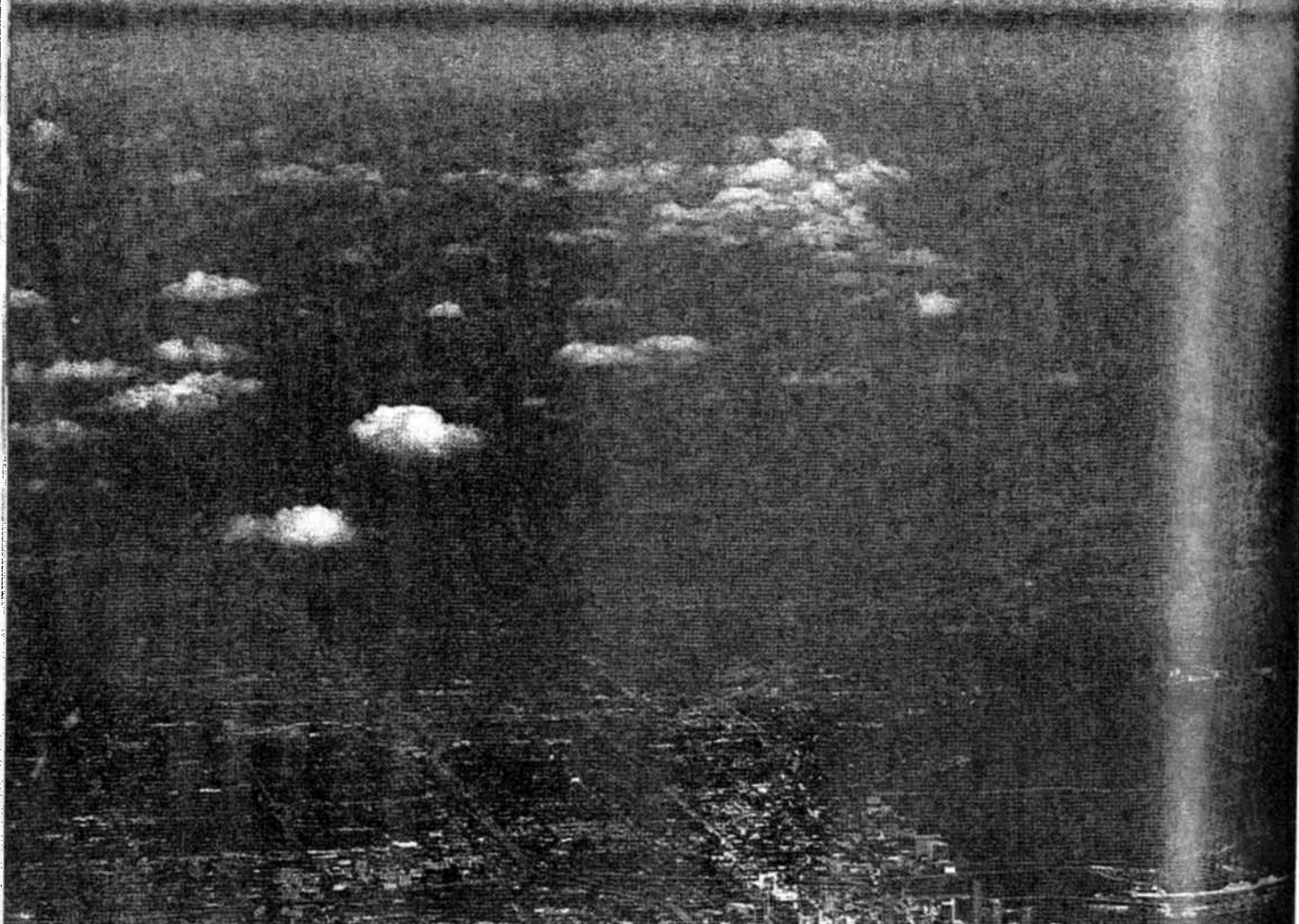


# Atmosphere

The air you breathe is part of Earth's atmosphere.

What makes up the atmosphere, and how do human activities affect it?



## PREVIEW

► **FOCUS QUESTIONS** In this chapter you will study the atmosphere and learn more about the key questions below.

**Section 1** How do other parts of the Earth system affect the composition of the atmosphere?

**Section 2** How does heat move through and affect the atmosphere?

**Section 3** Why does temperature vary?

**Section 4** How does human activity affect the atmosphere?

► **REVIEW TOPICS** As you investigate the atmosphere, you will need to use information from earlier chapters.

- geosphere, hydrosphere, biosphere (pp. 8–12)
- atoms and molecules (pp. 90, 93)
- gases in magma (p. 199)

## ► READING STRATEGY

### PREVIEW AND QUESTION

Start by skimming through Chapter 17. Notice the key ideas, the vocabulary, and the headings for each section and subsection. Look over any images or diagrams and read their captions. Record in your notebook any questions that come to mind. As you read, seek answers to your questions.



At our Web site, you will find the following Internet support for this chapter.

#### DATA CENTER

#### EARTH NEWS

#### VISUALIZATIONS

- Auroras
- Seasonal Changes in Sunlight
- Infrared Images of Surface Temperature
- Forest Fires as Seen from Space

#### LOCAL RESOURCES

#### CAREERS

#### INVESTIGATIONS

- What Can You Learn from a Thermometer on a Rising Balloon?
- How Does the Temperature at One Location Change over a Year?
- How Does the Ozone Layer Change over Time?

# 17.1

## KEY IDEAS

The composition of Earth's atmosphere remains fairly constant.

Gases move continually between the atmosphere and other parts of the Earth system.

The recycling of atmospheric materials maintains a delicate balance, and local events may have global consequences.

## The Atmosphere in Balance

In 1815, the violent eruption of the Tambora volcano in Indonesia propelled huge quantities of dust high into the atmosphere. This volcanic cloud blocked some incoming sunlight, and temperatures fell worldwide. In fact, the next year was known as the “year without a summer” in parts of Europe and North America. The global impact of this local event was dramatic but brief: temperatures soon returned to normal levels.

## The Composition of the Atmosphere

Scientists hypothesize that volcanic eruptions played the main role in forming Earth's early atmosphere. Gases released from volcanic eruptions—primarily carbon dioxide, sulfur dioxide, water vapor, and nitrogen—probably made up nearly all of this early atmosphere. Oxygen may have first entered the atmosphere as a result of sunlight splitting water vapor molecules into oxygen and hydrogen. However, the amount of oxygen in the atmosphere increased significantly as early life forms trapped the energy of sunlight through photosynthesis. The process of photosynthesis releases oxygen as a byproduct.

Today Earth's lower atmosphere is a mixture of many gases called air. The main gases in air are nitrogen and oxygen, which together form about 99 percent of dry air by volume. The remaining 1 percent is mostly argon and carbon dioxide. The atmosphere also contains tiny amounts of trace gases, such as helium, hydrogen, and neon. The table below shows the approximate percentages by volume of gases in dry air.

The percentages of nitrogen and oxygen are fairly constant throughout the atmosphere up to an altitude of about 80 kilometers. However, the amounts of some gases in the atmosphere vary from place to place and from time to time. For example, the amount of water vapor varies with location, season, and time of day. The water-vapor concentration is highest near the surface and decreases rapidly with altitude. Similarly, the amount of carbon dioxide in the air varies with the seasons. It is lowest during the periods of greatest photosynthesis (summer) and highest in winter.

**PHOTOSYNTHESIS** Most of the oxygen in the atmosphere is a byproduct of photosynthesis. Photosynthesis occurs both in the oceans and on land.

Principal Gases of Dry Air

Nitrogen	78.08%
Oxygen	20.95%
Argon	0.934%
Carbon dioxide	0.036%

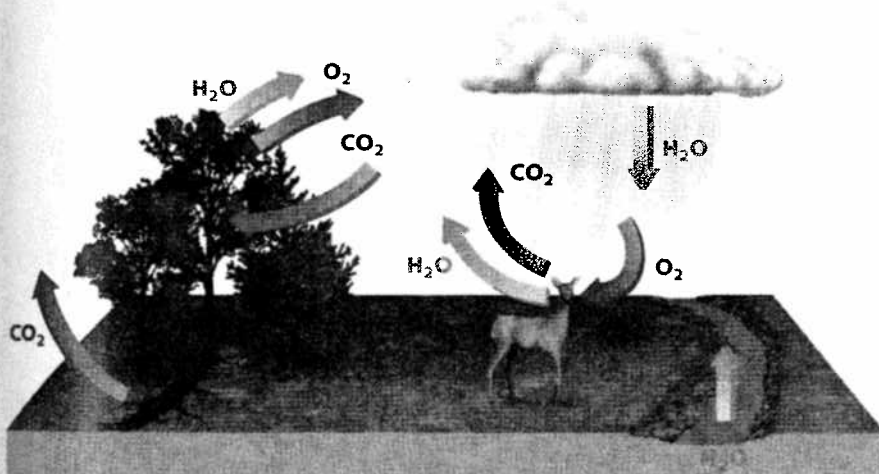
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SANTA CARITA DRIVE



In addition to gases, the atmosphere also contains a wide variety of tiny dust particles. Dust includes tiny grains of rock, dirt, pollen, salt crystals from sea spray, and soot from fires.

