Buffer Balancing Acts

Introduction

Buffers provide an essential acid–base balancing act—in consumer products, foods, lakes and streams, even living cells. What are buffers made of and how do they work?

Concepts

- Acids and bases
- pH
- Buffer

Materials (for each demonstration)

Alka-Seltzer® tablets, 2
Bromthymol blue indicator, 0.04%, 8 mL
Hydrochloric acid, HCl, 1 M, 50 mL
Sodium hydroxide, NaOH, 1 M, 50 mL
Sodium phosphate monobasic, NaH_2PO_4, 0.2 M, 200 mL
Sodium phosphate dibasic, Na_2HPO_4, 0.2 M, 200 mL
Universal indicator, 5 mL (and accompanying color chart)
Beakers, 400-mL, 4
Beral-type pipets, graduated, 2
Graduated cylinders, 10- and 250-mL
Stirring rod
Water, distilled or deionized

Safety Precautions

Hydrochloric acid and sodium hydroxide are corrosive liquids—avoid exposure to eyes and skin. Universal indicator contains ethyl alcohol and is a flammable liquid. Avoid exposure to heat, flames, and other ignition sources. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

Part A. What Is a Buffer?

1. Mix together 200 mL each of 0.2 M NaH_2PO_4 and 0.2 M Na_2HPO_4 to prepare 400 mL of a pH 7 phosphate buffer.
2. Set up four 400-mL beakers and label them #1–4.
3. Add 200 mL of distilled or deionized water to beakers #1 and 3, followed by 200 mL of the phosphate buffer to beakers #2 and 4.
4. Add about 2 mL of bromthymol blue indicator to each beaker. *(The solutions should all be green. This is the "neutral" color of the indicator, corresponding to pH values between 6 and 7.6.)*
5. Add 10 drops of 1 M HCl to the distilled water in beaker #1. *(Note the color change to yellow. This is the "acidic" color of the indicator.)*
6. Add 10 drops of 1 M HCl to the buffer in beaker #2. *(No color change—solution stays green.)*
7. Add an extra 10 drops of 1 M HCl to beaker #2. *(Still no color change. Look frustrated!)*
8. Use a graduated cylinder to add 5 mL of 1 M HCl to beaker #2. *(The frustration mounts as the solution remains green.)*
9. Continue adding 1 M HCl in 5-mL increments to beaker #2 until the color of the solution changes to yellow. *(This will probably take 2–3 more 5-mL portions of HCl, for a total of 15–20 mL.)*
10. Discuss the behavior of the buffer in beaker #2 when strong acid was added. What will happen if strong base is added?
11. Add 10 drops of 1 M NaOH to the distilled water in beaker #3. *(Note the color change to blue. This is the "basic" color of the indicator.)*
12. Repeat the general procedure described in steps 6–9, adding 1 M NaOH to the buffer solution in beaker #4. *(A total of 15–20 mL of NaOH will be needed to change the color of the buffer solution to blue.)*

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13. Discuss the composition and properties of a buffer. *(A buffer is a solution prepared from a weak acid and its conjugate base that resists pH changes upon addition of strong acid or base.)*

Part B. Buffer Action in a Consumer Product

1. Set up four clean beakers and relabel them #1–4, if necessary.
2. Add 200 mL of distilled or deionized water to each beaker. Dissolve one Alka-Seltzer tablet in each beaker #2 and 4.
3. Read the label on the Alka-Seltzer tablet and note the principal ingredients listed. Are there any weak acids and weak bases present that are capable of forming a buffer? *(The active buffer ingredients are citric acid and sodium bicarbonate.)*
4. Add about 20 drops (1 mL) of universal indicator solution to each beaker #1–4. Note the color of each solution and use the color chart to estimate the initial pH of each solution. *(The solutions should all be yellow-green, pH 6–7)*
5. Add 1 mL of 1 M HCl to beakers #1 and 2. Compare the indicator color and pH of each solution. *(Water will turn red, indicating a pH ≤ 4. The Alka-Seltzer solution should stay green, pH 6–7, suggesting that it is acting as a buffer.)*
6. Continue adding 1 M HCl in 1-mL increments to the Alka-Seltzer solution in beaker #2 until the indicator color is the same as that in beaker #1. How much acid must be added to overwhelm the buffer capacity of one Alka-Seltzer tablet? *(This will probably take about 20 mL of 1 M HCl.)*
7. Add 1 mL of 1 M NaOH to beakers #3 and 4. Compare the indicator color and pH of each solution. *(Water will turn purple, indicating a pH ≥ 10. The Alka-Seltzer solution should stay green, pH 6–7, suggesting that it acts as a buffer against both acid and base.)*
8. Continue adding 1 M NaOH in 1-mL increments to the Alka-Seltzer solution in beaker #4 until the indicator color is the same as that in beaker #3. How much base must be added to overwhelm the buffer capacity of one Alka-Seltzer tablet? *(This will take about 20 mL of 1 M NaOH. The buffer capacity of Alka-Seltzer is similar against both acids and bases.)*

