Sun causes liquid water to evaporate. Water evaporates from lakes, streams, and oceans and rises into Earth’s atmosphere. As water vapor rises, it cools and condenses to form clouds. Water droplets combine to form larger drops that fall to Earth as precipitation. This water soaks into the ground and enters lakes, streams, and oceans, or it falls directly into bodies of water and eventually evaporates, continuing the water cycle.

Section 11.3 Assessment

Section Summary

- Clouds are formed as warm, moist air is forced upward, expands, and cools.
- An air mass is stable if it tends to return to its original height after it starts rising.
- Cloud droplets form when water vapor is cooled to the dew point and condenses on condensation nuclei.
- Clouds are classified by their shapes and the altitudes at which they form.
- Cloud droplets collide and coalesce into larger droplets that can fall to Earth as rain, snow, sleet, or hail.

Understand Main Ideas

1. **MAIN Idea** Summarize the differences between low clouds, middle clouds, and high clouds.
2. **Describe** how precipitation forms.
3. **Determine** the reason precipitation will fall as snow rather than rain.
4. **Compare** stable and unstable air.

Think Critically

5. **Evaluate** how a reduction in the number of condensation nuclei in the troposphere would affect precipitation. Explain your reasoning.

WRITING in Earth Science

6. Describe the path a drop of rain might follow throughout the water cycle.

Earth Science and the Environment

Ozone Variation

Atoms, such as chlorine and bromine, when located in the stratosphere, can destroy ozone molecules. The decline in stratospheric ozone measured since the early 1980s might have been reversed due to a decrease in stratospheric chlorine.

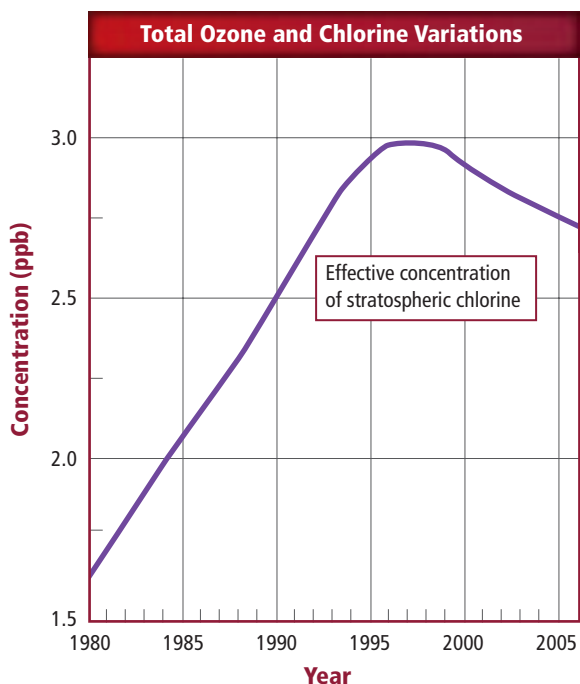
Variations in ozone amounts The total amount of ozone in the atmosphere over Earth's surface varies with location and also changes with time. Total ozone increases with latitude, being low at the equator and highest in the polar regions. Ozone amounts also vary seasonally, usually decreasing from winter to summer. The largest seasonal changes occur at high latitudes, particularly in the polar regions.

The Antarctic ozone hole Over Antarctica, the lowest ozone amounts occur in early spring. Since the late 1970s, total ozone amounts in the spring have greatly decreased.

This decrease in springtime ozone over Antarctica is called the Antarctic ozone hole. The Antarctic ozone hole is caused by chlorofluorocarbons (CFCs) and the presence of polar stratospheric clouds (PSCs). These clouds form over Antarctica during the winter in the lower stratosphere. CFCs break down, producing molecules that contain chlorine atoms. These molecules undergo chemical reactions on ice crystals in the PSCs, producing chlorine and other compounds that destroy ozone.

The Montreal Protocol Satellite measurements beginning in the late 1970s also showed a decrease in global ozone amounts of several percent. Concerns over decreasing ozone led to the adoption of the Montreal Protocol in 1987. This international agreement requires countries to phase out the production and use of CFCs and similar chemicals. As a result, levels of chlorine and other ozone-destroying chemicals in the stratosphere have been declining since the late 1990s, as shown in the graph.

Signs of recovery? Between 1996 and 2006, the decrease in total ozone leveled off in most regions. Part of these changes might be due to natural causes, such as solar variability, as well as to the Montreal Protocol. Measurements over several more years will be needed to determine whether the ozone decline has been reversed.



