Air

CHAPTER 12

READING WARM-UP

Before you read this chapter, take a few minutes to answer the following questions in your ***EcoLog***.

1. Describe the air quality in your area.
2. If there is air pollution in your area, what do you think causes it?

Nagano, Japan, is just one of many cities around the world that suffers from unhealthy levels of air pollution.

SECTION 1

What Causes Air Pollution?

In Mexico City, children rarely use the color blue when they make paintings of the sky. This metropolitan area of 20 million people is known as the most dangerous city in the world for children because of its very polluted air. When pollution levels are high, students are banned from playing outdoors until the emergency passes.

Clean air consists mostly of nitrogen and oxygen gas, as well as very small amounts of argon, carbon dioxide, and water vapor. When harmful substances build up in the air to unhealthy levels, the result is **air pollution.** Substances that pollute the air can be in the form of solids, liquids, or gases.

Most air pollution is the result of human activities, but pollutants can also come from natural sources. A volcano, for example, can spew clouds of particles and sulfur dioxide, SO_2, into the atmosphere. Natural pollutants also include dust, pollen, and spores.

Objectives

- Name five primary air pollutants, and give sources for each.
- Name the two major sources of air pollution in urban areas.
- Describe the way in which smog forms.
- Explain the way in which a thermal inversion traps air pollution.

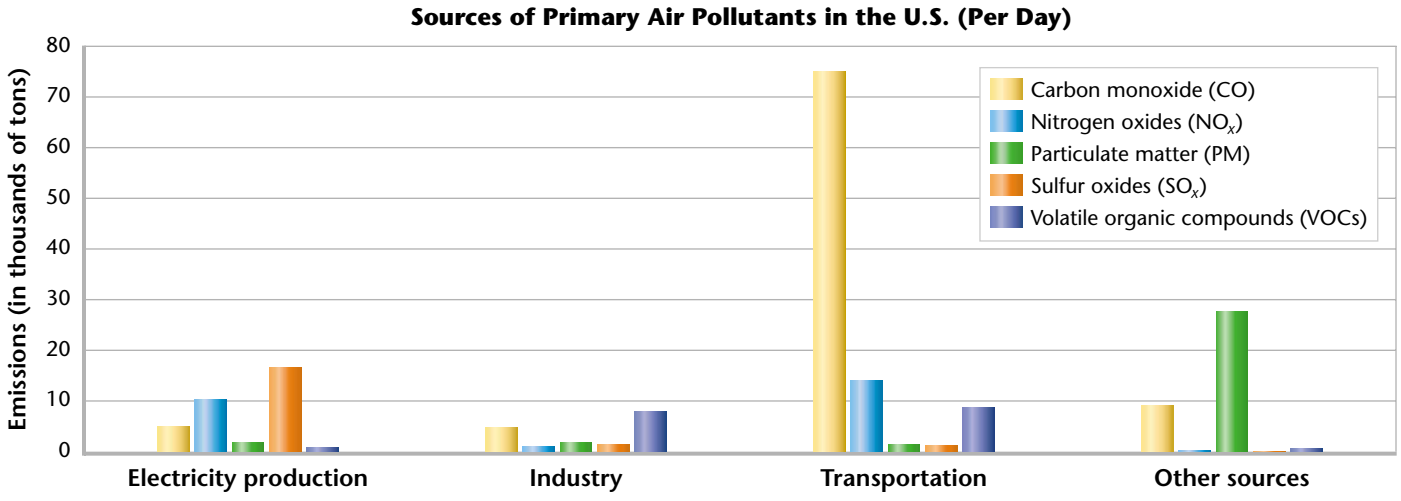
Key Terms

air pollution
primary pollutant
secondary pollutant
smog
temperature inversion

Primary and Secondary Pollutants

A pollutant that is put directly into the air by human activity is called a **primary pollutant.** An example of a primary pollutant is soot from smoke. **Figure 1** shows some sources of primary air pollutants. **Secondary pollutants** form when a primary pollutant comes into contact with other primary pollutants or with naturally occurring substances such as water vapor and a chemical reaction takes place. An example of a secondary pollutant is ground-level ozone. Ground-level ozone forms when the emissions from cars, trucks, and natural sources react with the ultraviolet rays of the sun and then mix with the oxygen in the atmosphere.

Figure 1 ▶ Each day in the United States, hundreds of thousands of tons of polluting emissions that result from human activity enter the air.



Source: U.S. Environmental Protection Agency.

Table 1 ▼

Primary Air Pollutants			
Pollutant	**Description**	**Primary Sources**	**Effects**
Carbon monoxide (CO)	CO is an odorless, colorless, poisonous gas. It is produced by the incomplete burning of fossil fuels.	Sources of CO are cars, trucks, buses, small engines, and some industrial processes.	CO interferes with the blood's ability to carry oxygen, slowing reflexes and causing drowsiness. In high concentrations, CO can cause death.
Nitrogen oxides (NO_x)	When combustion (burning) temperatures exceed 538°C, nitrogen and oxygen combine to form nitrogen oxides.	NO_x comes from burning fuels in vehicles, power plants, and industrial boilers.	NO_x can make the body vulnerable to respiratory infections, lung diseases, and cancer. NO_x contributes to the brownish haze seen over cities and to acid precipitation.
Sulfur dioxide (SO_2)	SO_2 is produced by chemical interactions between sulfur and oxygen.	SO_2 comes mostly from burning fossil fuels.	SO_2 contributes to acid precipitation as sulfuric acid. Secondary pollutants that result from reactions with SO_2 can harm plant life and irritate the respiratory systems of humans.
Volatile organic compounds (VOCs)	VOCs are organic chemicals that vaporize readily and form toxic fumes.	VOCs come from burning fuels. Vehicles are a major source of VOCs.	VOCs contribute to smog formation and can cause serious health problems, such as cancer. They may also harm plants.
Particulate matter (particulates or PM)	Particulates are tiny particles of liquid or solid matter.	Most particulates come from construction, agriculture, forestry, and fires. Vehicles and industrial processes also contribute particulates.	Particulates can form clouds that reduce visibility and cause a variety of respiratory problems. Particulates have also been linked to cancer. They may also corrode metals and erode buildings and sculptures.

Sources of Primary Air Pollutants As shown in **Table 1** above, household products, power plants, and motor vehicles are sources of primary air pollutants such as carbon monoxide, nitrogen oxide, sulfur dioxide, and chemicals called *volatile organic compounds* (VOCs). Carbon monoxide gas is an important component of the exhaust from vehicles. Vehicles are also a major source of nitrogen oxide emissions. Coal-burning power plants are another source of nitrogen oxide. Sulfur dioxide gases are formed when coal and oil, which contain sulfur, are burned. Power plants, refineries, and metal smelters contribute much of the sulfur dioxide emissions to the air. Vehicles and gas station spillage make up most of the human-made emissions of volatile organic compounds. VOCs are also found in many household products.

Particulate matter can also pollute the air and is usually divided into fine and coarse particles. Fine particles enter the air from fuel burned by vehicles and coal-burning power plants. Sources of coarse particles are cement plants, mining operations, incinerators, wood-burning fireplaces, fields, and roads.

The History of Air Pollution

Air pollution is not a new phenomenon. Whenever something burns, pollutants enter the air. Two thousand years ago, Seneca, a Roman philosopher and writer, complained about the foul air in Rome. In 1273, England's King Edward I ordered that burning a particularly dirty kind of coal called sea-coal was illegal. One man was even hanged for disobeying this medieval "clean air act."

The world air-quality problem is much worse today because modern industrial societies burn large amounts of fossil fuels. As shown in **Figure 2**, most air pollution in urban areas comes from motor vehicles and industry.

Motor Vehicle Emissions

Almost one-third of our air pollution comes from gasoline burned by vehicles. According to the U.S. Department of Transportation, Americans drove their vehicles over 2.6 trillion miles in 1998. Over 90 percent of that mileage was driven by passenger vehicles. The rest was driven by trucks and buses.

Controlling Vehicle Emissions The Clean Air Act, passed in 1970 and strengthened in 1990, gives the Environmental Protection Agency (EPA) the authority to regulate vehicle emissions in the United States. The EPA required the gradual elimination of lead in gasoline, and as a result, lead pollution has been reduced by more than 90 percent in the United States. In addition, catalytic converters, which are required in automobiles, clean exhaust gases of pollutants before the pollutants are able to exit the tailpipe. The EPA estimates that cars and trucks today burn fuel 35 percent more efficiently and with 95 percent fewer emissions of pollutants, excluding carbon dioxide, than they did 30 years ago.

