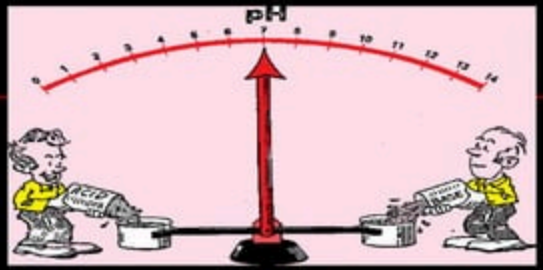
ACID BASE BALANCE



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Objectives.

- Concept of Acid & base.
- pH and H ion concentration.
- Handerson-Hasselbalch equation.
- Mechanisms to maintain acid base balance.
- Applied aspects.

ACIDS

- Acids are the substances which can donate H+ ion (proton).

- These are hydrogen containing substances which can dissociate in soln. to release H+.

$$HCl \longrightarrow H^+ + Cl^-$$

- Not all hydrogen containing substances are acids; e.g. Carbohydrate.

- Tightly bound hydrogen; not liberated in solution.

ACIDS

- **Types of acids in the body:**

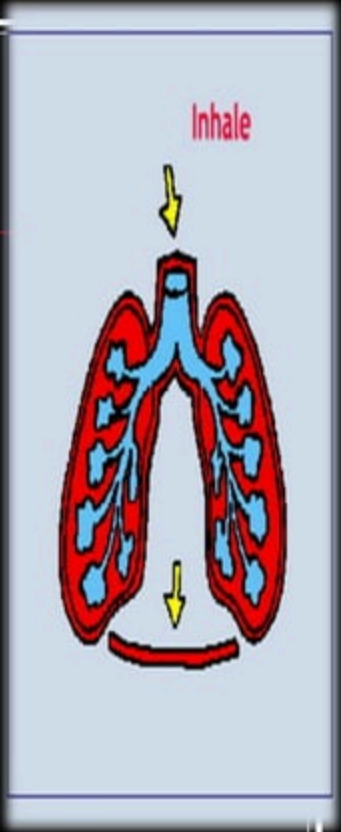
1. Volatile Acids:

- Can leave the solution and enter the environment.
- H_2CO_3 is the only volatile acid in the body.

$$H_2CO_3 \rightleftharpoons H_2O + CO_2$$

2. Non-Volatile Acids (Fixed Acids/Metabolic Acids):

- Acids that do not leave the solution.
- All other acids in the body.
- Ex: Pyruvic acid, Lactic acid, Phosphoric acid etc.



ACIDS

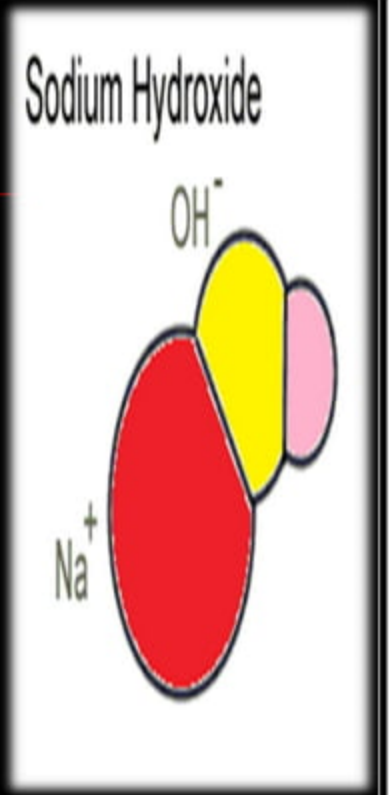
- Physiologically important acids:
  - **Carbonic acid (H_2CO_3)**
  - **Phosphoric acid (H_3PO_4)**
  - **Pyruvic acid ($C_3H_4O_3$)**
  - **Lactic acid ($C_3H_6O_3$)**
- These acids are products of various metabolisms in the body.
- Dissolved in body fluids.

BASE

- Base is a substance which can accept H+ ion (proton).,e.g. Hydroxyl ion (OH-).

$$OH^- + H^+ \longrightarrow H2O$$

- **Physiologically important bases:**
  - ***Bicarbonate (HCO_3^-)***
  - ***Biphosphate (HPO_4^{-2})***

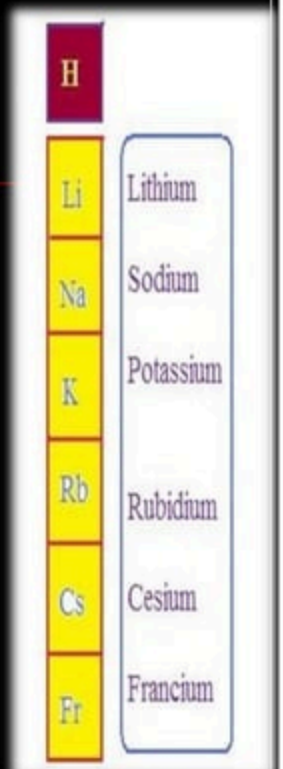


Alkali

- Used synonymously with base.
- Molecule formed by combination of an alkaline metal (Na,K,Li) with a highly basic ion.
  - *Ex- NaOH, KOH, $NaHPO_4$*
- Base portion of these molecules react quickly with H^+ to remove these from solution, i.e. alkalis act as typical bases.

$$NaOH \longrightarrow Na^+ + OH^-$$

$$+ H^+ \longrightarrow H2O$$



Acids & Bases can be classified as strong or weak acid/base

- ***Strong acid/base:***
  - One that dissociates completely in a solution.
  - Ex: HCl, H2SO4, NaOH

$$HCl \longrightarrow H^+ + Cl^-$$

$$NaOH \longrightarrow Na^+ + OH^-$$

- **Weak acid/base:**
  - One that dissociates partially in a solution.
  - Ex: H2CO3, $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$

PH SCALE

- H^+ concentration in extracellular fluid (ECF)

4×10^{-8} (0.00000004)

$$pH = \log 1 / H^+ \text{ concentration}$$

$$pH = \log 1 / H^+ \text{ concentration}$$
$$pH = \log 1 / 4 \times 10^{-8}$$
$$pH = 7.2$$

- Normal blood pH is **7.35 - 7.45**
- pH range compatible with life is **6.8 - 8.0**

