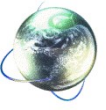


**Adama General and Medical
College and Medical
Department of Biomedical
Sciences
G. Physiology**



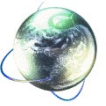
Lata M.

The roots of education are bitter, but the fruit is sweet.



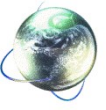
Introduction to Physiology

- **The term - Greek words - physis = nature and logos = study.**
 - ✓ **It is the study of the functions of living things.**
- **Physiology focuses on MOA.**
 - ✓ **The goal - understand the function of living organisms and their parts.**
- **Life - functional characteristics.**
- **Human physiology - how the body systems**



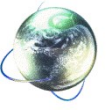
Introduction cont'd...

- **Human physiology - concerned with the characteristics of the human body that allow us to -**
 - ✓ **Sense our environment, move about, think and communicate, reproduce, and perform all of the functions that enable us to survive and thrive as living beings.**
 - ✓ **It is called the science of regulation of the body.**



Levels of Organization in the Body

- **How the body is structurally organized into a total functional unit.**
- 1. **Chemical level :- *can be compared to the letters of the alphabet.***
- **Atoms - smallest building blocks of matter.**
 - ✓ **CHON - most common atoms in the human.**
- **Atoms combine to form a molecule.**
 - **Molecules are the chemical building blocks.**

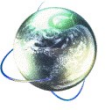


Level of organization cont'd...

- **Atoms and molecules are the inanimate raw ingredients.**

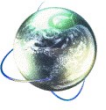
2. Cellular level.

- **Cells - basic units of life and formed by molecules.**
- ✓ ***Words are the smallest elements of language that make sense.***
- **Cell - smallest independently functioning unit (building blocks).**



Level of organization cont'd...

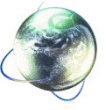
- **In the human - muscle cell, nerve cell, connective cell and epithelial cell.**
- **Common characteristics of all cells -**
 - 1. Bounded.**
 - 2. Undertake metabolism.**
 - 3. In their life history, they possess a nucleus.**



Level of organization cont'd...

3. Tissue level.

- **Tissue - groups of cells of similar specialization.**
 - ✓ ***Words are put together to form sentences.***
- **There are 4 basic types of tissues.**
 - ✓ **Epithelial tissue - covers body and forms glands.**
 - ✓ **Connective tissue - connects, supports, and protects body organs.**



Level of organization cont'd...

- ✓ **Muscular tissue - contracts to make body parts move and generates heat.**
- ✓ **Nervous tissue - carries information from one part of the body to another through nerve impulses.**

4. Organ level.

- **Organs - two or more types of primary tissue organized together to perform a particular function or functions.**

✓ **Combination of different sentences form**



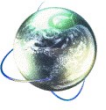
Level of organization cont'd...

- **Organs - brain, heart, lungs, intestines, and liver.**
- **Each organ performs one or more specific physiological functions.**

5. Organ system level

- **Organ system - collection of organs that perform related functions and interact to accomplish a common activity.**

✓ ***Chapter in our language analogy consists of related paragraphs.***

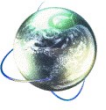


Level of organization cont'd...

- **Human body - 11 systems.**
- **Each body system depends on the proper functioning of other systems.**

6. Organismal level.

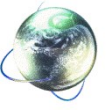
- **Organism - the body systems are packaged together into a functional whole body.**
- ✓ ***An organism can be compared to a book in our analogy.***



Basic Life Processes

1. Metabolism

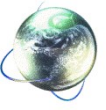
- **All the chemical processes that occur in the body.**
 - ✓ **Catabolism - breakdown of complex chemical substances into simpler components.**
 - ✓ **Anabolism - the building up of complex chemical substances from smaller, simpler components.**



Basic life processes cont'd...

2. Responsiveness

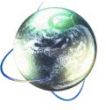
- **The body's ability to detect and respond to changes.**
 - ✓ **It could be within the body and outside the body.**
- **Different cells in the body respond to environmental changes in characteristic ways.**
 - ✓ **Nerve cells respond by generating electrical signals.**



Basic life processes cont'd...

3. Movement

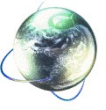
- **Includes motion of the whole body, individual organs, single cells, and even tiny structures inside cells.**
 - ✓ **Coordinated action of leg muscles moves your whole body.**
 - ✓ **Gallbladder contracts and releases bile into the GIT.**
 - ✓ **When a body tissue is infected, certain white blood cells...**



Basic life processes cont'd...

4. Growth

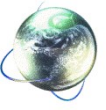
- **An increase in body size.**
 - ✓ **Results from an increase in the size of existing cells, an increase in the number of cells, or both.**
- **A tissue sometimes increases only in size.**



Basic life processes cont'd...

5. Differentiation

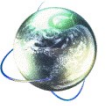
- **Development of a cell from an unspecialized to a specialized state.**
- **Each type of cell in the body has a specialized structure and function.**
 - ✓ **That differs from that of its precursor (ancestor) cells.**
- **A single fertilized human egg develops into an embryo, and then into a fetus, an infant, a child, and finally an adult**



Basic life processes cont'd...

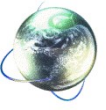
6. Reproduction

- **Either:-**
 - ✓ **The formation of new cells - tissue growth, repair, or replacement, or**
 - ✓ **The production of a new individual.**
- **In humans, the former process occurs continuously throughout life.**



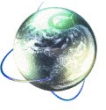
Historical Background

- **William Harvey** in 1628, correctly described the direction of circulation of blood.
- He described that :
 - ✓ Heart - pumps blood,
 - ✓ Arteries - transport oxygenated blood,
 - ✓ Systemic capillaries - exchange of substances &
 - ✓ Veins - return deoxygenated blood.
- For this reason he is known to be the father of physiology.



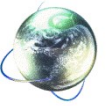
Historical background cont'd...

- **Claud Bernard** described that every cell in body is bathed with the fluid environment called ECF.
 - ✓ ECF contains all the needed substances for cells.
 - ✓ He called ECF is the internal environment of the body (Mileue interieore).
- **Walter cannon** termed the maintenance of constant conditions in the ECF as homeostasis.



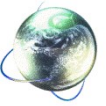
Homeostasis

- **It is maintenance of nearly static or constant conditions in the internal environment (ECF) of the body.**
- **It reflects the ability of the body to maintain a relatively stable metabolism and to function normally despite many constant changes.**
- **The changes may be internal or external, and the body must respond appropriately.**
- **Generally, all organs of the body perform their functions to maintain constant conditions in the ECF.**



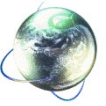
Homeostasis cont'd...

- **For example**
 - ✓ **The kidneys maintain constant water and ionic concentration.**
 - ✓ **The GIT provides nutrients.**
- ***An organism in homeostasis when its internal environment contains optimum amount of nutrients, gases, electrolytes, H₂O, hormones...***



Feedback Control Mechanisms Of The Homeostasis

- **Communication within the body is essential for homeostasis.**
 - ✓ **Accomplished chiefly by the nervous and endocrine systems.**
- ***Feedback loop* - cycle of events in which the status of a body condition is monitored, evaluated, changed, remonitored, reevaluated.**
 - ✓ **Each monitored variable is termed as *controlled condition*.**



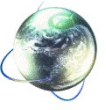
Feedback mechanism cont'd...

- **A feedback system has three basic components.**

1. A *sensor* - monitors changes in a controlled condition and sends input to a control center.

- ✓ This pathway is called an afferent pathway.
- ✓ The input is in the form of nerve impulses or chemical signals.

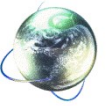
2. *Control center* - sets the range of values within which a controlled condition should be maintained (set point).



Feedback mechanism cont'd...

- ✓ **Evaluates the input it receives from receptors, and**
- ✓ **Generates output commands when they are needed.**
 - **Output - typically occurs as nerve impulses, or hormones or other chemical signals.**
 - **This pathway is called an efferent pathway.**

3. Effector - causes a change to reverse the situation and return the value to the normal



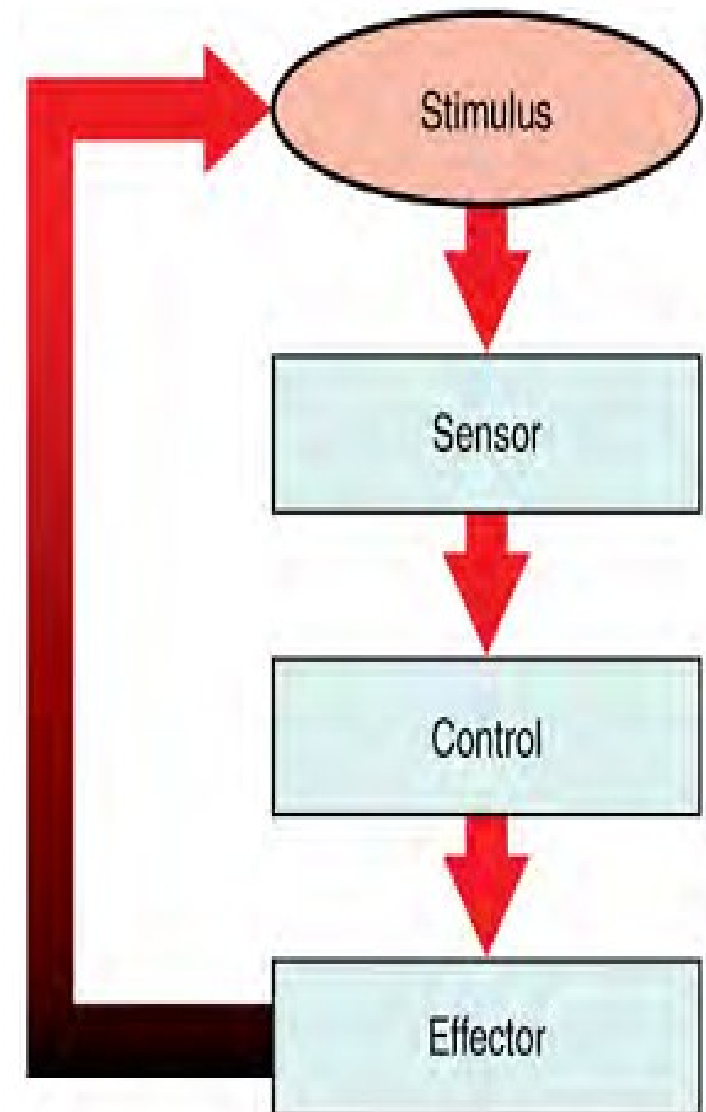
Feedback mechanism cont'd...

✓ **Nearly every organ or tissue in the body can behave as an effector.**

• **Two types of feedback mechanisms -**

✓ **The Negative Feedback Mechanism**

✓ **The Positive Feedback Mechanism**





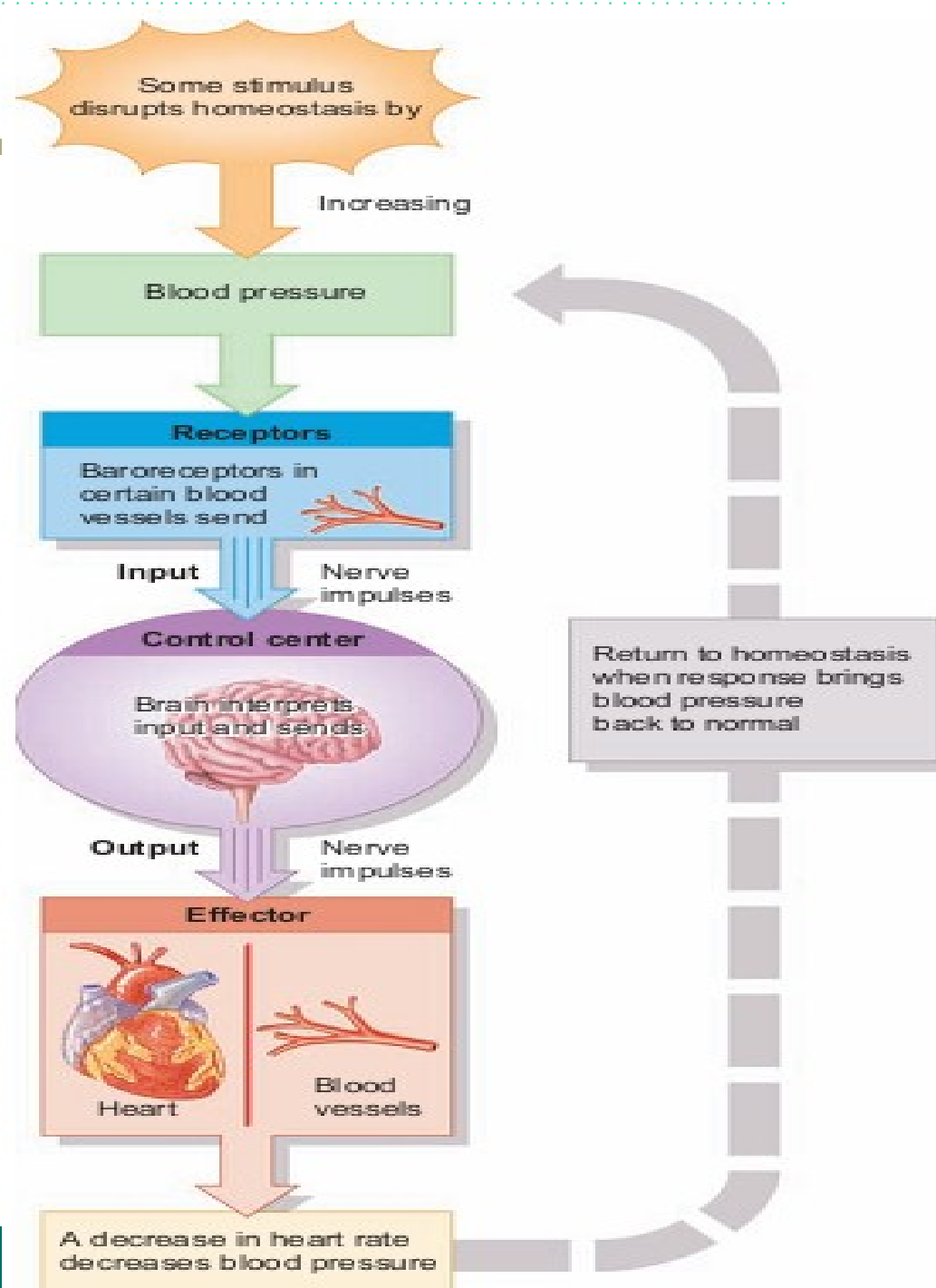
The Negative Feedback Mechanism

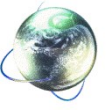
- **Works by producing an effect which opposes the initiating stimulus.**
- **The output shuts off the original effect of the stimulus or reduces its intensity and keeps some aspect of the body within its normal range.**
- **It cause the variable to change in a direction opposite to that of the initial change, returning it to its “ideal” value.**
- **Most homeostatic values of the body are controlled by NFM.**

NFM cont'd...

- **Example**

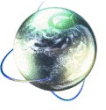
- ✓ **Control of ABP**
- ✓ **Control of BGL**
- ✓ **Control of BT**





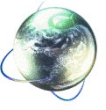
The Positive Feedback Mechanism

- **Works by producing an effect which enhances or repeats the same action like that of the starting stimulus.**
- **The response to the stimulus does not stop or reverse the stimulus, but instead keeps the sequence of events going.**
- ✓ **The PFM also called viscous circle (cascades).**
 - **Most of the action of this mechanism disturbs the internal environment and**



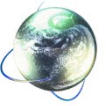
PFM cont'd...

- **PFM can sometimes be useful.**
 - ✓ **Blood clotting.**
 - ✓ **Generation and propagation of the action potential.**
 - ✓ **Child birth (labor).**
 - ✓ **Complex action of immune system.**



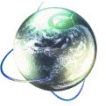
Homeostatic Control Systems

- **Control system - functionally interconnected network of body components.**
 - ✓ **Operate to maintain a given factor in the internal environment relatively constant around an optimal level.**
- **The control system -**
 - ✓ **Detect deviations from normal,**
 - ✓ **Integrate this information, and**



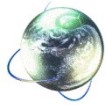
Cont'd...

- ✓ **Make appropriate adjustments in the activity of the body parts.**
- **The human body has thousands of control systems that are essential for homeostasis.**
- **Control systems can be**
 - ✓ ***Intrinsic/local/ controls* - built into or are inherent in an organ.**
 - ✓ ***Extrinsic/systemic/ controls* - regulatory mechanisms initiated outside an organ to alter the organ's activity.**



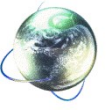
Cont'd...

- ✓ **It maintains most factors in the internal environment.**
- ✓ **The nervous system and endocrine system are the two controlling bodies of homeostasis.**
- **Extrinsic control - coordinated regulation of several organs toward a common goal.**
 - ✓ **Intrinsic controls serve only the organ in which they occur.**
- ***Coordinated, overall regulatory mechanisms are crucial for maintaining the homeostasis as a***



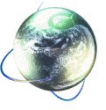
Comparison of the Nervous and Endocrine Systems

Property	Nervous System	Endocrine System
Anatomic Arrangement	A “wired” system: a specific structural arrangement exists between neurons and their target cells, with structural continuity in the system	A “wireless” system: endocrine glands are widely dispersed and not structurally related to one another or to their target cells
Type of Chemical Messenger	Neurotransmitters released into the synaptic cleft	Hormones released into the blood
Distance of Action of the Chemical Messenger	Short distance (diffuses across the synaptic cleft)	Long distance (carried by the blood)
Specificity of Action on the Target Cell	Dependent on the close anatomic relationship between neurons and their target cells	Dependent on the specificity of target cell binding and responsiveness to a particular hormone
Speed of Response	Generally rapid (milliseconds)	Generally slow (minutes to hours)
Duration of Action	Brief (milliseconds)	Long (minutes to days or longer)
Major Functions	Coordinates rapid, precise responses	Controls activities that require long duration rather than speed



Body Fluid

- **Dilute, watery solutions containing dissolved chemicals.**
- **In the average young adult male - constitute between 55% - 60% of total body mass (about 42L by volume).**
 - ✓ **18% of the body weight is protein and related substances, 7% is mineral, and 15% is fat.**
- **BF can change, depending on age, gender and degree of obesity.**
- **Composition of body fluids**



Cont'd...

✓ **Solutes -**

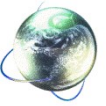
○ **Electrolytes - *salts, all acids and bases, and some proteins.***

○ **Non-electrolytes - *glucose, lipids, creatinine, and urea.***

• **Electrolytes have greater osmotic power than non-electrolytes.**

• **Body fluids are present in two main compartments.**

1. Intracellular fluid (ICF) or cytosol: the fluid



Cont'd...

2. Extracellular fluid (ECF): the fluid without cells.

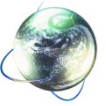
✓ **It about is 1/3 (14 L) of body fluid by volume.**

- **There are two types of ECF.**

a) Plasma - the fluid portion of the blood.

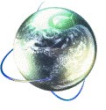
✓ **It about is 1/4 (3L) or 20% of the ECF.**

b) Interstitial fluid (IF) - fluid that surrounds and bathes the cells.



