FLUID AND ELECTROLYTE BALANCE.

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• DEFINITION :

- Fluid balance is an aspect of the homeostasis of body in which the amount of water in the body needs to be controlled, via osmoregulation and behavior, such that the concentrations of electrolytes (salts in solution) in the various body fluids are kept within healthy ranges.
- The core principle of fluid balance is that the amount of water lost from the body must equal the amount of water taken in; for example, in humans, the output (via respiration, perspiration, urination, defecation, and expectoration) must equal the input (via eating and drinking, or by parenteral intake).

- **Total Water content in -**

~Young males:60%

Older males:52%

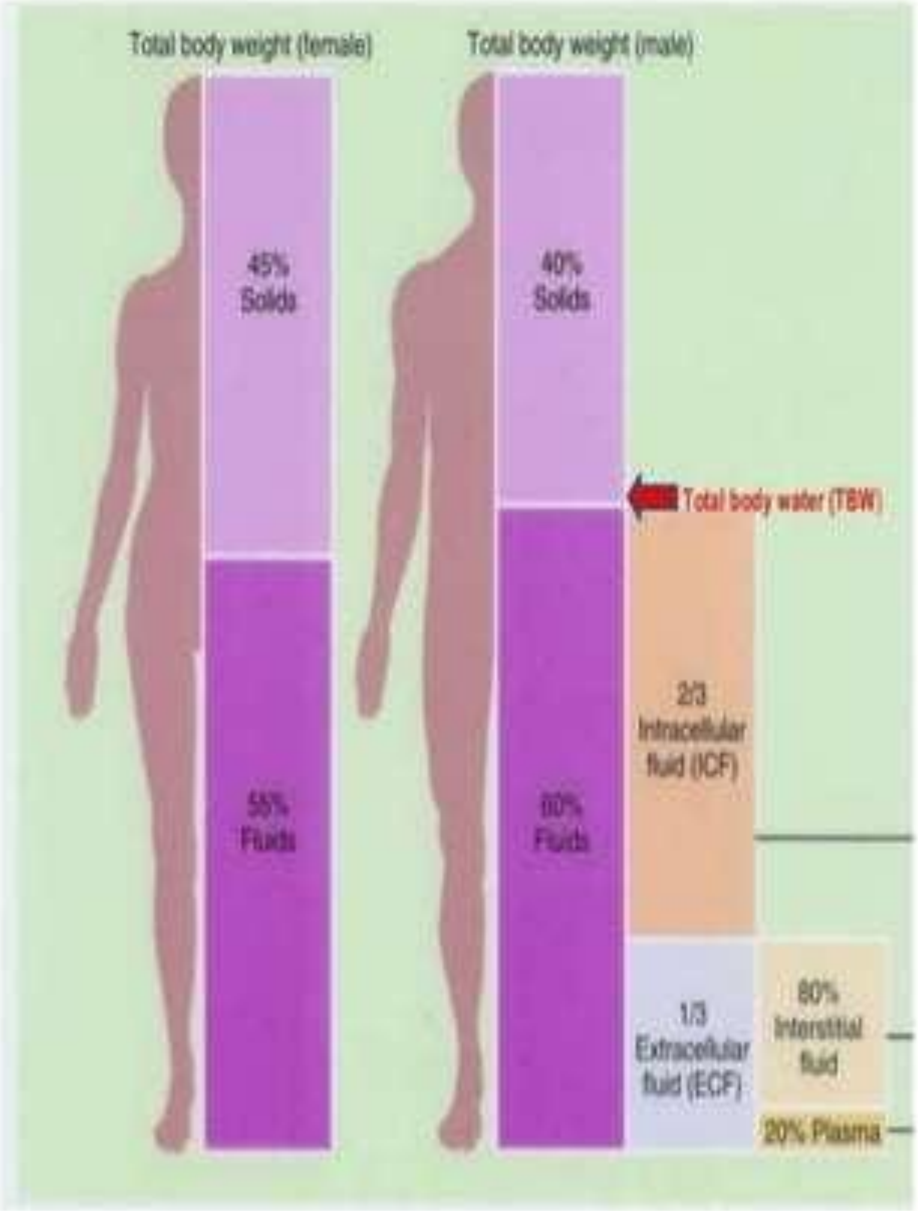
~Young females:55%

Older females:47%

~Infants : 75-80%

*65% at 1 year age.

~Obese: 25-30% less than lean people.



- Fluid can enter the body as preformed water, ingested food and drink and to a lesser extent as metabolic water which is produced as a by product of aerobic respiration and dehydration synthesis.
- Fluid can leave the body through urine,faeces and other insensible loses.
- For females, an additional 50 ml/day is lost through vaginal secretions.
- Daily water balance as shown in table 1.

Table 1: Approximate daily water balance in health

Intake (ml)		Output (ml)	
Water from beverages	1200	Urine	1500
Water from solid food	1000	Insensible losses from skin and lungs	900
Metabolic water from oxidation	300	Faeces	100

- Total of 2500ml intake = 2500 ml of output.

FLUID AND ELECTROLYTE IMBALANCE:

Any abnormality in the concentration of fluid and electrolytes in the body leads to fluid-electrolyte imbalances.

FLUID IMBALANCE :

- Deficient volume leads to

  - Hypovolemia & - Dehydration

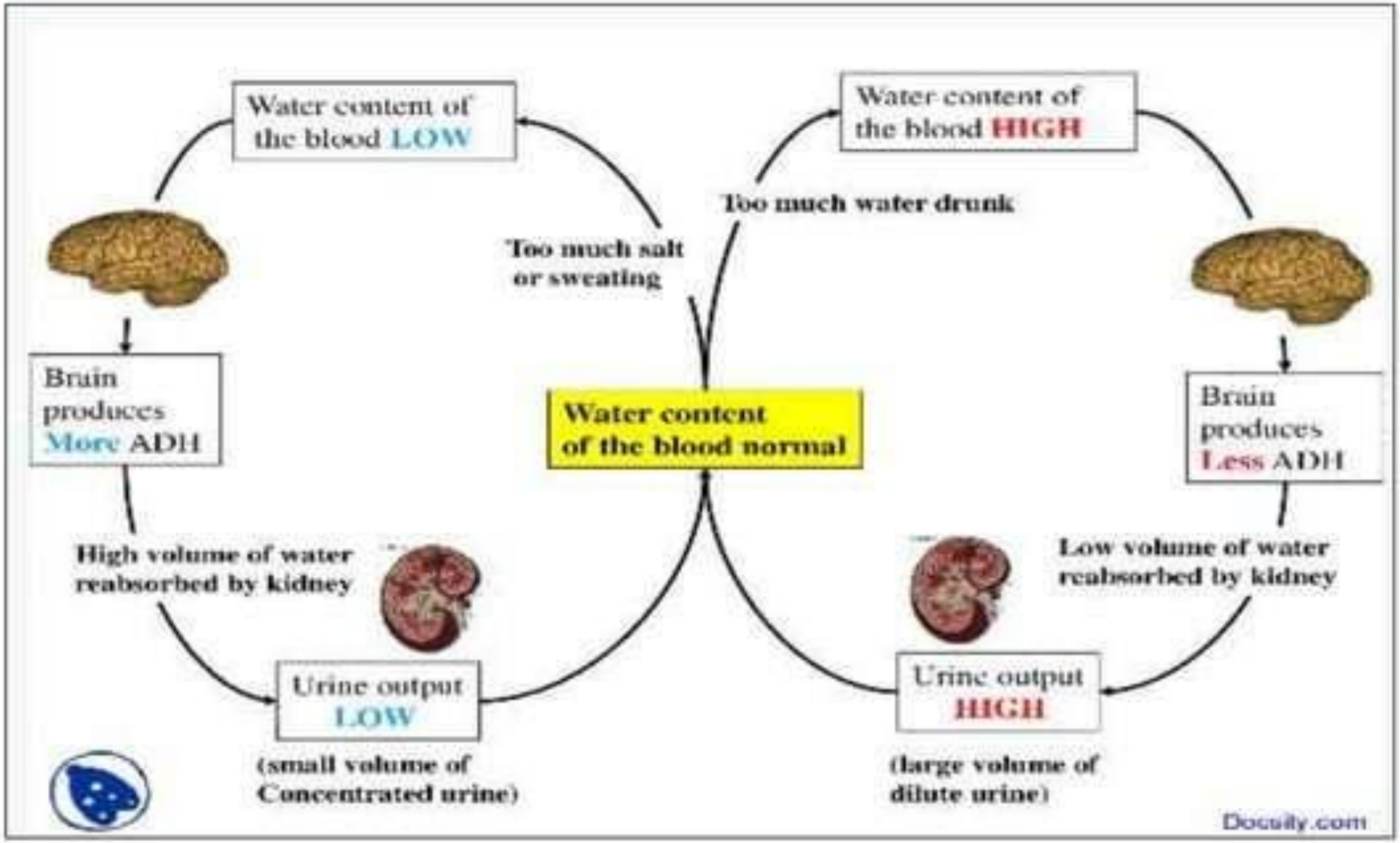
- Conditions : fever, sweating, burns, tachypnea, surgical drains, polyuria, or ongoing significant gastrointestinal loses.

