# 16. BUFFER PROPERTIES

## Initial Question

Buffers are solutions that are resistant to changes in their pH when acids or bases are added. For example, human blood contains the bicarbonate ion. This ion can accept hydrogen ions to remove excess acidity in the blood or can donate hydrogen ions to remove alkalinity in the blood. Once the bicarbonate ions are used up, blood can rapidly become either too acidic or too basic. In other words, the bicarbonate buffer system in blood has a limited capacity.

How are buffers made, and what determines their capacity?

## Materials and Equipment

### *Model 1*

- Data collection system
- pH sensor
- Analytical balance
- Volumetric flask, 100-mL or 250-mL[1]
- Beakers (2), glass, 50-mL
- Sodium acetate ($NaCH_3COO$), about 1.0 g[2]
- Ammonium chloride ($NH_4Cl$), about 1.0 g[2]
- 0.3 M Acetic acid ($CH_3COOH$), 100 mL[2]
- 0.3 M Ammonia ($NH_3$), 100 mL[2]
- Distilled water, 150 mL[2]
- Marking pen

[1]The volume of the flask depends on the buffer assigned from the Model 1 Data Table.

[2]The volume and mass needed depends on the buffer assigned from the Model 1 Data Table.

### *Model 2*

- Universal indicator, 3 drops
- Beral pipets (2)
- Test tubes (3), 20 mm × 150 mm, glass, 25-mL
- 0.10 M Hydrochloric acid (HCl), 20 mL
- 0.10 M Sodium hydroxide (NaOH), 20 mL
- Buffer solution from Model 1
- Distilled and deionized water

### *Applying Your Knowledge*

- Data collection system
- pH sensor
- Beakers (2), 50-ml
- Volumetric flask, 100-ml
- Two of the following, to create 100 mL of buffer:
  0.3 M Acetic acid ($CH_3COOH$)
  0.3 M Sodium acetate ($NaCH_3COO$)
  0.3 M Sodium phosphate dibasic ($Na_2HPO_4$)
  0.3 M Sodium phosphate monobasic ($NaH_2PO_4$)
  0.3 M Ammonia ($NH_3$)
  0.3 M Ammonium chloride ($NH_4Cl$)
  0.3 M Potassium phosphate ($K_3PO_4$)
  0.3 M Phosphoric acid ($H_3PO_4$)
- 6 M Sodium hydroxide (NaOH), 5 drops[1]
- 6 M Hydrochloric acid (HCl), 5 drops[1]
- Stirring rod

[1]Your teacher will add the 5 drops of NaOH and HCl to test your buffer.

## Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear your goggles.
- This lab uses strong acids and bases. If you come in contact with either of them, flush the area with plenty of water.

## Getting Your Brain in Gear

1. For each solution described below, determine if it acts as a buffer. Explain your reasoning.

    a. 0.50 mole of $HCl$ and 0.50 mole of $NaCl$ in 250 mL of water

    b. 0.50 mole of $HNO_2$ and 0.50 mole of $NaNO_2$ in 250 mL of water

    c. 1.00 mole of $CH_3COOH$ and 0.50 mole $NaOH$ in 250 mL of water

2. Consider a buffer made of an equal number of moles of $HF$ and $NaF$.

    a. Write a net ionic equation to illustrate how the buffer solution reacts to keep the pH stable when strong acid is added.

    b. Write a net ionic equation to illustrate how the buffer solution reacts to keep the pH stable when strong base is added.

## MODEL 1

### Building Model 1 – Buffer Preparation

1. After your instructor assigns you a buffer from Model 1 to prepare, refer to the Model 1 Data Table to determine the chemicals and the molarities you will need for your buffer.

   Solution assigned: ________________________________________

2. What component(s) of your assigned buffer system are available (refer to the Materials and Equipment list for Model 1)?

   ________________________________________________________________________

   ________________________________________________________________________

3. Calculate the number of moles of weak acid and conjugate base, or weak base and conjugate acid, you will need in the final solution to make the buffer you have been assigned.

4. Calculate the mass of the solid and volume of solution you will need to make your assigned buffer.

5. Obtain the appropriate size volumetric flask.

6. Fill the volumetric flask halfway with distilled water.

7. Obtain ________ grams of solid _________________________ and add it to the volumetric flask.

   *NOTE: Do* not *fill the flask with water.*

8. Use a graduated cylinder to measure __________ milliliters of _______________________ and add it to the volumetric flask. Swirl the flask to mix the solution.

