Buffer System

MEDEMIA ACADEMY

Introduction

- **Acid:** A substance that can release Hydrogen ions .

- **Base:** A substance that can accept Hydrogen ions

- **pH:** The Concentration of Hydrogen ions in a solution .

- **pH** $= -\log_{10}[H^+]$, $P = -\log$

(there is an inverse relation between Ph and Acidity)

Calculating pH

- **What is the pH of a solution whose hydrogen ion concentration is 3.2 X 10–4 mol/L?**
  - pH = -log [H+]

    = -log (3.2 X 10-4)

    = -log (3.2) - log(10-4)

    = -0.5 + 4

    = 3.5

pH	$[H^+]$ (mol/l)	
1	10^{-1}	↑
2	10^{-2}	
3	10^{-3}	Increasing acidity
4	10^{-4}	
5	10^{-5}	
6	10^{-6}	
7	10^{-7}	Neutral
8	10^{-8}	
9	10^{-9}	
10	10^{-10}	Increasing alkalinity
11	10^{-11}	
12	10^{-12}	
13	10^{-13}	
14	10^{-14}	↓

Dissociation Constants (Ka)

- ❖**Definition**: The tendency of any acid (HA) to lose a proton and form its conjugate base (A-)
- ❖The stronger the acid, the greater its tendency to lose its proton. (stronger Acid has Higher Ka and lower pKa)
  - ○ **Strong acids**: are acids that dissociate completely in solution like HCl.

$$HCl \rightarrow Cl^- + H^+$$

  - ○ **Weak acids**: are acids that dissociate only to a limited extent like H_2CO_3.

$$H_2CO_3 \rightarrow HCO_3^- + H^+$$

$$\underset{\text{Acid}}{HA} \rightleftharpoons \underset{\text{Conjugate Base}}{A^-} + H^+$$

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

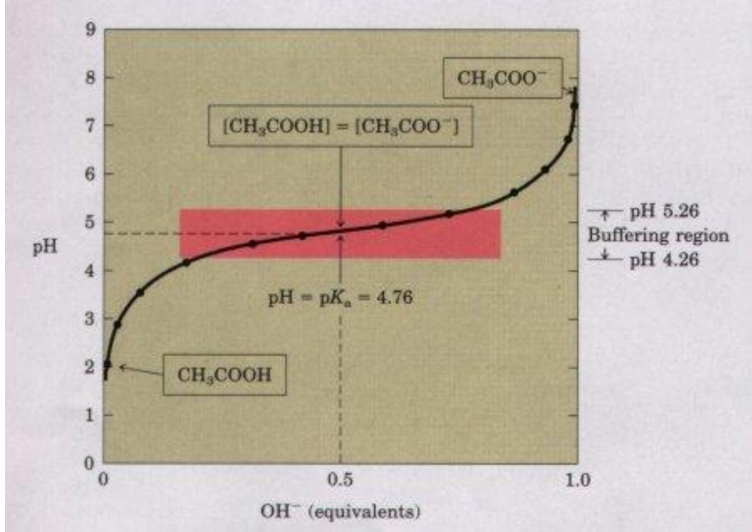
Buffers

- **A buffer**: is a solution that resists pH changes when acids or bases are added to the solution.
  - Buffer solutions consist of a weak acid (undissociated acid) and its conjugate base .
  - A buffer works because added acids (H+) are neutralized by the conjugate base (A-) which is converted to the acid (HA).

$$\underset{\text{Acid}}{HA} \rightleftharpoons \underset{\text{Conjugate Base}}{A^-} + H^+$$

Cont ..

- pKa = -log Ka
  - pKa of an acid : is the pH at which 50% dissociation occurs .
  - Strong acids have strong tendency to dissociate and thus have high Ka value and low pKa value .
- **Two factors determine the effectiveness of a buffer**
  - its pKa relative to the pH of the solution (when the Acid and its conjugated base are equal , in other words , when the 50% of Acid dissociate)
  - its concentration



Henderson-Hasselbalch Equation

- Equation describes the relationship between the acid and its conjugate base with pH and pKa
  - The most effective buffers is when pH=pKa means it has equal concentrations of acid [HA] and its conjugate base [A-] .
  - At pH = pKa ± 1 the buffer capacity falls to 33% of the maximum value. Therefore the buffer is effective one point up or down the pH pKa value

$$pH = pK_a + \log_{10} \frac{[\text{Conjugate Base}]}{[\text{Acid}]}$$

Solving Problems using Henderson Hasselbalch Equation

Calculate the pK_a of lactic acid, given that when the concentration of lactic acid is 0.010 M and the concentration of lactate is 0.087 M, the pH is 4.80.