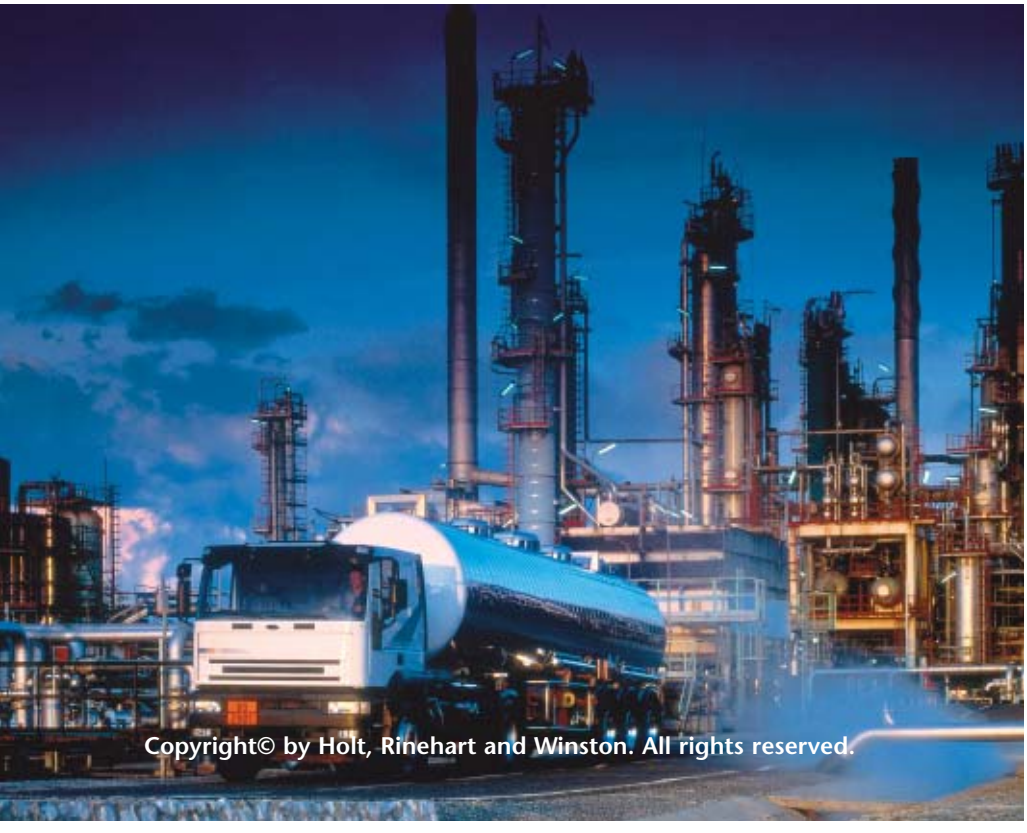


Figure 2 ▶ The refinery shown in this photograph is a source of volatile organic compounds. The tanker truck in the foreground is emitting nitrous oxide into the atmosphere.

Geofact

Sea-Coal In 12th-century London, wood was becoming too scarce and too expensive to use as a fuel source. Large deposits of coal called *sea-coal* that are found off the northeast coast of England provided a plentiful alternative. However, this soft coal did not burn efficiently. The sea-coal produced mostly smoke and not much heat. The smoke from the coal emanated from London homes and factories and combined with fog to produce smog.

Connection to Law

Off with His Head! Around 1300 CE, King Edward II of England forbade the burning of coal while Parliament was in session. "Be it known to all within the sound of my voice," King Edward II said, "whosoever shall be found burning coal shall suffer the loss of his head."

MATHPRACTICE

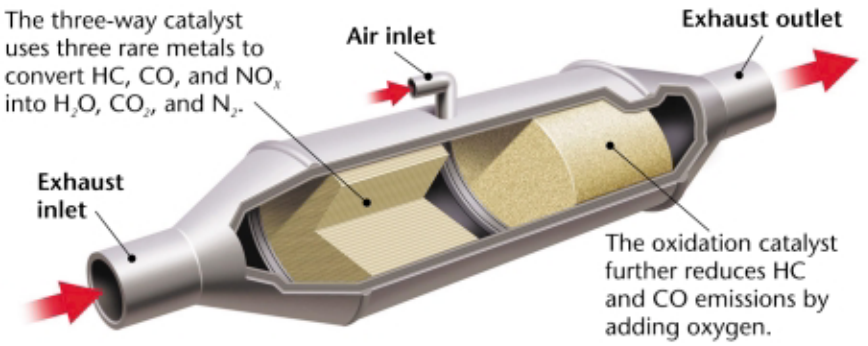
Utility Incentives for Zero-emission Vehicles

The Los Angeles Department of Water and Power provides discounts of $0.025 per kilowatt hour (kWh) for electricity used to recharge electric vehicles. If the energy charge per kWh is $0.02949 and you use 150 kWh hours of electricity per month to recharge your vehicle, how much money would you save on your electric bill each month? each year? How much would you save if you had three electric cars?

California Zero-Emission Vehicle Program In 1990, the California Air Resources Board established the zero-emission vehicle (ZEV) program. *Zero-emission vehicles* are vehicles that have no tailpipe emissions, no emissions from gasoline, and no emission-control systems that deteriorate over time. **Figure 3** illustrates the catalytic converter emission-control system that is in use today as well as the ways an automobile contributes to air pollution.

By the year 2016, 16 percent of all vehicles sold in California are required to be zero-emission vehicles. This requirement includes sports utility vehicles (SUVs), trucks, small vans, and automobiles. At present, ZEVs such as electric vehicles are for sale in California, and vehicles with advanced batteries are being demonstrated by the major automakers. Vehicles powered by hydrogen fuel are being developed and will qualify as zero-emission vehicles. Partial zero-emissions vehicles are also included in the program. These vehicles include hybrid-electric cars and cars powered by methanol fuel cells. Zero-emission vehicle programs have also been adopted by Maine, Massachusetts, New York, and Vermont.

Figure 3 ▶ The catalyst material in a catalytic converter (top) causes a chemical reaction that changes exhaust emissions to less harmful substances. The bottom illustration shows a car's contribution to air pollution.



Interior

▶ Car seats may be covered in plastic that contains a volatile organic compound called *vinyl chloride.*

▶ Each time an air conditioner is installed in a car, 1.1 kg (2.5 lb) of chlorofluorocarbons (CFCs) are released into the air. Each time an air conditioner is recharged, 0.5 kg (1 lb) of CFCs are released.

Body and Frame

▶ Steel smelters send thousands of metric tons of sulfur dioxide into the air each year.

▶ Many auto factories in Mexico, Eastern Europe, and some Asian countries lack pollution-control devices.

Fuel Tank

▶ When filling the car with gasoline, VOCs escape into the atmosphere.

Exhaust

▶ Car exhaust is a major source of nitrogen oxides, carbon monoxide, and hydrocarbons.

▶ In developing countries, car exhaust may contain over a thousand poisonous substances.

▶ Each car releases 4.5 metric tons (5 tons) of carbon dioxide every year.

Figure 4 ▶ In 1996, the federal government established standards to reduce emissions of VOC-producing chemicals used in dry cleaning.

Ecofact

Air Pollution's Impact on Birds
Scientists in Finland have documented the effects of harmful emissions from a copper smelter in Finland on two species of birds that live nearby. The two species of birds respond differently to the pollutants containing heavy metals and acidic substances. One species appears to suffer directly from the toxic effects of the pollutants. The other species suffers because the amount of insect food for its nestlings has been reduced. When heavy metal emissions from the smelter decreased, a rapid improvement in breeding success and decrease in the heavy metal found in the bones of nestlings was observed.

Industrial Air Pollution

Many industries and power plants that generate our electricity must burn fuel to get the energy they need. They usually burn fossil fuels. Burning fossil fuels releases huge quantities of sulfur dioxide and nitrogen oxide into the air. Power plants that produce electricity emit at least two-thirds of all sulfur dioxide and more than one-third of all nitrogen oxides that pollute the air.

Some industries also produce VOCs, which are chemical compounds that form toxic fumes. As shown in **Figure 4,** some of the chemicals used in dry cleaning are sources of VOCs. Oil refineries, chemical manufacturing plants, furniture refinishers, and automobile repair shops also contribute to the VOCs in the air. When people use some of the products that contain VOCs, more VOCs are added to the air.

Regulating Air Pollution From Industry The Clean Air Act requires many industries to use scrubbers or other pollution-control devices. Scrubbers remove some of the more harmful substances that would otherwise pollute the air. A *scrubber,* as shown in **Figure 5,** is a machine that moves gases through a spray of water that dissolves many pollutants. Ammonia is an example of a pollutant gas that can be removed from the air by a scrubber.

Electrostatic precipitators are machines used in cement factories and coal-burning power plants to remove dust particles from smokestacks. In an electrostatic precipitator, gas containing dust particles is blown through a chamber containing an electrical current. An electrical charge is transferred to the dust particles, which causes them to stick to one another and the sides of the chamber. The clean gas is released from the chamber, and the concentrated dust particles can then be collected and removed. Electrostatic precipitators remove 22 million metric tons (20 million tons) of ash generated by coal-burning power plants from the air each year in the United States.

Figure 5 ▶ Scrubbers work by spraying gases with water, which removes many pollutants.