WRITING in Earth Science

Magazine Article Research how natural processes, such as volcanic eruptions, solar activity, and air movements affect ozone levels in the stratosphere. Write a magazine article that reports what you found. To learn more about the ozone layer, visit glencoe.com.

GEO LAB

INTERPRET PRESSURE-TEMPERATURE RELATIONSHIPS

Matt Meadows

Background: As you go up a mountain, both temperature and air pressure decrease. Temperature decreases as you get farther away from the atmosphere's heat source—Earth's surface. Pressure decreases as you ascend the mountain because there are fewer particles in the air above you. Pressure and temperature are also related through the expansion and compression of air, regardless of height.

Question: How does the expansion and compression of air affect temperature?

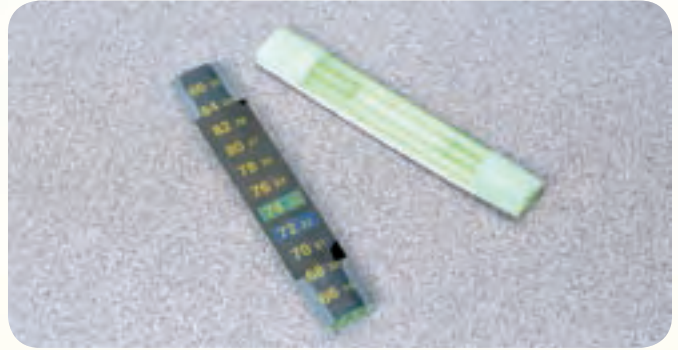
Materials

clean, clear, plastic 2-L bottle with cap
plastic straws
scissors
thin, liquid-crystal temperature strip
tape
watch or timer

Safety Precautions

Procedure

1. Read and complete the lab safety form.
2. Working with a partner, cut two pieces of straw, each the length of the temperature strip. Then cut two 2-cm pieces of straw.
3. Lay the two long pieces on a table. Place the two shorter pieces within the space created by the longer pieces so that the four pieces form a supportive structure for the temperature strip as shown in the figure.
4. Tape the four pieces of straw together. Place the temperature strip lengthwise on the straws. Tape the strip to the straws.
5. Slide the temperature-strip-straw assembly into the clean, dry bottle. Screw the cap on tightly.
6. Place the sealed bottle on the table so that the temperature strip faces you and is easy to read. Do not handle the bottle any more than is necessary so that the temperature will not be affected by your hands.
7. Record the temperature of the air inside the bottle as indicated by the temperature strip.



8. Position the bottle so that half its length extends beyond the edge of the table. Placing one hand on each end of the bottle, push down on both ends so that the bottle bends in the middle. Hold the bottle this way for 2 min while your partner records the temperature every 15 s.
9. Release the pressure on the bottle. Observe and record the temperature every 15 s for the next 2 min.

Analyze and Conclude

1. **Interpret Data** What was the average temperature of the air inside the bottle as you applied pressure? How did this differ from the average temperature of the bottled air when you released the pressure?
2. **Graph** the temperature changes you recorded throughout the experiment.
3. **Explain** how these temperature changes are related to changes in pressure.
4. **Predict** how the experiment would change if you took the cap off the bottle.
5. **Infer** Given your observations and what you know about the behavior of warm air, would you expect the air over an equatorial desert at midday to be characterized by high or low pressure?

WRITING in Earth Science

Research how pressure changes can affect the daily weather. Share your findings with your classmates. For more information on weather, visit glencoe.com.



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

Vocabulary

Key Concepts

Section 11.1 Atmospheric Basics

- conduction (p. 288)
- convection (p. 288)
- exosphere (p. 286)
- mesosphere (p. 284)
- radiation (p. 287)
- stratosphere (p. 284)
- thermosphere (p. 284)
- troposphere (p. 284)

MAIN Idea Energy is transferred throughout Earth's atmosphere.

- 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.

Section 11.2 Properties of the Atmosphere

- dew point (p. 295)
- humidity (p. 294)
- latent heat (p. 295)
- relative humidity (p. 294)
- saturation (p. 294)
- temperature inversion (p. 292)

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

- At the same pressure, warmer air is less dense than cooler air.
- Air moves from regions of high pressure to regions of low pressure.
- The dew point of air depends on the amount of water vapor the air contains.
- Latent heat is released when water vapor condenses and when water freezes.

