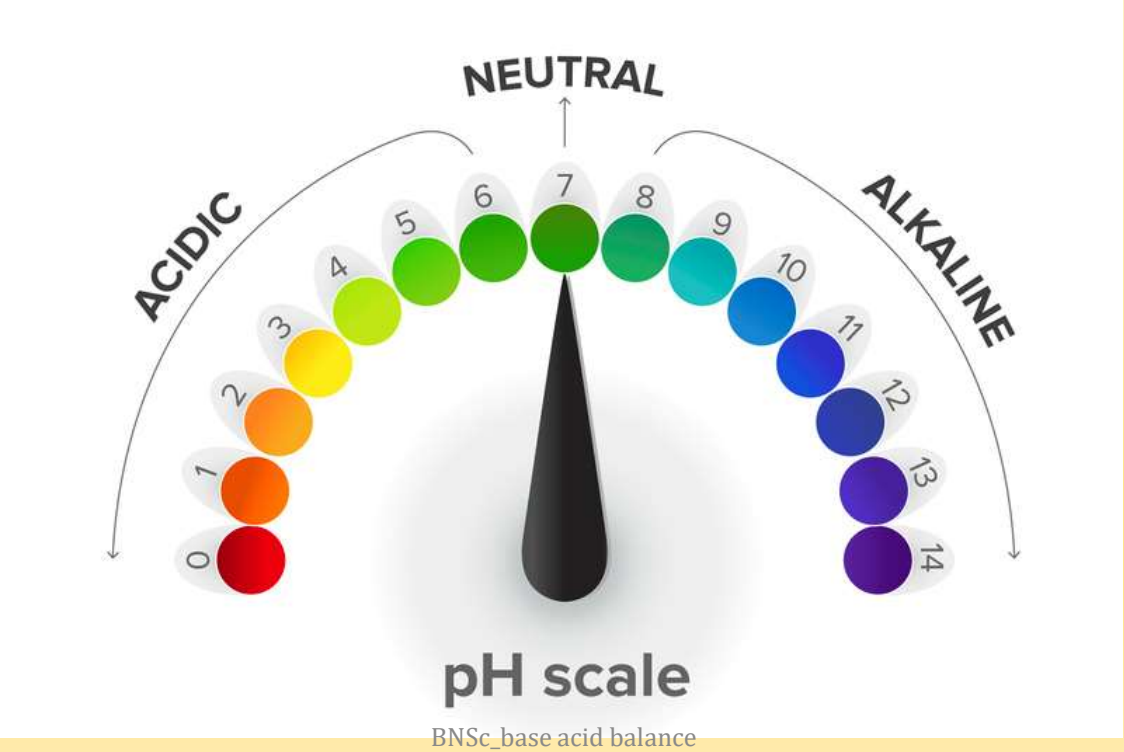
Diyah Candra Anita

ACID BASE BALANCE



Introduction

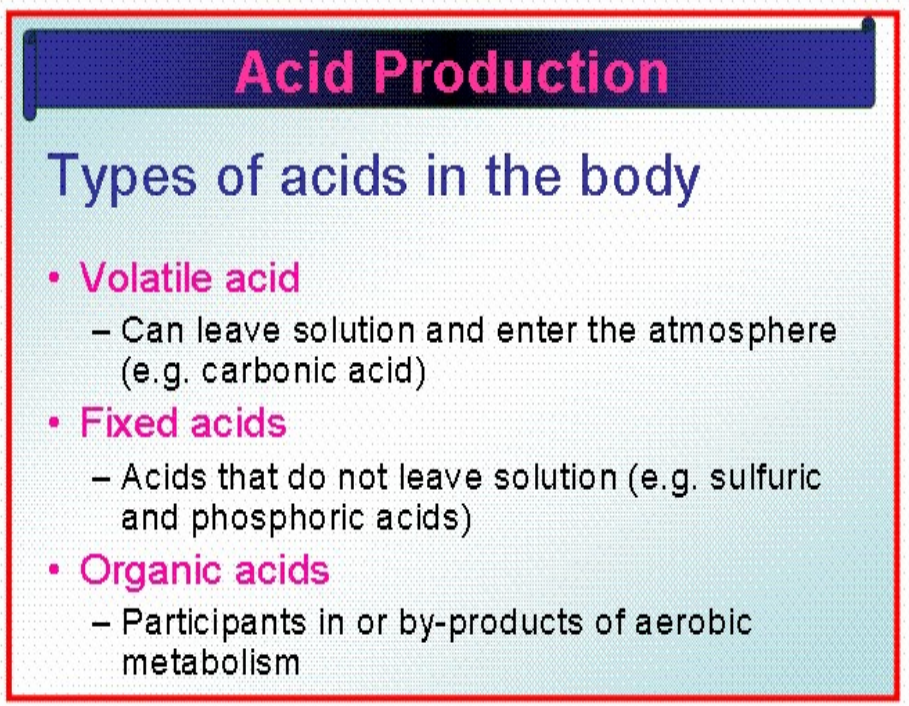
- Acid Base Balance is a **physiological and biochemical mechanism** associated to **body/blood pH**.
  - pH is a Hydrogen ion concentration.
  - pH = - log [H^+]
  - Different compartment of human body has specific pH.
  - pH has role in Enzyme activity.

Why blood pH is Altered?

- **Addition** of various **acids or alkalies** by metabolic activities **alters body/blood pH.**

Sources and Types of Acids and Alkalies Added During Metabolic Life Processes

- Acids are H^+ donors.
- Bases are H^+ acceptors, or give up OH^- in solution
- **Acids and Bases can be strong or weak:**
  - **A strong acid or base** is one that dissociates **completely** in a solution
    - HCl, NaOH, and H_2SO_4
  - **A weak acid or base** is one that **dissociates partially i**n a solution
    - H_2CO_3, $C_3H_6O_3$, and CH_2O, Lactate.



Acid

- **Acidic Substances of body:**
  - Carbonic acid(H_2CO_3)
  - Phosphoric acid(H_3PO_4)
  - Sulphuric acid (H_2SO_4)
- **Organic Acids:**
  - Lactate, Acetoactate, Pyruvate
- **Alkaline Substances of body:**
  - Citrate
  - Bicarbonates.

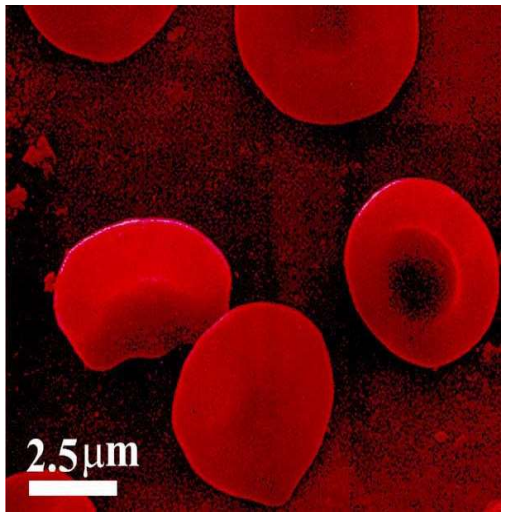
What is Acid Base Balance?

