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 (°F) scale, used mainly in the United States, and the Celsius (°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.

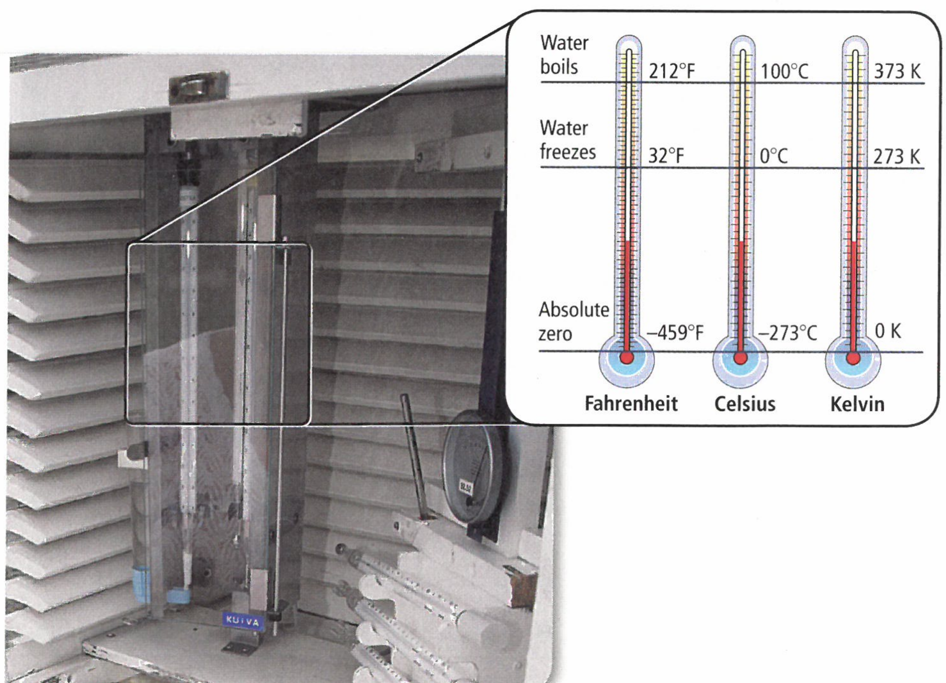


Figure 11.9 Temperature can be measured in degrees Fahrenheit, degrees Celsius, or in kelvin. The Kelvin scale starts at 0 K, which corresponds to –273°C and –459°F.

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

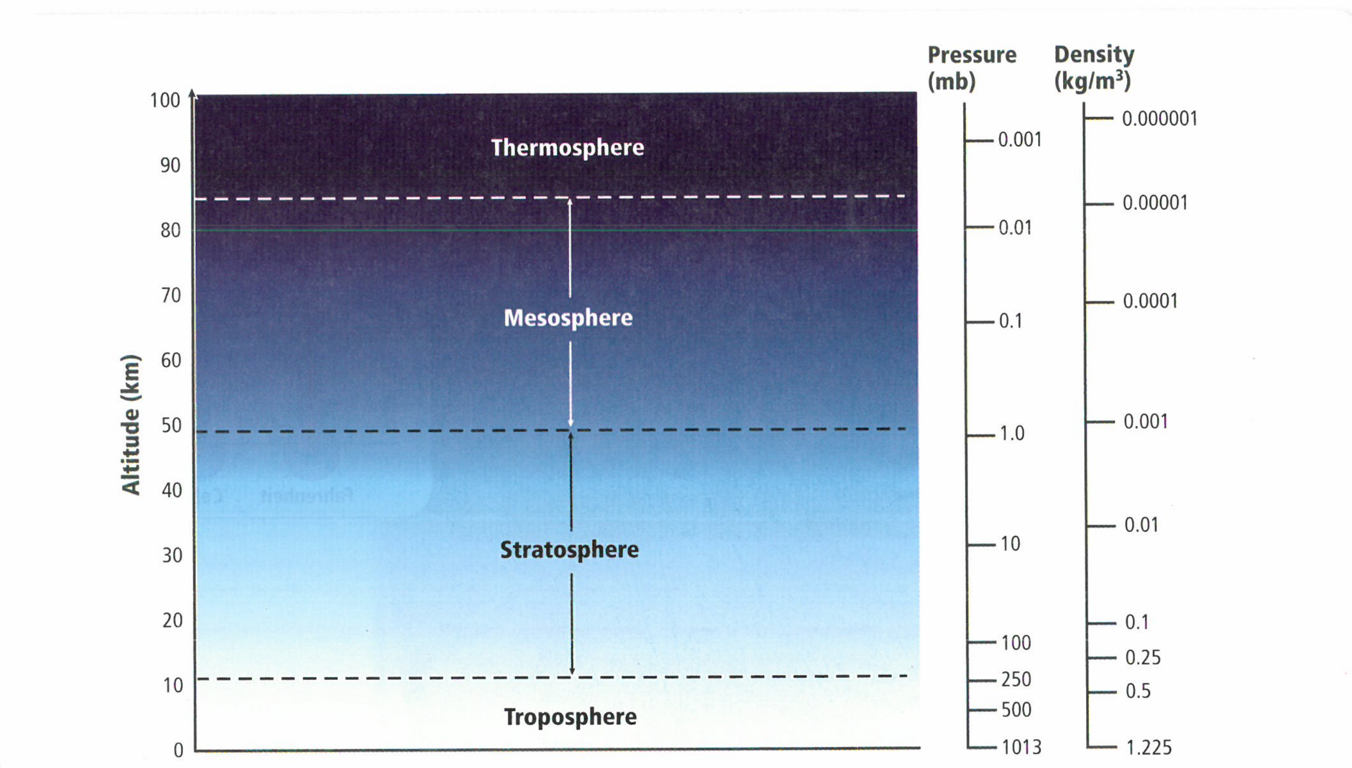
If you hold your hand out in front of you, Earth's atmosphere exerts a downward force on your hand due to the weight of the atmosphere above it. The force exerted on your hand divided by its area is the pressure exerted on your hand. Air pressure is the pressure exerted on a surface by the weight of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