PH SCALE

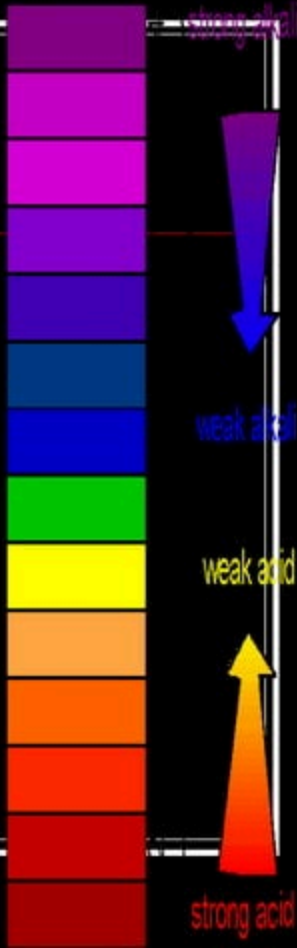
$$pH = - \log [H^+]$$

$$pH = \log 1/ [H^+]$$

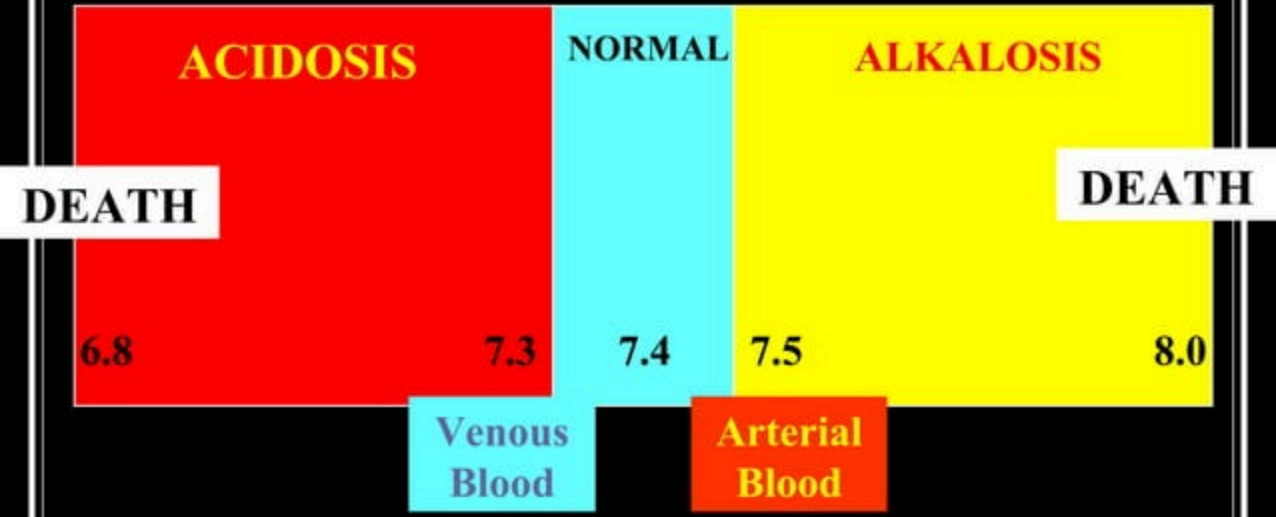
- ***pH is inversely related to H^+ concentration.***
  - **low pH – indicates high H^+ concentration.**
  - **high pH – indicates low H^+ concentration.**

- pH = 4 has 10 times more free H^+ concentration than pH = 5 and 100 times more free H^+ concentration than pH = 6

- ***pH range from 1-14.***
  - **pH < 7 – Acidic**
  - **pH > 7 – Basic**
  - **pH = 7 - Neutral**

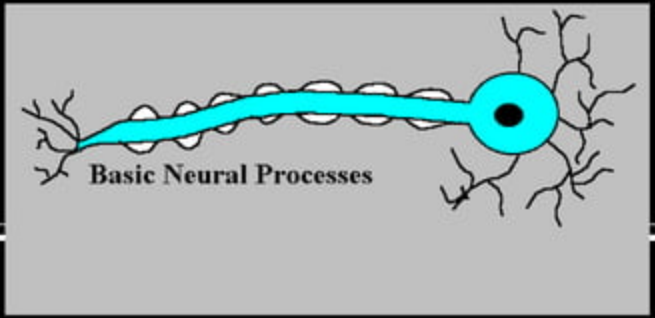


PH of the ECF is regulated very precisely



EFFECTS OF pH change

- ***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

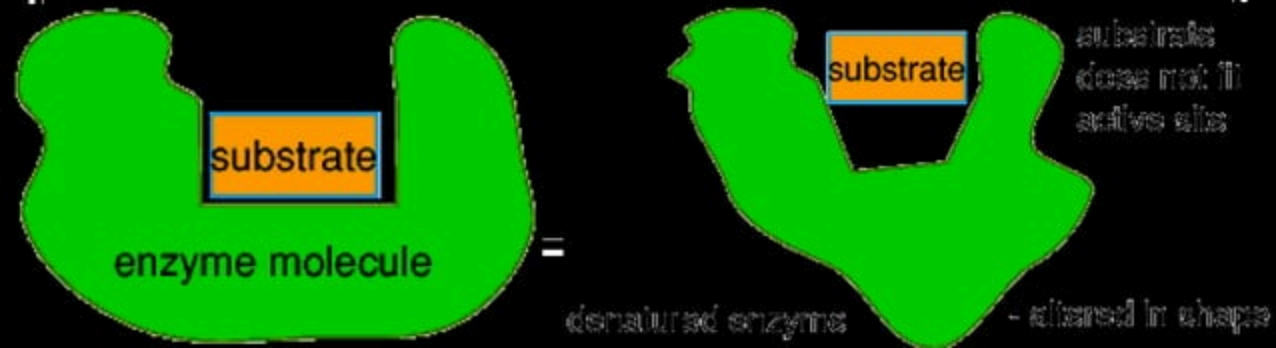


Changes in cell excitability

- ***pH decrease (more acidic) depresses the central nervous system***
  - Can lead to loss of consciousness
- ***pH increase (more basic) can cause over-excitability***
  - 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 $K^{\pm}$ LEVELS

- In kidney Na^{+} is absorbed in tubules in exchange of K^{+} or H^{+} ($K^{+} > H^{+}$).

- In acidosis more H^{+} is secreted thus preserving the K^{+}, causing hyperkalemia.

ACID BASE BALANCE

- Maintenance of the pH of body fluids at a level that allow optimal function.
- pH maintenance means maintaining **[H^+]**.
- ***This involves two important ions which are regulated by various chemical & physiological process:***

H^+

HCO_3^-

ACID BASE BALANCE

- ***Chemical processes:***
  - The first line of defence to an acid or base load.
  - Include the ***extracellular and intracellular buffers.***

- ***Physiologic processes:***
  - 1. Changes in cellular metabolism.
  - 2. Excretion of volatile acids by the **lungs**
  - 3. Excretion of fixed acids by the **kidneys**

ACID BASE BALANCE

- *Maintained by **three** mechanisms:*
  - **1) Chemical Buffers**
    - React very rapidly (less than a second)
  - **2) Respiratory Regulation**
    - Reacts rapidly (seconds to minutes)
  - **3) Renal Regulation**
    - Reacts slowly (minutes to hours)

1) Buffer Systems

2) Respiratory Responses
3) Renal Responses
4) Intracellular Shifts of Ions

Buffers.

