15.1 What is weather?

Science Words

weather
humidity
relative humidity
saturated
dew point
fog
precipitation

Objectives

- Explain the role of water vapor in the atmosphere and how it affects weather.
- Describe how clouds form and how they are classified.
- Compare the development of rain, hail, sleet, and snow.

Factors of Weather

"What's the weather going to be today?" That's probably one of the first things you ask when you get up. Weather information can affect what you wear to school, how you get to and from school, and what you do after school.

Everyone discusses the weather. Can you explain what it is? **Weather** refers to the present state of the atmosphere and describes current conditions. One kind of weather is seen in **Figure 15-1.** Important factors determining the state of the atmosphere are air pressure, wind, temperature, and the amount of moisture in the air.

In Chapter 14, you learned about air pressure and how water moves around the hydrosphere in the water cycle. In the water cycle, the sun provides the energy to evaporate water into the atmosphere, where it forms clouds and eventually falls back to Earth.

The water cycle forms the basis of our weather. But the sun does more than just evaporate water. It also heats air, causing the winds that you learned about in Chapter 14. The interaction of air, water, and the sun causes weather.

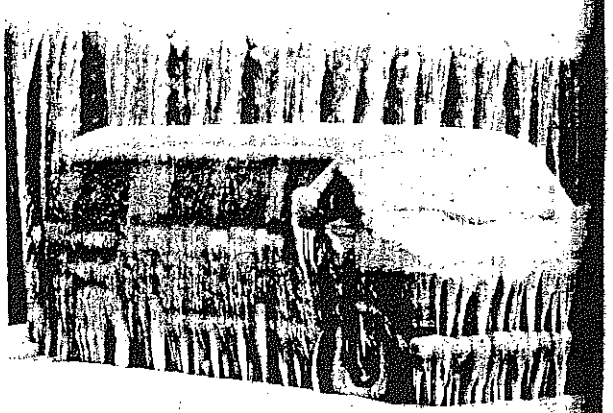


Figure 15-1
The weather influences what you can do.

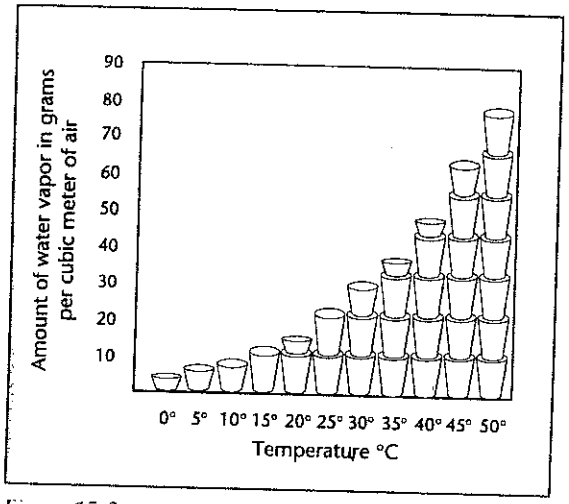


Figure 15-2
This graph shows that as the temperature of air increases, air can hold more water vapor.

Humidity

The sun evaporates water into the atmosphere. How does this happen? How can the atmosphere hold water? The air of the atmosphere is somewhat like a sponge. The holes in a sponge enable it to hold water. The atmosphere holds water in a similar way. Water vapor molecules fit into spaces between the molecules that make up air. The amount of water vapor held in air is called **humidity.**

Humidity varies from day to day because the temperature of the air changes. The amount of water vapor that air can hold depends on the temperature. At cooler temperatures, molecules in air move more slowly. This slow movement in cool air allows water vapor molecules to join together (condense). At warmer temperatures, air and water vapor molecules move too quickly to join together. The higher energy of the molecules in warm air prevents condensation and allows more water molecules to remain as water vapor than in cooler air. If you look at **Figure 15-2,** you'll see that at 25°C, a cubic meter of air can hold a maximum of 22 g of water vapor. The same air cooled to 15°C can hold only about 13 g of water vapor.

On hot summer days when the air seems damp and sticky, people often comment on the high humidity. When they mention humidity, they are actually talking about the relative humidity.

CONNECT TO LIFE SCIENCE

Birds and mammals maintain a constant internal temperature. When the temperature outside the bodies of birds and mammals changes, their body temperature is regulated to remain fairly constant. On the other hand, the internal temperature of fish and reptiles changes when the temperature around them changes. ***Infer*** from this which group is more likely to survive a quick change in the weather.

When the air next to the glass cools to its dew point, condensation forms on the glass.

Relative Humidity

Have you ever heard a weather forecaster speak of relative humidity? **Relative humidity** is a measure of the amount of water vapor that air is holding compared to the amount it can hold at a specific temperature. When air contains as much moisture as possible at a specific temperature, it is **saturated.** If you hear a weather forecaster say the relative humidity is 50 percent, that means the air on that day contains 50 percent of the water needed for the air to be saturated.

