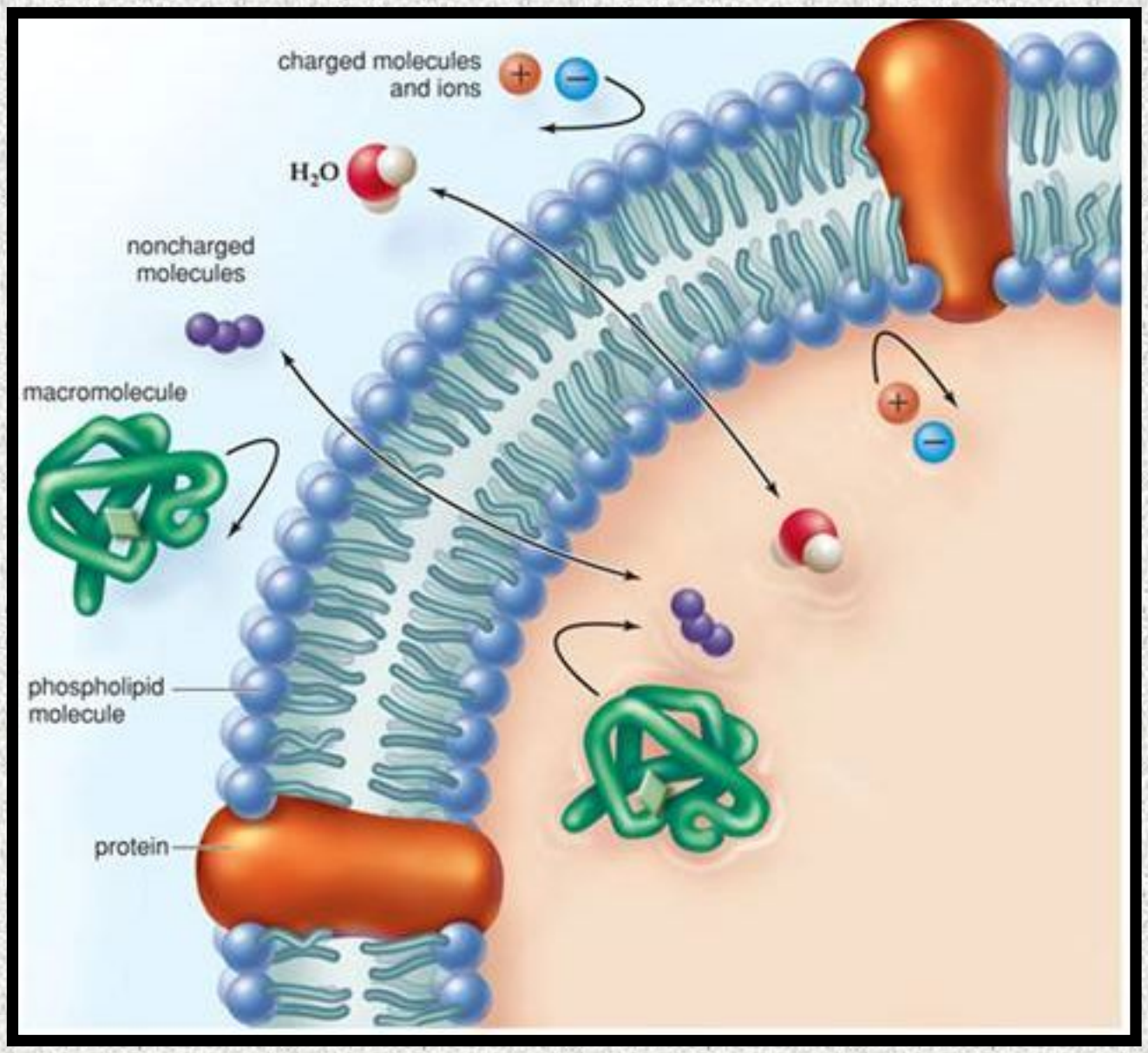
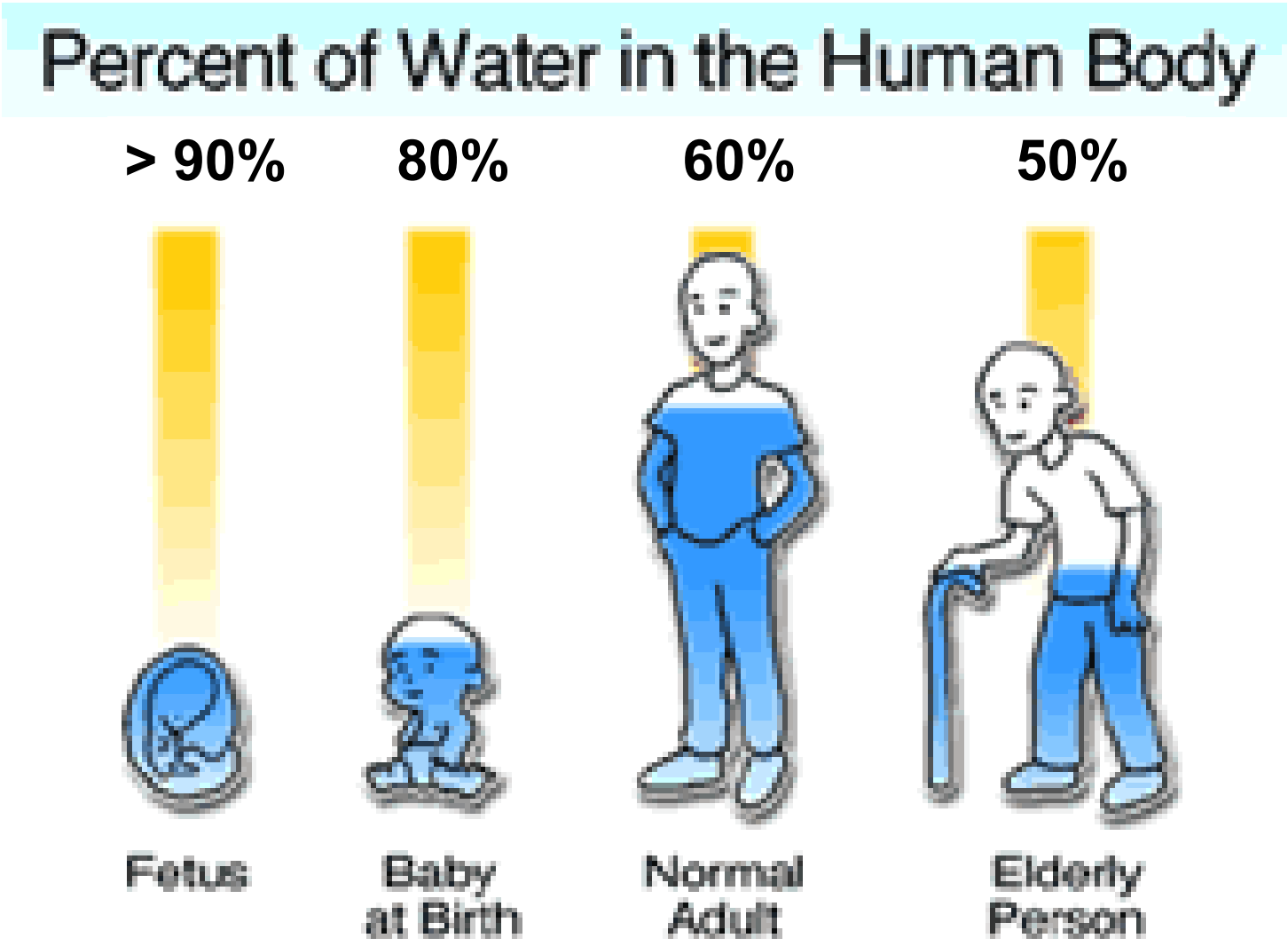
Introduction to Cell Physiology (Transmembrane Transport of Molecules)

