EXPERIMENT 3

Comparing Buffered and Unbuffered Solutions

Relevant Textbook Reading

Smith, chapter 8

Materials Needed:

0.2 M acetic acid
0.2 M NaH_2PO_4
0.2 M NaOH
Orange IV Indicator
toothpicks
0.2 M HCl
0.2 M Na_2HPO_4
Universal Indicator
Alizarin Yellow R Indicator
9 spot plates

Background

The pH of a solution is a measure of the number of H_3O^+ (hydronium) ions in that solution. The pH is defined as pH = $-\log [H_3O^+]$. The pH scale generally ranges from 0 to 14. When the pH = 7, $[H_3O^+] = [OH^-]$ and the solution is neutral (neither acidic or basic). When $[H_3O^+] > [OH^-]$, the pH is less than 7 and the solution is acidic. When $[H_3O^+] < [OH^-]$, the pH is greater than 7 and the solution is basic.

A buffer is a solution that resists changes in pH when strong acids or bases are added. Our body fluids require buffers so that a drastic change in ions does not cause a imbalance that would harmfully affect the functions of proteins, enzymes, and other species present. Changes in hydronium (H_3O^+) ions and hydroxide (OH^-) ions are specifically damaging to the delicate physiological makeup of our bodies. For example, if the pH of blood drops significantly below 7.2, (the physiological pH), hemoglobin will not bind oxygen.

A buffer system is a solution of a weak acid or base, combined with one of its salts. A weak acid or base ionizes to a much smaller extent than strong acids and bases. The ions exist in equilibrium with the molecular acid or base. For example, acetic acid is a weak acid and sodium acetate ($NaC_2H_3O_2$) is a salt of the acid.

$$\underset{\textbf{Acetic acid}}{HC_2H_3O_{2(aq)}} \rightleftharpoons H^+_{(aq)} + \underset{\textbf{acetate}}{C_2H_3O_2^-{}_{(aq)}}$$

The salt provides the acetate needed to neutralize any H^+ added. The acetic acid will neutralize OH^- added. The pH is determined by the amount of hydronium ion present. If either solution is added, the amount of H+ present in solution will change very little, and therefore the pH will retain nearly its original value.

$$H^+_{(aq)} + C_2H_3O_2^-{}_{(aq)} \longrightarrow HC_2H_3O_{2(aq)}$$

added and consumed by the acetate ion

$$OH^-_{(aq)} + HC_2H_3O_{2(aq)} \longrightarrow H_2O_{(l)} + C_2H_3O_2^-{}_{(aq)}$$

added and consumed by the acetic acid

Measuring pH

There are several ways pH can be monitored. The most inexpensive way is to use pH paper, which is a paper saturated with dyes that change color in response to a change in pH. Another way is to use a pH meter, which is an electronic device that generates a small voltage proportional to the hydronium ion content. Indicators used in this experiment are liquid indictors which are compounds that change color at one or more particular pH. A *Universal indicator* is a mixture of several indicators that result in color changes throughout a wide pH range. The corresponding relationship of colors and pH ranges is indicated in the table below.

pH	**Universal Indicator color**	**pH**	**Universal Indicator color**
4.0	Red	7.5	Dark green
5.0	Orange-red	8.0	Light green
5.5	Orange	8.5	Blue-green
6.0	Yellow-orange	9.0	blue
6.5	Yellow-green	9.5	Violet
7.0	Dark green-yellow	10.0	Red-violet

Other indicators used in this experiment include Orange IV ("O4") and Alizarin Yellow R ("AY)". These indicators are useful for monitoring the pH of highly acidic and highly basic solutions (see table below).

	Red	Orange	Yellow
Orange IV (O4)	pH < 1.4	pH = 1.4-2.6	pH > 2.6
Alizarin Yellow R (AY)	pH > 12	pH = 10-12	pH < 10

In this experiment, you will observe the effects of the addition of HCl(aq) and NaOH(aq) to several different solutions. The number of drops needed for a pH (color) change will be used to compare the resistance to pH change, or buffering capacity, of the various substances.