As shown in **Figure 15-2,** air at 40°C is saturated when it contains about 50 g of water vapor per cubic meter of air. Air at 25°C is saturated when it contains 22 g of water vapor per cubic meter of air. If air at 25°C contains only 11 g of water vapor in each cubic meter of air, the relative humidity is 50 percent. Saturated air has relative humidity of 100 percent.

Additional water vapor in saturated air will condense back to a liquid or freeze, depending on the temperature. The temperature at which air is saturated and condensation takes place is the **dew point.** The dew point changes with the amount of moisture in the air.

You've probably seen water droplets form on the outside of a glass of cold milk, as in **Figure 15-3.** The cold glass cooled the air next to it to its dew point. The water vapor in the air condensed and formed water droplets on the glass. Dew on grass in the early morning forms the same way. When air near the ground is cooled to its dew point, water vapor condenses and forms droplets on the grass.

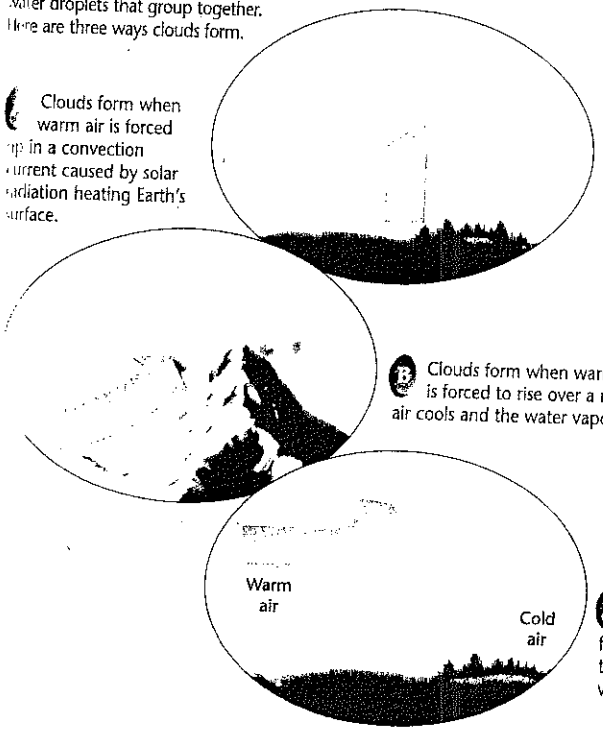
Weather affects history. Research what happened to American colonial troops at Valley Forge during the War of Independence in the winter of 1777–1778. Imagine that you were a soldier at Valley Forge during that winter. In your Science Journal, describe your experiences.

Why are there clouds in the sky? Clouds form as warm air is forced upward, expands, and cools, as shown in **Figure 15-4.** As the air cools, the amount of water vapor needed for saturation decreases and the relative humidity increases. When the relative humidity reaches 100 percent, the air is saturated. Water vapor begins to condense in tiny drops around nuclei, small particles of dust, salt, and smoke in the atmosphere. These drops of water are so small they become suspended in the air. When millions of these drops collect, a cloud forms.

As you will see in **Figure 15-5** on page 426, there are many different types of clouds in the sky. Clouds are classified mainly by shape and height. Some clouds stack up vertically, reaching high into the sky, while others are low and flat. Some dense clouds bring rain or snow, while thin clouds appear on mostly sunny days.

The three main cloud types are stratus, cumulus, and cirrus. Stratus clouds form layers or smooth, even sheets in the sky. When layers of air cool below their dew point temperatures, stratus clouds appear. Stratus clouds usually form at low altitudes. Stratus clouds are associated with both fair weather and precipitation; sometimes they form a dull, gray blanket that hangs low in the sky and brings drizzle. When air is cooled to its dew point and condenses near the ground, it forms a stratus cloud called **fog. Figure 15-7** on page 430 shows a stratus cloud fog in San Francisco.

Clouds form when moist air is pushed high enough to reach its dew point. The water vapor condenses, forming water droplets that group together. Here are three ways clouds form.



A Clouds form when warm air is forced up in a convection current caused by solar radiation heating Earth's surface.

B Clouds form when warm, moist air is forced to rise over a mountain. The air cools and the water vapor condenses.

C Clouds form when two air masses meet. Warmer air is forced up over the cold air. As the warm air cools, the water vapor in it condenses.

