The Body and pH

- Homeostasis of pH is tightly controlled
- Extracellular fluid = 7.4
- Blood = 7.35 – 7.45
- < 6.8 or > 8.0 death
- Acidemia = below 7.35
- Alkalemia = above 7.45
Small changes in pH can lead to major disturbances

- Most enzymes function only with narrow pH ranges
- Acid-base balance can also affect electrolytes ($\text{Na}^+\text{, K}^+, \text{Ca}^{2+}\text{, Cl}^-$)
- Can also affect hormones, receptors, functional proteins
The body produces more acids than bases

- Acids are taken in with foods
- Acids are produced by metabolism of lipids and proteins
- Cellular metabolism produces $CO_2$.

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

**Control of Acids**

1. **Buffer systems**
   
   Take up $H^+$ or release $H^+$ as conditions change
   
   Buffer pairs – weak acid and a base
   
   Exchange a strong acid or base for a weak one
   
   Results in a much smaller pH change

2. **Respiratory system**

3. **Kidney excretion**
Bicarbonate buffer

- Sodium Bicarbonate (NaHCO$_3$) and carbonic acid (H$_2$CO$_3$)
- Maintain a 20:1 ratio: HCO$_3^-$ : H$_2$CO$_3$

\[
\text{HCl} + \text{NaHCO}_3 \leftrightarrow \text{H}_2\text{CO}_3 + \text{NaCl}
\]

\[
\text{NaOH} + \text{H}_2\text{CO}_3 \leftrightarrow \text{NaHCO}_3 + \text{H}_2\text{O}
\]

Phosphate buffer

- Major intracellular buffer
- Buffer in kidneys

\[
\text{H}^+ + \text{HPO}_4^{2-} \leftrightarrow \text{H}_2\text{PO}_4^{-}
\]

\[
\text{OH}^- + \text{H}_2\text{PO}_4^- \leftrightarrow \text{H}_2\text{O} + \text{HPO}_4^{2-}
\]

Protein Buffers

- Includes hemoglobin, work in blood and ISF
- Carboxyl group gives up H$^+$
- Amino Group accepts H$^+$
2. Respiratory mechanisms

- Exhalation of carbon dioxide
- Powerful, but only works with volatile acids
- Doesn’t affect fixed acids like lactic acid
- $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
- Body pH can be adjusted by changing rate and depth of breathing

3. Kidney excretion

- Can eliminate large amounts of acid
- Can also excrete base
- Can conserve and produce bicarbonate ions
- Most effective regulator of pH
- If kidneys fail, pH balance fails
ACID-BASE BALANCE - PHYSIOLOGIC STATE

\[ \text{pH} = \text{pK} + \log \frac{[\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]} \]

Tissue

- \( \text{R-COOH} \)
- \( \text{Na}^+ \), \( \text{HCO}_3^- \)
- \( \text{H}_2\text{O} \)

Lungs

- \( \text{CO}_2 \)
- \( \text{CA} \)

Blood

- \( \text{Na}^+ \), \( \text{HCO}_3^- \)
- \( \text{H}_2\text{CO}_3 \)
- \( \text{CO}_2 \)
- \( \text{H}_2\text{O} \)

Kidney

- \( \text{Na}^+ \), \( \text{R-COOH} \)
- \( \text{HCO}_3^- \)
- \( \text{CO}_2 \)
- \( \text{H}_2\text{O} \)

Urine
Rates of correction

- Buffers function almost instantaneously
- Respiratory mechanisms take several minutes to hours
- Renal mechanisms may take several hours to days
Acid-Base balance disorders

- pH < 7.35 acidosis
- pH > 7.45 alkalosis
- The body response to acid-base imbalance is called **compensation**
- May be **complete** if brought back within normal limits
- **Partial compensation** if range is still outside norms.
Acidosis

- Principal effect of acidosis is depression of the CNS through ↓ in synaptic transmission.
- Generalized weakness
- Deranged CNS function the greatest threat
- Severe acidosis causes
  - Disorientation
  - coma
  - death

Alkalosis

- Alkalosis causes over excitability of the central and peripheral nervous systems.
- It can cause:
  - Nervousness
  - muscle spasms or tetany
  - Convulsions
  - Loss of consciousness
  - Death
Compensation

- If underlying problem is metabolic, hyperventilation or hypoventilation can help: respiratory compensation.
- If problem is respiratory, renal mechanisms can help: metabolic compensation.
Respiratory Acidosis

- **Carbonic acid excess** caused by blood levels of $CO_2$ above 45 mm Hg.
- **Hypercapnia** - high levels of $CO_2$ in blood
- Chronic conditions:
  - Depression of respiratory center in brain that controls breathing rate - drugs or head trauma
  - Paralysis of respiratory or chest muscles
  - Emphysema