Dr. Denny C.W. Ma

Transport of Molecules



Water Content of the Body



Water Content of the Body

Lungs: 90% water

Blood: 82%

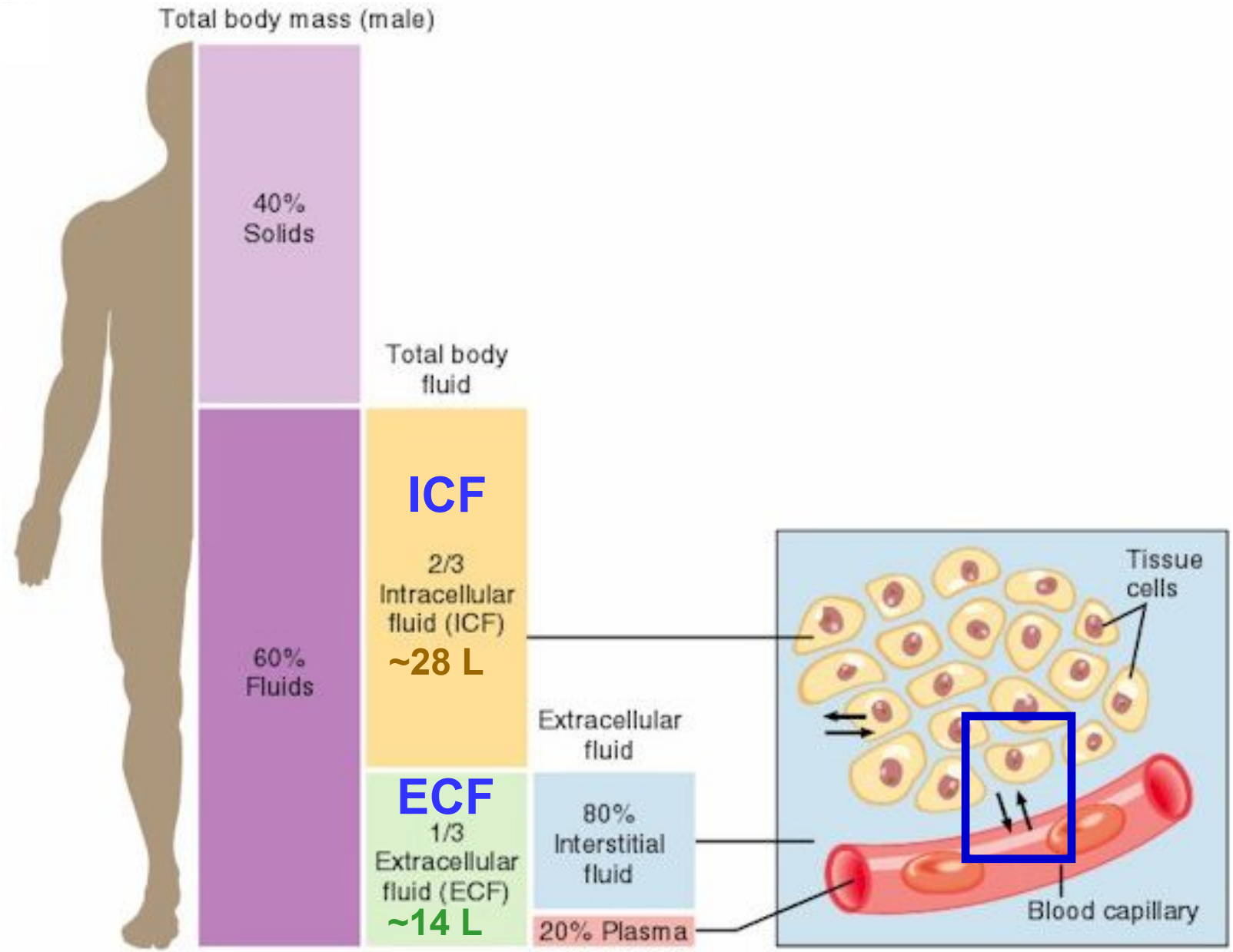
Skin:80%