## Recycling of Atmospheric Materials

The composition of the atmosphere has remained stable throughout Earth's recent history because our planet is an efficient recycling system. Elements and compounds are constantly moving between the atmosphere and the other parts of the Earth system—the geosphere, hydrosphere, and biosphere. An overall balance is maintained, however, because the amount of a given substance leaving the atmosphere equals the amount of that same substance entering the atmosphere over the same period of time.



**A COMPLEX BALANCE** This illustration shows some of the key pathways by which substances important to living things cycle into and out of the atmosphere.

The illustration above provides a simplified view of the ways in which oxygen (O<sub>2</sub>), carbon dioxide (CO<sub>2</sub>), and water (H<sub>2</sub>O) cycle in and out of the atmosphere. For example, plants take carbon dioxide from the air for photosynthesis and release oxygen as a byproduct of that same process. In contrast, animals inhale oxygen and exhale carbon dioxide. Carbon dioxide is also returned to the atmosphere through the decomposition of organic materials. Finally, water vapor enters the atmosphere through evaporation, transpiration from plants, and the exhaled breath of animals. Water leaves the atmosphere in the form of precipitation.

## A Delicate Balance

The balance maintained by recycling in the atmosphere may be disturbed by a variety of factors, both natural and of human origin. For example, a large body of evidence indicates that the amount of carbon dioxide in the atmosphere has steadily increased in recent years. Data collected at the Mauna Loa Observatory in Hawaii show that average CO<sub>2</sub> levels rose more than 16 percent between 1959 and 1999. This increase is due primarily to human activities, especially the burning of fossil fuels, such as coal,



## Environmental Consultant

**E**nvironmental consultants are able to combine their interest in the environment with their talent for creative problem solving. One aspect of the environment in which many consultants specialize is air quality. While some consultants focus their attention on outdoor air quality, others work to improve the indoor air quality of buildings and homes. By keeping up-to-date on government regulations and advances in industrial technology, these consultants help companies monitor and minimize air pollution in a cost-effective way. An environmental consultant may work with a company's employees to design a scrubber for a smokestack or a more effective air-ventilation system

for the inside of a building.

Most environmental consultants hold a bachelor's or an advanced degree in environmental, chemical, or civil engineering. In order to specialize in air quality, a strong background in atmospheric science is especially helpful. Computer knowledge is also essential for developing the sophisticated computer models that are used to assess air-quality trends and potential problems. A willingness to travel is important, since environmental consultants must visit sites to perform air-quality tests. One reward of being an environmental consultant is knowing that you are helping to promote a cleaner environment. ■



**ENVIRONMENTAL CONSULTANTS** study both outdoor and indoor environments. This scientist is in Antarctica.



Learn more about a career as an environmental consultant.

Keycode: ES1701

gasoline, and natural gas. These rising CO<sub>2</sub> levels are suspected of contributing to global warming, which you will read about in Section 17.4.

The atmosphere's sensitive balance involves not only matter like gases but also energy. Energy from the sun is constantly entering the atmosphere. The movement of energy through the atmosphere and other parts of the Earth system plays a critical role in keeping Earth habitable. You will learn more about Earth's energy balance in the next section.

### 17.1 Section Review

- 1 Describe how the composition of the atmosphere has changed over time.
- 2 Which two gases make up most of the atmosphere?
- 3 Draw a diagram showing some of the ways in which carbon dioxide enters and leaves the atmosphere.
- 4 **CRITICAL THINKING** In what ways might the loss of vegetation as a result of deforestation affect the atmosphere's balance?
- 5 **BIOLOGY** Use print or Internet resources to research the role of microorganisms in returning nitrogen or carbon dioxide to the atmosphere.

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# Heat and the Atmosphere

Energy from the sun drives the weather and is essential to almost all life on Earth. How does energy from the sun reach Earth across nearly 150 million kilometers of space? What happens to the energy after it reaches Earth?

## How Heat Energy Moves

Heat energy enters and moves through the atmosphere in three different ways—radiation, conduction, and convection.

Energy from the sun reaches Earth through radiation. **Radiation** is the transfer of energy through space in the form of visible light, ultraviolet rays, and other types of electromagnetic waves. All objects warmer than absolute zero emit some form of radiation. Unlike conduction and convection, radiation does not require a medium. Thus radiation is the only way that energy can travel through outer space.

**Conduction** is the transfer of heat energy through collisions of the atoms or molecules of a substance. When you walk barefoot on hot ground, for example, heat moves by conduction from the ground to the soles of your feet. Air touching warm ground is also heated by conduction.

**Convection** is the transfer of heat energy in a liquid or gas through the motion of the liquid or gas caused by differences in density. For example, in a pot of simmering water, the water at the bottom of the pot is heated by conduction and becomes less dense. Because it is less dense, it rises and is replaced by downward-flowing water that is colder and denser. Similarly, warm air in the atmosphere rises, transferring heat upward by convection.

# 17.2

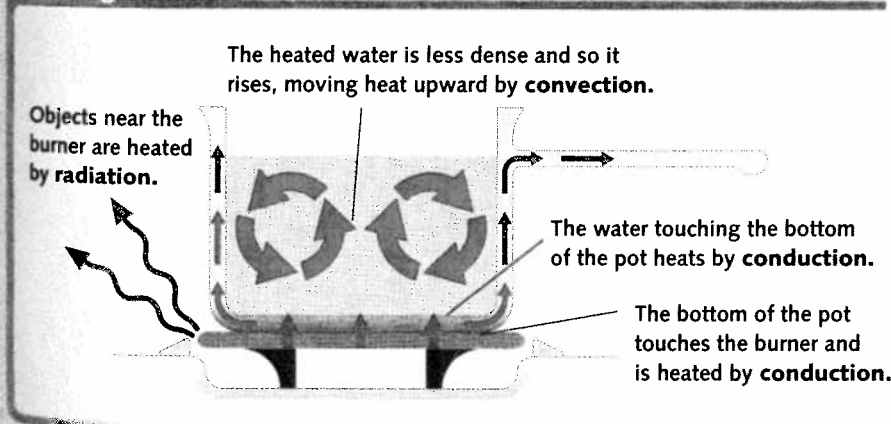
## KEY IDEA

Energy from the sun heats the atmosphere and Earth's surface. This heat spreads throughout the atmosphere and is also radiated back into space.

## KEY VOCABULARY

- radiation
- conduction
- convection
- temperature
- heat
- troposphere
- stratosphere
- ozone
- mesosphere
- thermosphere
- ionosphere
- insolation

### Heating Water



## VOCABULARY STRATEGY

In the words *conduction* and *convection*, the prefix *con-* means "with" or "together"; *-duction* is from a Latin word that means "to lead" and *-vection* is from a Latin word that means "to carry."

## Heat and Temperature

Although heat and temperature are related, they are not the same. The atoms or molecules that make up any substance, even a solid, are in constant motion. The faster the atoms or molecules are moving, the greater their kinetic energy, or energy of motion. The **temperature** of a substance is a measure of the average kinetic energy of the atoms or molecules in that substance. For example, molecules of water that is almost boiling move



30-Minute

## Mini LAB

### Changes of State

#### Materials

- small Styrofoam cup
- short thermometer
- water
- shallow pan

#### Procedure

- 1 Fill the cup half full of water. Place the thermometer in the cup. Freeze overnight.
- 2 Fill the pan with lukewarm water. Place the cup and thermometer in the pan.
- 3 Record the initial temperature. Record the temperature every minute until the ice has melted. Graph your data.

#### Analysis

Describe the trend in temperature as the ice melts. Why does the temperature stop rising as water changes phases? What is the heat source melting the ice?

much more rapidly (and thus have more kinetic energy) than molecules of water that is nearly freezing. For this reason, the temperature of boiling water is greater than the temperature of freezing water.

Temperature is a measure of the average kinetic energy of the particles of a substance, but **heat** can be thought of as the total kinetic energy of all of the particles of the substance. For example, a large cup of tea has more heat than a smaller cup of tea at the same temperature. Heat always flows from a substance at a higher temperature to a substance at a lower temperature. For instance, when ice melts, it absorbs heat energy from its surroundings. The heat melts the ice instead of raising its temperature, so the melted water is at the same temperature as the ice even though the water has more heat energy.

A thermometer measures temperature, not heat. Scientists measure temperature using the Celsius scale, which is based on the properties of water. At sea level, ice melts at 0°C, and water boils at 100°C. For a comparison of Celsius and other temperature scales, see page 696.

