Buffer Solutions

- A **buffer solution** is a solution that can resist a change in pH when a moderate amount of a strong acid or strong base is added
  - A buffer solution is created when a solution contains approximately equal amounts of a *conjugate acid-base pair* in relatively large amounts
  - To have a conjugate acid-base pair in equal amounts, only weak acids/weak bases can be used to create a buffer solution

- A buffer can be prepared in three different ways:

1. Adding equal amounts of each component of the conjugate acid-base pair
   - Ex. Equal amounts of ethanoic acid and sodium ethonate are mixed together to form a buffer solution.

$CH_3COOH / NaCH_3COO$

is the same as

CH_3COOH / CH_3COO^- Na^+ is just a spectator ion!

2. Adding a small amount of strong base to an excess amount of weak acid
   - Ex. A small amount of sodium hydroxide is added to methanoic acid

some left over

$HCOOH_{(aq)}$ + $NaOH_{(aq)}$ $\longrightarrow$ $NaHCOO_{(aq)}$ + $H_2O_{(l)}$

some produced

excess amount of weak acid

small amount of strong base that will react completely

or

$Na^+ : HCOO^-$

$\therefore$ $HCOOH / HCOO^-$ present to form a buffer

3. Adding a small amount of strong acid to an excess amount of weak base
   - Ex. A small amount of hydrochloric acid is added to ammonia

some left over

$NH_{3(aq)}$ + $HCl_{(aq)}$ $\longrightarrow$ $NH_4^+{}_{(aq)}$ + $Cl^-_{(aq)}$

some produced

excess amount of weak base

small amount of strong acid that will completely react

- How does a buffer solution resist a change in pH?
  - Consider the buffer solution that is made using ethanoic acid and sodium ethanoate ($CH_3COOH/NaCH_3COO$) same as CH_3COOH / CH_3COO^-
  - By adding a strong acid to the buffer, the ethonate ions (the base component of the buffer solution) will react with hydronium ions/hydrogen ions and convert them into a product that doesn't affect the pH.

* Remember only OH^- ions and H_3O^+/H^+ ions affect the pH of a solution!

$$CH_3COO^-_{(aq)} + H^+_{(aq)} \longrightarrow CH_3COOH_{(aq)}$$

$$\rightarrow CH_3COO^-_{(aq)} + H_3O^+_{(aq)} \overset{OR}{=\!=} CH_3COOH_{(aq)} + H_2O_{(l)}$$

notice how none of the products will actually affect pH!

  - By adding a base to the buffer, essentially the ethanoic acid (the acid component of the buffer solution) will react with hydroxide ions and convert them into a product that doesn't affect the pH.

$$CH_3COOH_{(aq)} + OH^-_{(aq)} \longrightarrow CH_3COO^- + H_2O_{(l)}$$

- However, when the components of the conjugate acid-base pair are completely consumed by the addition of a strong acid or base, the buffer fails and the pH changes dramatically. This is known as the **buffer capacity** and is the limit of the buffer solution to resist an change in pH

*****Now try the Practice Problems*****

Practice Problems

1. Which of the following solution pairs, when mixed in *equal quantities*, will not form an effective buffer?
    a. $HNO_{3(aq)}$ and $NaNO_{3(aq)}$
    b. $C_6H_5COOH_{(aq)}$ and $NaC_6H_5COO_{(aq)}$
    c. $NH_{3(aq)}$ and $NH_4Cl_{(aq)}$
    d. $HCl_{(aq)}$ and $NaOH_{(aq)}$

2. Explain why an aqueous mixture of $NaCl_{(aq)}$ and $HCl_{(aq)}$ does not act as a buffer, but an aqueous mixture of $NH_{3(aq)}$ and $NH_4Cl_{(aq)}$ does.

3. Describe how a buffer system solution is different from an aqueous acidic or basic solution.

4. Write the reaction of a carbonic acid/hydrogen carbonate ion buffer
    a. when a small amount of $HCl_{(aq)}$ is added
    b. when a small amount of $NaOH_{(aq)}$ is added

5. What happens if a large/excess amount of a strong acid or base is added to a buffer?

Solutions

1. Solution "a" will not form a buffer solution because HNO_3 is a strong acid and will completely ionize in solution. Therefore no acid component will be left of the conjugate acid-base pair.

   Also, solution "d" will not form a buffer either because it is composed of a strong acid and a strong base. The strong acid and strong base will react completely and only the products of $NaCl_{(aq)}$ and $H_2O_{(l)}$ will remain in solution, which is not a buffer solution because there is no conjugate acid-base pair.

2. $NaCl_{(aq)}$ is a salt and will dissociate/break down into its ions ($Na^+_{(aq)}$ and $Cl^-_{(aq)}$) in water. $HCl_{(aq)}$ is a strong acid and will completely ionize into $H^+_{(aq)}$ and $Cl^-_{(aq)}$ because it is a strong acid. Therefore, no conjugate acid-base pair is present.

   $NH_{3(aq)}$ is a weak base and $NH^{4+}_{(aq)}$ is a weak acid. Since both are present in solution, the conjugate acid-base pair can exist, which means a buffer solution can form.

3. A buffer solution contains approximately <u>*equal amounts*</u> of a conjugate acid-base pair. An aqueous acidic or basic solution will react with water to produce its conjugate pair, but only in very small amounts because weak acids and weak bases only react very little to produce small amounts of products.

4.

   a. $HCO_3^-{}_{(aq)} + HCl_{(aq)} \rightarrow H_2CO_{3(aq)} + Cl^-_{(aq)}$

   b. $H_2CO_{3(aq)} + NaOH_{(aq)} \rightarrow NaHCO_{3(aq)} + H_2O_{(l)}$

   Notice how the products produce in both reactions will not affect the pH because only H^+/H_3O^+ and OH^- ions can affect the pH.

5. Initially the buffer can resist a change in pH. However, when a large amount of strong acid or strong base is added, the buffer will reach its capacity and will fail, resulting in a dramatic change in pH.