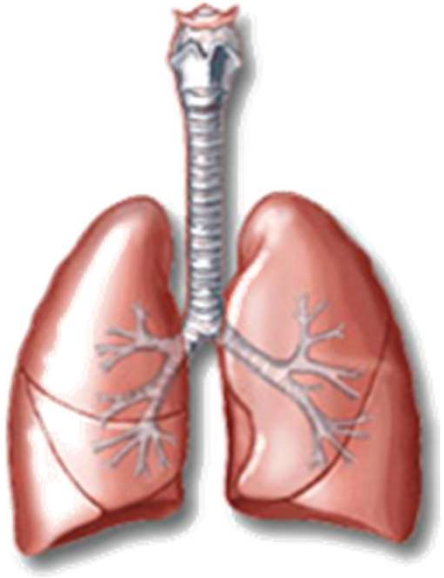
- **Homeostatic Mechanisms That Regulate Blood/Body pH**
- Acid Base balance is a **homeostatic mechanism** → Carried out to **regulate the altered pH of blood** and other body compartments **to its normal constant range.**
- **Maintenance of Acid Base balance** → Is a prime requisite to maintain normal healthy and active life.
- Acid-Base Balance
  - It is the regulation of **HYDROGEN** ions.
  - *The more Hydrogen ions, the more acidic the solution and the LOWER the pH*
  - The acidity or alkalinity of a solution is measured as **pH**

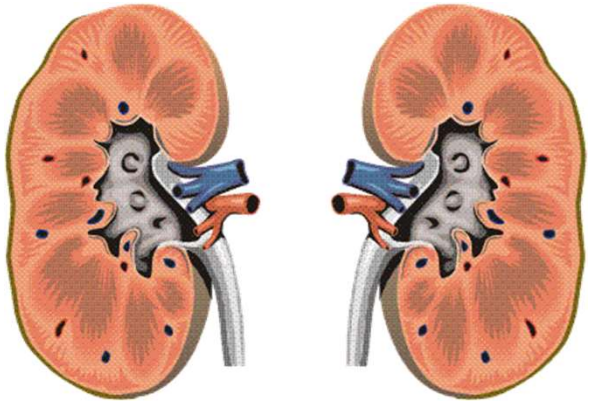
Acid Base Balance Regulates pH

- pH of blood and other body compartments are precisely regulated.
- pH is always tried to be maintained to its normal constant range.
- Acid Base Balance maintains the blood pH at normal constant narrow range of 7.35-7.45.
- pH of the medium directly affects the enzyme activities
  - Optimum pH is an essential requisite for enzyme activities and normal metabolism
- It is prerequisite for regulating blood/body pH:
  - To maintain normal/optimal Enzyme activities
  - Normal metabolism
  - Normal Coordination
  - Normal Health

Factors Regulating Acid Base Balance







- **First Line of Defense:** Blood Buffer System
- **Second Line of Defense:** Respiratory Mechanism
- **Third Line of Defense:** Renal Mechanism

- **Chemical Buffers :** React very rapidly (less than a second)
- **Respiratory Regulation :** Reacts rapidly (seconds to minutes)
- **Renal Regulation :** Reacts slowly (minutes to hours)

Role of Blood Buffer System

- First line of defense in mechanism of Acid Base Balance.
- **Acids (H^+) added are neutralized by** the **salt part of buffer.**

Extracellular Buffers:

- **Bicarbonate Buffer**
  - $NaHCO_3/H_2CO_3$ (20:1 at 7.4 pH)
- **Phosphate Buffer**
  - Na_2HPO_4/NaH_2PO_4 (4:1 at 7.4 pH)
- **Protein Buffer**
  - Na-Protein/H-Protein

Intracellular Buffers:

- **Bicarbonate Buffer**
  - $KHCO_3/H_2CO_3$
- **Phosphate Buffer**
  - K_2HPO_4/KH_2PO_4
- **Protein Buffer**
  - K-Hb/H-Protein

Mechanism Action of Buffer Systems

- **Buffers mixture of weak acids and its salts**
- **Resist change in pH of blood** when small amount of acids or alkalis added to the medium.
- **Buffers act quickly but not permanently**

Bicarbonate Buffer System
Respiratory Buffer System

- Acid - Base balance is primarily concerned with Bicarbonate Buffer mechanism :
  - **H2CO3/** Hydrogen **(H^+)**
  - Bicarbonate **(HCO_3^-) (Alkali Reserve)**

H^+

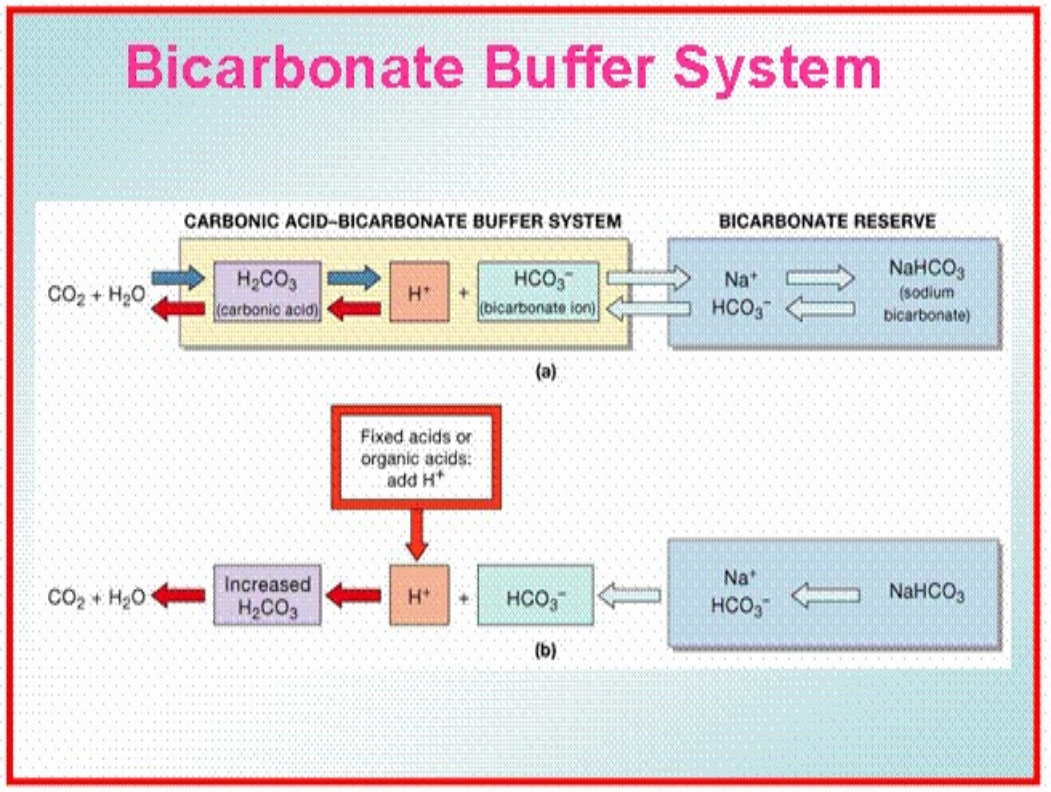
HCO_3^-

Bicarbonate Buffer: Chief Buffer system of Blood

- **NaHCO3** the salt part of buffer neutralizes the strong and non volatile acids added to blood.
- It constitutes **Alkali reserve($HCO3^-$)**
- Sodium Bicarbonate ($NaHCO_3$) and carbonic acid (H_2CO_3) → Maintain a **20:1** ratio → HCO_3^- : H_2CO_3

  $HCl + NaHCO_3 \leftrightarrow H_2CO_3 + NaCl$

  $NaOH + H_2CO_3 \leftrightarrow NaHCO_3 + H_2O$
- Action of Bicarbonate (NaHCO3) **converts strong** dissociable acid into **weak non dissociable acid** (H2CO3) and a neutral salt **without altering the pH**