9. Fill the volumetric flask to the mark with distilled water. Mix the solution thoroughly by inverting the flask several times.

10. Rinse a 50-mL beaker three times with distilled water.

11. Rinse the 50-mL beaker twice with small portions of your buffer solution.

12. Pour about 25 mL of your buffer solution into the 50-mL beaker and measure the pH of your solution. Record the pH in the Model 1 Data Table.

13. Why is it necessary to rinse the 50-mL beaker with distilled water, and then with the solution you want to test?

_______________________________________________

_______________________________________________

_______________________________________________

14. Label and save your remaining buffer for building Model 2. Share your pH data with your classmates to complete the Model 1 Data Table.

## Model 1 – Buffer Preparation

Table 1: Model 1 Data Table—pH of buffers of different volumes and concentrations

| Solution Number | Molarity of Weak Base | p*Ka* | Molarity of Conjugate Acid | Ratio of Weak Base to Conjugate [BOH] / [B+] | Total Volume of Buffer Solution | pH of Buffer Solution | \|p$K_a$– pH\| |
|---|---|---|---|---|---|---|---|
| 1 | 0.05 M $NH_3$ | | 0.05 M $NH_4^+$ | | 100 mL | | |
| 2 | 0.10 M $NH_3$ | | 0.10 M $NH_4^+$ | | 100 mL | | |
| 3 | 0.10 M $NH_3$ | | 0.10 M $NH_4^+$ | | 250 mL | | |
| 4 | 0.15 M NH3 | | 0.15 M $NH_4^+$ | | 100 mL | | |
| 5 | 0.15 M $NH_3$ | | 0.05 M $NH_4^+$ | | 100 mL | | |
| 6 | 0.05 M $NH_3$ | | 0.15 M $NH_4^+$ | | 100 mL | | |
| **Solution Number** | **Molarity of Weak Acid** | **p*Ka*** | **Molarity of Conjugate Base** | **Ratio of Weak Acid to Conjugate [HA] / [A¯]** | **Total Volume of Buffer Solution** | **pH of Buffer Solution** | **\|p$K_a$– pH\|** |
| 7 | 0.05 M $CH_3COOH$ | | 0.05 M $CH_3COO^-$ | | 100 mL | | |
| 8 | 0.10 M $CH_3COOH$ | | 0.10 M $CH_3COO^-$ | | 100 mL | | |
| 9 | 0.10 M $CH_3COOH$ | | 0.10 M $CH_3COO^-$ | | 250 mL | | |
| 10 | 0.15 M $CH_3COOH$ | | 0.15 M $CH_3COO^-$ | | 100 mL | | |
| 11 | 0.15 M $CH_3COOH$ | | 0.05 M $CH_3COO^-$ | | 100 mL | | |
| 12 | 0.05 M $CH_3COOH$ | | 0.15 M $CH_3COO^-$ | | 100 mL | | |

## Analyzing Model 1 – Buffer Preparation

15. Use a reference source to look up the $K_a$ and determine the p$K_a$ of the weak acid or conjugate acid involved in each of the solutions in the Model 1 Data Table.

16. Calculate the weak acid or weak base to conjugate ratio for each buffer solution in Model 1.

    a. Which ratios of weak acid or weak base to the conjugate solution have the pH of the buffer the closest to the p$K_a$?

17. Compare the buffers having the same molarity of components, but with different total volumes. Does the volume of the buffer system prepared affect the pH of the resulting solution? Provide specific examples from Model 1 to support your answer.

18. How would you respond to a person who mistakenly said "Buffers are made so that the solution remains neutral"? Provide specific examples from Model 1 to support your answer.

19. Suppose you wanted to make a buffer solution that would keep the pH near 3. Which of the following mixtures would suffice?

| | |
|---|---|
| Solution A | 0.10 M lactic acid and 0.10 M sodium lactate |
| Solution B | 0.10 M hypochlorous acid 0.10 M sodium hypochlorite |
| Solution C | 0.10 M benzoic acid and 0.10 M sodium benzoate |

## MODEL 2

### Building Model 2 – Buffer Capacity

1. Rinse three test tubes several times with distilled water. Assign one pipet for the deionized water, one for the buffer, and one for the universal indicator.

2. Place 10 drops of deionized water in a test tube. Add one drop of universal indicator to the water and note the initial color. Add 0.10 M HCl solution drop-wise, mixing between drops, until the solution changes to red-orange (pH ≤ 3). In Model 2, record the number of drops of HCl solution added to make this color change occur.