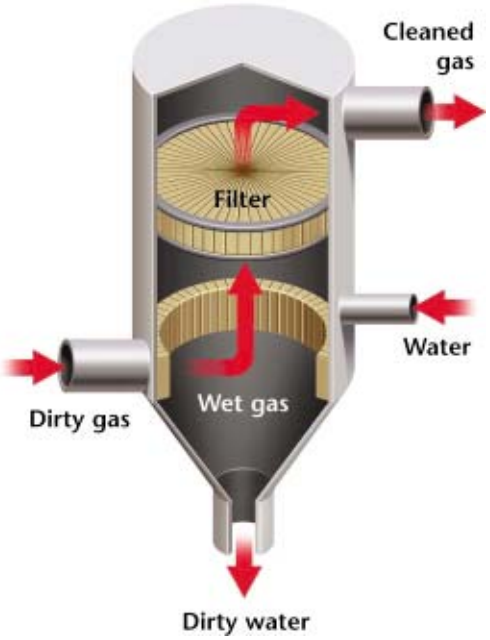


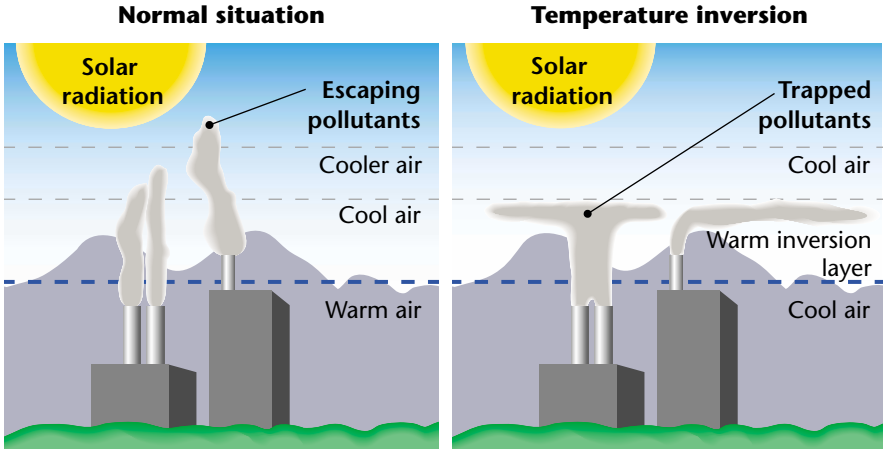
Figure 6 ▶ The diagram below shows how smog is formed. Large cities with dry, sunny climates and millions of automobiles often suffer from smog.

Smog When air pollution hangs over urban areas and reduces visibility, it is called **smog.** As you can see in **Figure 6,** smog results from chemical reactions that involve sunlight, air, automobile exhaust, and ozone. Pollutants released by vehicles and industries are the main causes of smog. Los Angeles, California, Denver, Colorado, and Phoenix, Arizona, are examples of cities that have smog.

Temperature Inversions The circulation of air in the atmosphere usually keeps air pollution from reaching dangerous levels. During the day, the sun heats the surface of the Earth and the air near the Earth. The warm air rises through the cooler air above and carries pollutants away from the ground and into the atmosphere.

Sometimes, however, pollution is trapped near the Earth's surface by a temperature inversion. Usually, air temperatures decrease with height, but in an area with a **temperature inversion,** the air above is warmer than the air below. **Figure 7** shows how a temperature inversion traps pollutants near the Earth's surface. The warmer air above keeps the cooler air at the surface from moving upward. So, pollutants are trapped below with the cooler air. If a city is located in a valley, the city has a greater chance of experiencing temperature inversions. Los Angeles, which is surrounded on three sides by mountains, often has temperature inversions that trap smog in the city.

Figure 7 ▶ Normal air circulation is shown at left, whereas a temperature inversion, in which pollutants are trapped near the Earth's surface, is shown at right.



SECTION 1 Review

1. **Name** five primary air pollutants, and give important sources for each.
2. **Name** the two major sources of air pollution in urban areas.
3. **Describe** the way in which smog forms.
4. **Define** the term *temperature inversion*. Explain how temperature inversion traps pollutants near Earth's surface.

CRITICAL THINKING

5. **Making Decisions** Read the passage on the California Zero-Emission Vehicle Program. Should automobile makers be made to adhere to quotas of zero-emission vehicles set by states, even if the quota causes automakers to lose revenue? READING SKILLS
6. **Analyzing Relationships** Can you think of any other possible type of pollution-control device that could be used to remove particulates from smokestacks in a manner similar to an electrostatic precipitator?

SECTION 2

Air, Noise, and Light Pollution

Air pollution can cause serious health problems. People who are very young or very old and people who have heart or lung problems can be most affected by air pollutants. Decades of research have shown convincing evidence linking air pollution to disease. But because pollution adds to the effects of existing diseases, no death certificates list the cause of death as air pollution. Instead, diseases such as emphysema, heart disease, and lung cancer are cited as causes of death. The American Lung Association has estimated that Americans pay tens of billions of dollars a year in health costs to treat respiratory diseases caused by air pollution.

Short-Term Effects of Air Pollution on Health

Many of the effects of air pollution on people's health are short-term and are reversible if their exposure to air pollution decreases. The short-term effects of air pollution on people's health include headache; nausea; irritation to the eyes, nose, and throat; tightness in the chest; coughing; and upper respiratory infections, such as bronchitis and pneumonia. Pollution can also make the condition of individuals who suffer from asthma and emphysema worse.

Long-Term Health Effects of Air Pollution

Long-term effects on health that have been linked to air pollution include emphysema, lung cancer, and heart disease. Long-term exposure to air pollution may worsen medical conditions suffered by older people and may damage the lungs of children.

Objectives

- Describe three possible short-term effects and long-term effects of air pollution on human health.
- Explain what causes indoor air pollution and how it can be prevented.
- Describe three human health problems caused by noise pollution.
- Describe solutions to energy waste caused by light pollution.

Key Terms

sick-building syndrome
asbestos
decibel (dB)

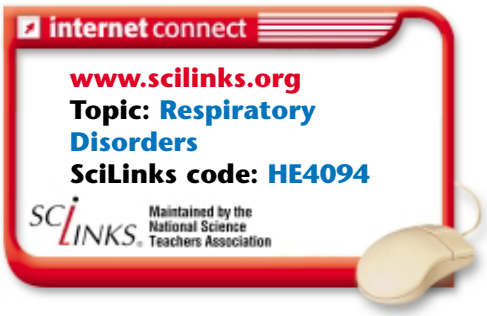


Figure 8 ▶ This police officer wears a smog mask as he directs traffic in Bangkok, Thailand.

Connection to Chemistry

Formaldehyde Formaldehyde is a colorless gas that has a strong odor. It is a very common industrial and commercial chemical that is used to make building materials and household products. In the home, significant amounts of formaldehyde are found in adhesives in plywood, particle board, furniture, and carpet. Other sources of formaldehyde may be foam insulation, gas stoves, tobacco smoke, and dry-cleaned clothing. The health effects of formaldehyde may include eye irritation, burning sensations in the throat, nausea, and difficulty breathing.

Indoor Air Pollution

The quality of air inside a home or a building is sometimes worse than the quality of the air outside. Plastics and other industrial chemicals are major sources of pollution. These compounds can be found in carpets, building materials, paints, and furniture, particularly when these items are new. **Figure 9** shows examples of some indoor air pollutants.

Buildings that have very poor air quality have a condition called **sick-building syndrome.** Sick-building syndrome is most common in hot places where buildings are tightly sealed to keep out the heat. In Florida, for example, a new, tightly sealed county courthouse had to be abandoned. Half of the people who worked there developed allergic reactions to fungi that were growing in the air-conditioning ducts, ceiling tiles, carpets, and furniture.

Identifying and removing the sources of indoor air pollution is the most effective way to maintain good indoor air quality. Ventilation, or mixing outdoor air with indoor air, is also necessary for good air quality. When activities such as renovation and painting, which cause indoor air pollution, are undertaken, ventilation should be increased.

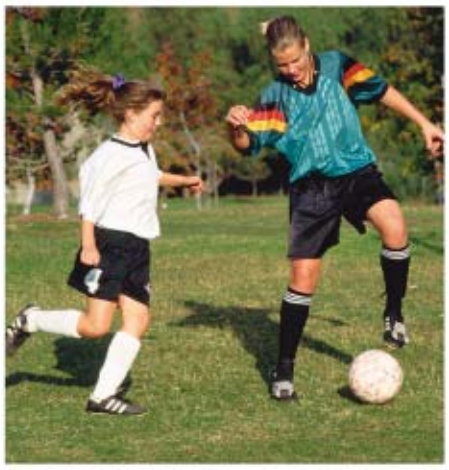
CASE STUDY

The Health Effects of Ground-Level Ozone

You have learned that the ozone layer in the stratosphere shields the Earth from the harmful effects of ultraviolet radiation from the sun. At the surface of the Earth, however, ozone is a human-made air pollutant that at certain concentrations may affect human health.

