

Water, Electrolyte and Acid-Base Balance

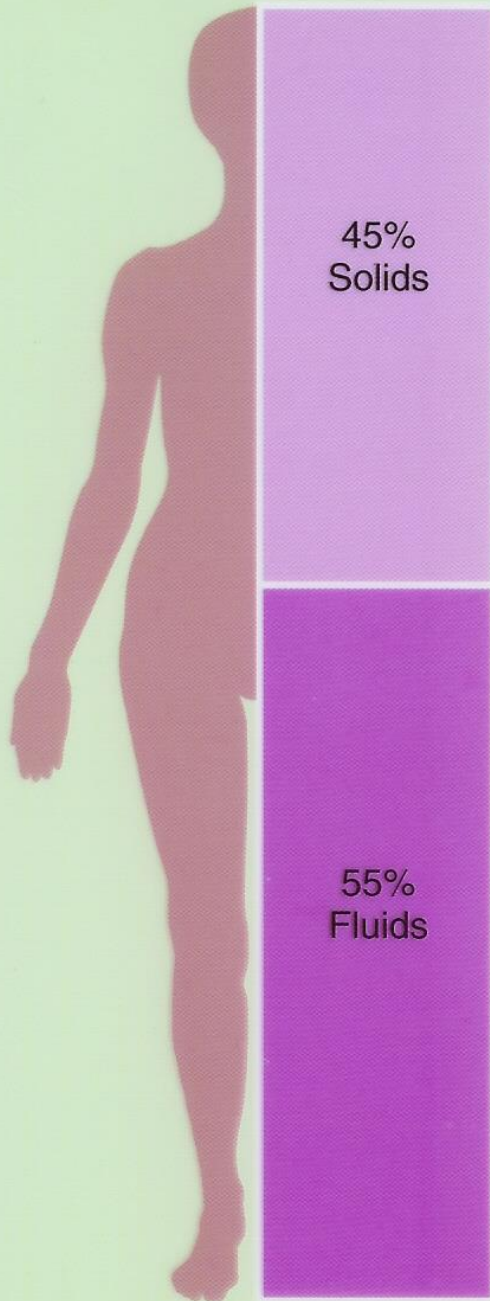
Water

- ▶ Water is the major component of all living organisms.
- ▶ It constitutes 60-70% or more of the weight of most living things, and it pervades all portions of every cell.
- ▶ Water is the universal solvent and dispersing agent, as well as a very reactive chemical compound. Water is an essential constituent of all cell structures and is the medium in which all the chemical reactions of a cellular metabolism take place.
- ▶ Water is a major component of every body cell, tissue and organ constituting about 50-70%.
- ▶ Approximately 90% of the water present in the human body is present in a cell the basic unit of the body.
- ▶ It plays an important role in almost every body function.
- ▶ It is distributed throughout the body as the major component of the intracellular and extracellular fluid.

