Acid Rain

In this experiment, you will observe the formation of four acids that occur in acid rain:

- carbonic acid, \( \text{H}_2\text{CO}_3 \)
- nitrous acid, \( \text{HNO}_2 \)
- nitric acid, \( \text{HNO}_3 \)
- sulfurous acid, \( \text{H}_2\text{SO}_3 \)

Carbonic acid occurs when carbon dioxide gas dissolves in rain droplets of unpolluted air:

\[
(1) \quad \text{CO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{CO}_3(aq)
\]

Nitrous acid and nitric acid result from a common air pollutant, nitrogen dioxide (\( \text{NO}_2 \)). Most nitrogen dioxide in our atmosphere is produced from automobile exhaust. Nitrogen dioxide gas dissolves in rain drops and forms nitrous and nitric acid:

\[
(2) \quad 2 \text{NO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{HNO}_2(aq) + \text{HNO}_3(aq)
\]

Sulfurous acid is produced from another air pollutant, sulfur dioxide (\( \text{SO}_2 \)). Most sulfur dioxide gas in the atmosphere results from burning coal containing sulfur impurities. Sulfur dioxide dissolves in rain drops and forms sulfurous acid:

\[
(3) \quad \text{SO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_3(aq)
\]

In the procedure outlined below, you will first produce these three gases. You will then bubble the gases through water, producing the acids found in acid rain. The acidity of the water will be monitored with a pH Sensor.

**OBJECTIVES**

In this experiment, you will

- Generate three gaseous oxides, \( \text{CO}_2 \), \( \text{SO}_2 \), and \( \text{NO}_2 \).
- Simulate the formation of acid rain by bubbling each of the three gases into water and producing three acidic solutions.
- Measure the pH of the three resulting acidic solutions to compare their relative strengths.

**MATERIALS**

- computer
- Vernier computer interface
- LoggerPro
- Vernier pH Sensor
- wash bottle with distilled water
- ring stand
- 100 mL beaker
- 20 x 150 mm test tube
- solid NaNO₂
- solid NaHCO₃
- solid NaHSO₃
- 1 Beral pipet with 1.0 M HCl
- 3 Beral pipets with a 2 cm stem
- 3 Beral pipets with a 15 cm stem
- utility clamp
- tap water
PROCEDURE

1. Obtain and wear goggles.

2. Obtain three short-stem and three long-stem Beral pipets. Label the short-stem pipets with the formula of the solid they will contain: “NaHCO₃”, “NaNO₂”, and “NaHSO₃”. Label the long-stem pipets with the formula of the gas they will contain: “CO₂”, “NO₂”, and “SO₂”. You can use a 100 mL beaker to support the pipets.

3. Obtain a beaker containing solid NaHCO₃. Squeeze the bulb of the pipet labeled “NaHCO₃” to expel the air, and place the open end of the pipet into the solid NaHCO₃. When you release the bulb, solid NaHCO₃ will be drawn up into the pipet. Continue to draw solid into the pipet until there is enough to fill the curved end of the bulb, as shown in Figure 1.

4. Repeat the Step 3 procedure to add solid NaNO₂ and NaHSO₃ to the other two Beral pipets. **CAUTION:** Avoid inhaling dust from these solids.

5. Obtain a Beral pipet with 1.0 M HCl from your teacher. **CAUTION:** HCl is a strong acid. Gently hold the pipet with the stem pointing up, so that HCl drops do not escape. Insert the narrow stem of the HCl pipet into the larger opening of the pipet containing the solid NaHCO₃, as shown in Figure 2. Gently squeeze the HCl pipet to add about 20 drops of HCl solution to the solid NaHCO₃. When finished, remove the HCl pipet. Gently swirl the pipet that contains NaHCO₃ and HCl. Carbon dioxide, CO₂, is generated in this pipet. Place it in the 100 mL beaker, with the stem up, to prevent spillage.

6. Repeat the procedure in Step 5 by adding HCl to the pipet containing solid NaHSO₃. Sulfur dioxide, SO₂, is generated in this pipet.

7. Repeat the procedure in Step 5 by adding HCl to the pipet containing solid NaNO₂. Nitrogen dioxide, NO₂, is generated in this pipet. When you have finished this step, return the HCl pipet to your teacher. Leave the three gas-generating pipets in the 100 mL beaker until Step 10.