3. Place 10 drops of your buffer solution in a test tube. Add one drop of universal indicator to the solution and note the initial color. Add 0.10 M HCl solution drop-wise, mixing between drops, until the solution changes to red-orange (pH ≤ 3). Record the number of drops of HCl solution added to make this color change occur.

   *NOTE: If your solution contains $CH_3COOH$ and $CH_3COO^-$, then don't carry out this step.*

4. Place 10 drops of deionized water in a test tube. Add one drop of universal indicator to the water, and note the initial color. Add 0.10 M NaOH solution drop-wise, mixing between drops, until the solution changes to purple (pH ≥ 11). Record the number of drops of NaOH solution added to make this color change occur.

5. Place 10 drops of your buffer solution in a test tube. Add one drop of universal indicator to the solution, and note the initial color. Add 0.10 M NaOH solution drop-wise, mixing between drops, until the solution changes to purple (pH ≥ 11). Record the number of drops of NaOH solution added to make this color change occur.

   *NOTE: If your solution contains $NH_4^+$ and $NH_3$, then don't carry out this step.*

6. Share your data with your classmates to complete the Model 2 Data Table.

## Model 2 – Buffer Capacity

Drops of HCl needed in distilled water to turn the color red-orange: ____________________

Drops of NaOH needed in distilled water to turn the color purple: ____________________

Table 2: Model 2 Data Table—Comparing buffer capacity

| Solution Number | Molarity of Weak Base | Molarity of Conjugate Acid | Total Volume of Buffer Solution | Drops of HCl Needed | Drops of NaOH Needed |
|---|---|---|---|---|---|
| 1 | 0.05 M $NH_3$ | 0.05 M $NH_4^+$ | 100 mL | | |
| 2 | 0.10 M $NH_3$ | 0.10 M $NH_4^+$ | 100 mL | | |
| 3 | 0.10 M $NH_3$ | 0.10 M $NH_4^+$ | 250 mL | | |
| 4 | 0.15 M $NH_3$ | 0.15 M $NH_4^+$ | 100 mL | | |
| 5 | 0.15 M $NH_3$ | 0.05 M $NH_4^+$ | 100 mL | | |
| 6 | 0.05 M $NH_3$ | 0.15 M $NH_4^+$ | 100 mL | | |
| **Solution Number** | **Molarity of Weak Acid** | **Molarity of Conjugate Base** | **Total Volume of Buffer Solution** | **Drops of HCl Needed** | **Drops of NaOH Needed** |
| 7 | 0.05 M $CH_3COOH$ | 0.05 M $CH_3COO^-$ | 100 mL | | |
| 8 | 0.10 M $CH_3COOH$ | 0.10 M $CH_3COO^-$ | 100 mL | | |
| 9 | 0.10 M $CH_3COOH$ | 0.10 M $CH_3COO^-$ | 250 mL | | |
| 10 | 0.15 M $CH_3COOH$ | 0.15 M $CH_3COO^-$ | 100 mL | | |
| 11 | 0.15 M $CH_3COOH$ | 0.05 M $CH_3COO^-$ | 100 mL | | |
| 12 | 0.05 M $CH_3COOH$ | 0.15 M $CH_3COO^-$ | 100 mL | | |

## Analyzing Model 2 – Buffer Capacity

The *buffer capacity* of a solution is related to the number of moles of acid and base that the solution can neutralize without a significant change in pH.

For each set of solutions shown below, consider the similarities and differences in their components. Refer to both the Model 1 Data Table and the Model 2 Data Table.

7. Compare the buffer volume, molarity, and pH:

   a. What is the molarity ratio of weak base to conjugate acid in solutions 2 and 3?

   ______________________________________________

   b. Was there a change in pH between solutions 2 and 3?

   ______________________________________________

   c. What is the molarity ratio of weak acid to conjugate base in solutions 8 and 9?

   ______________________________________________

d. Was there a change in pH between solutions 8 and 9?

e. For solutions 2 and 3, and solutions 8 and 9, was there a difference in the number of drops of HCl or NaOH needed to obtain pH 1 or pH 14?

f. Considering the previous questions, what can be concluded about changing the volume of the buffer system without changing the ratio of weak acid to conjugate base, or weak base to conjugate acid, and its effect on pH?

