29. Air Pollution and Acid Rain

Objectives

Determine the effect air pollutants (CO_2, SO_2, and NO_2) have on the pH of water. Through this investigation, students:

- Describe the relationship between air pollutants and acid rain.
- Discuss the effect changes in the pH of water have on the environment.

Procedural Overview

Students gain experience conducting the following procedures:

- Perform chemical reactions to generate three types of gases (CO_2, SO_2, and NO_2) that are common air pollutants.
- Graph pH versus Time data as each type of gas is bubbled through a beaker of water.
- Determine the overall change in pH for each gas tested and relate these finding to the causes and effects of acid rain.

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Erlenmeyer flask, 50-mL
- Beaker, 50-mL
- Graduated cylinder, 50- or 100-mL
- One-hole s topper to fit the flask
- Tubing connector [1]
- Tubing to fit the tubing connector, 20-cm
- Volumetric pipet with bulb, 10-mL
- Sodium bicarbonate ($NaHCO_3$), 5 g
- Sodium bisulfite ($NaHSO_3$), 5 g
- Sodium nitrite ($NaNO_2$), 5 g
- 1.0 M Hydrochloric acid (HCl), 15 mL[2]
- Water or deionized water, 60 mL
- Wash bottle containing distilled or deionized water
- Balance (1 per class)

[1]A piece of glass tubing can be substituted.

[2]To prepare using concentrated (12 M) or dilute (6 M) hydrochloric acid (HCl), refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Acids, bases, and pH
- Most organisms function best within a narrow pH range
- Human activities that cause air pollution

Related Labs in This Guide

Labs conceptually related to this one include:

- Soil pH
- pH of Household Chemicals

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Note: There are no Tech Tips to list in this section as this activity does not use a data collection system.

- Starting a new experiment on the data collection system (1.2)
- Connecting a sensor to your data collection system (2.1)
- Recording a run of data (6.2)
- Displaying data in a graph (7.1.1)
- Adjusting the scale of a graph (7.1.2)
- Showing and hiding data runs in a graph (7.1.7)
- Naming a data run (8.2)
- Viewing statistics of data (9.4)
- Saving your experiment (11.1)
- Printing (11.2)

Background

The Creation of Acid Rain

Acid rain is not only rain, but any other form of precipitation that is acidic. As this acidic water flows over and through the ground, it affects a variety of plants and animals. The strength of these effects depends on many factors, including: 1) the acidity of the water, 2) the chemistry and buffering capacity of the soils involved, and 3) the types of fish, trees, and other living things that rely on the water.

Scientists discovered that sulfur dioxide (SO_2) and nitrogen oxides (including nitric oxide, (NO), and nitrogen dioxide (NO_2)), collectively known as NO_x, are the primary causes of acid rain. Acid rain results when these gases react in the atmosphere with water, oxygen, and other airborne chemicals to form various acidic compounds.

Sulfur dioxide and nitrogen oxides go through several complex pathways of chemical reactions in the atmosphere before they become the acids found in acid rain. One of the most important pathways involves the oxidation of sulfur dioxide (SO_2) to sulfur trioxide (SO_3) by ozone (O_3). Ultraviolet energy of sunlight increases the rate of most of these reactions by degrading ozone to oxygen gas (O_2) and an oxygen radical (O^-) that is a highly reactive oxidizer. The sulfur trioxide then reacts with water vapor to form sulfuric acid. These reactions are shown as follows:

$$2SO_2 + 2O^- \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4.$$

Dust or ice particles can transport this sulfuric acid through the atmosphere to settle on the ground as dry acid deposition. The sulfuric acid can also dissolve in rain or fog and settle on the ground as wet acid deposition. Scientists believe that sulfuric acid is primarily responsible for the formation of acid rain.

Sulfur dioxide also readily reacts with water to produce sulfurous acid. Students will explore this reaction of sulfur dioxide in this lab activity.

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

In the United States, about two-thirds of all SO_2 and one-quarter of all NO_x comes from electric power generation that relies on burning fossil fuels such as coal. Other sources include automobile exhaust, furnaces, paper pulp production, and metal smelters.

Carbon dioxide is also a source gas for acid rain. It produces a relatively weak acid, but still should be considered a source due to increased use of fossil fuels.