- Is a solution of weak acid & its salt with a strong base that prevent change in pH when H^+ ions are added or removed from the solution.
- Most effective within 1 pH unit of the pK of the buffer.
- Depend on absolute concentration of salt & acid.

REMEMBER.....

- Buffer cannot remove H+ ions from the body temporarily reduce free H+ ions
- H+ ions have to be ultimately removed by the renal mechanism.

Henderson-Hasselbalch equation

- HA $\rightleftharpoons$ H+ + A-

- When acid is added, --- H+ ion conc increases, reaction forced towards right leads to increase in un dissociated molecules.
- When base is added ---- reaction shift towards left, more H+ ion released from buffer to combine with base.

Most Effective Buffer.

- Henderson-Hasselbalch equation.
- $HA \rightleftharpoons H^+ + A^-$
- By the law of mass action, at equilibrium

$$K = \frac{[H+][A-]}{[HA]}$$

K= Dissociation constant of acid.

Henderson- Hasselbalch equation.

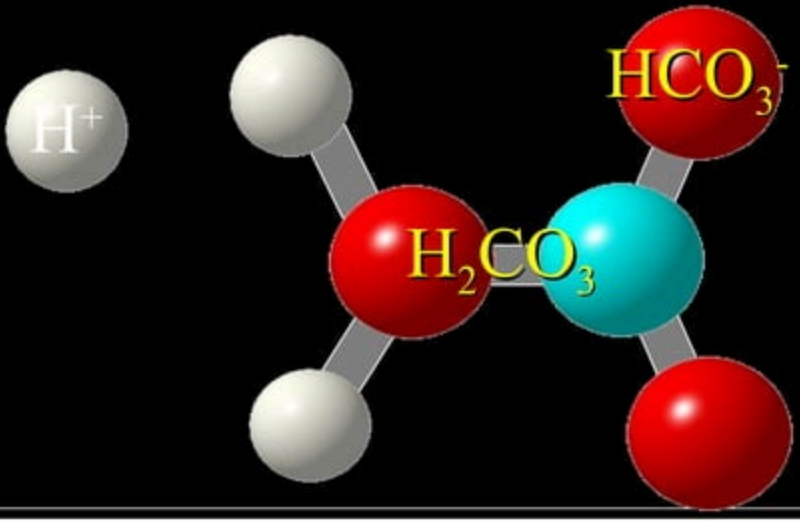
- $[H^+] = K [HA]/[A^-]$
- $pH = \log 1/ [H^+]$
- $\text{Log } 1/[H^+] = \log 1/K + \log [A^-]/[HA]$
- $pH = pK + \log [A^-]/[HA]$
- Thus $pH = pK$
- Thus most effective buffers in the body are those with pK close to the pH in which they operate.

  from this equation it is seen that buffering capacity of buffer system is greatest when amount of anion[A-] and undissociated acid [HA] is same.

BICARBONATE BUFFER SYSTEM

- Predominates in extracellular fluid (ECF)

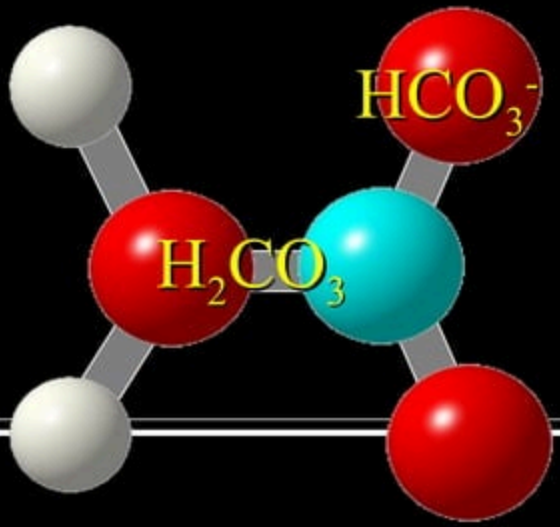
$$HCO_3^- + \text{added } H^+ \rightarrow H_2CO_3$$



BICARBONATE BUFFER SYSTEM

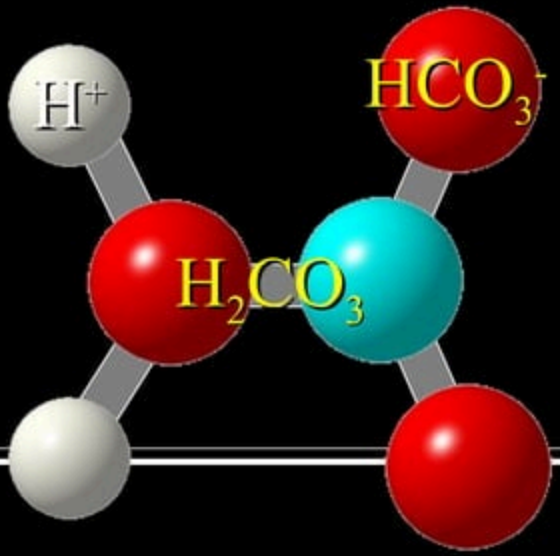
- Hydrogen ions ***generated*** by metabolism or by ***ingestion*** react with bicarbonate base to form more carbonic acid.

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3$$



BICARBONATE BUFFER SYSTEM

- Hydrogen ions that are **lost (vomiting)** causes carbonic acid to dissociate yielding replacement H^+ and bicarbonate.