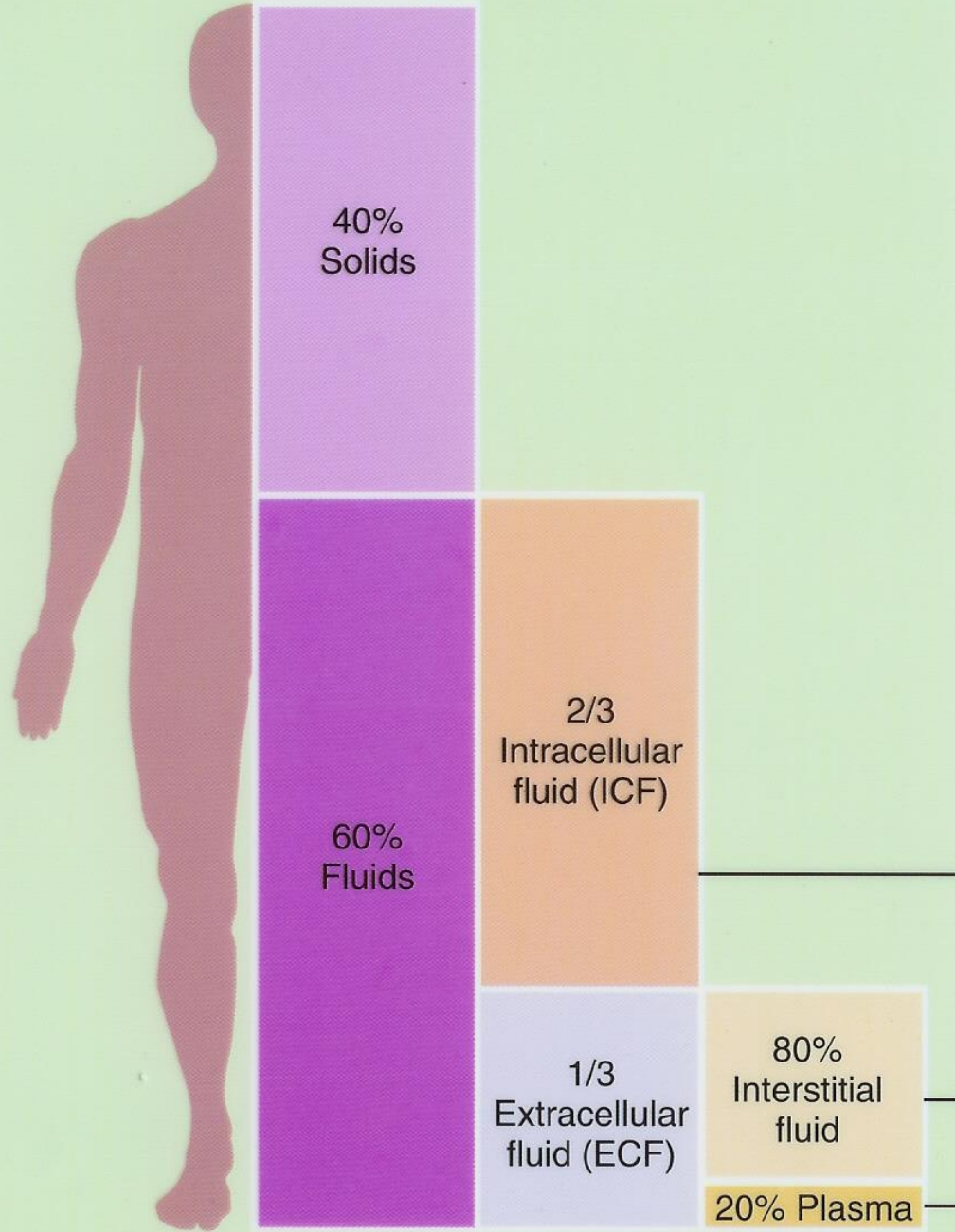
Water Balance

- ▶ Input = Output is balance
- ▶ Balance through osmosis
- ▶ Conc. of solutes determines direction
- ▶ Most solutes in body are **electrolytes**

Total body weight (female)



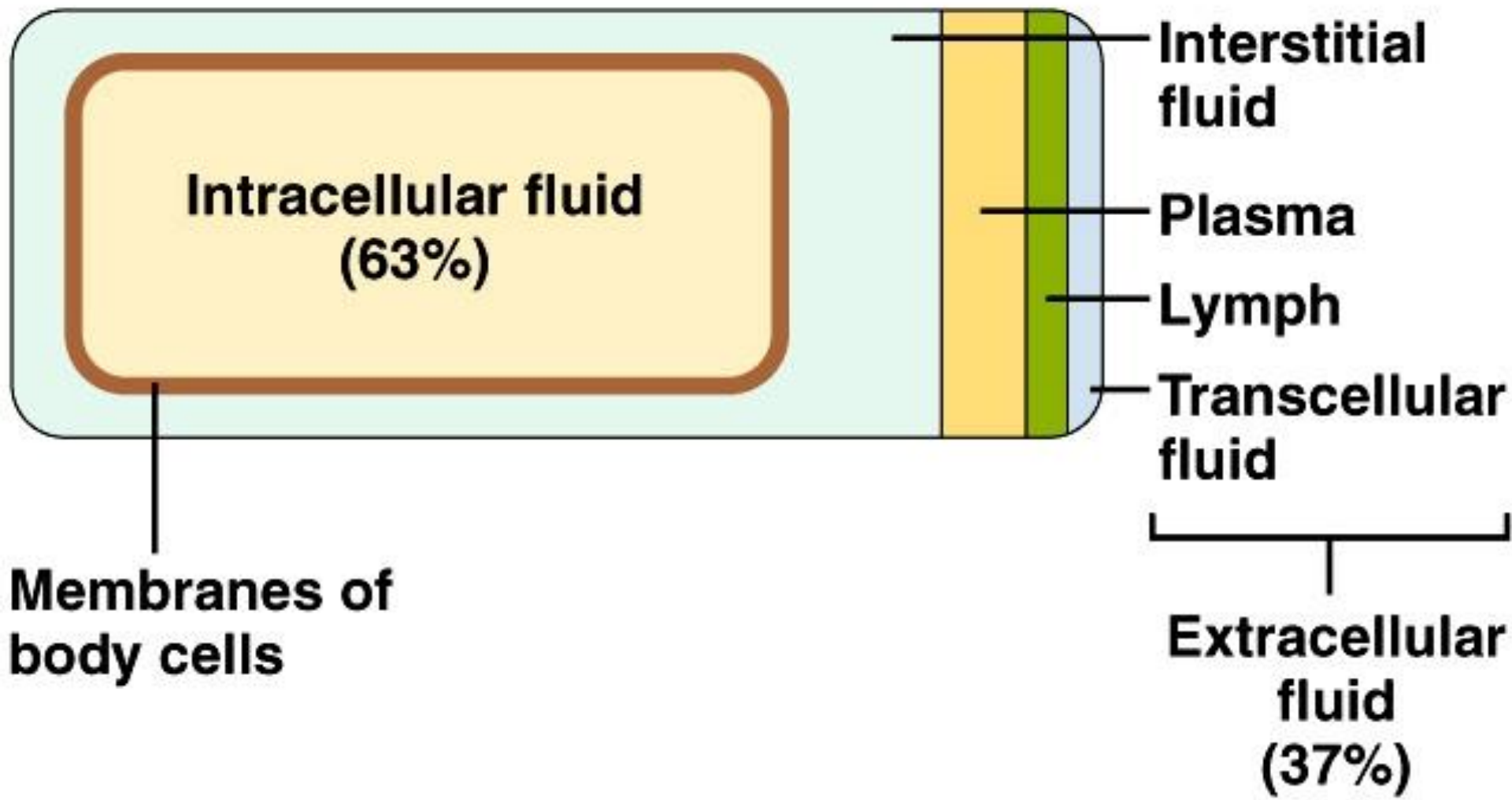
Total body weight (male)