$$\text{pH} = \text{p}K_a + \log \frac{[\text{lactate}]}{[\text{lactic acid}]}$$

$$\text{p}K_a = \text{pH} - \log \frac{[\text{lactate}]}{[\text{lactic acid}]}$$

$$= 4.80 - \log \frac{0.087}{0.010} = 4.80 - \log 8.7$$

$$= 4.80 - 0.94 = 3.9 \quad (\textit{answer})$$

Calculate the pH of a mixture of 0.10 M acetic acid and 0.20 M sodium acetate. The pK_a of acetic acid is 4.76.

$$\text{pH} = \text{p}K_a + \log \frac{[\text{acetate}]}{[\text{acetic acid}]}$$

$$= 4.76 + \log \frac{0.20}{0.10} = 4.76 + 0.30$$

$$= 5.1 \quad (\textit{answer})$$

Acids in Our Body

- **Volatile acid**: represented in our body by carbonic acid which is originated from CO2. So the main source of volatile acid is CO2 which can evaporate and get rid of it through lungs.

- **Nonvolatile acids**: include all acids produced in the body except the one that is produced from CO2
  - examples : lactic acid (fermentation), phosphoric acid, sulfuric acid (Protein breakdown), acetoacetic acid and beta-hydroxybutyric acid (ketone bodies).
  - Nonvolatile acids elimination is through the kidney.

Organs controlling pH

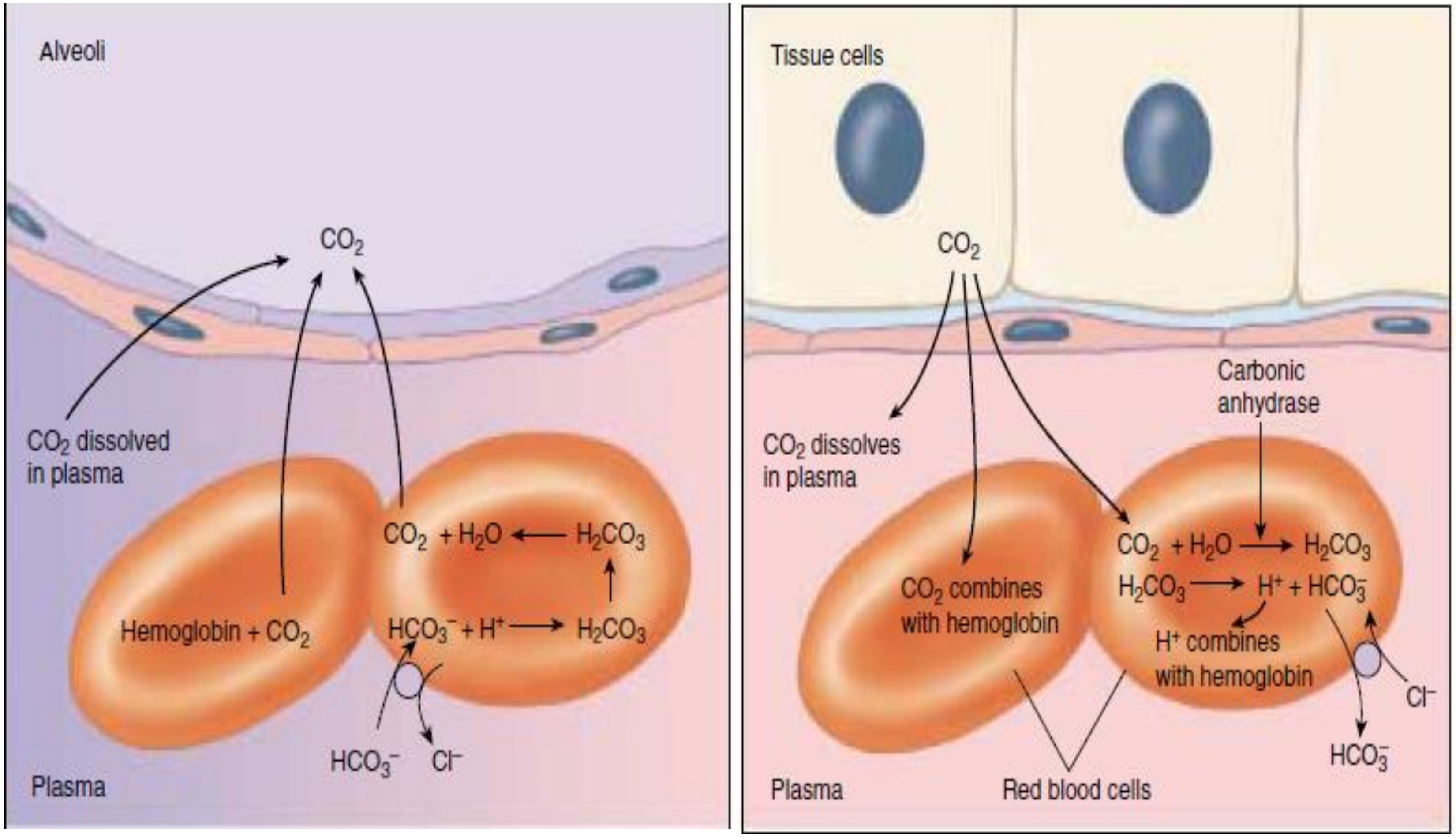
- Lungs function to regulate blood pH through bicarbonate system.
  - The respiratory tract can adjust the blood pH upward in minutes by exhaling CO_2 from the body.
- Kidney maintain a normal pH through:
  - Reabsorption of filtered bicarbonate.
  - Excretion of acids.
  - Kidneys need hours to days