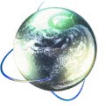
Cont'd...

- **Two general barriers separate ICF, interstitial fluid and blood plasma.**
 - ✓ **The plasma membrane of individual cells.**
 - **The plasma membrane is a selectively permeable barrier.**
 - ✓ **Capillary membranes of blood vessel.**
 - **Divide the interstitial fluid from blood plasma.**
- **Each fluid compartment has a distinctive pattern**



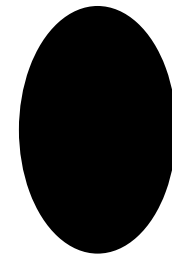
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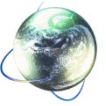
- **Intracellular fluid has low sodium and chloride.**
 - ✓ **But high potassium, magnesium, phosphate and sulfate.**
- **Extracellular fluid has high:-**
 - ✓ **Sodium, calcium, chloride and bicarbonate.**
- **The ionic composition both plasma and IF is similar.**
 - ✓ **The most important difference - the higher**



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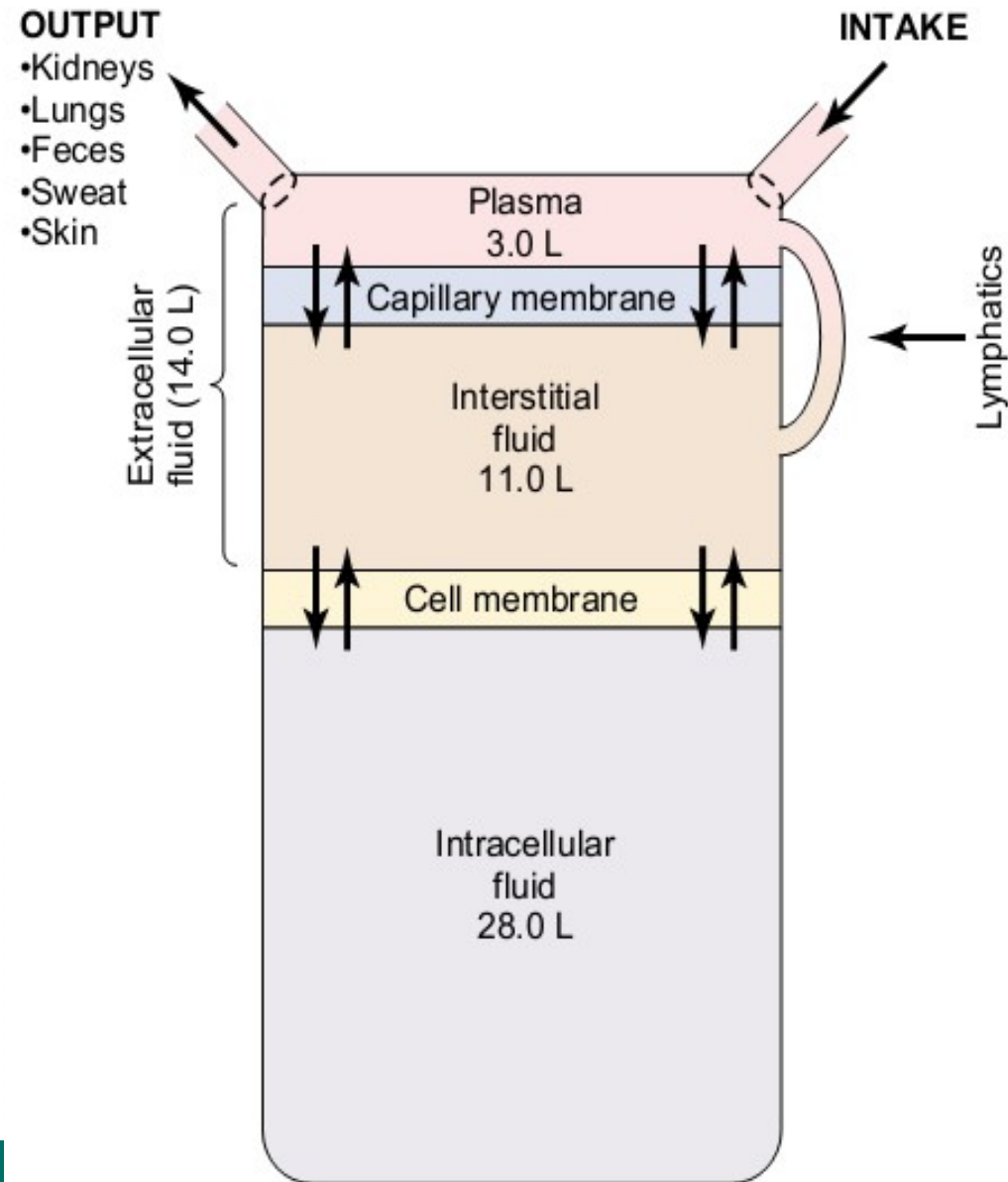
	<u>ECF</u>	<u>ICF</u>
🌿 Na⁺	♣ 142 meq/L	♠ 10 meq/L
🌿 K⁺	♣ 4 meq/L	♠ 140 meq/L
🌿 Ca²⁺	♣ 2.5 meq/L	♠ 0.0001 meq/L
🌿 Mg²⁺	♣ 1.2 meq/L	♠ 58 meq/L
🌿 Cl⁻	♣ 103 meq/L	♠ 4 meq/L
🌿 HCO₃⁻	♣ 28 meq/L	♠ 10 meq/L
🌿 PO₄³⁻	♣ 4 meq/L	♠ 75 meq/L
🌿 SO₄²⁻	♣ 1 meq/L	♠ 2 meq/L
🌿 Glucose	♣ 90 mg/dl	♠ 0 to 20 mg/dl
🌿 Aminoacids	♣ 30 mg/dl	♠ 200 mg/dl
🌿 Lipid (C, P, NF)	♣ 0.5 gm/dl	♠ 2 – 95 gm/dl
🌿 P_{O2}	♣ 40 mm Hg	♠ 20 mm Hg
🌿 P_{CO2}	♣ 45 mm Hg	♠ 50 mm Hg
🌿 pH	♣ 7.4	♠ 7.0

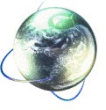




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- **No matter how remote a cell is from the external environment,**
 - ✓ **It can make life-sustaining exchanges with its own surrounding fluid.**





Regulation Of Body Fluid Volume

Water Gain/Day

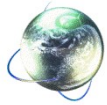
- **Ingested liquid** =
1600 ml (60%)
- **Ingested food** =
700 ml (30%)
- **Metabolic water** =
200 ml (10%)

Total = 2500 ml

Water Loss/Day

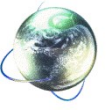
- ✓ **Kidneys = 1500 ml (60%)**
- ✓ **Insensible losses = 700ml (28%)**
- ✓ **Sweating = 200 (8%)**
- ✓ **GIT = 100 ml (4%)**

Total = 2500 ml



Cell Physiology

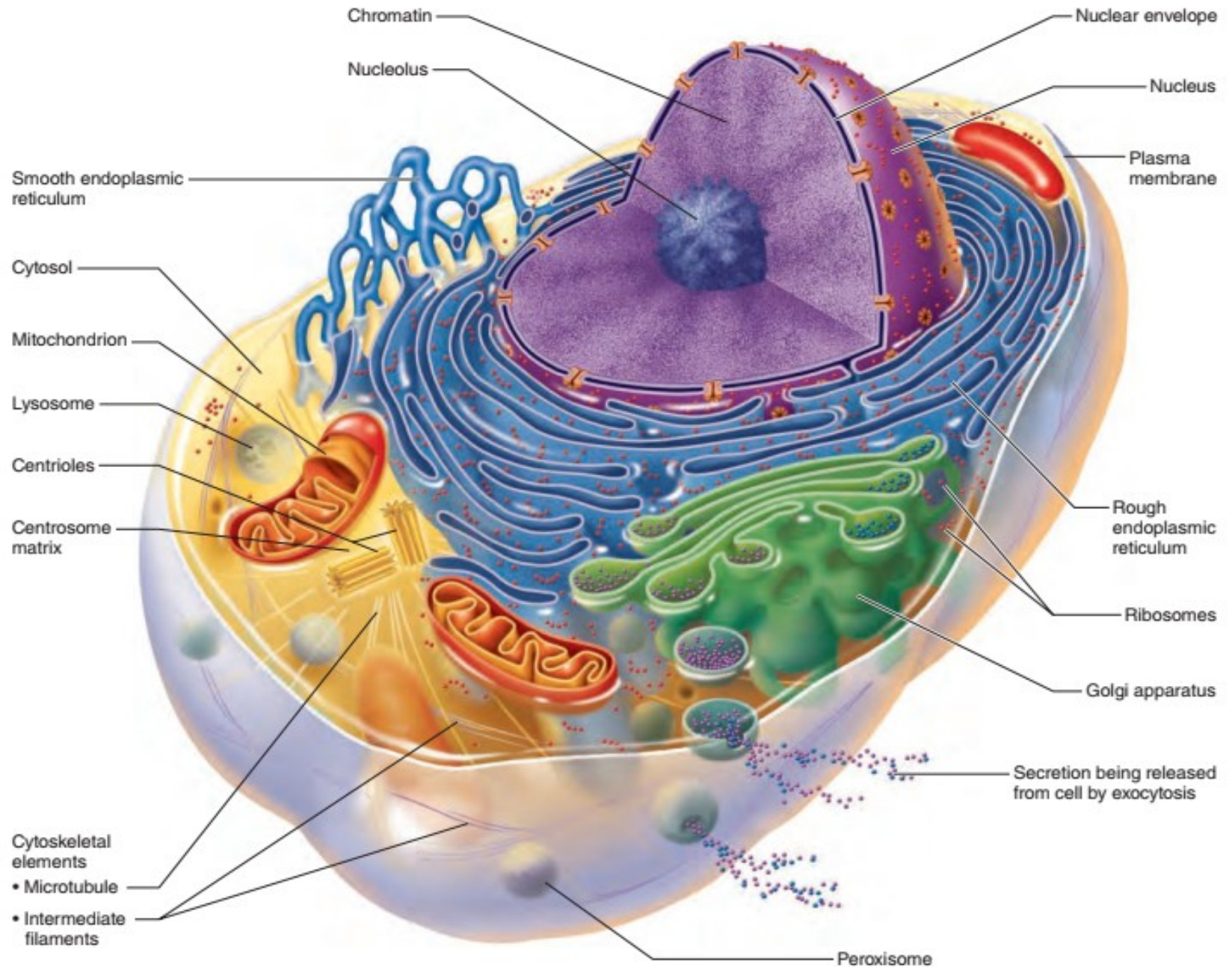
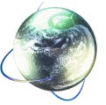
- **Cells - the fundamental units of life.**
- **Cells in a human body are classified into about 200 types.**
 - ✓ **All the cells - derived from a single fertilized ovum.**
- **The cell is not merely a bag of fluid, enzymes, and chemicals; it also contains intracellular organelles.**
- **A cell - basic structural and functional unit of living organisms**

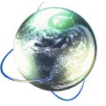


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- **A human cell has three main parts:**
 - ✓ ***The plasma membrane*** - outer boundary of the cell.
 - ✓ ***The cytoplasm*** - the intracellular fluid packed with organelles, small structures that perform specific cell functions.
 - ✓ ***The nucleus*** - an organelle that controls cellular activities.

◦ Typically the nucleus lies near the cell's





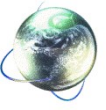
Cell Membrane

- **Thin, pliable, elastic structure that envelops the cell and only 7.5 to 10nm thick.**
- **Composition - proteins - 55 %, lipids - 42% and carbohydrates - 3%.**
 - ✓ **Its basic structure is a lipid bilayer.**
- **Membranes also delimit intracellular organelles, including the nucleus, Golgi apparatus, ER, mitochondria, and various vesicles.**



Cell Membranes Lipids

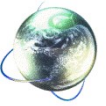
- **Most of the membrane lipids are glycerophospholipids.**
- **The most common glycerophospholipids -**
 - ✓ **Phosphatidylcholine (PC), phosphatidylethanolamine (PE), and phosphatidylserine (PS).**
- **Membranes also contain phosphatidylinositol (PI)**
 - ✓ **Plays an important role in signaling within the cytoplasm**



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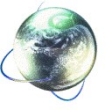
- **Cell membranes may also contain sphingolipids, including the phosphosphingolipid, sphingomyelin and glycosphingolipids.**
- **Membranes also contain cholesterol.**
- **All of these lipids are amphipathic because they have hydrophilic head groups and hydrophobic acyl tails.**
- **The lipid bilayer forms the basic “fabric” of the membrane.**

✓ **The foundation of lipid bilayer is composed of**



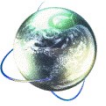
Cont'd...

- **The phosphate end of the phospholipid is hydrophilic, and the fatty acid portion is hydrophobic.**
- ✓ ***The phospholipids component is organized into a double layer with their hydrophobic (tail) directed toward the center of the membrane and polar heads directed outward facing ECF and ICF.***
- ***The lipid layer in the middle of the membrane is impermeable to the usual water-soluble substances, such as ions, glucose, and urea.***



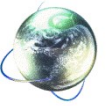
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- **The cholesterol molecules are also lipid in nature because their steroid nucleus is highly fat soluble.**
 - ✓ **It mainly help determine the degree of permeability.**
 - ✓ **It also controls much of the fluidity of the membrane.**
- ***The bilayer is asymmetrical, with the choline containing phospholipids (PC and sphingomyelin) in the outer half and the amino-containing phospholipids (PE and PS) in the***



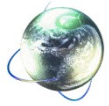
Cont'd...

- **The asymmetrical arrangement is produced as the membranes are assembled in the ER.**
- **The phospholipids are synthesized and inserted on the cytoplasmic side of the membrane; then a phospholipid translocator or “flippase” transfers PC to the noncytoplasmic side.**
- ✓ **Sphingomyelin and the glycosphingolipids are produced in the Golgi apparatus on the noncytoplasmic side.**



Membrane Proteins

- **Allow cell's to communicate with its environment.**
 - **There are two types: integral and peripheral proteins.**
- Integral Proteins*
- **They are firmly inserted into the lipid bilayer.**
 - **All integral proteins have both hydrophobic and hydrophilic regions.**
 - **Some protrude from one membrane face only.**



Cont'd...

- ✓ **Most of them span the entire membrane and protrude on both sides - transmembrane proteins.**

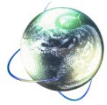
- **Functions of integral proteins are -**

- ✓ **Cluster together to form channels, or pores.**

- **Small, water-soluble molecules or ions can move.**

- ✓ **Others act as carriers.**

- **Bind to a substance and then move it**

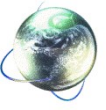


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- ✓ **Some of them are enzymes.**
- ✓ **Still others are receptors for hormones or other chemical messengers.**
 - **Relay messages to the cell interior - signal transduction.**

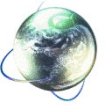
Peripheral Proteins

- **Not embedded in lipid bilayer - attach loosely to integral proteins.**
- ✓ **Easily removed without disrupting the membrane.**

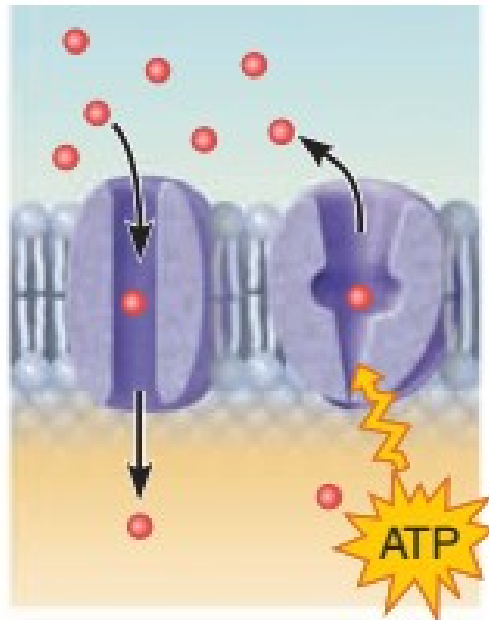


Cont'd...

- **It include a network of filaments - helps support the membrane from its cytoplasmic side.**
- **Functions of peripheral proteins are -**
 - ✓ **As enzymes or as controllers of transport of substances.**
 - ✓ **Others are motor proteins.**
 - **Involved in mechanical functions - changing cell shape during cell division and muscle cell contraction.**
 - ✓ **Still others link cells together**

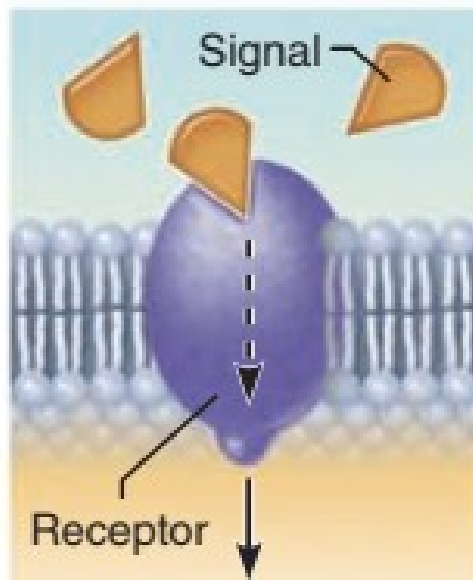


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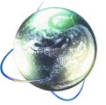
(a) Transport

- A protein (left) that spans the membrane may provide a hydrophilic channel across the membrane that is selective for a particular solute.
- Some transport proteins (right) hydrolyze ATP as an energy source to actively pump substances across the membrane.



(b) Receptors for signal transduction

- A membrane protein exposed to the outside of the cell may have a binding site that fits the shape of a specific chemical messenger, such as a hormone.
- When bound, the chemical messenger may cause a change in shape in the protein that initiates a chain of chemical reactions in the cell.

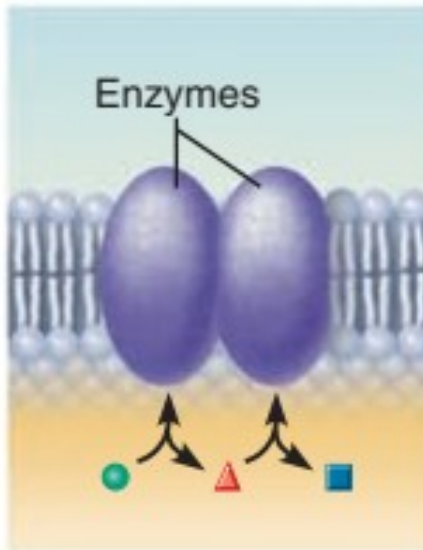


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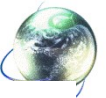
(c) Attachment to the cytoskeleton and extracellular matrix

- Elements of the cytoskeleton (cell's internal supports) and the extracellular matrix (fibers and other substances outside the cell) may anchor to membrane proteins, which helps maintain cell shape and fix the location of certain membrane proteins.
- Others play a role in cell movement or bind adjacent cells together.