## Structure of the Atmosphere

The temperature of the atmosphere changes dramatically at varying altitudes. Scientists use these temperature differences to divide the atmosphere into four layers: (1) troposphere, (2) stratosphere, (3) mesosphere, and (4) thermosphere.

### The Troposphere

The lowest layer of Earth's atmosphere is called the **troposphere** (TROH-puh-SFEER). In the troposphere, temperature decreases with altitude, as shown in the graph on page 371. Most of the sun's radiation is absorbed at Earth's surface, which in turn transfers heat to the atmosphere through conduction and radiation. Thus the air at the surface is warmest, and temperature generally decreases with altitude, or the distance from the warming effect of Earth's surface. The rate of cooling with altitude is highly variable, but on average the temperature of the air in the troposphere decreases about 6.5°C for each kilometer of altitude gain.

The temperature stops decreasing at the tropopause, the area between the troposphere and the stratosphere. The altitude of the tropopause varies according to latitude. At the equator, the tropopause is at an altitude of about 16 kilometers, but at the poles, it is at about 9 kilometers. (The jet stream is located just below the tropopause.)

Because the density of the atmosphere also decreases with altitude, the troposphere contains about 80 percent of the total mass of the atmosphere. It also contains most of the water vapor present in the atmosphere. Partly for this reason, almost all of Earth's weather occurs in the troposphere.

### The Stratosphere

Above the tropopause lies a clear, dry layer of the atmosphere called the **stratosphere** (STRAT-uh-SFEER). As you can see in the graph on page 371, the lower part of the stratosphere is about as cold as the tropopause. The upper part of the stratosphere warms steadily up to its top, the stratopause, which is about 50 kilometers above Earth's surface.

#### VOCABULARY STRATEGY

The names of the layers of the atmosphere contain Greek or Latin roots that give clues to the properties of the layers: *tropo* ("change" or "turning"), *strato* ("spreading out"), *meso* ("middle"), and *thermo* ("heat").

The temperature increase in the stratosphere is caused by the presence of **ozone**, a form of oxygen gas. (An ozone molecule consists of three oxygen atoms; an oxygen molecule contains two oxygen atoms.) Ozone absorbs ultraviolet rays from the sun and then releases some of this energy in the form of heat. You will learn more about ozone in Section 17.4.

### The Mesosphere and Thermosphere

The atmosphere's third layer, the **mesosphere** (MEHZ-uh-SFEER), extends between about 50 and 90 kilometers above Earth's surface. Because very little ozone is present in the mesosphere, temperatures again drop with increasing altitude.

Above 90 kilometers lies the atmosphere's fourth layer, the **thermosphere**. The atmosphere at this great altitude is extremely thin, but the few molecules and atoms present receive such intense solar radiation that temperatures can rise above 1000°C. The thermosphere is separated into layers of different gases, with heavier gases in the lower levels and lighter gases in the higher layers. The lowest layer is composed primarily of nitrogen molecules. Next, a layer of oxygen reaches to about 1000 kilometers. Above that layer is one of helium that extends to about 2400 kilometers. Above this helium layer, a layer of hydrogen thins out into space.

**STRUCTURE OF THE ATMOSPHERE** The graph below shows the approximate temperature at each altitude. The exact altitude and temperature of the pauses vary.

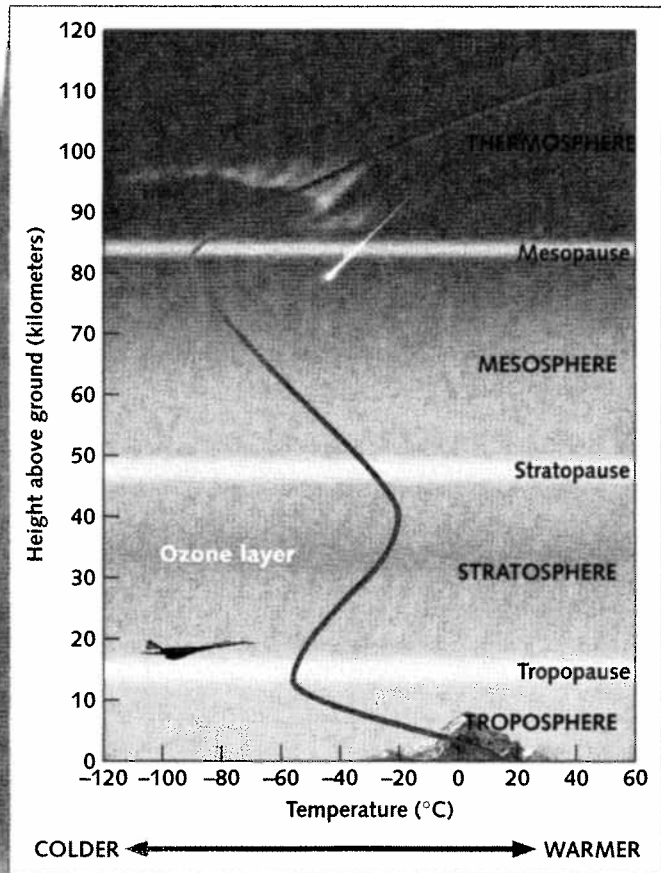
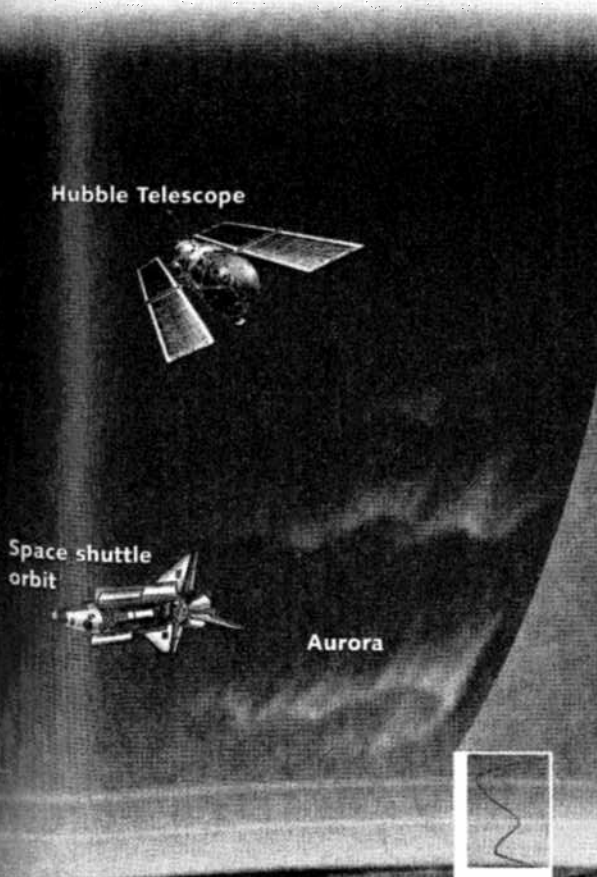


#### What Can You Learn from a Thermometer on a Rising Balloon?

Analyze changes in temperatures to find the boundaries of the atmospheric layers.

Keycode: ES1702

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**AURORA BOREALIS** is the name of the aurora in the Northern Hemisphere.



Observe auroras as seen from the ground and from space.

Keycode: ES1703

## The Ionosphere

The portion of the thermosphere between about 90 and 500 kilometers above Earth is also called the **ionosphere**, because the air there is highly ionized. These ions are formed when ultraviolet rays from the sun knock electrons off oxygen and nitrogen molecules and oxygen atoms.

The ionosphere is affected by solar events. Huge eruptions associated with sunspots send out large amounts of a form of radiation that disrupts radio communications. These solar eruptions also send out ionized particles. Because the particles are electrically charged, they are deflected by Earth's magnetic field to the North and South poles. At the poles, the ionized particles interact with air molecules to form auroras, colorful displays of light in the nighttime sky.

## Insolation and the Atmosphere

As you have seen, the atmosphere is a complex system in which energy is always flowing. The sun radiates energy into space in all directions. Earth's system receives only about one two-billionth of the sun's rays. This *incoming solar radiation* is called **insolation** (IHN-soh-LAY-shuhn). Some insolation is absorbed by gases in the atmosphere, and some reaches Earth's surface without interference. However, much of the insolation is scattered by collisions with gas molecules and dust in the atmosphere. Some of the scattered insolation returns to space, some is absorbed by the air, and some makes it to Earth's surface.

