15. INTRODUCTION TO BUFFERS

Initial Question

As you have seen in titration experiments, adding one drop of an acidic or basic solution to another solution can result in large changes in pH. However, many biological reactions only work within a narrow range of pH (between about 6 and 8). How does the body, a plant, or the soil keep the pH from changing drastically every time it comes in contact with an acid or base? In this lab, you will investigate solutions that help answer this question.

What is a buffer and what are the components of a buffer solution?

Materials and Equipment

Model 1

- Data collection system
- pH sensor
- Beaker (glass), 50-mL
- Graduated cylinder 25-mL
- Acetic acid (CH_3COOH), 20 mL
- Sodium acetate ($NaCH_3COO$) approx. 1 g
- Stirring rod
- Scoopula™ spatula
- Materials for pH sensor calibration (refer to Appendix A)

Model 2

- Data collection system
- pH sensor
- Beakers (5), 50-mL
- Graduated cylinder, 25-mL
- Graduated cylinder, 10-mL or volumetric pipet, 5-mL
- Solution 1: Distilled water, 20 mL
- Solution 2: 0.01 M Acetic acid (CH_3COOH), 20 mL
- Solution 3: 0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$), 20 mL
- Solution 4: 0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3), 20 mL
- Solution 5: 0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3), 20 mL
- 0.01 M Sodium hydroxide (NaOH), 25 mL
- Stirring rod
- Wash bottle

Applying Your Knowledge

- Data collection system
- pH sensor
- Beakers (2), 100-mL
- Stirring rod
- Bufferin™ tablet, 325 mg
- Aspirin tablet, 325 mg
- Mortar and pestle
- Distilled water, 100 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear goggles and work carefully to prevent spills
- Sodium hydroxide is corrosive. If you come in contact with it, flush the exposed area with large amounts of water.

Getting Your Brain in Gear

The Brønsted–Lowry Acid–Base Theory expands on the Acid–Base Theory of Svante Arrhenius. The Arrhenius theory is easy to use but covers a limited number of substances. Brønsted and Lowry developed a theory that includes far more. When discussing strong acids and bases, it is common practice to use the Arrhenius theory. When weak acids are involved, the Arrhenius theory is not always sufficient and other theories must be used.

1. What are the definitions of acids and bases according to Arrhenius?

    a. Acids

    b. Bases

2. What are the definitions of acids and bases according to Brønsted and Lowry?

    a. Acids

    b. Bases

3. According to the Brønsted–Lowry theory, when acids and bases are combined, they react to form conjugate acid–base pairs. When weak acids and bases react, water often becomes a reactant. For items "a" and "b," add the labels "Acid" and "Base" to the appropriate molecule indicated by the bracket. For "c" and "d," first draw the brackets and then label the acid and base pairs.

   Example:

   Acid Base

   $$NH_4^+ + OH^- \rightleftharpoons NH_3 + H_2O$$

   Base Acid

   (a)

   $$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

   (b)

   $$HSO_3^- + H_3O^+ \rightleftharpoons H_2O + H_2SO_3$$

   (c)

   $$CO_3^{2-} + H_3O^+ \rightleftharpoons H_2O + HCO_3^-$$

   (d)

   $$H_2O + H_2PO_4^- \rightleftharpoons H_3O^+ + HPO_4^{2-}$$

   e. What is different between the components of a conjugate acid–base pair?

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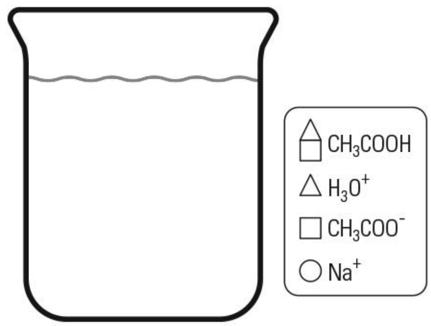
4. In this lab, you will be working with mixtures of solutions, such as acetic acid (CH_3COOH) mixed with sodium acetate ($NaCH_3COO$).

   a. Write the net ionic equation for the reaction of $NaCH_3COO$ and CH_3COOH.

   NOTE: Water is a reactant.

b. In the beaker below, draw a particulate-level representation showing what the $NaCH_3COO$ and CH_3COOH solution looks like at the molecular level. You do not need to explicitly represent the water molecules. Use the particulate key as a guide.



c. What is the conjugate acid of CH_3COO^-?