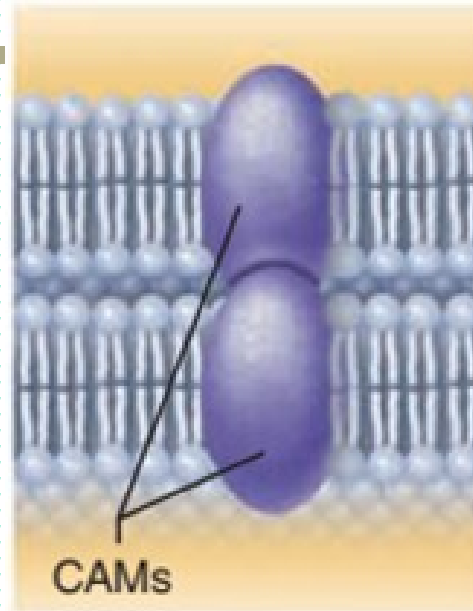


(d) Enzymatic activity

- A membrane protein may be an enzyme with its active site exposed to substances in the adjacent solution.
- A team of several enzymes in a membrane may catalyze sequential steps of a metabolic pathway as indicated (left to right) here.

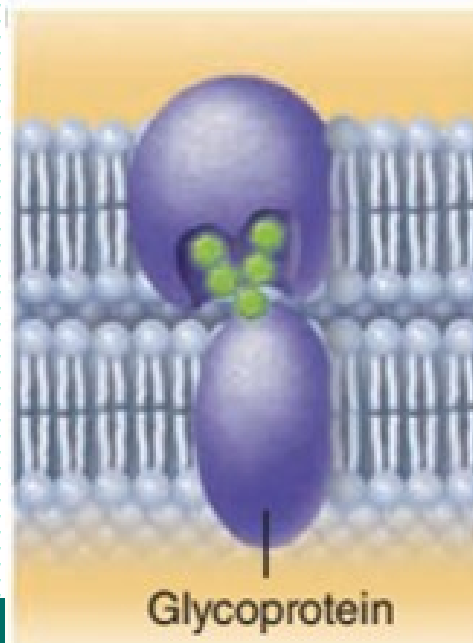


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(e) Intercellular joining

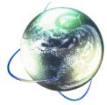
- Membrane proteins of adjacent cells may be hooked together in various kinds of intercellular junctions.
- Some membrane proteins (cell adhesion molecules or CAMs) of this group provide temporary binding sites that guide cell migration and other cell-to-cell interactions.



(f) Cell-cell recognition

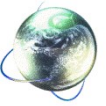
- Some glycoproteins (proteins bonded to short chains of sugars) serve as identification tags that are specifically recognized by other cells.

Figure  Membrane proteins perform many tasks. A single protein may perform a combination of these functions.



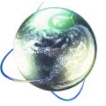
Membrane Carbohydrates

- **Occur almost invariably in combination with proteins or lipids.**
 - ✓ **In the form of glycoproteins or glycolipids.**
 - **About one tenth of the membrane lipid are glycolipids.**
 - ✓ **Proteoglycans - loosely attached to the outer surface.**
- **The “glyco” portions - almost invariably protrude to the outside of the cell.**

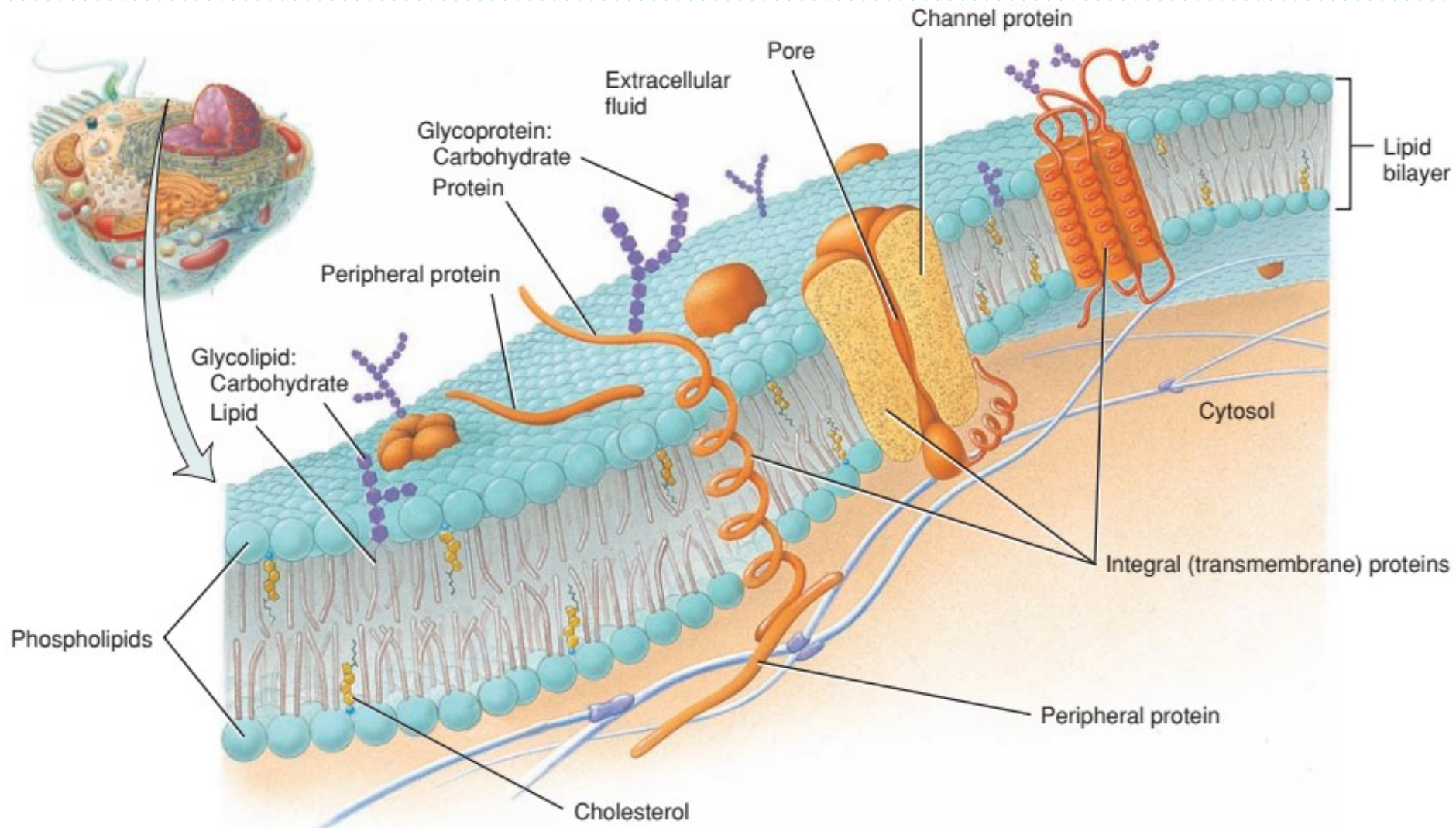


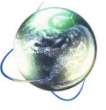
Cont'd...

- **Several important functions of membrane carbohydrates are -**
 - ✓ **Gives most cells an overall negative surface charge.**
 - ✓ **Attaching cells to one another.**
 - ✓ **Act as receptor substances.**
 - ✓ **Some carbohydrate moieties enter into immune reactions.**



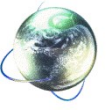
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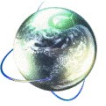
Function of the Plasma Membrane

- **Separates cellular contents from the ECF.**
- **Regulates passage of substances in and out.**
- **It provides receptors for NTs, hormones and drugs.**
- **It is a means of cell to cell contact.**
- **Plays an important role in the generation and transmission of electrical impulse in nerves and muscle.**
- **Involved in the regulation of cell growth and**



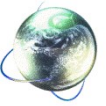
MEMBRANE TRANSPORT

- **The plasma membrane is selectively permeable.**
 - ✓ **Cells have mechanisms for the rapid movement of ions and solute molecules.**
- **These mechanisms are: -**
 - ✓ **Unassisted membrane transport - transportation through lipid.**
 - ✓ **Assisted membrane transport - transportation through proteins.**



Unassisted Membrane Transport

- **Two properties that influence permeability's of particles without assistance: -**
 - ✓ **The relative solubility of the particle in lipid and**
 - ✓ **The size of the particle.**
- **Particles that can penetrate the plasma membrane on their own are passively driven across the membrane by :**
 - ✓ **Diffusion down a concentration gradient or movement along an electrical gradient**



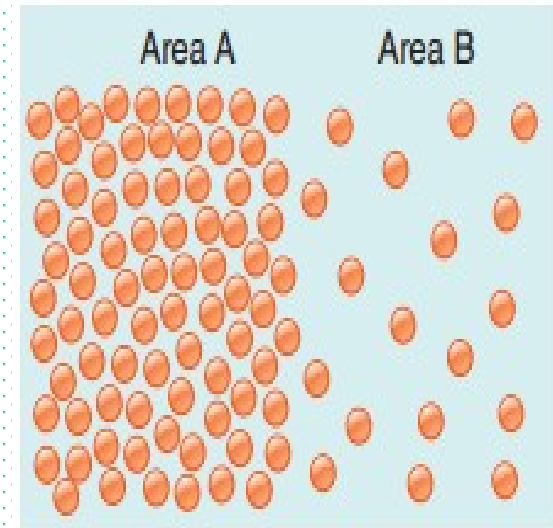
Simple Diffusion

- It is mov't from the area of higher to the area of lower concentration.

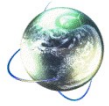
✓ The greater the concentration, the greater the likelihood of collisions.

✓ So, molecules tend to become evenly distributed over time.

✓ No ATP is required.



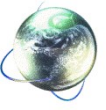
→ Diffusion from area A to area B
← Diffusion from area B to area A
→ Net diffusion



Unassisted MT cont'd...

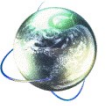
- Factors that influence the rate of net diffusion across a membrane according to the Fick law.**

Factor	Effect on the rate of simple diffusion
Diffusion gradient	The steeper, the higher the rate
Size of molecules or ions	The smaller the size, the higher the rate
Temperature	The higher the temperature, the higher the rate
Lipid solubility	The higher the lipid soluble, the higher the rate
Surface area	The larger the surface area, the higher the rate



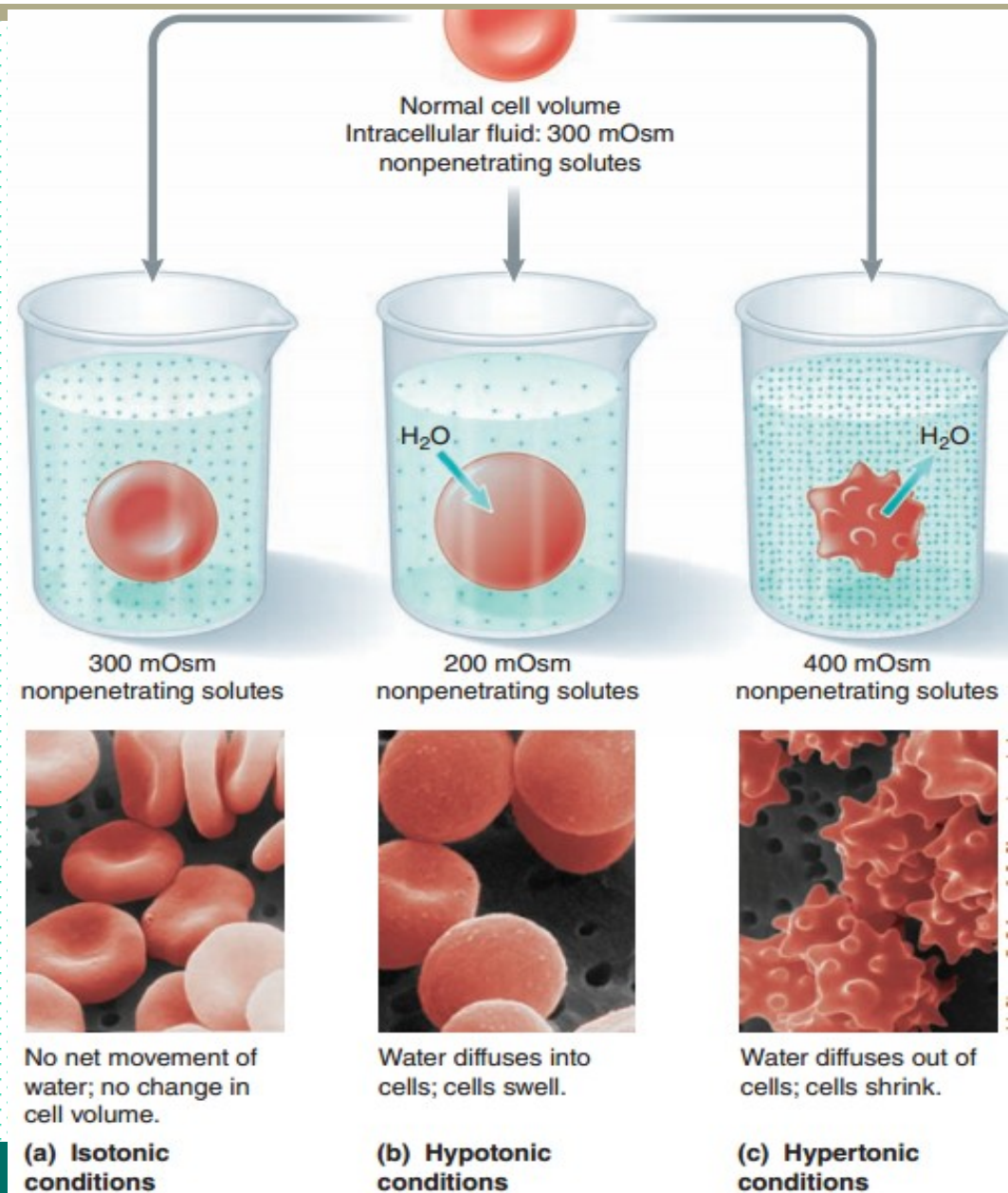
Osmosis

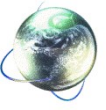
- **Osmosis is net diffusion of water down its concentration gradient through a selectively permeable membrane.**
- **Water molecules are strongly polar.**
- **Due to size, water molecules can readily permeate the plasma membrane.**
 - ✓ **However, this type of water movement across the membrane is relatively slow.**
- **In many cell types, membrane proteins form channels specific for the passage of water - aquaporins**



Unassisted MT cont'd...

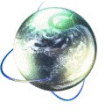
- **Water is at equilibrium across cell membranes only when the osmolality inside and outside the cell is the same.**
- **The driving force for net movement of water across the membrane is the concentration gradient of solute**





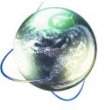
Assisted Membrane Transport

- **It is the transportation of poorly lipid-soluble polar molecules that cannot cross the plasma membrane (lipid).**
- **Cells use two different assisted mechanisms -**
 - ✓ **Carrier-mediated transport - for transfer of small water-soluble substances and**
 - ✓ **Vesicular transport - for movement of large molecules and multimolecular particles.**



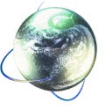
Carrier-mediated transport

- **It moves a range of ions and organic solutes across membranes selectively.**
- **It is accomplished by a membrane carrier changing its shape.**
- **It displays three important characteristics -**
 - ✓ **Specificity,**
 - ✓ **Saturation, and**
 - ✓ **Competition.**



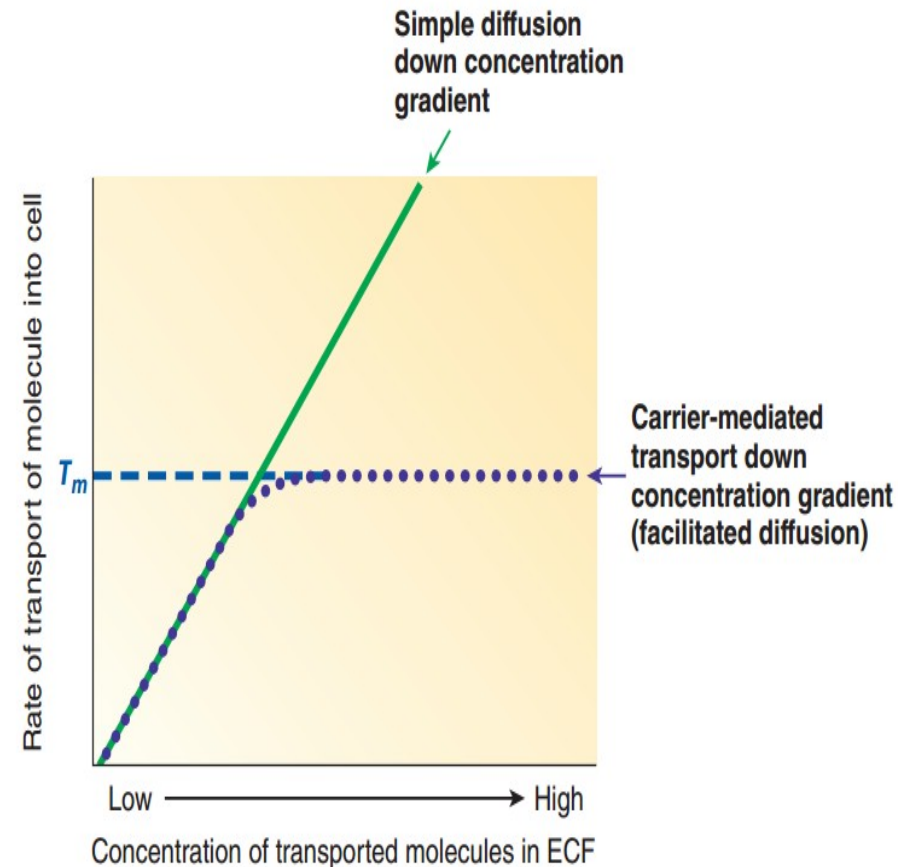
Facilitated Diffusion

- **Carrier-mediated transport takes two forms: -**
 - ✓ **Facilitated diffusion and**
 - ✓ **Active transport.**
- **Facilitated diffusion uses a carrier to facilitate the transfer.**
 - ✓ **It is passive carrier-mediated transport.**
- **In facilitated diffusion, the affinity of the binding site is the same when exposed to either the outside or the inside of the cell.**



Assisted MT cont'd...

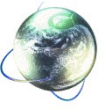
- **As a result of thermal energy, these carriers undergo spontaneous changes in shape.**
- ***Passengers are more likely to bind with the carrier on the high-concentration side than on the low concentration side.***





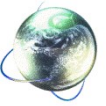
Unassisted MT cont'd...