- Excess fluid volume leads to

  - Hypervolemia & - Intoxication

- Conditions : heart failure, specifically of the right ventricle. cirrhosis, often caused by excess alcohol consumption or hepatitis. kidney failure, often caused by diabetes and other metabolic disorders.

FLUID IMBALANCE REGULATIONS



ELECTROLYTE IMBALANCES : .

Electrolytes are salts, acids, and bases, but electrolyte balance usually refers only to salt balance

- Salts are important for:

- Essential minerals

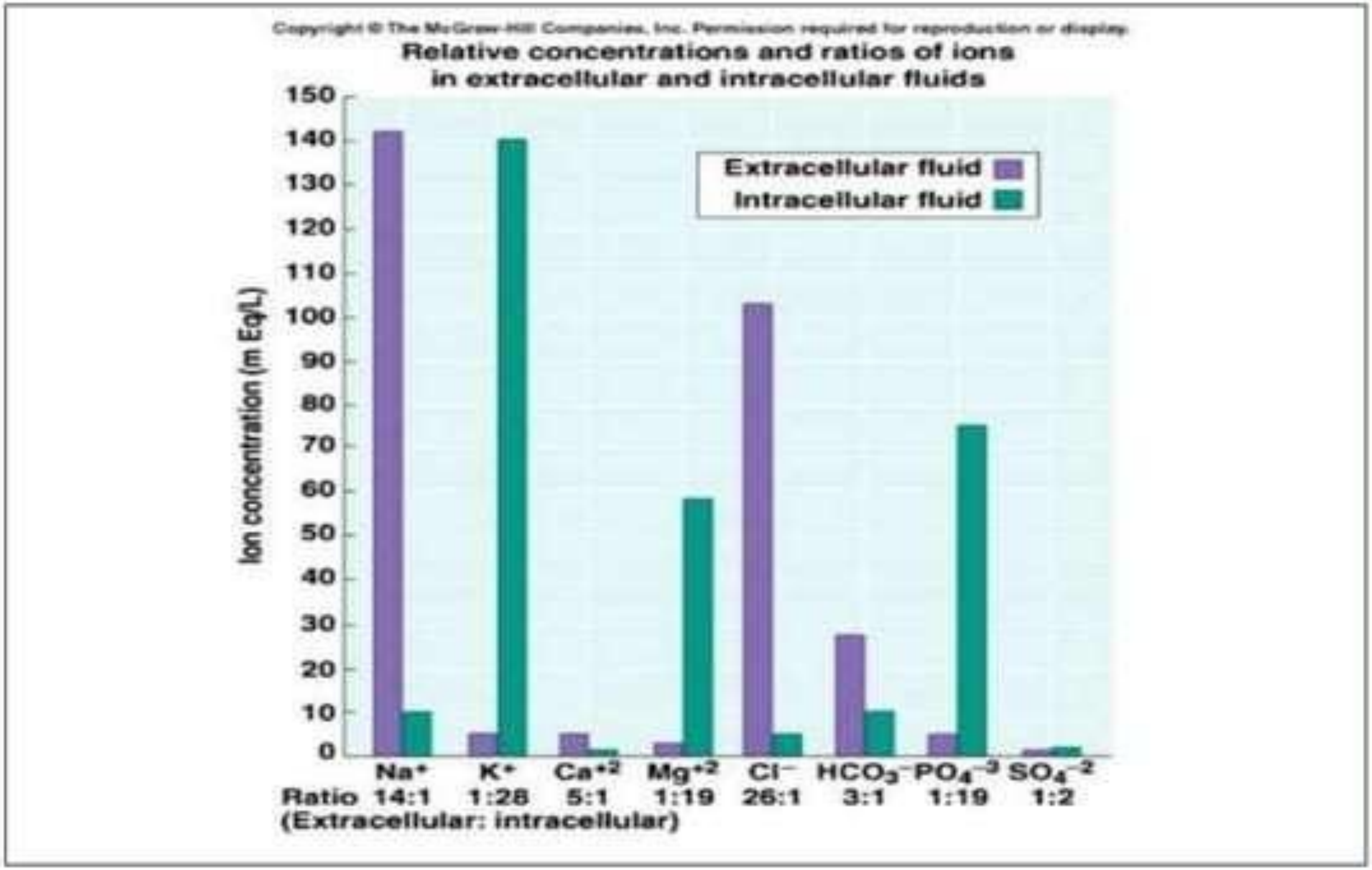
- Controls osmosis between fluid compartments

- Help maintain acid-base balance

- Carry electrical (ionic) current for action potentials.

ELECTROLYTES :

- The electrolytes in human bodies include: sodium, potassium, calcium, bicarbonate, magnesium, chloride, phosphate.
- The level of an electrolyte in the blood can become too high or too low, leading to an imbalance. Electrolyte levels can change in relation to water levels in the body as well as other factors.
- Important electrolytes are lost in sweat during exercise, including sodium and potassium. The concentration can also be affected by rapid loss of fluids, such as after a bout of diarrhea or vomiting.
- Some other causes include kidney diseases, congestive heart failure, Chemotherapy, poor diet, sever dehydration, some drugs such as diuretics.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Relative concentrations and ratios of ions in extracellular and intracellular fluids
Ion concentration (m Eq/L)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Extracellular fluid
Intracellular fluid
Na+ K+ Ca+2 Mg+2 Cl− HCO3− PO4−3 SO4−2
Ratio 14:1 1:28 5:1 1:19 26:1 3:1 1:19 1:2
(Extracellular: intracellular)

NORMAL RANGE OF ELECTROLYTES :

- The normal range for
  1. Sodium - 135 to 145 mmol/L
  2. Potassium - 3.7 to 5.2 mmol/L
  3. Calcium - 8.5 to 10.6 mg/dl
  4. Magnesium - 1.7 to 2.2 mg/dl
  5. Phosphate - 0.81 to 1.45 mmol/L
  6. Chloride - 97 to 107 mmol/L