BICARBONATE BUFFER SYSTEM

- This system is most important because the concentration of both components can be regulated:
  - ***Carbonic acid*** by the respiratory system
  - ***Bicarbonate*** by the renal system

PHOSPHATE BUFFER SYSTEM

- Most important in the intracellular system

$$Na_2HPO_4 + H^+ \rightleftharpoons NaH_2PO_4 + Na^+$$

H^+

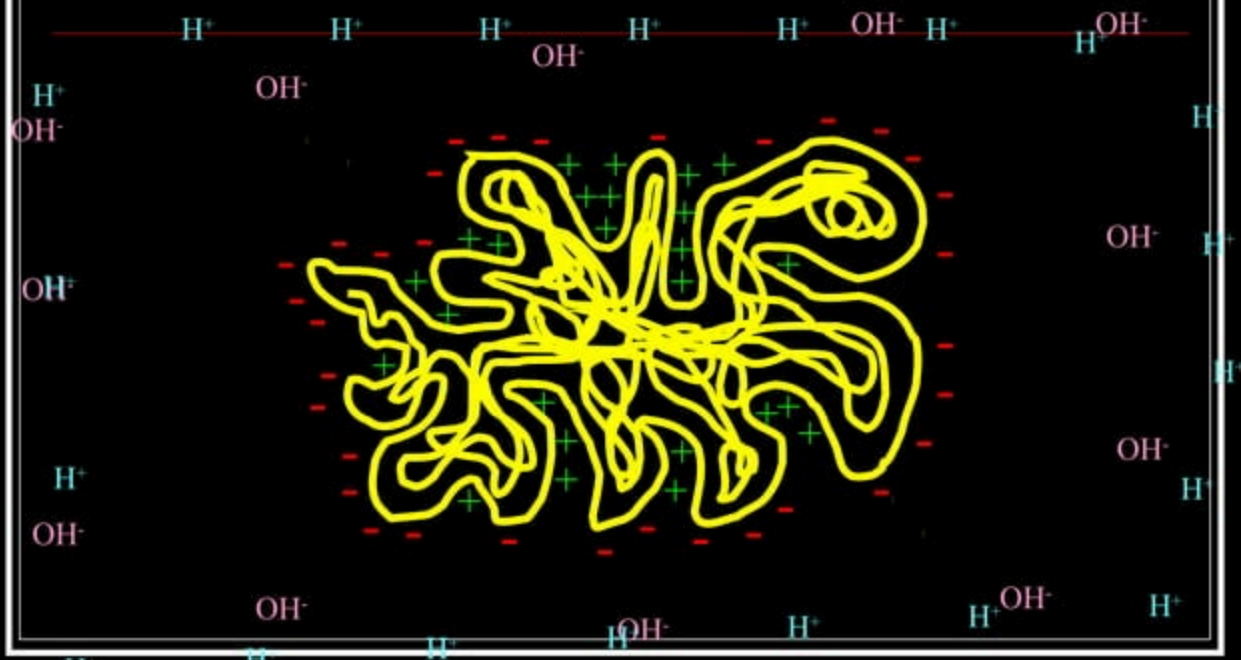
$+Na_2HPO_4$

$NaH_2PO_4 + Na^+$

PROTEIN BUFFER SYSTEM

- Most important intracellular buffer.
- The most abundant buffer of the body.
- Behaves as a buffer in both plasma and cells
- Hemoglobin is by far the most important protein buffer.

PROTEIN BUFFER SYSTEM



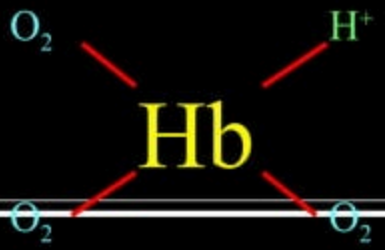
PROTEIN BUFFER SYSTEM

- **H^+** generated at the tissue level from the dissociation of **H_2CO_3** produced by the addition of **CO_2**.
- Bound **H^+** to **Hb** (Hemoglobin) does not contribute to the acidity of blood.

PROTEIN BUFFER SYSTEM

- As **H^+Hb** picks up **O_2** from the lungs the **Hb** which has a higher affinity for **O_2** releases **H^+** and picks up **O_2**
- Liberated **H^+** from **H_2O** combines with **HCO_3^-**

$$HCO_3^- \rightarrow H_2CO_3 \rightarrow CO_2 \text{ (exhaled)}$$



1) Buffer Systems

2) Respiratory Responses

3) Renal Responses

4) Intracellular Shifts of Ions

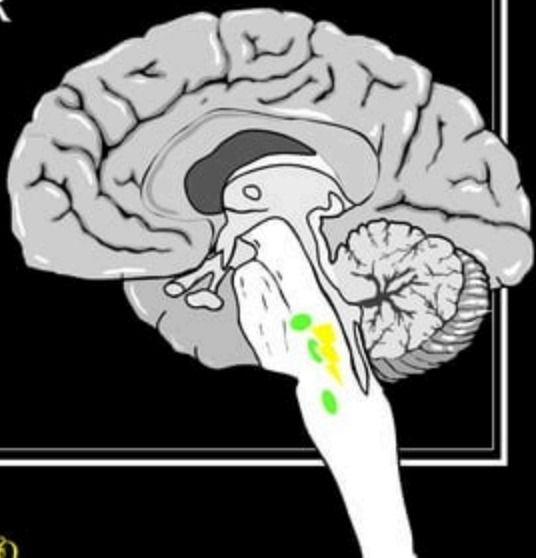
RESPIRATORY REGULATION

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

- **Respiratory regulation is by increasing or decreasing the exhalation of CO2 from the body.**
  - ***Hyperventilation*** in response to increased CO_2 or H^+ (low pH)
  - ***Hypoventilation*** in response to decreased CO_2 or H^+ (high pH)

RESPIRATORY REGULATION

- Respiratory center in brain is able to detect blood concentration levels of **CO_2** and **H^+**
- Increases in **CO_2** and **H^+** stimulate the respiratory center → ↑ RR
- But the effect diminishes in 1 - 2 minutes



1) Buffer Systems
2) Respiratory Responses
3) Renal Responses
4) Intracellular Shifts of Ions

RENAL RESPONSE

- The kidney compensates for Acid - Base imbalance within 24 hours and is responsible for long term control.
- ***The kidney in response:***
  - ***To Acidosis***
    - Retains bicarbonate ions and eliminates hydrogen ions. Produce new bicarbonate.
  - ***To Alkalosis***
    - Eliminates bicarbonate ions and retains hydrogen ions.

RENAL RESPONSE

- Large amount of HCO_3^- filtered & H^+ secreted by kidneys.
- Almost all (99%) HCO_3^- is absorbed by combining it with H^+.
- H^+ secreted = H^+ needed to absorb all HCO_3^- + excess H^+ formed in body.
- If **filtered HCO_3^- > secreted H^+** → net loss of base from blood.
- If **filtered HCO_3^- < secreted H^+** → net loss of acid from blood.