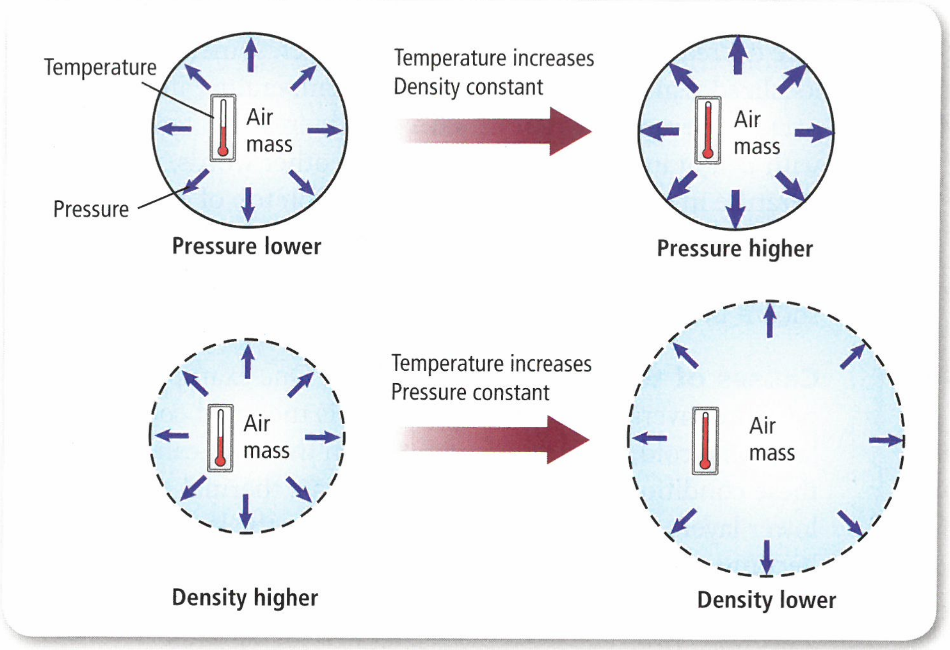


Figure 11.11 Temperature, pressure, and density are all related to one another. If temperature increases, but density is constant, the pressure increases. If the temperature increases and the pressure is constant, the density decreases.

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.

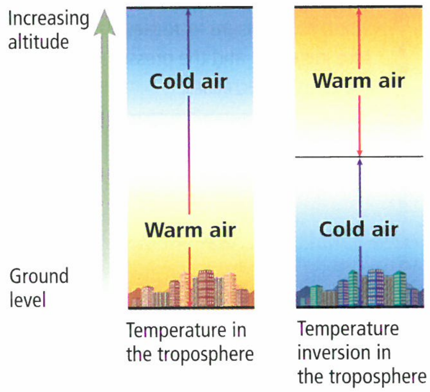
Temperature and density Heating a balloon causes the air inside to move faster, causing the balloon to expand and increase in volume. As a result, the air density inside the balloon decreases. The same is true for air masses in the atmosphere. At the same pressure, warmer air is less dense than cooler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

VOCABULARY

ACADEMIC VOCABULARY

Exert
to put forth (as strength)
Susan exerted a lot of energy playing basketball.