1. SODIUM :

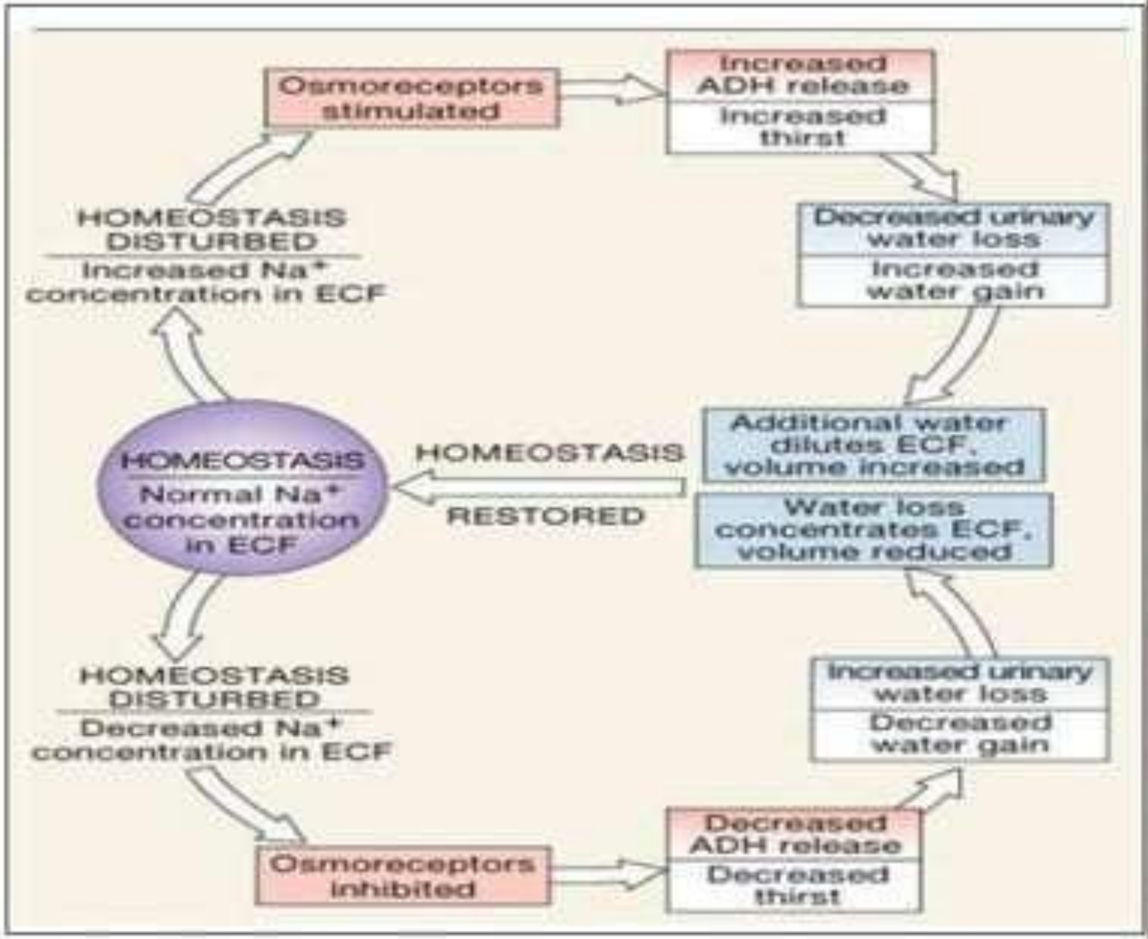
- Sodium holds a central position in fluid and electrolyte balance.
- Sodium is the single most abundant cation in the ECF
    - Accounts for 90-95% of all solutes in the ECF.
    - Contribute 280 mOsm of the total 300 mOsm ECF solute concentration.
- The role of sodium in controlling ECF volume and water distribution in the body is a result of:
    - Sodium being the only cation to exert significant osmotic pressure.
    - Sodium ions leaking into cells and being pumped out against their electrochemical gradient.
- Sodium concentration in the ECF normally remains stable
    - Rate of sodium uptake across digestive tract directly proportional to dietary intake.
    - Sodium losses occur through urine and perspiration.
- Changes in plasma sodium levels affect:
    - Plasma volume, blood pressure
    - ICF and interstitial fluid volume

- Large variations in sodium are corrected by homeostatic mechanisms.

- If sodium levels are too low, it is termed as HYPONATREMIA.

  • In this, antidiuretic hormone (ADH) and aldosterone are secreted.

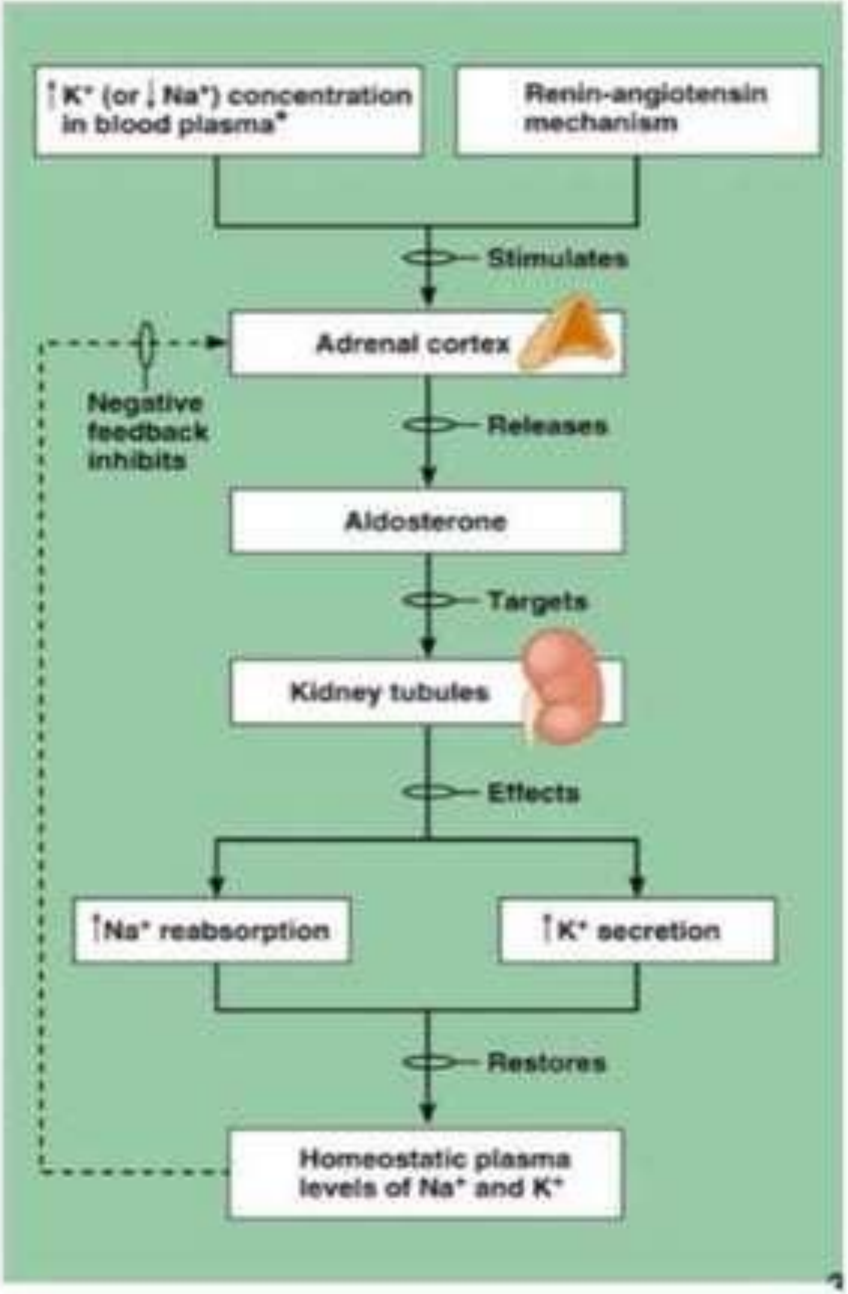
- **Regulation of Sodium Balance by ADH :-**



~ Regulation of Sodium Balance: Aldosterone

- A decrease in Na+ levels in the plasma stimulates aldosterone release.
- The kidneys detect the decrease in Na+ levels and cause a series of reactions referred to as the renin-angiotensin-aldosterone mechanisms.
- This is mediated by the juxtaglomerular apparatus, which releases renin in response to:
    - Sympathetic nervous system stimulation.
    - Decreased filtrate osmolality.
    - Decreased stretch (due to decreased blood pressure)
- Sodium reabsorption
    - 65% of sodium in filtrate is reabsorbed in the proximal tubules
    - 25% is reclaimed in the loops of Henle
- When aldosterone levels are high, all remaining Na+ is actively reabsorbed.
- Water follows sodium if tubule permeability has been increased with ADH.