Fluid compartments

- ▶ Separated by selectively permeable membranes
- ▶ Intracellular - $\frac{2}{3}$ (63%) of total body water
- ▶ Extracellular - $\frac{1}{3}$ (37%)
 - ▶ Interstitial fluid - 80% of extracellular water
 - ▶ Blood plasma - 20% of extracellular water

Total body water



**Intracellular fluid
(63%)**

**Interstitial
fluid**

Plasma

Lymph

**Transcellular
fluid**

**Extracellular
fluid
(37%)**

**Membranes of
body cells**

Composition of compartments

▶ Extracellular fluids:

- ▶ High in Na^+ , Cl^- , Ca^{++} , HCO_3^-
 - ▶ Blood plasma has more protein than interstitial fluid and lymph

▶ Intracellular fluids:

- ▶ High in K^+ , phosphate, Mg^{++} , and more protein than plasma

Movement of water

- ▶ **Hydrostatic pressure**

- pressure of fluids

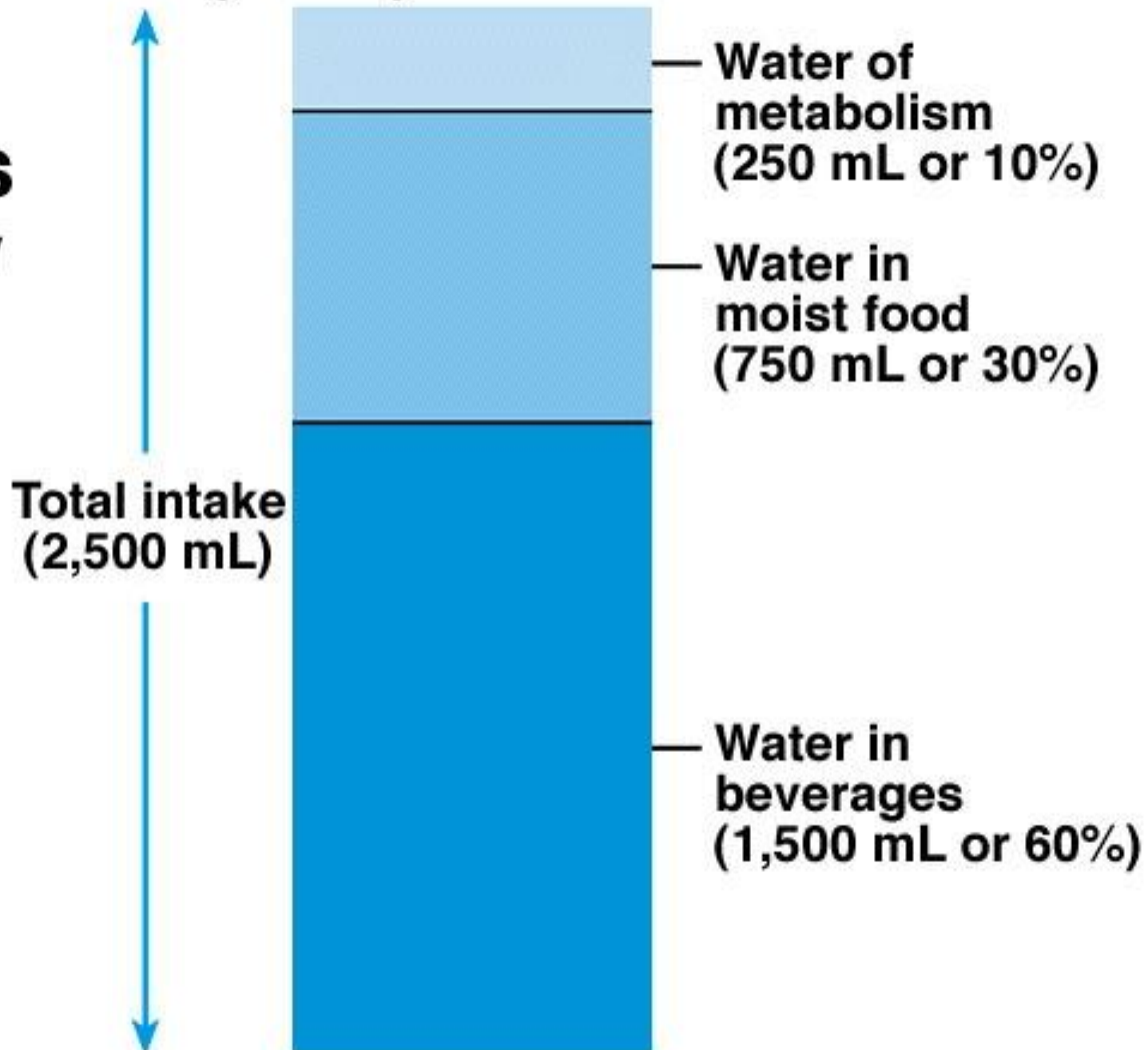
- ▶ **Osmotic pressure**

- solute concentration

- ▶ In blood it is colloid osmotic pressure (COP)

Average daily intake of water

Major Sources of Body Water



Regulation of water intake

