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.

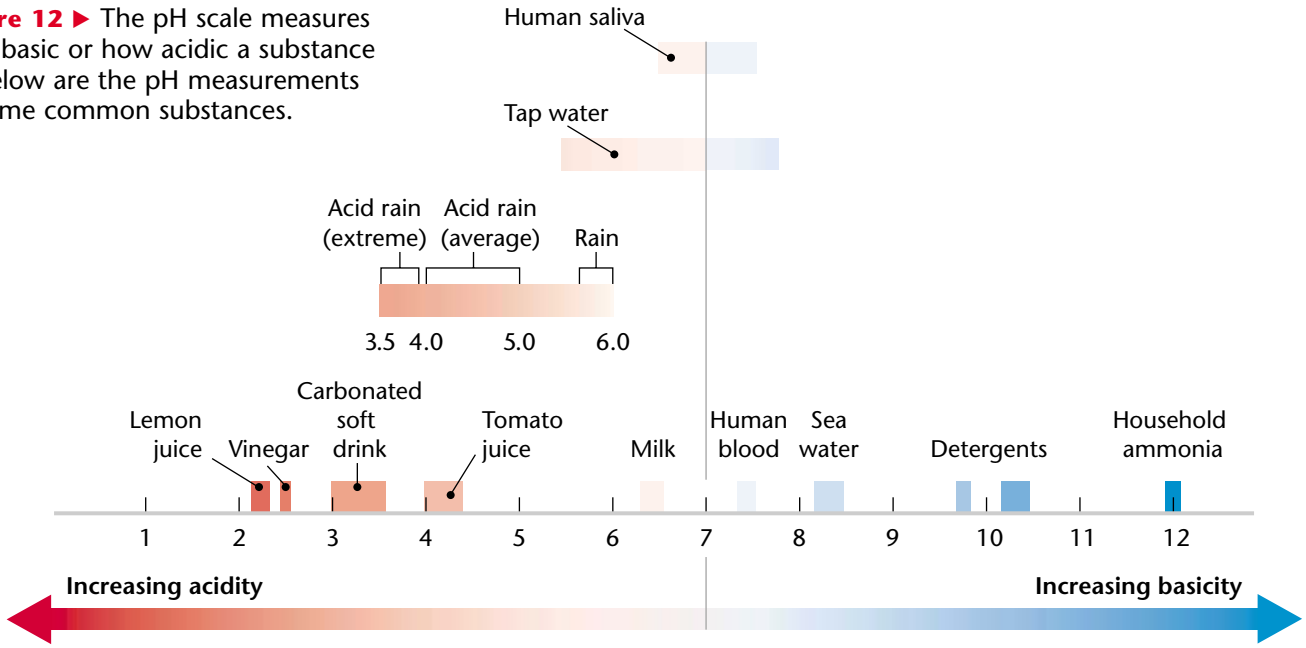


Figure 12 ▶ The pH scale measures how basic or how acidic a substance is. Below are the pH measurements of some common substances.

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.

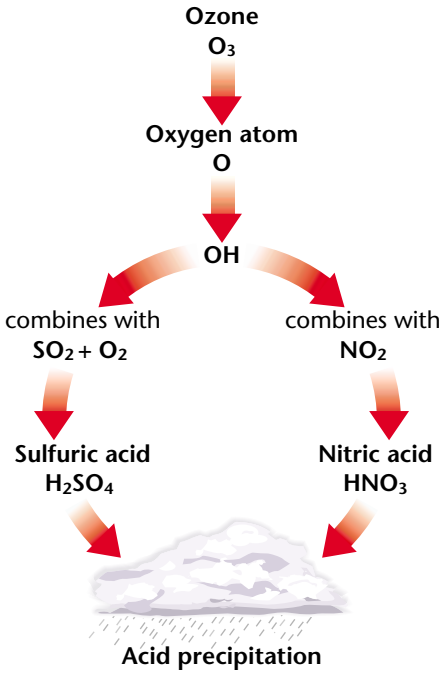


Figure 13 ▶ Sulfur oxides and nitrogen oxides combine with water in the atmosphere to form sulfuric and nitric acids. Rainfall that contains these acids is called *acid precipitation.*

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.