- **Weak acid H_2CO_3** formed during buffering action of **Bicarbonate buffer is then expired out by Lungs** → Thus **Bicarbonate buffer** is **connected to** the **respiratory system**
- **Bicarbonate buffer** is also **termed as Respiratory buffer.**
- **Alkali reserve** is represented by the **concentration of $NaHCO_3$** in the blood.
- **Alkali reserve concentration(HCO_3^-)** determines the **strength of buffering action** towards added H^+ ions by acids.
- **More** the concentration of **Alkali reserve, more is the buffering action** and vice a versa.
- **The blood buffers are effective as long as**
  - The **acid load added is not very high** and
  - The alkali **reserve (HCO_3^-) is not exhausted**

Phosphate Buffer/Urine Buffer

- When H+ ions added they are neutralized/fixed by Na2HPO4 (Alkaline Phosphate) and converted to **NaH2PO4 (Acid Phosphates).**
- **These acid phosphates then excreted out through kidneys** as **acidic urine**. → Thus Phosphate Buffer is connected to Excretory system .
- Phosphate Buffer also termed as Urine Buffer.
- When an alkali enters it is buffered by the acid phosphate NaH2PO4 which converted to **Na2HPO4 alkaline phosphate.** → Excreted in urine making it **alkaline urine.**

Role of Respiratory Mechanisms

- Respiratory system plays **second line of defense mechanism** of Acid Base Balance.
- Role of respiration in acid base balance is **short term regulatory process.**
  - **H2CO3 formed from Bicarbonate Buffer, is exhaled out through respiratory system.**
  - **Increased H2CO3 stimulates** the **respiratory center** in Medulla Oblongata.
  - This in turn **stimulates hyperventilation** which promptly removes H2CO3 from blood by expiration.
  - Exhalation of H2CO3 is as carbon dioxide by activity of enzyme Carbonic Anhydrase of Lungs.
  - $\mathbf{H^+ + HCO_3^- \leftrightarrow H_2CO_3 \leftrightarrow CO_2 + H_20}$

- Respiratory mechanism is powerful, but only works with **volatile acids;** Doesn't affect **fixed acids** like lactic acid.
- **Blood pH can be adjusted through respiratory mechanism → By changing rate and depth of breathing.**
- **Low H_2CO_3 concentration** in blood **depresses respiratory center**, causes **hypoventilation** i.e. slow and shallow respiration. → This **retains H_2CO_3** in blood.
- If Nervous center / Respiratory system fails → Acid Base Balance fails.

Role of Renal Mechanism

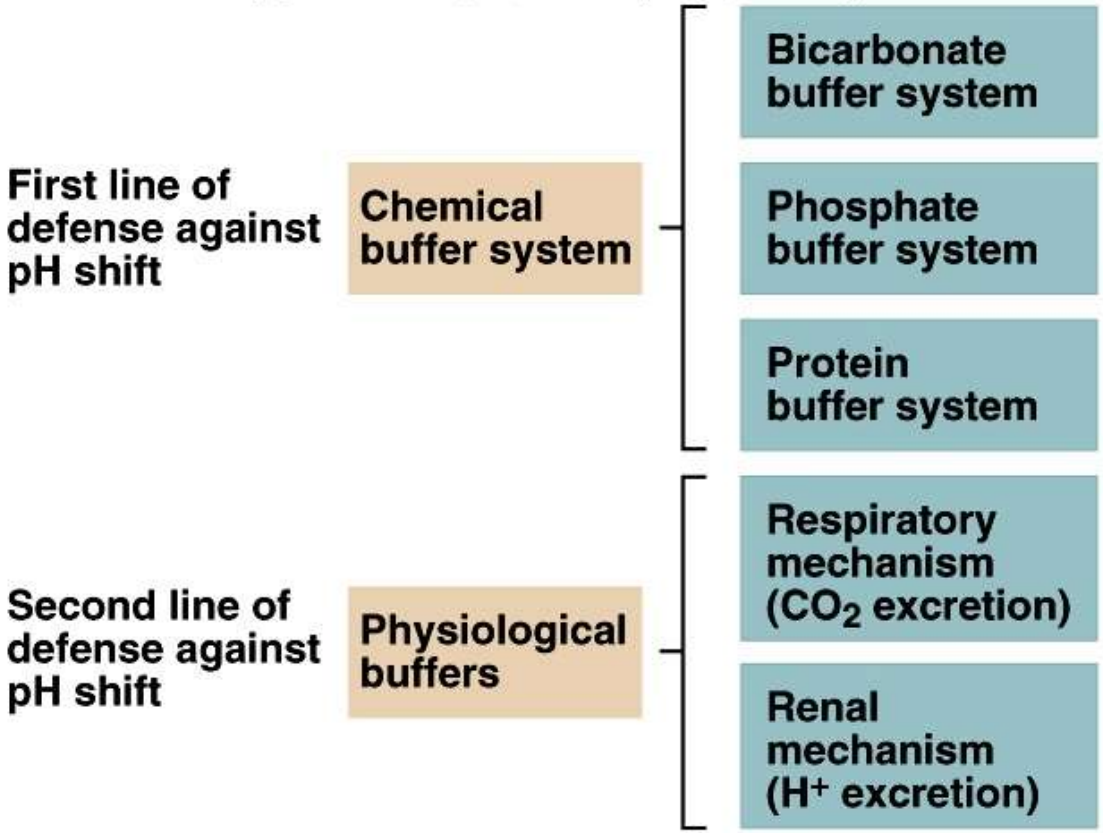
- **Renal mechanism** is the **third line of defense mechanism**.
- Role of renal mechanism is **long term regulatory process.**
- The **acid and alkaline phosphates** formed during **phosphate buffering** mechanism are filtered from blood and **excreted out through urine.** → Thus the **phosphate buffer system is directly connected to renal mechanism.**
- Renal mechanism conserve and produce Bicarbonate ions (Alkali reserve).
- Renal Mechanism is the **most effective regulator** of blood pH.
- **If kidneys fail, pH balance fails.**

Renal System maintains Acid Base Balance through:

- Reabsorption of Bicarbonate ($HCO3^-$) ions.
- Excretion of H^+ ions
- Excretion of titrable acids(Acid Phosphates)
- Excretion of Ammonium ions (Glutaminase activity)

