ACID - BASE BALANCE
And
it’s Disorders

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Surat
pH

- pH = -log (H+)
- Acidity depends on Hydrogen ion concentration.
- Lower the pH = Higher Hydrogen
- Higher the pH = Lower Hydrogen.
- Normal pH of plasma = 7.38 to 7.42
- At the pH of 7.4 = 40 nanomoles/litre.
ACID

- **Release hydrogen ions** in solutions.
- Donate protons.
- Strong acids donate Completely
  - HCL
- Weak acids dissociates incompletely.
  - H2CO3
Base

• Accept Hydrogen ions.
  — For example, HCO₃⁻.

• Strong Base accept proton Completely.
  — E.g. NaOH

• Weak acids accept incompletely in solution.
  — E.g. NH₃
Dissociation Constant (\(Ka\)):

- Since the dissociation of an acid is a freely reversible reaction.
- At equilibrium the ratio between dissociated and undissociated particle is a constant.

\[
(\text{HA}) \xrightarrow{} (\text{H}^+) + (\text{A}^-)
\]

\[
\text{Ka} = \frac{(\text{H}^+)(\text{A}^-)}{(\text{HA})}
\]

Henderson-Hasselbalch equation:

\[
\text{pH} = \text{pKa} + \log \frac{(\text{Base})}{(\text{Acid})}
\]
Henderson-Hasselbalch equation Derivation

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

\[ \log_{10} K_a = \log_{10} \left( \frac{[H^+][A^-]}{[HA]} \right) \]

\[ \log_{10} K_a = \log_{10}[H^+] + \log_{10} \left( \frac{[A^-]}{[HA]} \right) \]

\[ -pK_a = -pH + \log_{10} \left( \frac{[A^-]}{[HA]} \right) \]

\[ pH = pK_a + \log_{10} \left( \frac{[A^-]}{[HA]} \right) \]

- When base (A-) & acid (HA) are same in concentration.
- \( pH = pK_a. \)
Volatile & Non-Volatile acids

- During metabolism, acidic ions are produced.
- Added to the ECF.
- This has to be effectively buffered.

- Volatile acids
  - Carbonic acid.
    - Carbonic acid = Volatile = Eliminated as CO2 by Lung.

- Non Volatile
  - Lactate acid, Keto acids
    - Fixed acid are Buffered
    - Later, as H+, they are excreted by kidney
BUFFER SYSTEMS

ICF include

Phosphate buffer system

Protein buffer systems, including

Amino acid buffers (all proteins)

Hemoglobin buffer system (RBCs only)

ECF include

Carbonic acid–bicarbonate buffer system

Plasma protein buffers

CYTOPLASM
Three Main Way of Acid-Base Balance

1. **Blood Buffer Mechanism**
   1. Bicarbonate buffer
   2. Phosphate buffer
   3. Protein buffer
   4. Haemoglobin buffer

2. **Respiratory Buffer Mechanism**
   1. Heamoglobin buffer

3. **Renal Buffer Mechanism**
   1. H+ excretion / titrable acid excretion
   2. HCO3- reabsorption
   3. Ammonium ions excretion
**Blood Buffer**

- Buffers are solution which can resist changes in pH when acid or alkali is added.

- Buffers are of two types:
  1. Weak acids + Strong bases.
     - $\text{H}_2\text{CO}_3/\text{NaHCO}_3$ (Bicarbonate Buffer)
     - $\text{CH}_3\text{COOH}/\text{CH}_3\text{COONa}$ (acetate Buffer)
  2. Weak bases + Strong acids.
Distribution of Blood Buffers Systems

• Intra cellular buffers = 58%
  – 52% buffer activity is in tissue cells
  – 6% in RBCs.

• Extra cellular buffers = 42%
  – In plasma and extracellular space,
  – 40% by Bicarbonate system
  – 1% by Proteins
  – 1% by Phosphate buffer system.
Blood Buffer System

• Fast Acting
• Very Effective
• Not Permanent – Only Neutralize acid - bas

1. **Bicarbonate**
   – Most important buffer system in the body.

