Experiment 19

Acids, Bases, and Buffers rev 1/10

GOAL: The purpose of this experiment is to investigate the pH behavior of several aqueous solutions and to explore the effect of buffers on this behavior.

INTRODUCTION: Most of the substances we encounter in aqueous solutions can be categorized as acids, bases, or salts. Using the Bronsted definitions, acids are H⁺ donors, and bases are H⁺ acceptors. At a practical level, we often recognize aqueous acids as giving pH values below 7, and aqueous bases as giving values above 7.

Salts are a bit more complicated. They form ions in water. Ions may be acids, bases, or neutral. Ions that are conjugates of weak acids will be weak bases. For example, HCN is a weak acid, so its conjugate ion, CN⁻, is a weak base.

\[
\text{CN}^-_\text{(aq)} + \text{H}_\text{2}O_\text{(l)} \leftrightarrow \text{HCN}_\text{(aq)} + \text{OH}^+_\text{(aq)}
\]

Eqn 1

Similarly, ions that are conjugates of weak bases will be weak acids. NH₃ is a weak base, so its conjugate ion, NH₄⁺, is a weak acid.

\[
\text{NH}_4^+_\text{(aq)} + \text{H}_\text{2}O_\text{(l)} \leftrightarrow \text{NH}_3_\text{(aq)} + \text{H}_\text{3}O^+_\text{(aq)}
\]

Eqn 2

See Section 15.8 and 16.2 of your textbook for more on aqueous ions and their acid/base behavior.

Aqueous solutions can thus have a variety of pH behaviors depending upon what is dissolved in the water. In this experiment, your Preliminary Investigation will allow you to measure pH of several solutions and observe their behaviors when drops of acid and base are added. For most solutions, the pH will change quickly when acid or base is added. Buffers solutions are special in that they resist changes to pH until large amounts of acid or base are added. We use buffers anytime it is important to control pH. Living organisms use buffers in cells and fluids such as blood. Food scientists use buffers to slow spoilage. Laboratory chemists use buffers to control reactions.

In order to be a buffer, a solution must contain both halves of a weak acid/base conjugate pair. We can make these solutions in one of two ways. The most obvious is to directly add each half of the conjugate pair. So, for example, we could put some HCN and some KCN into a beaker of water. Because KCN is a soluble salt, it immediately ionizes to give us CN⁻. So, we have a buffer containing HCN and CN⁻. The second way to prepare is buffer is a bit sneakier. We start with just one half of the conjugate pair. We then add something that will react to form the other half of the conjugate pair from just a portion of the original. For example, we could start by putting 1 mole of HCN in a beaker of water. It isn’t a buffer since it only contains the acid form. Now let’s add 0.4 mole KOH. Since we’ve added a strong base, it will react with the acid present:

\[
\text{KOH} + \text{HCN} \rightarrow \text{K}^+ + \text{CN}^- + \text{H}_\text{2}O
\]

Eqn 3

Note that we have just formed CN⁻, the conjugate base of our original weak acid. And, we’ve been clever about the amounts. We started with 1 mole of HCN but only added 0.4 mole KOH. That means that
KOH is the limiting reagent. Only 0.4 mole of the HCN is converted to CN\(^-\). We are left with a mixture of 0.4 mole CN\(^-\) and 0.6 mole HCN—a buffer.

After completing the Preliminary Investigation, the class will discuss what was observed and you will choose two short Researchable Questions to investigate with a partner. One investigation will look at the behavior of different types of water. A second investigation will ask you to explore buffers, comparing at least three variations. At the end of the lab period, you will report on your findings to the class.

HAZARDS and PRE-LAB ASSIGNMENT:
In addition to your regular prelab entries, look up MSDS sheets for acetic acid and sodium acetate. Include a summary of the hazards that may be associated with handling these chemicals in our laboratory setting. All used solutions can go down the drain this week since the acids and bases will neutralize each other and we are not using any hazardous ions.

LABORATORY OBSERVATIONS AND DATA:
Your instructor will assign you a partner to work with in lab. Record your partner’s name in your lab notebook. You will each write up your own lab report, however, so be sure that you both have a complete set of notebook entries and data before leaving lab. As always, include what you do and what you observe in your lab notes. Whenever possible, collect data into well labeled tables. For examples, your pH measurements after addition of drops of acid should definitely be recorded in a table.

PRELIMINARY INQUIRY:

Part 1:
1. Because the pH of distilled water is greatly affected by dissolved CO\(_2\)(g), the instructor has boiled and cooled some distilled water to remove the dissolved gases. Half fill a clean 50-mL beaker with this de-gassed distilled water. Add a stir bar. Set the beaker on a stir plate and adjust the stirring rate so that the liquid is stirring gently.
2. Rinse the pH electrode with distilled water as demonstrated by the instructor.
3. Carefully immerse the pH electrode so that the spin bar does not strike it.
4. Record the pH of the water. It can be tough to get a good reading on distilled water, so don’t worry about fluctuations of this initial reading. Wait 15 seconds, and take a reading.
5. Now add 1 drop of 0.1 M HCl so that the drop lands in the water, not on the glass or electrode. Allow the acid to disperse and the pH to stabilize before you record the pH value. This should take just a few seconds, don’t wait longer.
6. Repeat this process, 1 drop at a time, until you have added a total of 6 drops of acid.
7. Discard the water, taking great care not to lose the stir bar. Rinse the beaker thoroughly with distilled water.
8. Now repeat this process with a new sample of degassed distilled water. Record the pH initially and also after the addition of 1-6 drops of 0.1 M NaOH. Discard the solution when you are done.