- ▶ Main regulator is **thirst**.
- ▶ Dehydration i.e 1% decrease in water causes:
 - ▶ Decreased production of saliva
 - ▶ Increased blood osmotic pressure BP - stimulates **osmo-receptors** in hypothalamus
 - ▶ Decreased blood volume - **renin** is produced

Average daily output of water

Water Output

Total output
(2,500 mL)



Water lost in
sweat (150 mL or 6%)

Water lost in
feces (150 mL or 6%)

Water lost through
skin and lungs
(700 mL or 28%)

Water lost
in urine
(1,500 mL or 60%)

Regulation of Water Output

- ▶ **Urine regulation**
- ▶ **Anti diuretic hormone (ADH)** in pituitary stimulated by high blood tonicity (low blood volume)
 - ▶ Acts on distal convoluted tubules and collecting ducts of kidney - permits reabsorption of water

▶ **Aldosterone** - is stimulated by angiotensin II through renin production

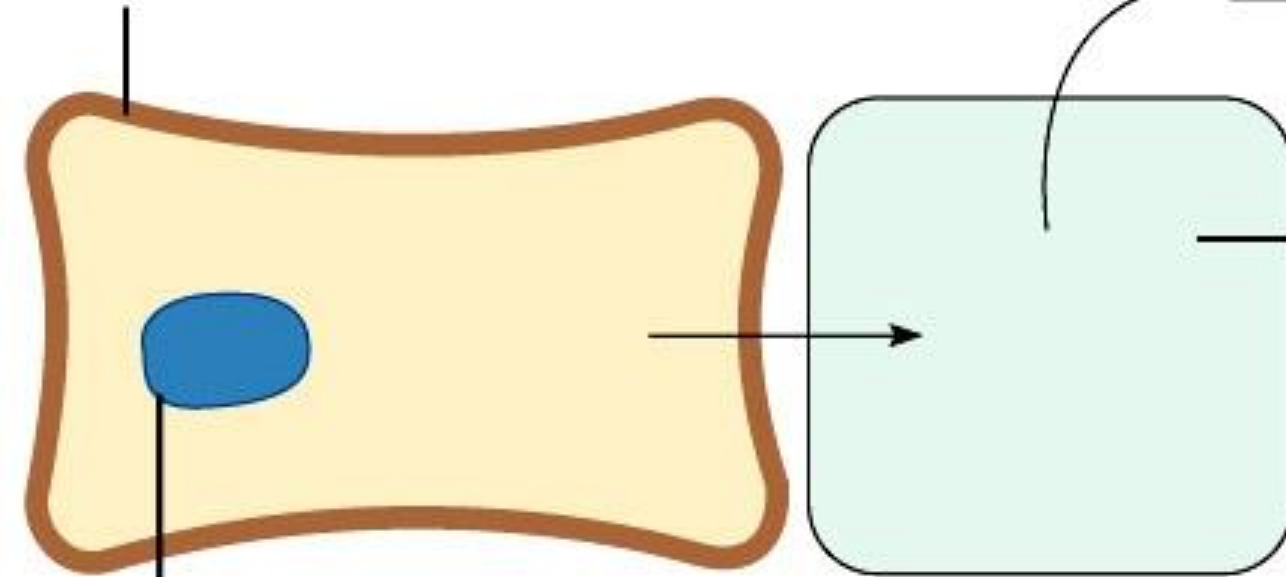
▶ Causes sodium (and water) reabsorbed

▶ **Atrial Natriuretic Peptide (ANP)** - causes sodium (and water) loss when pressure in right atrium is too high