2. **Phosphate Buffer system**
   – It is mainly intracellular buffer.
   – Its concentration in plasma is very low.
   – HPO4-/H2PO4-

3. **Proteins Buffer system**
   – Many proteins, not only albumin.

4. **Haemoglobin Buffer system**
Bicarbonate Buffer

- H$_2$CO$_3$/NaHCO$_3$ (Weak Acid / Strong Base)
- pK value = 6.1
- At pH = 7.4,
  - H$_2$CO$_3$:NaHCO$_3$ = 1:20
- High Concentration
- So Effective buffering capacity
Bicarbonate Blood Buffer

(a) The response to acidosis

- Increased respiratory rate lowers $P_{CO_2}$
- $CO_2 + H_2O \rightarrow H_2CO_3$ (carbonic acid)
- $H^+$ addition
- $H^+ + HCO_3^- \rightarrow H_2CO_3$ (bicarbonate ion)
- Kidneys: secretion of $H^+$, generation of $HCO_3^-$
- Bicarbonate reserve: $Na^+ HCO_3^-$ (sodium bicarbonate)

(b) The response to alkalosis

- Increased respiratory rate elevates $P_{CO_2}$
- $CO_2 + H_2O \rightarrow H_2CO_3$
- $H_2CO_3 \rightarrow H^+ + HCO_3^-$
- Kidneys: secretion of $HCO_3^-$
- Bicarbonate reserve: $Na^+ HCO_3^-$ (sodium bicarbonate)

Other buffer systems: absorb $H^+$, release $H^+$.
Phosphate Blood Buffer

- $\text{NaH}_2\text{PO}_4 / \text{Na}_2\text{HPO}_4$ (Strong Acid / Weak Base)
- pK value = 6.8
- At pH = 7.4,
  - $\text{NaH}_2\text{PO}_4 / \text{Na}_2\text{HPO}_4 = 1:4$ Ratio
- Low Concentration
- Less effective buffering
Phosphate Blood Buffer

- When Acidosis
  - Increase H+

\[
\begin{align*}
H_2PO_4^- & \leftrightarrow H^+ + HPO_4^{2-} \\
\end{align*}
\]

- When Alkalosis
  - Decrease H+

\[
\begin{align*}
H_2PO_4^- & \leftrightarrow H^+ + HPO_4^{2-} \\
\end{align*}
\]
Haemoglobin Buffer
(Respiratory Buffer System)

• With carriage of O2 & CO2 transport, also play as buffer.
• Deoxygenated haemoglobin has the strongest affinity for both CO2 and H+
• Thus, buffering effect is strongest in the tissues.
• Carbon dioxide then either combines
  • Directly with haemoglobin = Carbaminohaemoglobin.
  • Water to form carbonic acid.
VENOUS BLOOD

- CO₂
  - Cellular respiration in peripheral tissues

- Dissolved CO₂ (7%)
  - Red blood cell
    - CO₂ + Hb → Hb•CO₂ (23%)
    - CO₂ + H₂O → H₂CO₃
      - CA → HCO₃⁻
      - H⁺ + Hb → Hb•H

- Capillary endothelium
- Cell membrane
- Transport to lungs

- Dissolved CO₂ → CO₂
  - Hb•CO₂ → Hb + CO₂
  - HCO₃⁻ → H₂CO₃ → CA → H₂O + CO₂
  - Hb•H → H⁺ + Hb

- HCO₃⁻ in plasma
- CA
Renal Buffer System

• Long term balance
• Permanent Excretion of Acid-Base
• Through following mechanism
  1. H+ excretion / titrable acid excretion
  2. HCO3- reabsorption
  3. Ammonium ions excretion
1. H+ Excretion
2. Reabsorption of HCO$_3^-$
3. Excretion Ammonium Ions