Section 11.3 Clouds and Precipitation

- cirrus (p. 301)
- coalescence (p. 302)
- condensation nucleus (p. 297)
- cumulus (p. 301)
- orographic lifting (p. 299)
- precipitation (p. 302)
- stratus (p. 301)

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

- Clouds are formed as warm, moist air is forced upward, expands, and cools.
- An air mass is stable if it tends to return to its original height after it starts rising.
- Cloud droplets form when water vapor is cooled to the dew point and condenses on condensation nuclei.
- Clouds are classified by their shapes and the altitudes at which they form.
- Cloud droplets collide and coalesce into larger droplets that can fall to Earth as rain, snow, sleet, or hail.

Vocabulary Review

Match each description below with the correct vocabulary term from the Study Guide.

- outermost layer of Earth's atmosphere
- transfer of energy from a higher to a lower temperature by collisions between particles
- temperature at which condensation of water vapor can occur
- occurs when the amount of water vapor in a volume of air has reached the maximum amount
- the amount of water vapor present in air

Complete the sentences below using vocabulary terms from the Study Guide.

- _____ are small particles in the atmosphere around which water droplets form.
- The atmospheric layer that is closest to Earth's surface is the _____.
- Types of _____ include hail, sleet, and snow.

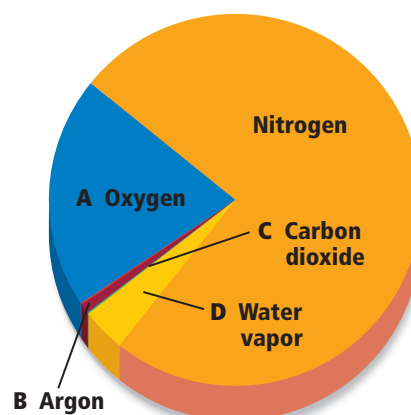
Each of the following sentences is false. Make each sentence true by replacing the italicized words with terms from the Study Guide.

- Convection* occurs when small cloud droplets collide to form a larger droplet.
- Mesosphere* is the layer of Earth's atmosphere that contains the ozone layer.
- The transfer of energy in matter or space by electromagnetic waves is called *latent heat*.
- When the bottom of a pan of water is heated and the water expands, becoming less dense than the surrounding water, it is forced upward. As it rises, the water cools and sinks back to the bottom of the pan. This process is called *precipitation*.
- When *saturation* occurs, an air mass is forced to rise over a topographic barrier.

Understand Key Concepts

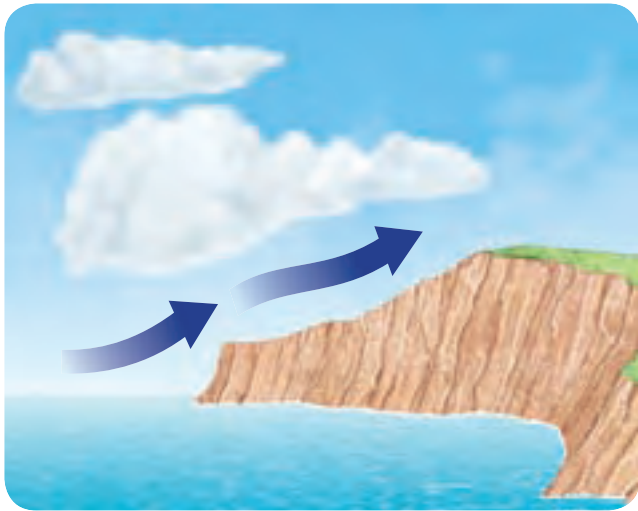
- Which gas has increased in concentration by about 0.011 percent over the past 150 years?
 - oxygen
 - nitrogen
 - carbon dioxide
 - water vapor

Use the diagram below to answer Question 15.



- Which gas is least abundant in Earth's atmosphere?
 - A
 - B
 - C
 - D
- Which is the primary cause of wind?
 - air saturation
 - pressure imbalances
 - pollution
 - movement of water
- Which causes latent heat?
 - condensation of water vapor
 - evaporation of water vapor
 - adiabatic heating
 - pressure increase
- Wind speed on Earth is reduced by
 - temperature
 - friction
 - weather
 - convergence

Use the diagram below to answer Question 19.



