15.3 - Buffering Capacity

Picture Here

Buffering Capacity

You've seen how buffered solutions minimize the pH-altering effects that the addition of a strong acid or base elicits.

Depending on how much chemical is involved, buffers can resist changes more or less.

The buffering capacity of a solution represents the amounts of H^+ or OH^- ions the buffer can absorb without a significant change in pH.

A buffer with a large capacity contains large concentrations of buffering components and so can absorb a relatively large amount of H^+ or OH^- ions and show little change.

Adding Strong Acid Example

Calculate the change in pH that occurs when 0.010 mole of gaseous HCl is added to 1.0 L of the following acetic acid buffers:

1. 5.00 M CH_3COOH and 5.00 M $NaCH_3COO$
2. 0.050 M CH_3COOH and 0.050 M $NaCH_3COO$

K_a for acetic acid is 1.8 E -5.

Note 1: Since the HCl is gaseous, volume change is negligible.

Note 2: Since 0.010 mol HCl is added to a 1.0 L solution, the molarity change will be 0.010 M (for both acetic acid and the acetate ion).

Adding Acid Answer (Slide 1)

First, calculate the pH of the original buffers.
Note: in the H & H equation since it is the log of the **ratio** of base to acid that matters, in this problem both of the buffers have the same ratio of 1 part base to 1 part acid.

Thus, pH: $$pH = pK_a + \log\left(\frac{[CH_3COO^-]}{[CH_3COOH]}\right)$$

$$pH = -\log 1.8E-5 + \log(1) = \boxed{4.74}$$

Next, the chemical reaction. The hydrogen ion of HCl will bind with the free acetate ion:

$$H^+ + CH_3COO^- \rightarrow CH_3COOH$$

1. Adding Acid Answer (Slide 2)

$$H^+ + CH_3COO^- \rightarrow CH_3COOH$$

Use Stoichiometry to calculate amount reacted:

Acetic acid: 5.00 M CH_3COOH + 0.010 M = 5.01 M:

Acetate ion: 5.00 M CH_3COO^- - 0.010 M = 4.99 M.

New pH Calc: $$pH = pK_a + \log\left(\frac{[CH_3COO^-]}{[CH_3COOH]}\right)$$

$$pH = -\log 1.8E-5 + \log\left(\frac{4.99}{5.01}\right) = \boxed{4.74}$$

Note: there is a pH change, but insignificant.

2. Adding Acid Answer (Slide 3)

$$H^+ + CH_3COO^- \rightarrow CH_3COOH$$

Use Stoichiometry to calculate amount reacted:

Acetic acid: 0.050 M CH_3COOH + 0.010 M = 0.060 M

Acetate ion: 0.050 M CH_3COO^- - 0.010 M = 0.040 M.

pH Calc: $$pH = pK_a + \log\left(\frac{[CH_3COO^-]}{[CH_3COOH]}\right)$$

$$pH = -\log 1.8E-5 + \log\left(\frac{0.040}{0.060}\right) = \boxed{4.56}$$

The acid affects this dilute buffer much more.

Preparing Buffer Solutions

Chemists sometimes have to determine how to prepare buffer solutions that will work in particular pH ranges.

With so many chemicals to choose from, a method exists for determining the best one.

First: know that buffers work best when the ratio of acid to conjugate base (or base/conj. acid) is 1:1 (smaller pH swings vs. acid or base addition).

Second: with the ratio of 1 : 1, the pK_a of the acid should be as close to the desired pH as possible.

Build Your Own Buffer Example

A chemist has four choices of acids and their sodium salts for making a buffer of pH 4.30:

A. chloroacetic acid (K_a = 1.35 E -3)
B. propanoic acid (K_a = 1.30 E -5)
C. benzoic acid (K_a = 6.40 E -5)
D. hypochlorous acid (K_a = 3.50 E -8)

3. If a solution is made by making 1.0 M solutions of the acid and its sodium salt in the same flask, which acid should the chemist select?

4. How could the chemist alter the amounts, to produce a closer value to the pH = 4.30 target?

Build Your Own Buffer Answer

3. The pK_a of the acid should be as close to the desired pH, (assuming that the ratio of acid to conjugate base is 1 : 1):

$$pH = pK_a + \log\left(\frac{A^-}{HA}\right) = pK_a + \log(1) = pK_a$$

So:

chloroacetic acid pK_a = -log 1.35 E -3 = 2.87
propanoic acid pK_a = -log 1.30 E -5 = 4.89
benzoic acid pK_a = -log 6.40 E -5 = 4.19
hypochlorous acid pK_a = -log 3.50 E -8 = 7.46

The closest acid/conjugate base pair is benzoic acid.

Build Your Own Buffer Answer

4. What ratio will of acid to conjugate base will produce the desired pH of 4.30?

Calculate $[H^+]$: $[H^+] = 10^{-4.30} = 5.01E-5$

Determine benzoic acid (C_6H_5COOH) equation:

$$C_6H_5COOH \rightleftharpoons C_6H_5COO^- + H^+$$

and use its H & H expression to find the ratio:

$$pH = pK_a + \log\left(\frac{[C_6H_5COO^-]}{[C_6H_5COOH]}\right)$$

$$pH - pK_a = \log\left(\frac{[C_6H_5COO^-]}{[C_6H_5COOH]}\right)$$

$$10^{pH-pK_a} = 10^{4.30-4.19} = \boxed{1.29} = \left(\frac{[C_6H_5COO^-]}{[C_6H_5COOH]}\right)$$

The chemist would have to use 1.29 times as much sodium benzoate as benzoic acid.

Homework

Preview 12.3

12.1-.2 Problems in your Booklet
Due: Next Class