The Effects of Acid Rain

The effects of acid rain are widespread. Acid rain causes acidification of lakes and streams. It damages trees at high elevations, such as red spruce trees above 600 meters, damages sensitive forest soils, and accelerates the decay of building materials (such as limestone and marble), metals (such as bronze) and automotive paint and other coatings. The stressful and sometimes deadly fluctuations in water systems due to acid rain cause aquatic life to experience chemical "shock" effects. For example, as the pH drops to 5.5, plankton, certain insects, and crustaceans begin to die and trout eggs do not hatch well.

Acid rain reduces crop productivity and forest growth rates while accelerating the rate at which "heavy" metals, such as lead and mercury, and nutrient cations (such as Mg^{2+} and K^{+}) leach from soils, rocks, and water body sediments. Scientists believe that acid rain causes increased concentrations of methylmercury in bodies of water—methylmercury is a neurotoxic molecule that accumulates in fish tissues and can cause birth defects in populations that ingest high concentrations of affected fish.

Pre-Lab Discussion and Activity

Air Pollution

Engage your students in a discussion about the visual signs of air pollution and the causes of air pollution.

1. Where have you been that has bad air pollution? How did you know that the air quality was bad?

Air pollution tends to be bad in large, industrial cities. The air quality is bad when there is a brownish haze covering the city. Some people have a hard time breathing and may experience wheezing and coughing.

2. What are the main causes of air pollution?

Air pollution is caused by both man-made and natural processes. Man-made process of air pollution are mostly related to the burning of fossil fuels. This includes power plants, factories, furnaces, automobiles, and airplanes. Natural sources include volcanic eruptions, forest fires, and biological processes.

3. What are some common air pollutants?

Common air pollutants include sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds such as methane (CH_4), particulate matter such as dust, toxic metals such as lead, chlorofluorocarbons (CFCs), ammonia (NH_3), odors, and radioactive pollutants.

Air Pollution and Environmental Problems

Discuss the relationship between air pollutants the environment. Lead the discussion to determining if air pollutants are related to acid rain.

4. How do air pollutants affect the environment?

Humans can develop health problems and diseases from air pollution. Air pollutants cause stains and discoloration on buildings and statues.

5. Is there a relationship between air pollutants and acid rain?

Answers will vary. This is the objective of the lab and should not be answered here. Just get students thinking about it.

6. What is acid rain and how can the acidity of water be measured?

Acid rain is when rain water has a pH of 5.6 or lower. The acid content of water can be measured using a pH sensor. Review the pH scale as needed.

7. How can we determine the effect of air pollutants on the pH of water?

One type of air pollutant can be added to water over time, if the pH is measured as this process takes place the data will determine whether or not that specific air pollutant affects the pH of water.

8. Air pollutants are found mixed in the air. How can a source of a single air pollutant be generated?

Chemical reactions can be used to generate specific chemical compounds including air pollutants.

Chemical Reactions Performed In this Lab

Tell students that they will generate a small amount of CO_2, SO_2, and NO_2 to determine the effect of these pollutants on the pH of water.

Review the chemical reactions that produce the gases they will be studying:

Sodium bicarbonate + hydrochloric acid → sodium chloride + water + carbon dioxide gas

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

Sodium bisulfite + hydrochloric acid → sodium chloride + water + sulfur dioxide gas

$$NaHSO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + SO_2(g)$$

Sodium nitrite + hydrochloric acid → sodium chloride + nitrogen dioxide gas

$$NaNO_2(s) + HCl(aq) \rightarrow NaCl(aq) + NO_2(g)$$

Lab Preparation

These are the materials and equipment to set up prior to the lab.

Follow these safety procedures as you begin your preparations:

- Wear eye protection, lab apron, and protective gloves when handling acids. Splash-proof goggles are recommended. Either latex or nitrile gloves are suitable.
- If acid or base solutions come in contact with skin or eyes, rinse immediately with a copious amount of running water for a minimum of 15 minutes.
- Diluting acids and bases create heat; be extra careful when handling freshly prepared solutions and glassware as they may be very hot.
- Always add acids and bases to water, not the other way around, as the solutions may boil vigorously.
- Handle concentrated acids and bases in a fume hood; the fumes are caustic and toxic.

Prepare the following solution:

1. Prepare 100 mL of 1.0 M hydrochloric acid from either concentrated (12 M) or dilute (6 M) HCl. This is enough for 10 lab groups.