19. Which mechanical process is causing the air to rise?
 - A. coalescence
 - B. convection
 - C. orographic lifting
 - D. convergence
20. Which is most likely to be a vertical development cloud?
 - A. cumulonimbus
 - B. cirrus
 - C. stratus
 - D. altocumulus
21. Almost all weather, clouds, and storms occur in which layer of the atmosphere?
 - A. thermosphere
 - B. mesosphere
 - C. stratosphere
 - D. troposphere
22. What color would be best for a home designed to absorb energy?
 - A. red
 - B. white
 - C. gray
 - D. black
23. Which temperature is coldest?
 - A. 32°F
 - B. 10°C
 - C. 280 K
 - D. 5°C

Constructed Response

24. **Explain** why precipitation from a cumulonimbus cloud is generally heavier than that from a stratus cloud.
25. **Identify** the role that evaporation and condensation play in Earth's water cycle.
26. **Compare** what happens to latent heat in the atmosphere during evaporation to what occurs during condensation.

Use the figure below to answer Question 27.



27. **Describe** the process that causes the cloud type shown to reach heights of over 6000 m.
28. **Determine** whether the average relative humidity on a small island in the ocean would likely be higher or lower than 100 km inland on a continent.
29. **Explain** If clouds absorb only a small amount of solar radiation, how is Earth's atmosphere heated?
30. **Distinguish** between convection and conduction as methods of transferring energy in the atmosphere.
31. **Compare** the temperature and composition of the troposphere and the stratosphere.
32. **Determine** what causes precipitation to fall as rain or snow.
33. **Relate** dew point and saturation.
34. **Describe** the importance of water vapor in the atmosphere.

Think Critically

35. **CAREERS IN EARTH SCIENCE** Research information about the workday of a weather observer.
36. **Predict** how the concentration of ozone molecules would change if the concentration of oxygen molecules decreased.
37. **Infer** Using the idea that almost all weather occurs in the troposphere, infer why many airliners usually fly at altitudes of 11 km or higher.
38. **Predict** whether afternoon summertime temperatures near the beach would be warmer or cooler than temperatures farther inland. Explain.
39. **Predict** why spring is often the windiest time of the year based on your knowledge of temperature and wind.
40. **Predict** how the energy absorbed by the Arctic Ocean would change if the amount of the sea ice covering the ocean is reduced. Keep in mind that sea ice reflects more incoming solar energy than water does.
41. **Assess** which cloud type would be of most interest to a hydrologist who is concerned with possible heavy rain and flooding over large regions. Why?
42. **Analyze** why relative humidity usually decreases after the Sun rises and increases after the Sun sets.

Concept Mapping

43. Use the following terms and phrases to construct a concept map that describes the process of the water cycle: *water cycle; evaporation; condensation; precipitation; water changes from liquid to gas; water changes from gas to liquid; water falls as rain, snow, sleet, or hail.* For more help, refer to the *Skillbuilder Handbook*.

Challenge Question

44. Based on what you know about radiation and conduction, what conclusion might you make about summer temperatures in a large city compared with those in the surrounding countryside?

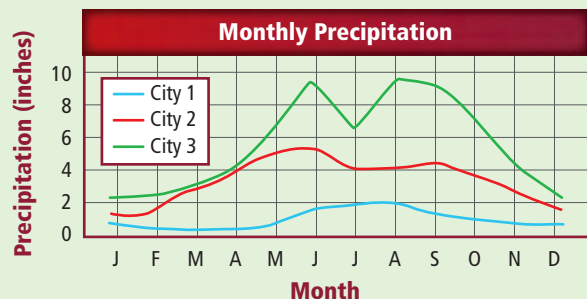
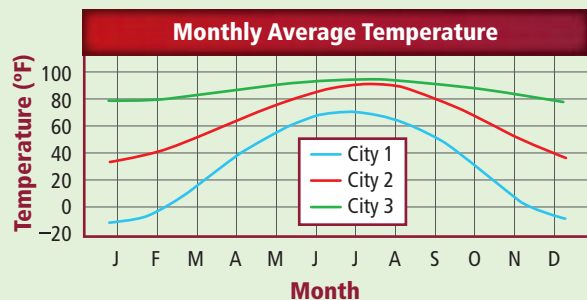
Additional Assessment

45. **WRITING in Earth Science** Write and illustrate a short story for elementary students that describes cumulonimbus cloud formation and the kinds of weather patterns they produce.

DBQ Document-Based Questions

Data obtained from: Climatological normals 1971–2000. *National Oceanographic and Atmospheric Administration, National Climatic Data Center.*

The graphs show the monthly variations in temperature and precipitation at three locations in the United States. Use the data to answer the questions below.



46. Estimate from the data which location probably receives the least annual solar radiation.
47. In which location would you expect heavy precipitation?
48. Deduce from the graphs which station probably receives the most annual snowfall.