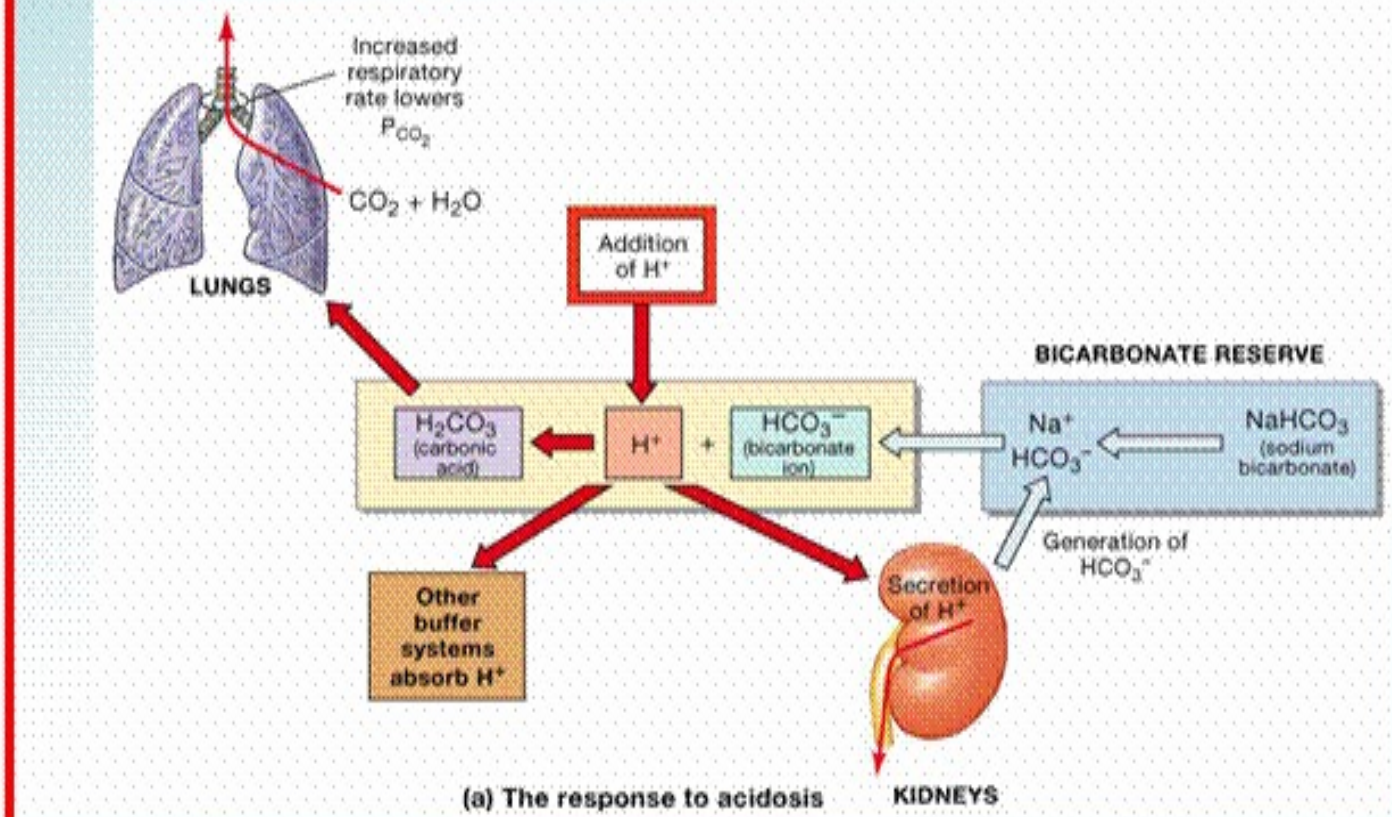
Rates of correction

- Buffers function almost instantaneously
- Respiratory mechanisms take several minutes to hours
- Renal mechanisms may take several hours to days



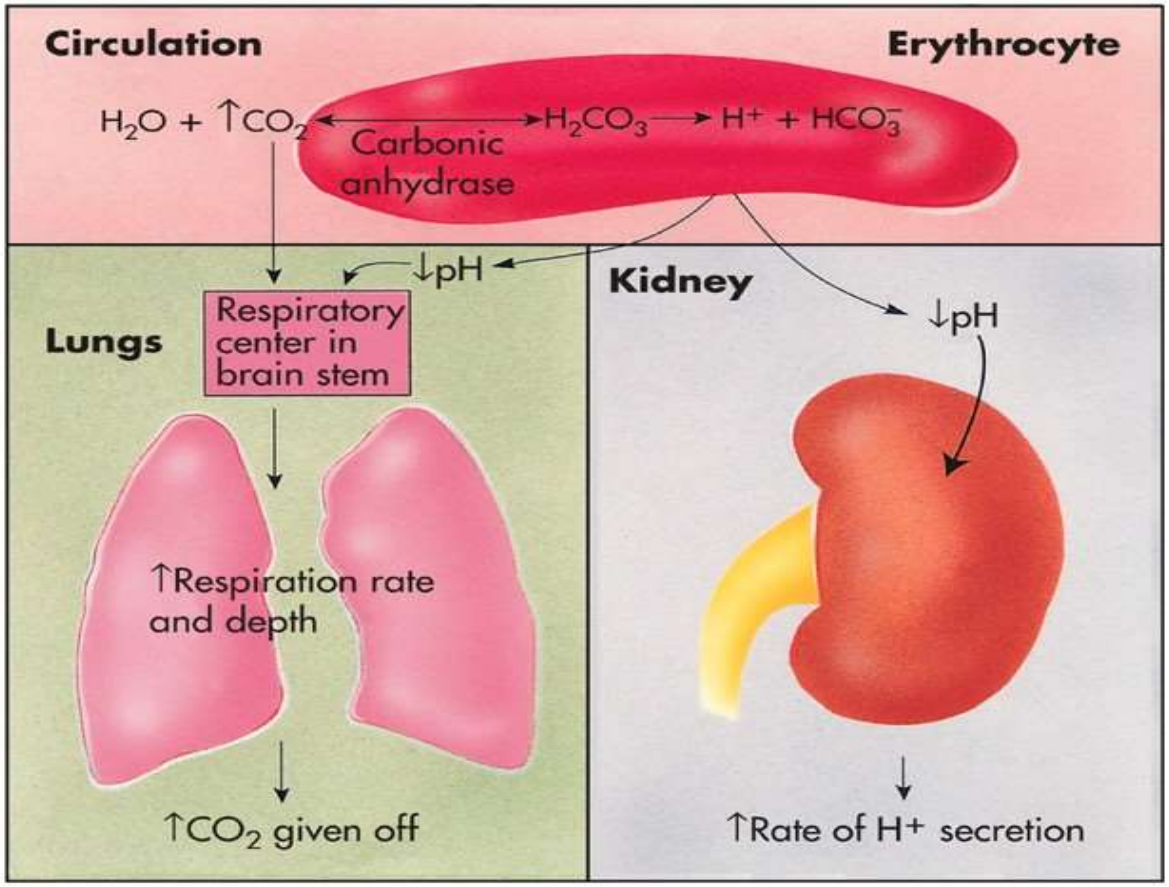
Respiratory & Renal Regulation of pH

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



MECHANISM FOR REGULATION OF ACID BASE BALANCE

- **Buffer system: temporary solution**
- **Respiratory mechanism provide short time regulation**
- **Renal mechanism : permanent solution**
- **Urine pH < plasma pH ,4.5-9.5**
- **Eliminate nonvolatile acid, buffered by cation (principally Na^+)**
- **Maintain alkali reserve**



From Thibodeau GA, Patton KT: *Anatomy & physiology*, ed 5, St Louis, 2003, Mosby.