Ozone forms from the reaction of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of heat and sunlight. High concentrations of ozone form in the atmosphere on sunny days that have high temperatures in the late spring, summer, and early fall. The sources of VOCs and NO_x emissions are largely motor vehicles, power plants, gasoline vapors, and chemical solvents. Most ozone pollution forms in urban and suburban areas. However, pollutants may be transported hundreds of kilometers from their source.

As ozone concentrations in the atmosphere increase, greater numbers of people may experience harmful health effects of ozone on the lungs. Some of the short-term effects of ozone on health include irritation of the respiratory system, a reduction in lung function, the aggravation of asthma, and inflammation to the lining of the lungs. Scientists believe that ozone may have other damaging effects on human health. Lung diseases such as bronchitis and emphysema may be aggravated by ozone. Scientists



▶ Children who engage in vigorous outdoor activities where pollutant concentrations are often high may have a greater risk of developing asthma or other respiratory illnesses.

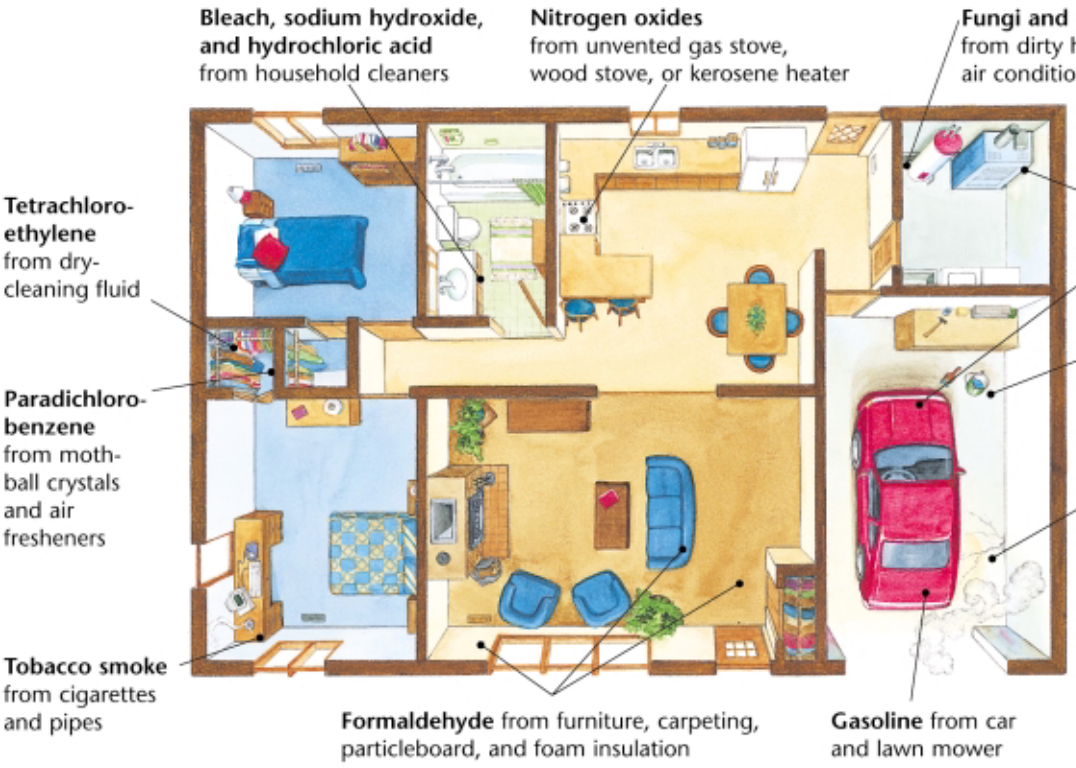


Figure 9 ▶ Some indoor air pollutants and their sources are shown here.

▶ A therapist performs a lung-function test on a patient by using a machine that measures various aspects of lung function.

believe that permanent lung injury may result from repeated short-term exposure to ozone pollution. Children who are regularly exposed to high concentrations of ozone may have reduced lung function as adults. Exposure to ozone may also accelerate the natural decline in lung function that is part of the aging process.

Those who are most at risk from ozone include children, adults who exercise or work outdoors, older people, and people who suffer from respiratory diseases. In addition, there are some healthy individuals who have unusually high susceptibility to ozone.

CRITICAL THINKING

1. Making Decisions Write a brief paragraph explaining whether or not lung-function tests should be mandatory for children who live in urban areas where high concentrations of ozone are frequent.
WRITING SKILLS

2. Making Decisions If lung-function tests become mandatory, who will pay for these tests, and who will provide the equipment? Would these tests be performed at school, in a doctor's office, or at a hospital?

Figure 10 ▶
Asbestos (right) forms in long, thin fibers. The worker above is removing debris from a structure that was built with asbestos.

Radon Gas Radon gas is colorless, tasteless, and odorless. It is also radioactive. *Radon* is one of the elements produced by the decay of uranium, a radioactive element that occurs naturally in the Earth's crust. Radon can seep through cracks and holes in foundations into homes, offices, and schools, where it adheres to dust particles. When people inhale the dust, radon enters their lungs. In the lungs, radon can destroy the genetic material in cells that line the air passages. Such damage can lead to cancer, especially among people who smoke. Radon is the second-leading cause of lung cancer in the United States.

Asbestos Several minerals that form in long, thin fibers and that are valued for their strength and resistance to heat are called **asbestos.** Asbestos is primarily used as an insulator and as a fire retardant, and it was used extensively in building materials. The U.S. government banned the use of most asbestos products in the early 1970s. Exposure to asbestos in the air is dangerous. Asbestos fibers that are inhaled can cut and scar the lungs, which causes the disease asbestosis. Victims of the disease have more and more difficulty breathing and may eventually die of heart failure. Schools in the United States have taken this threat seriously. Billions of dollars have been spent to remove asbestos from school buildings. **Figure 10** shows asbestos fibers and asbestos removal from a building.

Table 2 ▼

Intensity of Common Noises	
Noise	**Intensity (dB)**
Rocket engine	180
Jet engine	140
Rock-and-roll concert	120
Car horn	110
Chainsaw	100
Lawnmower	90
Doorbell	80
Conversation	60
Whisper	30
Faintest sound heard by the human ear	0

Noise Pollution

A sound of any kind is called a noise. However, some noises are unnecessary and can cause noise pollution. Noise is a pollutant that affects human health and the quality of human life. Airplanes, construction equipment, city traffic, factories, home appliances, and lawnmowers are some of the examples of things that make unnecessary sounds that commonly travel through the air. Health problems that can be caused by noise pollution include loss of hearing, high blood pressure, and stress. Noise can also cause loss of sleep, which may lead to decreased productivity at work and in the classroom.

The intensity of sound is measured in units called **decibels (dB).** The lowest point on the decibel scale is 0 dB and the highest point is 180 dB. For each increase in decibel intensity, the decibel level is 10 times higher than the previous level. For example, 20 dB is 10 times the intensity of 10 dB, 30 dB is 100 times the intensity of 10 dB, and 40 dB is 1,000 times the intensity of 10 dB. **Table 2** shows the intensity of some common sounds. A sound of 120 dB is at the threshold of pain. Permanent deafness may come as a result of continuous exposure to sounds over 120 dB.

Figure 11 ▶ This view of Seattle shows how lighting in urban areas can cause skyglow, which is an effect of light that can dramatically reduce our view of the night sky.

Light Pollution

Unlike air or water pollution, light pollution does not present a direct hazard to human health. However, light pollution does negatively affect our environment. The use of inefficient lighting in urban areas is diminishing our view of the night sky. In urban areas, the sky is often much brighter than the natural sky.

A more important environmental concern of inefficient lighting is energy waste. For example, energy is wasted when light is directed upward into the night sky and lost to space, as shown in **Figure 11.** Examples of inefficient lighting are billboards and other signs that are lit from below, the lighting of building exteriors, and poor-quality street lights. One solution to energy waste includes shielding light so it is directed downward. Using time controls so that light is used only when needed and using low-pressure sodium sources—the most energy-efficient source of light—wherever possible are two other solutions.

FIELD ACTIVITY

Light Pollution At night, in your neighborhood or from your front porch, note any efficient or inefficient uses of light that you see, and write down your observations in your ***EcoLog.***

SECTION 2 Review

1. **Describe** the long-term effects and the short-term effects of air pollution on health.
2. **Describe** two ways in which indoor air pollution can be prevented.
3. **Describe** some of the human health problems caused by noise pollution.
4. **Describe** several solutions to the energy waste associated with light pollution.

CRITICAL THINKING

5. **Making Comparisons** Read the descriptions of noise and light pollution in this section. Explain ways in which noise pollution and light pollution are similar and ways they are different. READING SKILLS
6. **Analyzing Relationships** Molds can grow in new, tightly sealed buildings where the humidity is high and the ventilation is poor. Explain how you would control the growth of mold in this type of environment.

SECTION 3

Acid Precipitation

Objectives

- Explain the causes of acid precipitation.
- Explain how acid precipitation affects plants, soils, and aquatic ecosystems.
- Describe three ways that acid precipitation affects humans.
- Describe ways that countries are working together to solve the problem of acid precipitation.