[Diagram showing the processes involving ammonium ions, hydrogen ions, bicarbonate, carbon dioxide, and glutamine in the renal system.]
Arterial Blood Gas (ABG) Analysis

METHOD of Sample collection:-

• Arterial samples is collected from Radial or Femoral artery.
• Collected in Heparin containing vial
• And transported immediately to laboratory.
• Avoid expose to atmospheric air

Use of ABG :-

• detection of hypoxemia and hypercapnia
• management of respiratory failure
• care of the ventilated patient
• detection of abnormalities of acid – base balance
<table>
<thead>
<tr>
<th>Parameter of ABG</th>
<th>Physiological Range</th>
<th>Pathological</th>
</tr>
</thead>
</table>
| 1 pH             | 7.35 to 7.45        | < 7.35 = Acidosis  
>7.45 = Alkalosis    |
| 2 SpO2           | 90 – 100 %          |              |
| 3 pO2            | 95 – 100 mmHg       | < 80% = Hypoxia |
| 4 pCO2           | 32 – 44 mmHg        | < 32= Respiratory alkalosis  
> 44 = Respiratory acidosis |
| 5 HCO3-          | 22 – 26 mmol/L      | < 22 = Metabolic acidosis  
> 26 = Metabolic alkalosis |
<p>| 6 Base Excess    | -2.0 to + 2.0 mmol/l|              |</p>
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Respiratory Acidosis

- Due to retention of CO2

**Causes**
- Brochopneumonia
- COPD
- Bronchial Asthma
- Morphine poisoning – Causing respiratory center depression
- Interstitial lung disease
- Central nervous system lesion
Respiratory Alkalosis

- Due to Excessive CO2 wash out

**Causes:**

- Hysterical attacks.
- Exercise
- High Grade fever.
- Hepatic coma.
- Thyrotoxicosis
- Pulmonary hypertention
- Pulmonary embolism
Metabolic Acidosis

- Due to Excessive H+ (organic acid) production
- Due to HCO- (base) Excretion

**Causes**
1. Hypovolemic – Cardiogenic Shock
2. Ischemic disease
3. Diabetic Ketoacidosis
4. Starvation Ketoacidosis
5. Salicylate – Methanol Poisoning
6. Severe Diarrhea
7. Enterostomy drainage
8. Renal tubular acidosis
9. Adrenal Insufficiency
Metabolic Alkalosis

- Due to HCO⁻ (base) production / Ingestion
- Due to Excessive H⁺ (organic acid) excretion

**Causes**

- Ingestion of alkali such as bicarbonate
- Prolonged vomiting
  - Pyloric stenosis
  - Intestinal obstruction
- Diuretic therapy
- Cushing syndrome
- Primary aldosteronism
Anion Gap

- Always in ECF
  - Conc. Of Cations = Conc. of Anions.
  - to maintain the electrical neutrality.
- Measurable Cation = Sodium + Potassium = 95% of Cations.
- Measurable Anion = Chloride + Bicarbonate = 86% of Anions.
- So, Difference between Measured Cations & Anions.
- **Unmeasured Anions = Anion Gap**
- Due to presence of protein anions, sulfate, phosphate & organic acids.
Anion Gap = $[\text{Na}^+] + [\text{K}^+] - [\text{Cl}^-] - [\text{HCO}_3^-]$

= 10 to 20 mmol/L
Type of Anion Gap

3. Low Anion Gap
High Anion Gap Acidosis

- Renal Failure
  - Decrease excretion of H+
  - Decrease re-absorption of HCO3-
- Diabetic ketoacidosis
- Alcohol abuse
- Lactic acidosis
- Tissue Hypoxia
- Circulatory failure
- Methanol – Salicylate Poisoning
Normal Anion Gap Acidosis

- Severe Diarrhea
  - (Hyperchloremic Acidosis)
- Acetazolamide (Carbonic anhydrase inhibitor)
- Uretero-enteric fistula
Low Anion Gap

- Hypoalbunemia
- Multiple myeloma