Investigation 6: Investigating Baby Wipes as a Buffer System

Focus Questions: *How do buffers work? How can we determine the buffer capacity of different buffer systems?*

Pre-lab required reading

Chemistry: An Atoms-Focused Approach: Section 16.3
Use of Volumetric Glassware – General
Use of Volumetric Glassware – Buret
Balance Use

Safety and Waste Disposal

- All solutions and solids can be rinsed down the drain with plenty of water.
- Used baby wipes can be discarded in the regular waste bins.

Background

Buffers

The concentration of hydronium ions in solution (pH) is very important to living systems. Many cellular processes require a particular pH, requiring complex mechanisms to maintain the pH within a specific range. Buffers are solutions which resist changes in pH, and they are often utilized to maintain this balance. In practice, buffers keep an environment at roughly the same pH, by reacting their weakly basic components with strong acid and reacting their weakly acidic components with strong base. Many commercially available products (contact lens solutions, over-the-counter drugs, baby wipes, etc.) take advantage of a buffer's ability to resist changes in pH, allowing the buffer systems to lessen or moderate the impact of adding a strong acid or strong base. In many cases maintenance of a particular pH increases shelf life, prevents bacterial growth, or contributes to the efficacy of a drug. During this lab investigation, we will focus on the preparation of different buffers (including one made from baby wipes) and compare their ability to resist pH changes.[1]

Changes in pH outside of the ideal region for a system are often associated with health problems and complications. For example, diaper rashes are often caused by an increase in pH. The excretion of feces and urine can result in the breakdown of urea (a primary component of urine) into ammonia (a basic compound), raising the pH. This basic condition can cause some biochemical changes that result in an increase in enzymes that break down the outer layer of skin leading to diaper rash.

The key to remedying diaper rash and irritation is maintaining a lower pH, which is also useful to prevent microbial growth in the diaper area. However, it is not simply enough to apply an acidic solution that neutralizes the basic pH; what is needed is a solution with a high buffer capacity to maintain a physiologically balanced pH. Baby wipes and their ability to minimize irritation was recently examined empirically in a study published by a group of researchers and physicians.[2] In their study they measured a baby's skin pH following different cleansing methods after excretion in a diaper. The researchers compared different wipes, some of which were standard wipes available at the store, some were simply wet washcloths, and some wipes contained a modified solution with a high buffer capacity. Not surprisingly, buffered wipes reduced irritation and outperformed other wipes in maintaining an ideal skin pH.

A buffer is defined as a solution that resists changes in pH when small amounts of acid or base are added. For an acid–base buffer, the pH is controlled by the equilibrium between the weak acid (HA), its conjugate base (A^-) and H_3O^+ concentrations:

$$HA\,(aq) + H_2O\,(l) \rightleftharpoons A^-\,(aq) + H_3O^+\,(aq) \qquad (1)$$

Note that for a system at equilibrium all of the species exist in the solution at the same time and both the forward and the reverse reaction occur. Buffers can resist stresses such as the addition of a strong acid or strong base because the solution contains both a weak acid (HA) and its conjugate weak base (A^-), which can readily react with a strong base (OH^-) and strong acid (H_3O^+), respectively. Since a buffer is an equilibrium system, if we add an acid or base, the added species will react and the equilibrium will shift to create more of the species on the other side of the reaction.

In this experiment we will be investigating three different buffer systems. The first buffer is an acetic acid/acetate buffer. Acetic acid has a K_a value of 1.8×10^{-5} and a pK_a of 4.76.[3] This buffer tends to be effective in the pH range of 3.76 to 5.76. The chemical reaction for this buffer is shown below:

$$CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COO^-_{(aq)} + H_3O^+_{(aq)} \tag{2}$$

The second buffer is an ammonia/ammonium ion buffer, which tends to be effective in the pH range of 8.24 to 10.24. The ammonium ion has a K_a value of 5.8×10^{-10} and the reaction for this buffer is shown below[3]:

$$NH_4^+{}_{(aq)} + H_2O_{(l)} \rightleftharpoons NH_{3(aq)} + H_3O^+_{(aq)} \tag{3}$$

The third buffer is obtained by squeezing out the solution from baby wipes. Typically, baby wipes use a citric acid buffer system, however there are many other ingredients in the formulation including preservatives and detergents.