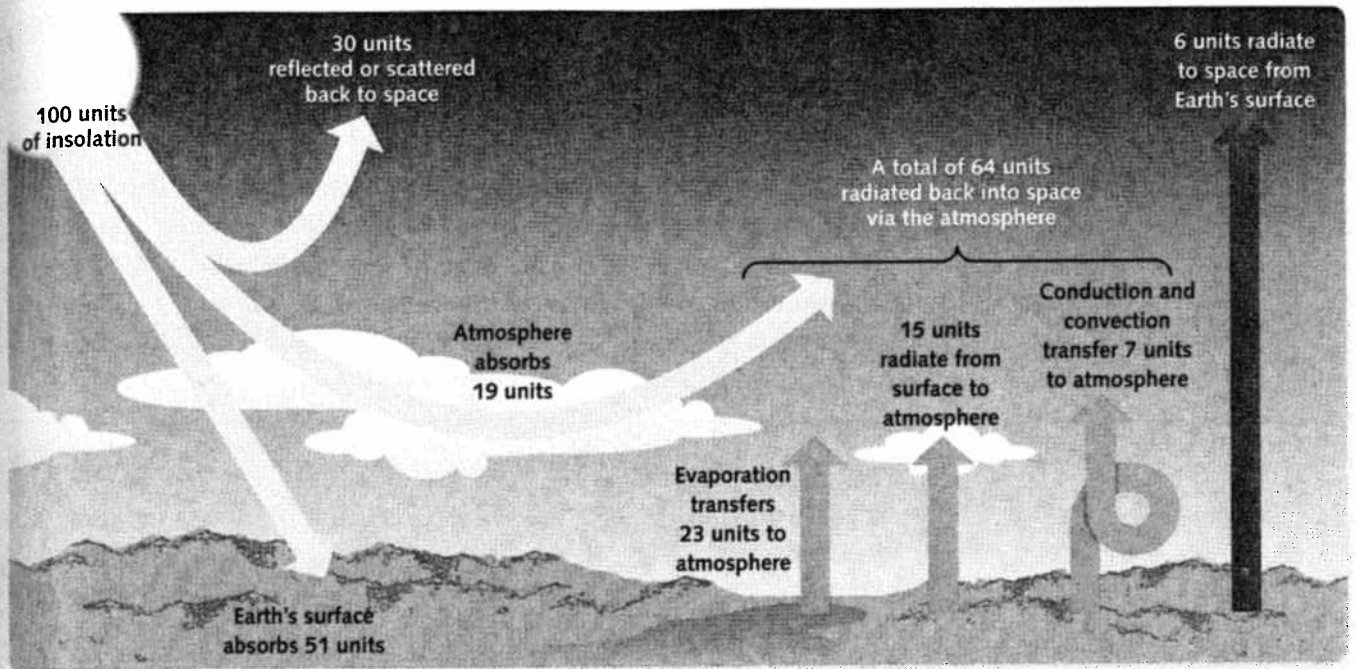
Scientists use the model of a global heat budget to represent the overall flow of energy into and out of the atmosphere. As long as the heat budget is in balance, global temperatures remain fairly constant over time. If the budget should become out of balance, the Earth system would heat up or cool down.

The diagram on page 373 illustrates the heat budget in balance. Suppose the Earth system receives 100 units of energy from the sun. As the diagram shows, 30 units of this insolation are reflected back to space, and the remaining 70 units are absorbed by the atmosphere or Earth's surface. When the budget is in balance, 70 units of energy are also radiated out to space by the atmosphere and by Earth's surface.

## Heat Budget of Earth and the Atmosphere

As you can see in the diagram, only a small percentage of insolation is absorbed by the atmosphere. In fact, most of the atmosphere's energy is transferred from the surface by radiation, conduction, and the evaporation and subsequent condensation of water. This energy transfer from Earth's surface is one of the major causes of weather.

Although Earth's atmosphere allows half of the incoming solar radiation to reach the surface, much of that energy is radiated back into the atmosphere as infrared radiation. The accumulation of carbon dioxide and water vapor in the atmosphere, however, absorbs most of the infrared radiation, thus preventing it from radiating directly back to space. A condition known as the greenhouse effect results when infrared radiation remains in Earth's atmosphere.



**GLOBAL HEAT BUDGET** This illustration, based on average data, shows what happens to the energy in 100 units of insolation. If the sky were clear and snow covered the ground, then more energy would reflect directly to space from Earth's surface. On an overcast day, the atmosphere either reflects or absorbs more insolation, so Earth's surface receives less.

Without the greenhouse effect, much of Earth's heat energy would be lost to outer space. In fact, Earth's average surface temperature would be about 33°C cooler than it is now—freezing! The greenhouse effect has actually helped Earth thrive as a planet. Recently, however, there has been such a significant increase in the levels of carbon dioxide in the atmosphere that Earth's heat budget may be out of balance. Many scientists warn of the possibilities of global warming. (See Section 17.4.)

## 17.2 Section Review

- 1 Describe three ways heat is transferred through the atmosphere.
- 2 Why does temperature generally decrease with altitude in the troposphere?
- 3 Compare the temperature changes in the stratosphere with those in the thermosphere. Include the role of ozone in your explanation.
- 4 Describe at least two paths that a unit of energy could take from its arrival at Earth's atmosphere until it is reradiated out to space.
- 5 **CRITICAL THINKING** Based on what you have learned about the layers of the atmosphere, explain why jets generally fly at or above the tropopause.
- 6 **PHYSICAL SCIENCE** Draw and label a diagram explaining why the water at the bottom of a pot of simmering water becomes less dense as it is heated.

# 17.3

## KEY IDEA

Many factors affect how much solar energy is absorbed by Earth's surface at any given time and place.

## KEY VOCABULARY

- isotherm

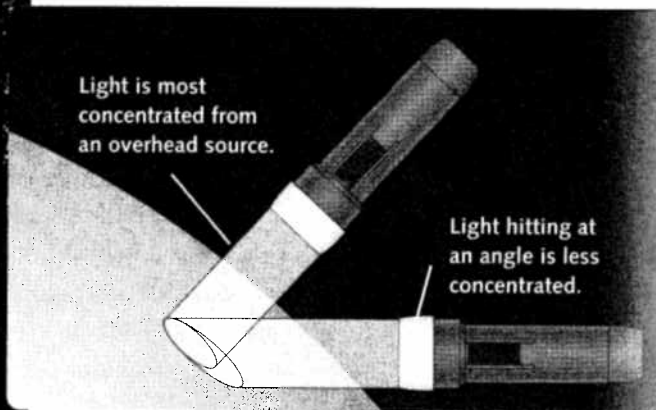
## Local Temperature Variations

Why does the temperature vary from place to place? The basic reason is that insolation heats Earth's surface and atmosphere unequally.

- The intensity of insolation varies with the time of day, the latitude, and the time of year.
- The characteristics of a material affect both how much insolation the material absorbs and how the absorbed energy affects the temperature. For example, on a sunny day dark pavement becomes hotter than grass.

## Intensity of Insolation

The intensity of insolation depends on the angle at which the sun's rays strike Earth's surface. When the sun is directly overhead, the angle of insolation is  $90^\circ$ , and Earth's surface receives the maximum amount of energy. As the angle of insolation decreases, the energy of the rays is spread out over a larger area, so the energy per unit area decreases. The sunlight must also travel farther through the atmosphere, so that more insolation is absorbed or reflected before it reaches Earth's surface. Both factors reduce the amount of solar energy that reaches Earth's surface.



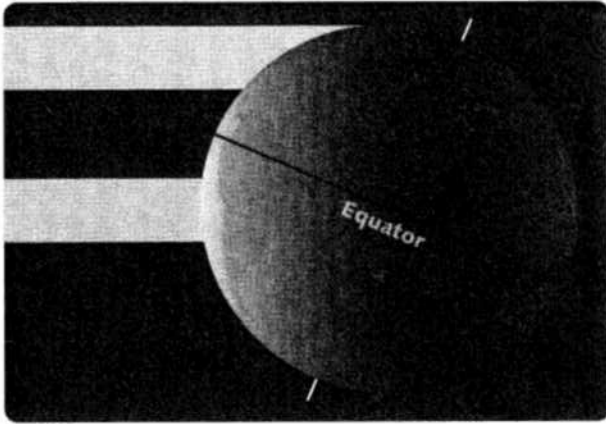
**ANGLE OF INSOLATION** When sunlight hits Earth's surface at an angle, its energy is spread over a greater area, so the insolation is less intense. The angle of sunlight varies with time of day, latitude, and time of year.

## Time of Day

Because the sun's rays are closest to vertical at noon, the intensity of insolation is greatest then. However, the highest temperature is generally not at noon. Instead, the warmest hour of the day is usually in the afternoon. For several hours after noon, the lower atmosphere receives more heat from the ground than it loses. Thus, its temperature keeps rising until well into the afternoon. The coldest hour usually comes just before sunrise because the ground and the lower air lose heat all through the night.

## Latitude

Because Earth is spherical, the sun's rays strike the surface at angles ranging from  $0^\circ$  to  $90^\circ$ . Near the equator, almost-vertical rays fall all through the year. Thus, these areas have hot climates. In high latitudes (near the poles, for example), the sun's rays generally strike the surface at low angles. Such areas may even have no sunlight at all for part of the year and are cold year-round.