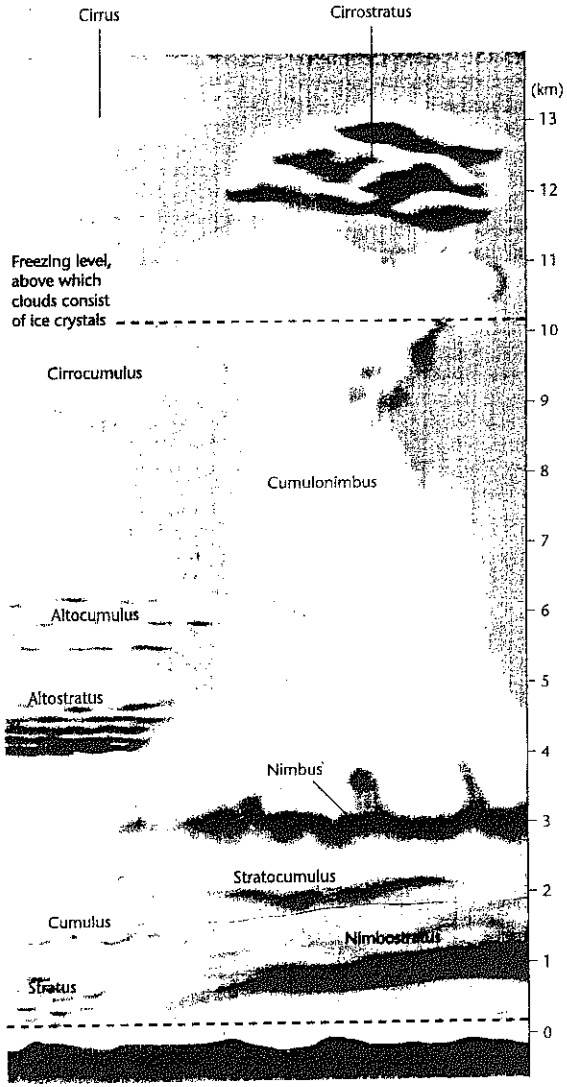
How can dew point be determined?

Procedure

1. Partially fill a metal can with room-temperature water. Dry the outer surface of the can.
2. Slowly stir the water and add small amounts of ice.
3. In a data table in your Science Journal, note the exact water temperature at which a thin film of moisture first begins to form on the outside of the metal can.
4. Repeat steps 1-3 two more times.
5. The average of the three temperatures at which the moisture begins to appear is the dew point temperature of the air around the container.

Analysis

1. What factors determine the dew point temperature?
2. Will a change in air temperature also cause the dew point temperature to change? Explain.



These are the most common types of clouds. *What do you think causes them to have different shapes?*

Cumulus clouds are masses of puffy, white clouds, often with flat bases. Some people refer to them as cauliflower clouds. They form when air currents rise. They may tower to great heights and can be associated with both fair weather and thunderstorms.

Cirrus clouds appear fibrous or curly. They are high, thin, white, feathery clouds containing ice crystals. Cirrus clouds are associated with fair weather, but they may indicate approaching storms.

Height

Some prefixes of cloud names describe the height of the cloud base. The prefix *cirro-* describes high clouds—clouds with a base starting above 6000 m; *alto-* describes middle elevation clouds—their base is between 2000 to 6000 m; and *strato-* refers to clouds below 2000 m. Some clouds' names combine the altitude prefix with the term *stratus* or *cumulus*.

Cirrostratus clouds are high clouds that look like fine veils. They are made of ice crystals that appear to form halos around the moon or sun. Usually cirrostratus clouds indicate fair weather, but they may also signal an approaching storm.

Altostratus clouds form at middle levels. They look like thick veils or sheets of gray or blue. If the clouds are not too thick, sunlight can filter through them. They produce light, continuous precipitation.

Rain Capacity

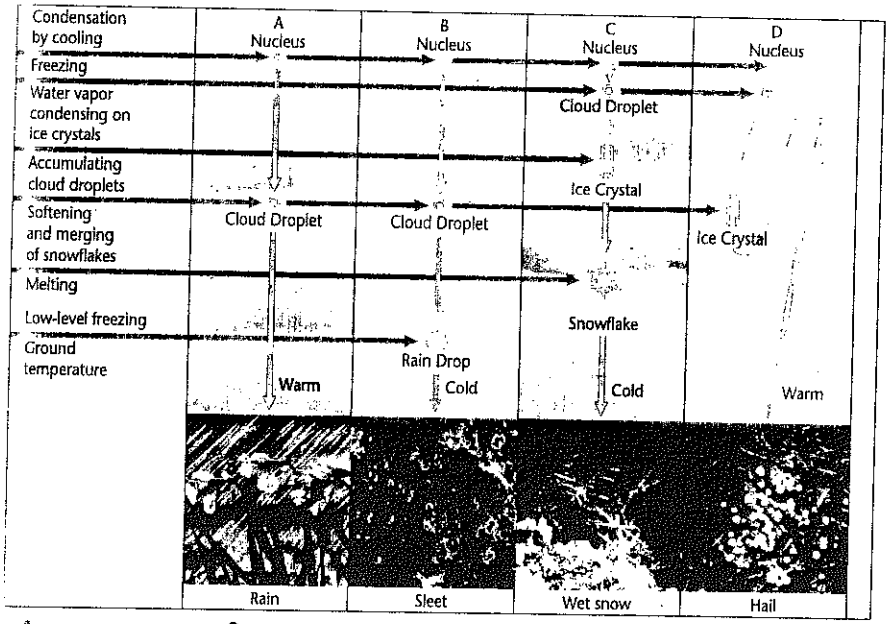
Nimbus clouds are dark clouds associated with precipitation. They are so full of water that no sunlight penetrates them. When a nimbus cloud is also a towering cumulus cloud, it is called a cumulonimbus cloud. Some cumulonimbus clouds grow huge, starting near Earth's surface and towering to nearly 18 000 m. Sudden, gigantic thunderstorms can be unleashed from them.