Acid Base Imbalance
OR Conditions Of Acid Base Disturbances

- Homeostasis of blood pH is **tightly controlled by mechanisms of Acid Base Balance.**
- Extracellular fluid = 7.4
- Blood pH regulated to = 7.35 – 7.45

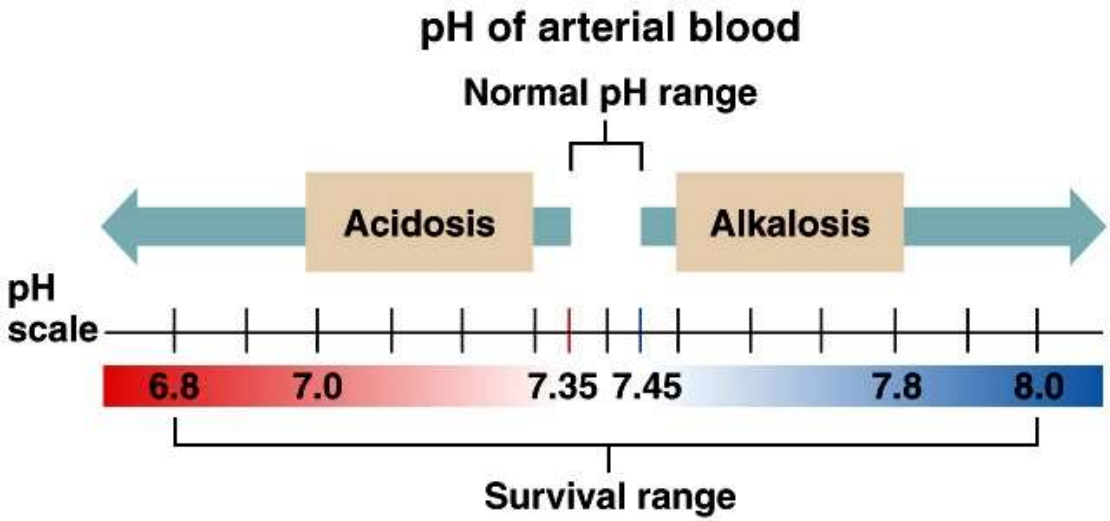
Occurrence of Acid Base Imbalance

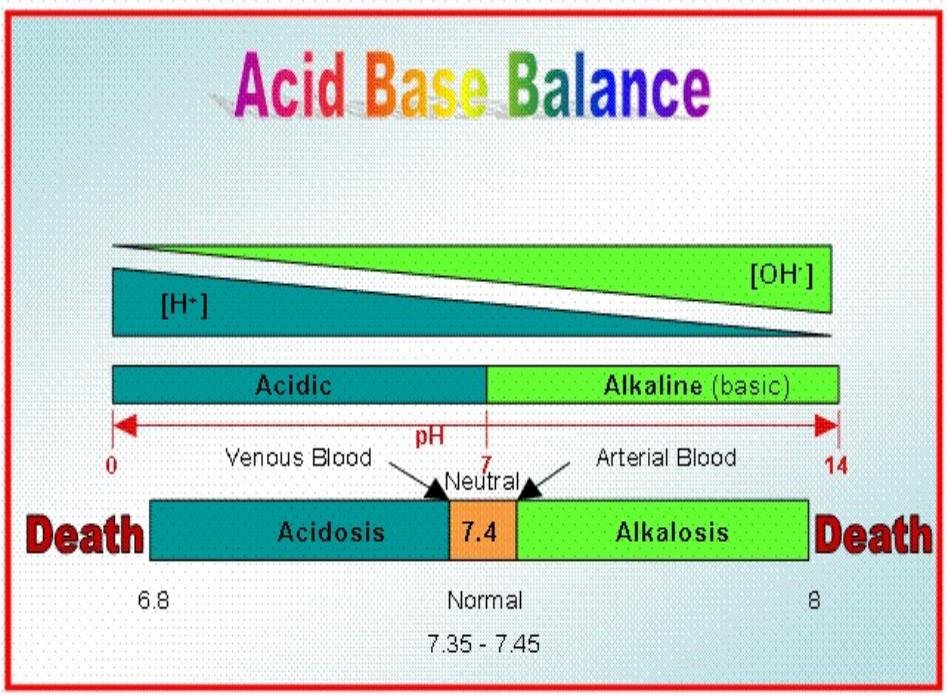
- When Factors involved in homeostatic mechanisms to regulate Acid Base Balance fails to work efficiently.
- Does not maintain the altered pH of blood to normal constant range.
- Results into Acid Base Imbalance.

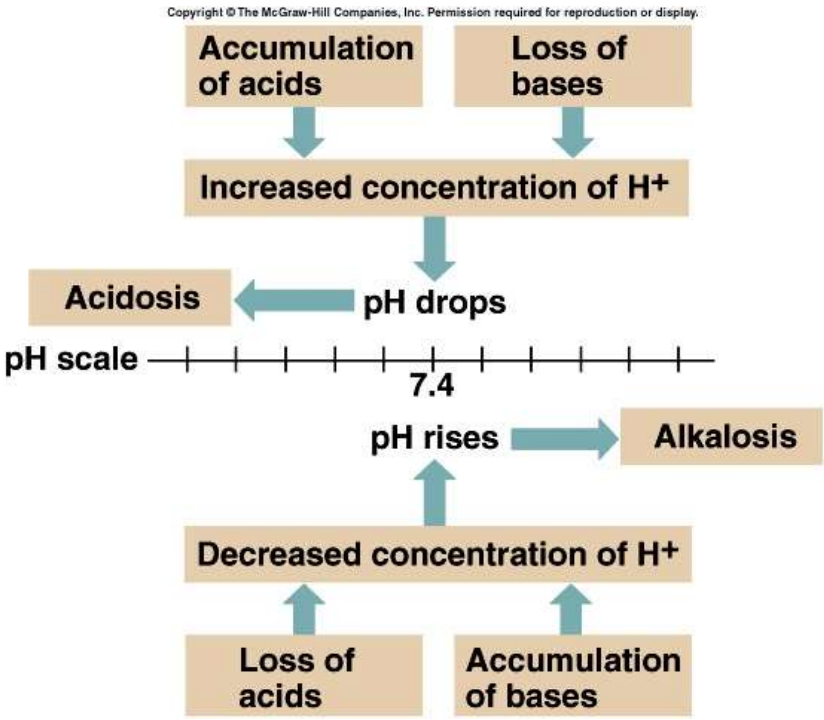
ACIDOSIS / ALKALOSIS

- Two major disturbances in **Acid-Base** balance
  - **Acidosis : Decreased pH/Increased H^+ ions**
  - **Alkalosis : Increased pH/Decreased H^+ ions**

- Acidosis (Acidemia) below 7.35
- Alkalosis (Alkalemia) above 7.45
- Blood pH < 6.8 or > 8.0 death occurs




Acid Base Balance
[OH-]
[H+]
Acidic
Alkaline (basic)
pH
0
Venous Blood
7
Arterial Blood
14
Neutral
Death
Acidosis
7.4
Alkalosis
Death
6.8
Normal
8
7.35 - 7.45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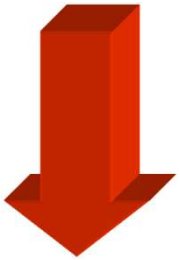
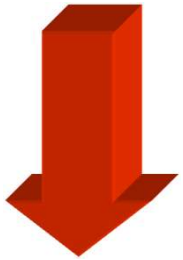
Accumulation of acids
Loss of bases
Increased concentration of H+
Acidosis
pH drops
pH scale
7.4
pH rises
Alkalosis
Decreased concentration of H+
Loss of acids
Accumulation of bases

Effect of Altered pH

- Altered pH may seriously disturbs the vital processes. → Might lead to fatality.
- Most enzymes function only with narrow pH ranges.
  - Extremes of **pH affects the enzymatic action** by **protonation or deprotonation** at the **active sites of Enzymes**. → Makes **Enzymes inactive**.
- **Inactivated Enzymes** affect metabolic reactions and metabolic pathways.
  - **Metabolism gets deranged** .
  - Leads to **metabolic syndromes.**