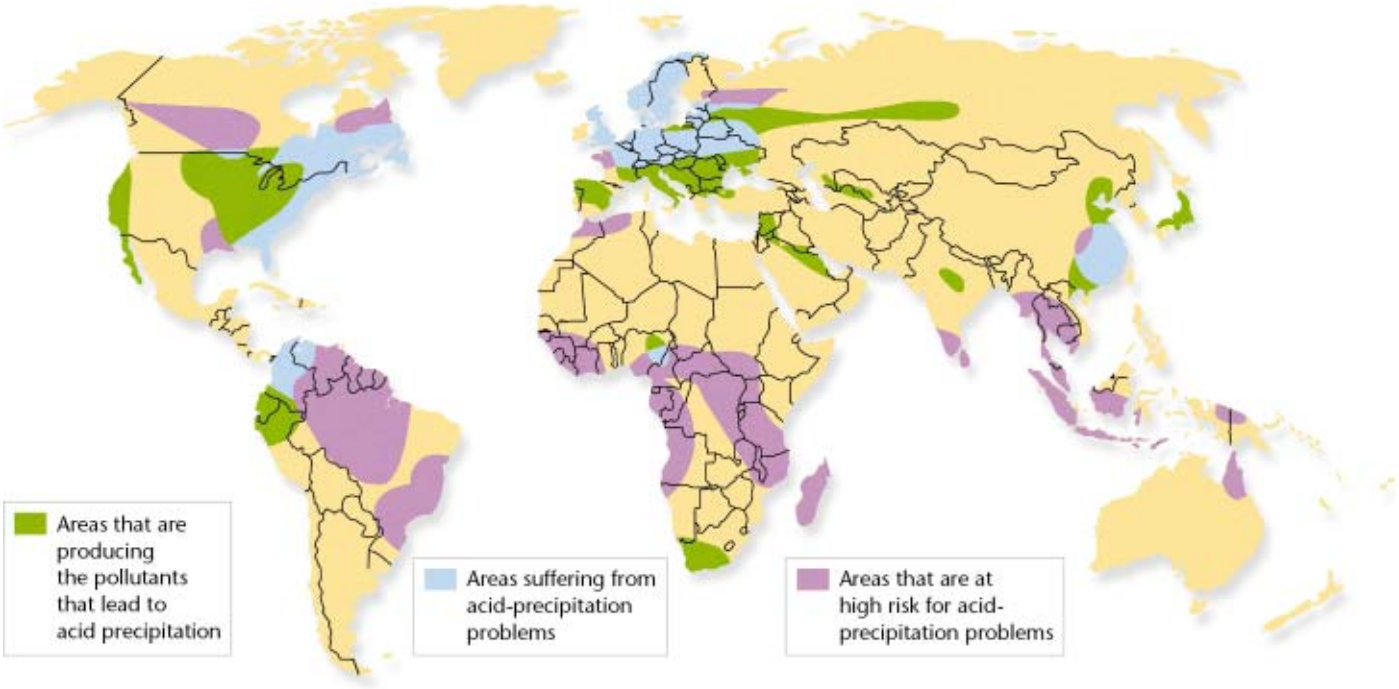


Figure 16 ▶ Acid precipitation is a global problem.

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.

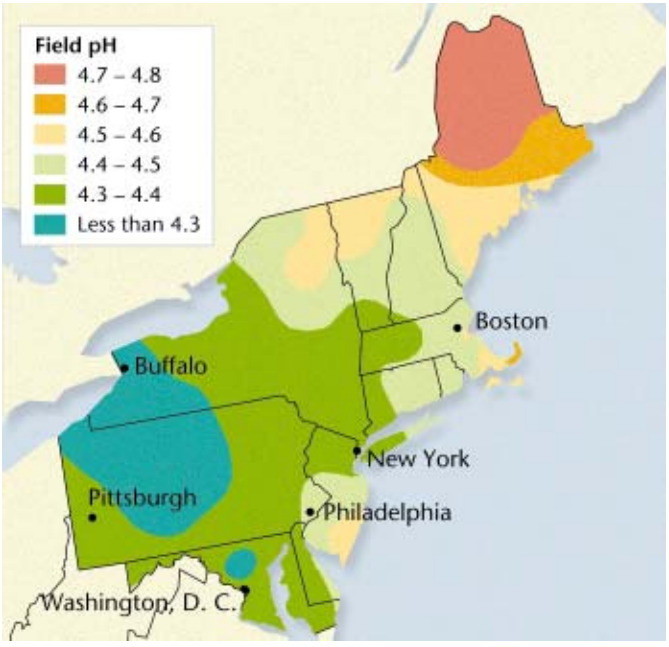
24. Explain why acid precipitation is a source of international conflict and why international cooperation is necessary to resolve the problem.