Muscle: 75%

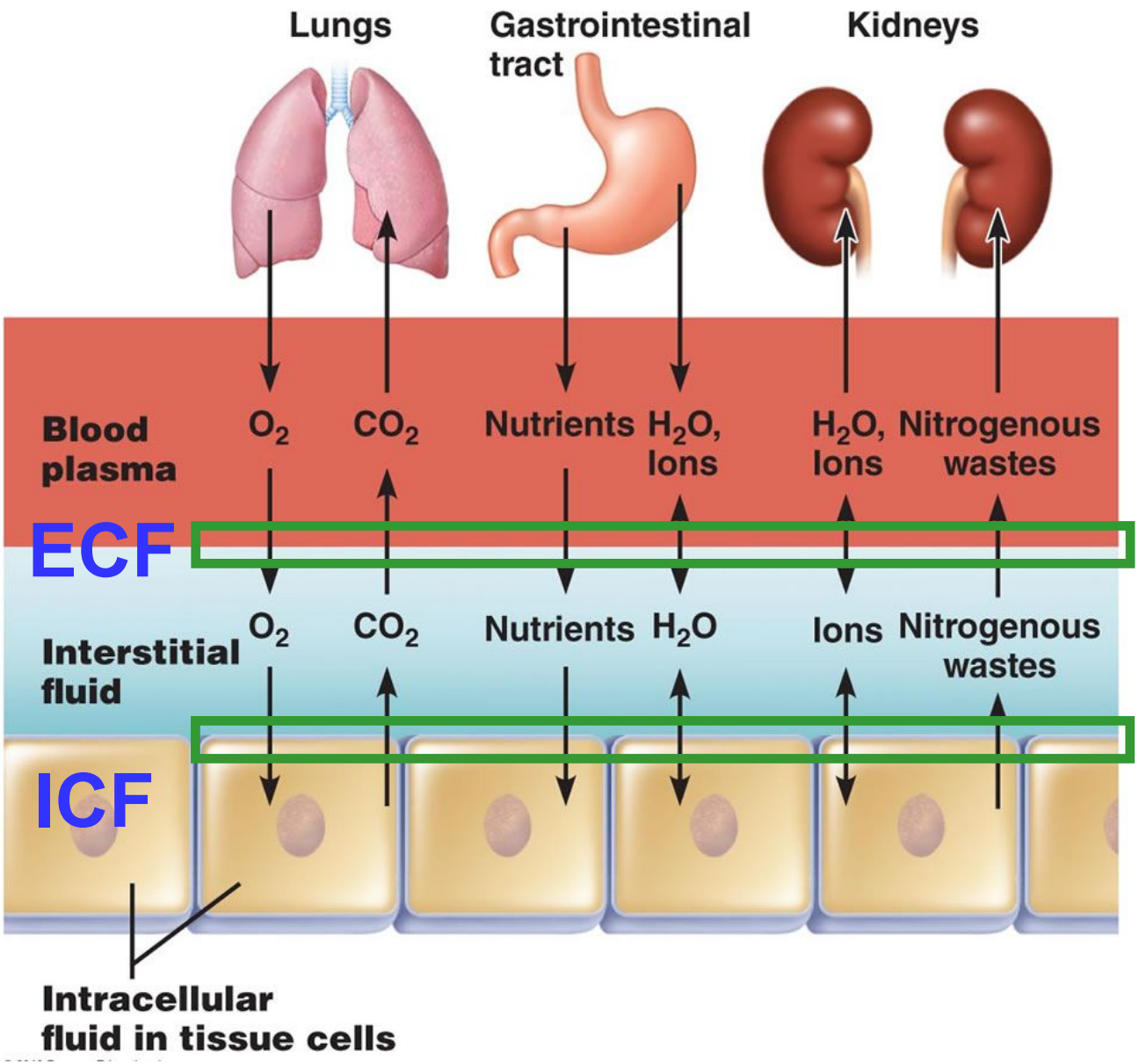
Brain: 70%

Bones: 22%

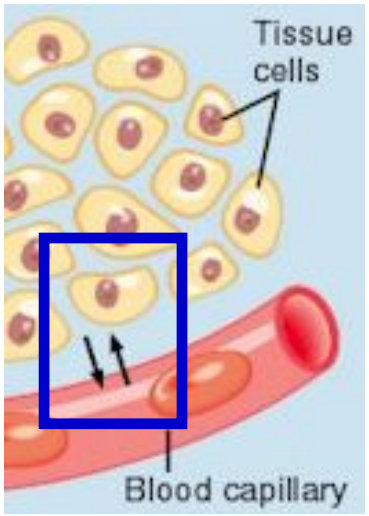
Water Content of the Body



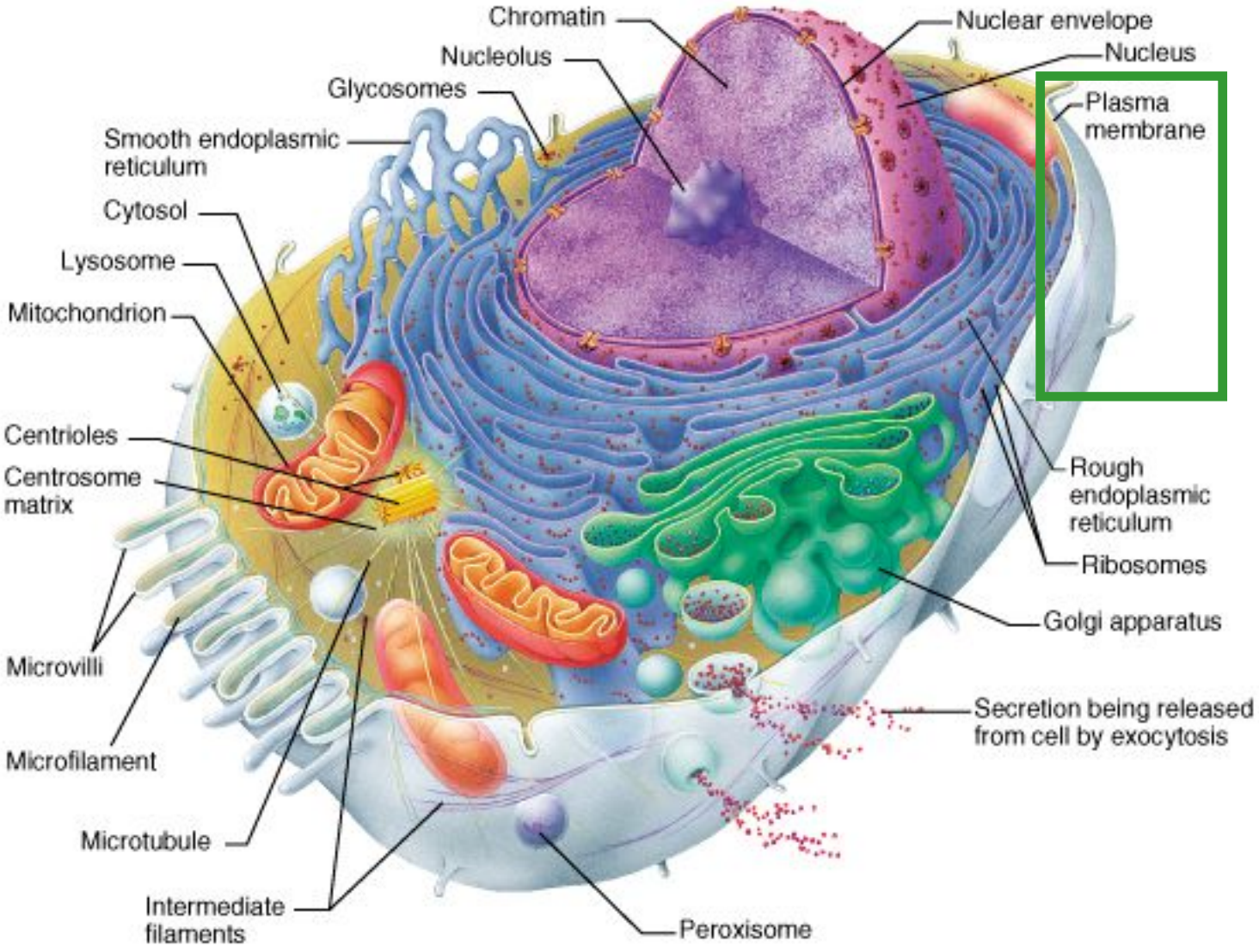