Nimbostratus clouds bring long, steady rain. They often have streaks that extend to the ground.

As long as the water drops in a cloud remain small, they stay suspended in the air. But when the water droplets combine and reach the size of 0.2 mm, they become too heavy and fall out of suspension in the cloud.

Figure 15-6

When water vapor in air collects on nuclei to form water droplets, the type of precipitation that is received on the ground depends on the temperature of the air.



A When the air near the ground is warm, water vapor forms raindrops that fall as rain.

B When the air near the ground is cold, sleet, made up of many small ice pellets, falls.

C When the air is very cold, water vapor forms snowflakes.

D Hailstones are pellets of ice that form as the ice nuclei go up and down in the cloud.

Problem Solving

Suppose you decide to make some spaghetti for lunch. You fill a large pot full of water and turn the burner to the highest temperature setting. After a few minutes of watching the pot, waiting for the water to boil, you get bored. You watch TV while you wait.

You get so interested in the show that you forget about the water. When you finally return to the kitchen, you see that the pot is now only half full of boiling water. On the wall above the stove are droplets of water.

What happened to half of the water that was originally put into the pot?
How did water get on the wall?

If you get into a car and the windows begin fogging up, what can you do to make the moisture disappear—turn on the heater or turn on the air conditioner, or does it matter? Explain your answer.

Figure 15-7
Fog surrounds the Golden Gate Bridge, San Francisco. Fog is a stratus cloud near the ground.

Water falling from clouds is called **precipitation.** Air temperature determines whether the water droplets form rain, snow, sleet, or hail—the four main types of precipitation. **Figure 15-6** on page 427 shows how four types of precipitation form. Drops of water falling in temperatures above freezing fall as rain. Snow forms when the air temperature is so cold (at least below freezing) that water vapor changes directly to a solid. Sleet forms when snow passes through a layer of warm air, melts, and then refreezes near the ground.

Hail is precipitation in the form of lumps of ice. Hail forms in cumulonimbus clouds of a thunderstorm when drops of water freeze in layers around a small nucleus of ice. Hailstones grow larger as they're tossed up and down by rising and falling convection currents. Most hailstones are smaller than 2.5 cm but can grow to the size shown in **Figure 15-8.** Of all forms of precipitation, hail produces the most damage immediately, especially if winds blow during a hailstorm. Falling hailstones can break windows and destroy crops.

Figure 15-8
A large hailstone appears to have a layered structure much like an onion.

By understanding the role of water vapor in the atmosphere, you can begin to understand weather. The relative humidity of the air helps determine whether a location will have a dry day or experience some form of precipitation. The temperature of the atmosphere determines the form of precipitation. Studying clouds can add to your ability to forecast weather.

Can you make it rain?

Procedure
1. Pour a few centimeters of hot water into a tall, clear, wide-mouthed jar.
2. Put ice cubes in a small plastic bag. Suspend the bag from the top of the jar, and let it hang down inside.

Analysis
1. In your Science Journal, describe what you see.
2. Describe what is happening to the water vapor in the jar.

Section Wrap-up

Review

When does water vapor in air condense?

How do clouds form?

How can the same cumulonimbus cloud produce both rain and hail?

Skill Builder

Concept Mapping
Make a network tree concept map that compares four clouds. Use these terms: *cirrus, cumulus, stratus, nimbus, feathery, fair weather, puffy, layered, precipitation, clouds, dark,* and *steady precipitation.* If you need help, refer to Concept Mapping in the **Skill Handbook.**

USING MATH

Use the graph in **Figure 15-2** to determine the amount of water vapor air can hold when its temperature is 50°C.

15.2 Weather Patterns

Science Words

air mass
front
tornado
hurricane

Objectives

- Describe the weather associated with fronts and high and low pressure areas.
- Explain how low pressure systems form at fronts.
- Relate thunderstorms to tornadoes.

Changes in Weather

Why do you ask about the weather in the morning when you get up? Isn't it safe to assume that the weather is the same as it was the day before? Of course not! Weather is always changing because of the constant movement of air and moisture in the atmosphere. These changes are generally related to the development and movement of air masses.

Air Masses

An **air mass** is a large body of air that has the same properties as the surface over which it develops. For example, an air mass that develops over land is dry compared with one that develops over water. Also, an air mass that develops in the tropics is warmer than one that develops at a higher latitude. When you witness a change in the weather from one day to the next, it is due to the movement of air masses. **Figure 15-9** shows air masses that affect the United States.