Water imbalances

- ▶ **Dehydration** is the major imbalance
 - ▶ Prolonged diarrhea or vomiting
 - ▶ Excessive sweating
- ▶ **Overhydration** occurs if amount of salt and other electrolytes in your body become too diluted or fluids are given too rapidly or in too large amounts.
 - ▶ Extra fluid puts strain on heart

**Cell
membrane**



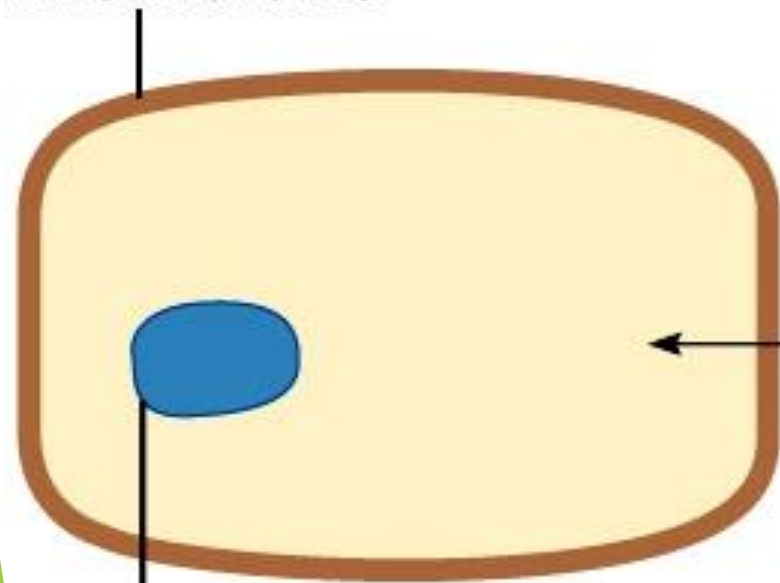
1 Water loss from
extracellular fluid
compartment

2 Solute
concentration
increases in
extracellular
fluid
compartment

3 Water leaves
intracellular fluid
compartment
by osmosis

Nucleus

**Cell
membrane**



Nucleus

1 Excess water is added to extracellular fluid compartment

2 Solute concentration of extracellular fluid compartment decreases

3 Water moves into intracellular fluid compartment by osmosis

- ▶ Water that moves back into capillaries depends on conc. of plasma proteins.
- ▶ Decrease in blood proteins caused by:
 - ▶ Dietary deficiency in proteins
 - ▶ Liver failure
 - ▶ Blockage of lymphatic system
 - ▶ Increased capillary permeability
 - ▶ Burns, infection

- ▶ Fluid moves from the blood to interstitial fluid.
- ▶ Of the three main compartments, ISF varies the most.
- ▶ **Edema** is a condition when large amounts of fluid in intercellular spaces
- ▶ Edema is caused by:
 - ▶ Decrease in plasma proteins
 - ▶ Retention of electrolytes, esp. Na⁺
 - ▶ Increase in capillary blood pressure

