Section 18.1

1 FOCUS

Section Objectives

18.1 **Identify** the gas that is most important for understanding atmospheric processes.
18.2 **Describe** what happens during a change of state.
18.3 **Compare and contrast** the abilities of cold air and warm air to hold water vapor.
18.4 **Define** relative humidity.
18.5 **Describe** the factors that affect the relative humidity of air.

Reading Focus

Build Vocabulary L2

Word Forms Point out that the words *evaporation*, *vapor*, and *vaporization* are related. Water vapor is a gas. The words *evaporation* and *vaporization* both contain the word *vapor*, and both essentially mean the same thing: the process by which a liquid changes into a gas, or vapor.

Reading Strategy L2

Sample answers:
a. Water is important for cloud formation.
b. how clouds form
c. Clouds form when air rises, expands, and cools to the dew point.
d. Water is important for precipitation.
e. how precipitation forms
f. Precipitation forms by Bergeron or collision-coalescence processes.

18.1 Water in the Atmosphere

Reading Focus

Key Concepts

- Which gas is most important for understanding atmospheric processes?
- What happens during a change of state?
- How do warm and cold air compare in their ability to hold water vapor?
- What is relative humidity?
- What can change the relative humidity of air?

Vocabulary

- precipitation
- latent heat
- evaporation
- condensation
- sublimation
- deposition
- humidity
- saturated
- relative humidity
- dew point
- hygrometer

Reading Strategy

Monitoring Your Understanding Before you read, copy the table. List what you know about water in the atmosphere and what you would like to learn. After you read, list what you have learned.

What I Know	What I Would Like to Learn	What I Have Learned
a. ?	b. ?	c. ?
d. ?	e. ?	f. ?

Figure 1 This downpour shows how precipitation can affect daily activities.

As you observe day-to-day weather changes, you can see the powerful role of water in the air. Water vapor is the source of all condensation and **precipitation,** which is any form of water that falls from a cloud. Look at Figure 1. Clouds and fog, as well as rain, snow, sleet, and hail, are examples of some of the more noticeable weather conditions. **When it comes to understanding atmospheric processes, water vapor is the most important gas in the atmosphere.** Water vapor makes up only a small fraction of the gases in the atmosphere, varying from nearly 0 to about 4 percent by volume. But the importance of water in the air greatly exceeds what these small percentages would indicate.

Water's Changes of State

The three states of matter are solid, liquid, and gas. Water can change from one state of matter to another—at temperatures and pressures experienced on Earth. This unique property allows water to freely leave the oceans as a gas and return again as a liquid, producing the water cycle. All water in the cycle must pass through the atmosphere as water vapor, even though the atmosphere only holds enough to make a global layer about 2 mm deep.

Reading Checkpoint *What is the range in volume percent of water in the atmosphere?*

504 *Chapter 18*

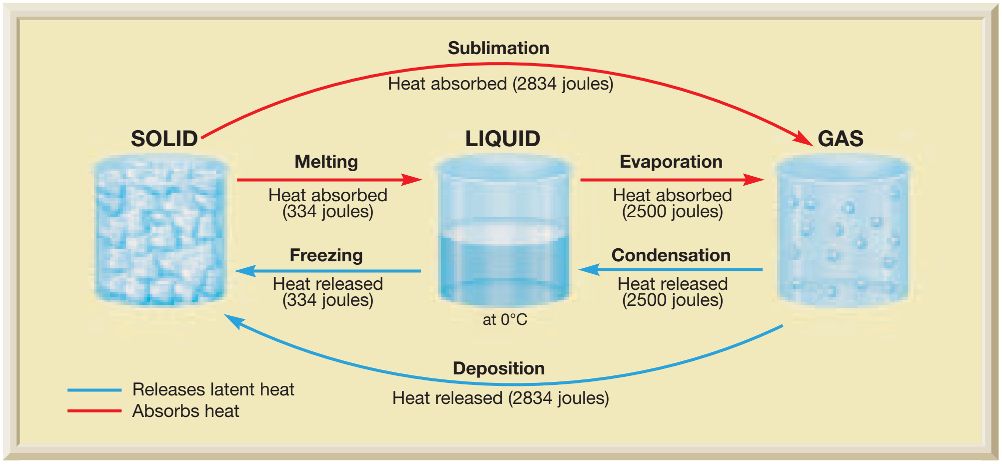


Figure 2 Changes of State The heat energy, in joules, is indicated for 1 gram of water.