Addition of a Strong Acid or Base to a Buffer

Buffers resist stresses such as addition of a strong acid or strong base by the reaction of the weak acid (HA) with strong base, and the reaction of the conjugate base (A^-) with strong acid. This essentially converts a strong acid or base into a weak acid or base. For example, if hydrochloric acid, HCl (recall that a strong acid is represented by H_3O^+ in solution), is added to the buffer it reacts with the base component of our buffer (the conjugate base, A^-) and some of the conjugate base is converted to the weak acid:

$$A^-_{(aq)} + H_3O^+_{(aq)} \rightarrow HA_{(aq)} + H_2O_{(l)} \tag{4}$$

The addition of HCl momentarily increases the $[H_3O^+]$ in the solution, however that additional $[H_3O^+]$ will be used up through reaction with the conjugate base, A^-. Thus, there is less H_3O^+ in the solution than you would expect and the pH change is very small. The buffer system behaves similarly when a strong base (such as NaOH) is added, however it reacts with the acid component of our buffer (HA) and some of the acid is converted to the conjugate base:

$$HA_{(aq)} + OH^-_{(aq)} \rightarrow A^-_{(aq)} + H_2O_{(l)} \tag{5}$$

Similarly, the addition of NaOH momentarily increases the $[OH^-]$ in solution, but because HA reacts with the strong base that is added, there is less OH^- in the solution than you would expect and the pH change is small.

Buffer Capacity

Note that all buffer solutions contain a limited number of weak acid and conjugate base molecules, so eventually a buffer will run out of the acid or conjugate base molecules to react with the added strong base or acid.

Buffer capacity is a measure of the efficiency of a buffer in resisting changes in pH. A simplified definition for the buffer capacity: the moles of strong acid or base that must be added to a buffer solution to change the pH of one liter of the solution by one pH unit, or:

$$buffer\ capacity = \frac{(number\ of\ moles\ of\ acid\ or\ base\ added\ to\ the\ buffer)}{|change\ in\ pH| \times (volume\ of\ buffer\ in\ L)} \tag{6}$$

Where $|change\ in\ pH|$ is the absolute value of final pH – initial pH.

Buffer Choice and Preparation

Each buffer system works optimally over a specific pH range,and depending on the target pH, different buffers can be used. The pH range over which a buffer optimally resists changes is near the pK_a of the acid. For example, the pK_a of acetic acid is 4.76, and so the optimal buffering ability occurs roughly around a pH of 4.76 ± 1. Furthermore, buffers work best (changes in pH are minimized) when there is roughly the same amount (moles) of acid and conjugate base.

Keeping in mind that buffers work best near the acid's pK_a and when using equimolar amounts of acid and base we will prepare several buffers in a way that maximizes their buffering capacity and then we will measure the buffer capacity.

Procedure

Calibrating the pH Electrode

1. Attach the power adapter to the LabQuest and plug it in. You will find the pH electrode in a tube of storage solution next to the computer. Connect the probe to the LabQuest 2 interface via the CH1 port. Turn on the LabQuest.
2. You will need jars of pH 4 and pH 10 buffer for a two-point calibration of the electrode. Use the buffer solutions in the jars provided. Do not discard the buffer solutions.
3. At the top of the display, tap **Sensors > Calibrate > 1 CH1: electrode amplifier**. This will open a new window called **Sensor Settings**. Tap **Calibrate Now**.
4. Remove the pH electrode from the storage solution. Rinse the electrode with deionized water (use a small beaker to collect the rinses); blot it dry using a KimWipe and place the electrode in the jar of pH 4 buffer solution. Swirl the jar gently for 15 seconds. In the box for **Value 1:** enter a value of "4" and tap **Keep** to store the calibration point.
5. Remove the electrode from the pH 4 buffer, rinse it with deionized water and blot dry. Place the electrode in the pH 10 buffer solution and swirl gently for 15 seconds. Enter "10" as the value for **Known Value 2** and tap **Keep** to store the second calibration point. Tap **OK**.
6. Remove the electrode from the pH 10 buffer, rinse with deionized water and place the electrode in a 100-mL beaker of deionized water. Your pH electrode is now calibrated.

Preparing the Buffered Solutions

You and your lab partner will prepare four buffer solutions volumetrically:

1: acetic acid/acetate buffer I:
10.0 mL 0.50 M acetic acid
0.41 – 0.42 g sodium acetate
Place materials in a 100.00-mL volumetric flask, dilute to the mark.

2: acetic acid/acetate buffer II:
10.0 mL 0.50 M acetic acid
0.11 – 0.12 g sodium acetate
Place materials in a 100.00-mL volumetric flask, dilute to the mark.

3: ammonia/ammonium buffer III:
10.0 mL 0.50 M aqueous ammonia
0.26 – 0.27 g ammonium chloride
Place materials in a 100.00-mL volumetric flask, dilute to the mark.

