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.

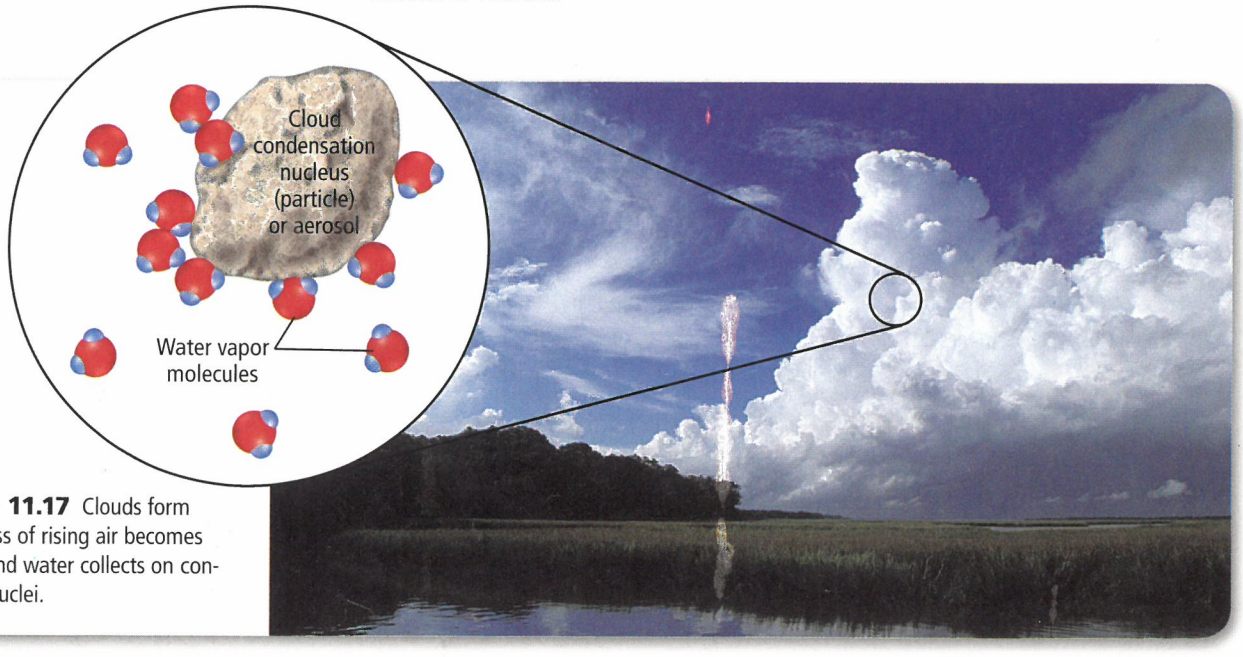


Figure 11.17 Clouds form when a mass of rising air becomes saturated and water collects on condensation nuclei.

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.