Solid to Liquid

The process of changing state requires that energy is transferred in the form of heat. When heat is transferred to a glass of ice water, the temperature of the ice water remains a constant 0°C until all the ice has melted. If adding heat does not raise the temperature, then where does this energy go? In this case, the added heat breaks apart the crystal structure of the ice cubes. The bonds between water molecules in the ice crystals are broken forming the noncrystalline substance liquid water. You know this process as melting.

The heat used to melt ice does not produce a temperature change, so it is referred to as **latent heat.** *Latent* means "hidden," like the latent fingerprints hidden at a crime scene. This energy, measured in joules or calories, becomes stored in the liquid water and is not released as heat until the liquid returns to the solid state.

Latent heat plays a crucial role in many atmospheric processes. For example, the release of latent heat aids in forming the towering clouds often seen on warm summer days. It is the major source of energy for thunderstorms, tornadoes, and hurricanes.

Liquid to Gas

The process of changing a liquid to a gas is called **evaporation.** You see in Figure 2 that it takes approximately 2500 joules of energy to convert 1 gram of liquid water to water vapor. The energy absorbed by the water molecules during evaporation gives them the motion needed to escape the surface of the liquid and become a gas. This energy is referred to as latent heat of vaporization.

You might have experienced a cooling effect when stepping dripping wet from a swimming pool or bathtub. This cooling results because it takes considerable energy to evaporate water. In this situation, the energy comes from your skin—hence the expression that "evaporation is a cooling process."

Customize for English Language Learners

Use a Cloze strategy for students with very limited English proficiency. Have students fill in the blanks in the following sentences while reading Water's Changes of State. **The three states of matter are ________, liquid, and ________. Changing state requires that ________ be absorbed or ________. The heat used to melt ice is ________ heat. The process of changing from liquid to gas is ________. The change from water vapor to liquid is ________. The conversion of a solid directly to a gas is ________.** *(gas, solid, energy, released, latent, evaporation, condensation, sublimation)*

2 INSTRUCT

Water's Changes of State

Integrate Biology L2

The Water Cycle Tell students that the water cycle is essential to life on land. Water evaporates from the oceans and from the leaves of plants. Some of the water vapor condenses and falls as precipitation over land. As the precipitation runs over the land back to the oceans, it is drunk by animals and absorbed by plants through their roots. Ask: **What would happen if water evaporated and condensed at temperatures not found on Earth's surface?** *(The water cycle would not exist.)* **What effect would this have on life on Earth?** *(Life would not be able to survive on land.)*
Logical

Use Visuals L1

Figure 2 Review the meaning of joules with students. Use this diagram to explain how water changes from one state to another. Ask: **Which processes absorb heat?** *(melting, evaporation, and sublimation)* **Which processes release heat?** *(freezing, condensation, and deposition)* **Give an everyday example of one of the processes shown.** *(Sample answers include ice cubes freezing in a freezer and water boiling in a pot on the stove.)*
Visual, Logical

Integrate Biology L2

Perspiration Tell students that the body cools itself by producing perspiration, or sweat. Sweat is mostly water. Ask: **How does perspiration cool the body?** *(As water evaporates, it absorbs heat from the skin.)* **Why do you think perspiration cools the body more effectively when the air is dry?** *(The water evaporates more easily when there is less water vapor already in the air.)*
Logical

Answer to . . .

Reading Checkpoint *Atmosphere is nearly 0 to about 4 percent water by volume.*

Moisture, Clouds, and Precipitation 505

Section 18.1 (continued)

Humidity

Address Misconceptions L2

Students may think that condensation occurs when air turns into a liquid. Emphasize that condensation consists of water droplets, and that water vapor is only a small part of air. The remaining components of air remain as gases. Have students draw diagrams of molecules to represent the main gases in air and draw an arrow from a water molecule to a drawing of a water droplet.
Logical, Visual

Address Misconceptions L2

Students may be somewhat mislead by the phrase "amount of water vapor air can hold" in the text. Explain that while this is a convenient phrase, air does not actually "hold" water the way a sponge does. Water vapor evaporates and condenses in response to changes in temperature independently of the gases in air. In fact, it would do so even if those other gases were not present.
Logical

The opposite process where water vapor changes to the liquid state is called **condensation.** In the atmosphere, condensation generates clouds and fog. For condensation to occur, water molecules must release their stored heat energy, called latent heat of condensation, equal to what was absorbed during evaporation. This released energy plays an important role in producing violent weather and can transfer great quantities of heat from tropical oceans toward the poles.

Solid to Gas Water also can be transformed from a solid to a vapor state. **Sublimation** is the conversion of a solid directly to a gas, without passing through the liquid state. You may have observed this change in watching the sublimation of dry ice, or frozen carbon dioxide. Dry ice sometimes is used to generate "smoke" in theatrical productions. **Deposition** is the reverse process, the conversion of a vapor directly to a solid. This change happens when water vapor is deposited as frost on cold objects such as grass or windows.