Disposal

All final solutions may be disposed of down the drain with plenty of excess water according to Flinn Scientific Disposal Method #26b. Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste.

Tip

- For best results, use either freshly distilled water, boiled distilled water, or bottled water as the control in Parts A and B. Distilled water may absorb large quantities of carbon dioxide from the air during storage. The presence of dissolved CO_2 will make distilled water acidic and give a yellow color with bromthymol blue (Part A, step 4). In areas of the country where the water is not hard, tap water may be a suitable control.

Discussion

The ability of buffers to resist changes in pH upon addition of strong acid or strong base can be traced to their chemical composition. All buffers contain a mixture of both a weak acid (HA) and its conjugate base (A^-) (Equation 1).

$$\underset{\textit{Weak acid}}{HA} + H_2O \rightarrow \underset{\textit{Conjugate base}}{A^-} + H_3O^+ \qquad \textit{Equation 1}$$

Buffers control pH because the buffer components react with and neutralize either strong acid or strong base added to the solution. The weak acid component HA reacts with sodium hydroxide to give water and the conjugate base component A^- (Equation 2). The conjugate base component A^- reacts with hydrochloric acid to give the weak acid component HA and chloride ion (Equation 3).

$$HA + NaOH \rightarrow NaA + H_2O \qquad \textit{Equation 2}$$

$$A^- + HCl \rightarrow HA + Cl^- \qquad \textit{Equation 3}$$

Buffer activity will continue as long as both components HA and A^- remain present in solution.

The pH of the phosphate buffer used in Part A is about 7.2, corresponding to the second ionization constant of phosphoric acid (Equations 4 and 5). At equal molar concentrations of HPO_4^{2-} and $H_2PO_4^-$, Equation 5 reduces to $[H_3O^+] = 6.2 \times 10^{-8}$.

$$H_2PO_4^- + H_2O \leftrightarrows HPO_4^{2-} + H_3O^+ \qquad \textit{Equation 4}$$

$$K_{a2} = \frac{[HPO_4^{2-}][H_3O^+]}{[H_2PO_4^-]} = 6.2 \times 10^{-8} \qquad \textit{Equation 5}$$

Alka-Seltzer contains 325 mg aspirin, 1.9 g sodium bicarbonate, and 1 g citric acid per tablet. The active "antacid" or buffering ingredients are sodium bicarbonate (0.022 moles), a weak base, and citric acid (0.005 moles), a weak acid. When the tablet dissolves in water, one mole of citric acid reacts with three moles of bicarbonate ion. The products of the neutralization reaction are citrate ion, carbon dioxide ("plop-plop-fizz-fizz") and water (Equation 6). Citrate ion is the conjugate base of a weak acid and thus acts as a buffer when strong acid is added (Equation 7). Excess sodium bicarbonate, on the other hand, provides buffering action against the addition of strong base (Equation 8).

$$H_3C_6H_5O_7(aq) + 3HCO_3^-(aq) \leftrightarrows C_6H_5O_7^{3-}(aq) + 3H_2O(l) + 3CO_2(g) \qquad \textit{Equation 6}$$

$$C_6H_5O_7^{3-}(aq) + 3H_3O^+(aq) \rightarrow H_3C_6H_5O_7(aq) + 3H_2O(l) \qquad \textit{Equation 7}$$

$$HCO_3^-(aq) + OH^-(aq) \rightarrow CO_3^{2-}(aq) + H_2O(l) \qquad \textit{Equation 8}$$

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
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

Reference

Flinn ChemTopic™ Labs, Vol. 13 Acids and Bases; Flinn Scientific: Batavia, IL, 2002.

Buffer Balancing Acts is available as a chemical demonstration kit from Flinn Scientific, Inc.

Catalog No.	Description
AP6288	Buffer Balancing Acts—Chemical Demonstration Kit

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