Blood as a buffer system

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Introduction

The maintenance of the blood pH is important for the proper functioning of our body and can be critical if not maintained.

The main buffers in blood are bicarbonate, haemoglobin, plasma proteins and phosphates.

Mainly, the buffer involves carbonic acid (H_2CO_3), a weak acid, and bicarbonate ion (HCO^{3-}), the conjugate base.

Buffers in the Blood

- The pH of blood is 7.35 – 7.45
- Changes in pH below 6.8 and above 8.0 may result in death
- The major buffer system in the body fluid is H_2CO_3/HCO_3^-
- Some CO_2, the end product of cellular metabolism, is carried to the lungs for elimination, and the rest dissolves in body fluids, forming carbonic acid that dissociates to produce bicarbonate (HCO_3^-) and hydronium (H_3O^+) ions.
- More of the HCO_3^- is supplied by the kidneys.
- $CO_2 + H_2O \leftrightarrow H_2CO_3$
- $H_2CO_3 + H_2O \leftrightarrow H_3O^+ + HCO_3^-$

Buffer

- **Mixtures of weak acids and their salts of strong bases OR Mixtures of strong acids and their salts of weak bases.**

Example: mixture of **acetic acid** and **sodium acetate**. $CH_3COOH + CH_3COONa \rightarrow Na^+ + H^+ + 2CH_3COO^-$

Resists change in pH on the addition of acid (H^+) or base (OH^-). **Weak acid: H^+ donor, Weak base: H^+ acceptor.**

Addition of alkali (NaOH) or acid (HCl): Salt is formed, but no free H+ or OH- will be available.

$$CH_3COOH + CH_3COONa + NaOH \rightarrow 2CH_3COONa + H_2O$$

$$CH_3COOH + CH_3COONa + HCl \rightarrow NaCl + 2CH_3COOH$$

❖ **Two factors determine effectiveness/capacity of buffers:**

1. Molar conc. of buffer components: Directly proportional.
2. Relative conc. of the conjugate base and the weak acid.

Ideal buffer: Equal concentrations of acidic and basic components.

Biological Buffer systems

- Buffer systems in the human body are **extremely efficient**.
- **Different systems work at different rates**.
- Takes only **seconds** for the chemical buffers in the blood to make adjustments to pH. The respiratory tract can adjust the blood pH upward in minutes by exhaling CO_2 from the body. The renal system can also adjust blood pH through the excretion of H^+ and the conservation of bicarbonate, but this process takes hours to days to have an effect.
- Principal buffers of **ECF**: Bicarbonate buffer, Protein buffer
  ICF: Phosphate buffer, Protein buffer
  RBC: Hemoglobin buffer

Bicarbonate Buffer System

- When an acid enters the bloodstream:

$$HCO_3^- + H_3O^+ \longrightarrow H_2CO_3 + H_2O$$

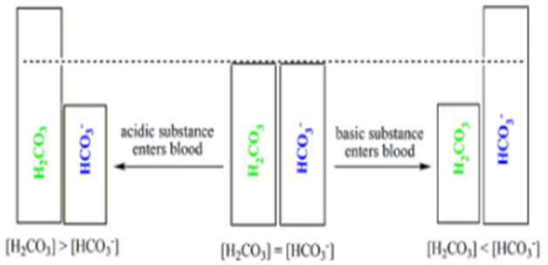
This is to prevent the blood from becoming acidic.

- When a base enters the bloodstream:

$$H_2CO_3 + OH^- \longrightarrow HCO_3^- + H_2O$$

This is to prevent the blood from becoming basic.

Due to this, the concentrations of H_2CO_3 and HCO^{3-} fluctu



The pH of blood is maintained at ~ 7.4 by the carbonic acid – bicarbonate ion buffering system.