Key Terms

acid precipitation
pH
acid shock

Imagine that you are hiking through the forests of the Adirondack Mountains in New York. You come to a lake and sit down to rest. You are amazed at how clear the water is; it is so clear that you can see the bottom of the lake. But after a few minutes you feel uneasy. Something is wrong. What is it? Suddenly, you realize that the lake has no fish.

What Causes Acid Precipitation?

This lake and thousands of lakes throughout the world are victims of acid precipitation, which is also known as acid rain. **Acid precipitation** is precipitation such as rain, sleet, or snow that contains a high concentration of acids. When fossil fuels are burned, they release oxides of sulfur and nitrogen. When the oxides combine with water in the atmosphere, they form sulfuric acid and nitric acid, which fall as acid precipitation. This acidic water flows over and through the ground, and into lakes, rivers, and streams. Acid precipitation can kill living things, and can result in the decline or loss of some local animal and plant populations.

A **pH** (power of hydrogen) number is a measure of how acidic or basic a substance is. A pH scale is shown in **Figure 12.** As you can see from the scale, the lower the pH number is, the more acidic a substance is; the higher a pH number is, the more basic a substance is. Each whole number on the pH scale indicates a tenfold change in acidity.

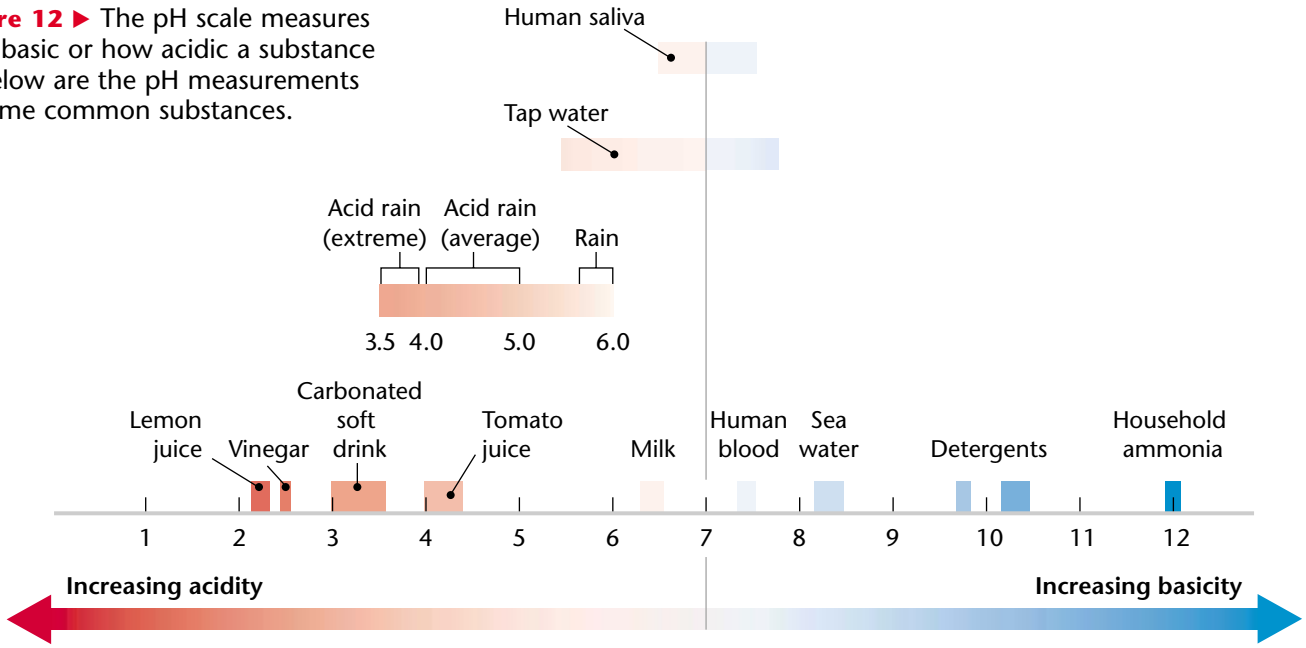


Figure 12 ▶ The pH scale measures how basic or how acidic a substance is. Below are the pH measurements of some common substances.

Pure water has a pH of 7.0. Normal precipitation is slightly acidic, because atmospheric carbon dioxide dissolves into the precipitation and forms carbonic acid. Normal precipitation has a pH of about 5.6. Precipitation is considered acid precipitation if it has a pH of less than 5.0. **Figure 13** shows how acid precipitation forms.

The pH of precipitation varies between different geographic areas. For example, Eastern Europe and parts of Scandinavia have precipitation with a pH of 4.3 to 4.5, whereas the remainder of Europe has precipitation with a pH values of 4.5 to 5.1. The pH of precipitation in the eastern United States and Canada ranges from 4.2 to 4.8. The most acidic precipitation in North America occurs around Lake Erie and Lake Ontario. It has a pH of 4.2.

How Acid Precipitation Affects Soils and Plants

Plant communities have adapted over long periods of time to the acidity of the soil in which they grow. Acid precipitation can cause a drop in the pH of soil and water. This increase in the concentration of acid is called *acidification*. Acidification changes the balance of a soil's chemistry in several ways. When the acidity of soil increases, some nutrients are dissolved and washed away by rainwater. Increased acidity causes aluminum and other toxic metals to be released and possibly absorbed by the roots of plants. Aluminum also causes root damage. Sulfur dioxide in water vapor clogs the openings on the surfaces of plants. **Figure 14** shows the harmful effects of acid precipitation on trees.

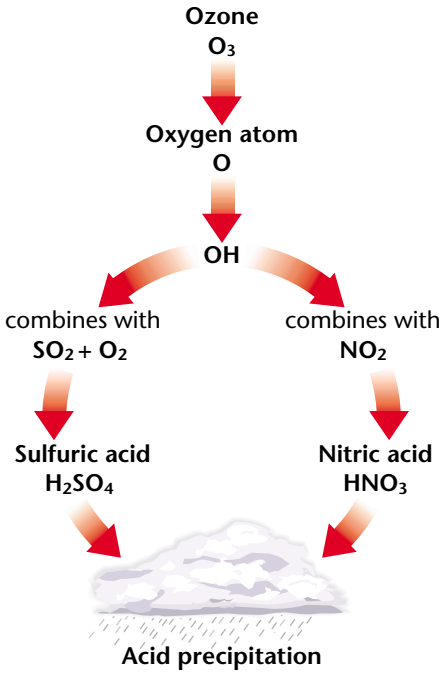


Figure 13 ▶ Sulfur oxides and nitrogen oxides combine with water in the atmosphere to form sulfuric and nitric acids. Rainfall that contains these acids is called *acid precipitation.*

Figure 14 ▶ The trees in this forest in Poland show the dramatic effect that acid precipitation can have on plants. Damage to more than 16 million acres in nine European countries has been linked to acid precipitation.

Figure 15 ▶ Fish are vulnerable to acid shock, a sudden influx of acidic water into a lake or stream that causes a rapid change in pH.

QuickLAB

Neutralizing Acid Precipitation

Procedure

1. Pour 1/2 Tbsp of **vinegar** into one cup of **distilled water,** and stir the mixture well. Check the pH of the mixture by using **pH paper.** The pH should be about 4.
2. Crush one stick of **blackboard chalk** into a powder. Pour the powder into the vinegar and water mixture. Check the pH of the mixture.

Analysis

1. Did the vinegar and water mixture become more or less acidic after the powdered chalk was poured in?

Acid Precipitation and Aquatic Ecosystems

Aquatic animals are adapted to live in an environment with a particular pH range. If acid precipitation falls on a lake and changes the water's pH, acid can kill aquatic plants, fish, and other aquatic animals. The change in pH is not the only thing that kills fish. Acid precipitation causes aluminum to leach out of the soil surrounding a lake. The aluminum accumulates in the gills of fish and interferes with oxygen and salt exchange. As a result, fish are slowly suffocated.

The effects of acid precipitation are worst in the spring, when acidic snow that accumulated in the winter melts and rushes into lakes and other bodies of water. This sudden influx of acidic water that causes a rapid change in the water's pH is called **acid shock.** This phenomenon causes large numbers of fish in a population to die, as shown in **Figure 15.** Acid shock also affects the reproduction of fish and amphibians. They produce fewer eggs, and these eggs often do not hatch. The offspring that do survive often have birth defects and cannot reproduce.

To counteract the effects of acid precipitation on aquatic ecosystems, some states in the United States and some countries spray powdered lime (calcium carbonate) on acidified lakes in the spring to help restore the natural pH of the lakes. Because lime has a pH that is basic, the lime raises the pH of the water. Unfortunately, enough lime cannot be spread to offset all acid damage to lakes.

Acid Precipitation and Humans

Acid precipitation can affect humans in a variety of ways. Toxic metals such as aluminum and mercury can be released into the environment when soil acidity increases. These toxic metals can find their way into crops, water, and fish. The toxins then poison the human body.