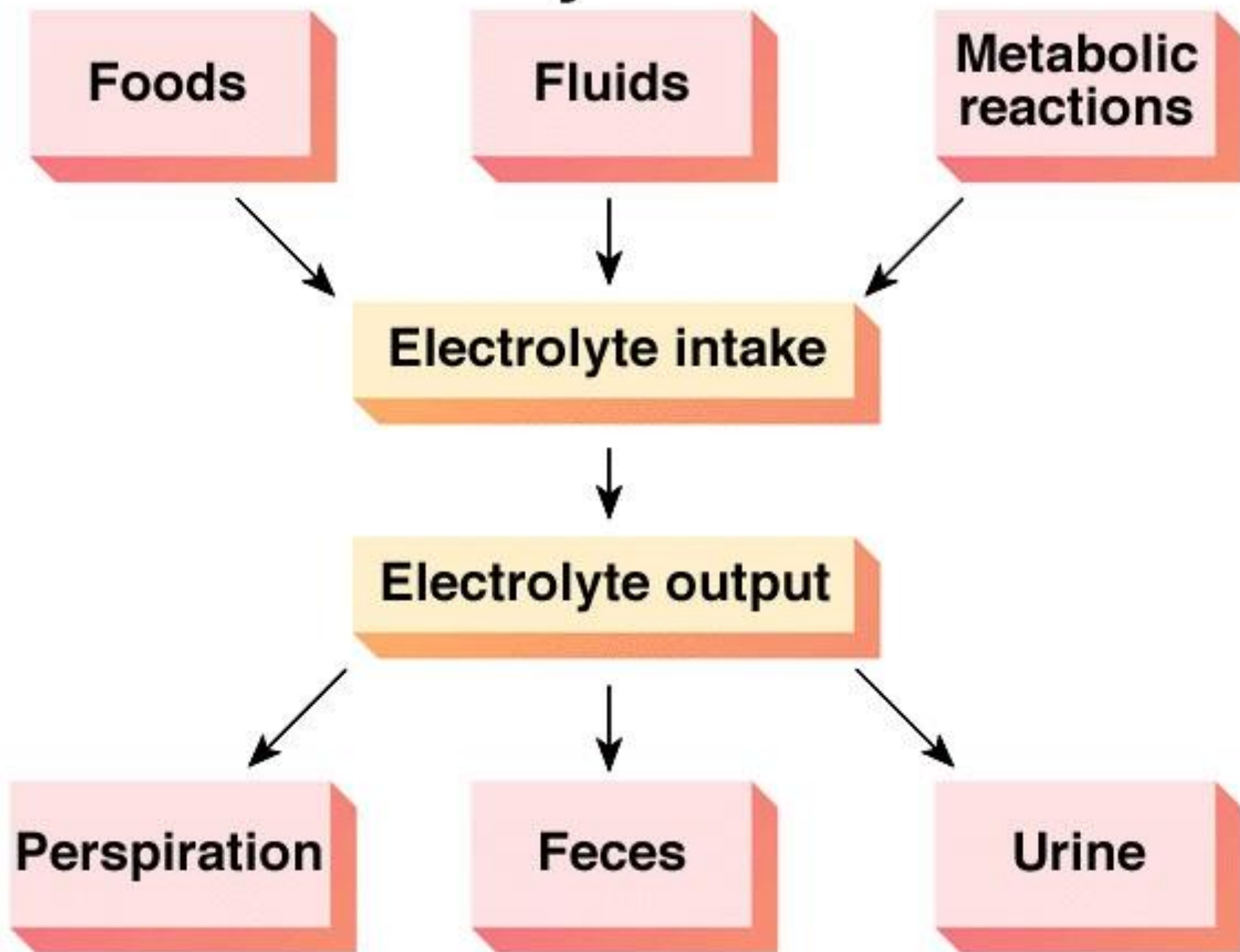
Electrolyte Balance

- ▶ Body fluids contain electrolytes and charged organic molecules
- ▶ A small percentage of molecules are non-electrolytes: glucose, urea, creatinine

Functions of electrolytes

- ▶ Control the osmosis of water
- ▶ Maintain acid-base balance
- ▶ Carry electric current - action potentials and secretion of neurotransmitters
- ▶ Cofactors needed for enzymes

Electrolyte Balance



Osmolarity

- ▶ Total conc. of dissolved particles determines osmolarity
- ▶ Glucose - one dissolved particle
- ▶ NaCl - dissolves into two particles
- ▶ One mole of NaCl = 2 osmoles
- ▶ Osmoles/L = osmolarity of solution

Sodium (Na^+)

- ▶ Extracellular cations - 90%
- ▶ Half osmolarity of Extracellular fluid
- ▶ Action potentials in nerve & muscle cells

- ▶ **Aldosterone** increases re-absorption from Distal convoluted tubule and collecting ducts
 - ▶ ↓ blood volume, ↓ extracellular Na^+ ,
↑ extracellular K^+
- ▶ **ANP** causes loss of Na^+

Potassium (K^+)

- ▶ Intracellular cation
- ▶ Membrane potential and repolarization
- ▶ **Aldosterone** - causes loss of K^+ in urine

Potassium/Sodium Balance

Potassium ion concentration increases

Sodium ions are conserved and potassium ions are excreted

Adrenal cortex is signaled

Renal tubules increase reabsorption of sodium ions and increase secretion of potassium ions

Aldosterone is secreted

Calcium (Ca⁺⁺)

- ▶ Extracellular cation
- ▶ Most abundant in bone, 98%
- ▶ Blood clotting, nerve and muscle function
- ▶ **Parathyroid hormone (PTH)** - re-absorption of bone and increases re-absorption from G.I tract and glomerular filtrate.
- ▶ **Calcitonin** inhibits osteoclasts and stimulates osteoblast, so calcium is removed from blood

Chloride (Cl⁻)

- ▶ Most common extracellular anion
- ▶ Cl⁻ diffuses easily between compartments -

- ▶ Parietal cells secrete Cl⁻ & H⁺
- ▶ **Aldosterone** indirectly adjusts Cl⁻
 - during reabsorption of Na⁺

Bicarbonate (HCO_3^-)

- ▶ Body's chief buffer
- ▶ Transports CO_2 in blood stream.