Model 1

Building Model 1 − Observing a Reaction System

1. Add 20 mL of acetic acid to a 50-mL beaker.

2. Calibrate the pH sensor.

   NOTE: You will need to re-calibrate the pH sensor for the other procedures if they are carried out in a different class period.

3. Measure the pH of the acetic acid solution and record the value in the Model 1 Data Table.

   NOTE: Make sure the glass bulb of the pH sensor is covered with solution.

4. Add a *pea size* amount of solid sodium acetate to the beaker. Use a stirring rod or gently swirl the solution until the sodium acetate dissolves.

5. Based on your reaction equation in the Getting Your Brain in Gear section, should the addition of $NaCH_3COO$ make the solution's pH increase, decrease or remain the same? Justify your answer.

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6. Measure the pH of the solution and record the value in the Model 1 Data Table.

Model 1 − Observing a Reaction System

Table 1: Model 1 Data Table–pH change in acetic acid due to added sodium acetate

Solution	pH
Acetic acid	
Acetic acid and sodium acetate	

Analyzing Model 1 − Observing a Reaction System

7. Did the pH of the solution increase, decrease, or remain the same?

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8. a. Does $NaCH_3COO$ dissociate in water?

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   b How should the dissociation be represented in water, as $NaCH_3COO$ (aq) or Na^+(aq) + CH_3COO^-(aq)?

9. Two possible reaction equations are shown below.

Equilibrium: $CH_3COOH\ (aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-\ (aq)$

Stoichiometric addition: $CH_3COOH\ (aq) + NaCH_3COO(aq) \rightarrow NaCH_3COO\ (aq) + CH_3COOH\ (aq)$

Which of these reaction equations best explains the change in the pH observed? Justify your answer.

10. Why is the Na^+ ion not shown in the equilibrium reaction?

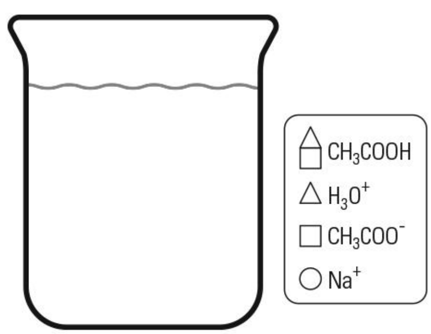
11. You answered the following questions in the Getting your Brain in Gear section. Revise your answer, if necessary, with the new information from Model 1.

In this lab, you will be working with mixtures of solutions, such as acetic acid (CH_3COOH) mixed with sodium acetate ($NaCH_3COO$).

a. Write a net ionic equation for the reaction of $NaCH_3COO$ and CH_3COOH.

NOTE: Water is a reactant.

b. In the beaker below, draw a particulate-level representation showing what the $NaCH_3COO$ and CH_3COOH solution looks like at the molecular level. You do not need to explicitly represent the water molecules. Use the particulate key as a guide.



MODEL 2

Building Model 2 – Observing the pH of Solutions

1. Using a graduated cylinder, measure 20 mL of each of the following five solutions into 50-mL beakers.

Table 2: Solutions to test

Solution #	Solution
1	Distilled water
2	0.01 M Acetic acid (CH_3COOH)
3	0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$)
4	0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3)
5	0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3)

2. Measure the initial pH of each solution and record the results in the Model 2 Data Table.

   NOTE: Make sure the glass bulb at the bottom of the pH meter is covered with solution.

3. Using a graduated cylinder or volumetric pipet, add 5.0 mL of 0.01 M NaOH(aq) to each of the five solutions. Swirl each beaker gently and then measure and record the pH.

Model 2 – Observing the pH of Solutions

Table 3: Model 2 Data Table–Compare pH after adding 0.01 M NaOH

Solution Number	Solution	Initial pH	pH after Adding Base
1	Distilled water		
2	0.01 M Acetic acid (CH_3COOH)		
3	0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$)		
4	0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3)		
5	0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3)		

Analyzing Model 2 – Observing the pH of Solutions

4. a. Which solution had the greatest change in pH?

   b. Which solution had the least change in pH?

5. A *buffer* is a solution that, upon addition of acid or base, does not have a large change in pH. Which of your solutions are buffers?