4: extract solution from 8 baby wipes
Place eight baby wipes in a 600 mL beaker. Use a 100-mL graduated cylinder to measure 80.0 mL of deionized water. Add the water to the beaker of wipes and allow the wipes to sit for at least 5 minutes. Gently stir the wipes with a spatula for one minute, then one at a time, remove each baby wipe from the beaker and wring dry by twisting and squeezing the baby wipe. Transfer the solution into a 100.00-mL volumetric flask and dilute to the mark.

Calculate the number of moles of acetic acid, acetate, ammonia, and ammonium in the buffer solutions. For this calculation, use the molarity of the acetic acid and aqueous ammonia on the reagent bottle; use 82.03 g/mole for the formula mass of sodium acetate; and 53.49 g/mole as the formula mass for ammonium chloride.

To prepare the buffers, use a 10-mL graduated cylinders to add the indicated amount of acetic acid and aqueous ammonia to clean 100.00-mL volumetric flasks.

Carefully weigh the indicated amounts of solid sodium acetate and ammonium chloride in a paper weighing cup. Record the exact mass of the solids in your notebook to the nearest 0.001 g. Add the solids to the appropriate flask. Add a small amount of water and mix well to dissolve the solids and then dilute to the mark with distilled water.

Determining Buffer Capacity
You will determine the buffering capacity of each of your solutions and compare this to the buffering capacity of an unbuffered solution (deionized water).

The Effect of Adding a Strong Acid (HCl)
Set up a 50-mL buret on a stand with a buret clamp. Obtain ~60 mL of 0.10 M HCl in a 250-mL beaker. Fill the buret with 0.10 M HCl. Measure 40.0 mL of the acetic acid/acetate buffer I in a 50- mL graduated cylinder and transfer to a 100-mL beaker. Add a magnetic stir bar to the beaker. Rinse the pH electrode with deionized water, dry it gently with a KimWipe and place it in the buffer solution. Do not allow the stir bar to hit the electrode. Measure and record the initial pH of your buffer and the initial buret reading. While stirring the solution continuously, slowly add HCl dropwise from the buret at a rate of about 1 drop per second. Continue adding the HCl until the pH changes by at least 1 pH unit. Record the final pH and buret reading in your notebook. Repeat this process for acetic acid/acetate buffer II, ammonia/ ammonium buffer III and for deionized water. Measure the initial pH of the deionized water immediately upon immersing the electrode.

The Effect of Adding a Strong Base (NaOH)
Obtain ~60 mL of 0.10 M NaOH in a 250-mL beaker. Rinse and fill a second 50-mL buret with 0.10 M NaOH. Using the same protocol, add 0.10 M NaOH to 40 mL samples of each buffer and 40 mL of deionized water. Remember to record the initial pH.

Determining the Buffer Capacity of Baby Wipes
Prepare an additional buffer using baby wipes and determine the buffering capacity of the resultant solution. Record the brand/type (such as Huggies/One & Done) of baby wipe in your notebook.

> Place eight baby wipes in a 600 mL beaker. Use a 100-mL graduated cylinder to measure 80.0 mL of deionized water. Add the water to the beaker of wipes and allow the wipes to sit for 5 minutes. Gently stir the wipes with a spatula for one minute, then one at a time, remove each baby wipe from the beaker and wring dry by twisting and squeezing the baby wipe. Transfer the solution into a 100.00-mL volumetric flask and dilute to the mark.
> Measure 40.0 mL of the baby wipes solution in a 50-mL graduated cylinder. Transfer the solution to a 100-mL beaker.

Use the same procedure as completed to measure the effect of adding HCl and NaOH to the acetate and ammonium buffer, add acid and base dropwise and determine the buffer capacity of the solution from the baby wipes. **Note that the concentration of the buffer in the baby wipes is very low. You will need a very small volume of HCl and NaOH to effect a large change in the pH. Add HCl and NaOH drop by drop and allow the pH to stabilize between additions.**

Cleanup and Storage of Equipment
All solutions and solids can be discarded down the drain with plenty of water.
Rinse the stir bar with deionized water and return it.
Disconnect the electrode and return it to the container of storage solution. Turn off the LabQuest and disconnect the power adapter.
Return all other equipment to its proper location (i.e., where you found it when you entered the lab).

References:

1. Rodriguez, J. G., *Hensiek, S., Meyer, J. R., Harwood, C.J., Town, M.H., Chem. Educ.* 2018, 95, 10, 1816–1820

2. Adam, R., Schnetz, B., Mathey, P., Pericoi, M., de Prost, Y. (2009). Clinical Demonstration of Skin Mildness and Suitability for Sensitive Infant Skin of a New Baby Wipe. *Pediatric Dermatology*, 26, 506-513.

3. Atkins, P.; Jones, L. “Chemical Principles: The Quest for Insight”, 6th ed.; Freeman: New York. 2013.