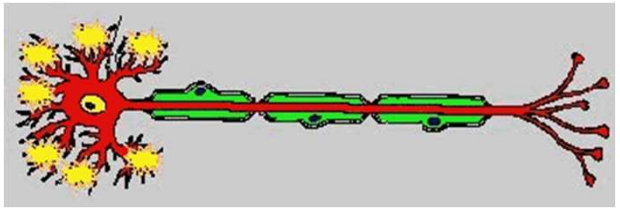
pH also affect excitability of Nerve and Muscle cells


pH

Excitability

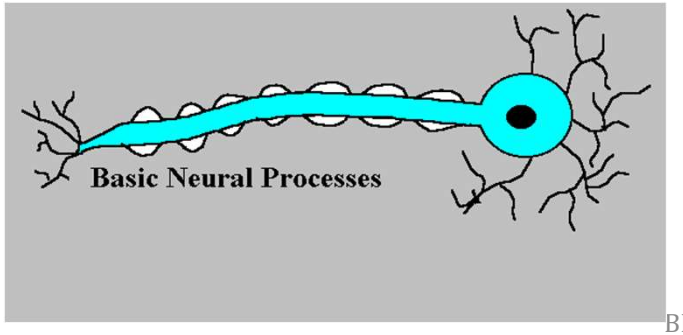

pH

Excitability

ACIDOSIS / ALKALOSIS



- pH changes have dramatic effects on normal cell function
  1. Changes in excitability of nerve and muscle cells
  2. Influences Enzyme activity
  3. Influences **K^+** levels/Retention of K^+

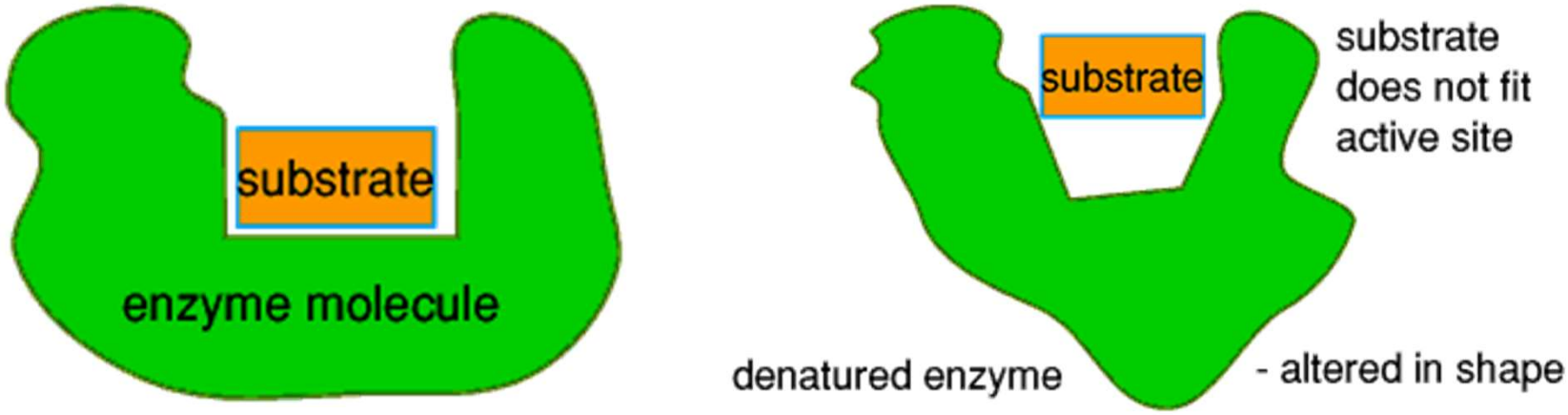


Changes In Cell Excitability

- **pH decrease** (more acidic) **depresses** the central **nervous system**
  - Can lead to loss of consciousness
- **pH increase** (more basic)causes **over excitability** of **nervous system.**
  - Tingling sensations, nervousness, muscle twitches

Influences On Enzyme Activity

- pH increases or decreases can alter the shape of the enzyme rendering it non-functional
- Changes in enzyme structure can result in accelerated or depressed metabolic actions within the cell



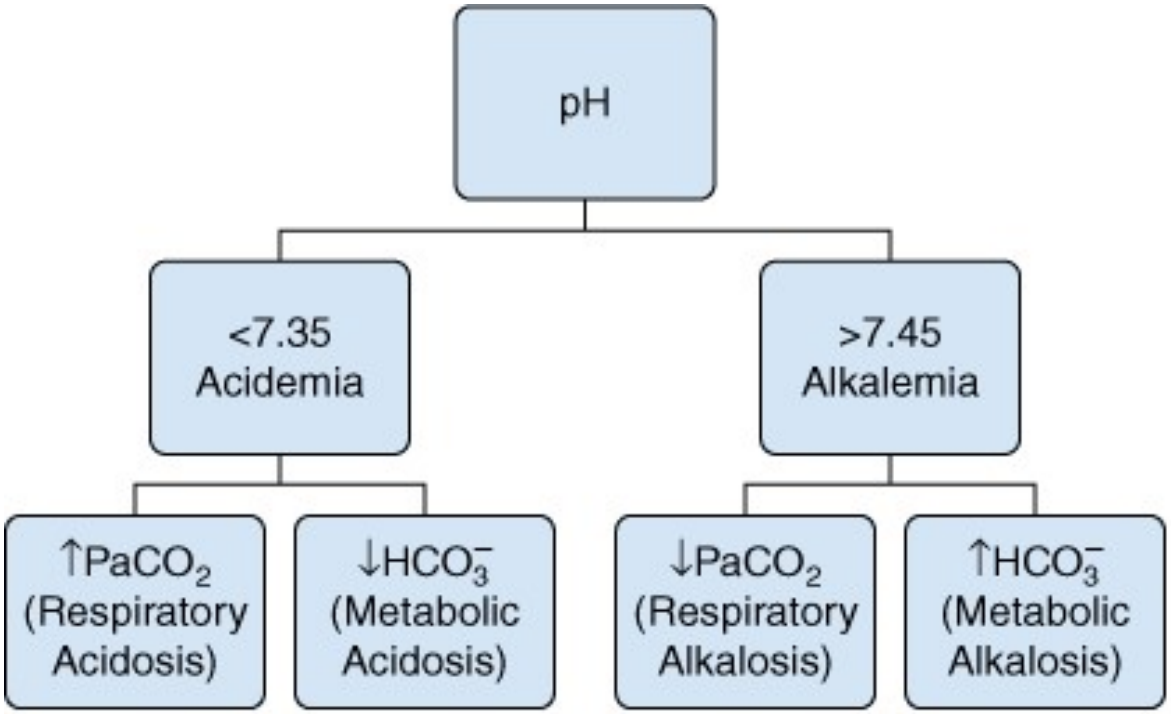
Influences On K^+ Levels

- If H^+ concentrations are high (acidosis) than H^+ is secreted in greater amounts
- This leaves less K^+ than usual excreted.
- The resultant K^+ retention can affect cardiac function and other systems

Small changes in pH can produce major disturbances

- Acid-base balance can also affect Electrolytes (Na^+, K^+, Cl^-)
- Can also affect Hormones

4 Types of Primary Acid-Base Disorders



Source: McKean S, Ross JJ, Dressler DD, Brotman DJ, Ginsberg JS: *Principles and Practice of Hospital Medicine*: www.accessmedicine.com