- **Ions that can permeate the membrane also move passively along their electrical gradient.**
 - ✓ **If a difference in charge exists, an electrical gradient that promotes movement of ions toward the area of opposite charge.**
- **Both an electrical and a concentration gradient may be acting on a particular ion at the same time.**
 - ✓ **The net effect is called an electrochemical gradient.**



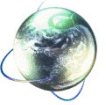
Active Transport

- **It also uses a carrier protein,**
 - ✓ **But it transports the substance uphill against its concentration gradient by using energy in the form of ATP.**
- **Two forms : -**
 - ✓ **Primary active transport and**
 - ✓ **Secondary active transport.**

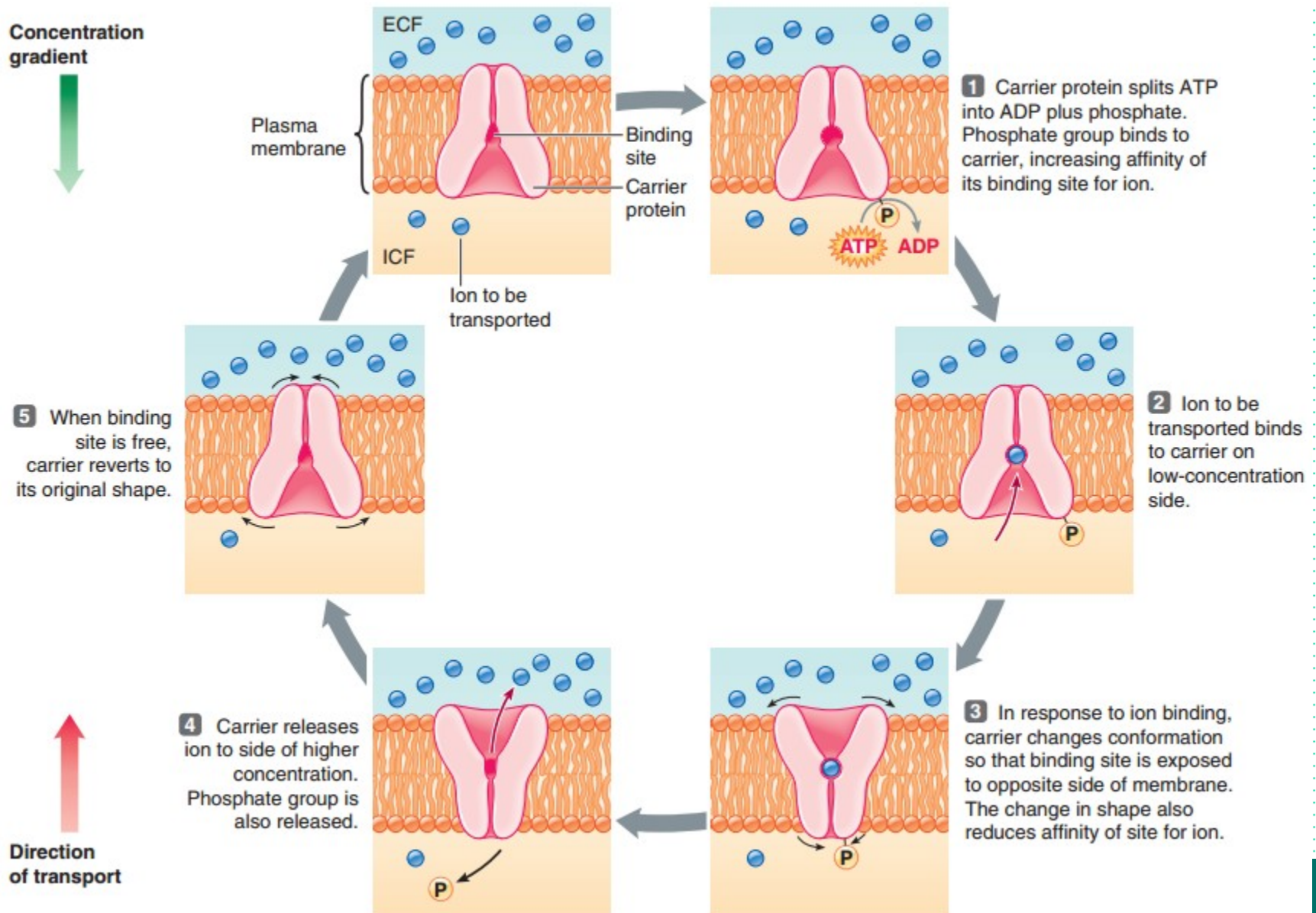


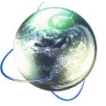
Primary Active Transport

- The binding site has a greater affinity for its passenger on the low concentration side.
 - ✓ ATP is required to vary the affinity of the binding site.
- The carrier acts as an enzyme that has ATPase activity.
- ATP energy is used in the phosphorylation-dephosphorylation cycle of the carrier.
 - ✓ It alters the affinity of the carrier's binding sites on opposite sides of the membrane so



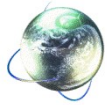
Assisted MT cont'd...





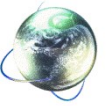
Assisted MT cont'd...

- **Primary active-transport pumps all move positively charged ions, namely, Na^+ , K^+ , H^+ , or Ca^{2+} , across the membrane.**
- **The simplest primary active-transport systems pump a single type of passenger.**
 - ✓ **For example, the Ca^{2+} pump in the plasma membrane transports Ca^{2+} out of the cell, keeping the Ca^{2+} concentration in the cytosol low.**
 - ✓ **Calcium pumps are P-type ATPases located in the plasma membrane and the membrane of**



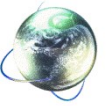
Assisted MT cont'd...

- **Proton (H^+) pumps are found in the membranes of the lysosomes and the Golgi apparatus.**
 - ✓ **Keeping the inside of the organelles more acidic.**
- **The proton pump is also present in the kidney.**
 - ✓ **Classified as V-type ATPases.**
- **F-type ATPases are located in the inner mitochondrial membrane.**
 - ✓ **This type of proton pump normally functions in reverse**



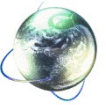
Assisted MT cont'd...

- Its principal function is to synthesize ATP by using the energy stored in a gradient of protons.
- More complicated primary active-transport mechanisms involve the transfer of two different passengers in opposite directions.
- $\text{Na}^+\text{--K}^+$ pump found in the plasma membrane of all cells.
- $\text{Na}^+/\text{K}^+\text{-ATPase}$ is known as a P-type ATPase.
- The $\text{Na}^+\text{--K}^+$ pump moves three Na^+ out of the cell for every two K^+ it pumps in.

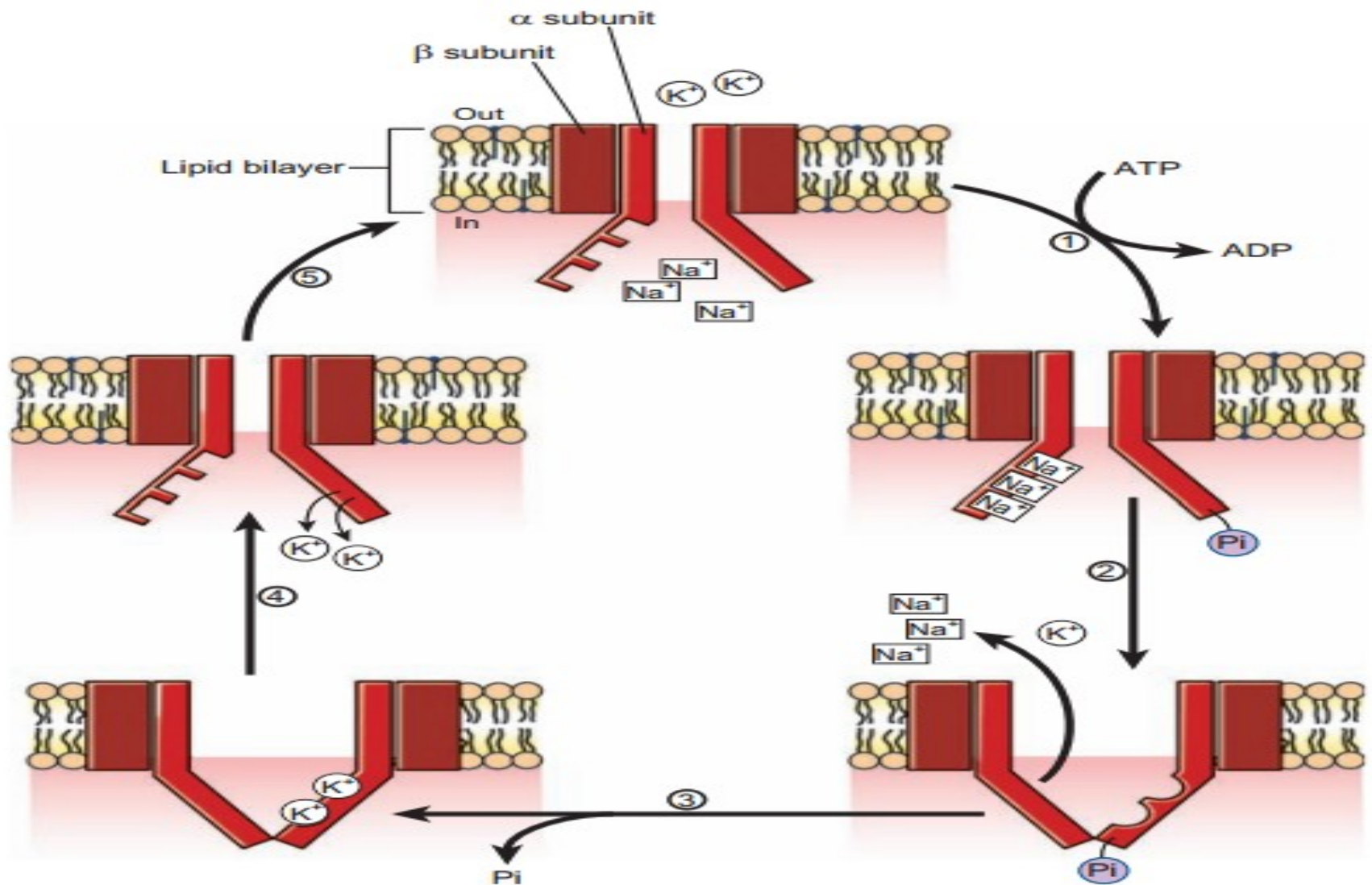


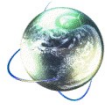
Assisted MT cont'd...

- ✓ **No direct exchange occurs of Na^+ for K^+ , however.**
- **The $\text{Na}^+\text{-K}^+$ pump consisting of two subunits.**
 - ✓ **The α subunit is the catalytic subunit that mediates active transport.**
 - ✓ **The smaller β subunit is essential for the proper assembly.**



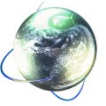
Assisted MT cont'd...





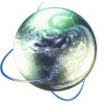
Assisted MT cont'd...

- **The $\text{Na}^+\text{-K}^+$ pump plays three important roles:**
 - ✓ **It establishes Na^+ and K^+ concentration gradients.**
 - ✓ **It helps regulate cell volume.**
 - ✓ **Indirectly serves as energy source for 2^o active transport.**
- **The $\text{H}^+/\text{K}^+\text{-ATPase}$ is also P-type ATPase.**
 - ✓ **This pump maintains the low pH in the stomach.**



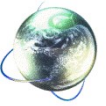
Assisted MT cont'd...

- **ATP-binding cassette transporters -**
 - ✓ They are involved in a nutrient uptake, cellular immune response, and stem cell biology.
- **Organic anion transporting polypeptides (OATPs)**
 - highly expressed in the liver, kidney, and brain.
 - ✓ Transport anionic and cationic chemicals, steroid, and peptide.
 - Thyroxine, bile acids, and bilirubin are



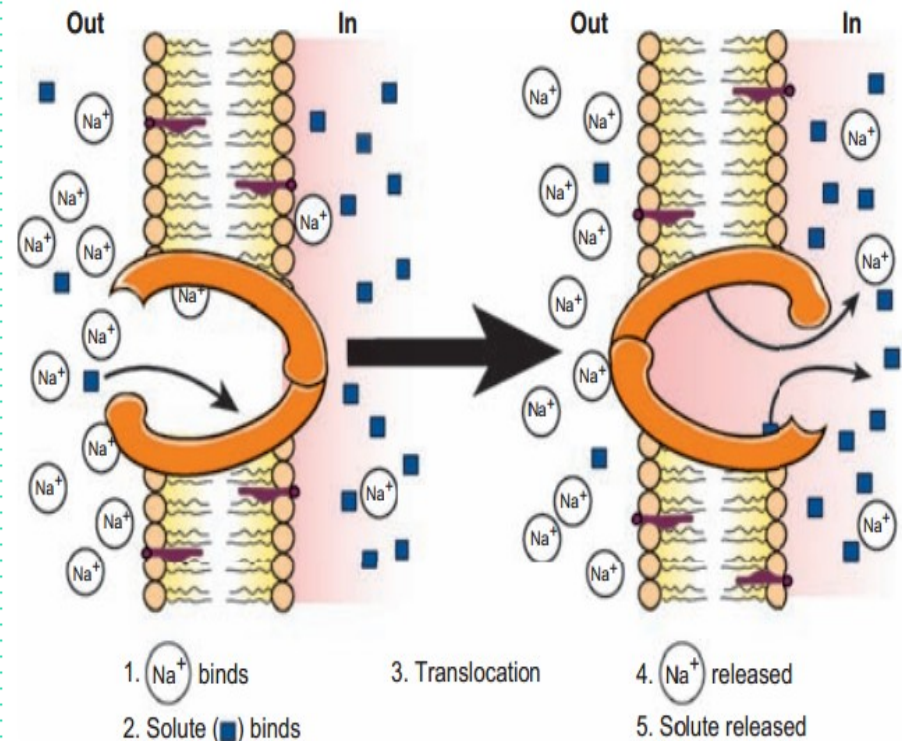
Secondary Active Transport

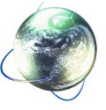
- **With 2^o active transport, the carrier does not directly split ATP to move a substance against its concentration gradient.**
 - ✓ **They do not directly use metabolic energy for transport.**
- **Use Na⁺ as the driver solute and use the energy of the sodium gradient to carry out the “uphill” transport of another important solute.**
 - ✓ **The Na⁺ gradient is maintained by the action of the Na⁺/K⁺-ATPase.**



Assisted MT cont'd...

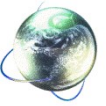
- In 2^o active transport, the transfer of the solute across the membrane is always occurs together with the transfer of the Na^+ .
- Secondary active carriers have two binding sites: one for the solute being moved



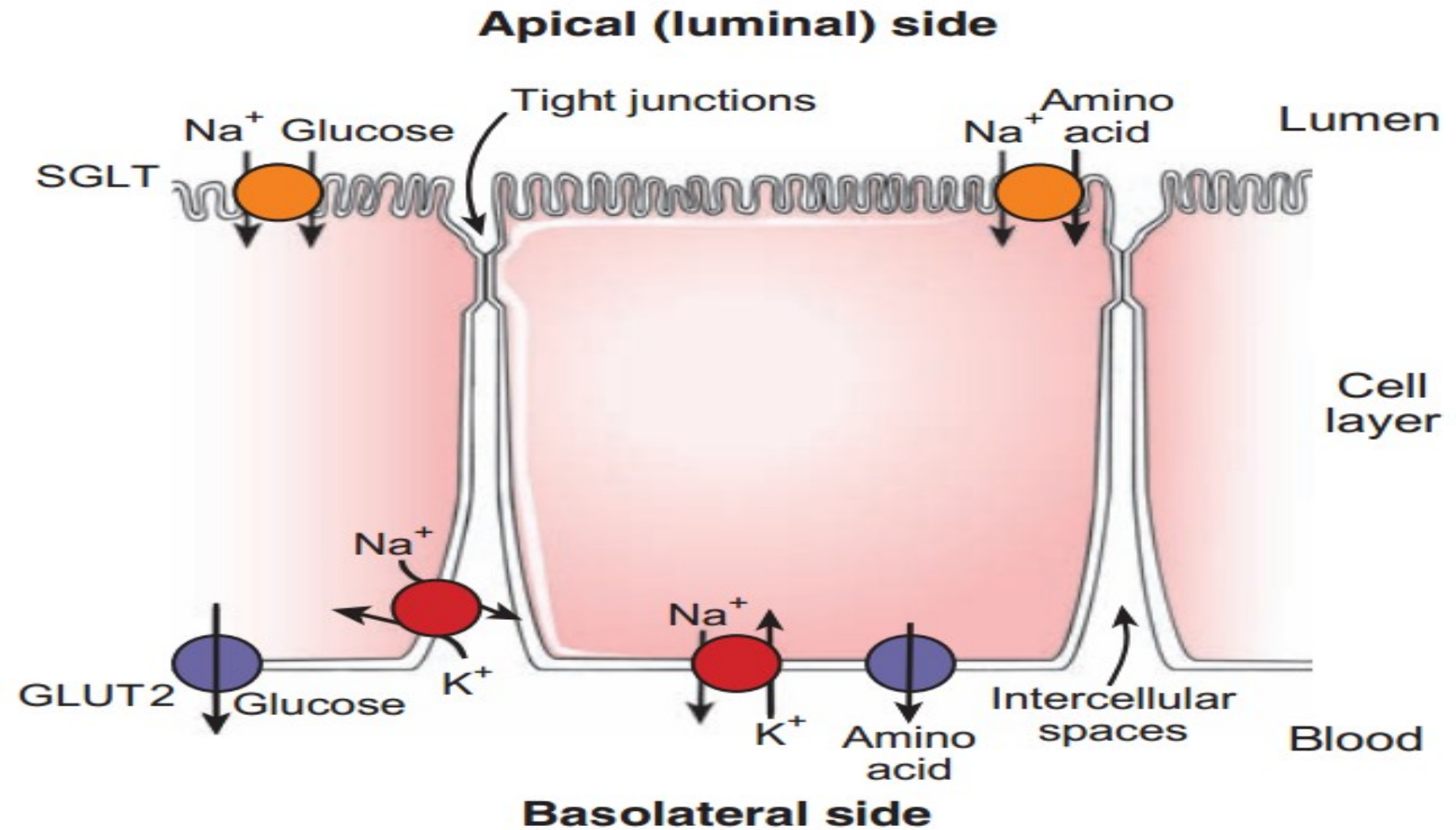


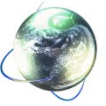
Assisted MT cont'd...

- **Secondary active transport occurs by two mechanisms depending on the direction the transported solute moves in relation to Na^+ movement:-**
 - ✓ **Symport and antiport**
- **In symport (co-transport), the solute and Na^+ move in the same direction, that is, into the cell.**
- **Symport carrier that co-transport Na^+ and glucose in intestinal epithelial cells known as SGLT.**



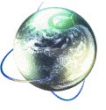
Assisted MT cont'd...





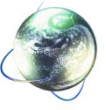
Assisted MT cont'd...

- **Another example of a symport system are**
 - ✓ **Families of sodium-coupled phosphate transporters in the intestine and renal proximal tubule.**
 - ✓ **Sodium-coupled chloride transporters in the kidney.**
- **In antiport (counter transport or exchange), the solute and Na^+ move through the membrane in opposite directions.**
- **The Na^+/H^+ exchanger are found mainly in the**



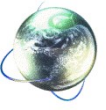
Assisted MT cont'd...