Acid precipitation can lead to other human health problems. Research has indicated that there may be a correlation between large amounts of acid precipitation received by a community and an increase in respiratory problems in the community's children.

The standard of living of some people is affected by acid precipitation. Decreases in numbers of fish caused by the acidification of lakes and streams can influence the livelihood of commercial fisherman and people involved in the sport-fishing industry. Forestry is also affected when trees are damaged by acid precipitation.

Acid precipitation can dissolve the calcium carbonate in common building materials, such as concrete and limestone. Some of the world's most important and historic monuments, including those made of marble, are being affected by acid precipitation. For example, sulfur dioxide has caused black crusts to form on the carbonate stones of historic Greek monuments.

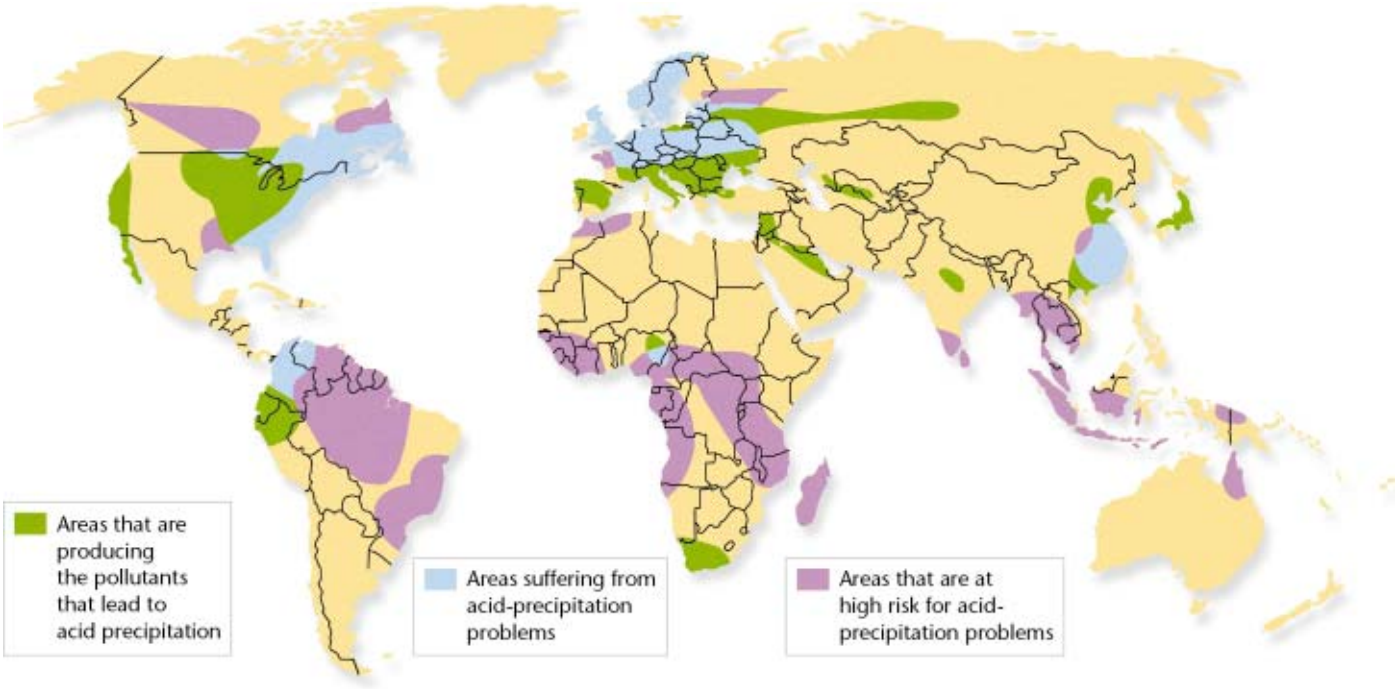


Figure 16 ▶ Acid precipitation is a global problem.

International Conflict and Cooperation

One problem in controlling acid precipitation is that pollutants may be released in one geographical area and fall to the ground hundreds of kilometers away. For example, almost half of the acid precipitation that falls in southeastern Canada results from pollution produced in Ohio, Indiana, Pennsylvania, Illinois, Missouri, West Virginia, and Tennessee. **Figure 16** shows areas of the world that produce pollutants and areas which are then affected by acid precipitation.

Because acid precipitation falls downwind, the problem of solving acid precipitation has been difficult, especially on the international level. In the spirit of cooperation, Canada and the United States signed the Canada–U.S. Air Quality Agreement in 1991. Both countries agreed to reduce acidic emissions that flowed across the Canada–U.S. boundary. More international agreements such as this may be necessary to control the acid-precipitation problem.

SECTION 3 Review

1. **Explain** how acid precipitation forms.
2. **Describe** the harmful effects that acid precipitation can have on plants, soils, and aquatic ecosystems.
3. **Describe** three ways in which acid precipitation can affect humans.
4. **Describe** a way in which countries are working together to solve the problem of acid precipitation.

CRITICAL THINKING

5. **Inferring Relationships** In addition to negatively affecting forestry and the fishing industry, how might acid precipitation affect local economies?
6. **Analyzing Viewpoints** Write a short essay in which you discuss whether or not a country that releases significant amounts of pollutants into the air that fall as acid precipitation in another country should be expected to pay some of the costs of cleanup. WRITING SKILLS

CHAPTER 12

Highlights

1 What Causes Air Pollution?

Key Terms

air pollution, 303
primary pollutant, 303
secondary pollutant, 303
smog, 308
temperature inversion, 308

Main Ideas

- Primary pollutants are pollutants put directly in the air by human activity.
- Secondary pollutants are formed when a primary pollutant comes into contact with other primary pollutants or with naturally occurring substances and a chemical reaction takes place.
- Most air pollution comes from vehicles and industry.
- Air pollution that hangs over cities and reduces visibility is called *smog*.
- Pollution can be trapped near the surface of the Earth by a condition known as temperature inversion.

2 Air, Noise, and Light Pollution

sick-building syndrome, 310
asbestos, 312
decibel (dB), 312

- Air pollution may have both long- and short-term effects on human health.
- The air indoors may be more polluted than the air outside. Plastics, cleaning chemicals, and building materials are major sources of indoor air pollution.
- Noise is a pollutant that affects human health and the quality of life.
- Inefficient lighting diminishes our view of the night sky and wastes energy.

3 Acid Precipitation

acid precipitation, 314
pH, 314
acid shock, 316

- Acid precipitation is precipitation such as rain, sleet, or snow that contains a high concentration of acids.
- Acid shock occurs when a sudden influx of acidic water enters a lake or stream and causes a rapid change in pH that harms aquatic life.
- Pollutants released in one geographical area may fall to the ground hundreds of kilometers away as acid precipitation—sometimes in another country.

CHAPTER 12 Review

Using Key Terms

Use each of the following terms in a sentence.

1. *air pollution*
2. *smog*
3. *temperature inversion*
4. *sick-building syndrome*
5. *pH*

For each pair of terms, explain how the meanings of the terms differ.

6. *primary pollutant* and *secondary pollutant*
7. *asbestos* and *radon*
8. *pH* and *acid precipitation*
9. *acidification* and *acid shock*

STUDY TIP

Predicting Exam Questions Before you take a test, do you ever attempt to predict what the questions will be? For example, of the 10 multiple-choice questions that appear on this page, how many would you have predicted to be asked in a review of this chapter? Before your next test, predict and answer possible exam questions.

Understanding Key Ideas

10. Which of the following air pollutants is *not* a primary pollutant?
    a. particulate matter
    b. ozone
    c. sulfur dioxide
    d. volatile organic compounds
11. A device used to clean exhaust gases before they exit an automobile's tailpipe is called a(n)
    a. electrostatic precipitator.
    b. catalytic converter.
    c. scrubber.
    d. None of the above
12. The majority of sulfur dioxide produced by industry comes from
    a. oil refineries.
    b. dry cleaners.
    c. chemical plants.
    d. coal-burning power plants.
13. Which of the following substances is *not* involved in the chemical reaction that produces smog?
    a. sunlight
    b. particulate matter
    c. automotive exhaust
    d. ozone
14. Which of the following respiratory diseases is considered a long-term effect of air pollution on human health?
    a. emphysema
    b. bronchitis
    c. pneumonia
    d. all of the above
15. Which of the following substances is a colorless, tasteless, and odorless radioactive gas?
    a. asbestos
    b. carbon monoxide
    c. radon
    d. ozone
16. A sound measuring 40 dB has how many times the intensity of a sound that measures 10 dB?
    a. 4 times
    b. 30 times
    c. 400 times
    d. 1,000 times
17. Which of the following choices is *not* an effective solution to the energy waste related to inefficient lighting?
    a. using low-pressure sodium lighting sources
    b. pointing lights on billboards and street signs upward
    c. placing light sources on time controls
    d. shielding light to direct it downward
18. Which of the following numbers on the pH scale would indicate that a substance is acidic?
    a. 5.0
    b. 7.0
    c. 9.0
    d. none of the above
19. Normal precipitation has a pH of
    a. 7.0.
    b. 5.6.
    c. 5.1.
    d. 4.5.