Temperature v. Height

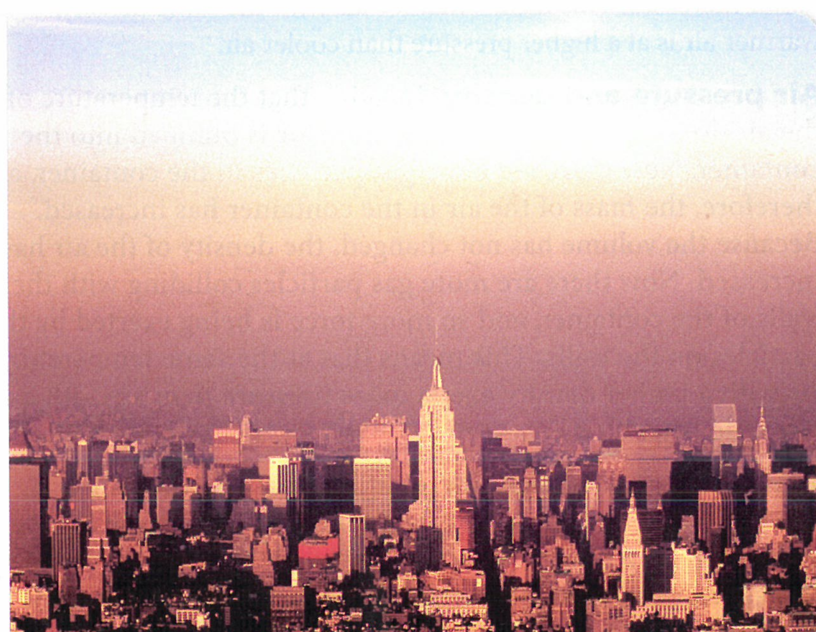


■ **Figure 11.12** In a temperature inversion, the warm air is located on top of the cooler air.

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 lowering 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.

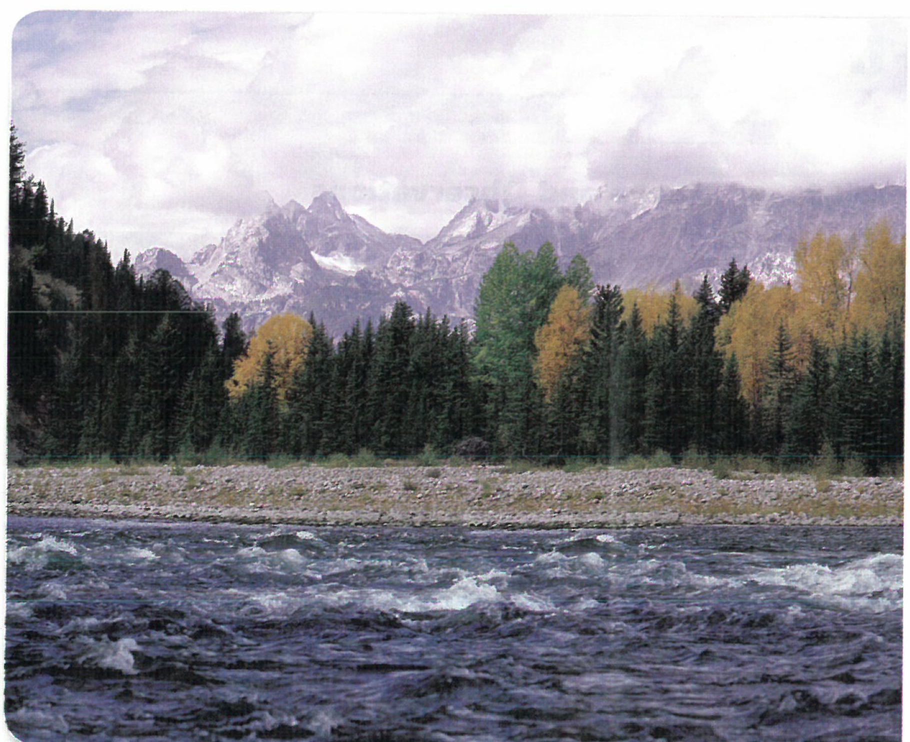


Figure 11.14 When wind blows over a forested area by a coast, it encounters more friction than when it blows over flatter terrain. This occurs because the wind encounters friction from the mountains, trees, and then the water, slowing the wind's speed.