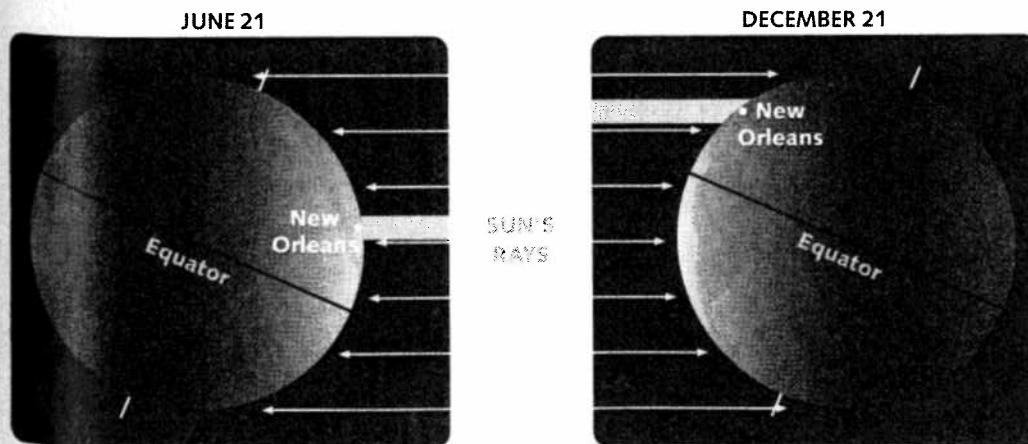


**LATITUDE** The angle of sunlight varies with latitude.

## Time of Year

Locations in middle latitudes (like most of the United States) get near-vertical rays in summer, so their summers are hot. The angle of the rays is less vertical in winter, so winters in middle latitudes are cold.

Like the day's highest temperature, the year's highest temperature occurs after the time of maximum insolation. In middle latitudes of the Northern Hemisphere, the time of strongest sunlight occurs around June 21. However, July is usually the warmest month. Similarly, the year's weakest sunlight occurs around December 21, but January is usually the coldest month. In the Southern Hemisphere, the warmest and coldest months are reversed.



**TIME OF YEAR** The angle of sunlight varies with time of year.



Observe seasonal changes in the amount of sunlight reaching locations on Earth.  
Keycode: ES1704

## Cloud Cover

The intensity of the insolation that reaches Earth's surface depends not only on the angle of the sun's rays but also on how much energy makes it through the atmosphere without being absorbed, reflected, or scattered back to space. Because clouds reflect a significant amount of insolation back into space, more solar energy reaches Earth's surface on clear days than on cloudy days. Similarly, more radiation travels from Earth's surface out to space on clear nights than on cloudy nights.

## Heating of Water and Land

On a sunny day in summer, dry beach sand is much warmer than the nearby water. At night the same sand cools faster than the water and becomes colder. On a larger scale, continents are warmer than nearby ocean waters in summer. In winter the same continents become colder than the nearby waters.

Why does the temperature of land vary more than the temperature of water? The reason is that water and land warm up and cool off at different rates. Water warms much more slowly than land for many reasons:

- Heat energy from insolation spreads through a greater depth in water than on land. On land, insolation warms only the top few centimeters of soil, but the sun's rays penetrate to a depth of many meters in water. In addition, water spreads heat easily by convection because it is a fluid.
- In water, some solar energy is used in the process of evaporation. Therefore, less solar energy is available to raise the temperature of the water.
- Water needs more energy than land to raise its temperature the same amount. The amount of heat needed to raise 1 gram of a substance by 1°C is called the substance's specific heat. The specific heat of water is almost three times the specific heat of land. The higher the specific heat, the slower the temperature change.



Examine infrared images that show variation in surface temperature.

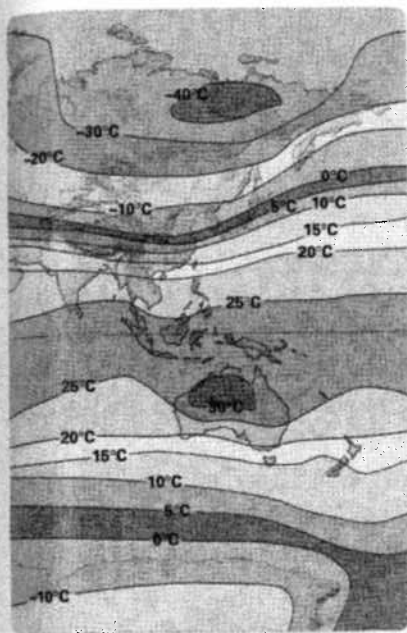
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Just as water and land absorb heat differently, various types of land surfaces absorb heat differently too. For example, dark surfaces absorb more energy than light surfaces. Rough surfaces absorb more energy than smooth ones. Wet ground warms more slowly than dry ground because wet ground contains water. Meadows warm more quickly than forests, and pavements get warm long before grassy lawns. Snow and ice reflect sunlight and remain cold.

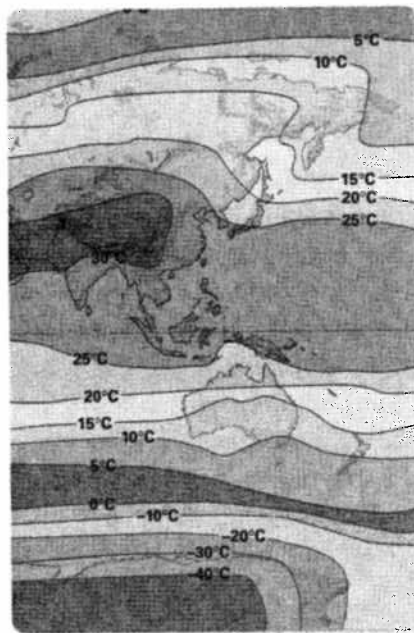
## Temperature Maps

The maps on the following page show mean, or average, temperatures in Asia and Australia for January and July. Notice that the warmest temperatures are to the south of the equator in January and to the north of the equator in July. The sun's rays are more vertical north of the equator in July. Notice also that the warmest and coldest temperatures are over land.

Land heats and cools more readily than water, so the continents are warmer than nearby oceans in the summer and colder than the nearby oceans in the winter.



MEAN SEA-LEVEL TEMPERATURES IN JANUARY



MEAN SEA-LEVEL TEMPERATURES IN JULY

The lines separating the temperature zones on the map are isotherms. **Isotherms** are lines that connect places with the same temperature. Because temperature decreases with altitude, the temperatures on the map are adjusted to eliminate the effect of altitude.

**How Does the Temperature at One Location Change over a Year?**

Compare animations of global insolation and temperature maps. List factors that affect global variations.

Keycode: ES1706

**VOCABULARY STRATEGY**

In the word *isotherm*, *iso-* means "equal" and *-therm* means "heat."

**17.3 Section Review**

- 1 How does the angle at which sunlight strikes Earth's surface affect the intensity of the sunlight?
- 2 When does the highest temperature of the day usually occur? Why?
- 3 Why is it warmer near the equator than near the poles?
- 4 In the United States, why is it colder in the winter and warmer in the summer?
- 5 Explain why water doesn't get as hot as land on a clear summer day.
- 6 **CRITICAL THINKING** The daily temperature range is the difference between the day's maximum and minimum temperatures. Why is the daily temperature range greater on clear days than on cloudy ones?
- 7 **PHYSICS** Work with a classmate to design an experiment that tests whether a black substance or a white substance would be better for collecting solar heat.

# 17.4

## KEY IDEA

Human activities affect the atmosphere by producing air pollutants and other substances that contribute to problems such as acid rain and ozone depletion.

## KEY VOCABULARY

- air pollutant
- temperature inversion

## Human Impact on the Atmosphere

The modern transportation and manufacturing technologies that provide many benefits for everyday life also have some negative effects on the environment. These effects include local air pollution as well as worldwide problems such as ozone depletion and global warming.

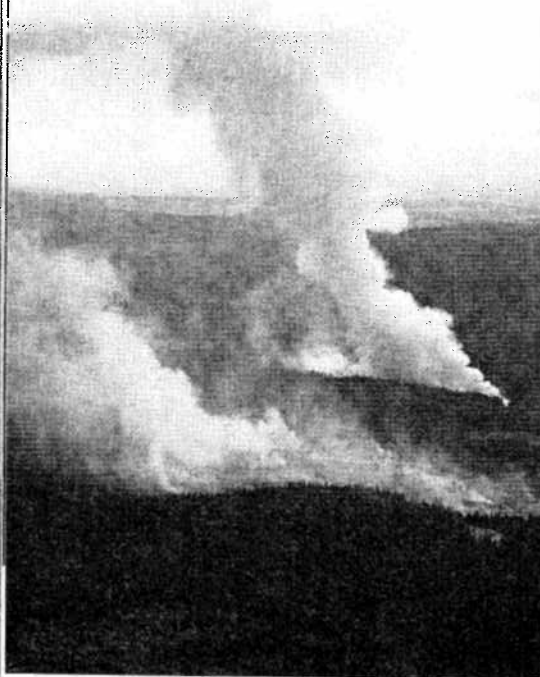
## Common Air Pollutants

An **air pollutant** is any airborne gas or particle that occurs at a concentration capable of harming humans or the environment. Although some air pollution is caused by natural sources such as volcanoes and forest fires, human activity produces a significant amount of the pollutants that are of greatest concern today. Locally, pollution can affect individuals by limiting their outdoor activity and causing health problems. On a global level, pollution contributes to several environmental problems, including acid rain and the depletion of the ozone layer.