Regulation of Sodium Balance: Aldosterone

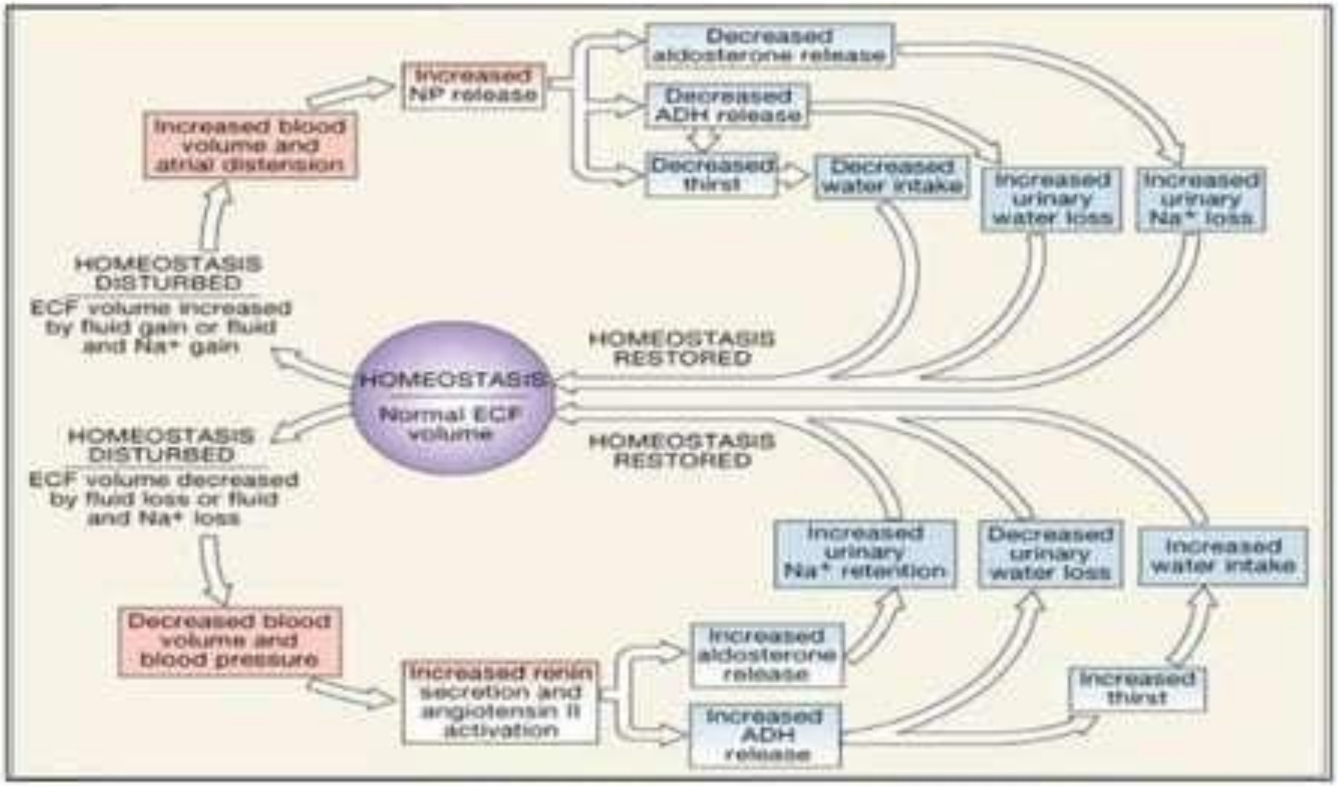


– If sodium levels are too high,it is termed as HYPERNATREMIA.

- In this, atrial natriuretic peptide (ANP) is secreted.

- **ATRIAL NATRIURETIC PEPTIDE (ANP) :**

  - Is released in the heart atria as a response to stretch (elevated blood pressure),
  - It has potent diuretic and natriuretic effects
  - It promotes excretion of sodium and water, inhibits angiotensin II production.



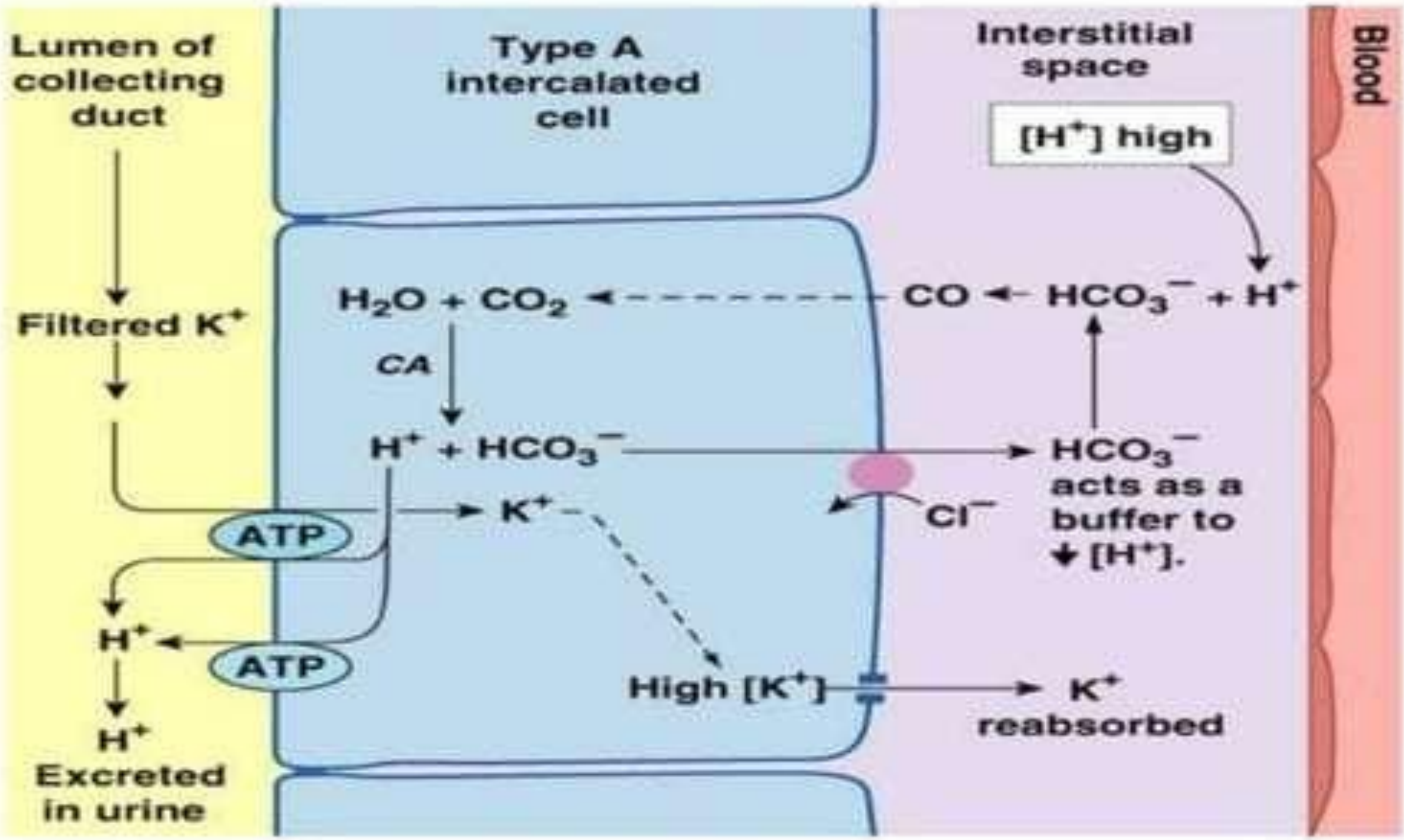
2. POTASSIUM :

- Total body potassium is determined by the balance between potassium intake and excretion.
- Potassium controls its own ECF concentration via feedback regulation of aldosterone release.

***Regulation of Potassium :**

- An increase in K+ levels stimulates the release of aldosterone through the renin-angiotensin-aldosterone mechanism or through the direct release of aldosterone from the adrenal cortex cells.
- Aldosterone stimulates potassium ion excretion from the kidneys.
- In cortical collecting ducts, for each Na+ reabsorbed, a K+ is excreted.
- When K+ levels are low, the amount of secretion and excretion is kept to a minimum.
- Excessive ECF potassium (**hyperkalemia**) decreases membrane potential
- Too little potassium (**hypokalemia**) causes hyperpolarization and nonresponsiveness.
- **Hyperkalemia** and **hypokalemia** can
    - Disrupt electrical conduction in the heart,
    - Lead to sudden death.
- Hydrogen ions shift in and out of cells lead to corresponding shifts in potassium in the opposite direction and interferes with activity of excitable cells.

POTASSIUM BALANCE :