Fluid Transport



Cell Membrane



Plasma Membrane

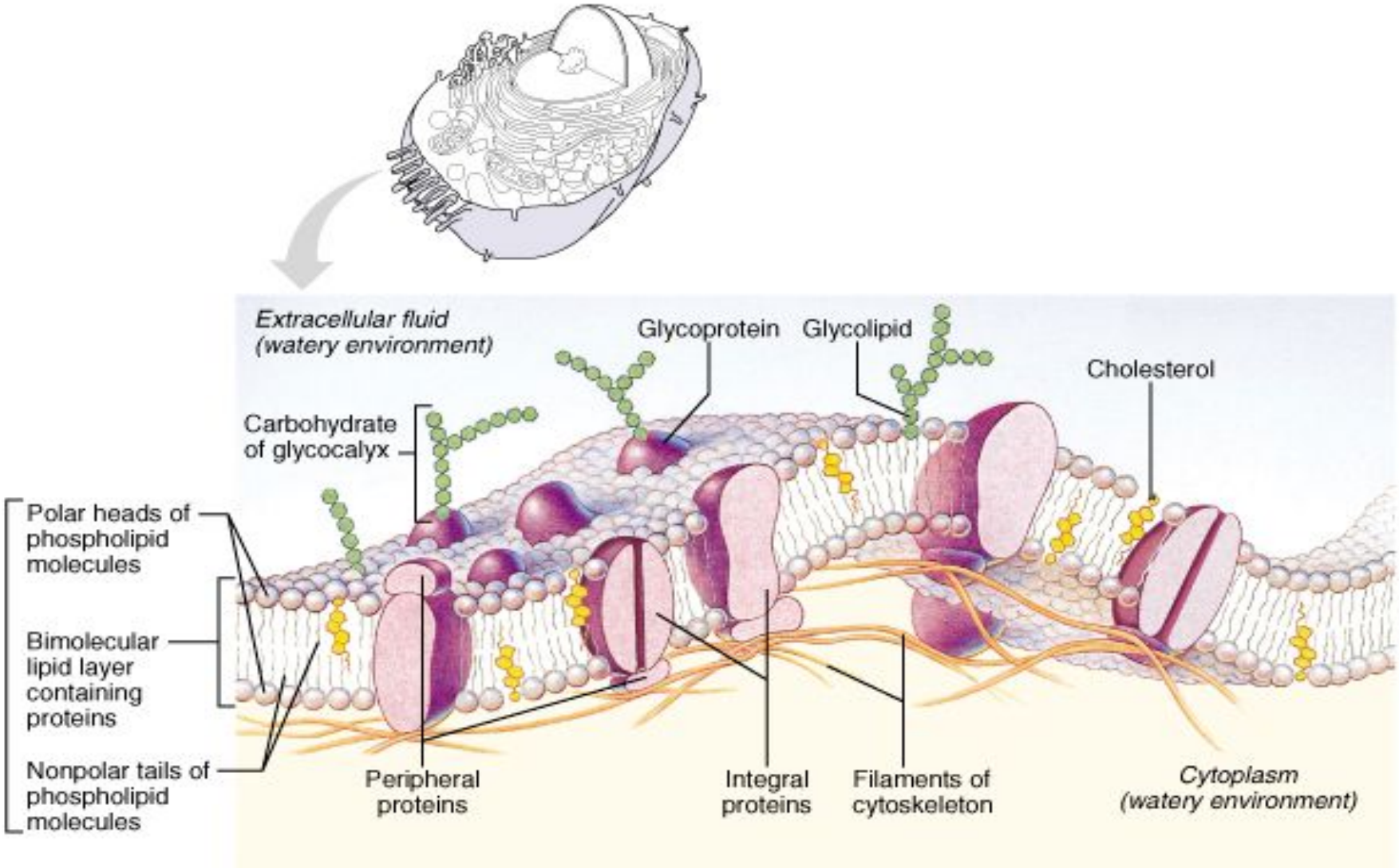


Plasma Membrane

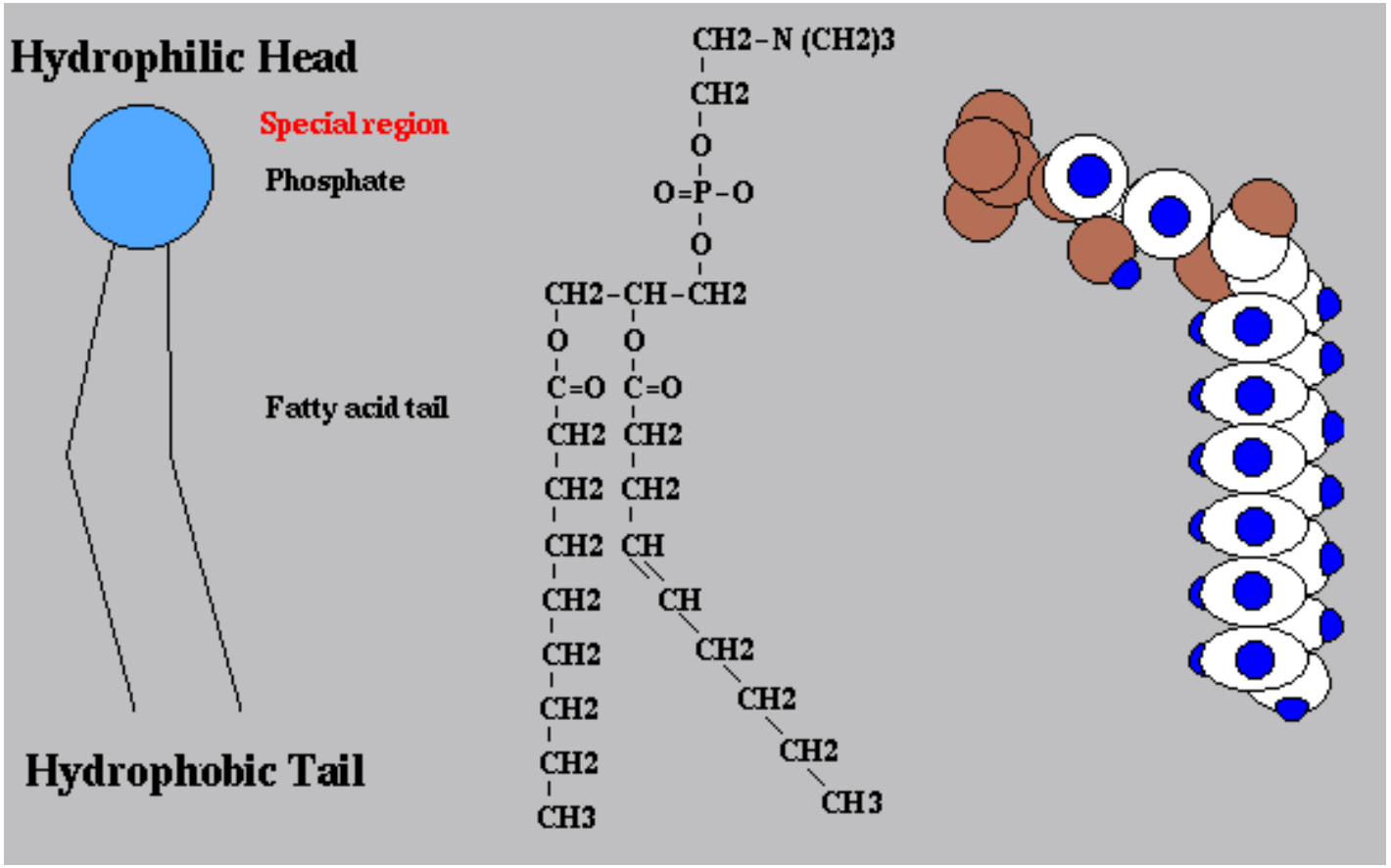
- Separates intracellular fluids (ICF) from extracellular fluids (ECF)
- Selectively permeable → regulates the traffic of molecules into & out of the cell
- Glycocalyx:
  - Coating on external surface
  - Specific biological markers (carbohydrate moieties of membrane glycolipids & glycoproteins)
  - For cell-cell recognition, communication & intercellular adhesion