In the United States, the Clean Air Act of 1970 identified six key pollutants as indicators of air quality. The table below lists these pollutants, their major sources, and their environmental effects.

Common Air Pollutants

Air Pollutant	Major Sources	Effects
Carbon monoxide (CO)	automobile exhaust	Reduces delivery of oxygen to body tissues; impairs vision and reflexes
Nitrogen dioxide (NO <sub>2</sub> )	burning of fossil fuels in power plants and automobiles	Irritates lungs and lowers resistance to respiratory infections; contributes to acid rain and smog
Sulfur dioxide (SO <sub>2</sub> )	burning of fossil fuels in power plants, oil refineries, paper mills, volcanoes	Irritates respiratory system; contributes to acid rain
Particulate matter (dust, smoke, soot, ash)	factories, power plants, oil refineries, paper mills, volcanoes	Contributes to respiratory problems; linked to some cancers
Lead (Pb)	smelters, battery plants	Damages nervous and digestive systems
Ozone (O <sub>3</sub> )	reactions of nitrogen oxides and hydrocarbons in the presence of sunlight	Reduces lung function and causes inflammation



**SMOKE** from forest fires contains carbon monoxide, carbon dioxide, and particulate matter. These substances contribute to global warming and smog.

As people have become more aware of the dangers of air pollution, efforts to prevent it have increased. The Environmental Protection Agency monitors levels of air pollution and establishes regulations aimed at reducing pollution. Scientists and environmental engineers are identifying

sources of pollution, tracking pollution trends, developing alternative energy sources, and refining devices and methods to limit industrial pollution. Private citizens are becoming more knowledgeable consumers and are purchasing products that don't harm the atmosphere. People have also become active in conservation efforts, such as recycling and limiting their use of fossil fuels.

## Acid Rain

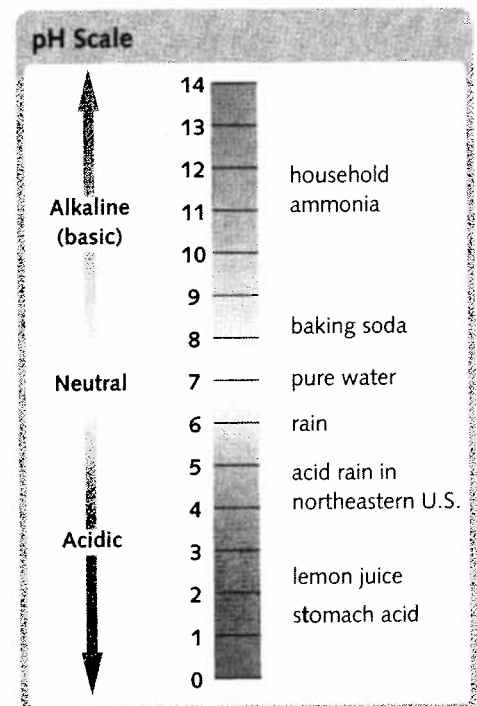
Acid precipitation, which is commonly called acid rain, forms when pollutants such as sulfur dioxide and nitrogen oxides react with water vapor in the air. The resulting acid precipitation can fall to the ground as rain or snow.

Acidity is measured using pH. The scale at the right shows how the pH of acid rain compares with the pH of some common substances. Notice that rain is naturally slightly acidic with a pH just under 6, but pollution has significantly increased the acidity of rain in some areas. On the pH scale, reading from 7 to 0, each whole number represents a tenfold change in acidity. In other words, pH 5 is ten times more acidic than pH 6, and pH 4 is 100 times more acidic than pH 6.

Acid precipitation can harm both plant and animal life. Most life forms can survive only within a limited range of pH, and acid rain can lower the pH beyond that range. This effect is noticeable in thousands of lakes and streams throughout the United States and Canada, where many fish populations have died out due to the increased acidity. Acid precipitation also harms forests by stripping away vital nutrients from the soil. This loss of nutrients limits the growth of trees and makes them vulnerable to damage and parasites. These harmful effects have damaged regional tree populations, such as the spruce trees found in the Appalachian Mountain range of the eastern United States.

Acid precipitation also damages structures built of limestone or marble. Reactions between acid rain and the calcite in limestone and marble dissolve the calcite, resulting in roughened surfaces and loss of carved details. Cultural monuments that have been damaged by acid rain, like the ancient Parthenon in Greece, are expensive to restore and are sometimes permanently damaged.

Observe forest fires as seen from space.  
Keycode: ES1707



**pH SCALE** The pH scale ranges from 0 to 14, with a value of 7 considered neutral.



**ACID RAIN** These scientists are sampling the acidity of a lake where the fish population has died out due to acid rain.

## Smog

The term *smog* was coined in the early 1900s to refer to the smoky fog in London, which resulted from emissions of particulate matter and other pollutants from factories. Today, smog is primarily used to refer to photochemical smog, a brownish haze that forms in air polluted with nitrogen oxides and hydrocarbons that come mainly from automobile exhaust. When these pollutants are present, solar radiation can trigger a chain of chemical reactions that form ozone and other harmful substances. Although ozone in the stratosphere protects Earth from ultraviolet radiation, ground-level ozone is a powerful lung irritant that can cause respiratory problems and illness. Ozone also stunts the growth of plants by interfering with photosynthesis. As a result, the ozone in smog can reduce crop yields and hurt the agricultural industry.

The severity of smog depends on atmospheric conditions. Usually convection mixes warm air from near Earth's surface with the cooler air above, thus diluting any pollutants. Sometimes, however, the air at Earth's surface is colder than the air above, so convection does not occur. This situation is called a **temperature inversion**. The warm air lying above the cooler air acts as a lid on the underlying air pollutants, trapping them close to the ground and allowing smog to build to dangerous levels.



NO INVERSION NEAR SURFACE



INVERSION NEAR SURFACE

## Ozone Depletion

In Section 17.2, you read about a layer of ozone in the stratosphere that absorbs harmful ultraviolet radiation. In the 1970s, scientists began to suspect that the ozone layer was being harmed by chlorofluorocarbons (KLAWR-oh-FLUR-oh-KAHR-buhnz), or CFCs, manufactured compounds that were widely used in products such as aerosol sprays, air conditioners, and solvents. Since the 1980s, scientists have documented a thinning of the global ozone layer. An extremely thin area of the ozone layer, popularly called the ozone hole, forms over Antarctica each spring.

Increased exposure to ultraviolet radiation results from ozone depletion and is dangerous to humans and the environment. Risks to

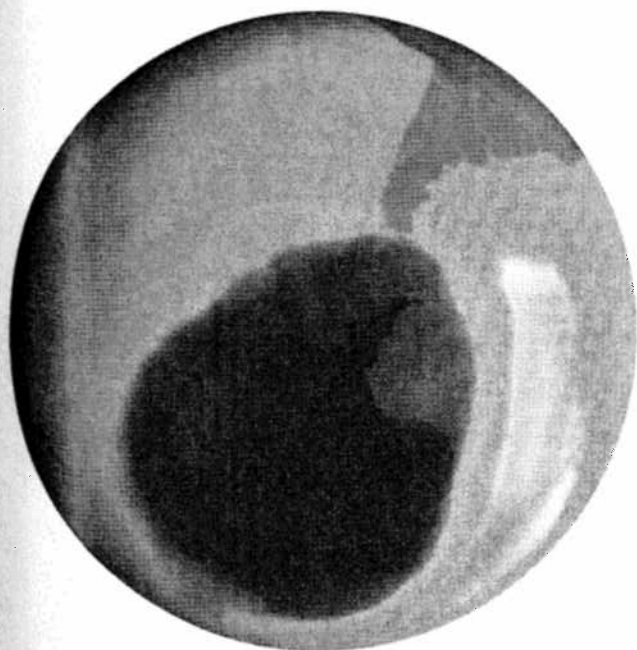
humans include certain types of skin cancer, cataracts, premature skin aging, and weakening of the immune system. Higher levels of radiation also harm crops and destroy sensitive marine life such as phytoplankton.