CHAPTER 12 Review

Short Answer

20. Define the term *zero-emission vehicle*. What types of vehicles qualify as zero-emission vehicles?

21. Identify five indoor air pollutants and examples of sources of each pollutant.

22. Explain the health hazards that radon gas poses for humans.

23. Identify a chemical that is used to counteract the effects of acid precipitation on aquatic ecosystems.

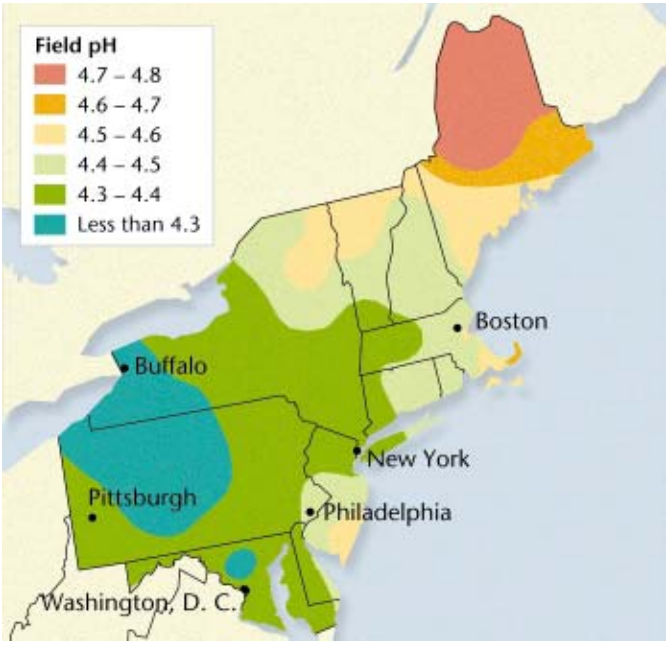
24. Explain why acid precipitation is a source of international conflict and why international cooperation is necessary to resolve the problem.

Interpreting Graphics

The map below shows the pH of precipitation that has been measured at field stations in the northeastern United States. Use the map and legend to answer questions 25–26.

25. Which area(s) of the northeastern United States have the most-acid precipitation?

26. Are the areas that have the highest pH located close to or far from major cities?



Concept Mapping

27. Use the following terms to create a concept map: *air pollution*, *primary pollutant*, *volatile organic compound*, *scrubber*, *secondary pollutant*, *smog*, and *temperature inversion*.

Critical Thinking

28. Making Decisions Five states now have zero-emission vehicle programs in place that will help decrease some primary pollutants. What would be the advantages or disadvantages of a federal program that required automobile makers to produce a set number of ZEVs nationwide?

29. Making Decisions In some cities, noise-pollution laws, such as restrictions placed on the use of leaf blowers, have been put in place. Do you think the benefits of noise reduction outweigh the costs of enforcing the law?

30. Inferring Relationships As you read under the head "International Conflict and Cooperation," about half of the acid precipitation that falls in southeastern Canada is produced by pollutants from the United States. How do the acid pollutants get from their sources to southeastern Canada? READING SKILLS

Cross-Disciplinary Connection

31. Health Asbestos, lead paint, tobacco, and many other products have been linked to adverse effects on human health. Research one such case that has been brought into the courts. Describe the allegations and the outcome of the trial and write a paragraph that explains whether you agree or disagree with the decision. WRITING SKILLS

Portfolio Project

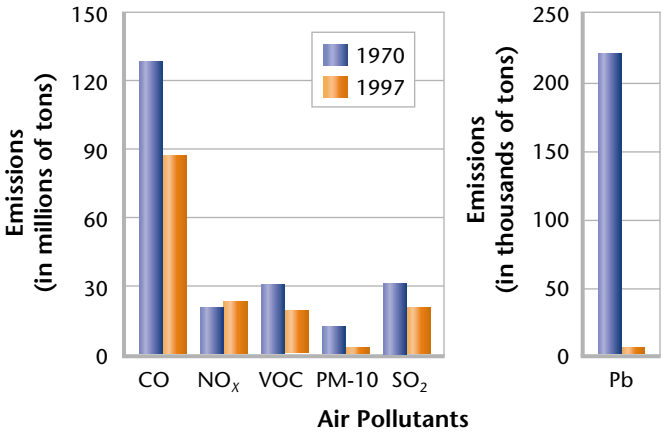
32. Make a Poster Create a poster similar to the diagram that appears in Figure 9. This diagram may be of your home, your garage, a portion of your school, or a particular classroom in your school. Use the diagram to identify and label potential sources of indoor air pollutants. Photographs may be used to document these sources.

MATH SKILLS

Use the graph below to answer questions 33 and 34.

33. Analyzing Data The graph below shows the change in air-pollution emissions in the United States between 1970 and 1997. Excluding NO_x, which emissions category experienced the greatest decrease over this period of time?

34. Interpreting Graphics Why is lead, Pb, shown separately from the other air pollutants?



WRITING SKILLS

35. Outlining Topics Outline the major sources of air pollution in the United States. Include information about pollution sources and pollution types.

36. Writing Persuasively Write a letter to a legislator that expresses your concern about a particular aspect of air, noise, or light pollution that is important to you.

READING FOLLOW-UP

Now that you have read the chapter, take a moment to review your answers to the **Reading Warm-Up** questions in your ***EcoLog.*** If necessary, revise your answers.

STANDARDIZED TEST PREP

Read the passage below, and then answer the questions that follow.

Lichens are unique organisms that consist of a fungus and microscopic alga that live together and function as a single organism. The alga is the photosynthetic partner, whereas the fungus absorbs water and minerals and anchors the plant. Lichens form crusts or leafy growths on rocks, trees, and bare ground. Lichens do not have roots. Instead, they absorb the nutrients they need directly from rain. Lichens grow very slowly and can live for centuries. Species of lichens have adapted to almost every environment in the world.

Lichens are sensitive to air pollution, particularly sulfur dioxide. When lichens are exposed to high levels of sulfur dioxide, they absorb the sulfur that is contained in rain. The sulfur destroys chlorophyll and inhibits photosynthesis. So, lichens are good indicators of air pollution. Lichens usually disappear from areas where sulfur dioxide levels are high. Where the air is free of pollutants, a greater number of lichens will usually be present. In areas where sulfur dioxide pollution is decreasing, lichens will slowly return and colonize the area.

1. Which of the following statements about lichens is true?
- **a.** Lichens are present when sulfur dioxide levels are high.
- **b.** Lichens absorb nutrients through their root systems.
- **c.** Lichens photosynthesize.
- **d.** Lichens grow only where the climate is moderate.

2. Where would you be most likely to see the greatest number of lichens?
- **a.** in areas where sulfur dioxide levels are high
- **b.** in areas where sulfur dioxide levels are low
- **c.** in areas where sulfur dioxide levels are decreasing
- **d.** in areas where sulfur dioxide is absent

CHAPTER 12

Exploration Lab: MODELING

Objectives

- **Perform** a chemical reaction that produces sulfur dioxide, a component of acid precipitation.
- USING SCIENTIFIC METHODS **Hypothesize** what the effects of acids that contain sulfur on plants will be.

Materials

beaker, 50 mL
clear plastic bags, large (2)
houseplants of the same type, potted (2)
sodium nitrite (2 g)
sulfuric acid, 1 M (2 mL)
twist tie or tape

The Acid Test

Acid precipitation is one of the effects of air pollution. When pollutants that contain nitrogen or sulfur react with water vapor in clouds, dilute acid forms. These acids fall to Earth as acid precipitation.

Often, acid precipitation does not occur in the same place where the pollutants are released. The acid precipitation usually falls some distance downwind—sometimes hundreds of kilometers away. Thus, the sites where pollutants that cause acid precipitation are released may not suffer the effects of acid precipitation.

Coal-burning power plants are one source of air pollution. These power plants release sulfur dioxide into the air. Sulfur dioxide reacts with the water vapor in air to produce acid that contains sulfur. This acid later falls to Earth as acid precipitation.

In this investigation, you will create a chemical reaction that produces sulfur dioxide. The same acids that result from coal-burning power plants will form. You will see the effects of acid precipitation on living things—in this case, plants.

Procedure

1. Place 2 g of sodium nitrite in a beaker. Place a plant and the beaker inside a plastic bag. Do not seal the bag.
   CAUTION: Steps 2–4 should be carried out *only* under a fume hood or outdoors.
2. Carefully add 2 mL of a 1 M solution of sulfuric acid to the beaker. Immediately seal the bag tightly, and secure the bag with a twist tie or tape. CAUTION: Because this reaction produces sulfur dioxide, a toxic gas, the bag should have no leaks. If a leak occurs, move away from the bag until the reaction is complete and the gas has dissipated.
3. Seal the same type of plant in an identical bag that does not contain sodium nitrite or sulfuric acid.

▶ **Step 1** Place a plant and a beaker that contains sodium nitrite into a plastic bag. Do not seal the bag.