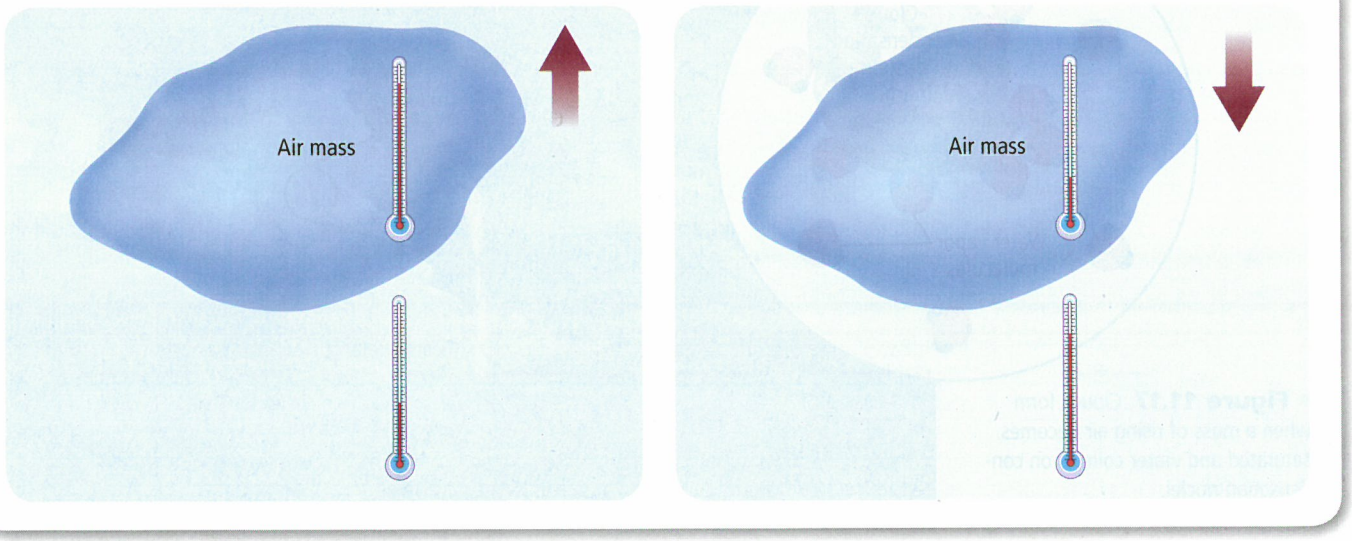
Atmospheric stability As an air mass rises, it cools. However, the air mass will continue to rise as long as it is warmer than the surrounding air. Under some conditions, an air mass that has started to rise sinks back to its original position. When this happens, the air is considered stable because 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 mass of air is greater than the temperature of the surrounding air, the air mass rises. When the temperature of the surrounding air is greater than that of the air mass, it sinks.



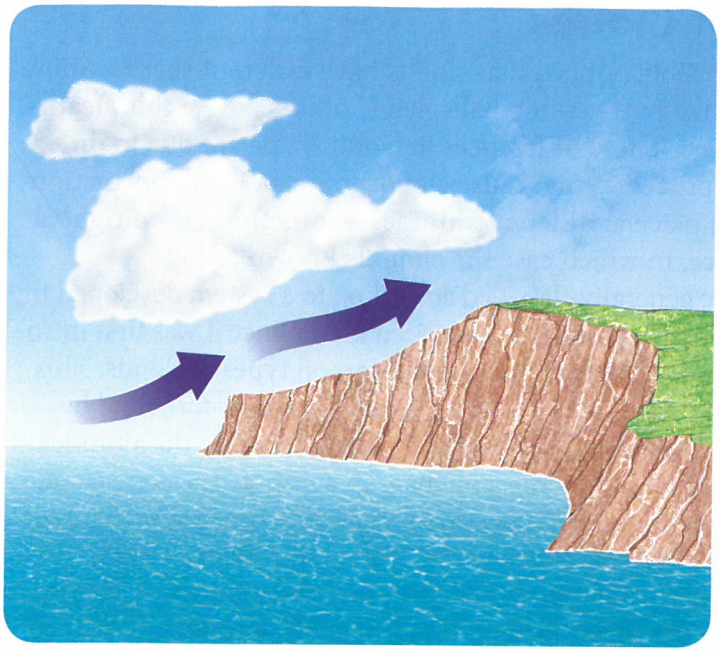


Figure 11.19 Orographic lifting occurs when warm, moist air is cooled because it is forced to rise over a mountain.

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 reaches 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 most common types of clouds. This system classifies clouds by the altitudes at which they form and by their shapes. There are three 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.