   Starting with concentrated (12 M) HCl

   a. Add approximately 50 mL of distilled water to a 100 mL beaker with a stir bar.

   b. Slowly add 8.3 mL of 12 M HCl to the beaker with continuous stirring.

   c. Allow the solution to cool, then carefully pour into a 100-mL volumetric flask and dilute to the mark with distilled water.

   d. Cap and invert three times to ensure complete mixing.

   Starting with dilute (6 M) HCl

   a. Add approximately 50 mL of distilled water to a 100 mL volumetric flask.

   b. Add 16.7 mL of 6 M HCl to the water and dilute to the mark with distilled water.

   c. Cap and invert three times to ensure complete mixing.

Teacher Tips:

- Use tap water unless the water in your area has a high level of dissolved solids which can produce a significant buffering action (as is the case for some well water, for example). The pH of distilled and deionized water is highly susceptible to large changes as a result of minute contaminants.
- Because the pH measurements in this activity are relative only to measurements within this lab, it is not necessary to calibrate the pH sensor to obtain useful and meaningful data.
- If your classroom does not have good ventilation, students can generate the CO_2 part of the activity at their lab benches. The parts for SO_2 and NO_2 can be performed by one group or the teacher under the fume hood in the chemistry lab and the results presented to the class for analysis.
- For students generating CO_2 at their workbench, you can substitute household white vinegar if you do not have 1.0 M HCl.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Hydrochloric acid is a corrosive irritant. Avoid contact with skin and eyes.
- Work in a well ventilated room (or under a fume hood) when creating sulfur dioxide and nitrogen dioxide.
- Do not remove the stopper from the Erlenmeyer flask once the reaction has started.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

4	3	2	5	1
Repeat the gas generation and data collection for NO_2 and SO_2.	Dispose of the contents of the flask and beaker and thoroughly rinse out the flask, beaker, and tubing.	Collect pH versus time data for water as CO_2 gas is bubbled through it.	Determine the changes in pH for each gas.	Set up equipment. Open a graph display.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Making carbon dioxide (CO_2) gas and measuring its effect on the pH of water

Set Up

1. ☐ Start a new experiment on the data collection system. (1.2)

2. ☐ Connect the pH sensor to the data collection system. (2.1)

3. ☐ Display pH on the *y*-axis of a graph with Time on the *x*-axis. (7.1.1)

4. ☐ What do you think will happen to the pH of the water when you dissolve CO_2 gas in it? Why?

Answers will vary according the student predictions. Since CO_2 creates carbonic acid in the solution, the pH will be lowered. Carbonic acid is a weak acid and there for the expected change will be small.

5. ☐ Measure 20 mL of water using the graduated cylinder.

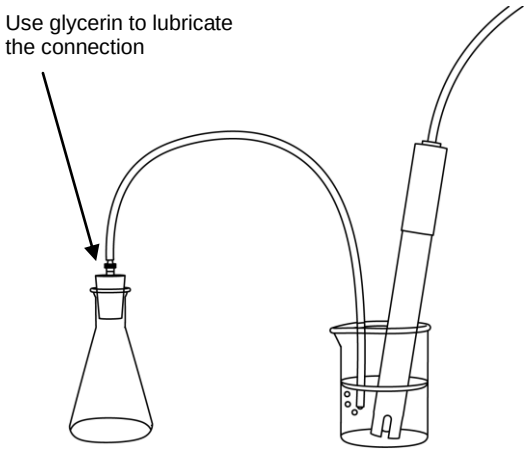
6. ☐ Pour the water into the 50-mL beaker.

7. ☐ Obtain a sample of powdered sodium bicarbonate ($NaHCO_3$) from the teacher.

8. ☐ Measure 5 grams of $NaHCO_3$.

9. ☐ Place the measured $NaHCO_3$ in the 50-mL Erlenmeyer flask.

10. ☐ Connect the tubing to the stopper using the tubing connector. See the picture below.



Note: If necessary, use glycerin to lubricate the connection so that the connector is well seated in the stopper.

11. ☐ Thoroughly rinse the pH sensor with distilled water.

12. ☐ Hold the rinsed pH sensor and the free end of the tubing beneath the surface of water in the beaker.

Collect Data

13. ☐ Start recording data. ◆(6.2)

14. ☐ Pipet 4 mL of 1.0 M hydrochloric acid (HCl) into the Erlenmeyer flask, immediately stopper the flask, and place the free end of the tubing in the water in the beaker.

CAUTION: Hydrochloric acid is a strong acid. Handle with care. Flush any spillage with a lot of water.