8. The following questions compare the number of moles of each buffer system component and the buffer capacity in solutions of equal volume:

a. What is the ratio of the number of moles of weak base between solutions 1 and 2 and between solutions 1 and 4?

b. Was there a change in pH between solutions 1, 2 and 4?

c. What is the ratio of the number of moles of weak acid between solutions 7 and 8 and between 7 and 10?

d. Was there a change in pH between solutions 7, 8, and 10?

e. For solutions 1, 2, and 4, and solutions 7, 8, and 10, was there a difference in the number of drops of HCl or NaOH needed to obtain pH 1 or pH 14?

f. Considering the previous questions, what can be concluded about buffer capacity and concentration? Give evidence from your data to support your answer.

9. Do buffer systems stop the pH from changing? Give evidence from your data to support your answer.

10. Do buffers with greater concentrations have greater buffer capacity? Give evidence from your data to support your answer.

11. If you wanted to make a buffer of pH 9.5 with a buffer capacity greater than that in Solution 1 of Model 2, what would have to change in the buffer system?

## Connecting to Theory

Buffers are made from a weak acid or base and their respective conjugate. Two nutritional labels are shown below. One is from Monster Energy® drink and the other is from Mountain Dew®. By inspecting each label, you should be able to identify an acid and its conjugate. Together these form a buffer solution.

Remember, when acids are made from polyatomic acids, their ending is changed to "ic." The polyatomic ion of the conjugate will have an "ate" ending.

### Nutrition Facts

Monster MW2 Assault Energy Drink
Serving Size - 8 fl. oz.
Servings per container - 2

**Amount Per Serving**
Calories - 100
Total Carb - 25g
Sugars - 25g
Vitamin B2 - 1.7mg
Vitamin B3 - 20mg
Vitamin B6 - 2mg
Vitamin B12 - 6mcg
Sodium - 1000mg
Taurine - 1000mg
Panax Ginseng - 200mg
Energy Blend - 2500mg

**Ingredients:** Carbonated Water, Sucrose, Glucose, Citric Acid, Sodium Citrate, Taurine, Natural Flavors, Panax Ginseng Root Extract, Phosphoric Acid, L-Caratine, Caffeine, Sorbic Acid, Benzoic Acid, Caramel Color, Niacinamide, Sucralose, Sodium Chloride, Glucuronolactone, Inositol, Gurana Seed Extract, Certified Color, Pyrodozine Hydrochloride, Riboflaven, Maltodextrin, Cyanocobalamin

Consume Responsibly - Limit 3 cans per day. Not recommended for children, pregnant women, or people sensitive to caffeine.

### Nutrition Facts

Halo 3 Mountain Dew Game Fuel
Serving Size - 1 Can

**Amount Per Serving**
Calories - 170
Total Carb - 0g
Sodium - 65mg
Total Carbohydrates - 46g
Sugars - 46g
Protein - 0g

Caffeine Content: 73mg/12 fl. oz.

**Ingredients:** Carbonated Water, High Fructose Corn Syrup, Citric Acid, Natural Flavors, Sodium Benzoate, Gum Arabic, Caffeine, Sodium Citrate, Yellow 5, Gylcerol Ester of Wood Rosin, Cacium Disodium Edta, Yellow 6, Red 40, Brominated Vegetable Oil

Halo 3 Mountain Dew Game Fuel is not a significant source of other nutrients.

## Applying Your Knowledge – Making Your Own Buffer System

Listed below are solutions that can be combined to make buffers. Your teacher will assign you a pH. Your job will be to make 100 mL of a buffer solution with that pH, using these components.

After your teacher measures the initial pH, you will divide your solution between two beakers.

Your teacher will add 5 drops of 6.0 M HCl to one beaker and measure the pH to determine if it has changed. Five drops of 6.0 M NaOH will be added to the other beaker and similar measurements will be made.

Your first task is to find all of the conjugate relationships in the list below. Show each relationship and the information needed to calculate the pH for each. You need to be ready to prepare the solution that matches the assigned pH.

0.3 M Ammonium chloride ($NH_4Cl$)

0.3 M Sodium acetate ($NaCH_3COO$)

0.3 M Sodium phosphate dibasic ($Na_2HPO_4$)

0.3 M Phosphoric acid ($H_3PO_4$)

0.3 M Potassium phosphate ($K_3PO_4$)

0.3 M Sodium phosphate monobasic ($NaH_2PO_4$)

0.3 M Acetic acid ($CH_3COOH$)

0.3 M Ammonia ($NH_3$)