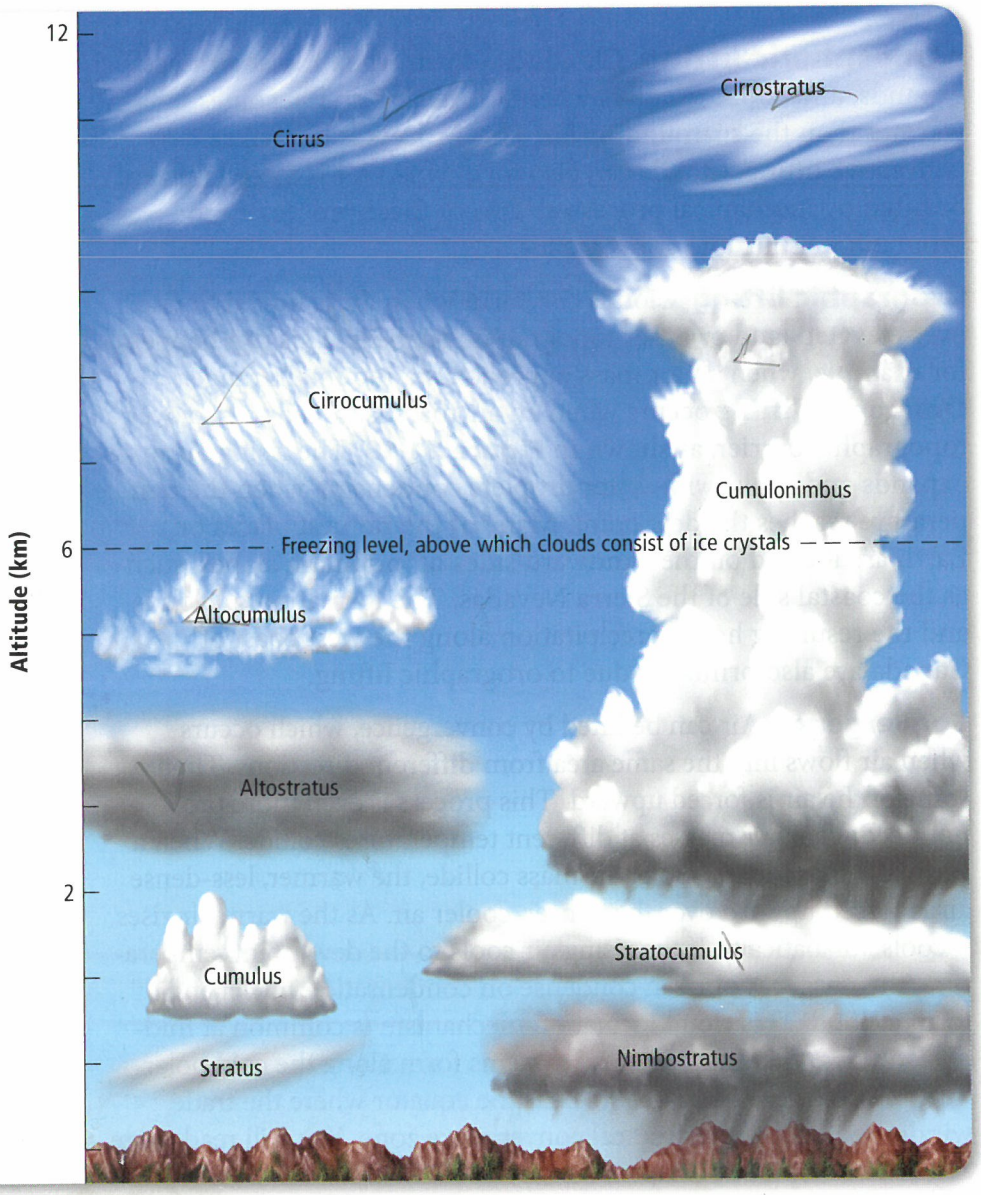


Figure 11.20 Clouds form at different altitudes and in different shapes.
Compare and contrast *cirrus and stratus clouds.*

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 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 the tropopause. Its top is then composed entirely 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.