Note: If necessary, adjust the scale of the graphs to show all data. ◆(7.1.2)

15. ☐ Record data for about 200 seconds (until the change in pH stops or stabilizes), then stop recording data. ◆(6.2)

16. ☐ Name your data run to reflect the sample type. ◆(8.2)

17. ☐ In this part of the lab you generated CO_2 gas by reacting HCl with $NaHCO_3$. What human-related and natural processes emit CO_2 gas into the atmosphere?

The main source of CO_2 gas emission into the atmosphere is the combustion of fossil fuels. This occurs in power plants, automobiles, and industrial factories. Natural processes such as respiration by plants and animals and volcanic eruptions also release CO_2 gas into the atmosphere.

18. ☐ Dispose of the contents of the flask and beaker as directed by your instructor.

19. ☐ Rinse the beaker, flask, and tubing with water.

Part 2 – Making sulfur dioxide (SO_2) gas and measuring its effect on the pH of water

20. ☐ What do you think will happen to the pH of the water when you dissolve SO_2 gas in it? Why?

Answers will vary according the student predictions. Since SO_2 creates sulfurous acid in the solution, the pH will be lowered. Sulfurous acid is a strong acid so the change in pH should be larger than the change observed using CO_2 gas.

21. ☐ Again measure 20 mL of water and repeat the steps in Part 1 using 5 g sodium bisulfite ($NaHSO_{3)}$ instead of $NaHCO_3$.

22. ☐ In this part of the lab you generated SO_2 gas by reacting HCl with $NaHSO_3$. What human-related and natural processes emit SO_2 gas into the atmosphere?

The main source of SO_2 gas emission into the atmosphere is the combustion of fossil fuels. This occurs in power plants, automobiles, and industrial factories. Natural processes such as volcanoes and the biological decay of organic matter release SO_2 gas into the atmosphere.

Part 3 – Making nitrogen dioxide (NO_2) gas and measuring its effect on the pH of water

23. ☐ What do you think will happen to the pH of the water when you dissolve NO_2 gas in it? Why?

Answers will vary according the student predictions. Since NO_2 creates nitric acid in the solution, the pH will be lowered. Nitric acid is a strong acid and so the change in pH should be greater than that of CO_2.

24. ☐ Repeat the steps in Part 1 using 5 g sodium nitrite ($NaNO_{2)}$ instead of $NaHCO_3$.

25. ☐ In this part of the lab you generated NO_2 gas by reacting HCl with $NaNO_2$. What human-related and natural processes emit NO_2 gas into the atmosphere?

The main source of NO_2 gas emission into the atmosphere is the combustion of fossil fuels. This occurs in power plants, automobiles, and industrial factories. Natural processes such as lightning discharges and biological process release NO_2 gas into the atmosphere.

26. ☐ Save your experiment and clean up according to your teacher's instructions. ◆(11.1)

Data Analysis

1. ☐ Determine the maximum and minimum pH values for each run of data and record them in Table 1 below.

a. Display the run of data you want to analyze. ◆(7.1.7)