- ▶ **Kidneys** are main regulators of bicarbonate: - - form HCO_3^- when levels are low and excrete it when levels are high.

Phosphate (HPO_4^{2-})

- ▶ Phosphate found in bones -15% in ionized form
- ▶ Combination with lipids, proteins, carbohydrates, nucleic acids and ATP.
- ▶ Part of phosphate buffer system
- ▶ **PTH** release phosphate from bones to be excreted by kidneys.
- ▶ **Calcitonin** removes phosphate by encouraging bone formation.

Acid-Base Balance

- ▶ pH - negative log of H^+ concentration
 - ▶ Affects functioning of proteins (enzymes)
 - ▶ Affects concentration of other ions
 - ▶ Modify hormone actions (proteins)
-
- ▶ Blood needs pH 7.35 - 7.45 for normal body function.
 - ▶ pH balance is done by controlling excess H^+

Control of Acid-Base Balance

1. Buffer systems
2. Exhalation of carbon dioxide
3. Kidney excretion

1. Buffer systems

- ▶ Two chemical substances that prevent a sharp change in pH of a solution.
- ▶ Buffers exchange strong acids for weaker acids that do not release as much H^+ and thus change the pH less.
- ▶ Bicarbonate buffer system
- ▶ Phosphate buffer system
- ▶ Protein buffer system

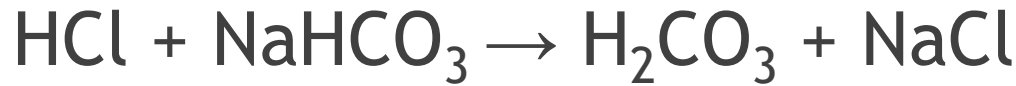
Bicarbonate Buffer System



sodium bicarbonate

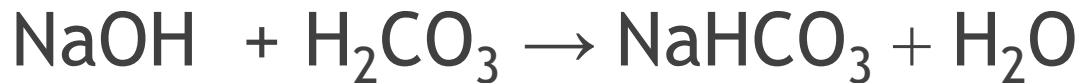
carbonic acid

Addition of a strong acid:



Carbonic acid does not dissociate completely, and so, pH change is much less.

Addition of a strong base:



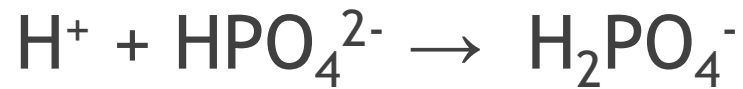
Water dissociates very little, and so, pH remains nearly the same.

- ▶ Blood needs to maintain a 20:1 ratio of bicarbonate ion : carbonic acid.
- ▶ Carbonic acid is the most abundant acid because it is constantly being formed by buffering fixed acids and by:



Phosphate Buffer System

- ▶ Present in extracellular and intracellular fluids (most) and renal tubules.