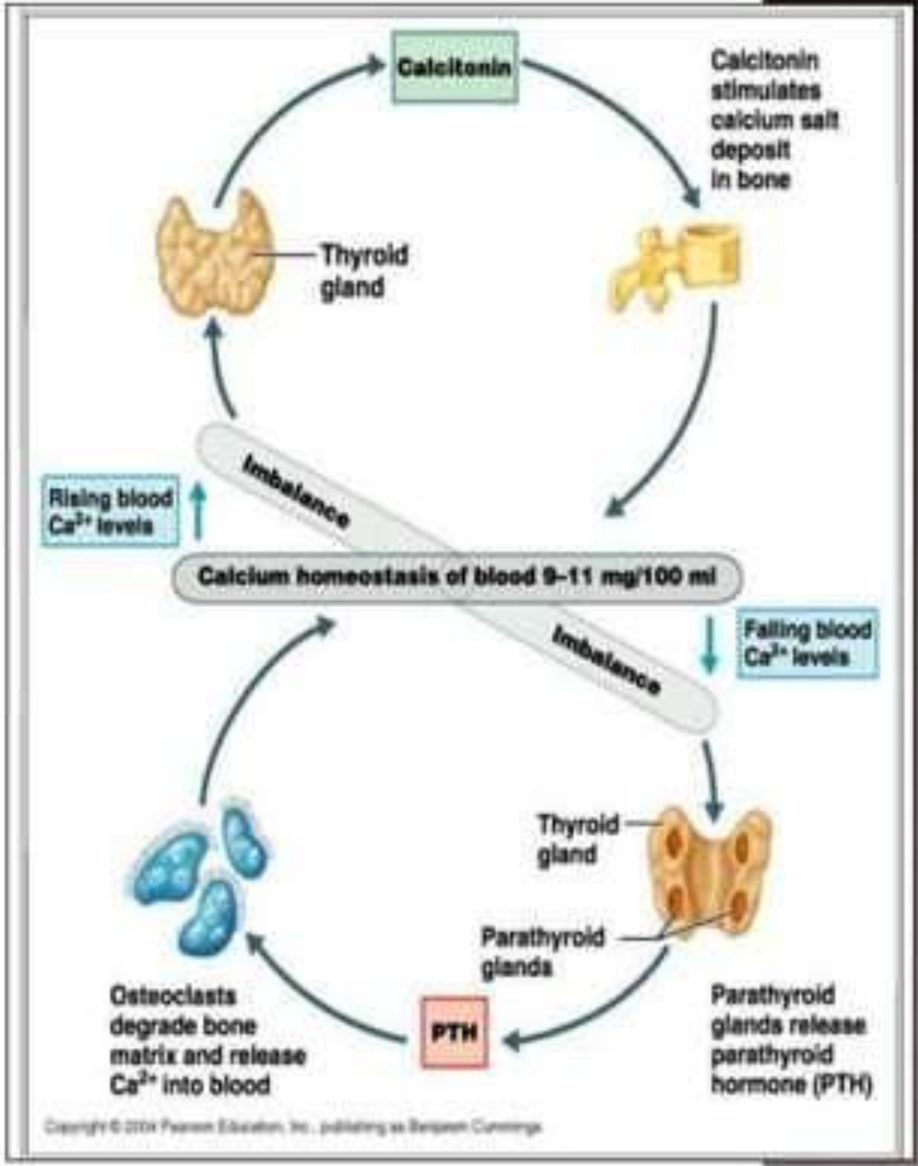
3. CALCIUM :

- Ionic calcium in ECF is important for blood clotting, cell membrane permeability, and secretory behavior.
- Increase in calcium levels , is **HYPERCALCEMIA.**
- Decrease in calcium levels, is **HYPOCALCEMIA.**
- Hypocalcemia increases excitability and causes muscle tetany.
- Hypercalcemia inhibits neurons and muscle cells and may cause heart arrhythmias.

*** Regulation of calcium :**

- Two hormones regulate blood calcium levels:
    1. Parathyroid Hormone (PTH) (made by the parathyroid glands)
    2. Calcitonin (CT) (made by the thyroid glands)
- As calcium-rich foods are ingested, blood calcium levels rise. The thyroid gland releases calcitonin (CT) .
    - CT binds to receptors on osteoblasts (bone-forming cells).
    - This triggers the osteoblasts to deposit calcium salts into bone throughout the skeletal system.
    - This causes the blood calcium levels to fall.
    - CT stops being produced when blood calcium levels return to normal.
- When blood calcium levels fall, the parathyroid glands (located on posterior surface of the thyroid gland) release PTH.
    - PTH binds to receptors on osteoclasts (bone-degrading cells) within the skeletal system.
    - The osteoclasts decompose bone and release calcium into the blood.
    - The blood calcium level rises.
    - PTH stops being produced when blood calcium levels return to normal.

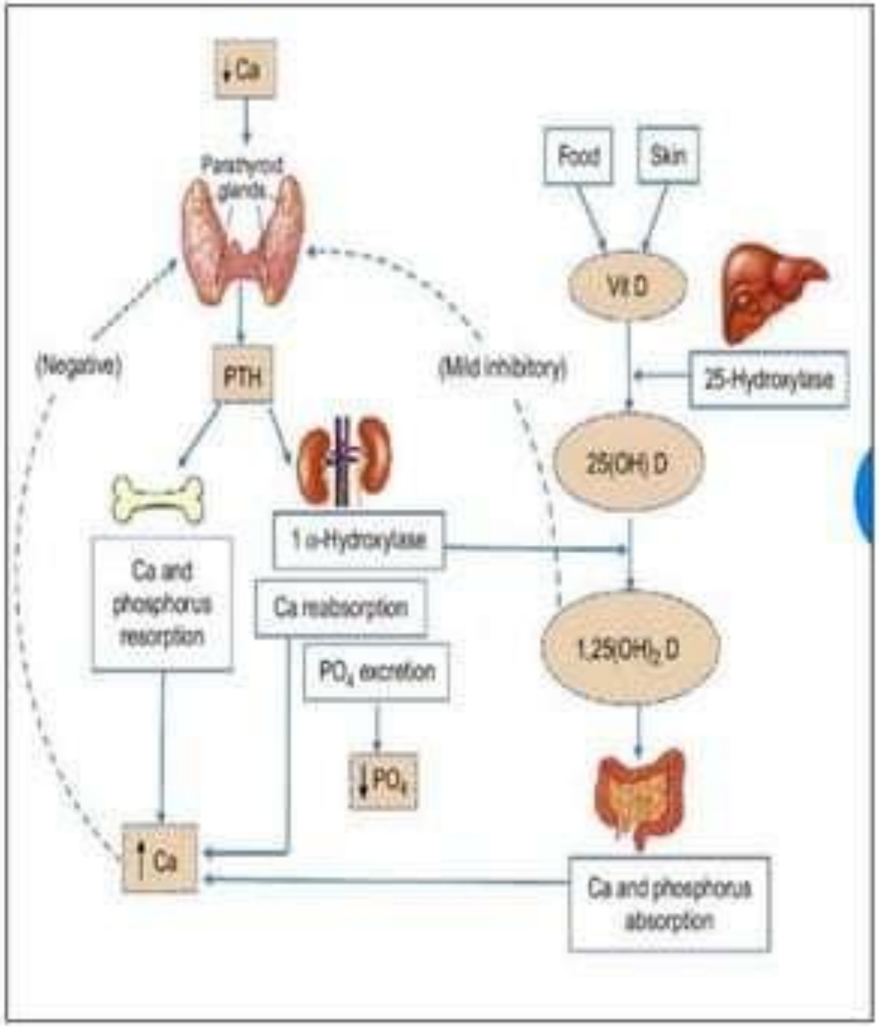
- Calcium reabsorption and phosphate excretion go simultaneously:
  - Filtered phosphate is actively reabsorbed in the proximal tubules.
  - In the absence of PTH, phosphate reabsorption is regulated by its transport maximum and excesses are excreted in urine.
  - High or normal ECF calcium levels inhibit PTH secretion.
  - Release of calcium from bone is inhibited.
  - Larger amounts of calcium are lost in feces and urine.
  - More phosphate is retained.