Acid-Base Balance Abnormalities

I. Respiratory

Acidosis

- High pCO_2, low pH
- Pneumonia, cystic fibrosis, etc
- Kidneys
  Retain bicarbonate

Alkalosis

- Low pCO_2, high pH
- Hyperventilation
- Kidneys
  Secrete bicarbonate

Kidneys compensate for the problem

Acid-Base Balance Abnormalities

II. Metabolic

Acidosis

- Low bicarbonate
- Low pH
- Too much alcohol
- Excessive loss of bicarbonate (diarrhea)
- Hyperventilation

Alkalosis

- High bicarbonate
- High pH
- Vomiting
- Excessive base intake
- Hypoventilation

Lungs compensate for metabolism

Respiratory Acidosis

- **Primary Carbonic acid excess**
- **Increased H2CO3/Increased pCO2**
- **Defect in respiratory centre** of brain
- **Defect in respiratory organ** system
- **Decreased elimination of H2CO3** by the lungs.
- **Hypoventilation**
- **Increased** blood levels of CO_2 above 45 mm Hg.
- **Hypercapnia –** high levels of pCO_2 in blood

- Respiratory acidosis develops when the lungs don't expel **CO_2** adequately.
- This can happen in diseases that severely affect the lungs.

Chronic conditions:

- Depression of respiratory center in brain that controls breathing rate – drugs or head trauma
- Paralysis of respiratory or chest muscles
- Emphysema
- Asthma
- Pneumonia
- Pulmonary edema
- Obstruction of respiratory tract
- Congestive Cardiac Failure

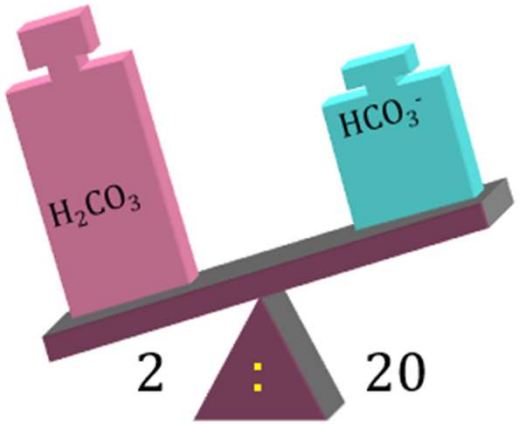
HYPOVENTILATION
Causes Respiratory Acidosis

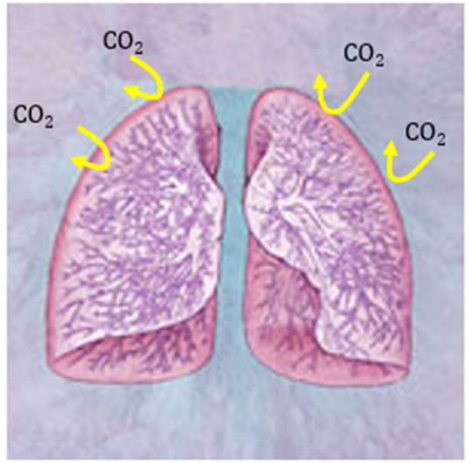
- breathing is suppressed holding CO_2 in body
- pH = 7.1

Elimination of CO_2

H^+

pH





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

Compensation for Respiratory Acidosis

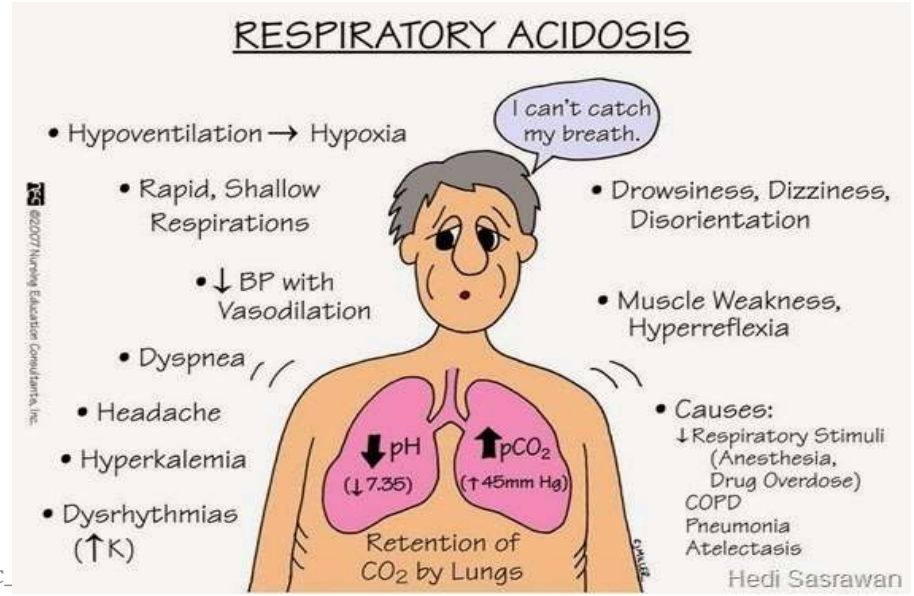
- **Kidneys eliminate hydrogen ion** and **retain bicarbonate ions.**

Signs and Symptoms of Respiratory Acidosis

- Breathlessness
- Restlessness
- Lethargy and disorientation
- Tremors, convulsions, coma
- Respiratory rate rapid, then gradually depressed
- Skin warm and flushed due to vasodilation caused by excess CO_2

Treatment of Respiratory Acidosis

- Restore ventilation
- IV lactate solution
- Treat underlying dysfunction or disease



Respiratory Alkalosis

- **Primary Carbonic acid deficit**
  - **Decreased H2CO3**
  - pCO_2 less than 35 mm Hg (hypocapnea)
  - Most common acid-base imbalance
  - Primary cause is **hyperventilation**
- Washes out excessive quantity of H2CO3 through expiration process of lungs.
- Stimulation of respiratory center in brain → Hyperventilation

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

Respiratory Alkalosis

- **Anxiety** is an emotional disturbance
- The most common cause of **hyperventilation,** and thus **respiratory alkalosis**, is noted in **anxiety**

High Altitude

- Low concentrations of $\mathbf{O_2}$ in the arterial blood reflexly stimulates ventilation in an attempt to obtain more $\mathbf{O_2}$
- Too much $\mathbf{CO_2}$ is "blown off" in the process

Respiratory center lesions

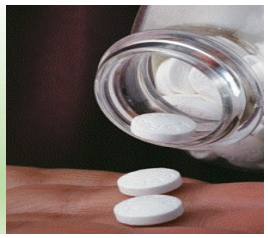
- Damage to brain centers responsible for monitoring breathing rates
  - Tumors
  - Strokes

Fever

- Rapid shallow breathing blows off too much $\mathbf{CO_2}$

Salicylate poisoning
(Aspirin overdose)

Ventilation is stimulated without regard to the status of $\mathbf{O_2}$, $\mathbf{CO_2}$ or $\mathbf{H^+}$ in the body fluids



Respiratory Alkalosis

- Kidneys compensate by:
  - **Retaining hydrogen ions**
  - **Increasing bicarbonate excretion**

- If **kidneys** are functioning normal → The conditions of respiratory acidosis or alkalosis are compensated.
  - **Kidneys conserve hydrogen ion**
  - **Excrete bicarbonate ion**