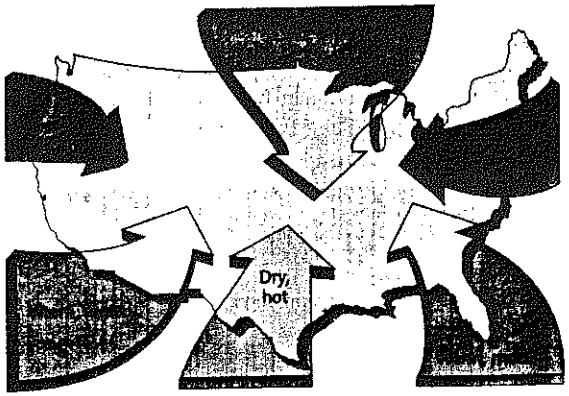


Figure 15-9

There are six major air masses that affect weather in the United States. Each air mass has the same characteristics of temperature and moisture content as the area over which it formed. *What air masses affect the weather in your region of the country?*

Pressure Systems

You have heard weather forecasters mention low and high pressure systems. What are they? In the atmosphere, great masses of air molecules push down from above, creating atmospheric pressure at Earth's surface. As you learned in the last chapter, atmospheric pressure at sea level varies over the surface of Earth. The temperature, the density, and the amount of water vapor of the air help determine the atmospheric pressure.

Variation in atmospheric pressure affects the weather. Areas of high pressure at Earth's surface are regions of descending air. Section 15-1 explained that clouds form when air rises and cools. The sinking motion in high pressure air masses makes it difficult for air to rise and clouds to form. That's why high pressure usually means good weather. Areas of low pressure usually have cloudy weather.

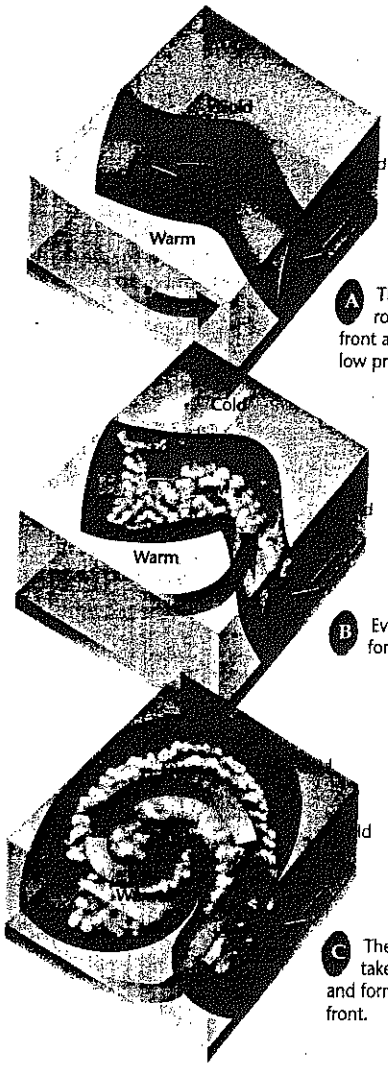
Fronts

In between regions of higher pressure will be areas of lower pressure. Low pressure systems form along the boundaries of air masses. The boundary between two different air masses is called a **front.** Storms and precipitation occur at these fronts.

At a front, air at the surface moves from the high pressure systems into the low pressure systems. As the air converges into the low pressure area, it flows under the less dense, warm air, forcing it upward. As the air in a low pressure system rises, it cools. At a certain elevation, the air reaches its dew point, and the water vapor in it condenses, forming clouds. **Figure 15-10** shows how a low pressure system can develop at the boundary between cold and warm air.

Figure 15-10

These diagrams show how a disturbance occurs along a front.

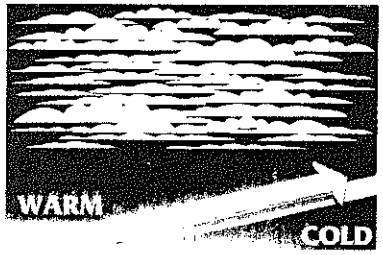


At fronts where two air masses with different characteristics meet, the air does not mix, but instead, the cold air mass moves under the warm air. The warm air rises. Winds begin. As surface winds blow from a high pressure area into a low pressure area, the Coriolis effect turns the winds and makes them circulate counterclockwise around the low pressure area.

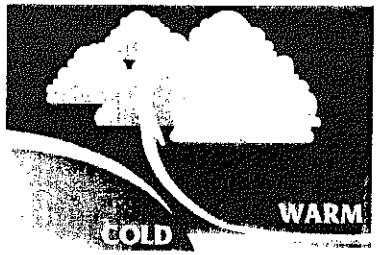
Most changes in weather occur at one of four types of fronts—warm, cold, occluded, or stationary, as illustrated in **Figure 15-11.** Fronts usually bring a change in temperature and always bring a change in wind direction.

Figure 15-11

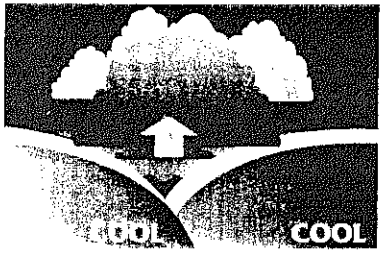
These diagrams show the structure of a warm, a cold, an occluded, and a stationary front.



