

Chemistry 141
Exploring Buffers – Lab Lecture
11/1-3/2010
Dr. Abrash

Q: What is the purpose of today's experiment?

Today we are going to study some of the properties of buffers.

Q: What are buffers?

Buffers are acid-base mixtures that help a system resist changes in pH when a strong acid or a strong base is added.

Q: Why are buffers important?

They are especially important in the biology of life forms, and in the environment. The proteins and nucleic acids in life forms tend to change shape with pH, and they are only functional over a narrow range of pHs. Therefore most living systems contain some form of natural buffer. Buffering also helps bodies of water resist damage from acid rain. In research labs, using buffers helps us hold pH to within ranges that we choose for our experiments.

Q: What are buffers made of?

Buffers consist of a combination of a weak acid and its conjugate base, or a weak base and its conjugate acid. One important environmental buffer system is the combination of bicarbonate ion, HCO_3^- , which is a weak acid, with carbonate ion, CO_3^{2-} , which is its conjugate base. Another example would be a mixture of ammonia, NH_3 , a weak base, with ammonium ion, NH_4^+ , its conjugate acid.

Q: How do buffers help a system resist changes in pH when a strong acid is added?

If a strong acid is added to an aqueous system with no buffer, every molecule that dissolves leads to the formation of a molecule of H_3O^+ . Since pH is defined as $\text{pH} = -\log[\text{H}_3\text{O}^+]$, every molecule of acid that dissolves ends up decreasing the pH.

In contrast, when a strong acid is added to an aqueous solution containing a buffer, instead of producing H_3O^+ directly, it reacts with the base part of the buffer to produce a weak acid. Since only a small portion of the weak acid produces H_3O^+ , the production of H_3O^+ is much smaller, and therefore the decrease in the pH is much smaller.

Q: How do buffers help a system resist changes in pH when a strong base is added?

If a strong base is added to an aqueous system with no buffer, at least one hydroxide ion, OH⁻, is produced for every molecule of base dissolved. Since $pOH = -\log[OH^-]$, every dissolved molecule decreases the pOH. Since pH is related to pOH by $pH = 14 - pOH$, every dissolved molecule of base will result in an increase of pH.

In contrast, when a strong base is added to an aqueous solution containing a buffer, instead of producing OH⁻ directly, the strong base reacts with the weak acid part of the buffer, producing a weak base. Since a weak base, by definition, only produces a small amount of OH⁻, the increase in pH will be much smaller.

Q: Ohhh! So that's why a buffer contains a weak acid and it's conjugate base (or vice versa). So it can moderate the effect of adding strong acid OR strong base.

Right.

Q: Do all buffer solutions start out with the same pH?

No. The pH of a buffer solution depends on the identity of the conjugate acid/base pair chosen, and the relative concentration of the conjugate acid and the conjugate base. The formula for the pH of a buffer solution is

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

where [HA] is the acid in the conjugate acid-base pair, [A⁻] is the base, and the pK_a is defined as

$$pK_a = -\log K_a$$

Q: Umm, so remind me again. What's the K_a ?

The K_a is the acid dissociation constant, an equilibrium constant that describes to what extent a weak acid dissociates. It is characteristic of a given acid, and is defined as

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

Q: When I make a buffer, can I use any ratio of conjugate acid to conjugate base that I want?

No. The ratio of conjugate acid to conjugate base needs to be between 10:1 and 1:10. If it falls outside of this range, adding strong acid or base will result in a large pH change.

Q: So after I make the buffer, I can add any amount of strong acid or strong base, and the buffer will keep minimizing the pH change?

The answer to this is also no. Each buffer has a so-called buffer capacity. The buffer capacity is the amount of strong acid or strong base that can be added before the buffer loses its ability to minimize pH changes. The buffer capacity is based on the number of moles of the conjugate acid and conjugate base that are dissolved in the solvent. The larger the number of moles of conjugate acid or base in the solution, the more strong acid or base can be added before the buffer capacity is exhausted.

Q: So what properties of buffers are we actually going to study in this lab?

We're going to study the buffer capacity of a propionic acid/sodium propionate buffer. (The propionic acid is the weak acid, and the propionate cation is the conjugate base.) Then each group will either prepare a 0.015 M acetic acid/ acetate buffer with pH 4.89 OR prepare an 0.015 M ammonia/ammonium buffer with pH 9.60.