Cumulative Review

49. Describe the properties of a contour line. (Chapter 2)
50. What process is explained by Bowen's reaction series? (Chapter 5)

Standardized Test Practice

Multiple Choice

1. What is the composition of dripstone formations?
- A. gravel
 - B. limestone
 - C. clay
 - D. sand



Use the diagram to answer Questions 2 and 3.

2. In which layer of Earth's atmosphere is air most likely warmed by conduction?
- A. troposphere
 - B. stratosphere
 - C. thermosphere
 - D. exosphere
3. Which is NOT true of ozone?
- A. It absorbs ultraviolet radiation.
 - B. Its concentration is decreasing.
 - C. It is concentrated in the atmospheric layer called the mesosphere.
 - D. It is a gas formed by the addition of one oxygen atom to an oxygen molecule.
4. Which describes the temperature of groundwater flowing through a natural spring?
- A. hotter than the region's average temperature
 - B. cooler than the region's average temperature
 - C. the same temperature no matter where the spring is located
 - D. the same temperature as the region's average temperature
5. Why do deserts experience wind erosion?
- A. There is limited rain to allow plants to grow and hold down sediment.
 - B. Saltation does not occur readily in desert areas.
 - C. The increased amount of heat increases wind patterns.
 - D. Wind can carry larger particles than water.
6. Which is NOT a significant agent of chemical weathering?
- A. oxygen
 - B. nitrogen
 - C. carbon dioxide
 - D. water

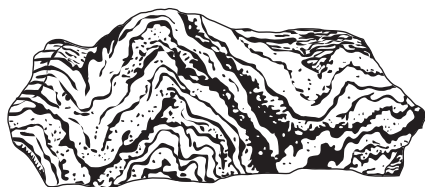
Use the table below to answer Questions 7 and 8.

Population of Unknown Organisms				
	Spring	Summer	Autumn	Winter
1995	564	14,598	25,762	127
1996	750	16,422	42,511	102
1997	365	14,106	36,562	136

7. What inference can be made based upon the data?
- A. Scientists have a hard time consistently tracking the organism.
 - B. The organism migrates yearly.
 - C. The organism is most abundant during summer and fall.
 - D. The organism should be placed on the endangered species list.
8. What would be the best graphical representation of this data?
- A. bar graph
 - B. line graph
 - C. circle graph
 - D. model
9. Which is most likely to cause orographic lifting?
- A. a sandy beach
 - B. a flowing river
 - C. a rocky mountain
 - D. a sand dune
10. Why are the lakes in Central Florida considered to have karst topography?
- A. They are depressions in the ground near caves.
 - B. They are part of a sinking stream.
 - C. They are layered with limestone.
 - D. They are sinkholes.

Short Answer

Use the illustration below to answer Questions 11–13.



11. What type of rock is shown above? What features indicate this?
12. Hypothesize how this sample of rock formed.
13. According to the rock cycle, what changes could occur in this rock? What new type of rock would be produced?
14. Describe temperature and heat.
15. Define ion and explain how an ion is formed.
16. Describe how a flood might cause residual soil to become transported soil.

Reading for Comprehension

Ozone Layer Recovery

Damage to the ozone layer, caused by chlorofluorocarbon (CFC) chemicals and other pollutants, may be starting to reverse itself, according to data collected by NASA satellites. Ozone degradation continues despite global bans on ozone-depleting pollutants. The rate has slowed enough in the upper stratosphere that scientists think ozone could start to be replenished there within several years.

Evidence suggests that international efforts to reduce chlorofluorocarbon (CFC) pollution are working. Some predictions suggest that the ozone layer will have recovered to preindustrial levels by the late twenty-first century, though total recovery could happen within 50 years.

17. According to the passage, what is the major cause of the replenishing of the ozone layer?
 - A. the ban of chlorofluorocarbons
 - B. preindustrial pollution
 - C. the upper stratosphere
 - D. NASA satellites
18. What can be inferred from this passage?
 - A. The ozone layer is recovering, but will never be fully restored.
 - B. CFC pollution is no longer occurring.
 - C. The upper stratosphere is the only layer with ozone depletion.
 - D. Ozone depletion in the upper stratosphere has slowed down.
19. According to the text, how long could it take for a full recovery of the ozone layer?
 - A. a decade
 - B. until the late twenty-first century
 - C. 50 years
 - D. several years
20. Why is it important that the ozone layer in the upper stratosphere is replenished?

NEED EXTRA HELP?

If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Review Section . . .	10.2	11.1	11.1	10.1	8.2	7.1	1.2	1.3	11.3	10.2	6.3	6.3	6.3	11.2	3.1	7.3