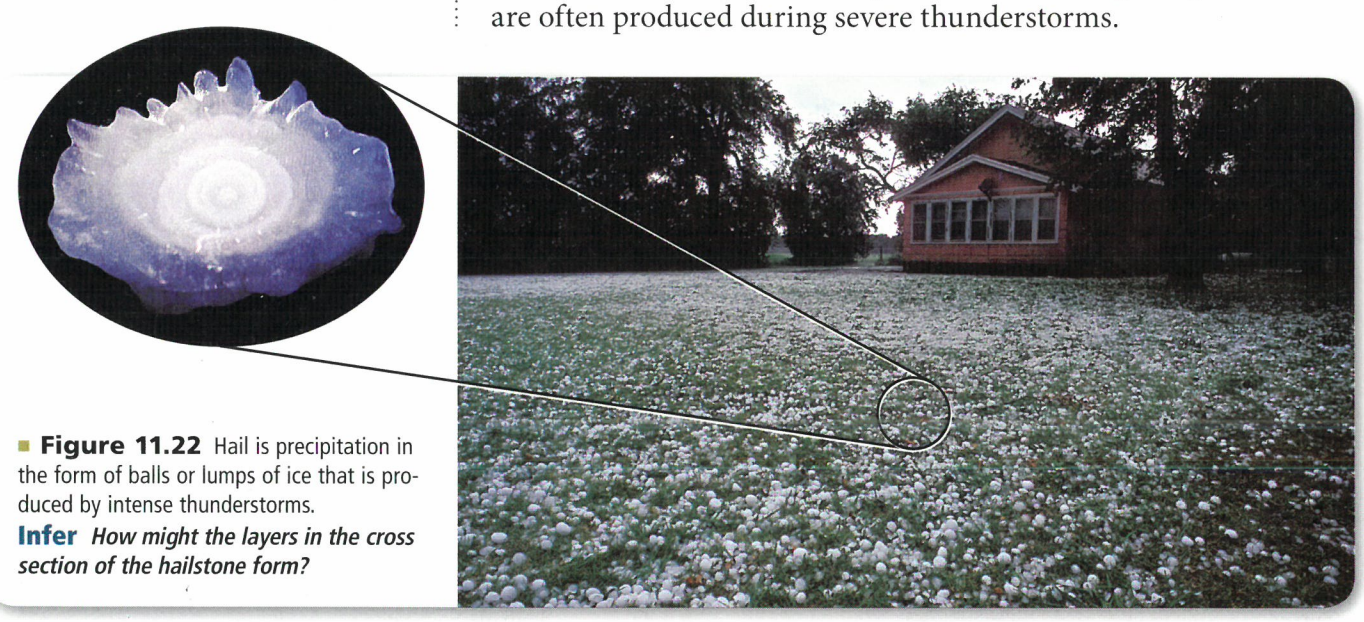


Figure 11.22 Hail is precipitation in the form of balls or lumps of ice that is produced by intense thunderstorms.
Infer *How might the layers in the cross section of the hailstone form?*

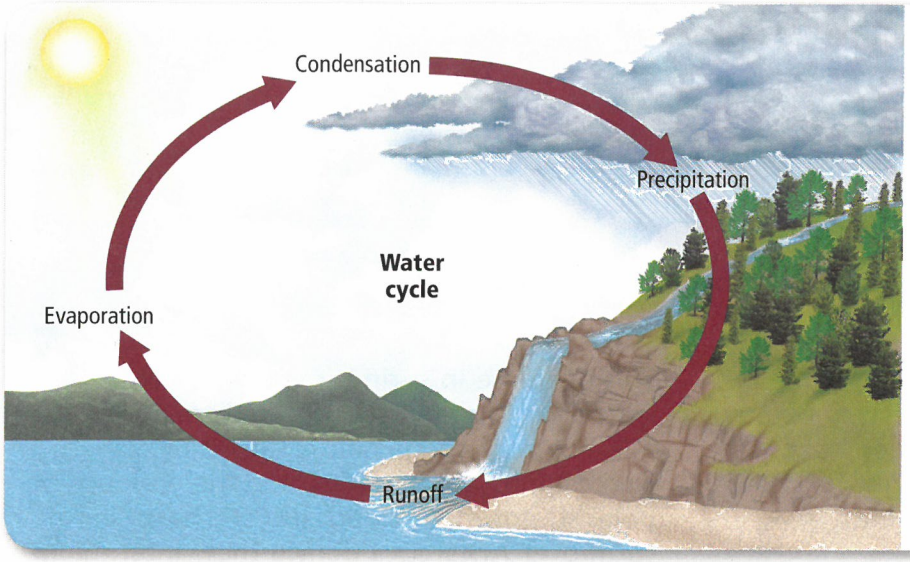


Figure 11.23 Water moves from Earth to the atmosphere and back to Earth in the water cycle.

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.