- ✓ **It uses the Na^+ gradient to remove H^+ from the cell.**
- ✓ **It is an electroneutral system because there is no net movement of charge.**
- **The other example of antiporters is $\text{Na}^+/\text{Ca}^{2+}$ exchange systems, found mainly in the plasma membrane of many cells.**
 - ✓ **Three Na^+ enter the cell and one Ca^{2+} ion leaves during each cycle.**
 - ✓ **It is an electrogenic system because there is a**



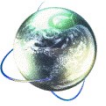
Vesicular Transport

- **The large polar molecules that are much too big for channels, and are transferred between the ICF and the ECF by vesicular transport.**
- **Has two forms : - endocytosis and exocytosis.**
- **Energy is needed to accomplish vesicle formation and vesicle movement.**
- ✓ **Vesicular transport requires energy expenditure by the cell.**

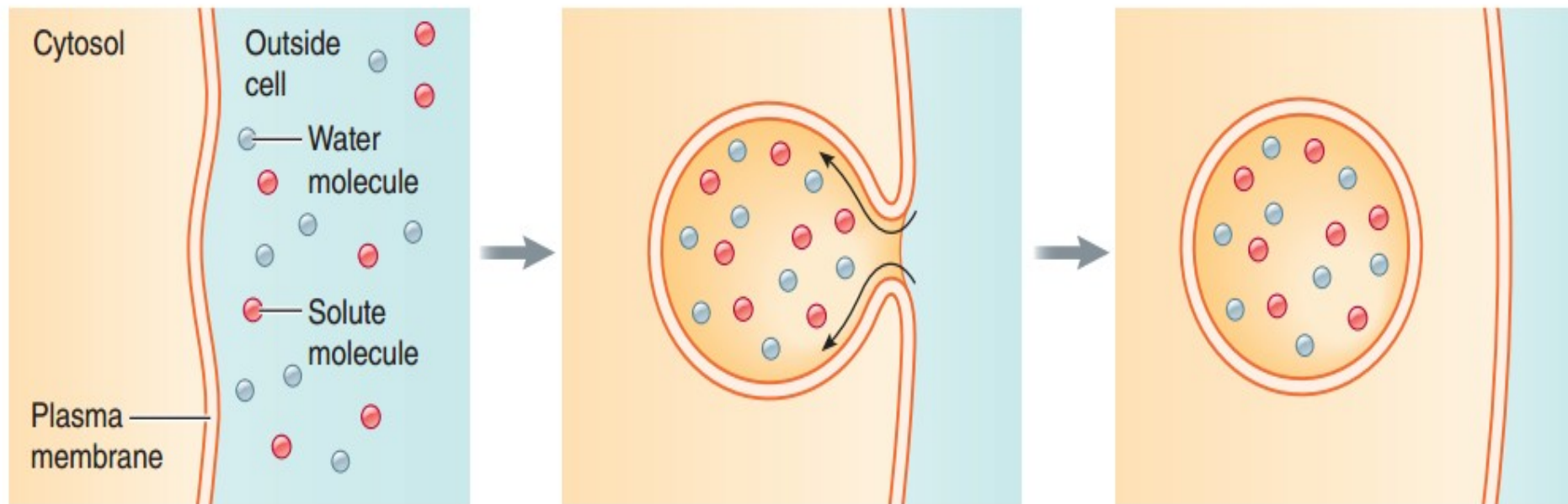


Endocytosis

- **The plasma membrane surrounds the substance to be ingested and then fuses over the surface, pinching off a membrane-enclosed vesicle.**
- **It has three forms:**
 - ✓ **Pinocytosis (non-selective uptake of a sample of ECF),**
 - ✓ **Receptor-mediated endocytosis (selective uptake of a large molecule), and**
 - ✓ **Phagocytosis (selective uptake of a multimolecular particle)**



Vesicular T cont'd...

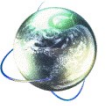


1 Solute molecules and water molecules are outside the plasma membrane.

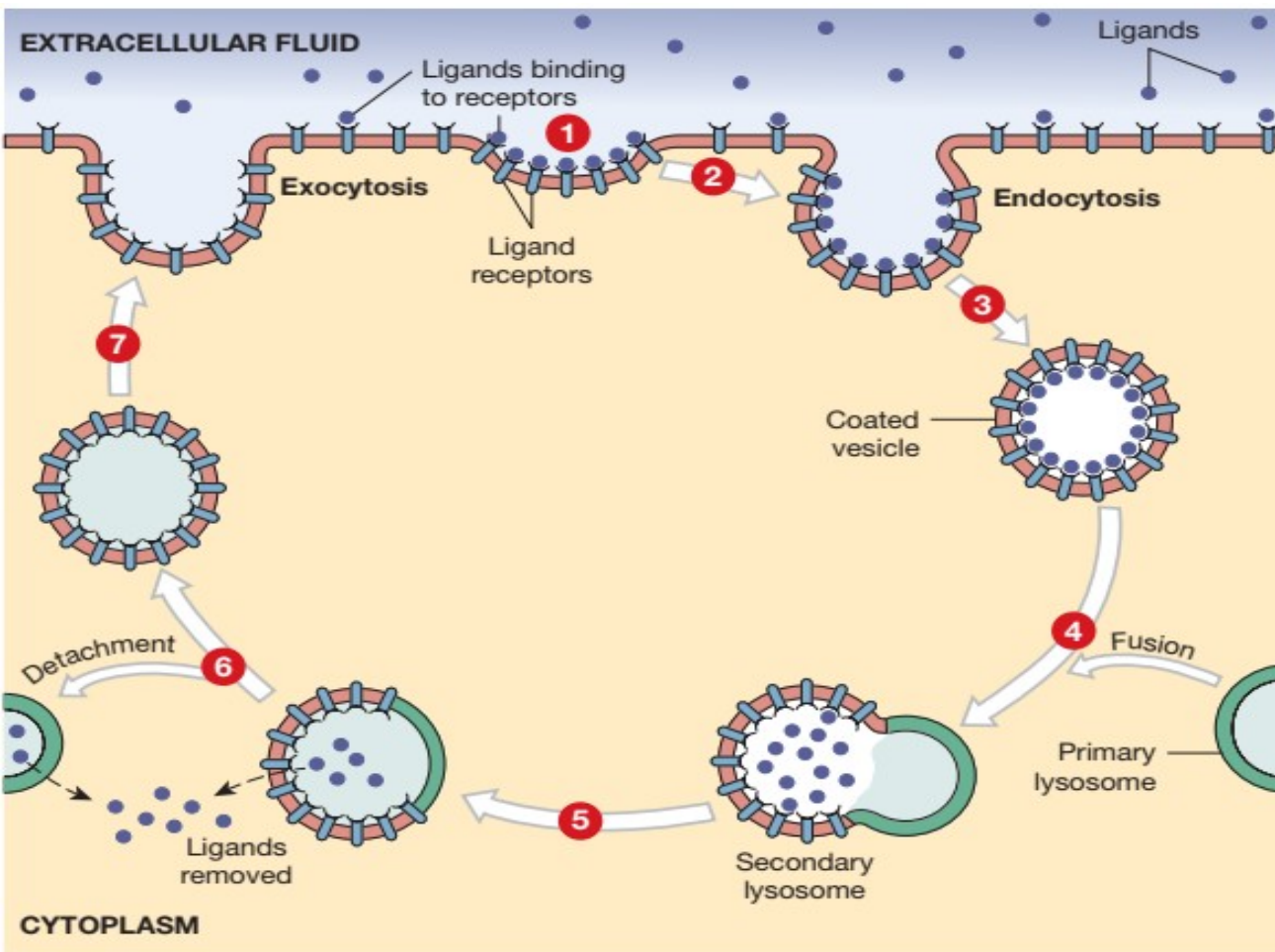
2 Membrane pockets inward, enclosing solute molecules and water molecules.

3 Pocket pinches off as endocytic vesicle containing sample of ECF.

(a) Pinocytosis

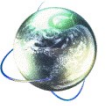


Vesicular T cont'd...

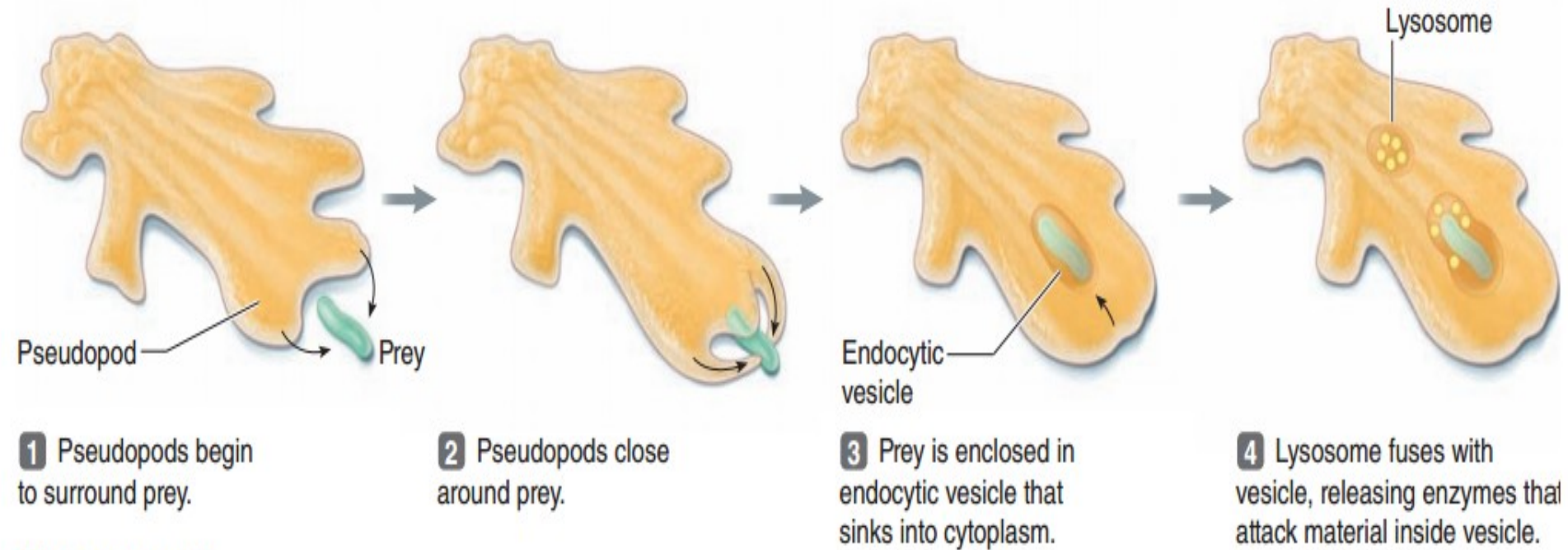


Receptor-Mediated Endocytosis

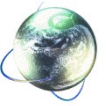
- 1** Target molecules (ligands) bind to receptors in plasma membrane.
- 2** Areas coated with ligands form deep pockets in plasma membrane surface.
- 3** Pockets pinch off, forming endosomes known as coated vesicles.
- 4** Coated vesicles fuse with primary lysosomes to form secondary lysosomes.
- 5** Ligands are removed and absorbed into the cytoplasm.
- 6** The lysosomal and endosomal membranes separate.
- 7** The endosome fuses with the plasma membrane, and the receptors are again available for ligand binding.



Vesicular T cont'd...

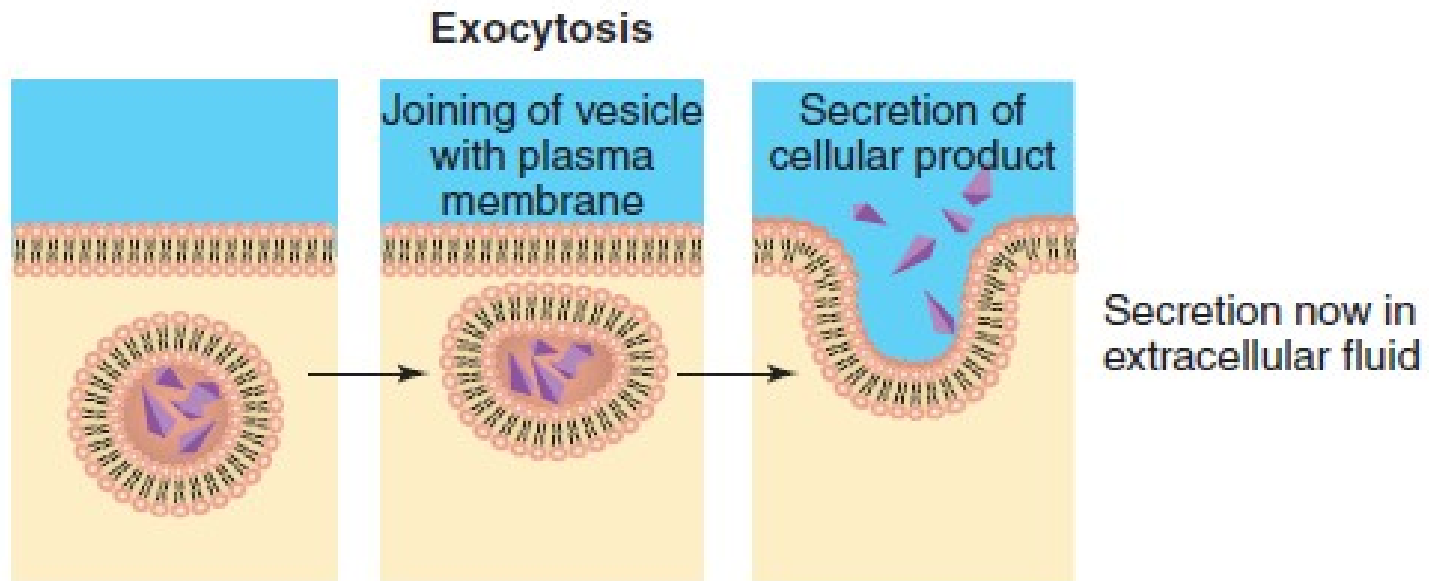


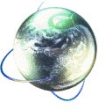
(c) Phagocytosis



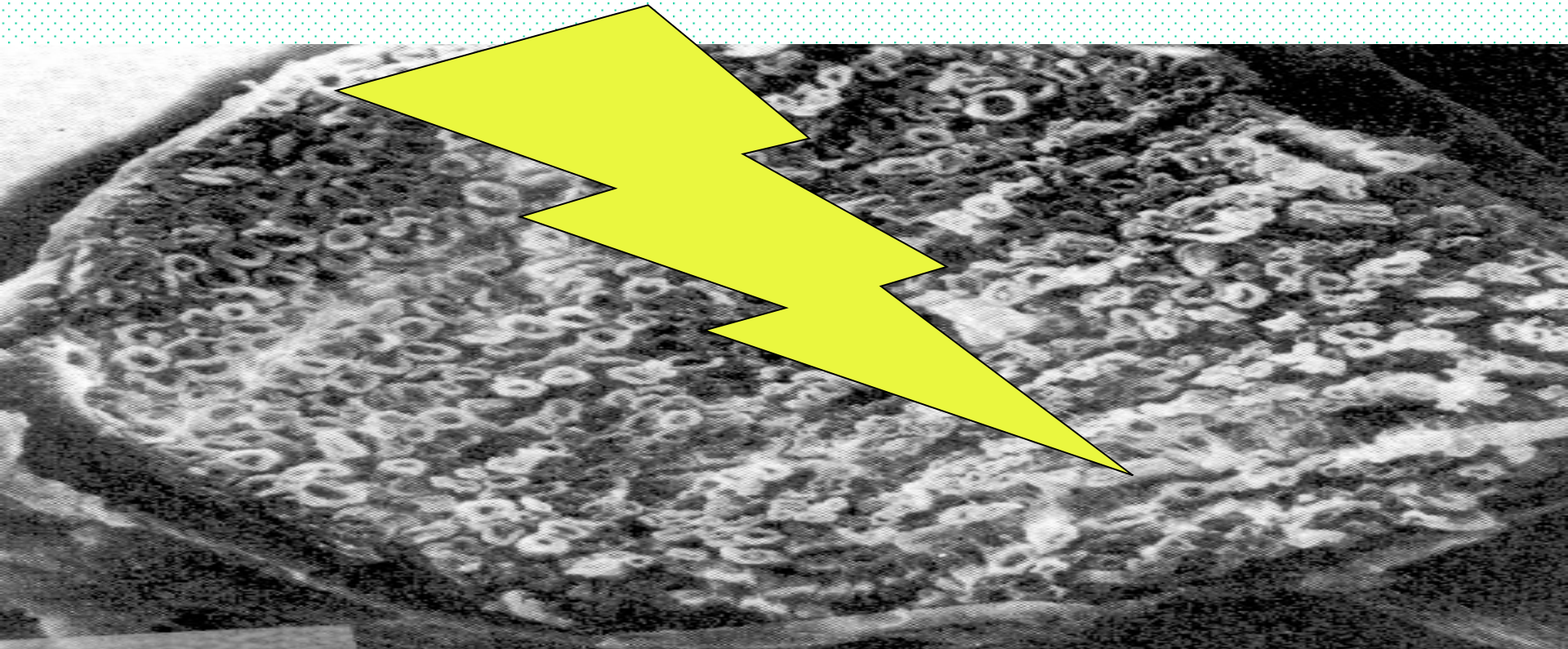
Exocytosis

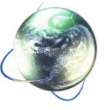
- **It is the primary mechanism for accomplishing secretion.**
- **There are two exocytic pathways: - constitutive**





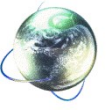
NERVE PHYSIOLOGY





Introduction

- **The nervous system - neurons and supporting cells.**
- **Neurons - basic structural and functional units of the nervous system.**
- **The human CNS contains about 10^{11} neurons.**
- **Neurons - excitable cells.**
 - ✓ **Due to the presence of the ion channels.**
- **Neurons - secretory cells.**



Neurons cont'd...