Humidity

The general term for the amount of water vapor in air is **humidity.** Meteorologists use several methods to express the water-vapor content of the air. These include relative humidity and dew-point temperature.

Table 1 Water Vapor Needed for Saturation

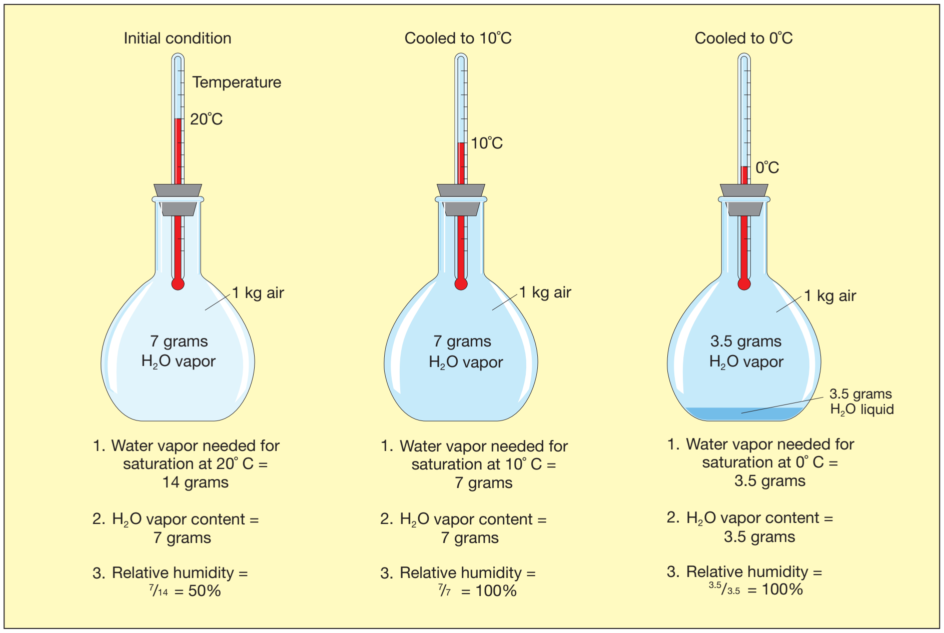
Temperature		Water Vapor Content at Saturation (g/kg)
°C	(°F)	
−40	(−40)	0.1
−30	(−22)	0.3
−20	(−4)	0.75
−10	(14)	2
0	(32)	3.5
5	(41)	5
10	(50)	7
15	(59)	10
20	(68)	14
25	(77)	20
30	(86)	26.5
35	(95)	35
40	(104)	47

Saturation Imagine a closed jar half full of water and half full of dry air. As the water begins to evaporate from the water surface, a small increase in pressure can be detected in the air above. This increase is the result of the motion of the water-vapor molecules that were added to the air through evaporation. As more and more molecules escape from the water surface, the pressure in the air above increases steadily. This forces more and more water molecules to return to the liquid. Eventually, the number of vapor molecules returning to the surface will balance the number leaving. At that point, the air is said to be **saturated.** The amount of water vapor required for saturation depends on temperature as shown in Table 1. **When saturated, warm air contains more water vapor than saturated cold air.**

Relative Humidity The most familiar and most misunderstood term used to describe the moisture content of air is relative humidity. **Relative humidity is a ratio of the air's actual water-vapor content compared with the amount of water vapor air can hold at that temperature and pressure.** Relative humidity indicates how near the air is to saturation, rather than the actual quantity of water vapor in the air.

Facts and Figures

Freezer burn is a term used to describe the dried-out appearance of food that has been left in a frost-free freezer for long periods of time. Frost-free freezers circulate fairly dry air. This causes ice on the freezer walls to sublimate and be removed by the circulating air. This process, however, also removes moisture from frozen foods that are not in airtight containers. Over a few months, these foods dry out rather than actually burn.



Relative humidity can be changed in two ways. First, it can be changed by adding or removing water vapor. In nature, moisture is added to air mainly by evaporation from the oceans and smaller bodies of water.

Second, because the amount of moisture needed for saturation depends on temperature, relative humidity varies with temperature. Notice in Figure 3 that when the flask is cooled from 20°C to 10°C, the relative humidity increases from 50 to 100 percent. However, once the air is saturated, further cooling does not change the relative humidity. Further cooling causes condensation, which keeps the air at its saturation level for the temperature. When air far above Earth's surface is cooled below its saturation level, some of the water vapor condenses to form clouds. Because clouds are made of liquid droplets, this moisture is no longer part of the water-vapor content of the air. **To summarize, when the water-vapor content of air remains constant, lowering air temperature causes an increase in relative humidity, and raising air temperature causes a decrease in relative humidity.**

Figure 3 Relative humidity varies with temperature.

