Buffer Solutions

- A **buffer** 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/bases can be present in a buffer solution.
  - Strong acids/bases cannot be present in a buffer solution
- EXAMPLE: When mixed in equal amounts, indicate which pair of chemicals can form a buffer solution.

a. $CH_3COOH_{(aq)}$ and $NaCH_3COO_{(aq)}$

↳ $CH_3COOH_{(aq)}$ is a weak acid

↳ $NaCH_3COO_{(aq)}$ is ionic & aqueous

↙ $Na^+_{(aq)}$ ↘ $CH_3COO^-_{(aq)}$

$CH_3COOH_{(aq)}$ & $CH_3COO^-_{(aq)}$ are both present as a conjugate acid/base pair ∴ buffer solution

b. $HBr_{(aq)}$ and $MgBr_{2(aq)}$

↳ $HBr_{(aq)}$ is a strong acid

∴ it 100% ionizes

$HBr_{(aq)} \longrightarrow H^+_{(aq)} + Br^-_{(aq)}$

none left — only products left

↳ $MgBr_{2(aq)}$ is ionic & aqueous

↙ ↘

$Mg^{2+}_{(aq)}$ $2Br^-_{(aq)}$

no conjugate acid/base pair present ∴ no buffer

- Even though strong acids and strong bases cannot be present in a buffer, they can be used to create a buffer. Consider the following situations.

1. 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 — none left over — some produced

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

large amount of weak acid — small amount of strong base that reacts completely — or $Na^+_{(aq)}$ & $HCOO^-_{(aq)}$

∴ $HCOOH$ / $HCOO^-$ conjugate pair present to form a buffer

2. 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 — none left over — some produced

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

large amount of weak base — small amount of strong acid that reacts completely

$\therefore$ $NH_{3(aq)}/NH_4^+{}_{(aq)}$ conjugate pair present to form a buffer

- How does a buffer solution resist a change in pH?
  - ✳ Remember only OH^- ions and H_3O^+/H^+ ions affect the pH/pOH of a solution

$$pH = -\log[H_3O^+] \quad \& \quad pOH = -\log[OH^-]$$

  - When OH^- ions or H_3O^+/H^+ are added to a buffer, the buffer converts or locks these ions into a form that does not affect the pH/pOH

- Consider the buffer solution that contains $NaHSO_{4(aq)}$ and $Na_2SO_{4(aq)}$ (spectator ions)
  - By adding a strong acid to the buffer, the base component of the buffer will react with hydronium ions/hydrogen ions ($H_3O^+_{(aq)}/H^+_{(aq)}$)

$SO_4^{2-}{}_{(aq)} + H_3O^+{}_{(aq)} \longrightarrow HSO_4^-{}_{(aq)} + H_2O_{(\ell)}$

OR

$SO_4^{2-}{}_{(aq)} + H^+{}_{(aq)} \longrightarrow HSO_4^-{}_{(aq)}$

* these products don't affect pH!

  - By adding a base to the buffer, the acid component of the buffer will react with hydroxide ions ($OH^-_{(aq)}$) and convert them into a product that doesn't affect the pH.

$HSO_4^-{}_{(aq)} + OH^-{}_{(aq)} \longrightarrow SO_4^{2-}{}_{(aq)} + H_2O_{(\ell)}$

* these products don't affect pH!

- However, when the components of the conjugate acid-base pair are completely consumed by the addition of a strong acid or strong 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 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. $HClO_{4(aq)}$ and $NaOH_{(aq)}$
    e. $NaCl_{(aq)}$ and $HCl_{(aq)}$
    f. $H_3PO_{4(aq)}$ and $K_2PO_{4(aq)}$
    g. $NH_4CN_{(aq)}$ and $HCN_{(aq)}$

2.
    a. Write out the acid-base reaction for $KOCl_{(aq)}$.
    b. Does this solution create an effective buffer? Explain.

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

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

Answers

1. b, c, g

2.

a. $KOCl_{(aq)} + H_2O_{(l)} \leftrightarrow HOCl_{(aq)} + OH^-_{(aq)} + K^+_{(aq)}$ (with spectator ions)

or $OCl^-_{(aq)} + H_2O_{(l)} \leftrightarrow HOCl_{(aq)} + OH^-_{(aq)}$ (without spectator ions)

b. A buffer solution contains approximately *equal amounts* of a conjugate acid-base pair. Since $OCl^-_{(aq)}$ is a weak base, the solution containing $KOCl_{(aq)}$ *does* have a conjugate acid present but only in very small amounts. Therefore, this solution will *not be* an effective buffer.

3.

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

or $HCO_3^-{}_{(aq)} + H_3O^+_{(aq)} \rightarrow H_2CO_{3(aq)} + H_2O_{(l)}$ (spectator ions not included)

or $HCO_3^-{}_{(aq)} + H^+_{(aq)} \rightarrow H_2CO_{3(aq)}$ (spectator ions not included)

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

or $H_2CO_{3(aq)} + OH^-_{(aq)} \rightarrow HCO_3^-{}_{(aq)} + H_2O_{(l)}$ (spectator ions not included)

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

4. 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.