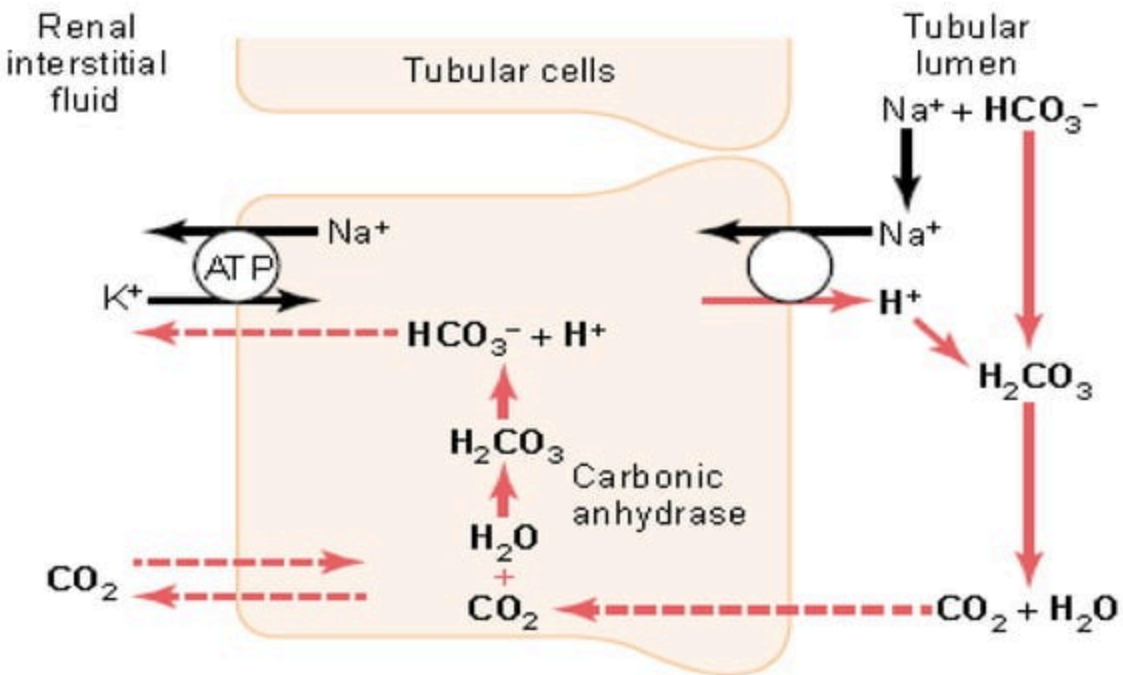
RENAL RESPONSE

- ***Alkalosis (↓ H^+)*** ➔ ↓ absorption of HCO_3^- ➔ HCO_3^- exc. In urine.
- **Acidosis (↑ H^+)** ➔ all HCO_3^- is absorbed & kidneys produce new HCO_3^-
- **So kidneys regulate extracellular fluid H+ concentration through three fundamental mechanisms:**
- *(1) secretion of H+,*
- *(2) reabsorption of filtered HCO3-, and*
- *(3) production of new HCO3-.*

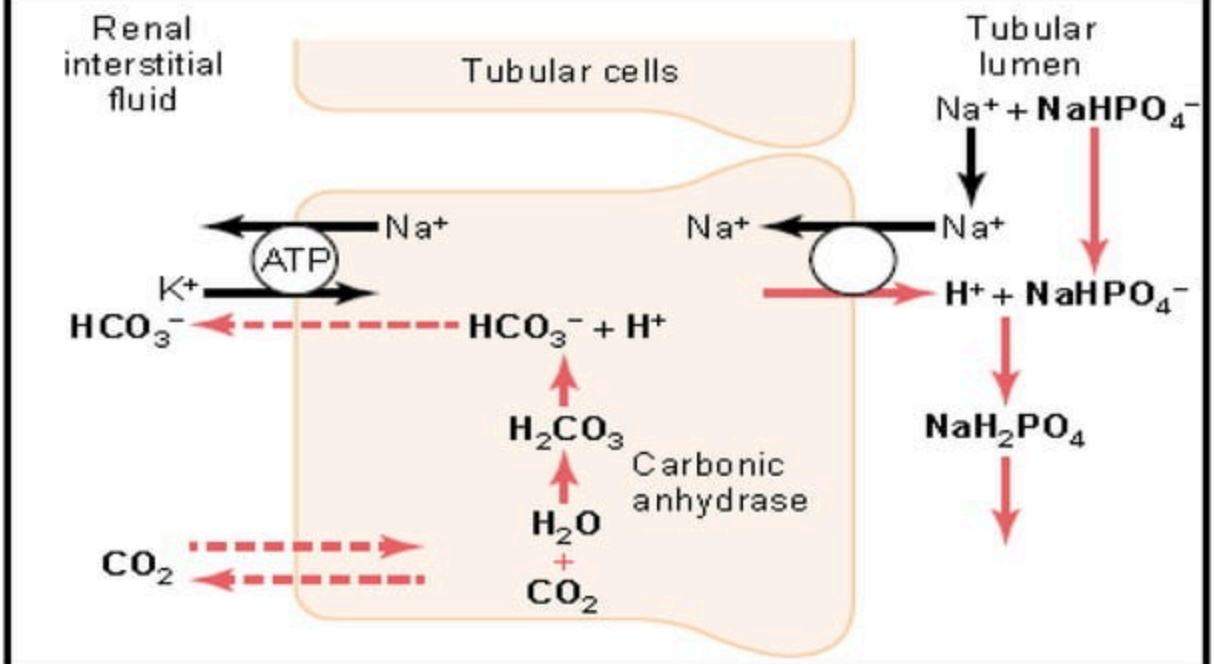
RENAL RESPONSE

- Secretion of H+ occurs in all segments of nephron.
- **Secreted H+ is buffered with :**
  - ***HCO_3^- in proximal segments*** → resulting in absorption of HCO3-
  - ***Na_2HPO_4 & NH_3 in distal segments*** → resulting in production of new HCO3-