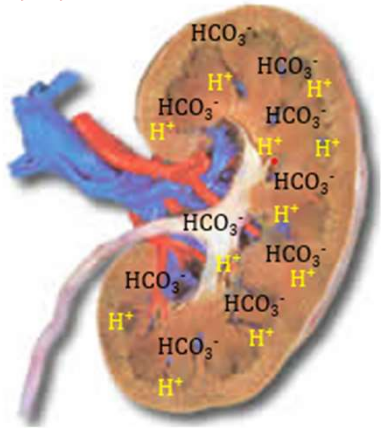
HYPERVENTILATION

Causes Respiratory Alkalosis

↑ Elimination of CO_2

↓ H^+

↑ pH

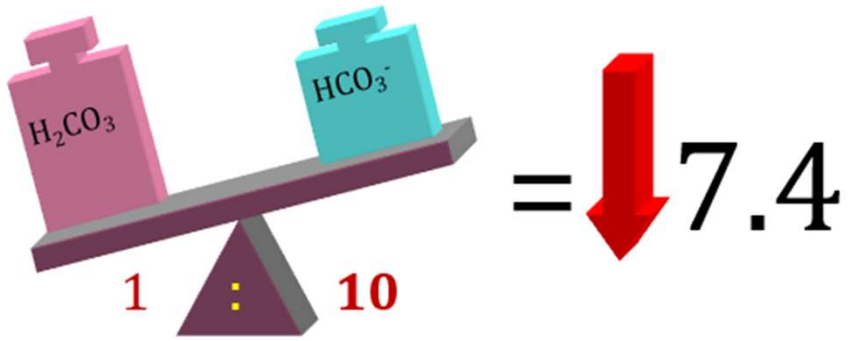


Treatment:

- Treat underlying cause
- Breathe into a paper bag
- IV Chloride containing solution Cl^- ions replace lost bicarbonate ions

Metabolic Acidosis

- **Primary Alkali deficit**
- **Bicarbonate deficit** - blood concentrations of bicarbonate drop below 22mEq/L
- Causes:
  - **Loss of bicarbonate through diarrhea or renal dysfunction.**
  - **Overproduction production of acids (lactic acid or ketones)**
  - **Failure of kidneys to excrete H^+**
- Occurs when there is a decrease in the normal 20:1 ratio
  - Decrease in blood **pH** and bicarbonate level
- Excessive **H^+** or decreased **HCO_3^-**



The causes of metabolic acidosis can be grouped into **five** major categories

1) Ingesting an acid or a substance that is metabolized to acid
2) Abnormal Metabolism
3) Kidney Insufficiencies
4) Strenuous Exercise
5) Severe Diarrhea

Symptoms of Metabolic Acidosis

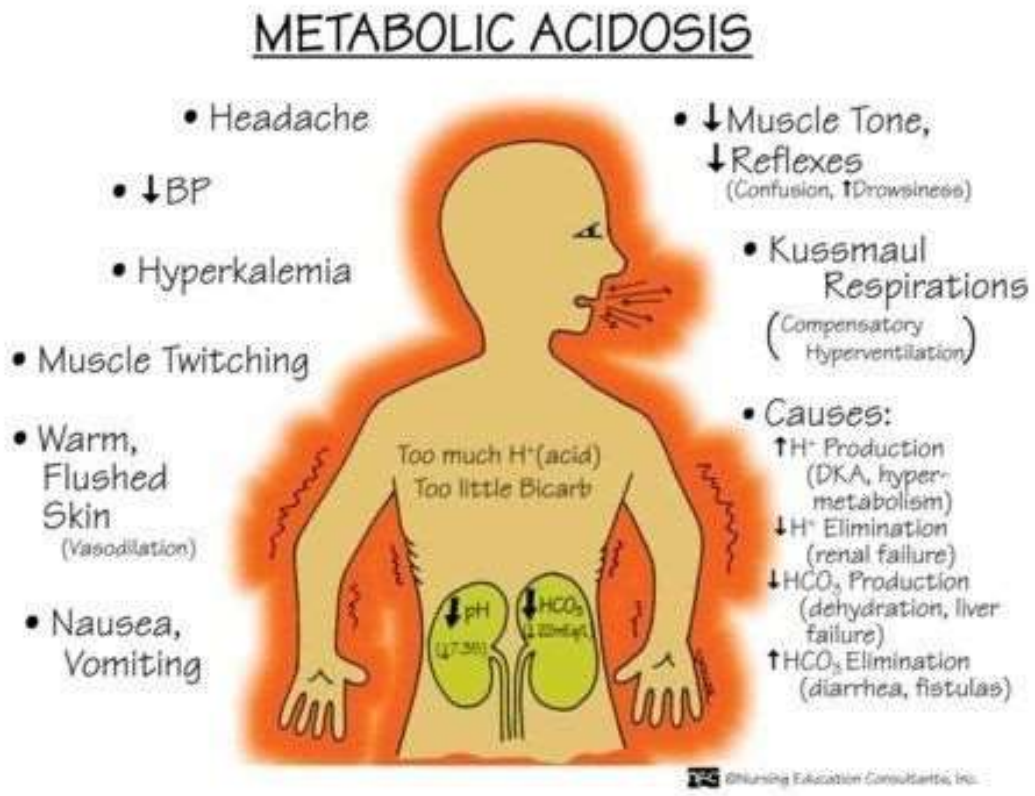
- Headache, lethargy
- Nausea, vomiting, diarrhea
- Coma
- Death

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.

Treatment of Metabolic Acidosis

IV lactate solution



Metabolic Alkalosis

- **Bicarbonate Excess** - concentration in blood is greater than 26 mEq/L
- Causes:
  - **Excess vomiting = loss of stomach acid**
  - Excessive use of alkaline drugs
  - Certain diuretics
  - Endocrine disorders
  - Heavy ingestion of antacids
  - Severe dehydration
  - Cushings Syndrome
  - Prolonged exposure to x rays and UV rays

- Elevation of **pH** due to an increased 20:1 ratio
  - May be caused by:
    - An **increase** of bicarbonate
    - A **decrease** in hydrogen ions
  - Imbalance again cannot be due to **CO_2**
  - Increase in **pH** which has a non-respiratory origin

Metabolic Alkalosis

- Can be the result of:
  - **1) Ingestion of Alkaline Substances**
  - **2) Vomiting (loss of HCl)**

- Baking soda (**$NaHCO_3$**) often used as a remedy for gastric hyperacidity
  - **$NaHCO_3$** dissociates to **Na^+** and **HCO_3^-**

Symptom for Metabolic Alkalosis

- Respiration slow and shallow
- Hyperactive reflexes ; tetany
- Often related to depletion of electrolytes
- Atrial tachycardia
- Dysrhythmias

Arterial Blood Gas(ABG)Analyzer

determines Acid Base Balance and Imbalance

1. **Note** whether **the pH** is low (acidosis) or high (alkalosis)
2. Decide which value, pCO_2 or HCO_3^- , is outside the normal range
3. If the cause is a **change in pCO_2,/H2CO3** the problem **is respiratory.**
4. If **the change is in HCO_3^-** the problem is **metabolic..**

- Arterial pH: 7.35 – 7.45
- HCO_3^-: 22 – 26 mEq/L
- PCO_2: 35 – 45 mmHg
- TCO_2: 23 – 27 mmol/L
- PO_2: 80 – 100 mmHg
- Base Excess: -2 to +2
- Anion Gap: 12 – 14 mEq/L

THANK YOU