- ✓ **The release of a neurotransmitter occurs only in the synapses.**

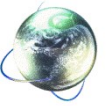
- **Neurons are quiescent cells.**

- ✓ **Renew their constituents during their entire life.**

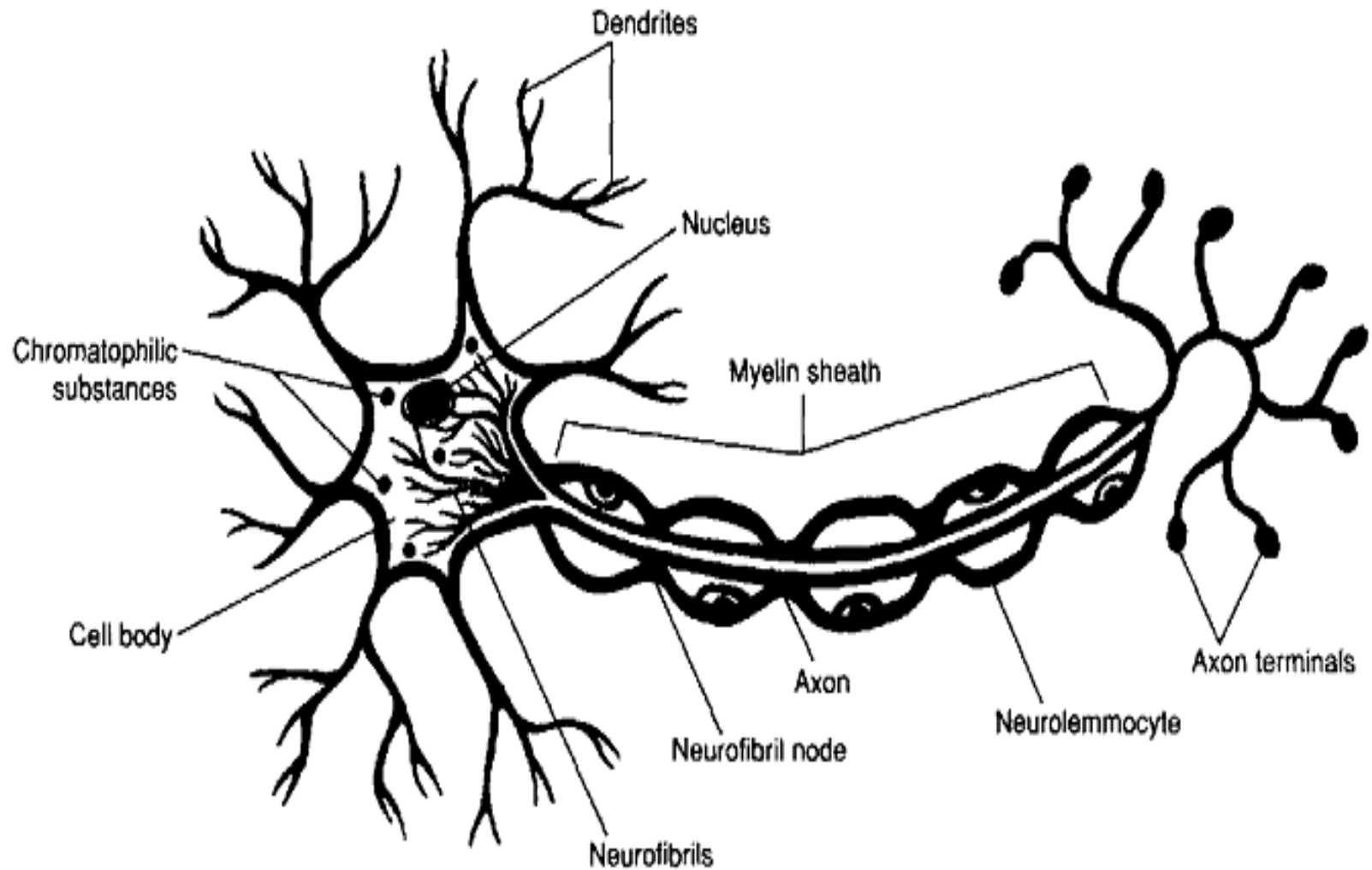
- **Although neurons vary, they have two**

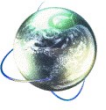
- ✓ **Cell body and**

- ✓ **Neuronal processes**



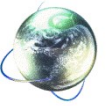
Neurons cont'd...





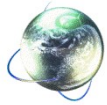
Neurons cont'd...

- **Cell body - enlarged portion - contain the nucleus and its perikaryon.**
- **Function of the soma - nutritional center of the neuron.**
 - ✓ **The cell body and larger dendrites contain Nissl bodies.**
- **The soma of the neuron also acts as a sort of integrator.**
- **The cell bodies within the CNS are frequently clustered - *nuclei*.**



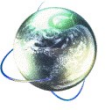
Neurons cont'd...

- **Neuronal processes - dendrites and axon.**
- **Dendrites - thin, branched processes that extend from the cell body.**
 - ✓ **Provide a receptive area.**
- **The dendrites that emerge from the soma are simple perikaryal extensions - the primary dendrites.**
 - ✓ **Between one and nine primary dendrites emerge from the soma.**



Neurons cont'd...

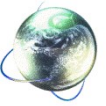
- **The primary dendrites divide successively to give a dendritic tree with specific characteristics.**
- **The dendrites are morphologically -**
 - ✓ **Irregular outline, diameter which decreases along their branchings, acute angles between the branches, and ultrastructural characteristics.**
- **The axon is a longer process that conducts impulses away from the cell body.**



Neurons cont'd...

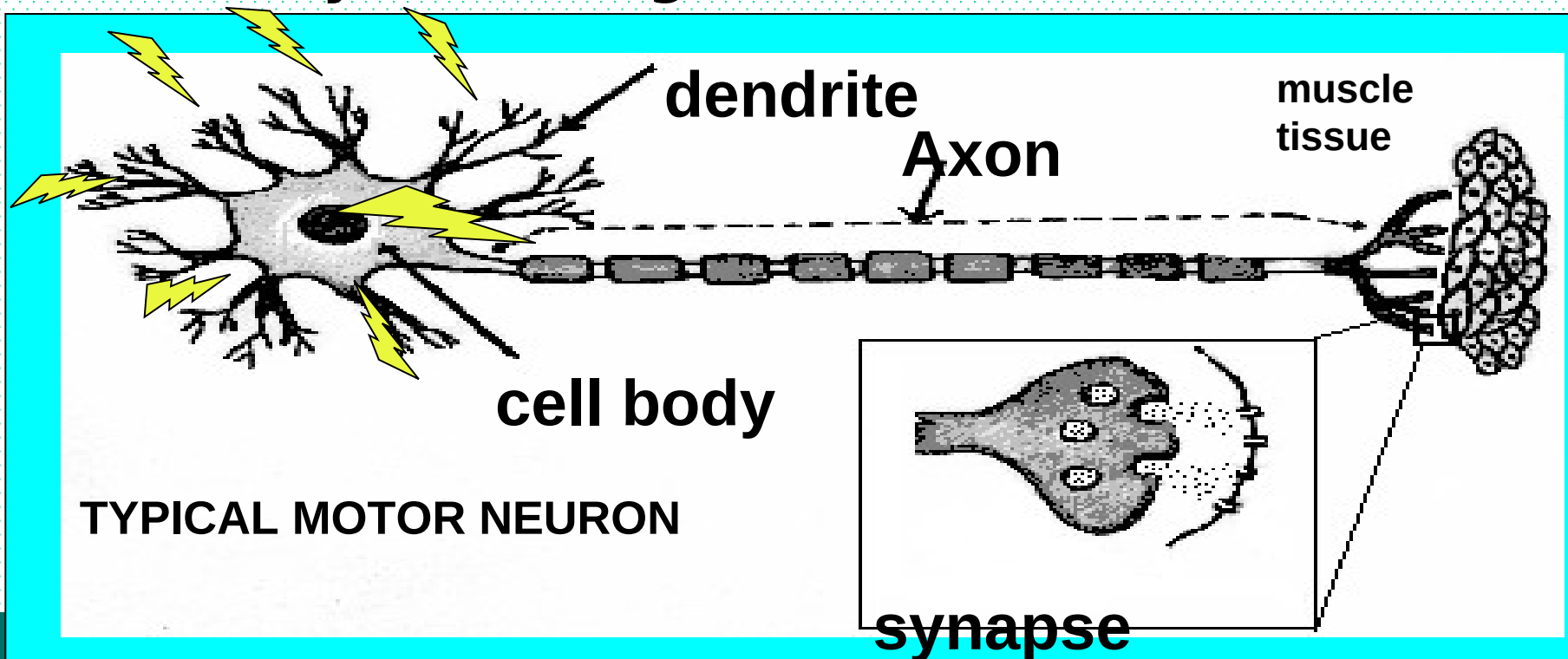
✓ **Smooth appearance, a uniform diameter along its entire extent, by the right-angles with the main axon and by its ultrastructural characteristics.**

- **Axons are narrow from their origin, and do not usually contain ribosomes or endoplasmic reticula.**
- **The origin of the axon near the cell body - the axon hillock.**
- **Axons vary in length.**



Neurons cont'd...

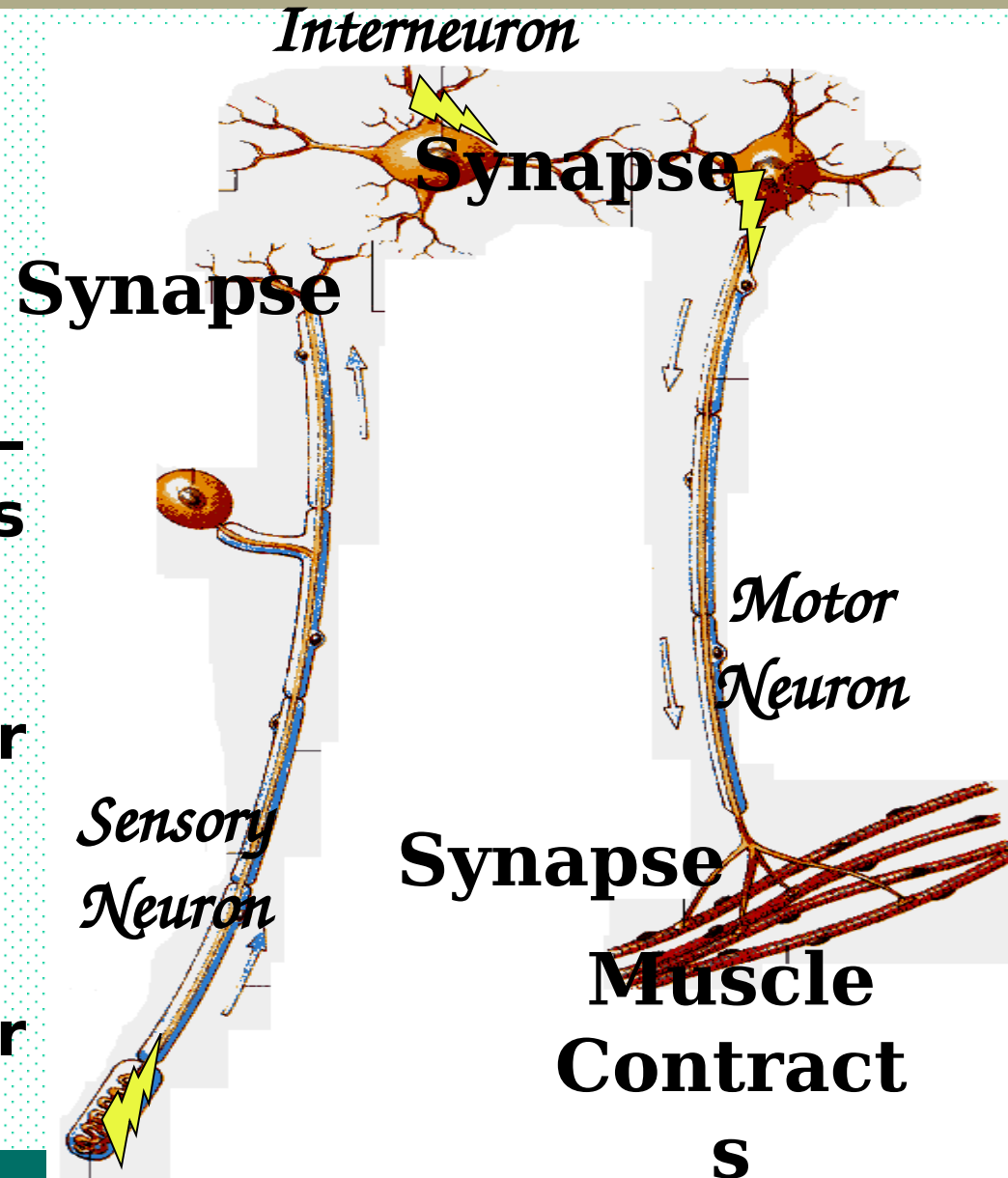
- 0 Each ending in a number of synaptic knobs which are also called terminal buttons or boutons.
- 0 They contain granules or vesicles in which

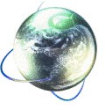




Classification of Neurons

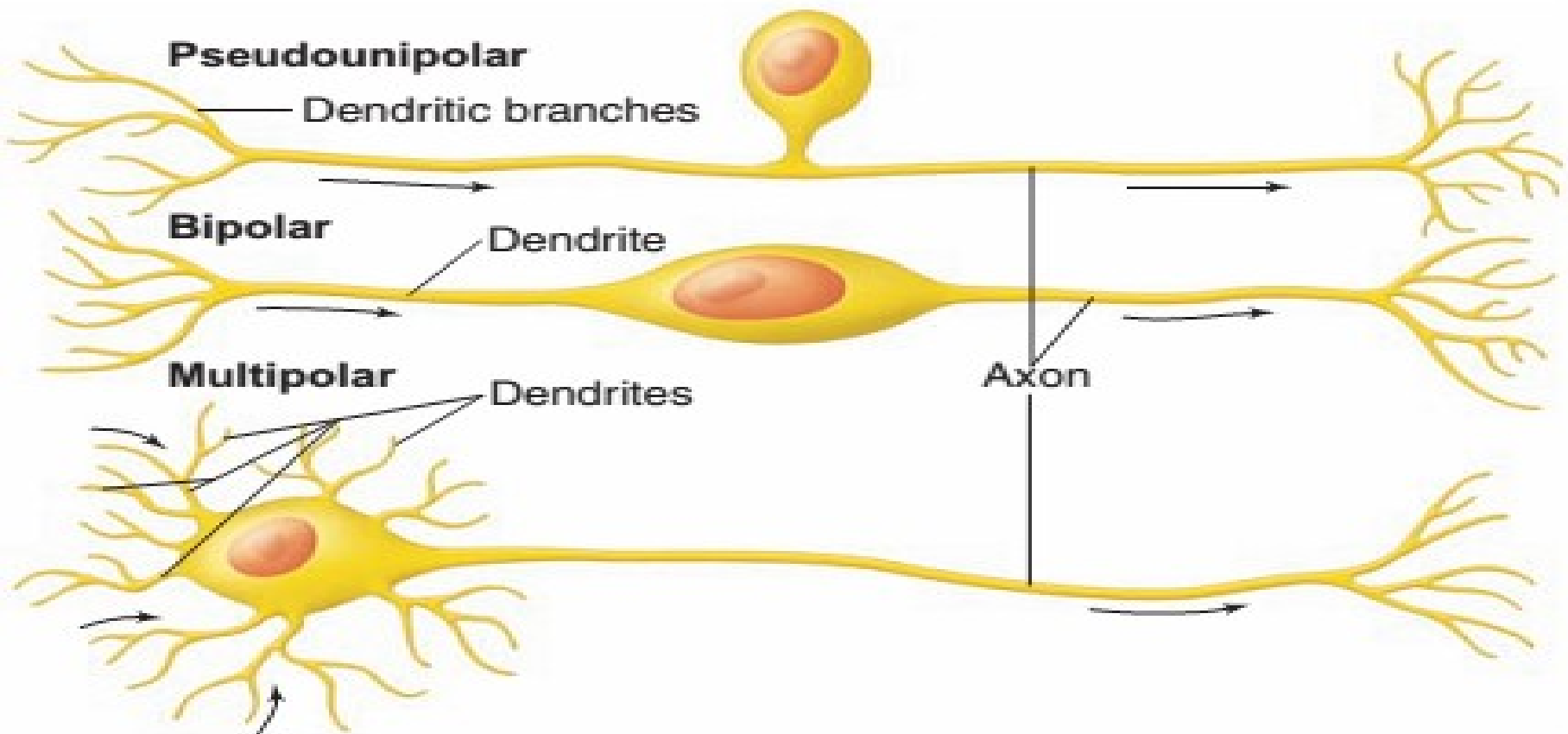
- **Functional classification**
direction of impulses conduction.
- 1. **Sensory, or afferent, neurons.**
- 2. **Association neurons, or interneurons.**

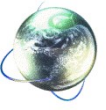




Classification of neurons cont'd...

- **Structural classification - number of processes that extend from the cell body.**

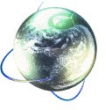




Classification of neurons cont'd...

Axonal Projection

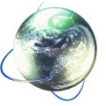
- **Neurons with long axons - projection neurons (or principal neurons or Golgi type I cells).**
- **Neuron that has all processes confined to one region of the brain -interneurons (or intrinsic neurons or Golgi type II cells).**
 - ✓ **Some of these cells have very short axons.**
 - ✓ **Others seem to lack a conventional axon altogether - anaxonal.**



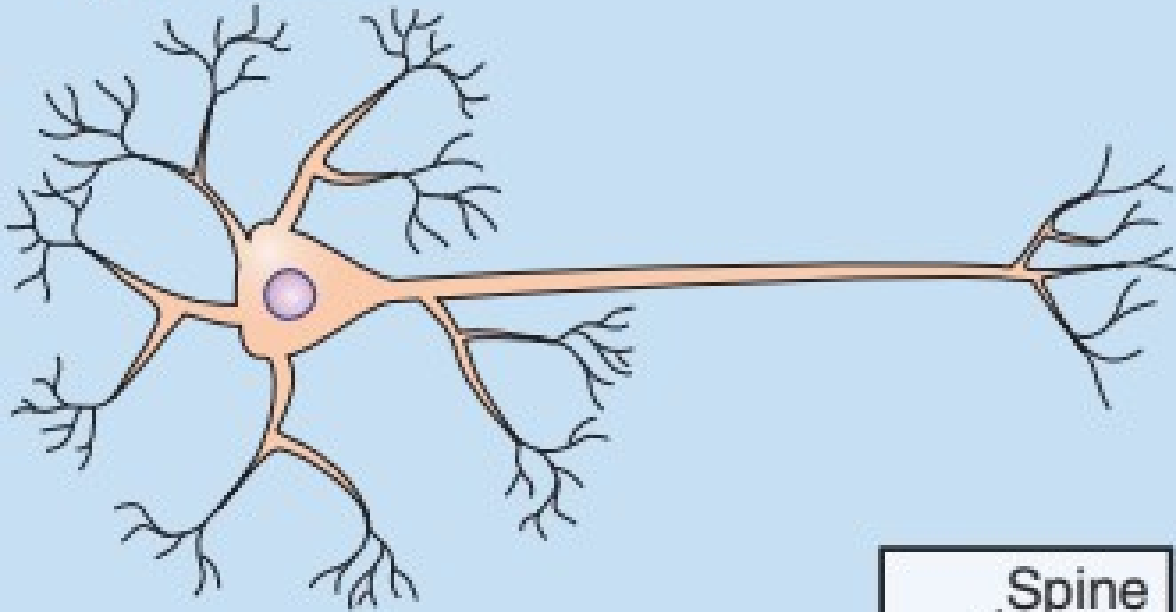
Classification of neurons cont'd...

