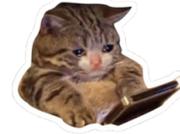


Buffer System



Acids, Bases, and pH

- Acid: Substance that can release hydrogen ions (protons H⁺).
- Base: Substance that can accept hydrogen ions.
- pH: A measure of the concentration of hydrogen ions [H⁺]; it determines the acidity of a solution.
- Formula:
$$pH = -\log_{10}[H^+]$$
- The letter “p” in pH or pKa means “-log”.

 Example: What is the pH of a solution whose [H⁺] = 3.2 × 10⁻⁴ mol/L?

$$pH = -\log(3.2 \times 10^{-4}) = -\log(3.2) - \log(10^{-4}) = -0.5 + 4 = 3.5$$

Dissociation Constants (Ka)

- When an acid loses a proton → its conjugate base is formed.
- Ka measures the strength of an acid:
$$K_a = \frac{[A^-][H^+]}{[HA]}$$
- Strong acids → dissociate completely (e.g., HCl → Cl⁻ + H⁺).
- Weak acids → partially dissociate (e.g., H₂CO₃ → HCO₃⁻ + H⁺).

pKa

- $pKa = -\log K_a$ and $K_a = 10^{-pKa}$
- pKa = pH at which 50% dissociation occurs.
- Strong acid → high Ka, low pKa.
- Weak acid → low Ka, high pKa.

 Example:

- Strong acid $K_a = 10^7 \rightarrow pKa = -7$.
- Weak acid $K_a = 10^{-12} \rightarrow pKa = 12$.

Buffers

- Definition: A buffer is a solution that resists pH changes when acids or bases are added.
- Made of a weak acid (HA) and its conjugate base (A⁻).
- Mechanism:
- Added acid (H⁺) → neutralized by A⁻.
- Added base (OH⁻) → neutralized by HA.
- Effectiveness depends on:
 1. pKa relative to solution pH.
 2. Buffer concentration.

▶ Henderson–Hasselbalch Equation

- Buffer is most effective when $pH = pKa \rightarrow [acid] = [base]$.
- At $pH = pKa \pm 1 \rightarrow$ buffer capacity falls to 33%.

$$pH = pKa + \log_{10} \frac{[A^-]}{[HA]}$$

🫁 Organs Controlling pH

1. Lungs \rightarrow regulate blood pH via bicarbonate system; exhaling $CO_2 \uparrow$ pH.
2. Kidneys \rightarrow maintain pH by:
 - Reabsorbing bicarbonate.
 - Excreting acids.

🔥 Acids in the Body

- Volatile acid: Carbonic acid (H_2CO_3) from $CO_2 \rightarrow$ eliminated via lungs.
- Nonvolatile acids: All others (e.g., lactic acid, phosphoric acid, sulfuric acid, ketone bodies) \rightarrow eliminated via kidneys.

🔴 Transport of CO_2

CO_2 is transported in 3 forms:

1. 10% \rightarrow dissolved in plasma.
2. 20% \rightarrow bound to Hb as carbaminohemoglobin.



(H^+ binds Hb \rightarrow stabilizes deoxy-Hb and promotes O_2 release).

3. 70% \rightarrow as bicarbonate:
 - $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ (enzyme: carbonic anhydrase).
 - H^+ binds Hb.
 - HCO_3^- leaves RBC in exchange for $Cl^- \rightarrow$ chloride shift.

🧩 Bicarbonate Buffer System

- Maintains blood pH 7.35–7.45.
 - Equation: $pH = 6.1 + \log \frac{[HCO]}{[HCO]}$
 - Normal values: $[HCO_3^-] = 24$ mmol/L, $[CO_2] = 1.2$ mmol/L.
- $$pH = 6.1 + \log(20) = 7.4$$

📌 Changes:

- $\uparrow CO_2$ (e.g., hypoventilation) \rightarrow pH drops to ~ 7.1 (acidosis).
- $\uparrow HCO_3^-$ (e.g., renal compensation) \rightarrow pH rises to ~ 7.7 (alkalosis).

Protein Buffers (Hemoglobin)

- Hb = 574 amino acids, ~36 are histidines.
- Histidine imidazole groups (pKa ~5.5–8.5) act as buffers.
- H⁺ binds His-146 (β) → stabilizes T-state Hb → promotes O₂ release.
- Explains why venous pH (7.35) is only slightly lower than arterial pH (7.45).

Phosphate Buffer (Intracellular)

- $\text{H}_3\text{PO}_4 \rightleftharpoons \text{H}_2\text{PO}_4^- + \text{H}^+ \rightleftharpoons \text{HPO}_4^{2-} + \text{H}^+$
- pKa ≈ 7.2 → close to physiological pH.
- Important in RBCs and intracellular fluid.
- Organic phosphates (ATP, glucose-6-phosphate) also act as buffers.