Q: How do we study the buffer capacity?

We make two titration curves, one by adding strong base to the buffer, and one by adding strong acid to the buffer. After we've collected the data for the titration curves we determine the equivalence points by analyzing the curves. The equivalence points allow us to determine the number of moles of acid and base that make up the buffer, and therefore the buffer capacity.

Q: What is a titration curve?

A titration curve is a graph of pH vs volume of titrant (strong acid or strong base) added to the solution.

Q: How do we determine the pH?

We'll use a device called a pH meter. After calibration with a standard solution, this allows us to accurately determine the pH of a solution.

Q: Can you remind me what an equivalence point is?

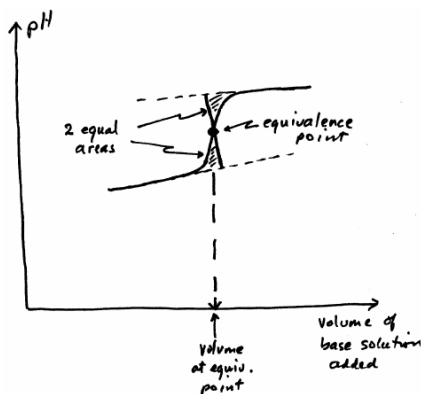
It's the point at which the number of moles of titrant (the stuff you add) equals the amount of the substance in the solution that we're titrating. It tells us how much of a substance is in a solution. So if we're titrating our weak acid with a strong base, then at the equivalence point the number of moles of strong base equals the number of moles of weak acid we started out with. If we're titrating our conjugate base with a strong acid, then at the equivalence point, the number of moles of strong acid equals the number of moles of the conjugate base. Therefore, the equivalence points tell us the number of moles of each component of the buffer, and therefore the buffer strength.

Q: What are the features of a titration curve when a weak acid is titrated with a strong base?

[Draw a typical curve] In this case there is a small increase in pH followed by a plateau region called a buffer region in which the pH increases slowly. Near the equivalence point the pH rapidly increases. Past the equivalence point the rate of increase levels off until the pH approaches that of the strong base.

Q: How do we determine the equivalence point?

How to identify equivalence points from the titration curve generated for Part (A):



- Extend the nearly level regions before and after the equivalence points with a dotted line.
- Draw a straight line from the top dotted line to the bottom such that the line passes through the center of the sharp region of the titration curve. The shaded area enclosed on either side of the line should be very close to equal.
- Identify the equivalence point, which is the point where the straight line crosses the curve

Figure 3: Identifying an Equivalence Point

Note that, for Part (B), you can use the data given in the printouts to locate the 1st and 2nd equivalence points (ie the data in the column labeled "1st deriv pH/mL").

Q: Once we determine the equivalence points, how do we determine the moles of the propionic acid, and propionate ion?

The moles of strong acid will be given by the molarity of the strong acid times the volume at the equivalence point. Since the moles of strong acid equal the moles of the propionate anion, this tells you the moles of propionate. Similarly, the moles of strong base will be given by the molarity of the strong base times the volume at the

equivalence point. Since the moles of strong base equal the moles of propionic acid, this tells us the moles of the propionic acid.

Q: How do we get the concentrations right when designing our own buffers?

You begin with the Henderson-Hasselbalch equation we cited above:

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

You'll know the pKa of your weak acid. Then you just have to adjust the ratio of your conjugate base to your conjugate acid so that the ratio gives you your desired pH, and so that the total concentration of the conjugate acid and base together is .015 M.

Q: Do you have any experimental tips for us?

Sure:

1) Regarding the pH Meter:

Please don't use the electrode of the pH meter to stir your solutions. It is very fragile. Please make sure that the electrode does not touch the bottom of your beaker.

In between measurements, please set the pH meter to standby.

When moving the electrode from one solution to another be sure to rinse it with deionized water.

Q: What do we turn in for our lab report this week?

This is described clearly on pages 127-128 of your lab manual.

Q: How much are we allowed to collaborate on this lab report?

You and your lab partners can collaborate on all parts of the lab report.