# Buffer Balancing Acts

Buffers

## 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? This demonstration explores the properties of buffers and their consumer applications.

## Concepts

- pH
- Weak acid
- Buffer
- Conjugate base

## Materials

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, Na2HPO4, 0.2 M, 200 mL

Universal indicator, 5 mL (includes accompanying color chart)

Water, distilled or deionized

Beakers, 400-mL, 4

Beral-type pipets, graduated, 2

Graduated cylinders, 10- and 250-mL

Stirring rod

Universal indicator color chart

## *Safety Precautions*

*Hydrochloric acid and sodium hydroxide solutions are corrosive liquids. Avoid exposure to eyes and skin. Universal indicator solution is an alcohol-based solution and is flammable. Avoid exposure to flames and other ignition sources. Wear chemical splash goggles and chemical-resistant gloves and apron. Consult current Material Safety Data Sheets for additional safety, handling, and disposal information.*

## Preparation

A buffer is made up of a weak acid and its conjugate base. The pH of a buffer depends on the nature of the weak acid and the ratio of the weak acid and conjugate base components. This demonstration examines the properties of a buffer prepared from equal amounts of $NaH_2PO_4$ and $Na_2HPO_4$ solutions. Mix together 200 mL each of 0.2 M $NaH_2PO_4$ and 0.2 M $Na_2HPO_4$ solutions to prepare 400 mL of the phosphate buffer needed for Part A.

## Procedure

**Part A. What Is a Buffer?**

1. Set up four 400-mL beakers and label them #1–4.
2. Add 200 mL of distilled or deionized water to beakers #1 and 3.
3. Add 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 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 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 until the color 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 with respect to excess strong acid. What will happen if strong base is added?
11. Add 10 drops of 1 M NaOH to beaker #3. *(Note the color change to blue. This is the "basic" color of the indicator.)*
12. Add 10 drops of 1 M NaOH to beaker # 4. *(No color change—solution stays green.)*
13. Add an extra 10 drops of NaOH to beaker #4. *(Still no color change—but you are not surprised!)*
14. Add 5 mL of 1 M NaOH to beaker #4. *(The solution remains green.)*
15. Continue adding 1 M NaOH in 5-mL increments until the color changes to blue. *(This will probably take 2–3 more 5-mL portions of NaOH, for a total of 15–20 mL.)*
16. Pour the solutions down the drain with plenty of excess water and rinse the beakers with distilled or deionized water for use in Part B.
17. Invite student discussion to come up with a working definition 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.
3. Dissolve one Alka-Seltzer tablet in each beaker #2 and 4.
4. 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.)*
5. 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. If the water in the control beakers #1 and 3 is not yellow–green, add 1–2 mL of pH 7 buffer.)*
6. 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.)*
7. 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.)*
8. Relate the acid-neutralizing ability of Alka-Seltzer to the definition and uses of antacids.
9. 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.)*
10. 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

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

## Tips

- For best results, use either freshly distilled water or bottled water as the control in beakers #1 and 3 in Part A. Distilled water, in particular, absorbs large quantities of carbon dioxide from the air during storage. The presence of dissolved $CO_2$ may make the water acidic enough to turn yellow with bromthymol blue indicator solution (step 4). In areas of the country where the water is not hard, tap water may be a suitable control.
- The resistance of buffers to pH changes can be illustrated using pH measurements. The Flinn pH Meter (Catalog No. AP8673) contains a large, easy-to-read display and provides a convenient and inexpensive way to measure the pH of solutions.

## Discussion

The ability of buffers to resist changes in pH upon addition of a strong acid or base can be traced to their chemical composition. All buffers contain a mixture of both a weak acid (HA) and its conjugate base ($A^-$). The buffer components HA and $A^-$ are related to each other by means of the following ionization reaction that describes the behavior of the weak acid in water (Equation 1).

$$\underset{\text{weak acid}}{HA} + H_2O \leftrightarrows \underset{\text{conjugate base}}{A^-} + H_3O^+ \qquad \textit{Equation 1}$$

Buffers control pH because the two buffer components are able to react with and therefore neutralize strong acid or strong base added to the solution. The weak acid component HA reacts with any strong base, such as sodium hydroxide (NaOH), added to the solution to give water and the conjugate base component $A^-$ (Equation 2). The conjugate base component $A^-$ reacts with any acid, such as hydrochloric acid (HCl), added to the solution to give its acid partner HA and neutral chloride ion (Equation 3).

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

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

These complementary neutralization reactions can be visualized as a cyclic process (Figure 1). Buffer activity will continue as long as both components remain present in solution. If one of the components $A^-$ or HA is completely consumed, however, the buffer capacity will be exhausted and the buffer will no longer be effective.

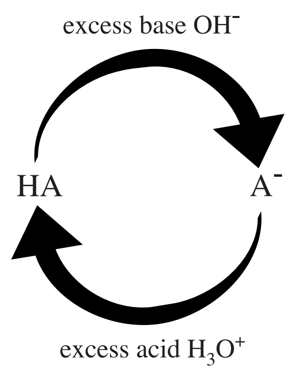


**Figure 1.**

The pH of the phosphate buffer used in Part A should be 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 $[H_3O^+] = 6.2 \times 10^{-8}$. *Note:* $pH = -\log[6.2 \times 10^{-8}] = 7.2$.

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

$$Ka_2 = \frac{[HPO_4^{2-}][H_3O^+]}{[H_2PO_4^-]} = 6.2 \times 10^{-8} \qquad \textit{Equation 5}$$

 

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. Citric acid is a triprotic acid (three ionizable hydrogens). 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). Because citrate ion is the conjugate base of a weak acid, it 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

## Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Buffer Balancing Acts* activity, presented by Irene Cesa, is available in *Buffers*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

## Materials for *Buffer Balancing Acts* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Buffer Balancing Acts—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

| Catalog No. | Description |
|---|---|
| AP6288 | Buffer Balancing Acts—Chemical Demonstration Kit |
| AP8673 | Flinn pH Meter |
| B0173 | Bromthymol Blue Solution, 0.04%, 100 mL |
| H0013 | Hydrochloric Acid Solution, 1 M, 500 mL |
| S0148 | Sodium Hydroxide Solution, 1 M, 500 mL |
| S0097 | Sodium Phosphate, Monobasic, Reagent, 100 g |
| S0222 | Sodium Phosphate, Dibasic, Reagent, 100 g |
| U0001 | Universal Indicator Solution |
| AP5367 | Universal Indicator Color Chart |
| GP1048 | Beaker, Borosilicate Glass, 400-mL |

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