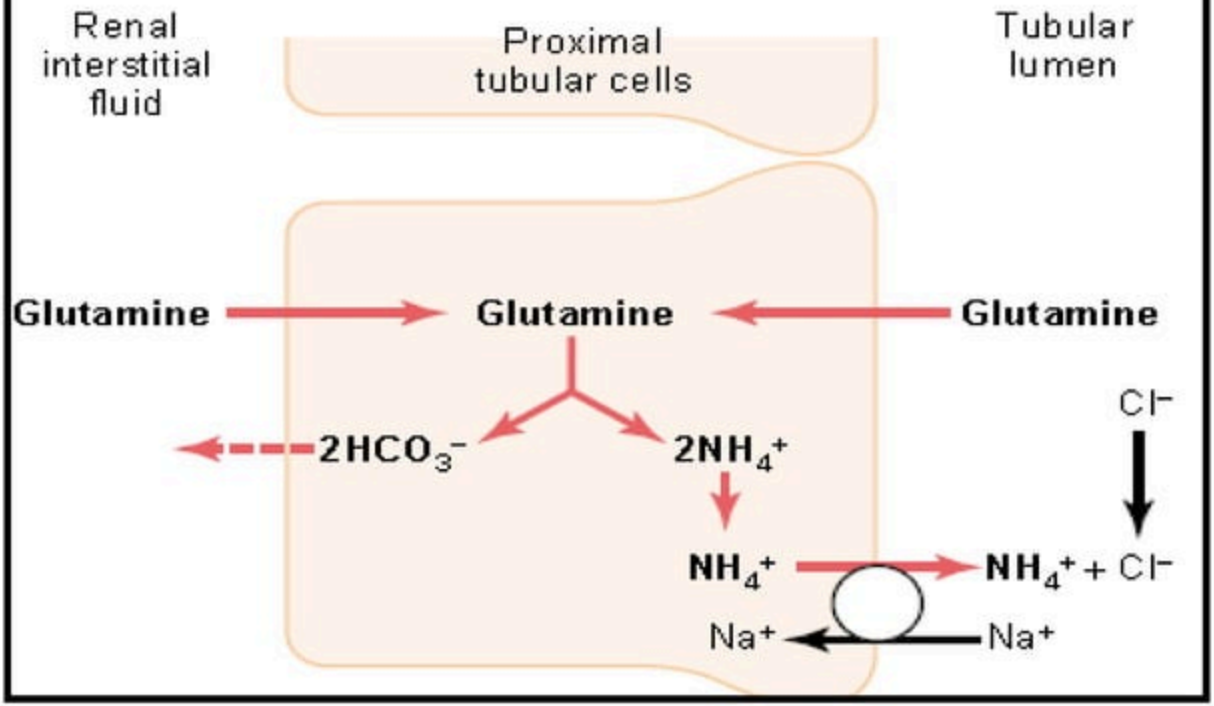
HCO3- absorption in proximal segment



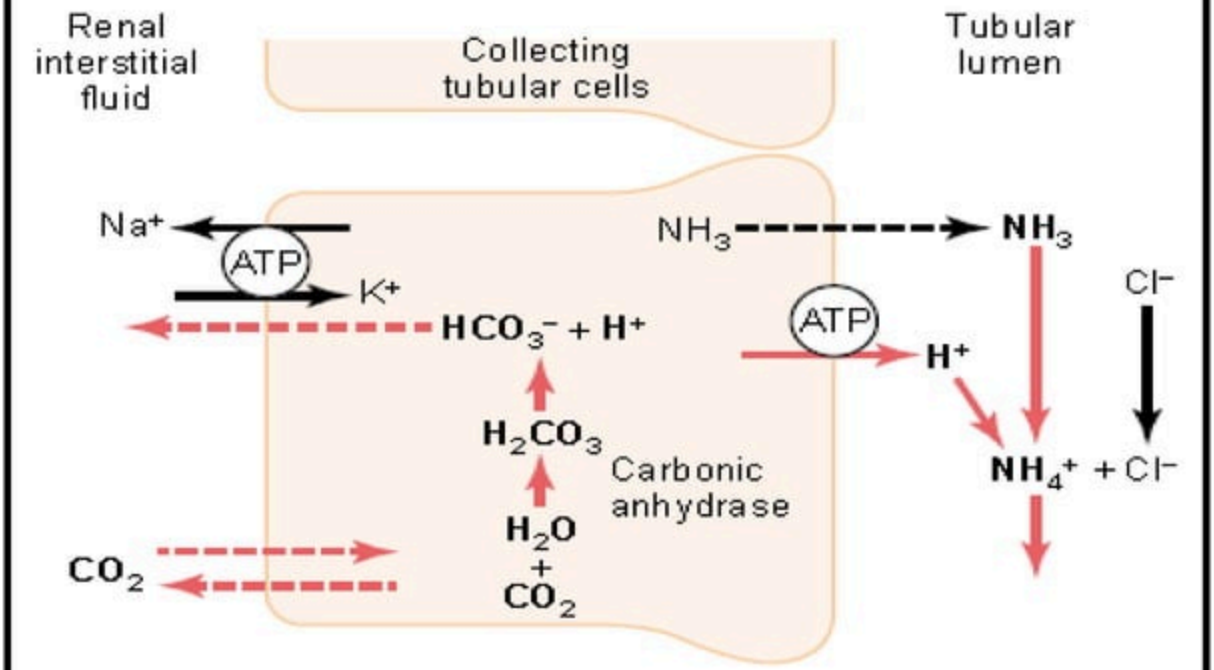
Production of new HCO3- by phosphate buffer in distal tubule