Carbonate buffer

$$H_2CO_3 + H_2O \leftrightarrow H_3O^+ + HCO_3^-$$

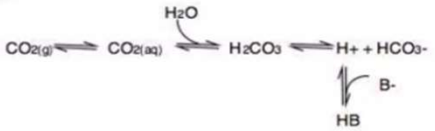
- Excess acid (H_3O^+) in the body is neutralized by HCO_3^-
- $H_2CO_3 + H_2O \leftarrow H_3O^+ + HCO_3^-$
- Equilibrium shifts left
- Excess base (OH^-) reacts with the carbonic acid (H_2CO_3)
- $H_2CO_3 + OH^- \rightarrow H_2O + HCO_3^-$
- Equilibrium shifts right

Importance of the bicarbonate-carbonic acid buffering system

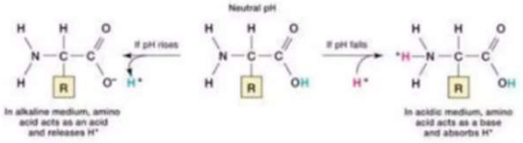
1. H_2CO_3 dissociates into CO_2 and H_2O, allowing H_3O^+ to be eliminated as CO_2 by the lungs
2. Changes in P_{CO_2} modify the ventilation rate
3. HCO_3^- concentration can be altered by kidneys

Other Blood Buffer Systems

- Haemoglobin Figure 1



- Plasma Protein:



- Phosphate:

Other important buffers

- The phosphate buffer system ($HPO_4^{2-}/H_2PO_4^-$) plays a role in plasma and erythrocytes.
- $H_2PO_4^- + H_2O \leftrightarrow H_3O^+ + HPO_4^{2-}$
- Any acid reacts with monohydrogen phosphate to form dihydrogen phosphate

dihydrogen phosphate monohydrogen phosphate

- $H_2PO_4^- + H_2O \leftarrow HPO_4^{2-} + H_3O^+$
- The base is neutralized by dihydrogen phosphate

dihydrogen phosphate monohydrogen phosphate

- $H_2PO_4^- + OH^- \rightarrow HPO_4^{2-} + H_3O^+$

Proteins act as a third type of blood buffer

- Proteins contain – COO^- groups, which, like acetate ions (CH_3COO^-), can act as proton acceptors.
- Proteins also contain – NH_3^+ groups, which, like ammonium ions (NH_4^+), can donate protons.
- If acid comes into blood, hydronium ions can be neutralized by the – COO^- groups
- $- COO^- + H_3O^+ \rightarrow - COOH + H_2O$
- If base is added, it can be neutralized by the – NH_3^+ groups
- $- NH_3^+ + OH^- \rightarrow - NH_2 + H_2O$

- The concentration of carbonic acid in the body is associated with the partial pressure of CO_2.
- When CO_2 level rises, producing more H_2CO_3, the equilibrium produces more H_3O^+, which lowers the pH – ***acidosis***.
- Decreasing of CO_2 level due to a hyperventilation, which expels large amounts of CO_2, leads to a lowering in the partial pressure of CO_2 below normal and the shift of the equilibrium from H_2CO_3 to CO_2 and H_2O. This shift decreases H_3O^+ and raises blood pH – ***alkalosis***.

Respiratory Acidosis: $CO_2 \uparrow$ pH $\downarrow$

- Symptoms: Failue to ventilate, suppression of breathing, disorientation, weakness, coma
- Causes: Lung disease blocking gas diffusion (e.g., emphysema, pneumonia, bronchitis, and asthma); depression of respiratory center by drugs, cardiopulmonary arrest, stroke, poliomyelitis, or nervous system disorders
- Treatment: Correction of disorder, infusion of bicarbonate

Respiratory Alkalosis: $CO_2 \downarrow$ pH $\uparrow$

- Symptoms: Increased rate and depth of breathing, numbness, light-headedness, tetany
- Causes: hyperventilation due to anxiety, hysteria, fever, exercise; reaction to drugs such as salicylate, quinine, and antihistamines; conditions causing hypoxia (e.g., pneumonia, pulmonary edema, and heart disease)
- Treatment: Elimination of anxiety producing state, rebreathing into a paper bag

Hemoglobin:

- Plays an important role more than other proteins as a buffer due to :
- Relatively high concentration
- Relatively rich histidine (pk=7.0)
- Role in transport of blood gases