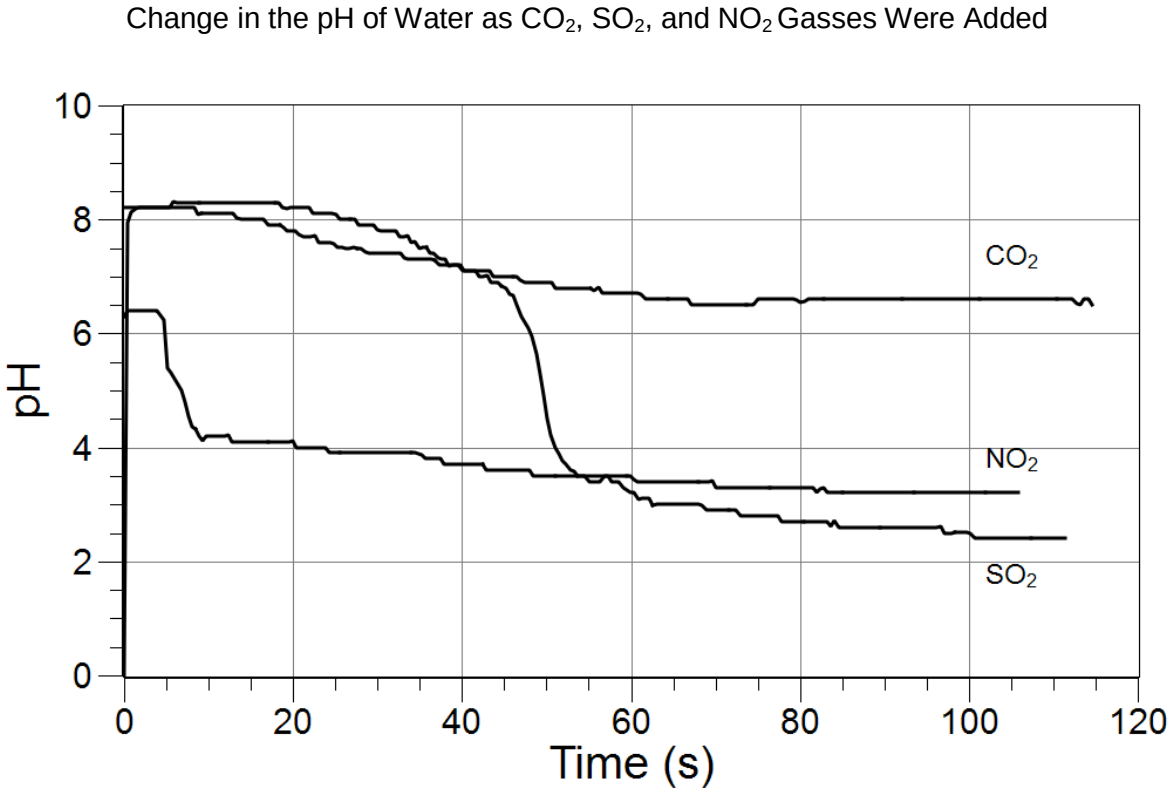
b. Use the statistics tool to find the maximum and minimum pH of the data run. ◆(9.4)

Table 1: pH change due to gases dissolved in water

Gas	Maximum pH	Minimum pH	Change in pH
Carbon dioxide	8.2	6.5	1.7
Sulfur dioxide	8.3	2.9	5.4
Nitrogen dioxide	6.4	3.2	3.2

2. ☐ Calculate the change in pH and record your answers in Table 1 above.

3. ☐ Sketch or print a graph of pH versus Time for all three gases on one set of axes. Be sure to label each run of data. Also label the overall graph, the *x*-axis, the *y*-axis, and include units on the axes. ◆(11.2)



Analysis Questions

1. Were your three predictions about CO_2, SO_2, and NO_2 correct? Did the pH of the water change as you expected for each gas? Explain.

Answers will depend on what students predicted. They should briefly discuss why they were correct or not correct.

2. What effect do air pollutants (CO_2, SO_2, and NO_2) have on the pH of water? Use your data to support your answer.

The air pollutants tested, CO_2 SO_2, and NO_2, all caused the pH of water to decrease. In all three cases the maximum pH was recorded before the gases had been added and the minimum pH was recorded after the gases had been added. This means that all the gases caused the pH of water to be lower.

3. Do all the gases you tested contribute equally to acid rain? Use your data to explain your answer.

SO_2 and NO_2 gases are stronger contributors to acid rain than CO_2 gas. SO_2 gas lowered the pH in water the most (a change of 5.4) which means it will create acid rain with the lowest pH. This was followed by NO_2 gas, which caused the pH of water to be lowered by 3.2 and will also rain to be quite acidic. Out of the three gases CO_2 gas had the smallest affect on the waters pH and only dropped it by 1.7 units.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Explain the relationship between air pollution and acid rain.

Air pollutants such as SO_2, NO_2, and CO_2 cause acid rain. These air pollutants cause acid rain by reacting with oxygen, water, and other chemicals in the atmosphere to form acidic compounds. The acid compounds formed cause the pH of rain to be lower than normal and result in acid rain.

2. How does acid rain affect aquatic ecosystems?

Acid rain causes the pH of lakes, streams, and other bodies of water to decrease. Aquatic organisms can only survive in water with a specific pH range. When the pH of the water decreases below this range the aquatic organisms can die. If the organisms themselves do not die, they can be affected in other ways. Their food sources such as plankton and small insects could die leaving them without food or their reproduction systems could be affected resulting in smaller numbers of offspring.

3. How does acid rain affect terrestrial ecosystems?

Acid rain causes the pH of soil to decrease. When soils become more acidic the minerals that plants need are more easily leached from the soil and washed away with rain. Crop productivity and forest growth rates are decreased. Animals that depend on these crops for survival are affected.

