17. Air Pollution and Acid Rain

Driving Questions

In this activity, you will use chemical reactions to generate gases that are common man-made (anthropogenic) air emissions.

- Can anthropogenic gases in the atmosphere significantly lower the pH of rain, snow, and fog?
- If so, what are some chemical reactions that lead to this change in pH?

Background

Acid rain is rain, or 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. It can also accelerate the dissolving of metals found in soils and rock. The strength of the 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.

Acid rain produces stressful and sometimes deadly fluctuations in water systems, causing aquatic life to experience chemical "shock" effects. For example, as the pH drops to 5.5, plankton, certain insects, and crustaceans begin to die. Trout eggs do not hatch well.

The effects of acid rain are widespread. Acid rain can damage concrete, stone, and metal structures. It can reduce crop productivity and forest growth rates, and may remove protective layers from plant leaves, causing them to be more susceptible to disease. Acid rain accelerates the rate at which "heavy" metals such as lead and mercury, and nutrient cations such as magnesium (Mg^{2+}) and potassium (K^{+}), are leached from soils, rocks, and sediments of surface water. Scientists believe acid rain causes increased concentrations of methylmercury in bodies of water—methylmercury is a neurotoxic molecule that is accumulated in fish tissues and can cause birth defects in populations that ingest high concentrations of it.

Materials and Equipment

For each student or group:

- pH sensor
- Erlenmeyer flask, 50-mL
- 1-hole rubber stopper for flask
- Beaker, 40-mL
- Graduated pipet, 4-mL and pipet bulb
- Glass tubing for rubber stopper
- Flexible Teflon® tubing to fit glass tubing, 20 cm
- Graduated cylinder, 50- or 100-mL
- Sodium bicarbonate ($NaHCO_3$), 5 g
- Sodium bisulfite ($NaHSO_3$), 5 g
- Sodium nitrite ($NaNO_2$), 5 g
- 1 M HCl (15 mL)
- Water or deionized water, 1 L
- Wash bottle containing distilled or deionized water

Safety

Add these important safety precautions to your normal laboratory procedures:

- Work under a vented hood when creating sulfur dioxide and nitrogen dioxide.
- Do not touch the hydrochloric acid (HCl). Handle the pipet with HCl with extreme care.
- Do not remove the rubber stopper from the Erlenmeyer flask once the reaction has started.
- After completing the lab, wash your hands.
- Wear safety glasses and lab coats or aprons.

Procedure

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

Create gas generators, and measure pH

You will create CO_2, NO_2, and SO_2, as follows:

Mix sodium bicarbonate ($NaHCO_3$) with hydrochloric acid (HCl) to produce carbon dioxide gas (CO_2).
Mix sodium nitrite ($NaNO_2$) with hydrochloric acid (HCl) to produce nitrogen dioxide (NO_2).
Mix sodium bisulfite ($NaHSO_3$) with hydrochloric acid (HCl) to produce sulfur dioxide gas (SO_2).

1. ☐ Make predictions: What do you think will happen to the pH of the water when you dissolve these gases in it? Which gas will produce the largest change in pH?

_____

_____

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

Set Up

2. ☐ Start a new experiment on the data collection system.
3. ☐ Connect the pH sensor to the data collection system.
4. ☐ Display pH on the y-axis of a graph with time on the x-axis.
5. ☐ Measure 20.0 mL of water using the graduated cylinder.
6. ☐ Pour the water into the 40-mL beaker.

7. ☐ Thoroughly rinse the pH electrode with distilled water.

8. ☐ Place the rinsed pH electrode in the beaker.

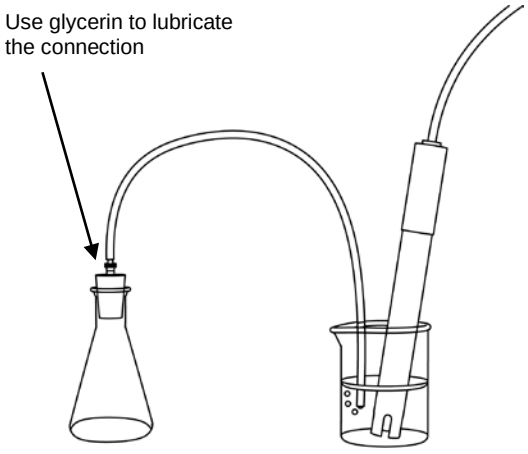
9. ☐ Obtain a sample of powdered sodium bicarbonate ($NaHCO_3$) from the teacher.