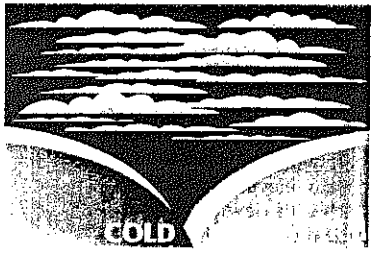
A A warm front develops when a less dense, warm air mass slides over a departing cold air mass. Precipitation occurs over a wide band. Look for high cirrus clouds to form as water vapor condenses. *What other clouds occur at a warm front?*



B In a cold front, a cold air mass pushes under a warm air mass and forces the warm air aloft along a steep front. There is a narrow band of violent storms. Cold fronts often move at twice the speed of warm fronts. Cumulus and cumulonimbus clouds form along the front. *What weather do these clouds bring?*



C An occluded front results from two cool air masses merging and forcing warmer air between them to rise. Strong winds and heavy precipitation may occur.



D A stationary front occurs when pressure differences cause a warm front or a cold front to stop moving. A stationary front may remain in the same place for several days. Weather conditions include light wind and precipitation across the entire frontal region.

Weather affects you every day. Usually, you can still go about your business regardless of the weather. If it's raining, you can still go to school. Even if it snows a little, you can still get to school. But some weather conditions, such as those caused by blizzards, thunderstorms, and tornadoes, prevent you from going about your normal routine. Severe weather poses danger to people and animals.

Thunderstorms

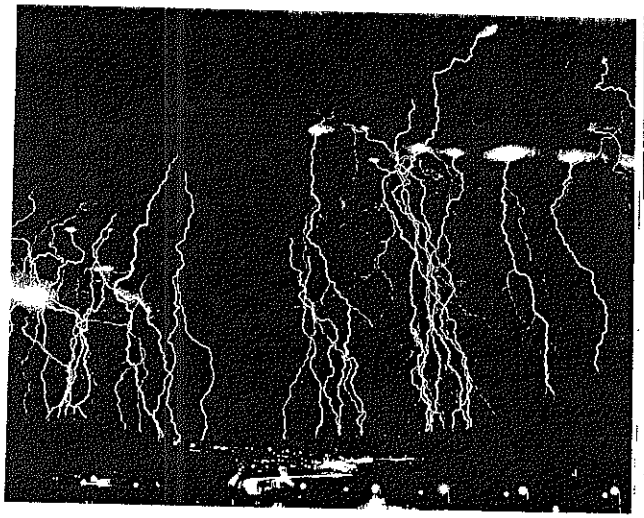
In a thunderstorm, heavy rain falls, lightning flashes, thunder roars, and maybe hail falls. What forces cause such extreme weather conditions? Thunderstorms occur inside warm, moist air masses and at fronts. They occur when warm, moist air moves upward rapidly, cools, condenses, and forms cumulonimbus clouds that can reach heights of 18 km. As the rising air reaches its dew point, water droplets and ice form and begin falling the long distance through the clouds toward Earth's surface. The falling droplets collide with other droplets and grow larger. The heavier raindrops fall, dragging down the air with them and creating downdrafts of air that spread out at Earth's surface. These downdrafts cause the strong winds associated with thunderstorms.

Thunderstorms also contain thunder and lightning. Lightning, like that in **Figure 15-12,** occurs when a rapid uplift of air builds up electric charges in the clouds. Some places in the clouds have a positive electrical charge and some have a negative electrical charge. When current flows between regions of opposite electrical charge, lightning flashes. Bolts of lightning can leap from cloud to cloud and from Earth to clouds.

Thunder results from the rapid heating of the air around a bolt of lightning. Lightning can reach temperatures of about 30 000°C, more than five times the temperature of the surface of the sun! This extreme heat causes the air around the lightning to expand rapidly. Then it cools quickly and contracts. The molecules, moving rapidly back and forth, form sound waves heard as thunder.

Figure 15-12

This time-elapsed photo shows a thunderstorm over Arizona.



USING MATH

The speed of light is 300 000 kilometers per second. The speed of sound in air is 332 meters per second. How much faster does light travel than sound? Explain why you do not usually see lightning and hear the thunder it creates at the same time.

Thunderstorms can cause a lot of damage. Their heavy rain sometimes causes flooding, and lightning can strike objects and set them on fire. Strong winds generated by thunderstorms can also cause damage. If a thunderstorm has winds traveling faster than 89 km per hour, it is classified as a severe thunderstorm. Hail from a thunderstorm can make dents in cars and the aluminum siding on houses. Although rain from thunderstorms helps crops grow, hail has been known to flatten and destroy a crop in a matter of minutes.

Tornadoes

Some of the most severe thunderstorms produce tornadoes. A **tornado** is a violent, whirling wind that moves in a narrow path over land, usually in a direction from southwest to northeast. Most tornadoes form along a front. In very severe thunderstorms, the wind at different heights blows in different directions and at different speeds. This difference in wind direction and speed is called *wind shear*. A strong updraft will tilt the wind shear and produce rotation inside the thunderstorm. A funnel cloud appears. **Figure 15-13** shows how a tornado funnel forms. Recall the tornado you made in the Explore activity.