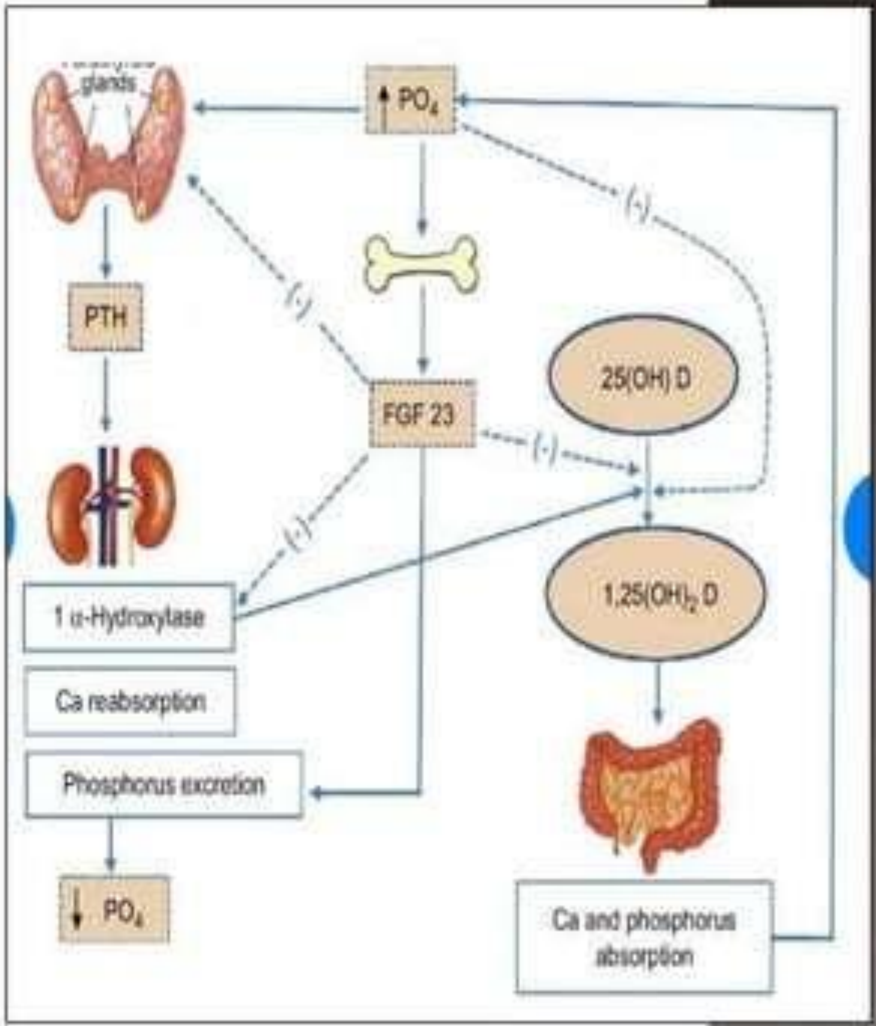


4. PHOSPHATE :

- Phosphate is an electrolyte, which is an electrically charged substance that contains the mineral phosphorus.
- Your body needs some phosphate to strengthen your bones and teeth, produce energy, and build cell membranes. Yet in larger-than-normal amounts, phosphate can cause bone and muscle problems and increase your risk for heart attacks and strokes.
- A high phosphate level is often a sign of kidney damage. It's more common in people with chronic kidney disease (CKD), especially in those with end-stage kidney disease.
- Having a high level of phosphate or phosphorus in your blood is known as **hyperphosphatemia.**
- And low level of phosphate or phosphorus is known as **hypophosphatemia.**

REGULATION OF PHOSPHATE :





5. MAGNESIUM :

- Magnesium is one of the body's electrolytes, which are minerals that carry an electric charge when dissolved in body fluids such as blood, but the majority of magnesium in the body is uncharged and bound to proteins or stored in bone.
- Bone contains about half of the body's magnesium. Blood contains very little. Magnesium is necessary for the formation of bone and teeth and for normal nerve and muscle function. Many enzymes in the body depend on magnesium to function normally. Magnesium is also related to the metabolism of calcium and the metabolism of potassium.
- The level of magnesium in the blood depends largely on how the body obtains magnesium from foods and excretes it in urine and stool and less so on the total body stores of magnesium.

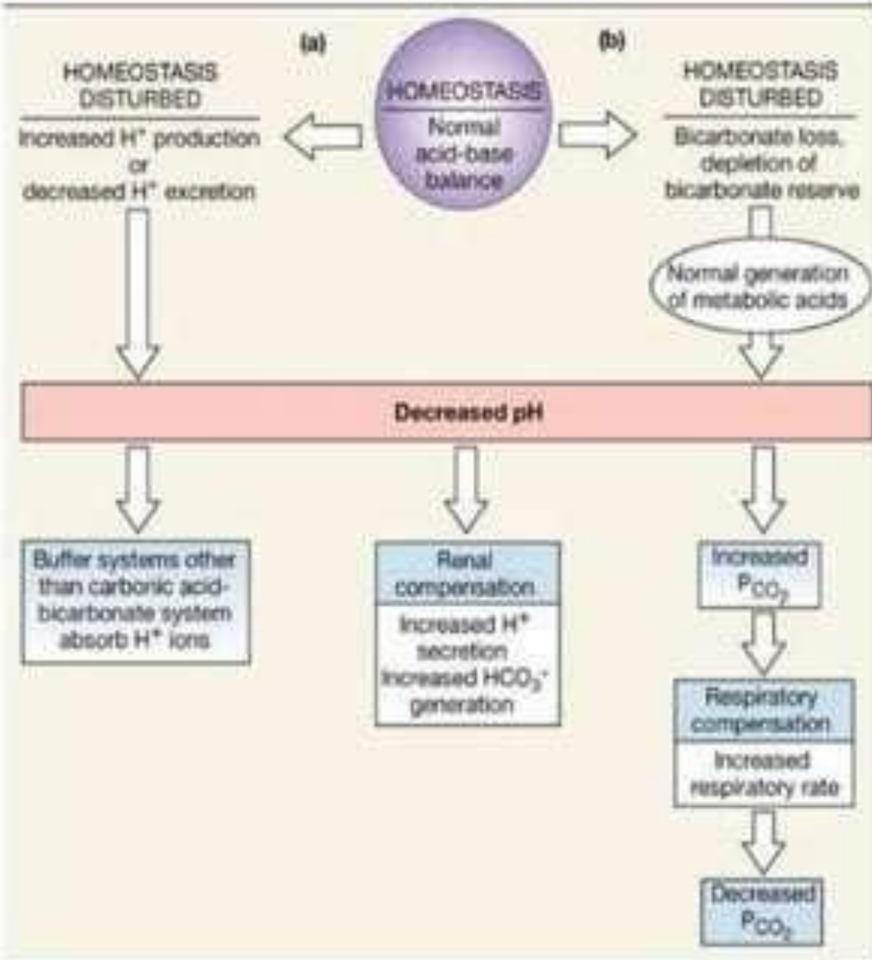
- The level of magnesium in the blood can become
  - Too high - **Hypermagnesemia**
  - Too low - **Hypomagnesemia**

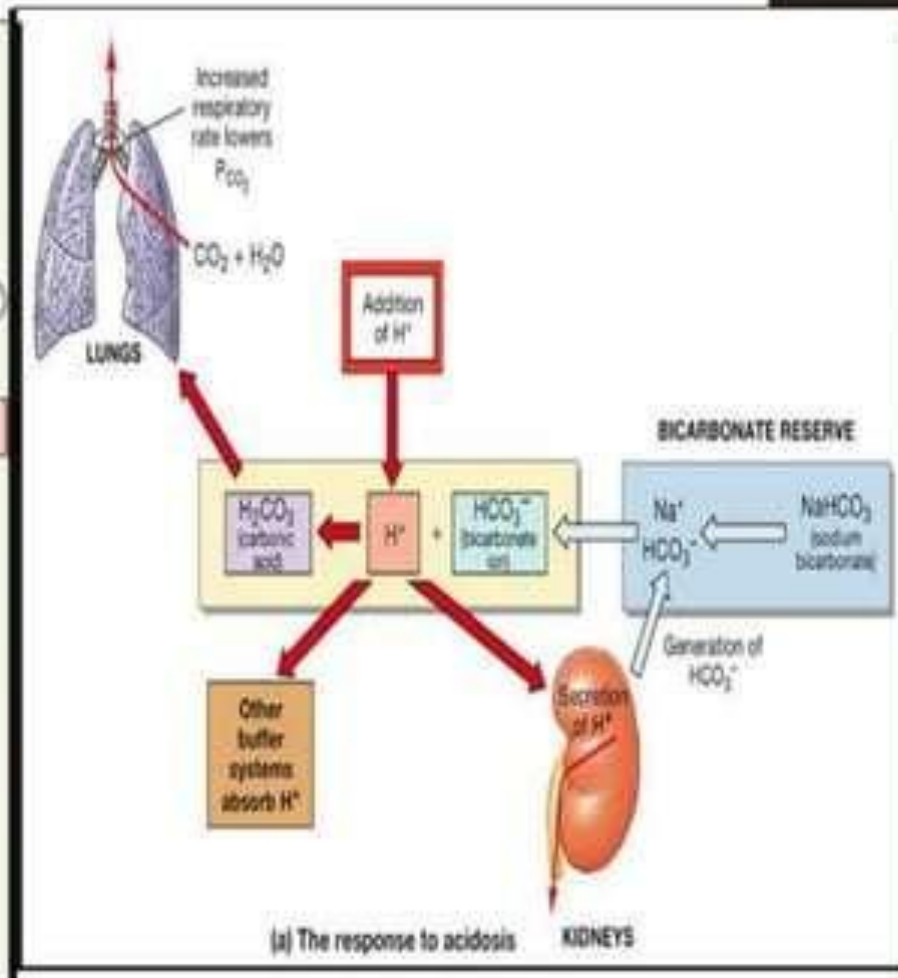
- Hypermagnesemia is uncommon. It usually develops only when people with kidney failure are given magnesium (Epsom) salts or take drugs that contain magnesium (such as some antacids or laxatives).