10. ☐ Measure 5 grams of $NaHCO_3$

11. ☐ Place the measured $NaHCO_3$ in the Erlenmeyer flask.

12. ☐ Assemble the stopper, glass tubing or barbed connector, and flexible tubing.

Note: If necessary, use glycerin to lubricate the connection so that the connector or glass tubing is well seated in the rubber stopper



13. ☐ Pipet 4 mL of 1.0 M hydrochloric acid (HCl) into the Erlenmeyer flask, and immediately stopper the flask.

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

Collect Data

14. ☐ Place the free end of the flexible tubing in the water in the beaker, and immediately start recording data.

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

16. ☐ Name your run to reflect the sample type.

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

18. ☐ 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

19. ☐ Repeat the steps in Part 1 using 5 g $NaHSO_3$ instead of $NaHCO_3$.

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

20. ☐ Repeat the steps in Part 1 using 5 g $NaNO_2$ instead of $NaHCO_3$.

21. ☐ Save your experiment, and clean up according to your teacher's instructions.

Data Analysis

1. ☐ From the graph display for each run, determine the maximum and minimum pH values, and record them in Table 1.

2. ☐ Complete Table 1.

Table 1: pH change due to gases dissolved in water

Gas	Final pH	Initial pH	Change in pH (pH_{final} - $pH_{initial}$)
Carbon dioxide			
Sulfur dioxide			
Nitrogen dioxide			

Analysis Questions

1. **Was your prediction correct regarding what would happen to the pH when you dissolved the gases in it? Why or why not?**

2. **The following chemical reactions are involved in this lab. Write each formula using chemical notation.**

   a. One molecule of carbon dioxide gas dissolves in water to form one bicarbonate ion and one hydrogen ion.

   b. Two nitrogen dioxide gas molecules dissolve in water to form one nitrate ion, one nitrite ion, and two hydrogen ions.

   c. One sulfur dioxide gas molecule dissolves in water to form one bisulfite ion and one hydrogen ion.

3. **Which gas created the smallest change in pH of the water?**

4. **Compare your results with those from other groups. What factors might have caused some of the variability in the change of the observed pH?**

5. **For the three reactions of gas dissolving in water, what caused the reduction of the pH of the water in which these gases are dissolved?**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **What industrial or other man-made (anthropogenic) gases emitted into the atmosphere are considered the primary gases that cause acid rain? What are some sources of these gases?**

2. **Scientists have found that sulfuric acid is the primary acid that causes acid rain. What are some of the chemical reactions that produce sulfuric acid in the atmosphere? Why does radiation from the sun speed up this reaction?**

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

4. **Discuss the relationship between acid rain and the sulfur and nitrogen cycles.**

5. **What are some ways to treat the effects of acid rain?**

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

7. **Although carbonic acid produces only a small decrease in the pH of water, why is it of concern in the environment?**

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_x and SO_x 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 to decrease to a level outside their tolerance.
   C. Acid rain affects soil chemistry and the ability of plant roots to take in nutrients.
   D. Acid rain increases the mobility of toxic metals in ecosystems.
   E. All of the above are true.
   F. Only A, B, and C are true.

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

   A. Solar radiation
   B. Buffers in soils and water
   C. Water in the atmosphere
   D. Nitrogen gas (N_2) in the atmosphere
   E. All of the above
   F. Only A and C

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

   A. 3.6
   B. 4.6
   C. 5.6
   D. 6.6
   E. 7.6

4. **Acid rain has been linked to**

   A. Contamination of fish with highly toxic methylmercury
   B. Damage to fish through reactions that create high aluminum concentrations in the water.
   C. Reduced nutrient uptake by tree roots
   D. Weakening trees, so they become more susceptible to other types of damage
   E. All of the above