Concerns about ozone depletion have led more than 170 nations to sign the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, a treaty to reduce and eventually eliminate the production of all CFCs and other ozone-depleting substances by 2006. Based on the success of this agreement, stratospheric ozone levels are expected to return to normal by about 2050.

### How Does the Ozone Layer Change over Time?

Use an interactive animation to compare images of the amount of ozone over the Southern Hemisphere by month or by year.

Keycode: ES1708



#### OZONE HOLE

In this computer-generated image, the dark blue area indicates a region with very low ozone concentration in the Southern Hemisphere, October 1999.

## Global Warming

Available data indicate that the average global temperatures have increased by about 1°C since the late 1800s. It is possible that this global warming is part of the natural cycle of temperature change that has occurred throughout Earth's history. However, many scientists are concerned that human activities are most likely contributing to global warming.

Recall from Section 17.2 that carbon dioxide, water vapor, and other naturally occurring molecules in the atmosphere keep Earth's surface warm through the greenhouse effect. The level of greenhouse gases in the atmosphere has risen significantly in the past two centuries. This increase is due primarily to human activities such as the burning of fossil fuels and global deforestation, both of which release CO<sub>2</sub>. Global deforestation also contributes to higher CO<sub>2</sub> levels both because burning trees releases CO<sub>2</sub> and because trees are no longer present to absorb CO<sub>2</sub> from the atmosphere after they have been cut down or burned.

The connections among human activity, greenhouse gases, and a rise in global temperatures are complex and difficult to predict. Atmospheric scientists are currently using computer models to investigate the potential impact of increased levels of greenhouse gases on Earth's temperatures. Most models predict that warming will continue, but there is still uncertainty about the extent of the warming and its likely effects.

## Scientific Thinking

### ANALYZE

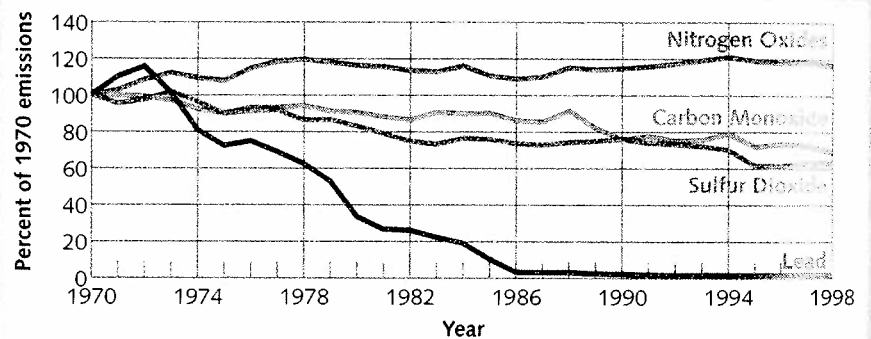
Given the uncertainty about the precise causes and effects of global warming, some governments are choosing to reduce emissions of greenhouse gases, while others are resisting such actions. What are the potential benefits of reducing greenhouse gas emissions? What might be the risks associated with not reducing emissions?

Preliminary evidence indicates that possible effects include

- rising sea levels due to melting polar ice caps;
- increasing frequency and severity of storms and hurricanes;
- more frequent heat waves and droughts; and
- relocation of major crop-growing areas.

Given the potential impact of these effects, studies of greenhouse gases and climate will remain a critical area of research for years to come. Meanwhile, governments have begun to take action. Some nations have passed laws to limit their own production of greenhouse gases. The Kyoto Protocol, an international agreement established in 1997, proposed a dramatic reduction in greenhouse gas emissions worldwide. However, controversy about the terms of this agreement and its implementation continued into the early years of the twenty-first century.

National Emissions of Pollutants



**EMISSIONS OF POLLUTANTS** What does the increase in the emissions of nitrogen oxides since 1970 tell you?

## 17.4 Section Review

- 1 List some examples of pollutants created by the burning of fossil fuels. What are the effects of these pollutants?
- 2 What are some of the damaging effects of acid rain?
- 3 Explain how a temperature inversion affects smog.
- 4 What are some human activities suspected of contributing to global warming?
- 5 **CRITICAL THINKING** A new car today produces 60 to 80 percent less pollution than a car in the 1960s, yet air quality has improved less than expected. What are some possible reasons why cleaner exhaust has not significantly reduced total emissions from cars?
- 6 **PAIRED ACTIVITY** Work with a partner to create a poster or other visual display contrasting surface-level ozone and ozone in the stratosphere. Be sure to include information about the formation and effects of ozone in these two different layers of the atmosphere.

## New Ideas Help Fight Air Pollution

*Is air pollution an inevitable effect of modern society? Is it possible to run cars and generate electricity without polluting the air? As pollution issues become more critical, more of the world's best thinkers are tackling these problems.*

What can be done to meet society's energy needs without degrading the environment?

Several promising developments will help reduce air pollution. Hybrid electric cars hit the market in 2000, sending the auto industry in a new direction. A hybrid car burns gasoline in a small combustion engine. Leftover kinetic energy recovered during braking keeps a charge in the battery that accelerates the car. This combination of electricity and gasoline creates the highest mileage efficiency of any car ever sold in the mass market, without restrictive range limitations.

Even these cars might be old news before the decade is out. Several automakers plan to sell cars powered

by fuel cells that run on liquid hydrogen. Fuel cells make electricity from chemical reactions. With hydrogen as the fuel, the only waste products are water and heat. Fuel cells offer potential for powering homes and businesses, too.

In California, wind power produces electricity at a cost-competitive price. As the cost of generating wind power continues to fall, wind farms featuring hundreds of tower-mounted rotors are expected to crop up around the country.

Perhaps the most futuristic idea comes from NASA. The space agency is investigating Space Solar Power,

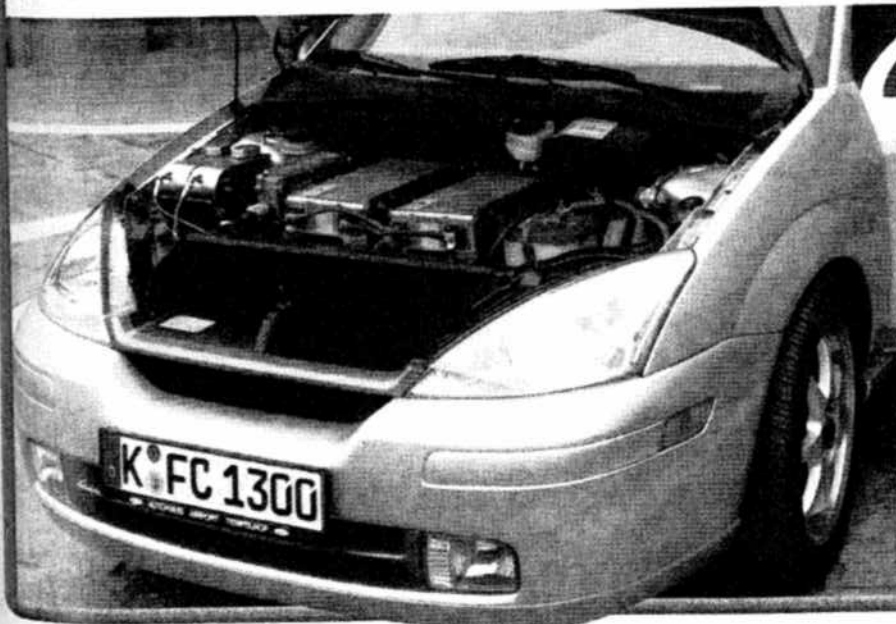


**DEVELOPING TECHNOLOGY** This engineer is removing a fuel cell from an electric generator. These small generators may change the way electricity is delivered.

which involves placing large solar collectors into orbit. These satellites would beam vast amounts of microwave energy to power stations on Earth, where it would enter local electrical power grids.

Advances in technology will lead to new solutions to today's daunting pollution problems and secure a sustainable environment for the future. ■

**REDUCING POLLUTION** Fuel-cell-powered cars, such as this one, emit no harmful exhausts.



### Extension

#### SCIENCE NOTEBOOK

There are tradeoffs to everything. Consider the possible issues with alternative energy solutions and cleaner energy options. Are the costs worth the benefits? Explain.



Learn how air pollution can be reduced.

Keycode: ES1709

## Absorption and Radiation of Heat

### SKILLS AND OBJECTIVES

- **Record** temperature changes produced by heat absorption and radiation.
- **Compare** light and dark materials and dull and shiny materials in terms of the amount of heat they absorb and radiate.
- **Compare** the “land” and “ocean” in terms of the heat they absorb and radiate.