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

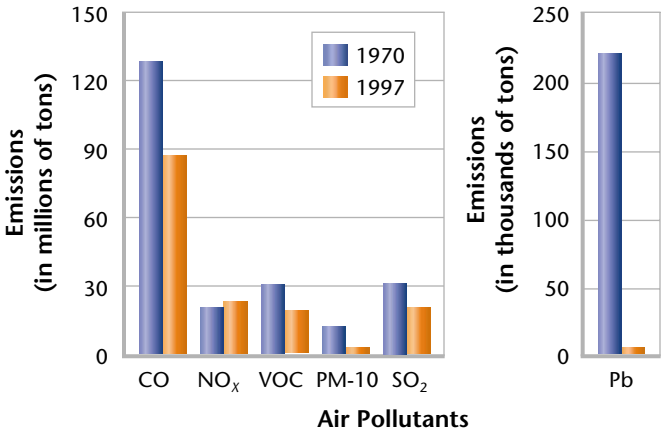
32. Make a Poster Create a poster similar to the diagram that appears in Figure 9. This diagram may be of your home, your garage, a portion of your school, or a particular classroom in your school. Use the diagram to identify and label potential sources of indoor air pollutants. Photographs may be used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

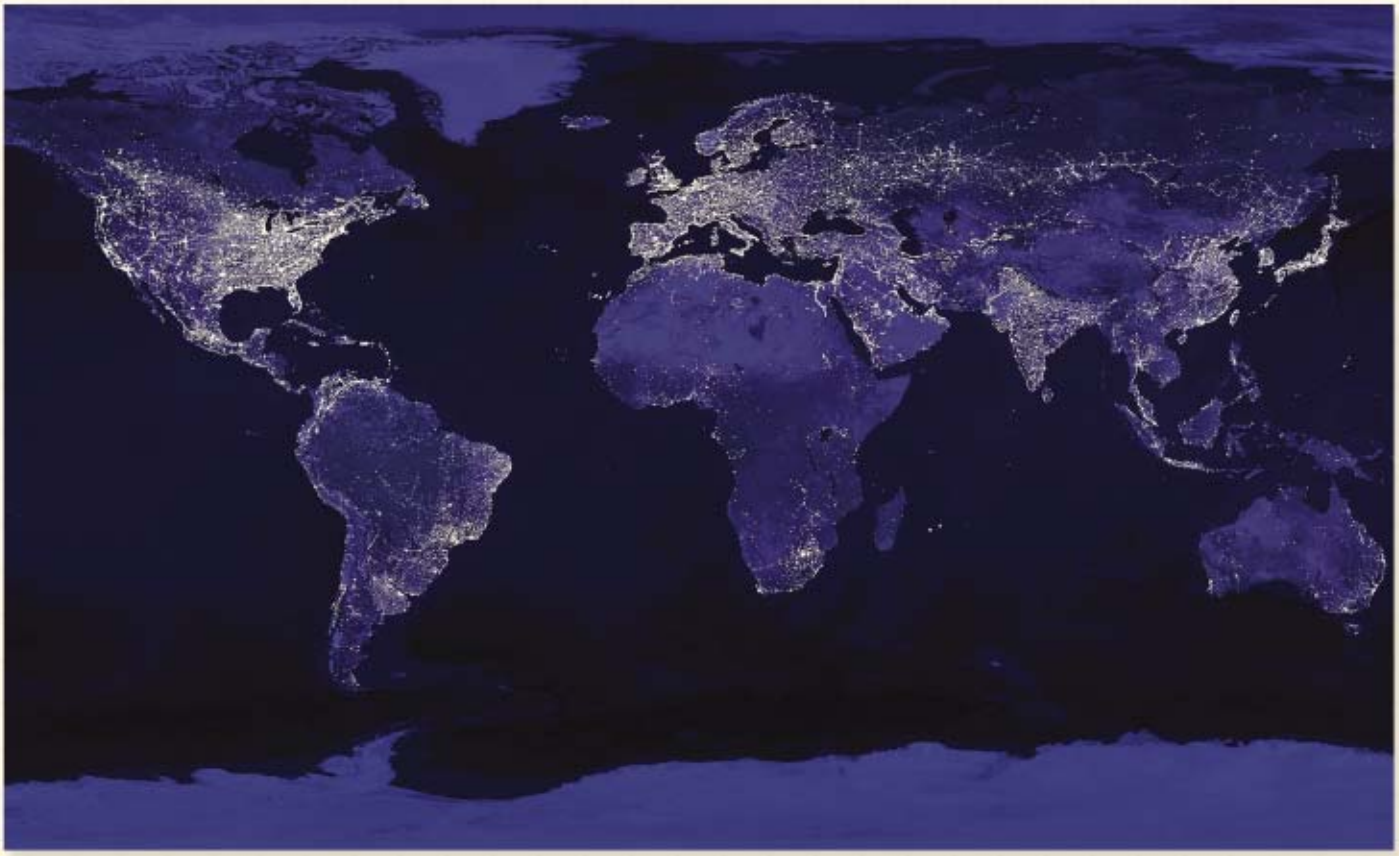
3. **Drawing Conclusions** In what ways is this a realistic model of acid precipitation?
4. **Drawing Conclusions** In what ways is this experiment *not* a realistic simulation of acid precipitation?

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?