- Hypomagnesemia is caused due to consuming large amounts of alcohol, Protracted diarrhea, High levels of aldosterone, vasopressin (antidiuretic hormone), or thyroid hormones, Drugs that increase magnesium excretion, including diuretics, the antifungal drug amphotericin B, and the chemotherapy drug cisplatin, Chronic use of a proton pump inhibitor.

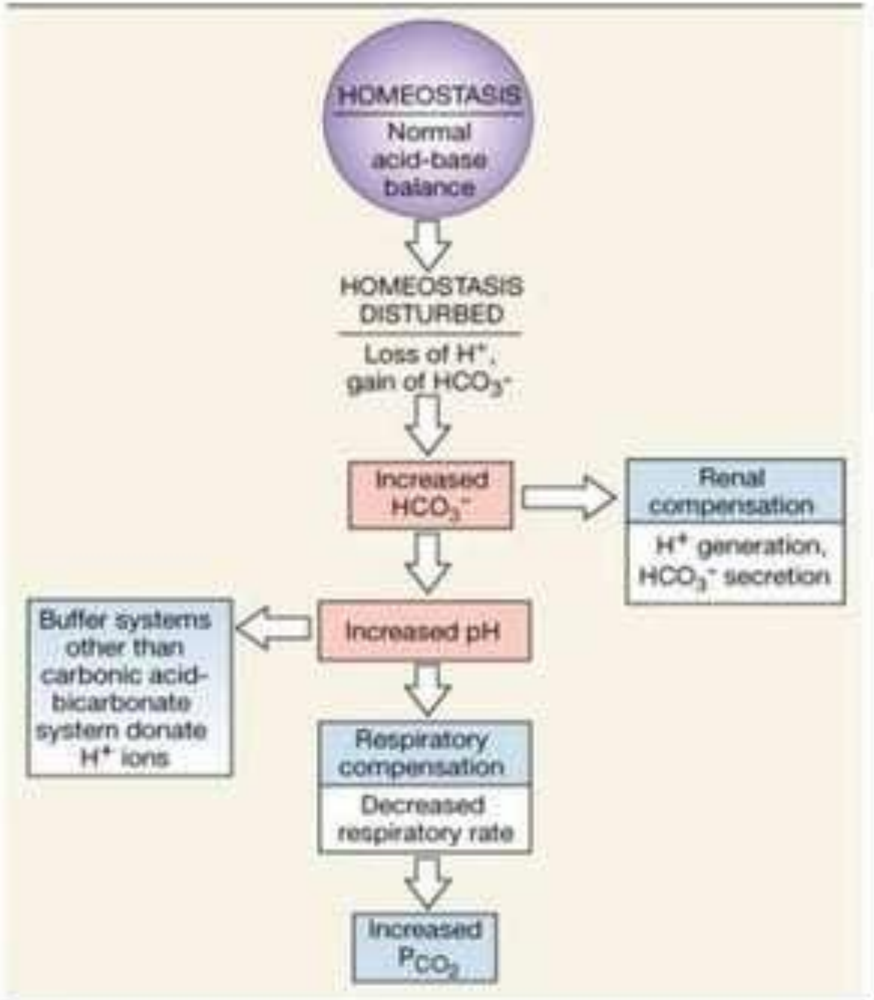
ACID - BASE BALANCE :

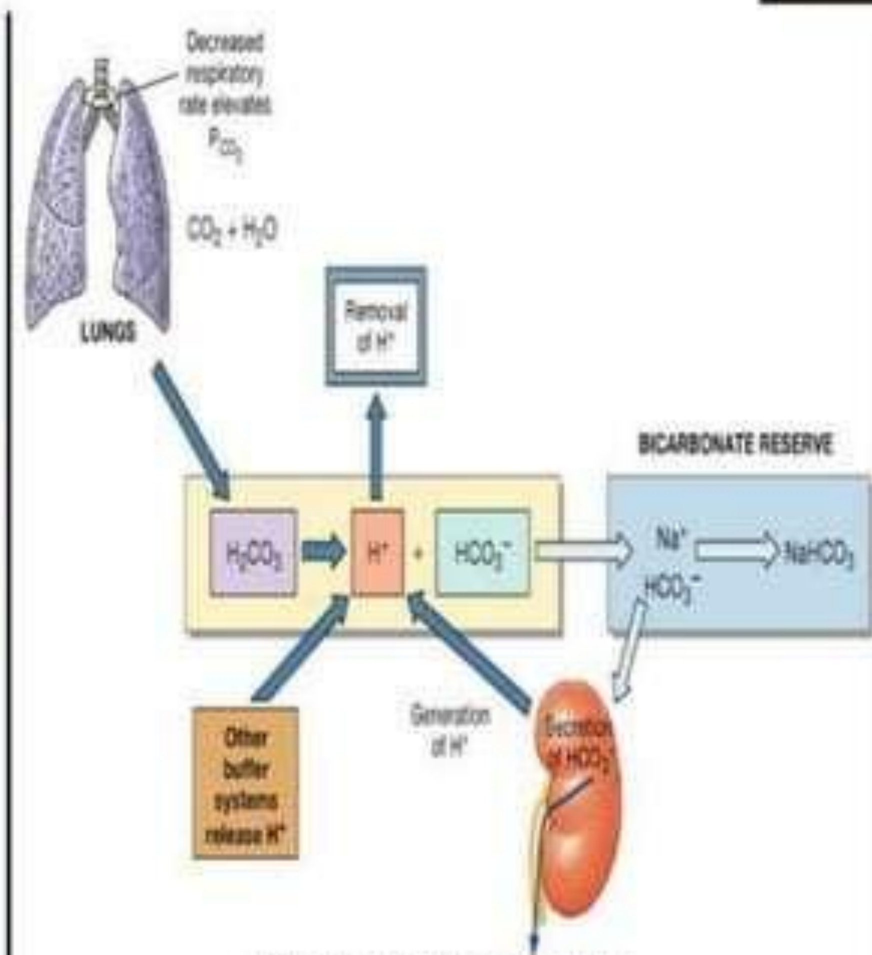
- Molecules that are dissolved in water may dissociate into charged ions.
- An acid is a substance that increases the number of H+ ions in a solution.
- A base is a substance that decreases the number of H+ ions in a solution.
- Normal pH of body fluids:
  - Arterial blood is 7.4
  - Venous blood and interstitial fluid is 7.35
  - Intracellular fluid is 7.0
- Important part of homeostasis because cellular metabolism depends on enzymes, and enzymes are sensitive to pH.
- Challenges to acid-base balance due to cellular metabolism: produces acids – hydrogen ion donors.
- **Acidosis** (physiological acidosis) is a blood pH below 7.35. Its principal effect is depression of the central nervous system by depressing synaptic transmissions.
- **Alkalosis** is a blood pH above 7.45. Its principal effect is overexcitability of the central nervous system through facilitation of synaptic.





(a) The response to acidosis





(b) The response to alkalosis

Sources of Hydrogen Ions :

- Most hydrogen ions originate from cellular metabolism
  - Breakdown of phospho rus-containing proteins releases phosphoric acid into the ECF.
  - Anaerobic respiration of glucose produces lactic acid.
  - Fat metabolism yields organic acids and ketone bodies.
  - Transporting carbon dioxide as bicarbonate releases hydrogen ions.

Hydrogen Ion Regulation :

- Concentration of hydrogen ions is regulated sequentially by:
  - Chemical buffer systems act within seconds.
  - The respiratory center in the brain stem acts within 1-3 minutes.
  - Renal mechanisms require hours to days to affect pH changes.

Chemical Buffer Systems :

• A buffer is a solution whose function is to minimize the change in pH when a base or an acid is added to the solution.

• Most buffers consist of a weak acid (which releases H+ ions) and a weak base (which binds H+ ions).

• If an acidic solution is added to a buffer solution, the buffer will combine with the extra H+ ions and help to maintain the pH.

• If a basic solution is added to a buffer solution, the buffer will release H+ ions to help maintain the pH.

• There are many different buffers and each one stabilizes the pH of the solution within a specific pH range.

•One buffer may be effective within a range of pH 2 to pH 6, while another buffer may be effective within a range of pH 10 to pH 12.

