

Biological buffering of blood

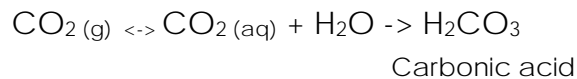
There are three major contributors to regulating the pH of blood. Bicarbonate, phosphate and proteins

Blood pH Must be Kept Close to 7.4

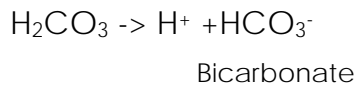
- Hydrogen ion is extremely reactive and effects many molecules which regulate physiological processes
- Blood pH is set at a slightly alkaline level of 7.4 (pH 7.0 is neutral)
- A change of pH of 0.2 units in either direction is considered serious
- Blood pHs below 6.9 or above 7.9 are usually fatal if they last for more than a short time

- The bicarbonate system is the most important and is controlled by the rate of respiration

- Carbon dioxide in water reacts to form carbonic acid



- The pKa of carbonic acid is 6.35. the pH of blood is 7.4 so the acid is greater than 1 pH away from the pKa and it is primarily dissociated



- Under physiological conditions the equilibrium for the first reaction is far to the left, and the combined pKa for the two reactions is 6.4:

- At first glance this does not look like a good buffer for blood. The buffering capacity is poor. To maintain a pH of 7.4 there would have to be a ratio of 11 to 1 of bicarbonate to carbon dioxide.

$$\text{pH} = 6.4 + \text{Log} [\text{HCO}_3^-]/[\text{CO}_2]$$

Because this is an open system, the CO₂ dissolved and the bicarbonate can rapidly change

Changes resulting in loss of carbonic acid are replaced by CO₂ dissolving - This is an open system

Normal concentration of carbon dioxide is 1.2 mM and bicarbonate is 15 mM

Acidosis and Alkalosis

A decrease in arterial carbon dioxide partial pressure causes the bicarbonate/carbon dioxide ratio to exceed 20 and the pH to rise above 7.45 - Alkalosis

Increases in partial pressure of CO₂ have the opposite affect and decrease the pH below 7.2 - Acidosis

There can be *metabolic* reasons for either condition

- Metabolic *acidosis* results from an increase in loss of bicarbonate (such as diarrhea) or overproduction of acids (ketosis, anaerobic metabolism)
- Metabolic *alkalosis* results from Conditions that lead to a reduced amount of fluid in the body, like vomiting or excessive urination due to use of diuretic drugs, or excess bicarbonate ingestion.

There can also *respiratory* reasons for either condition:

- Respiratory *acidosis* results from hypoventilation which is manifested by the accumulation of CO₂ in the blood and a drop in blood pH.
 - o Central Nervous System Depression (Sedatives, CNS disease, Obesity Hypoventilation syndrome)
 - o Lung Disease (emphysema, pneumonia)
 - o Musculoskeletal disorders (Myasthenia Gravis, Polio)
- Respiratory *alkalosis* results from hyperventilation which is manifested by excess elimination of CO₂ from the blood and a rise in the blood pH
 - o Catastrophic CNS event (CNS hemorrhage)
 - o Drugs (salicylates, progesterone)
 - o Pregnancy (especially the 3rd trimester)
 - o Decreased lung compliance (interstitial lung disease)
 - o Liver cirrhosis
 - o Anxiety

Adjusting Levels - Compensation

- In reality the kidneys regulate the bicarbonate concentration. If there is too little bicarbonate, the kidneys filter and excrete H⁺, causing a shift in the equilibrium to increase bicarbonate.
- If there is too much bicarbonate, Kidneys will excrete it.

The carbon dioxide is replaced by metabolism (Food -> H₂O and CO₂)

Changes in breathing can increase or decrease the CO₂

- Breathe too fast and what happens. Decrease the breathing rate and alter the pH as well. (think of the last time you got sick and threw up)

Titration of a buffer

The easiest way to visualize the buffer action is to draw the titration curve.

- Note where the pH resists change (within 1 pH unit of the midpoint)
- The midpoint is the pK of a dissociable group
- At the midpoint $\text{pH} = \text{pK}$ and $[\text{HA}] = [\text{A}^-]$

Summary of pH

1 pK is defined as the $-\log$ of K where K is an equilibrium constant

2 pK is the pH of the solution where the $[\text{HA}] = [\text{A}^-]$

3 pK is the pH at the midpoint of a titration curve

4 pK is the pH where half of the acid is ionized

5 pK measures the concentration of protons in the solution that suppresses ionization

6 An acidic group with a pK of 4 is 100 times weaker than one with a pK of 2

A group with a pK of 6 is 90% ionized at pH 7, 50% at pH 6, and 10% at pH 5