Procedure

Obtain nine spot plates and label each plate with a wax pencil as 1-9. Label each well on each plate as A, B, or C.

A. Pure Water

1. Place 20 drops of distilled water (using the correct pipet) into wells 1 A-C and 6A. Add one drop of Universal Indicator to the water in 1A and 1B. Add one drop of Orange IV to 1C. Add one drop of Alizarin Yellow R to 6A. Mix the solutions with a clean toothpick and record the initial color of each.
2. Counting drops and mixing after each addition, add 0.2 M HCl dropwise to wells 1A and 1C until you see a color change. Record the final color and drop count for each.
3. Counting drops and mixing after each addition, add 0.2 M NaOH dropwise to wells 1B and 6A until you see a color change. Record the final color and drop count.

B. Aqueous Acetic Acid (CH_3CO_2H)

1. Add 10 drops of 0.2 M CH_3CO_2H solution and 10 drops of distilled water to wells 2A-C. Add one drop of Universal Indicator (UI) to 2A. Add one drop of Orange IV (O4) to 2B and add one drop of Alizarin Yellow R (AY) to 2C. Mix the solutions and record the initial color of each.
2. Counting drops and mixing after each addition, add 0.2 M NaOH dropwise to wells 2A and 2C until you see a color change. Record the color and drop count for each. Continue to add the

NaOH solution until no further color changes are observed making sure to note the colors and drop counts needed for each on your data sheet.

3. Counting drops and mixing after each addition, add 0.2 M HCl to well 2B. Record the color and drop counts as before.

From here on it is understood that you will count the drops and mix thoroughly after each addition *<u>and observe and note the resulting color changes and drop counts</u>*.

C. Aqueous Sodium Acetate ($NaCH_3CO_2$)

1. Add 10 drops of 0.2 M $NaCH_3CO_2$ solution and 10 drops of distilled water to wells 3A-C and 6B. Add 1 drop UI to 3A and 3B. Add one drop O4 to 3C. Add one drop AY to 6B. Mix thoroughly and record the initial color of each.
2. Add 0.2 M HCl to 3A and 3C.
3. Add 0.2 M NaOH to 3B and 6B.

D. Aqueous Sodium Dihydrogen Phosphate (NaH_2PO_4)

1. Add 10 drops of 0.2 M NaH_2PO_4 solution and 10 drops of distilled water to wells 4A-C. Add one drop UI to 4A. Add one drop O4 to 4B. Add one drop AY to 4C. Mix thoroughly and record the initial color of each.
2. Add 0.2 M HCl to 4B.
3. Add 0.2 M NaOH to 4A and 4C.

E. Aqueous Sodium Hydrogen Phosphate (Na_2HPO_4)

1. Add 10 drops 0.2 M Na_2HPO_4 solutions and 10 drops of distilled water to wells 5A-C and 6C. Add one drop UI to 5A and 5B. Add one drop O4 to 5C. Add one drop AY to 6C. Mix thoroughly and record the initial color of each.
2. Add 0.2 M HCl to 5A and 5C.
3. Add 0.2 M NaOH to 5B and 6C.

F. Aqueous Acetic Acid/Sodium Acetate ($CH_3CO_2H/NaCH_3CO_2$)

1. Add 10 drops of 0.2 M CH_3CO_2H solution and 10 drops of 0.2 M $NaCH_3CO_2$ solution to wells 7A-C. Add one drop UI to 7A. Add one drop O4 to 7B. Add one drop AY to 7C. Thoroughly mix and record the initial color of each.
2. Add 0.2 M HCl to 7B.
3. Add 0.2 M NaOH to 7A and 7C.

G. Aqueous NaH_2PO_4/Na_2HPO_4

1. Add 10 drops of 0.2M NaH_2PO_4 solution and 10 drops of 0.2 M Na_2HPO_4 solution to wells 8A-C and 9A. Add one drop UI to 8A and 8B. Add one drop O4 to 8C. Add one drop AY to 9A. Thoroughly mix and record the initial color of each.
2. Add 0.2 M HCl to 8A and 8C.
3. Add 0.2 M NaOH to 8B and 9A.