### MATERIALS

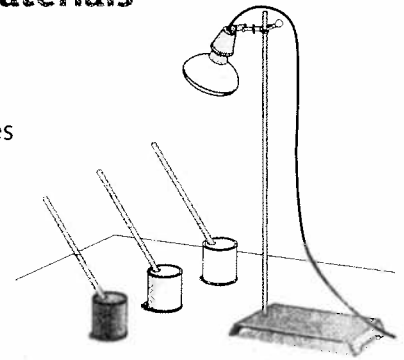
- 3 empty soup cans (1 painted dull white, 1 painted dull black, and 1 shiny silver, each with a hole punched in the unopened end for inserting a thermometer)
- 3 250-mL beakers
- 3 thermometers with ranges of 0°C to at least 50°C
- desk lamp or clip-on lamp with incandescent bulb of at least 100 watts
- ring stand
- 3 ring clamps
- stopwatch
- topsoil
- water
- coarsely ground concrete
- 2 sheets of graph paper

The effects of the sun’s radiation vary depending on the type of surface. In this investigation, you will compare the effect of heat absorption and radiation on objects of different colors and reflectivity. You will then investigate absorption and radiation on several types of surfaces: land, represented by soil; ocean, represented by water; and urban areas, represented by concrete.

### Procedure

#### Part A: Light and Dark Materials

- 1 Set up the apparatus and place the cans with their open ends down. Put thermometers through the holes in the closed ends of the cans. The thermometers should be at the same angle, slanting in the same direction.
- 2 Set the lamp at a height of 12 cm above the cans. Make sure the cans are equidistant from the lamp. Before turning on the lamp, make sure the thermometer readings are at room temperature.
- 3 Copy the data table and record the room temperature for all 3 cans under 0 minutes. Then switch on the lamp. Record the temperatures of the cans every 2 minutes for the next 10 minutes. At the end of 10 minutes, turn off the lamp and continue to record the temperatures every 2 minutes for an additional 10 minutes.
- 4 On a sheet of graph paper, plot the times and temperatures for the black can and connect the points with a smooth curve. Repeat for the white can and the shiny can. Label each curve on the graph.

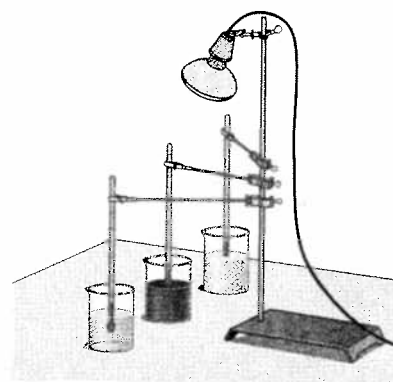


		Heating and Cooling Temperatures (°C)										
		Heating						Cooling				
TIME (minutes):		0	2	4	6	8	10	12	14	16	18	20
Part A	Black can temperature											
	White can temperature											
	Shiny can temperature											
Part B	Water temperature											
	Soil temperature											
	Concrete temperature											

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## Part B: Land and Ocean

- 5 Fill half of one beaker with water at room temperature. Fill half of the second beaker with soil. Fill half of the third beaker with the concrete.
- 6 Arrange the apparatus as shown to the right. Set up one thermometer in the soil with its bulb just below the surface. Repeat the setup for the beakers filled with water and concrete.
- 7 Set the lamp at a height of 30 cm above the water, concrete, and soil surfaces. Make sure the beakers are equidistant from the lamp.
- 8 Repeat Step 3 for the beakers filled with water, soil, and concrete.
- 9 Repeat Step 4 for the data collected for the water, soil, and concrete.



## Analysis and Conclusions

1. Study the three curves on your graph from Part A. Which can warmed up most in the first 10 minutes? Which can warmed up the least?
2. The greater the amount of heat absorbed or radiated, the greater the change in temperature. Which can absorbed the most heat? Which can radiated the most heat? Explain your answer.
3. How do color and shininess affect absorption and radiation? How might the choice of color or of metallic paint affect the temperature inside a car?
4. Which material in Part B absorbed more heat in the first 10 minutes?
5. Compare the graphs from Parts A and B. Which surfaces absorbed and radiated the most heat? How are they similar?
6. The sun shines with equal intensity on a stretch of tilled land, a concrete road, and the ocean. Which area will heat up most during the day? Which area will cool the slowest at night? Explain.
7. Portland, Maine, and Pierre, South Dakota, are located at approximately  $44^{\circ}\text{N}$  latitude. Portland is close to the Atlantic coast and Pierre is in the middle of North America. Which city is warmer on average in the summer? In the winter, Earth's surface tends to lose heat. On average, which city do you predict will be colder in the winter? Explain your answers.

# CHAPTER 17

## REVIEW

### Summary of Key Ideas

**17.1** Earth's atmosphere contains nitrogen and oxygen, with small amounts of other gases. Gases move between the atmosphere and other parts of the Earth system, yet the composition of the atmosphere remains fairly constant. Local events can change the composition of the atmosphere, with global consequences.

**17.2** Heat moves by radiation, convection, and conduction. The atmosphere is divided into layers based on temperature. An imbalance in Earth's heat budget changes Earth's mean temperature.

**17.3** The intensity of insolation depends upon the angle at which sunlight strikes Earth's surface. The intensity is greatest at low latitudes, during the summer, and around noon. Land heats and cools more readily than water. Isotherms shift with the seasons, more dramatically over land than over water.

**17.4** Pollutants can react with water vapor to form acid precipitation, be trapped by temperature inversions to cause thick smog, reduce the amount of ozone in the ozone layer, and contribute to global warming.

### KEY VOCABULARY

air pollutant (p. 378)	ozone (p. 371)
conduction (p. 369)	radiation (p. 369)
convection (p. 369)	stratosphere (p. 370)
heat (p. 370)	temperature (p. 369)
insolation (p. 372)	temperature inversion (p. 380)
ionosphere (p. 372)	thermosphere (p. 371)
isotherm (p. 377)	troposphere (p. 370)
mesosphere (p. 371)	

### Vocabulary Review

Explain the difference between the terms in each pair.

1. conduction, convection
2. convection, radiation
3. troposphere, stratosphere

Write the term from the key vocabulary list that best completes the sentence.

4. The bottom layer in a(n) \_\_\_\_\_ of air is colder than the air above it.
5. On a map, all of the points on a(n) \_\_\_\_\_ are the same temperature.
6. Although in the stratosphere it is beneficial to humans, \_\_\_\_\_ near Earth's surface is harmful to humans.

### Concept Review

7. Which gas makes up most of the atmosphere?
8. Describe several ways in which gases enter and leave the atmosphere.
9. Why is air warmer at the top of the stratosphere than at the top of the troposphere?
10. Describe three ways energy is transferred from Earth's surface to the atmosphere.
11. If there were no greenhouse gases in the atmosphere, how would Earth's temperature be different than it is today? Explain your thinking.
12. Why are the poles colder than the equator?
13. Describe at least two ways humans increase the amount of carbon dioxide in the atmosphere.
14. **Graphic Organizer** Copy and complete the table below to summarize how insolation depends on location and time.

SUMMARY Intensity of Insolation		
	Greatest	Least
Time of day	around noon	nighttime
Time of year	?	?
Latitude	?	?

## Critical Thinking

- 15. Contrast** Explain how the composition of the atmosphere differs from the atmosphere over a field of wheat and from the atmosphere over a tropical forest.
- 16. Communicate** Draw and label a diagram to describe how convection helps to cool the waters of a lake in autumn.
- 17. Hypothesize** The atmosphere of Venus is about 97 percent carbon dioxide. How would Venus's heat budget differ from Earth's? Explain.
- 18. Analyze** Describe at least two ways in which Earth's heat budget could become out of balance.
- 19. Hypothesize** Refer to the section about albedo in Unit 1 (pages 17–18). Based on what you know, write a hypothesis about whether buildings in warm areas should be painted with light colors or dark colors.
- 20. Infer** Why are temperature inversions near Earth's surface unlikely on cloudy nights?

## Interpreting Graphs

A student performed an experiment to compare the heating and cooling rates of soil and water. She placed identical containers, one filled with soil and the other filled with water, at equal distances from a light source. A thermometer was placed in each container to record the temperatures. She turned the light on and recorded the temperatures each minute for 10 minutes. Then she turned the light off and again recorded the temperatures each minute for 10 minutes. A graph of her data is shown at right.

21. In which container did the material warm faster?
22. In which container did the material cool faster?
23. Which container held the water?
24. Did the soil and water both warm the same amount? Why or why not?
25. The smallest daily temperature ranges at Earth's surface are less than  $1^{\circ}\text{C}$ . Where are they and why? What sort of location would usually have the largest temperature range? Why?

## Internet Extension



Learn more about instruments used to study the atmosphere.

Keycode: ES1710

## Writing About the Earth System

**SCIENCE NOTEBOOK** Because of plate tectonics, the continents were once closer to the equator than they are today. How would the temperature of the continents at that time have been different from their temperatures today? Currently, much of the land at high latitudes is ice covered. Was there more or less ice on Earth when the continents were closer to the equator? How might this difference in ice cover have affected the heat budget? Explain your thinking.