8. Use a utility clamp to attach a 20 × 150 mm test tube to the ring stand. Add about 4 mL of tap water to the test tube. Remove the pH Sensor from the pH storage solution, rinse it off with distilled water, and place it into the tap water in the test tube.

9. Connect the pH Sensor to the computer interface. Prepare the computer for data collection by opening the file “22 Acid Rain” from the Chemistry with Computers folder. Check to see that the pH is between 6 and 8 for the water.

10. Squeeze all of the air from the bulb of the long-stem pipet labeled “CO₂”. Keep the bulb completely collapsed and insert the long stem of the pipet down into the gas-generating pipet labeled “NaHCO₃”, as shown in Figure 3. Be sure the tip of the long-stem pipet remains above the liquid in the gas-generating pipet. Release the pressure on the bulb so that it draws gas up into it. Store the long-stem pipet and the gas-generating pipet in the 100 mL beaker.

11. Repeat the procedure in Step 10 using the pipets labeled “NaNO₂” and “NO₂”.

12. Repeat the procedure in Step 10 using the pipets labeled “NaHSO₃” and “SO₂”.

Figure 1

Figure 2

Figure 3
13. Insert the long-stem pipet labeled “CO₂” into the test tube, alongside the pH Sensor, so that its tip extends into the water to the bottom of the test tube (see Figure 4).

14. To begin collecting data, click [Collect]. After 15 seconds have elapsed, gently squeeze the bulb of the pipet so that bubbles of CO₂ slowly bubble up through the solution. Use both hands to squeeze all of the gas from the bulb. When data collection stops after 120 seconds, examine the data in the table and determine the initial pH value (before CO₂ was added) and the final pH value (after CO₂ was added and pH stabilized). To confirm these two values, click the Statistics button, and examine the minimum and maximum values in the pH box displayed on the graph. Record the initial and final pH values in your data table. Close the Statistics box by clicking in the upper left corner of the box.

15. Rinse the tip of the pH Sensor thoroughly with distilled water and return it to the sensor storage solution. Discard the contents of the test tube as directed by your teacher. Rinse the test tube thoroughly with tap water. Add 4 mL of tap water to the test tube. Place the pH Sensor in the test tube and check to see that the input display shows a pH value that is about the same as the previous initial pH. If not, rinse the test tube again.

16. From the Experiment menu, choose Store Latest Run. This stores the data so it can be used later, but it will be still be displayed while you do your second and third trials.

17. Repeat Steps 13-16 using NO₂ gas.

18. Repeat Steps 13-14 using SO₂ gas. When you are finished, rinse the pH Sensor with distilled water and return it to the sensor storage solution. Discard the six pipets as directed by your Instructor.

19. Label all three curves by choosing Text Annotation from the Insert menu, and typing “carbon dioxide” (or “nitrogen dioxide”, or “sulfur dioxide”) in the edit box.

20. Print copies of the graph, with all three data sets displayed.

**PROCESSING THE DATA**

1. For each of the three gases, calculate the change in pH (ΔpH), by subtracting the initial pH from the final pH. Record these values in your data table.

2. In this experiment, which gas caused the smallest drop in pH?

3. Which gas (or gases) caused the largest drop in pH?

4. Coal from western states such as Montana and Wyoming is known to have a lower percentage of sulfur impurities than coal found in the eastern United States. How would burning low-sulfur coal lower the level of acidity in rainfall? Use specific information about gases and acids to answer the question.

5. High temperatures in the automobile engine cause nitrogen and oxygen gases from the air to combine to form nitrogen oxides. What two acids in acid rain result from the nitrogen oxides in automobile exhaust?
6. Which gas and resulting acid in this experiment would cause rainfall in *unpolluted* air to have a pH value less than 7 (sometimes as low as 5.6)?

7. Why would acidity levels usually be lower (pH higher) in actual rainfall than the acidity levels you observed in this experiment? Rainfall in the United States generally has a pH between 4.5 and 6.0.

### DATA AND CALCULATIONS TABLE

<table>
<thead>
<tr>
<th>Gas</th>
<th>Initial pH</th>
<th>Final pH</th>
<th>Change in pH (ΔpH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
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<tr>
<td>NO₂</td>
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<td>SO₂</td>
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