The Hemoglobin Buffer System

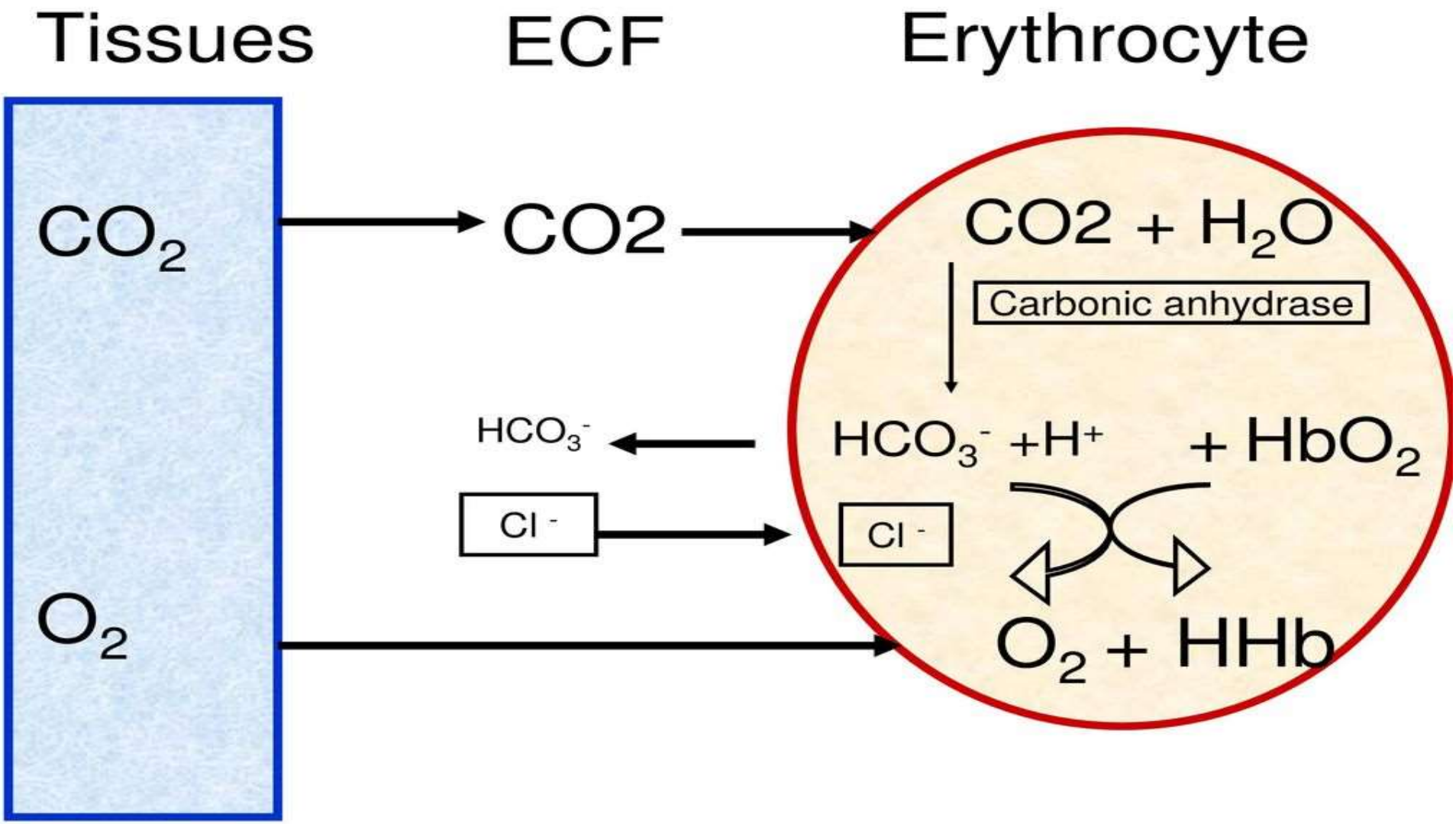
CO_2 diffuses across RBC membrane

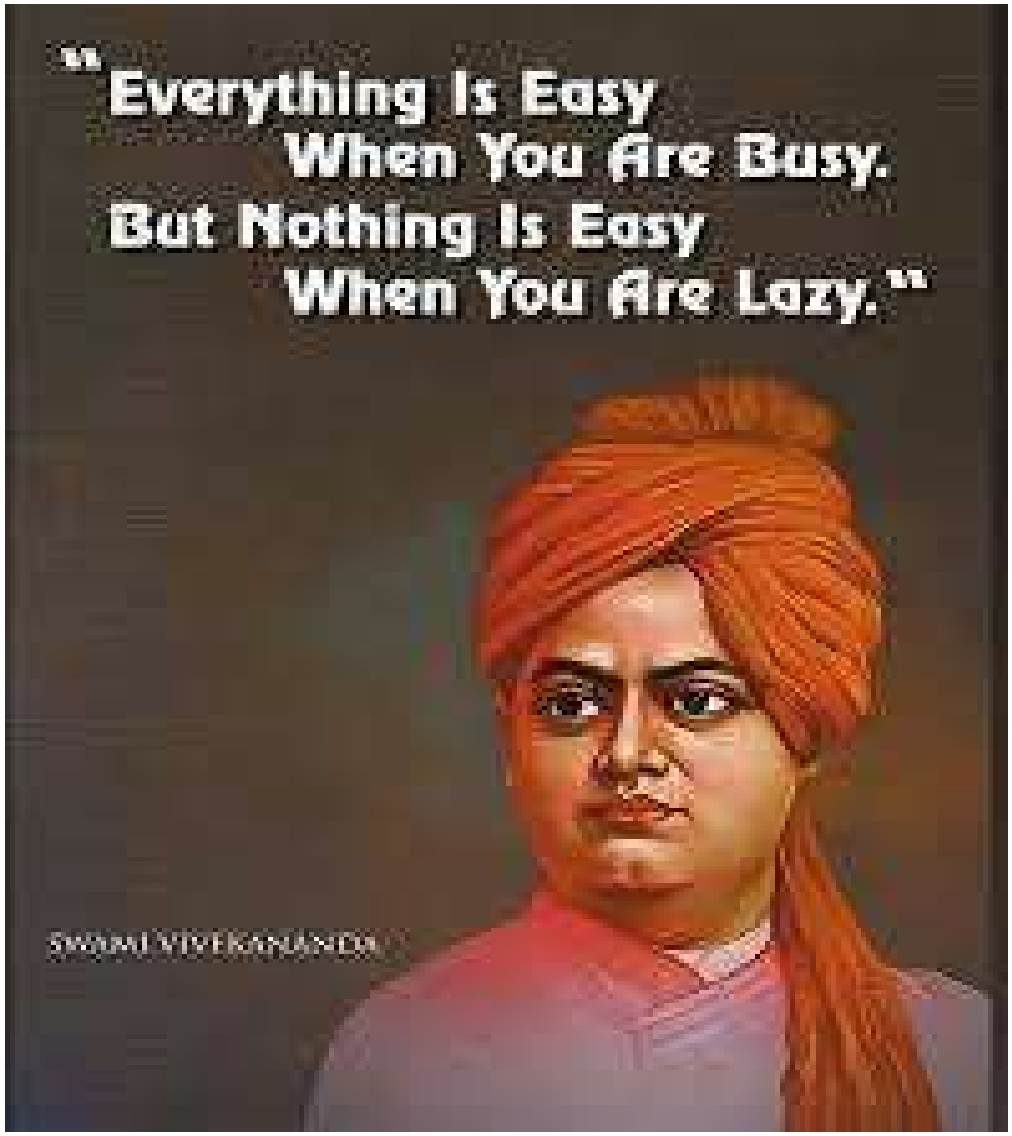
- ✓No transport mechanism required

As carbonic acid dissociates

- ✓Bicarbonate ions diffuse into plasma
- ✓In exchange for chloride ions (chloride shift)

- Hydrogen ions are buffered by hemoglobin molecules
  - ✓Is the only intracellular buffer system with an immediate effect on ECF pH
  - ✓Helps prevent major changes in pH when plasma P_{CO_2} is rising or falling


Tissues
ECF
Erythrocyte
CO_2
O_2
CO2
$CO2 + H_2O$
Carbonic anhydrase
HCO_3^-
$HCO_3^- + H^+ + HbO_2$
Cl^-
Cl^-
$O_2 + HHb$


"Everything Is Easy
When You Are Busy.
But Nothing Is Easy
When You Are Lazy."
SWAMI VIVEKANANDA