4. What are some ways to prevent the formation of acid rain?

The formation of acid rain can occur by reducing or eliminating man-made forms of air pollution. This can be done by: 1) using alternate forms of energy such as solar energy or wind energy instead of fossil fuels; 2) Install the use of technologies such as scrubbers on smoke stacks to reduce emissions; 3) Install catalytic converters in cars to convert nitric oxide gases to nitrogen gas; 4) Conserve energy. Using less energy will require burning less fossil fuels, which contain sulfur and nitrogen; 5) Develop more fuel efficient cars.

5. Coal from states in the western United States, like Montana and Wyoming, has a lower percentage of sulfur impurities than coal found in the eastern United States. How would the burning of low-sulfur coal change acid rain?

Burning low-sulfur coals would decrease the amount of acid rain by reducing the amounts of sulfur oxides emitted into the atmosphere.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which of the following is true about acid rain?

- **A.** Acid rain is linked to NO_2 and SO_2 molecules in the atmosphere.
- **B.** Acid rain can result in the death of many species of water-dwelling organisms when it causes the pH of lakes systems to move to a range outside their tolerance.
- **C.** Acid rain affects soil chemistry and the ability of plant roots to take in nutrients.
- **D. All of the above are true.**
- **E.** None of the above are true.

2. Which of the following play important roles in the formation of acid rain?

- **A.** Gases in the atmosphere
- **B.** Soil types
- **C.** Water in the atmosphere
- **D. A and C are correct**
- **E.** A, B and C are all correct

3. In general, rain exerts harmful effects on ecosystems when it falls below a pH of:

- **A.** 1.6
- **B.** 2.6
- **C.** 3.6
- **D. 5.6**
- **E.** 7.6

4. How do air pollutants (CO_2, SO_2, and NO_2) affect the pH of water?

- **A.** Air pollutants increase the pH of water.
- **B. Air pollutants decrease the pH of water.**
- **C.** Air pollutants either increase or decrease the pH of water.
- **D.** Air pollutants have no affect on the pH of water.
- **E.** Air pollutants only affect the pH of acidic water.

5. Significant sources of SO_2 and NO_2 in the atmosphere are:

- **A.** Sunshine and water moisture
- **B. Burning coal, auto exhaust, and factories**
- **C.** Photosynthesis and respiration
- **D.** Manure waste from cattle and sheep farms
- **E.** All of the above

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Many types of air **pollutants** are released into the atmosphere by factories, coal-burning power plants, **automobiles**, and furnaces. Among the pollutants are gases like sulfur dioxide (SO_2) and **nitrogen dioxide** (NO_2). These gas pollutants are the **primary** cause of acid rain. **Acid rain** occurs when these gases react in the **atmosphere** with water, oxygen, and other chemicals to form various acidic compounds. Rain with a pH of 5.6 or **lower** is considered to be acid rain.

2. Acid rain affects a variety of plants and animals. Some types of **organisms**, such as plankton, certain insects, crustaceans, and trout eggs are especially susceptible to damage due to **low** pH of the water. Acid ran can also accelerate the leaching of **metals** and nutrients found in soils and rock. It reduces crop **productivity** and forest growth rates. Acid rain may remove **protective** layers from plant leaves, causing the plants to be more susceptible to **disease**. Scientists believe that acid rain causes increased concentrations of toxic **methylmercury** dissolved in surface water. Acid rain can **damage** concrete, stone, and metal structures.

Extended Inquiry Suggestions

What is the pH of your local rainwater? Have students design a way to collect rainwater and then measure the pH of the sample using a pH sensor.

What is the pH of a local water system? Have students collect samples from a local pond, stream, lake, or river. Then, determine the pH of the samples using a pH sensor.

Visit a local cemetery and observe the wearing away of the headstones or other grave markers over time. Military cemeteries use limestone markers that are more easily affected by acid rain than the granite markers in some private cemeteries. Use the dates on the marker stones and the condition of the stones to determine which ones acid rain may have damaged. Remember that these materials would naturally deteriorate when exposed to the weather and rain (even clean rain). Acid rain would accelerate this damage.

Have students write, produce, and direct a special “weather special” segment for TV on the effect of weather patterns and the travel of acid rain over large distances. Contact the weather bureau or a local television station's weather department to ask about the wind patterns in your area. This information and data for your area may also be available on the Internet.

Have students contact a local natural resource specialist from your local zoo or park, Ask that person to tell you about the impact, if any, of both acid rain and dry acid deposition in the lakes.