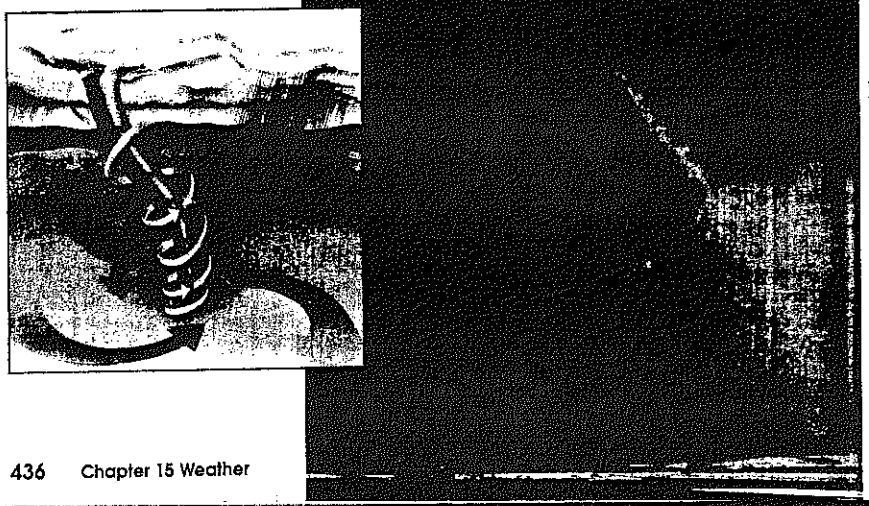
Some tornado funnels do not reach Earth. Funnel clouds that touch down pick up dirt and debris from the ground, giving the funnels their dark gray or black color. Sometimes tornadoes strike Earth, go back up into the atmosphere, then dip down and strike another area.

When tornadoes touch the ground, their destructive winds rip apart buildings and trees. Winds of the tornado can reach up to 500 km per hour. High winds can blow through broken windows. When winds blow inside a house, they can lift off the roof and blow out the walls, making it look as though the building exploded. The updraft in the center of a powerful tornado can lift animals, cars, and even houses into the air. Although tornadoes rarely exceed 200 m in diameter and usually last only a few minutes, they are often extremely destructive.

Tornadoes occur worldwide, but most tornadoes touch down in the United States—about 700 per year. Tornadoes most frequently

Figure 15-13

The diagram shows how wind forms a funnel cloud like the one to the right in a farm field. The destructive winds of a tornado can reach up to 500 km per hour.

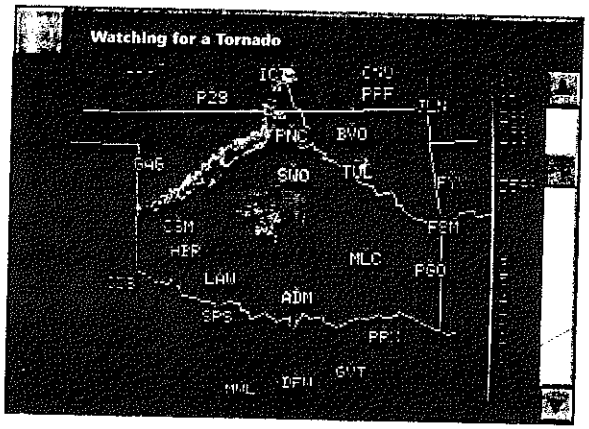


USING TECHNOLOGY

Tailing a Tornado

A tornado can develop in less than an hour and can destroy property and kill people within a matter of minutes.

Next Generation Weather Radar, or NEXRAD, is a system of radar stations that uses Doppler radar to track severe weather storms such as tornadoes. Doppler radar sends out radio waves toward the storms. The waves reflect off the water droplets of storm clouds and are recorded at the radar station. The shift in frequency of the reflected signals allows meteorologists to determine the position, strength, and wind speed of the storm. Doppler radar helps scientists detect funnel clouds before they touch down. The weather service issues an advisory if the conditions are right for a tornado to form. If a tornado is spotted, the weather service issues a warning to people in its path.



GRAPHING CALCULATOR

Assume a tornado is moving toward your town at a speed of 100 km/h. The relationship among distance (Y), time (X), and this speed is given by $Y = 100 \times X$. Use a graphing calculator to graph this relationship. Use the resulting graph to find out how much time you would have to prepare for the storm if it is 160 km from your town.

strike the Midwest and South, usually in spring or early summer. Texas, Oklahoma, and Kansas report the most tornadoes.

Hurricanes

The most powerful storm is the hurricane. A **hurricane** is a large, swirling, low pressure system that forms over tropical oceans. It is like a machine that turns heat energy from the ocean into wind. A storm must have winds of at least 120 km per hour to be called a hurricane.

Hurricanes are similar to low pressure systems on land, but they are much stronger. **Figure 15-14** illustrates the mechanics of the hurricane. In the North Atlantic, the southeast trade winds and the northeast trade winds sometimes meet. A low pressure area develops in the middle of the swirl and begins rotating counterclockwise in the northern hemisphere. This usually happens between 5° and 20° north latitude, where the water is quite warm. Around the middle of the low pressure area, warm, moist air is forced up. As it rises to higher elevations, it cools and moisture condenses.