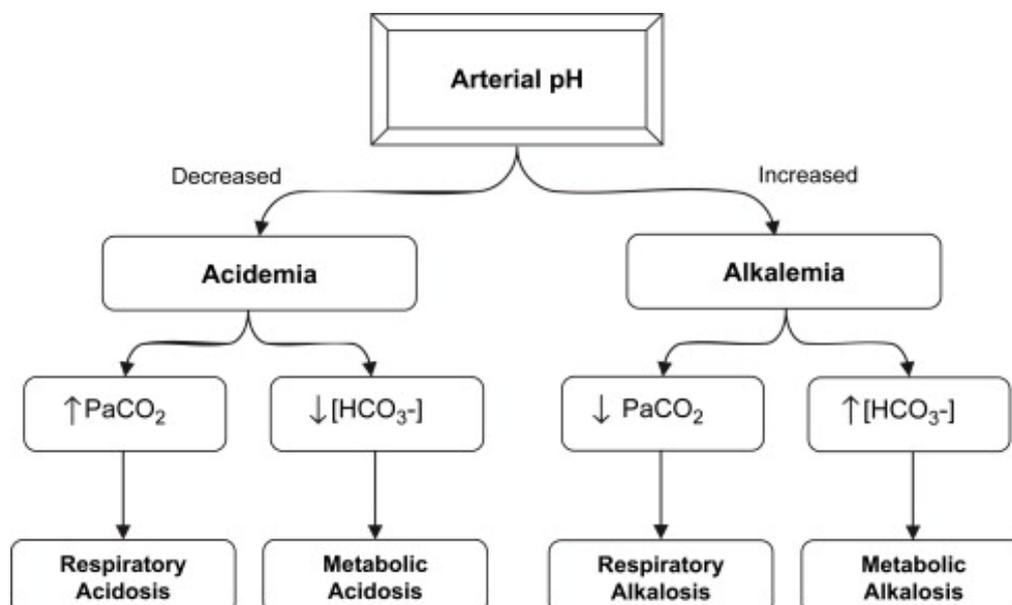
Acid-Base Disorders

1. Respiratory Acidosis

- Cause: Hypoventilation → CO₂ retention → ↓ pH.
- Examples:
 - Airway diseases (asthma, COPD).
 - Chest diseases (sarcoidosis).
 - CNS depression (drugs).
 - Neuromuscular diseases.
 - Severe obesity restricting lung expansion.

2. Respiratory Alkalosis

- Cause: Hyperventilation → excessive CO₂ loss → ↑ pH.
- Examples:
 - Hysteria, CNS disorders.
 - Drug overdose (e.g., salicylates).
 - Fever.
 - Sometimes causes fainting → slows breathing as protective reflex.





- ✓ **pH = $-\log[H^+]$, determines acidity.**
- ✓ **Ka measures acid strength; pKa = $-\log Ka$. Strong acid → high Ka, low pKa.**
- ✓ **Buffers (weak acid + conjugate base) stabilize pH, most effective when pH = pKa.**
- ✓ **Main body buffers: Bicarbonate (blood), Hemoglobin (protein), Phosphate (intracellular).**
- ✓ **Organs:**
 - Lungs remove CO_2 rapidly (minutes).
 - Kidneys adjust HCO_3^- and acids slowly (hours–days).
- ✓ **CO_2 transport: dissolved (10%), carbamino-Hb (20%), bicarbonate (70%).**
- ✓ **Disorders:**
 - Respiratory acidosis (hypoventilation).
 - Respiratory alkalosis (hyperventilation).

جدول 1: Acidosis vs Alkalosis 🇮🇷

Alkalosis	Acidosis	Feature
Blood pH > 7.45	Blood pH < 7.35	Definition
> 7.8	< 7.0	Life-threatening level
Hyperventilation → CO_2 loss	Hypoventilation → CO_2 retention	Respiratory cause
Excess HCO_3^- (e.g., vomiting, diuretics)	Excess acids (e.g., lactic acidosis, ketoacidosis) or ↓ HCO_3^-	Metabolic cause
Hysteria, fever, salicylate overdose, CNS disorders	Asthma, COPD, obesity hypoventilation, CNS depression	Examples

جدول 2: Buffers in the Body 🇮🇷

Function	pKa	Components	Location	Buffer System
Main blood buffer (works with lungs + kidneys)	6.1	H_2CO_3 / HCO_3^-	Extracellular (blood plasma)	Bicarbonate Buffer
Binds H^+ , promotes O_2 release in tissues	5.5–8.5 (varies)	Histidine residues in Hb	Blood (RBCs)	Protein Buffer (Hemoglobin)
Maintains intracellular pH	7.2	$H_2PO_4^- / HPO_4^{2-}$	Intracellular & RBCs	Phosphate Buffer
Support intracellular buffering	~7.0	ATP, glucose-6-phosphate	Cells	Organic Phosphates

Ka vs pKa :3 جدول

Weak Acid	Strong Acid	Property
Low (e.g., 10^{-12})	High (e.g., 10^7)	Ka
High (positive, larger number)	Low (negative or small number)	pKa
Partial	Complete	Dissociation
Produces moderately low pH	Produces very low pH	pH effect

Transport of CO₂ in Blood :4 جدول

Mechanism	% of CO ₂	Transport Form
Simple diffusion	~10%	Dissolved in plasma
$\text{CO}_2 + \text{HbNH}_2 \rightleftharpoons \text{HbNHCOO}^- + \text{H}^+$	~20%	Carbaminohemoglobin
$\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}^+$ (carbonic anhydrase, chloride shift)	~70%	Bicarbonate (HCO_3^-)



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