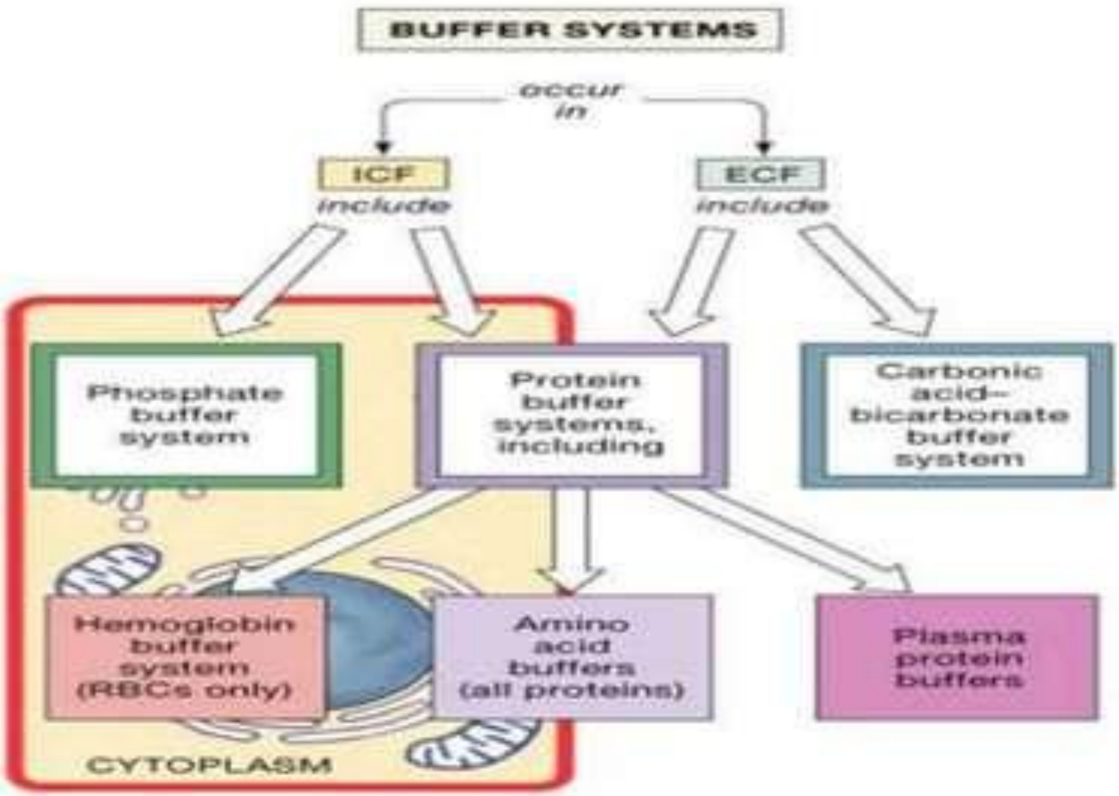
• Strong Acids - all their H+ is dissociated completely in water.

Weak Acids - dissociate partially in water and are efficient at preventing pH changes.

Strong Bases - dissociate easily in water and quickly tie up H+

Weak Bases - accept H+ more slowly (e.g., $HCO3^{-}$ and NH3).

- The three main buffer systems in our bodies are the:
  1. bicarbonate buffer system
  2. phosphate buffer system
  3. protein buffer system



1. Bicarbonate Buffer System :

- Is a mixture of carbonic acid (H_2CO_3) and its salt, sodium bicarbonate ($NaHCO_3$) (potassium or magnesium bicarbonates.
- If strong acid is added:
  - Hydrogen ions released combine with the bicarbonate ions and form carbonic acid (a weak acid).
  - The pH of the solution decreases only slightly.
- If strong base is added:
  - It reacts with the carbonic acid to form sodium bicarbonate (a weak base).
  - The pH of the solution rises only slightly.
- This system is the only important ECF buffer.

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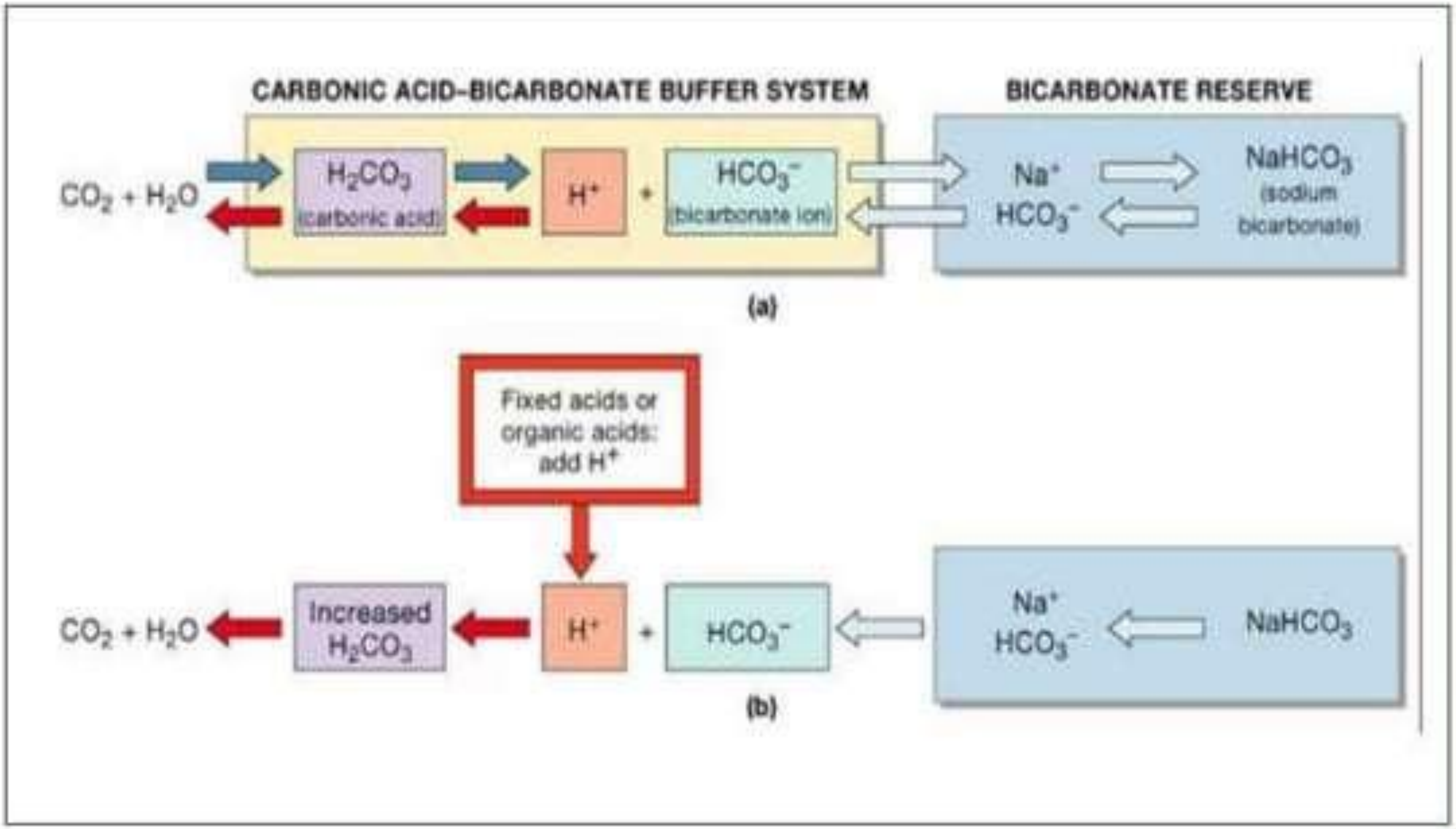
CARBONIC ACID–BICARBONATE BUFFER SYSTEM
BICARBONATE RESERVE
$CO_2 + H_2O$
H_2CO_3
(carbonic acid)
H^+
+
HCO_3^-
(bicarbonate ion)
Na^+
HCO_3^-
$NaHCO_3$
(sodium bicarbonate)
(a)
Fixed acids or organic acids: add H^+
$CO_2 + H_2O$
Increased H_2CO_3
H^+
+
HCO_3^-
Na^+
HCO_3^-
$NaHCO_3$
(b)

2. Phosphate Buffer System :

- Nearly identical to the bicarbonate system.
- Its components are:
  - Sodium salts of dihydrogen phosphate ($NaH2PO4^{-}$), a weak acid
  - Monohydrogen phosphate ($Na2HPO42^{-}$), a weak base.
- This system is an effective buffer in urine and intracellular fluid.

3. Protein Buffer System :

- Plasma and intracellular proteins are the body's most plentiful and powerful buffers.
- Some amino acids of proteins have:
  - Free organic acid groups (weak acids)
  - Groups that act as weak bases (e.g., amino groups)
- Amphoteric molecules are protein molecules that can function as both a weak acid and a weak base.

THANK YOU