Figure 15-15 shows a hurricane hitting land. When a hurricane strikes land, the high winds, tornadoes, heavy rains, and high waves of the storm surge cause a lot of damage. Floods from the heavy rains can cause additional damage. The weather of the hurricane can destroy crops, demolish buildings, and kill people and other animals. In 1992, Hurricane Andrew hit Florida and Louisiana, killing 14 people and causing more than 25 billion dollars in damage.

As long as a hurricane is over water, the warm, moist air rises and provides energy for the storm. When a hurricane reaches land, however, its supply of warm, moist air disappears and the storm loses power.

USING MATH

The numbers of fatalities due to hurricanes in the United States are as follows:

1940s	216
1950s	877
1960s	587
1970s	217
1980s	118

Make a bar graph of these data.

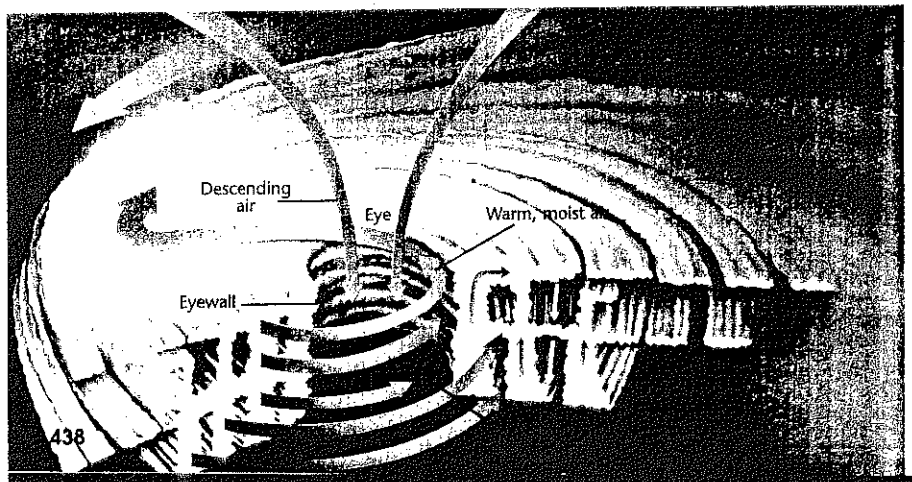


Figure 15-14

In this hurricane cross section, the small red arrows indicate rising warm, moist air. This rising air forms cumulus and cumulonimbus clouds in bands around the eye. The blue arrows indicate cool, dry air sinking in the eye and between the cloud bands. The large red arrows indicate the circular motion of the rising spiral cloud bands.

Most hurricanes in the United States strike along the Gulf of Mexico or along the Atlantic Coast. Mexico often sustains damage from hurricanes along its Pacific coast as well as its Atlantic coast. Find out what happens to the islands of the Caribbean Ocean during an average hurricane season.

Changes in weather affect your life. The interaction of air and water vapor cause constant change in the atmosphere. Air masses meet and fronts form, causing changes in weather. Severe weather can affect human lives and property.

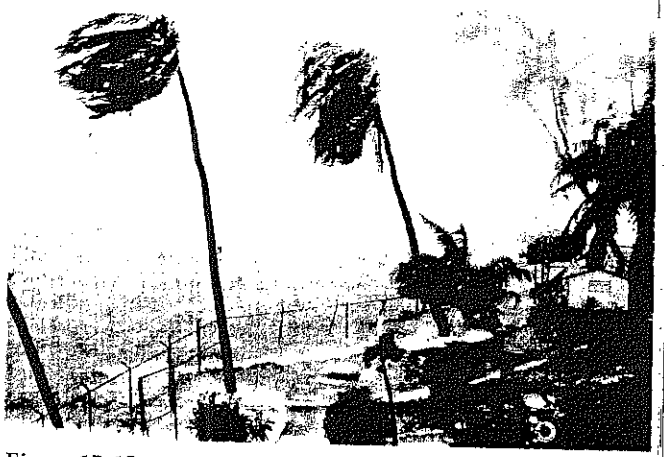


Figure 15-15

Hurricanes can be very destructive, killing people and destroying property.

Section Wrap-up

Review

1. Why do high pressure areas usually have clear skies?
2. Explain how a tornado evolves from a thunderstorm.
3. Think Critically: How do two fronts form at a low pressure area? Which would bring the most severe weather?

Skill Builder

Recognizing Cause and Effect

Use your knowledge of weather to answer the following questions. If you need help, refer to Recognizing Cause and Effect in the **Skill Handbook.**

1. What effect does a warm, dry air mass have on the area over which it moves?
2. What causes a cold front? What effect does a cold front produce?
3. Describe the cause and effect of an occluded front that might form over your city.

Using Computers

Spreadsheet Make a spreadsheet comparing warm fronts, cold fronts, stationary fronts, and occluded fronts. Indicate what kind of clouds and weather systems form with each.