6. How are the two compounds present in each buffer solution related to one another?

7. Consider a buffer solution formed from 0.1 M HF and 0.1 M NaF.

   NOTE: NaF is soluble.

   a. What FOUR species, besides water, are extensively present in solution? (Hint: the 4th one is from the dissociation of HF.)

   b. Which of these ions is present as a spectator ion?

   c. What equilibrium exists for the remaining ions?

8. a. If a compound containing H^+ is added to this solution, what direction will the equilibrium reaction shift and what species is consumed in the process?

   b. Why is it necessary, then, to have NaF as well as HF present for this solution to behave as a buffer?

9. a. If a compound containing OH^- ions is added to this solution, what reaction will occur?

   b. What direction will the equilibrium reaction shift and what species is consumed in the process?

c. Why, then, is it necessary to have HF as well as NaF present for this solution to behave as a buffer?

10. The equilibrium reaction equation for the acetic acid/acetate buffer system is:

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons H_3O^+ (aq) + CH_3COO^-(aq)$$

a. Using the equilibrium reaction, explain why the pH changes only a little when a small amount of HCl is added.

b. Using the equilibrium reaction, explain why the pH changes only a little if a small amount of NaOH is added to the buffer system above.

11. Record the initial pH from the corresponding buffer systems in Model 2 in Table 4.

Table 4: Buffer systems

Solution Number	Buffer Solution Components	Initial pH	pK_a
3	0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$)		
4	0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3)		
5	0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3)		

12. Chemists often characterize acids by their pK_a. The pK_a is defined as

$$pK_a = -\log(K_a)$$

The K_a of each of the acids and bases used in the buffers in Model 1 are given below. Calculate the pK_a for each and record them in Table 4.

acetic acid	$CH_3COOH\ (aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$	$K_a = 1.8 \times 10^{-5}$
bisulfite	$HSO_3^-\ (aq) \rightleftharpoons H^+(aq) + SO_3^{2-}(aq)$	$K_a = 1.0 \times 10^{-7}$
bicarbonate	$HCO_3^-\ (aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$	$K_a = 5.6 \times 10^{-11}$

13. Identify a relationship between the pK_a of the acids and bases and the pH of the buffer solutions.

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14. Use a reference source to find an acid that will be the foundation of a buffer solution with a pH of 6.5.

15. Suggest a compound that will provide a conjugate base for the acid you chose in the previous question.

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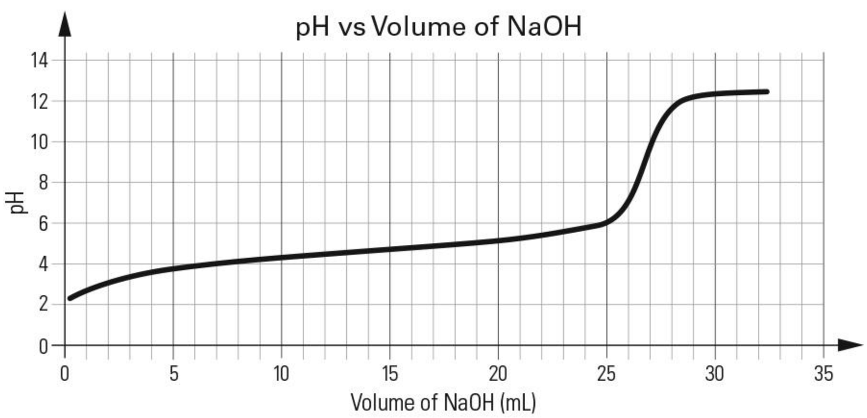
Connecting to Theory

Looking at a weak acid–strong base titration curve, you will find a region of the curve that is nearly flat in the acidic region. This occurs because, with this combination of reagents, a buffer solution has been created. As OH^- is added to a weak acid, the conjugate base is formed. The buffer solution created resists changes in pH, causing this region of the curve to appear relatively flat.



Applying Your Knowledge – Determining the Buffering Ability of Bufferin™

1. Obtain one 325 mg tablet of aspirin and a 325 mg tablet of Bufferin. Crush each tablet and place them in separate beakers containing 50 mL of distilled water. Stir until they are dissolved.

2. Measure and record the pH of each solution.

Table 5: Comparison of aspirin and Bufferin

Sample	pH
Aspirin	
Bufferin	

3. Record the active ingredients from the bottles of the two tablets you examined.

4. Using words and reaction equations, explain the observed data.