Dendritic Geometry

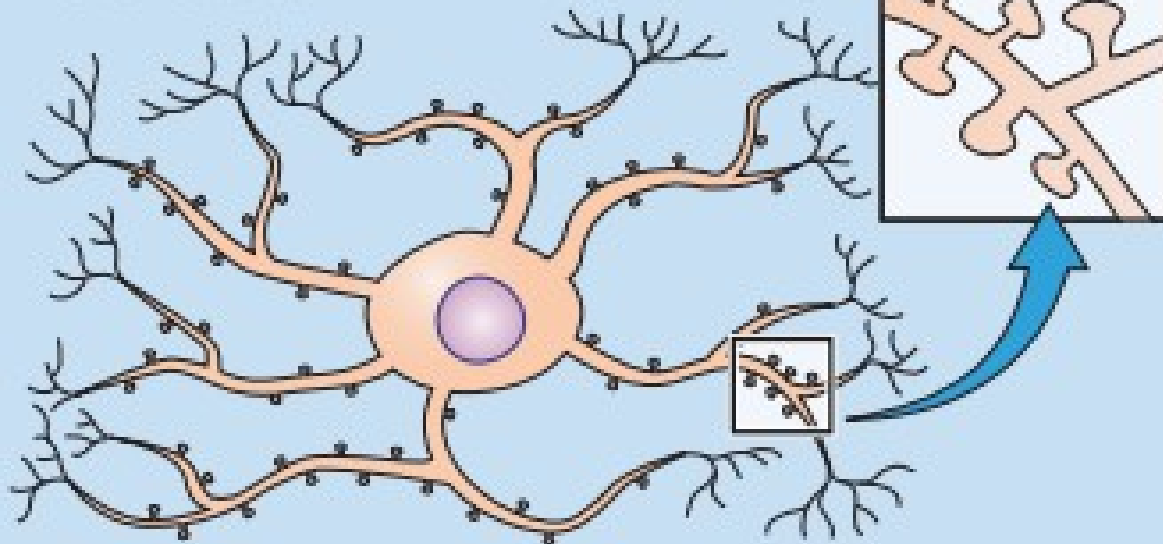
- Pyramid-shaped spread of dendrites - pyramidal cells.**
- Radial-shaped spread of dendrites - stellate cells.**
- This classification often includes the presence or absence of dendritic spines.**
- All pyramidal cells appear to have spines, but stellate cells may have them (spiny) or not (aspiny).**

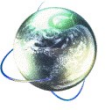


Pyramidal cell



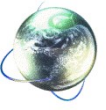
Stellate cell





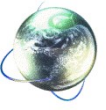
ELECTRICAL SIGNALS IN NEURONS

- **Excitable cells - electrical signals**
 - ✓ **Graded potentials**
 - ✓ **Action potentials**
 - **In a muscle fiber - muscle action potential.**
 - **In a neuron - nerve action potential (nerve impulse).**



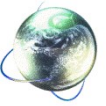
Ion Channels

- **Open - specific ions to move down their electrochemical gradient.**
 - ✓ **As ions move, they create a flow of electrical current.**
- **Open and close due to the presence of “gates.”**
 - ✓ **The gate is a part of the channel protein that can seal the channel pore shut or move aside to open the pore.**
- **The electrical signals - rely on four types of ion**

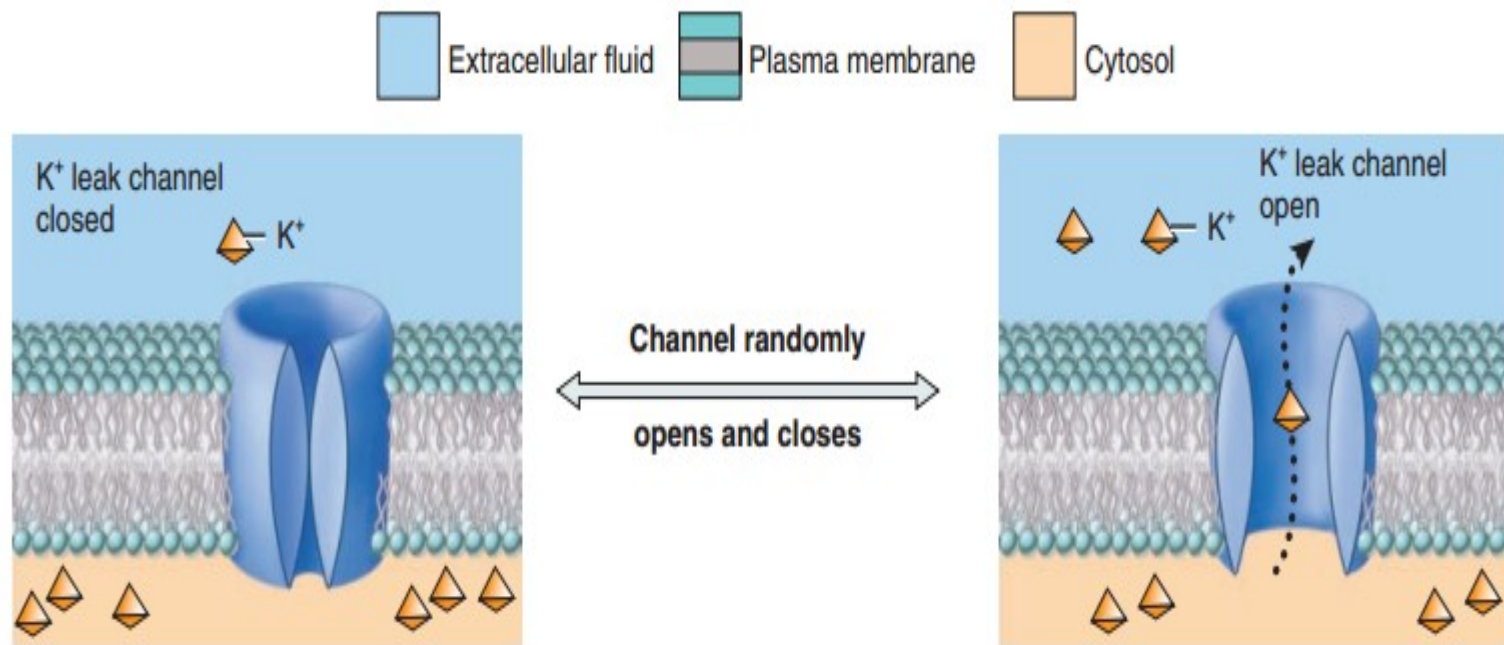


Ions channels cont'd...

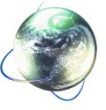
- 1. Leak channels - gates randomly alternate between open and closed.**
- Found - dendrites, cell bodies, and axons of all types of neurons.**
- The membrane's permeability to K^+ is much higher than its permeability to Na^+ .**
- ✓ Plasma membranes - many more K^+ leak channels than Na^+ leak channels.**
- ✓ The K^+ leak channels are leakier than the Na^+ leak channels.**



Ions channels cont'd...



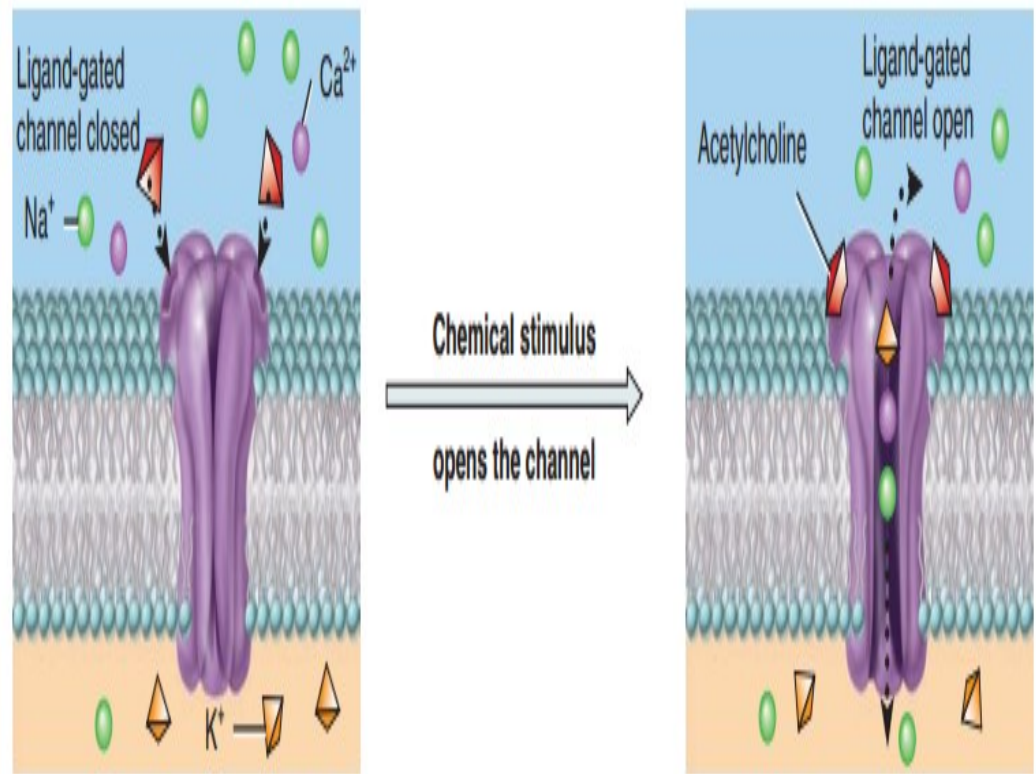
(a) Leak channel



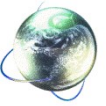
Ions channels cont'd...

2. Ligand-gated channel - opens and closes - binding of a ligand.

- Chemical ligands - NT, hormones, and particular ions.**



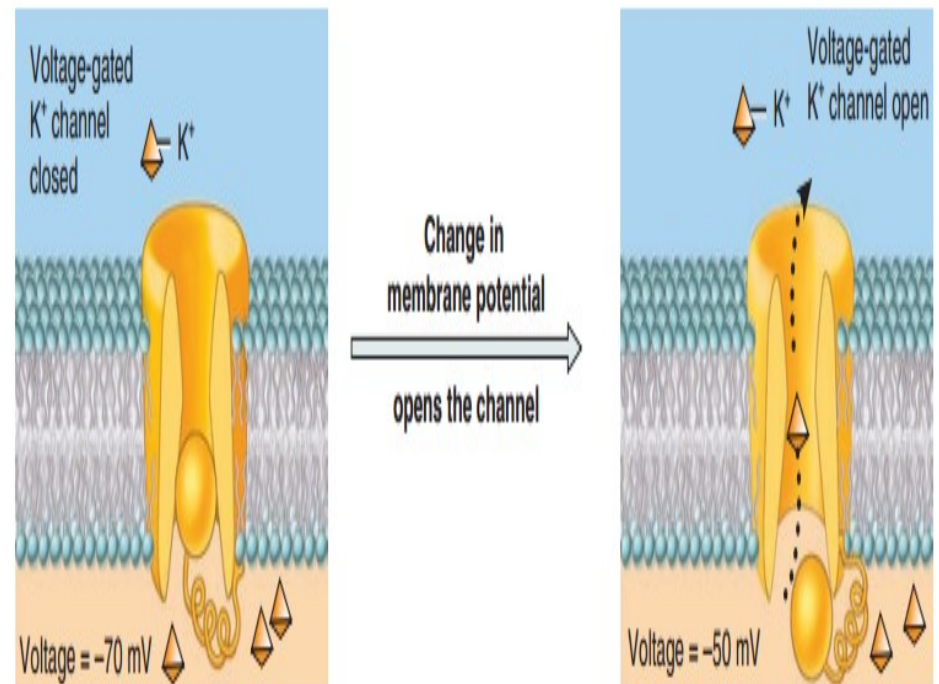
(b) Ligand-gated channel



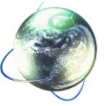
Ions channels cont'd...

3. Mechanically gated channel - opens or closes - mechanical stimulation.

- ✓ **The force distorts the channel from its resting position.**



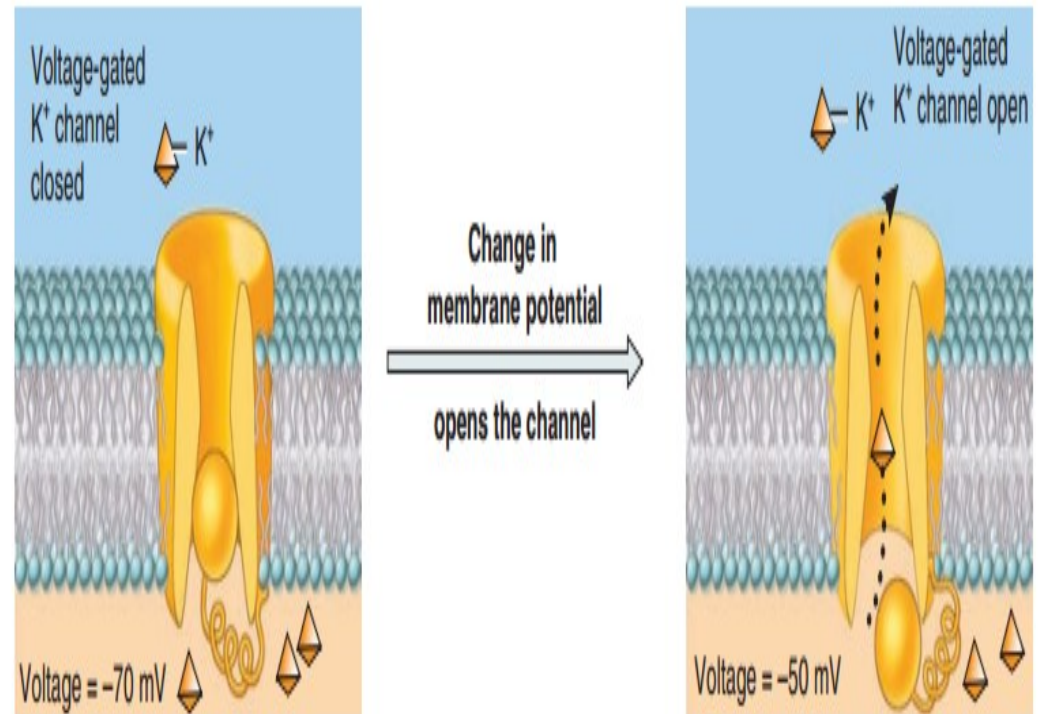
(d) Voltage-gated channel



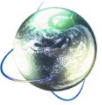
Ions channels cont'd...

4. Voltage-gated channel - opens - change in membrane potential.

- ✓ **Participate in the generation and conduction of action**

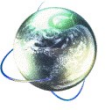


(d) Voltage-gated channel



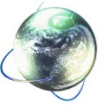
Ion Channels in Neurons

TYPE OF ION CHANNEL	DESCRIPTION	LOCATION
Leak channels	Gated channels that randomly open and close.	Found in nearly all cells, including dendrites, cell bodies, and axons of all types of neurons.
Ligand-gated channels	Gated channels that open in response to binding of ligand (chemical) stimulus.	Dendrites of some sensory neurons such as pain receptors and dendrites and cell bodies of interneurons and motor neurons.
Mechanically gated channels	Gated channels that open in response to mechanical stimulus (such as touch, pressure, vibration, or tissue stretching).	Dendrites of some sensory neurons such as touch receptors, pressure receptors, and some pain receptors.
Voltage-gated channels	Gated channels that open in response to voltage stimulus (change in membrane potential).	Axons of all types of neurons.



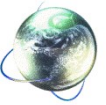
Resting Membrane Potential

- **Build up of charge difference - only very close to the membrane.**
 - ✓ **Separation of +ve and -ve form of potential energy - millivolts.**
- **A cell that exhibits a membrane potential is said to be polarized.**
- **In neurons, the RMP ranges from -40 to -90 mV.**
 - ✓ **A typical value is - 70 mV.**

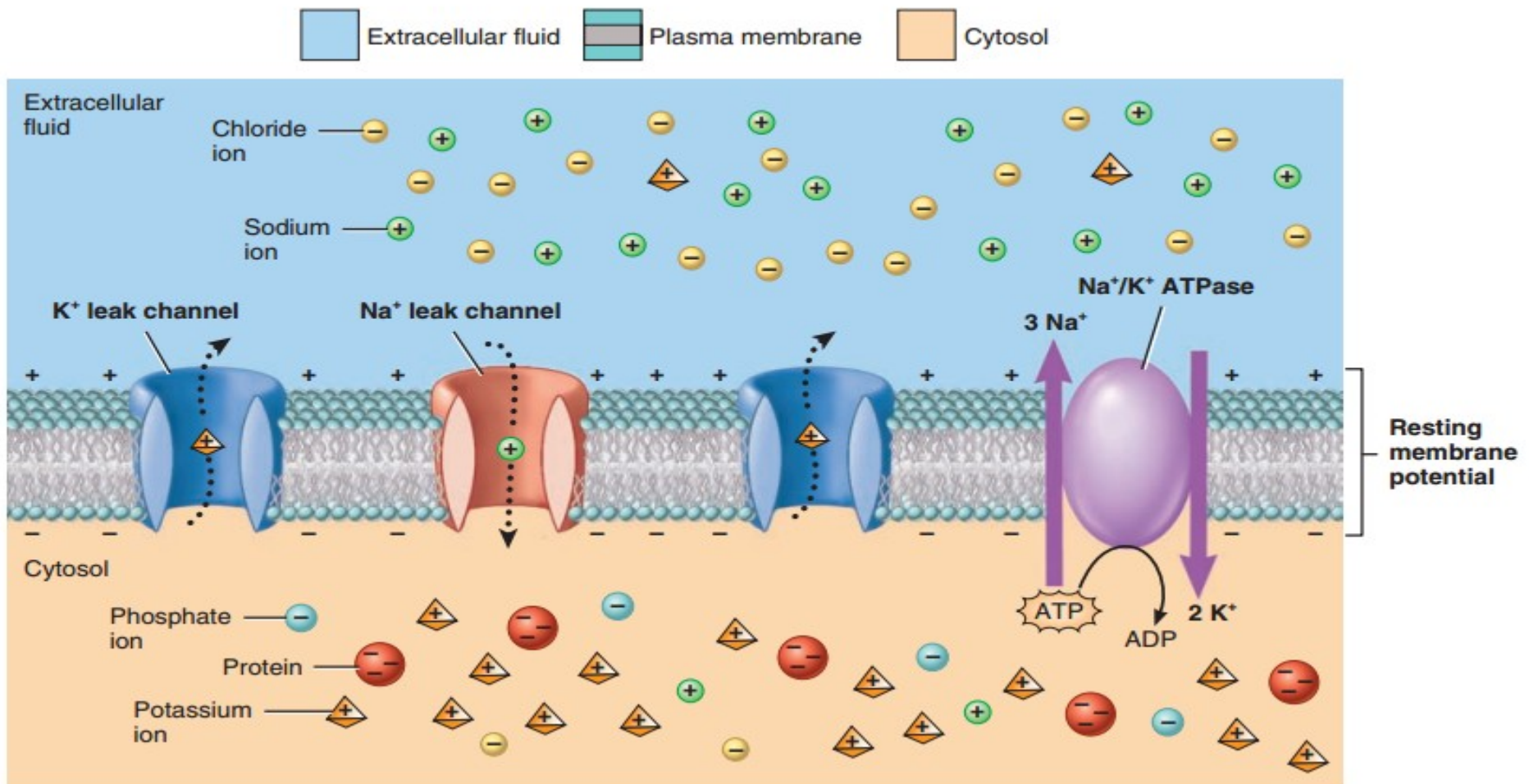


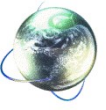
RMP cont'd...

- **The resting membrane potential arises**
 - 1. Unequal distribution of ions**
 - 2. Inability of most anions to leave the cell.**
 - 3. Electrogenic nature of the Na^+/K^+ ATPases.**



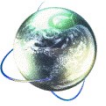
RMP cont'd...