- **Acute conditions:**
  - Adult Respiratory Distress Syndrome
  - Pulmonary edema
  - Pneumothorax

Compensation for Respiratory Acidosis

- Kidneys eliminate hydrogen ion and retain bicarbonate ion
RESPIRATORY ACIDOSIS

\[ \text{pH} = pK - \log \frac{[\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]} \]

compensation: 
- \( \uparrow \text{HCO}_3^- \)
- \( \uparrow \text{H}^+ \) secretion

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TISSUE

\( \text{R-COOH} \)

\( \text{H}_2\text{O} \)

\( \text{CO}_2 \)

hyperventilation

LUNGS

\( \text{H}_2\text{O} \)

\( \text{CO}_2 \)

\( \text{CA} \)

BLOOD

\( \text{Na}^+ \text{HCO}_3^- \)

\( \text{H}_2\text{O} \)

\( \text{Na}^+ \text{HCO}_3^- \)

\( \text{H}_2\text{CO}_3 \)

\( \text{Na}^+ \text{HCO}_3^- \)

KIDNEY

\( \text{Na}^+ \text{HCO}_3^- \)

\( \text{H}_2\text{O} \)

\( \text{CO}_2 \)

\( \text{CA} \)

\( \text{H}_2\text{CO}_3 \)

URINE

\( \text{Na}^+ \text{HCO}_3^- \)

\( \text{H}_2\text{CO}_3 \)
Respiratory Alkalosis

- Carbonic acid deficit
- \( pCO_2 \) less than 35 mm Hg (hypocapnea)
- Most common acid-base imbalance
- Primary cause is hyperventilation

- Conditions that stimulate respiratory center:
  - Oxygen deficiency at high altitudes
  - Pulmonary disease and Congestive heart failure - caused by hypoxia
  - Acute anxiety
  - Fever, anemia
  - Early salicylate intoxication
  - Cirrhosis
  - Gram-negative sepsis

Compensation of Respiratory Alkalosis

- Kidneys conserve hydrogen ion
- Excrete bicarbonate ion
RESPIRATORY ALKALOSIS

\[ \text{pH} = \text{pK} + \log \frac{[\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]} \]

compensation \[\downarrow \text{HCO}_3^-\]

excretion by kidney

\[ \text{CO}_2 \rightleftharpoons \text{CO}_2 \]

\[ \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{O} \]
Metabolic Acidosis

- **Bicarbonate deficit** - blood concentrations of bicarbonate below 22mmol/L
- **Causes:**
  - Loss of bicarbonate through diarrhea or renal dysfunction
  - Accumulation of acids (lactic acid or ketones)
  - Failure of kidneys to excrete H+

Compensation for Metabolic Acidosis

- Increased ventilation
- Renal excretion of hydrogen ions if possible
- $K^+$ exchanges with excess $H^+$ in ECF
- ($H^+$ into cells, $K^+$ out of cells)
METABOLIC ACIDOSIS

\[ pH = pK + \log \frac{[HCO_3^-]}{[H_2CO_3]} \]

Compensation: ↓ HCO_3^- (hyperventilation)

↑ HCO_3^- (kidney)
a) Metabolic balance before onset of acidosis

\[ \text{H}_2\text{CO}_3 : \text{Carbonic acid} \]
\[ \text{HCO}_3^- : \text{Bicarbonate ion} \]
\[ (\text{Na}^+ \cdot \text{HCO}_3^-) \]
\[ (\text{K}^+ \cdot \text{HCO}_3^-) \]
\[ (\text{Mg}^{++} \cdot \text{HCO}_3^-) \]
\[ (\text{Ca}^{++} \cdot \text{HCO}_3^-) \]

b) Metabolic acidosis

\[ \text{HCO}_3^- \text{ decreases because of excess presence of ketones, chloride, or organic acid ions} \]

Primary change

- pH — decreases
- \( \text{PCO}_2 \) — no change
- \( \text{HCO}_3^- \) — decreases

Primary compensation

\[ \text{HCO}_3^- + \text{H}^+ \rightarrow \text{H}_2\text{CO}_3 \]

0.75 : 10

Body’s correction

- Acidic urine
- Kidneys conserve \( \text{HCO}_3^- \) and eliminate \( \text{H}^+ \) ions in acidic urine

Hyperactive breathing to “blow off” \( \text{CO}_2 \)

d) Therapy required to restore metabolic balance

Lactate

Lactate-containing solution

Lactate solution used in therapy is converted to bicarbonate ions in the liver