Combination of H+ with Ammonia buffer

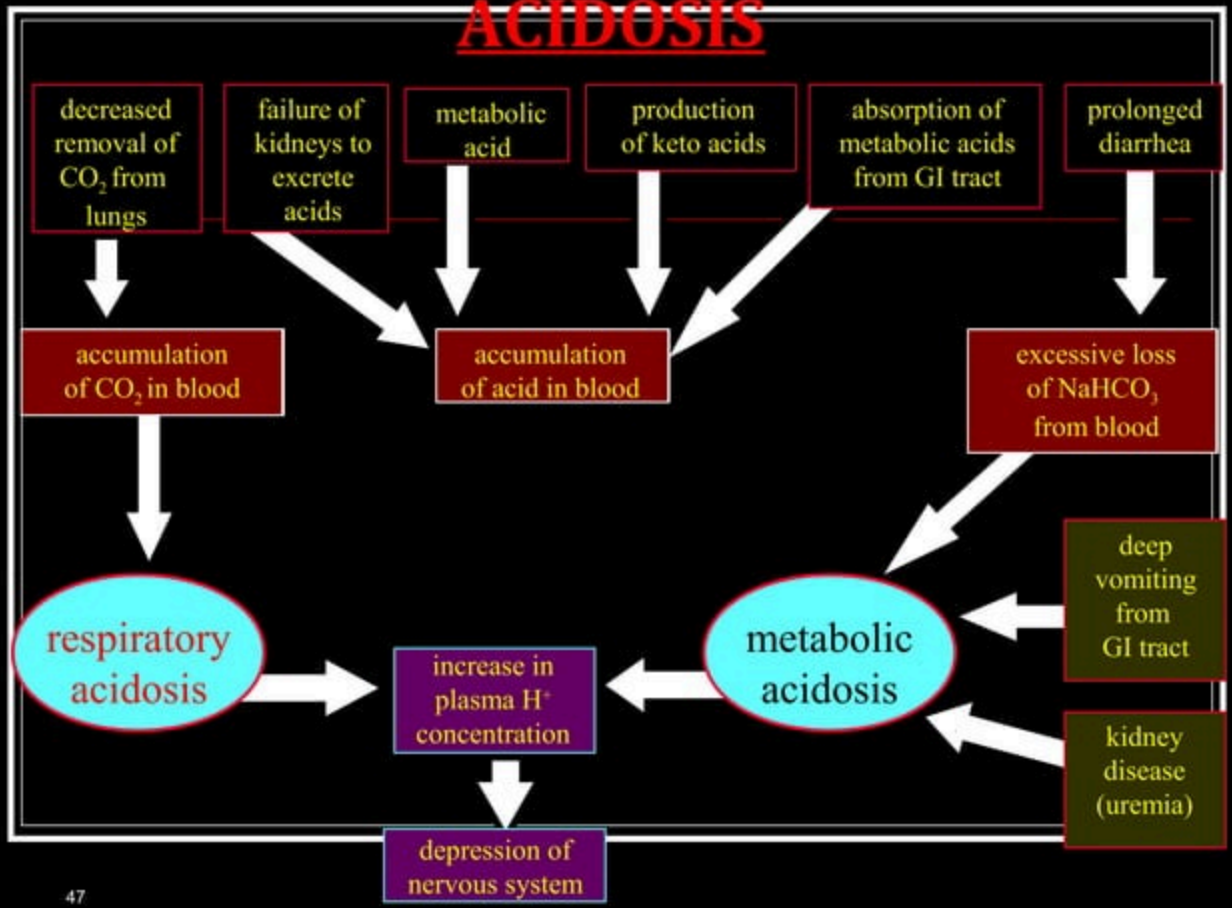


Combination of H+ with Ammonia in collecting tubules



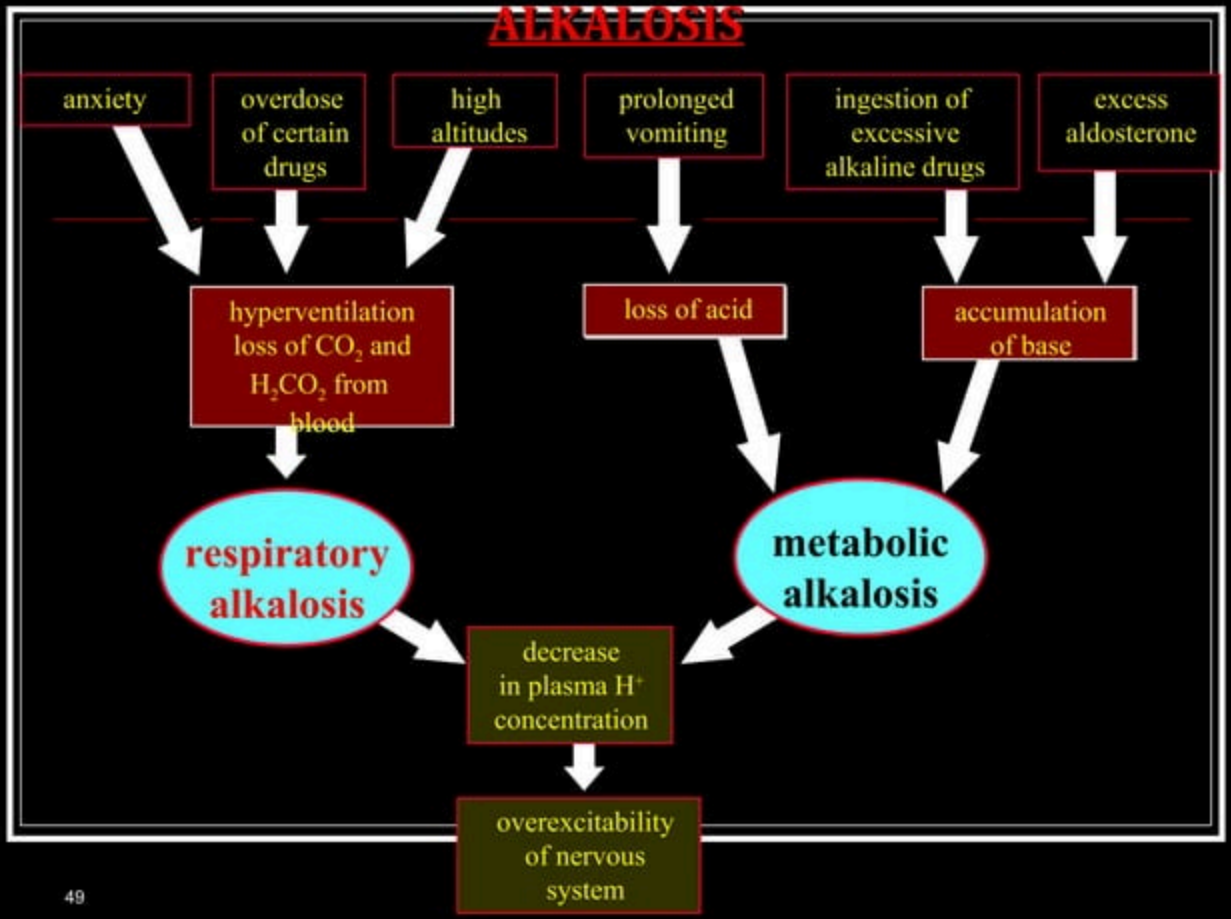
Disorders of Acid-Base Balance

- ***Acidosis:***
  - ↓ pH of ECF.
  - May be d/t ↑ acid / ↓ base.
- **May be:**
  - ***Respiratory Acidosis***
    - d/t ↓ elimination of CO_2 by lungs. (↑ acid)
  - ***Metabolic Acidosis:***
    - d/t ↑ loss of HCO_3^- by the kidneys. (↓ base)


ACIDOSIS
decreased removal of CO_2 from lungs
failure of kidneys to excrete acids
metabolic acid
production of keto acids
absorption of metabolic acids from GI tract
prolonged diarrhea
accumulation of CO_2 in blood
accumulation of acid in blood
excessive loss of $NaHCO_3$ from blood
respiratory acidosis
increase in plasma H^+ concentration
metabolic acidosis
deep vomiting from GI tract
kidney disease (uremia)
depression of nervous system

Disorders of Acid-Base Balance

- ***Alkalosis:***
  - ↑ pH of ECF.
  - May be d/t ↑ base / ↓ acid.
- **May be:**
  - ***Respiratory Alkalosis***
    - d/t ↑ elimination of CO_2 by lungs. (↓ acid)
  - ***Metabolic Alkalosis:***
    - d/t ↓ loss of HCO_3^- by the kidneys. (↑ base)


ALKALOSIS
anxiety
overdose of certain drugs
high altitudes
prolonged vomiting
ingestion of excessive alkaline drugs
excess aldosterone
hyperventilation loss of CO_2 and H_2CO_3 from blood
loss of acid
accumulation of base
respiratory alkalosis
metabolic alkalosis
decrease in plasma H^+ concentration
overexcitability of nervous system