Clean Up and Waste Disposal - Transfer all the solutions to the waste beaker provided. Thoroughly rinse the wells. Then rinse them with distilled water. Dry the wells with an absorbent towel.

EXPT 3. COMPARING BUFFERED AND UNBUFFERED SOLUTIONS

PRE-LABORATORY QUESTIONS

Names ____Section ____________ Date ___________

1. Explain the following terms:

   a. pH

   b. buffer system

   c. acid-base indicator

2. Using the table for pH/color correlation for Universal indicator and subsequent information, state what the solution color would be for each of the following solutions. (UI = universal indicator; O4 = orange IV)

   a. pH= 9 using UI

   b. pH= 5 using UI

   c. pH=9 using O4

   d. pH=5 using O4

EXPT 3. COMPARING BUFFERED AND UNBUFFERED SOLUTIONS

IN-LAB OBSERVATIONS/DATA

Names ____Section _____________ Date ____________

Solution tested: H_2O

well number→	1A	1B	1C	6A
indicator				
initial color				
solution added				
# of drops				
final color				

Solution tested: CH_3CO_2H

well number→	2A	2B	2C
indicator			
initial color			
solution added			
# of drops/color			
# of drops/color			
# of drops/color			
# of drops/color			
# of drops/color			

Solution tested: $NaCH_3CO_2$

well number→	3A	3B	3C	6B
indicator				
initial color				
solution added				
# drops/color				
# drops/color				
# drops/color				
# drops/color				
#drops/color				

Solution tested: NaH_2PO_4

well number→	4A	4B	4C
indicator			
initial color			
solution added			
# of drops/color			
# of drops/color			
# of drops/color			
# of drops/color			
# of drops/color			

Solution tested: Na_2HPO_4

well number→	5A	5B	5C	6C
indicator				
initial color				
solution added				
# drops/color				
# drops/color				
# drops/color				
# drops/color				
#drops/color				

Solution tested: $CH_3CO_2H/NaCH_3CO_2$

well number→	7A	7B	7C
indicator			
initial color			
solution added			
# of drops/color			
# of drops/color			
# of drops/color			
# of drops/color			
# of drops/color			

Solution tested: NaH_2PO_4/Na_2HPO_4

well number→	8A	8B	8C	9A
indicator				
initial color				
solution added				
# drops/color				
# drops/color				
# drops/color				
# drops/color				
#drops/color				

EXPT 3. COMPARING BUFFERED AND UNBUFFERED SOLUTIONS

REPORT SHEET

Names ____Section _____________ Date ___________

Results Table

Solution	initial pH	# of drops of HCl to decrease solution to pH <2.6	# of drops of NaOH to increase solution to pH >11
H_2O	__________	__________	__________
CH_3CO_2H	__________	__________	__________
$NaCH_3CO_2$	__________	__________	__________
NaH_2PO_4	__________	__________	__________
Na_2HPO_4	__________	__________	__________
$CH_3CO_2H/NaCH_3CO_2$	__________	__________	__________
NaH_2PO_4/Na_2HPO_4	__________	__________	__________

Questions

1. Which solutions fit the definition of a buffer by only slowly changing in pH when either strong acid or strong base was added? Use your results to defend your answer and then explain theoretically why these solutions meet the theoretical requirement for a buffer.

2. Show, with the appropriate chemical equations, how the acetic acid/sodium acetate buffer prevents each of the following:

   a. a large decrease in pH when HCl is added

   b. a large increase in pH when NaOH is added

3. Which solution has the higher pH?

   a. 0.2 M $NaCH_3CO_2$ or 0.2 M CH_3CO_2H

   b. 0.2 M NaOH or 0.2 M $NaCH_3CO_2$

   c. 0.2 M Na_2HPO_4 or 0.2 M NaH_2PO_4

4. Write the chemical equation for the reaction that occurred when you added HCl solution to NaH_2PO_4/Na_2HPO_4 solution.