Go Online SCILINKS NSTA

For: Links on atmospheric moisture
Visit: www.SciLinks.org
Web Code: cjn-6181

Build Reading Literacy L1

Refer to **p. 502D**, which provides the guidelines for visualizing.

Visualize Tell students that forming a mental image of concepts they are learning helps them remember new concepts. After students have read about saturation and relative humidity, have them visualize the individual water molecules moving from the surface of the water into the air and back into the water. Then encourage students to draw diagrams that demonstrate the differences among these three types of bonds.
Visual

Teacher Demo

Water From Plants L2

Purpose Students will observe transpiration from plants and condensation of water.

Materials small potted house plant, clear plastic bag

Procedure Cover the plant with the plastic bag, and leave it in a sunny spot for about 15 minutes. Then have students observe the inside of the bag. Ask students what they see on the inside of the bag. *(droplets of water)* Then ask where the water came from. *(It came from the plant's leaves.)* Explain that the release of water by plants is called transpiration. Ask what process formed the droplets on the inside of the bag. *(condensation)*

Expected Outcome Droplets of water will form on the inside of the bag.
Visual, Logical

Go Online NSTA SCILINKS

Download a worksheet on atmospheric moisture for students to complete, and find additional teacher support from NSTA SciLinks.

Build Science Skills

L2

Measuring Have students work in small groups to build hair hygrometers as follows. Wash a long human hair. Tie or tape one end of the hair to a ring stand or other support. Tie or tape a small washer or button to the other end of the hair so it hangs about 4 cm off the table. Tape or glue a toothpick vertically to the washer or button. Tape an index card to the side of a small cardboard box and place it behind the toothpick. As humidity changes, the hair will stretch or contract. Students can calibrate the hair hygrometer according to weather reports or readings from a psychrometer.
Visual, Logical

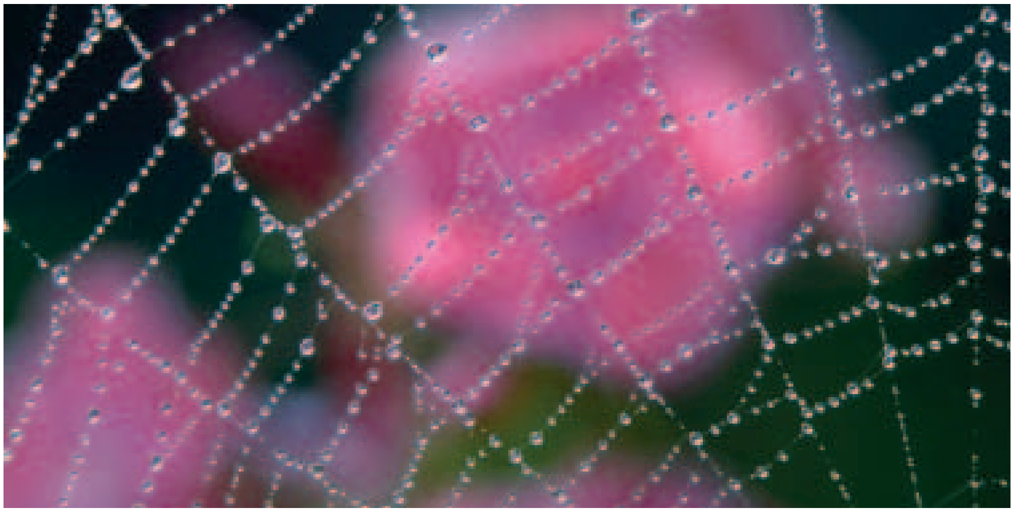


Figure 4 Dew on a Spider Web

Dew Point Another important measure of humidity is the dew-point temperature. The dew-point temperature or simply the **dew point** is the temperature to which a parcel of air would need to be cooled to reach saturation. If the same air was cooled further, the air's excess water vapor would condense, typically as dew, fog, or clouds. During evening hours, objects near the ground often cool below the dew-point temperature and become coated with water. This is known as dew, shown on the spider web in Figure 4.

For every 10°C increase in temperature, the amount of water vapor needed for saturation doubles. Therefore, relatively cold saturated air at 0°C contains about half the water vapor of saturated air at a temperature of 10°C, and roughly one-fourth that of hot saturated air with a temperature of 20°C as shown in Table 1 on page 506. Because the dew point is the temperature at which saturation occurs, high dew-point temperatures indicate moist air, and low dew-point temperatures indicate dry air.