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

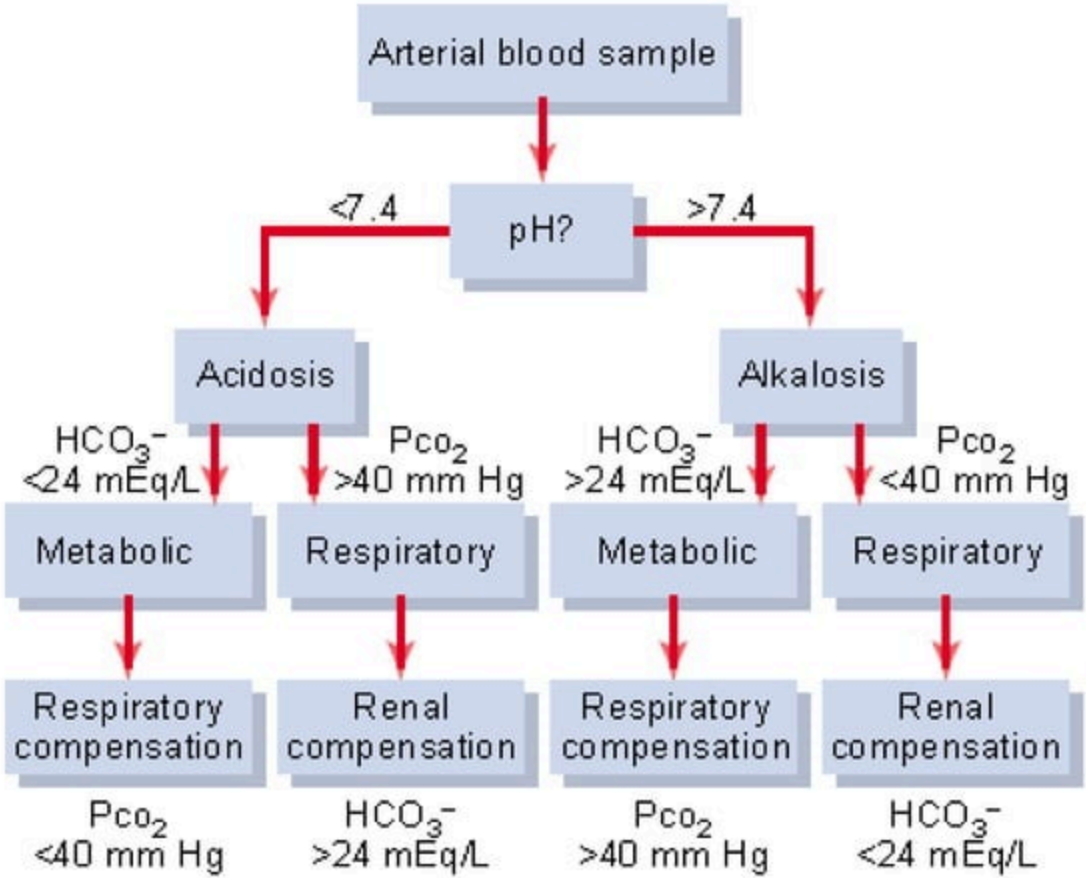
Diagnosing Acid-Base imbalance

- *Remember 3 important values:*

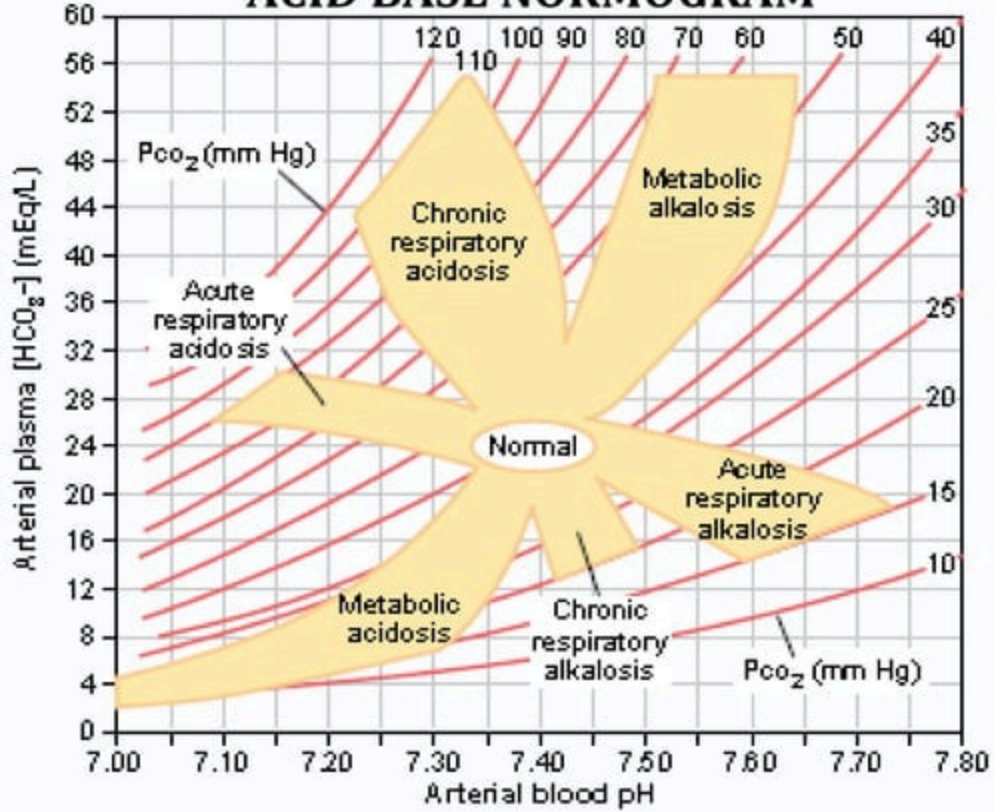
pH = 7.4

pCO2 = 40 mm Hg

HCO3- = 24 mmol/l


Arterial blood sample
pH?
<7.4
>7.4
Acidosis
Alkalosis
HCO_3^- <24 mEq/L
Pco_2 >40 mm Hg
HCO_3^- >24 mEq/L
Pco_2 <40 mm Hg
Metabolic
Respiratory
Metabolic
Respiratory
Respiratory compensation
Renal compensation
Respiratory compensation
Renal compensation
Pco_2 <40 mm Hg
HCO_3^- >24 mEq/L
Pco_2 >40 mm Hg
HCO_3^- <24 mEq/L

ACID BASE NORMOGRAM



Today's thought.

"Too many people spend
money they haven't earned,
to buy things they
don't want,
to impress people they
don't like."

- Will Smith -