Part 2:
9. Take two clean 50-mL beakers to the supply bench and get 15 mL each of 0.01 M acetic acid (HC\(_2\)H\(_3\)O\(_2\)) and 0.01 M sodium acetate (NaC\(_2\)H\(_3\)O\(_2\)).
10. Measure and record the pH of each solution. Be sure that you rinse the electrode with distilled water each time you switch to a new solution.
11. Now combine the two solutions and add your stir bar. Adjust the stirring rate so that the liquid is stirring gently. Measure and record the pH of the combined solution.
12. Now add 1 drop of 0.1 M HCl so that the drop lands in the solution, not on the glass or electrode. Allow the acid to disperse and the pH to stabilize before you record the pH value.
13. Continue this process, 1 drop at a time, until you have added a total of 6 drops of acid.
14. If the pH has not changed at least one pH unit from its original value, continue adding acid, counting the drops until the pH has changed by 1 unit. (You don’t need to measure pH with each drop, just find how long it takes to reach a 1 unit change.)
15. Discard the solution, taking great care not to lose the stir bar. Rinse the beaker thoroughly.
16. Now repeat this process with a new sample of mixed acetic acid and sodium acetate. This time add 0.1 M NaOH. Discard the solution when you are done.

DISCUSSION:
Return to the prelab side of the room with your lab partner. Working as a pair, answer these questions in your lab notebook. Consult the Introduction and your textbook for help.

1. Give the formulas of the ions that form when NaC₂H₃O₂ dissolves. What was the pH of your sodium acetate solution? Which ion is responsible for this pH? Write a balanced chemical equation showing that ion reacting with water. This equation will look very much like Eqn 1 or Eqn 2 from the Introduction.

2. Define “buffer.” Which of your solutions behaved as buffers? Which did not?

3. Your team will do 2 inquiries similar to that in the Preliminary Investigation. For the first, you will explore the effect of acid and/or base on different types of water. For the second, you will explore salt solutions and buffers. See the List of Available Materials below. For each of the two inquiries, list 2 Researchable Questions that you could explore using these materials.

Available materials for Investigation 1:
- Distilled water; Trexler tap water; Water over granite; Water over limestone; Ocean water
- A selection of plain, flavored, and carbonated bottled waters

Available materials for Investigation 2:
- 0.01 solutions of H₃PO₄; NaH₂PO₄; HCl, NaOH, NaCl, NH₃; NH₄Cl; Na₂CO₃; NaHCO₃

Participate in the discussion led by your instructor. As directed by the instructor, choose your 2 Researchable Questions from the lists generated by the class.

INVESTIGATIONS:
For each of your 2 investigations, prepare your Research Plan in your notebook. The sections should be

a. Researchable Question
b. Hypothesis
c. Variables (Manipulated (independent), Responding (dependent), and Controlled variables)
d. Procedure
e. Data Table

1. Get your plans approved by the instructor, make any needed changes, and then conduct your investigations.
2. After you complete your investigations, return to the prelab side of the room and complete one Investigation Report form (available at the Instructor’s bench) for each investigation (2 total).

3. Prepare to share the key points orally with the rest of the class.

4. During the class discussion, you will be asked to briefly share your investigation with the rest of the class. You may modify or expand upon your conclusions based upon class discussion. Take notes on the investigations of others in your lab notebook since the lab report will include questions on the work of other groups. (All the Investigation Report forms will be available for viewing online the day after you complete this experiment.)

5. Be sure that you turn in all your Investigation Report forms before leaving lab.

LAB REPORT RESULTS:

For your Results Section, write a short summary for each of your two investigations. Be sure to include each of the points addressed by your research plan, and then discuss all your data and what you can conclude from it.

LAB REPORT QUESTIONS:

1. Consult the Investigation Reports online for the first investigation on types of water. In a couple of paragraphs describe some of the interesting information found. Draw from several different investigations. You may want to do some comparisons. Make general statements about what was found and then give specific examples of data to support your generalizations.

2. Below is a list of acids and bases used in this experiment. For each, write a balanced chemical equation showing their reaction with water (see the Introduction for examples).
   
   HCl, HC\textsubscript{2}H\textsubscript{3}O\textsubscript{2}, NH\textsubscript{3}, H\textsubscript{3}PO\textsubscript{4}

3. Below is a list of salts used in this experiment. For each, give the formulas of the ions that form when the salt dissolves in water. Look through the Investigation Reports online to find the pH of each solution. Decide which ion is responsible for this pH, and then write a balanced chemical equation showing that ion’s reaction with water. Your chemical equations should look very much like Eqn 1 or Eqn 2 from the Introduction.
   
   Na\textsubscript{2}C\textsubscript{2}H\textsubscript{3}O\textsubscript{2}, NH\textsubscript{4}Cl, Na\textsubscript{2}CO\textsubscript{3}, NaHCO\textsubscript{3}, NaH\textsubscript{2}PO\textsubscript{4}

4. All buffers must have two types of substances present. What are these? Some of the solutions considered in Investigation 2 were buffers. Give examples of buffers that were investigated and what two substances made them buffers.

5. The buffer that you explored in the Preliminary Investigation had equal amounts of acetic acid and sodium acetate. Compare what you found when you added acid and base. Were the responses similar or very different? Some of the Investigation 2 summaries report on buffers that were made with different amounts of the two components. Find an example, and describe how that solution behaved upon addition of acid and base.