Figure 5 Sling Psychrometer This psychrometer is used to measure both relative humidity and dew point.
Interpreting Photographs ***Identify the wet bulb and the dry bulb in this photograph.***

Measuring Humidity Relative humidity is commonly measured by using a **hygrometer.** One type of hygrometer, called a psychrometer, consists of two identical thermometers mounted side by side. See Figure 5. One thermometer, the dry-bulb thermometer, gives the present air temperature. The other, called the wet-bulb thermometer, has a thin cloth wick tied around the end.

To use the psychrometer, the cloth wick is saturated with water and air is continuously passed over the wick. This is done either by swinging the instrument freely in the air or by fanning air past it. Water evaporates from the wick, and the heat absorbed by the evaporating water makes the temperature of the wet bulb drop. The loss of heat that was required to evaporate water from the wet bulb lowers the thermometer reading. This temperature is referred to as the wet-bulb temperature.

Facts and Figures

You may have noticed that dew often forms on grass. The reason for this is that grass releases water vapor in a process called transpiration. On calm nights, this causes the relative humidity of the air near the grass to be much higher than the relative humidity of the air even a few inches above the surface. As a result, dew forms on grass before it does on most other objects.

The amount of cooling that takes place is directly proportional to the dryness of the air. The drier the air, the more moisture evaporates, and the lower is the temperature of the wet bulb. The larger the difference is between temperatures observed on the thermometers, the lower the relative humidity. If the air is saturated, no evaporation will occur, and the two thermometers will have identical readings. To determine the precise relative humidity and to calculate the dew point, standard tables are used.

A sling psychrometer would not be all that useful in a weather balloon used to monitor conditions in the upper atmosphere. A different type of hygrometer is used in instrument packages that transmit data back to a station on the ground. The electric hygrometer contains an electrical conductor coated with a chemical that absorbs moisture. The passage of current varies with the amount of moisture absorbed.

Q&A

Q *Why is the air in buildings so dry in the winter?*

A If the water-vapor content of air stays constant, an increase in temperature lowers the relative humidity, and a drop in temperature raises the relative humidity. During winter months, outside air is comparatively cold. When this air is drawn into a building, it is heated to room temperature. This causes the relative humidity to drop, often to uncomfortably low levels of 10 percent or lower. Living with dry air can mean static electrical shocks, dry skin, sinus headaches, or even nosebleeds.

Section 18.1 Assessment

Reviewing Concepts

1. What is the most important gas for understanding atmospheric processes?
2. What happens to heat during a change of state?
3. How does the temperature of air influence its ability to hold water?
4. What does relative humidity describe about air?
5. List two ways that relative humidity can be changed.
6. What does a low dew point indicate about the moisture content of air?

Critical Thinking

7. **Interpreting Illustrations** Study Figure 2. For 1 gram of water, how do the energy requirements for melting and evaporation compare?

Math Practice

8. The air over Fort Myers, Florida, has a dew point of 25°C. Fort Myers has twice the water vapor content of the air over St. Louis, Missouri, and four times the water vapor content as air over Tucson, Arizona. Determine the dew points for St. Louis and Tucson.

Use Community Resources L2

Invite a meteorologist to the class to discuss relative humidity and other weather factors. Ask students to prepare questions in advance to ask the visitor.
Interpersonal

3 ASSESS

Evaluate Understanding L2

Ask students to describe at least three changes of state and explain whether heat is absorbed or released during each change. For each change of state, students should name the process and describe the type of change. For example, for sublimation, students would indicate that the phase change is from solid to gas.

Reteach L1

Use Figure 3 to review the concept of relative humidity. Make sure to emphasize the difference between humidity and relative humidity. Ask: **How does lowering air temperature affect relative humidity?** *(It increases relative humidity.)* **How does raising air temperature affect relative humidity?** *(It decreases relative humidity.)*

Math Practice

Solutions
8. St. Louis dew point: 15°C; Tucson dew point: 5°C

Section 18.1 Assessment

1. Water vapor is the most important.
2. Heat is absorbed or released, depending on the change of state.
3. When saturated, warm air contains more water vapor than cold air.
4. Relative humidity describes how near the air is to being saturated.
5. Relative humidity can be changed by adding or removing water vapor or by changing temperature.
6. The air is dry.
7. More energy is required for evaporation to occur than for melting to occur. About 7.5 times more energy is required for evaporation.

Answer to . . .

Figure 5 *The wet-bulb thermometer is on the left. The dry-bulb thermometer is on the right.*