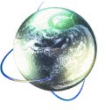
Graded Potentials

- **Small deviation from the membrane potential.**
 - ✓ **Membrane more polarized - hyperpolarizing graded potential.**
 - ✓ **Membrane less polarized - depolarizing graded potential.**
- **Occurs - mechanically gated or ligand-gated channels.**
 - ✓ **Mainly in the dendrites and cell body.**



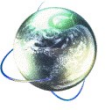
GP cont'd...

- **Vary in amplitude - depending on the strength of the stimulus.**
 - ✓ **How many ligand-gated or mechanically gated channels have opened (or closed) and how long each remains open.**
- **Flow of current is localized - decremental conduction.**
- **Useful for short-distance communication only.**



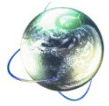
GP cont'd...

- **GP have different names.**
 - ✓ **When a GP occurs in the dendrites or cell body in response to a NT - postsynaptic potential.**
 - ✓ **Occur in sensory receptors and sensory neurons - receptor potentials and generator potentials of respectively.**



Generation of Action Potentials

- **Rapidly occurring events.**
- **The threshold in a particular neuron usually is constant.**
- **The generation of an AP depends on whether a particular stimulus is able to bring the MP to threshold.**
- ✓ **Occur in response to threshold or suprathreshold stimulus.**



Stages of the Action Potential

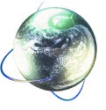
1. Resting stage (Polarization stage).

- ✓ **At resting, the membrane is polarized at -70 mV in a typical neuron.**
 - **The firing level is at -55 mV.**

2. Depolarization stage.

- ✓ **The inside becomes less negative than at resting potential.**
- ✓ **Depolarization ends at +35 mV**

3. Repolarization stage.

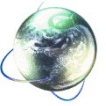


Action P cont'd...

- ✓ **The membrane returns to resting potential after having been depolarized.**

4. Hyperpolarization stage.

- ✓ **The inside becomes more negative than at resting potential.**
- **The duration of an action potential is always the same in a given excitable cell.**
- ✓ **In a neuron, an action potential lasts for only 1 msec.**

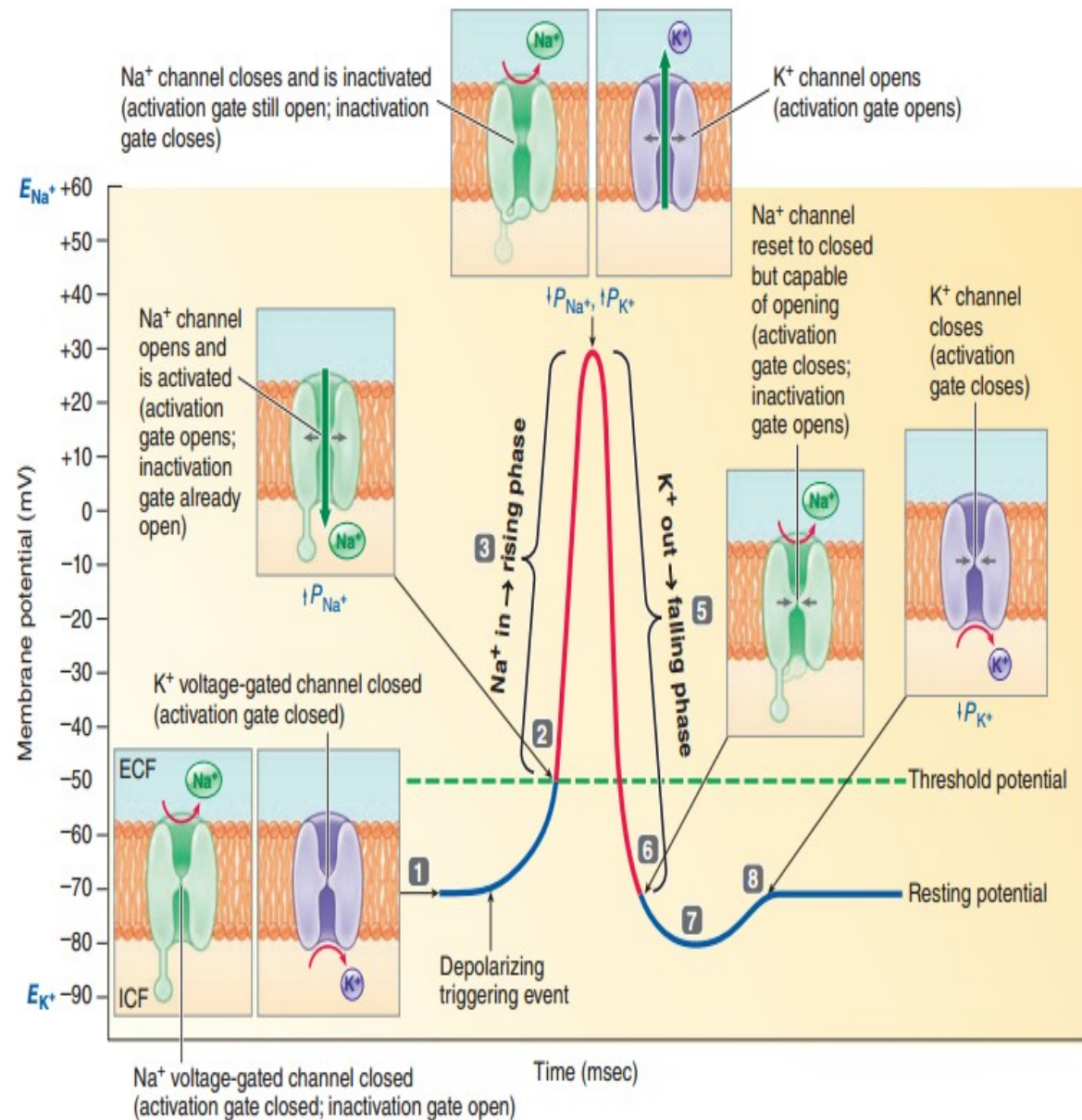


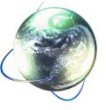
Action P cont'd...

- **Action potentials take place as a result of two specific types of channels:**

✓ **Voltage-gated Na^+ channels and**

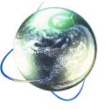
✓ **Voltage-gated K^+ channels**





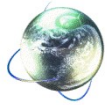
Refractory Period

- **The period of time - cannot generate another AP in response to a normal threshold stimulus.**
- **ARP - very strong stimulus cannot initiate a second AP.**
 - ✓ **Coincides with period of Na^+ channel activation and inactivation.**
 - ✓ **Inactivated Na^+ channels cannot reopen.**
- **Graded potentials do not exhibit a refractory period.**



RP cont'd...

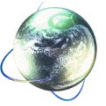
- **Under normal body conditions, the maximum frequency of nerve impulses in different axons ranges between 10 and 1000 per second.**
 - ✓ **Large-diameter axons - ARP - 0.4 msec.**
 - ✓ **Small-diameter axons - 4 msec.**
- **RRP - second AP can be initiated, but only by a larger-than-normal stimulus.**
 - ✓ **Coincides with period when voltage-gated K^+ channels are still open.**



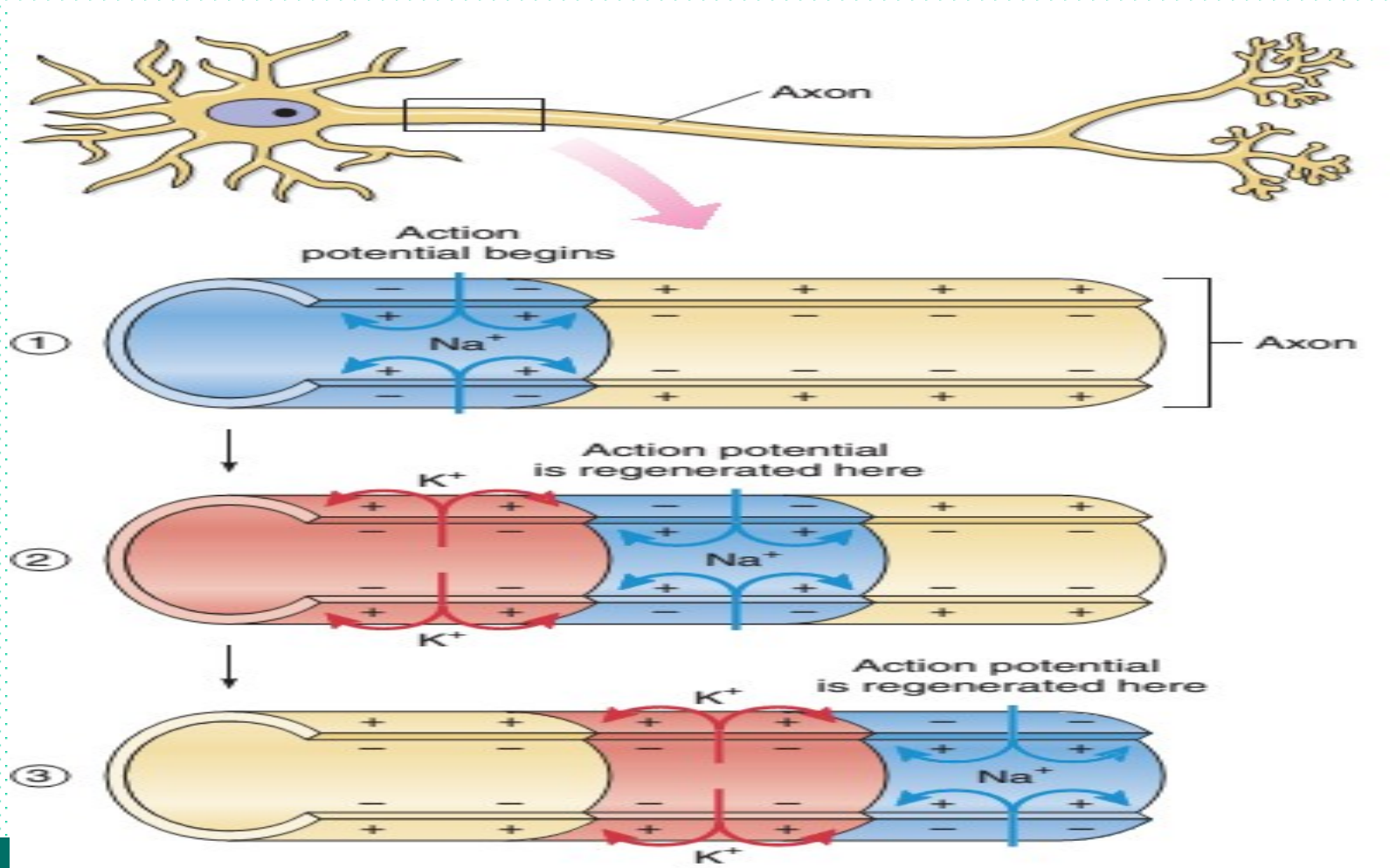
CONDUCTION OF NERVE IMPULSES

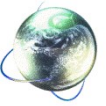
Conduction in an Unmyelinated Axon

- **Unmyelinated axon every patch of membrane - Na^+ and K^+ channels.**
 - ✓ **AP - produced along the entire length of the axon.**
- **The type of conduction - continuous conduction.**
- **AP must be produced at every fraction of a micrometer - conduction rate is relatively slow.**
 - ✓ **Conduction rate is somewhat faster if unmyelinated axon is thicker**



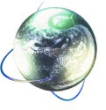
Conduction in unmyelinated cont'd...





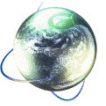
Conduction in a Myelinated Axon

- **The myelin sheath provides insulation for the axon, preventing movements of Na^+ and K^+ through the membrane.**
 - ✓ **The myelin has interruptions - the nodes of Ranvier.**
- **The nodes of Ranvier - separated by very short distance (1 to 2 mm).**
 - ✓ **Na^+ channels are highly concentrated at the nodes (estimated at 10,000 per square micrometer) and almost absent in the regions**

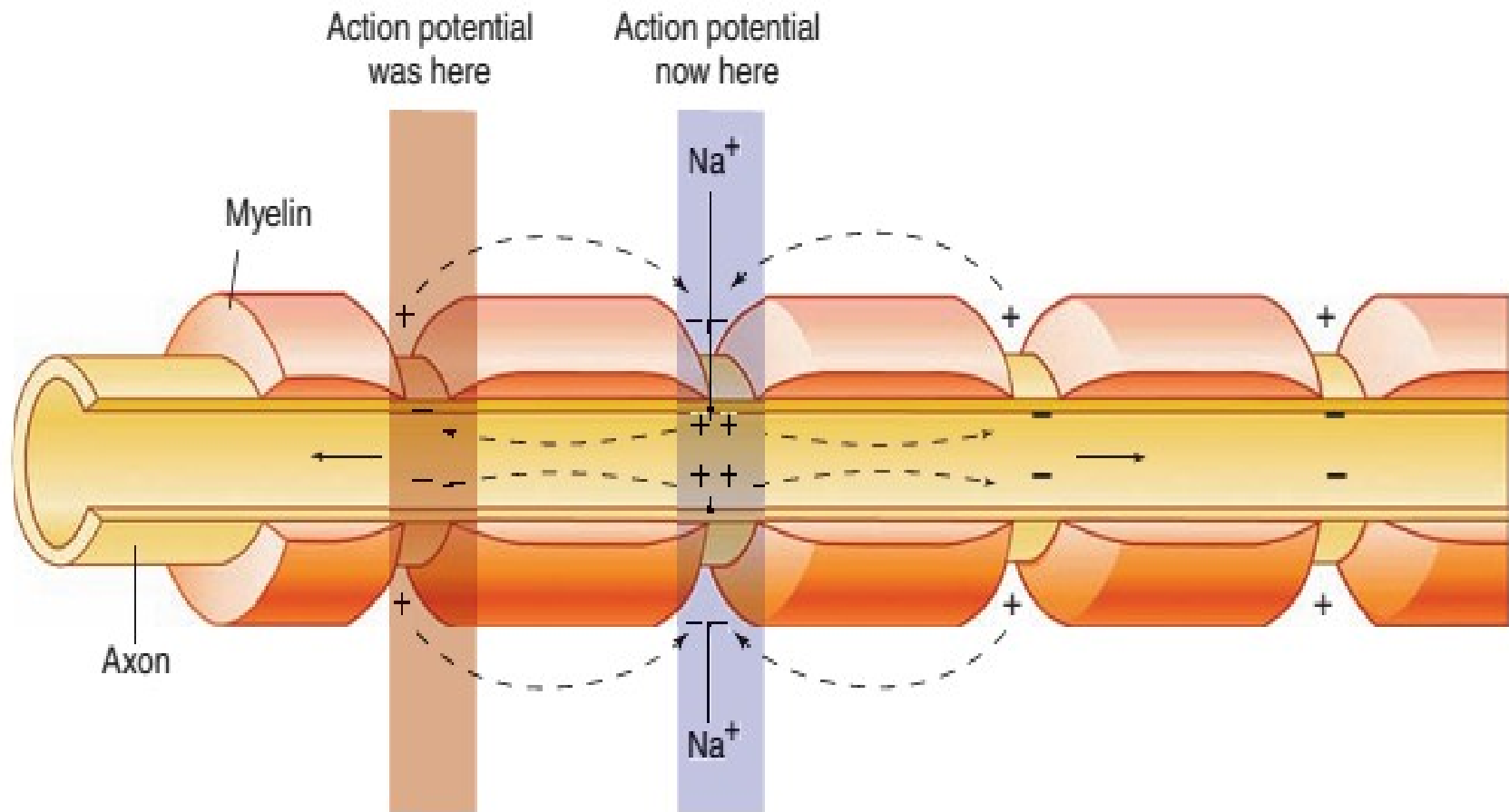


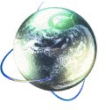
Conduction in myelinated cont'd...

- **AP occur only at the nodes of Ranvier and seem to “leap” from node to node - saltatory conduction.**
- **Myelinated axons conduct the AP faster than unmyelinated axons.**
- **Conduction rates vary from 1.0 m/sec to faster than 100 m/sec.**
- **The speed of AP conduction is increased -**
 - ✓ **Increased diameter of the axon and**
 - ✓ **Myelination**



Conduction in myelinated cont'd...





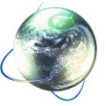
A SYNAPSE

- **The functional connection between a neuron and a second cell.**
- **In the CNS, this other cell is a neuron.**
 - ✓ **Axodendritic, axosomatic, and axoaxonic synapses.**
- **In the PNS, the other cell - neuron, muscle or gland.**
 - **Myoneural, or neuromuscular junctions.**



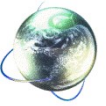
Types of Synaptic Transmission

- **Two major types - the chemical synapse and the electrical synapse.**
- **In the CNS, almost all the synapses are chemical synapses.**
 - ✓ **The first neuron secretes neurotransmitter.**
 - **ACh, NE, E, histamine, GABA, glycine, serotonin, and glutamate.**
- **Electrical synapses - direct open fluid channels that conduct electricity from one cell to the next**



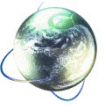
A synapse cont'd...

- ✓ **Consist of gap junctions - allow free movement of ions from the interior of one cell to the interior of the next.**
- ✓ **Only a few examples of gap junctions - in the CNS.**
- ✓ **Way of gap junctions - smooth muscle fiber and cardiac muscle cell.**



“One-way” Conduction at Chemical Synapses

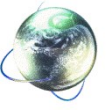
- **Chemical synapses transmit the signals in one direction.**
 - ✓ **It is quite different from conduction through electrical synapses, which often transmit signals in either direction.**
- **Presynaptic terminals - 10,000 to 200,000 minute synaptic knobs.**
 - ✓ **Motor neurons - about 80 to 95% of them on the dendrites and only 5 to 20% on the soma.**
- **These are the ends of nerve fibrils that originate**



PRE- & POSTSYNAPTIC STRUCTURE & FUNCTION

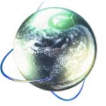
- **The presynaptic terminal contain terminal knobs, boutons, end-feet.**
- **The terminal has two internal structures - transmitter vesicles and mitochondria.**
 - ✓ **The transmitter vesicles contain the transmitter substance.**
 - ✓ **The mitochondria provide ATP - supplies the energy for synthesizing new transmitter substance.**

• **There are three kinds of synaptic vesicles:**



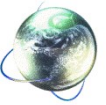
A synapse cont'd...

- ✓ **Small, clear synaptic vesicles that contain acetylcholine, glycine, GABA, or glutamate;**
- ✓ **Small vesicles with a dense core that contain catecholamines; and**
- ✓ **Large vesicles with a dense core that contain neuropeptides.**
- **Each presynaptic terminal of a chemical synapse is separated from the postsynaptic structure by a synaptic cleft that is 20–40 nm wide.**



A synapse cont'd...

- **Across the synaptic cleft are many neurotransmitter receptors in the postsynaptic membrane, and usually a postsynaptic thickening called the postsynaptic density.**
- **The postsynaptic density is an ordered complex of specific receptors, binding proteins, and enzymes induced by postsynaptic effects**



A synapse cont'd...

