Equilibrium in a Syringe

Effect of Pressure on the Solubility of CO_2

FLINN SCIENTIFIC CHEM FAX!

Introduction

When carbon dioxide gas dissolves in water, it forms a weak acid solution due to the following reversible reaction:

$$2CO_2(g) + H_2O(l) \rightleftarrows CO_2(aq) + H^+(aq) + HCO_3^-(aq) \qquad \textit{Equation 1}$$

The hydrogen ion concentration in solution depends on the amount of dissolved carbon dioxide. In this demonstration, the effect of pressure on the solubility of carbon dioxide and on the position of equilibrium for this reversible reaction will be observed.

Concepts

- Equilibrium
- LeChâtelier's principle
- Gas solubility
- Acid–base indicators

Materials

Bromcresol green indicator solution, 0.04%, 5 mL

Seltzer water, 25 mL

Beaker, 50-mL

Beral-type pipet, graduated

Color chart or pH reference strip for bromcresol green

Syringe, 30-mL

Syringe tip cap (septum)

Safety Precautions

Wear chemical splash goggles and chemical-resistant gloves and apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Obtain about 25 mL of seltzer water in a 50-mL beaker and add 2 mL of bromcresol green indicator using a graduated, Beral-type pipet. Swirl to mix the solution.
2. Draw about 6 mL of the seltzer/indicator solution into a 30-mL syringe and seal the syringe by pushing a tip cap firmly on its open end. Record the initial volume of liquid in the syringe. *(The initial volume should be about 6.0 mL.)*
3. Compare the color of the seltzer/indicator solution with the bromcresol green color chart to determine the pH of the seltzer water. Record the initial pH of the solution. *(The seltzer/indicator solution is yellow-green, corresponding to a pH of 4.0.)*
4. Expand the volume of gas in the syringe by withdrawing the plunger until it stops. While holding the plunger in the withdrawn position, shake the solution until the solution no longer effervesces and its color no longer changes. *Note:* According to Boyle's Law, increasing the applied volume should decrease the pressure of the gas in the syringe.
5. Determine the pH of the solution and record both the pH and the total volume of liquid plus gas in the syringe. *(The new pH is 4.4 at an expanded volume of 16.1 mL.)*
6. Recall that pH and $[H^+]$ are inversely related—the higher the pH, the lower the hydrogen ion concentration. What effect does decreasing the pressure have on the solubility of carbon dioxide gas and the position of equilibrium for Equation 1? *(Decreasing the pressure shifts the equilibrium shown in Equation 1 to the left, reducing the solubility of carbon dioxide gas and decreasing the hydrogen ion concentration.)*
7. Note the volume of carbon dioxide gas in the syringe. Compress and shake the mixture in the syringe until both the color and volume no longer change. *Note:* According to Boyle's Law, decreasing the applied volume should increase the pressure of the gas in the syringe.

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8. Determine the pH of the solution and record both the pH and the total volume of liquid plus gas in the syringe. *(The new pH is 4.0 at a compressed volume of 7.1 mL.)*
9. What effect does increasing the pressure have on the solubility of carbon dioxide gas and the position of equilibrium for Equation 1? *(Increasing the pressure shifts the equilibrium shown in Equation 1 to the right, increasing the solubility of carbon dioxide gas and increasing the hydrogen ion concentration.)*
10. Repeat step 4 by withdrawing the plunger until it stops. While holding the plunger in the withdrawn position, shake the solution until the color no longer changes.
11. Determine the pH of the solution at the increased volume and record both the pH and the total volume of liquid plus gas in the syringe. *(Note that the process can be repeated several times. Equilibrium will reestablish itself to give a pH of 4.4 at an expanded volume of 15.0 mL.)*

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The seltzer water may be flushed down the drain according to Flinn Suggested Disposal Method #26b.

Tips

- Any unflavored, unbuffered seltzer will work as a source of dissolved carbon dioxide. Do not use soda water or club soda, which contains sodium bicarbonate. Club soda is essentially a buffered solution—its pH will not change.
- The following information can be used to prepare a color chart for bromcresol green:

Color	pH	Color	pH
Yellow	3.8	Dark green	4.6
Yellow-green	4.0	Blue-green	4.8
Light green	4.2	Blue	5.0
Green	4.4	Blue	5.2

Discussion

This activity involves three reversible reactions: the solubility of carbon dioxide in water, the reaction of aqueous carbon dioxide and water to form H_2CO_3, and the weak acid ionization of H_2CO_3 to give HCO_3^- and H^+ ions. For simplicity's sake in terms of classroom discussion, these reactions are combined in Equation 1. The position of equilibrium for this overall reaction can be determined by measuring the concentration of H^+ ions in solution. Seltzer water is used as a source of dissolved carbon dioxide, and the concentration of H^+ ions is estimated using bromcresol green as an indicator. The indicator is yellow when the pH is less than 3.8, blue when the pH is greater than 5.2, and various shades of green in the pH range 4.0–4.8. A sealed syringe is used to provide a closed system.

$$2CO_2(g) + H_2O(l) \rightleftarrows CO_2(aq) + H^+(aq) + HCO_3^-(aq) \qquad \textit{Equation 1}$$

The effect of pressure on the solubility of carbon dioxide gas can be explained in terms of LeChâtelier's Principle:

> *"If a system at equilibrium is disturbed by a change in temperature, pressure, or the concentration of one of its components, the system will tend to shift its equilibrium position so as to counteract the effect of this disturbance."*

When the total pressure above the seltzer/indicator solution is reduced (by increasing the applied volume), the indicator changes from yellow-green to green, corresponding to a pH change from 4.0 to 4.4. Since a pH increase corresponds to a decrease in the hydrogen ion concentration, the results indicate that the equilibrium shown in Equation 1 is shifted to the left as the pressure decreases—the solubility of carbon dioxide decreases. This is in agreement with LeChâtelier's Principle. Carbon dioxide gas is forced out of solution, back into the gas phase. The reverse effect is observed when the pressure is increased. The relationship between pressure and the amount of dissolved carbon dioxide is also an example of Henry's Law, which states that the amount of a gas dissolved in solution is proportional to the pressure of the gas above the solution.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Evolution and equilibrium
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, motions and forces

Reference

This activity was adapted from *Equilibrium*, Volume 15 in the *Flinn ChemTopic™ Labs* series; Cesa, I., Editor; Flinn Scientific, Inc., Batavia, IL (2003).

Materials for *Equilibrium in a Syringe* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1732	Syringe, without Needle, 35 mL
AP8958	Syringe Tip Cap
B0064	Bromcresol Green Indicator Solution, 0.04%, 100 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.