Transport of CO_2

- ❖ CO_2 is carried in the blood by 3 ways :
  - o 10% dissolved in Plasma
  - o 20% attached with Amino group of Hemoglobin making Carbamino Hbg .
    - $HbNH_2 + CO_2 \leftrightarrow HbNHCOO^- + H^+$
    - The H^+ released bind the side chain of the amino acid histidine (His-146 (β)) in the two β chains of hemoglobin
  - o 70% of the CO_2 diffuses into the red blood cells, the enzyme carbonic anhydrase catalyzes the combination of CO_2 with water to form carbonic acid (H_2CO_3).

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

Transport of CO2



Transport of CO_2

- Carbonic acid dissociates into bicarbonate (HCO_3^-) and hydrogen (H^+) ions.
  - The H^+ binds to hemoglobin and force $Hb(O_2)_4$ to dissociate its O_2 which diffuses out of RBC.
  - the bicarbonate moves out of the erythrocyte into the plasma via a transporter that exchanges one chloride ion for a bicarbonate (this is called the “chloride shift”).
  - The blood carries bicarbonate to the lungs. The lower pCO_2 of the air inside the alveoli causes the carbonic anhydrase reaction to proceed in the reverse direction that leads to formation of CO_2.

The Bicarbonate Buffer System

- ❖Bicarbonate and other buffers normally maintain the pH of extracellular fluid in human's body between 7.35 and 7.45.
  - o The pH of a bicarbonate buffer system depends on the concentration of H2CO3 as proton donor and HCO3- as proton acceptor.

$$CO_2 + H_2O \underset{}{\overset{\text{carbonic anhydrase}}{\rightleftharpoons}} H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

The Bicarbonate Buffer System

- The respiratory center in brain which controls the rate of breathing, is sensitive to changes in pH.
  - As the pH falls, individuals breathe more rapidly and expire more CO2.
  - As the pH rises, they breathe more slowly.

- What happen when CO2 is increased?

$$pH = pKa + \log \frac{[HCO_3^-]}{Pco_2}$$

- What happen when increasing the concentration of HCO3- ?

Other Types of Buffers

1. **Hemoglobin as Protein Buffer**
   - The pKa of the various histidine residue (imidazole groups) on the different plasma proteins range from about 5.5 to about 8.5 thus providing a broad spectrum of buffer pairs.
   - The H+ released bind the side chain of the amino acid histidine (His-146 (β)) in the two β chains of hemoglobin
   - Only a small number of hydrogen ions generated in the blood remains free not attached to Hb. This explains why the acidity of venous blood (pH = 7.35) is only slightly greater than that of arterial blood (pH = 7.45).

Other Types of Buffers

2. **Phosphate buffer the Intracellular pH**
    - Phosphoric acid ($H3PO4$) dissociate to conjugate base dihydrogen phosphate ion ($H2PO{-}4$) and $H+$
    - Dihydrogen phosphate ion dissociate to conjugate base hydrogen phosphate ($HPO2{-}4$) and $H+$ with a pKa of 7.2 which is very close to physiologcal pH
    - $H2PO4- \leftrightarrow HPO4-2+ H+$

3. **Organic phosphate anions**, such as glucose 6-phosphate and ATP, also act as buffers

Respiratory acidosis

- **Respiratory acidosis** is caused by hypoventilation so there is retention of CO_2 and a drop in pH, making the blood too acidic and is caused by condition restricting the exhaling of CO_2 from the lungs such as :
  - Diseases of the airways (such as asthma and chronic obstructive lung disease)
  - Diseases of the chest (such as sarcoidosis)
  - Diseases affecting the nerves and muscles that "signal" the lungs to inflate or deflate
  - Depression of the respiratory centres in the medulla by different drugs.
  - Severe obesity, which restricts how much the lungs can expand

Respiratory alkalosis

- **Respiratory alkalosis :** Results from hyperventilation that causes too much dissolved CO_2 to be removed from the blood, which raises the blood pH. And may be caused from :
  - hysteria (any psychological dysfunction of unknown cause)
  - central nervous system diseases
  - overdose of some drugs (e.g salicylate)
  - fever