Day	Control Plant	Experimental Plant
1		
2		
3		

4. After 10 minutes, cut both bags open. Stay at least 5 m from the bags as the sulfur dioxide gas dissipates. Keep the plants and bags under the fume hood.
5. Predict the effects of the experiment on each plant over the next few days. Record your predictions.
6. Observe both plants over the next three days. Record your observations below.

Analysis

1. **Examining Data** How closely did your predictions about the effects of the experiment on each plant match your observations?
2. **Explaining Events** What does this experiment suggest about the effects of acid precipitation on plants?

Conclusions

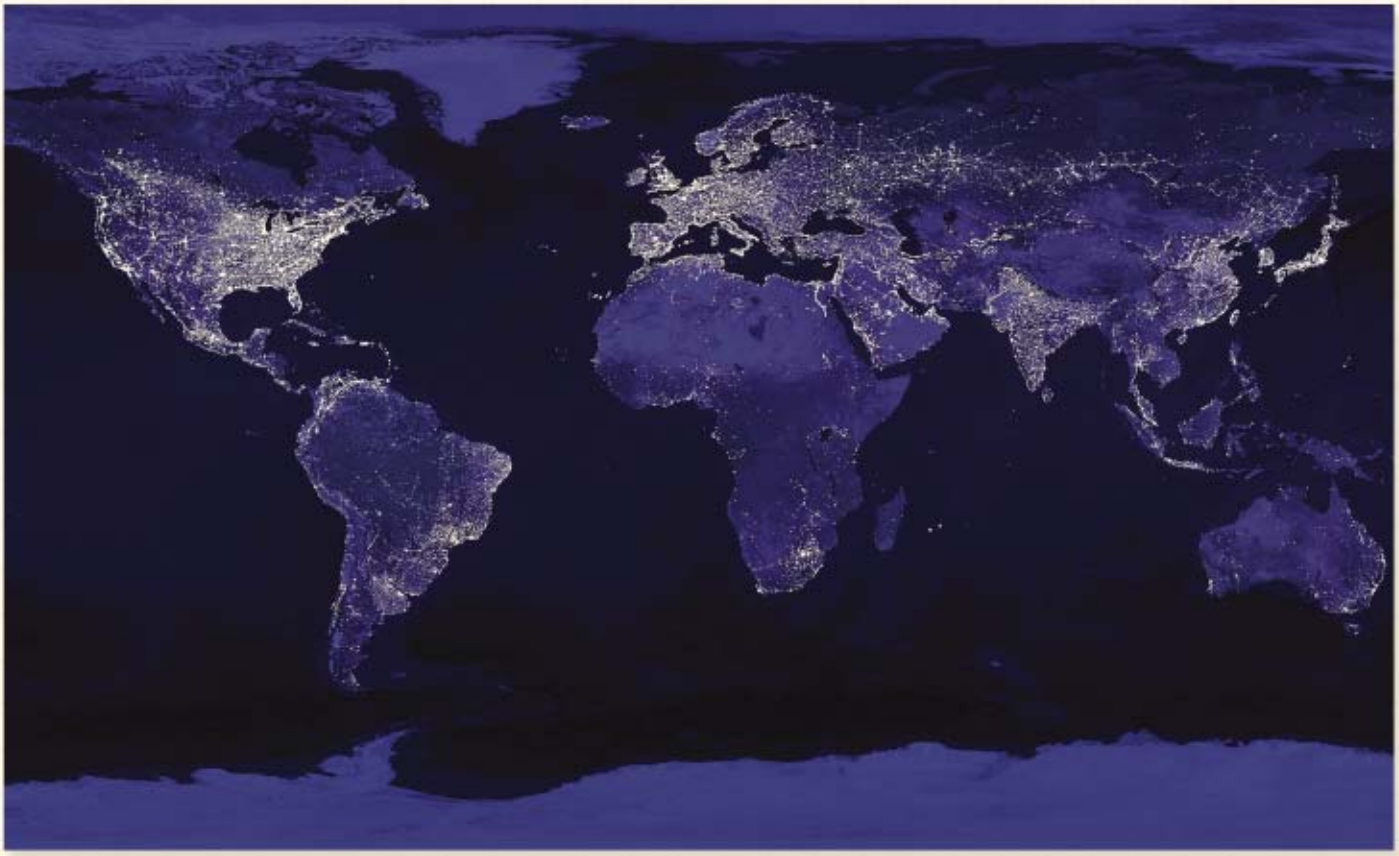
3. **Drawing Conclusions** In what ways is this a realistic model of acid precipitation?
4. **Drawing Conclusions** In what ways is this experiment *not* a realistic simulation of acid precipitation?

Extension

1. **Analyzing Models** Would you expect to see similar effects occur as rapidly, more rapidly, or less rapidly in the environment? Explain your answer.
2. **Building Models** Acid precipitation is damaging to plants because the sulfur dioxide contained in the water vapor clogs the openings on the surfaces of plants and interferes with photosynthesis. What kind of a safe model would demonstrate the damaging effects of acid precipitation in the form of water vapor on plant photosynthesis? Would this model be a realistic simulation of acid precipitation?

MAPS in action

LIGHT SOURCES



MAP SKILLS

This map of what the Earth looks like from space at night shows light sources that are human in origin. The map is a composite image made from hundreds of images taken by orbiting satellites. Use the map of light sources on Earth to answer the questions below.

1. **Inferring Relationships** Using the brightness of the light sources on the map as a key, can you estimate the locations of some of the most densely populated areas on Earth? Where are some of these areas?

2. **Inferring Relationships** Some climatic conditions on Earth, such as extreme cold, heat, wetness, or a thin atmosphere, make parts of our planet less habitable than others. Examples of areas on our planet that do not support large populations include deserts, high mountains, polar regions, and tropical rain forests. From the map, can you identify regions of the Earth where climatic conditions may not be able to support large human populations. What are some of these places?

3. **Finding Locations** Many large cities are seaports that are located along the coastlines of the world's oceans. From the map, can you pick out light sources along coastlines that might indicate the sites of large ports? Identify some of these cities by name.

4. **Inferring Relationships** From the differences in the density of the light sources, can you pick out any international borders?

THE DONORA, PENNSYLVANIA, KILLER SMOG

For the residents of the small Monongahela Valley town of Donora, Pennsylvania, living with the smoke that billowed from the local zinc smelter was an everyday occurrence—until October 26, 1948. On that night, a temperature inversion and an absence of wind began to trap a deadly mixture of sulfur dioxide, carbon monoxide, and metal dust that would hang in the valley air for five days. Over that period of time, 20 residents lost their lives and 7,000 other residents—about half of the town's population—suffered some form of respiratory problems.

The Weekend of the Killer Smog

By Saturday afternoon, October 29, 1948, the yellowish smog had become so thick that spectators in the stands at a local high-school football game could not see the players on the field. Only the whistles of the referees could be heard. By nightfall, driving was unsafe. This proved to be catastrophic because doctors recommended that any residents who suffered from respiratory ailments be evacuated from town. In an attempt to alleviate the suffering of people who were struggling to breathe, several local firemen carried oxygen tanks through the streets to different homes. Because of the low visibility, the firemen had to feel their way along buildings and fences. Because the supply of oxygen was limited, only a few breaths of oxygen could be given to each person. Eleven people died that night. A makeshift morgue was set up in the local community center.

Even as the killer smog choked the valley, the zinc smelter continued production throughout the night. The smelter continued sending more gases and dust into the air over Donora. The smelter was shut down only when the magnitude of the problem became apparent—6:00 A.M. on Sunday, October 30, 1948.

Later that day, a drizzling rain began to fall and washed the pollutants from the sky. By the time the rain fell, 20 people ages 52 to 85, who suffered from respiratory ailments, were dead. Thousands of other people were at home in bed or were filling the corridors and examining rooms of the two area hospitals. People who were less affected by the smog suffered from nausea and vomiting, headaches, and abdominal cramps. Some victims were choking or coughing up blood. The zinc smelter resumed operation on Monday morning, October 31.

The Aftermath

The smog of Donora was one of the United States' most serious environmental disasters. Shortly after the incident, investigations were undertaken by the Pennsylvania Department of Health, the U.S. Public Health Service, and other agencies. This was the first time an organized attempt was made to document the effects of air pollution on health in the United States. The knowledge that air pollution could be linked directly to the deaths of individuals resulted in legislation at the local, regional, state, and federal levels. These laws were set to limit emissions of sulfur dioxide, carbon monoxide, particulate matter, and other pollutants. The greatest legacy of the Donora tragedy was passage of the Clean Air Act of 1970.

▶ This historical photo from the *Pittsburgh Gazette* captures the town of Donora, Pennsylvania, as it is enveloped in smog at noon on Saturday, October 28, 1948.

What Do You Think?

Who do you think should be held responsible for the Donora, Pennsylvania, disaster? Explain your answer. Given what you know about the regulation of industrial pollutants under the Clean Air Act, do you think another incident such as the Donora killer smog could happen in the United States today?