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. 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

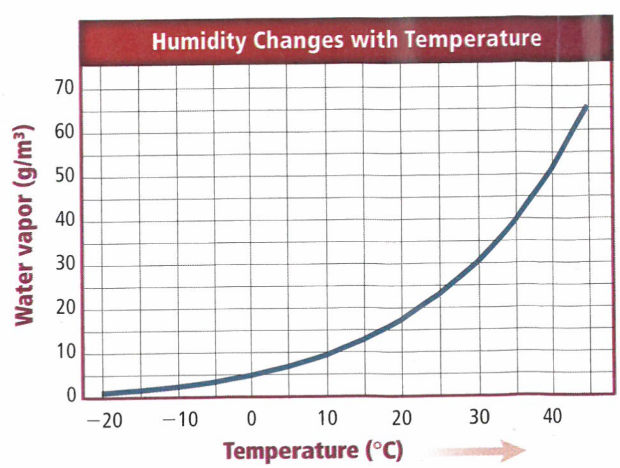
Interpret the Graph

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 name *dew point* comes from the fact that when the temperature falls to this level, dew begins to form. 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.

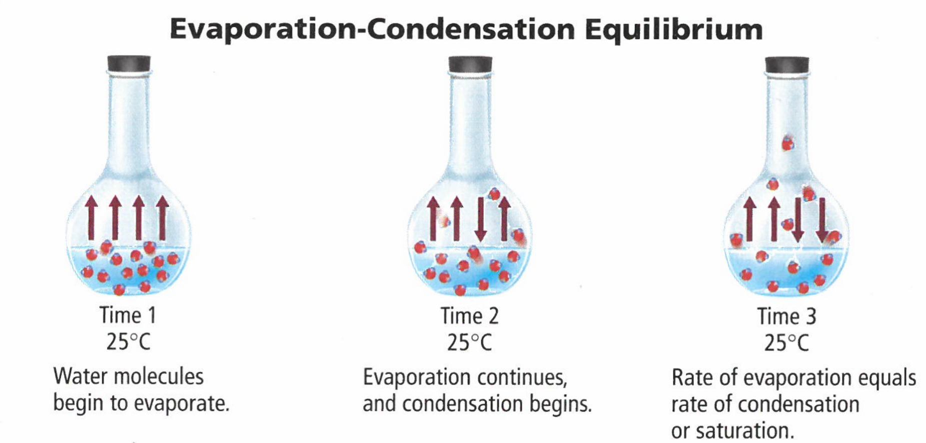
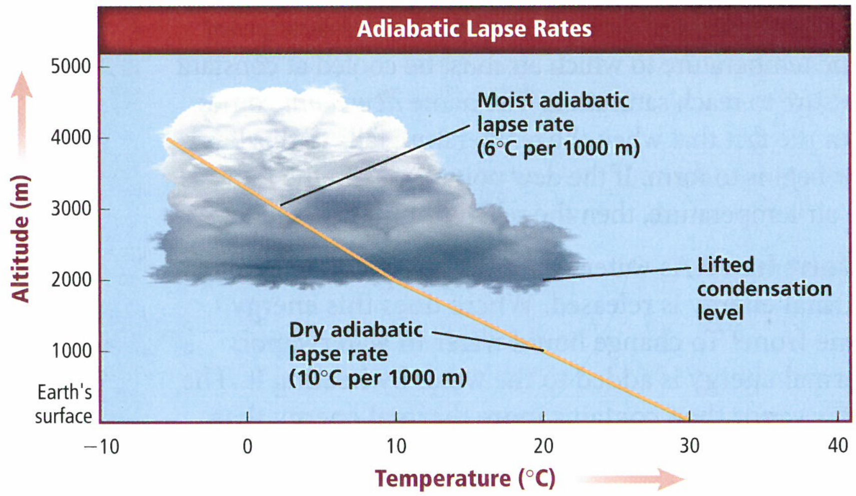


Figure 11.15 During evaporation, water molecules escape from the surface of the liquid and enter the air as water vapor. During condensation, water molecules return to the liquid state. At equilibrium, evaporation and condensation continue, but the amount of water in the air and amount of water in the 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 reach saturation. 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, as shown in **Figure 11.16,** because water vapor in the air is condensing as the air rises and is releasing latent heat.

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?

Earth Science Online **Self-Check Quiz** glencoe.com