monohydrogen phosphate dihydrogen phosphate



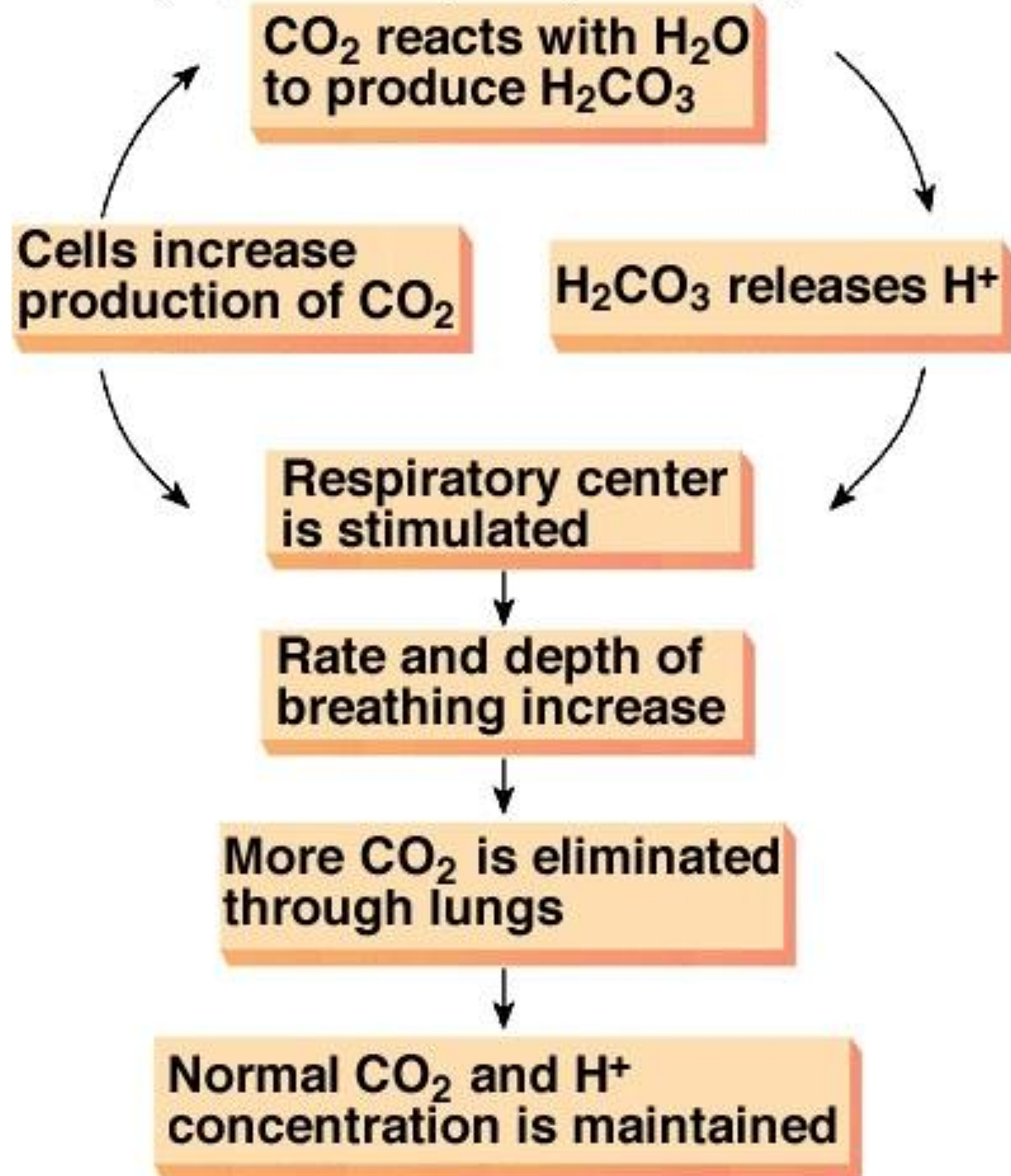
Protein Buffer System

- ▶ Abundant in body cells and plasma.
- ▶ Carboxyl group $\text{-COOH} \leftrightarrow \text{-COO}^- + \text{H}^+$
- ▶ Amino group $\text{-NH}_2 \leftrightarrow \text{-NH}_3^+$

2. Exhalation of CO₂

- ▶ Carbonic acid eliminated by breathing out CO₂
- ▶ Body pH adjusted in about 1-3 min

Carbon Dioxide Balance



3. Kidney excretion of H⁺

- ▶ Metabolic reactions produce fixed acids.
- ▶ Kidneys eliminate more acids than lungs
- ▶ Kidney also excrete bases
- ▶ Kidney excrete acids and conserve HCO₃⁻
- ▶ Kidneys **effective regulators** of pH

**High intake
of proteins**



**Increased
metabolism
of amino acids**



**Increased
formation of
sulfuric acid
and phosphoric
acid**



**Increased concentration
of H⁺ in body fluids**

**Increased
concentration
of H⁺ in urine**



**Concentration
of H⁺ in body
fluids returns
toward normal**



**Increased secretion
of H⁺ into fluid of
renal tubules**



Regulators work at different rates

- ▶ Buffers - first line of defense - work almost instantaneously.
- ▶ Secondary defenses take longer to work:
 - ▶ Respiratory mechanisms take several min to hours
 - ▶ Renal mechanisms take several days

First line of defense against pH shift

Chemical buffer system

Bicarbonate buffer system

Phosphate buffer system

Protein buffer system

Second line of defense against pH shift

Physiological buffers

Respiratory mechanism (CO₂ excretion)

Renal mechanism (H⁺ excretion)

pH imbalances

- ▶ Any pH below optimum pH range - **acidosis**
- ▶ Any pH above this range - **alkalosis**
- ▶ Body response to acid-base imbalance - **compensation**
- ▶ Respiratory acidosis if carbonic acid is excess (blood CO_2 is too high)
- ▶ Respiratory alkalosis if carbonic acid is deficit
- ▶ Metabolic acidosis is a **bicarbonate deficit**
- ▶ Metabolic alkalosis is a **bicarbonate excess**