Fluid Mosaic Model

Lipid bilayer contains phospholipids, glycolipids & cholesterol

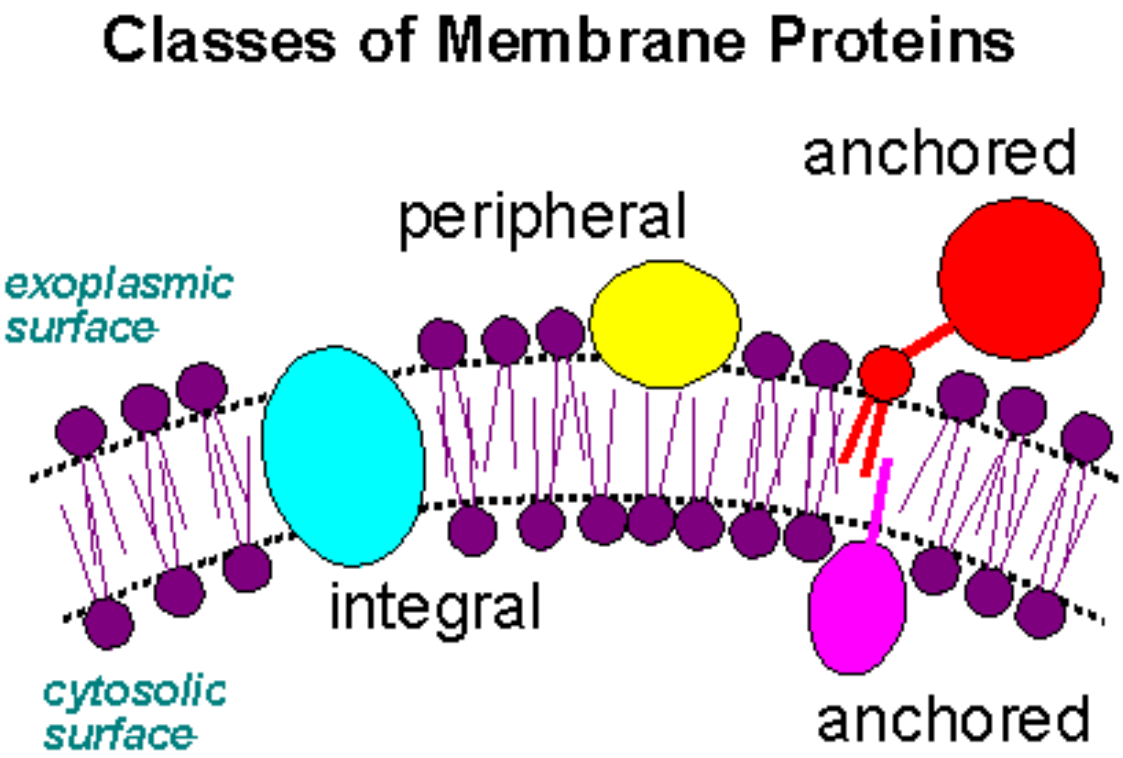


Phospholipid Molecules



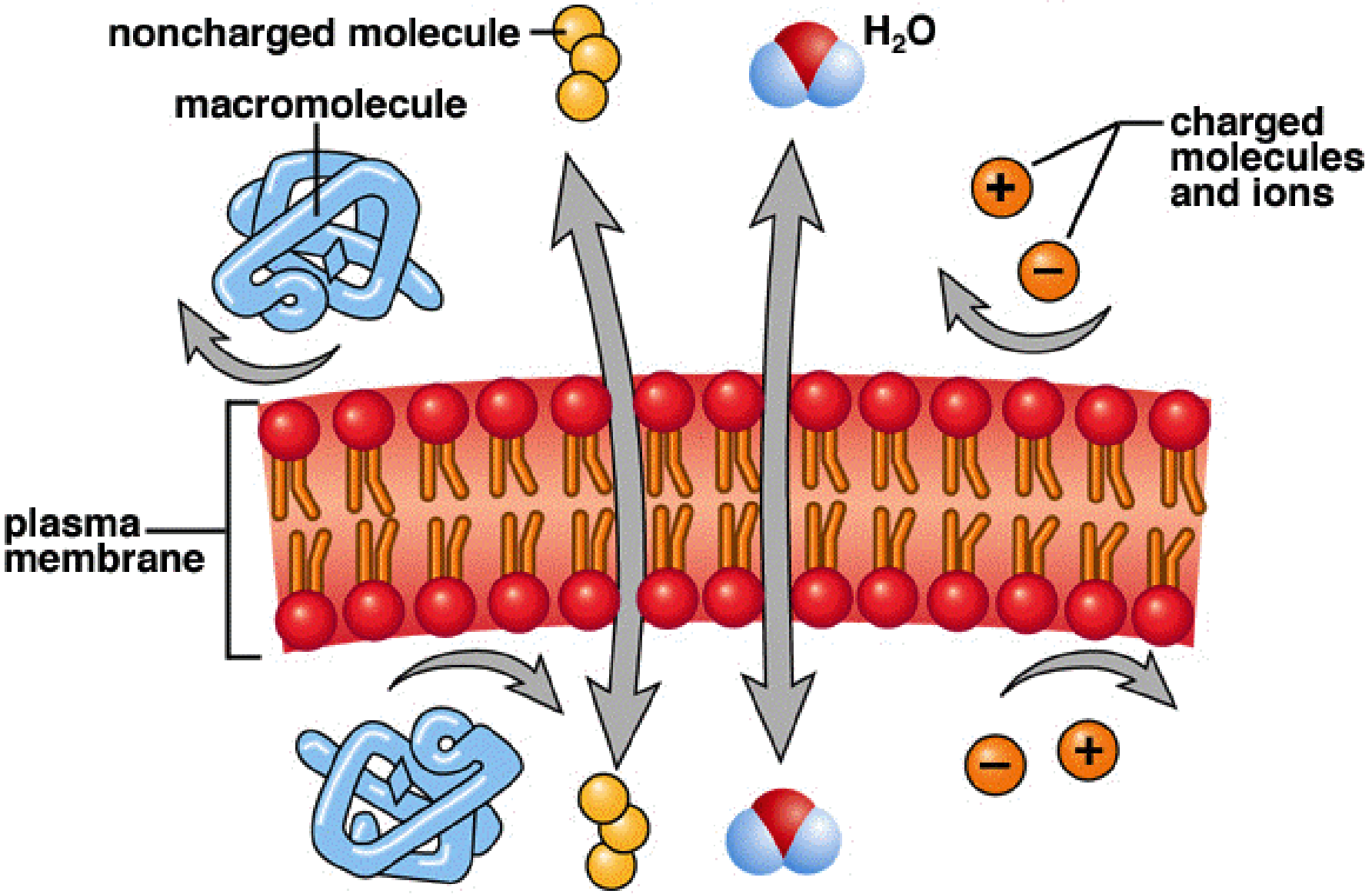
- **Head** (phosphate portion) – relatively soluble in water (polar, hydrophilic)
- **Tails** (lipid) – relatively insoluble (non-polar, hydrophobic)

Membrane Proteins



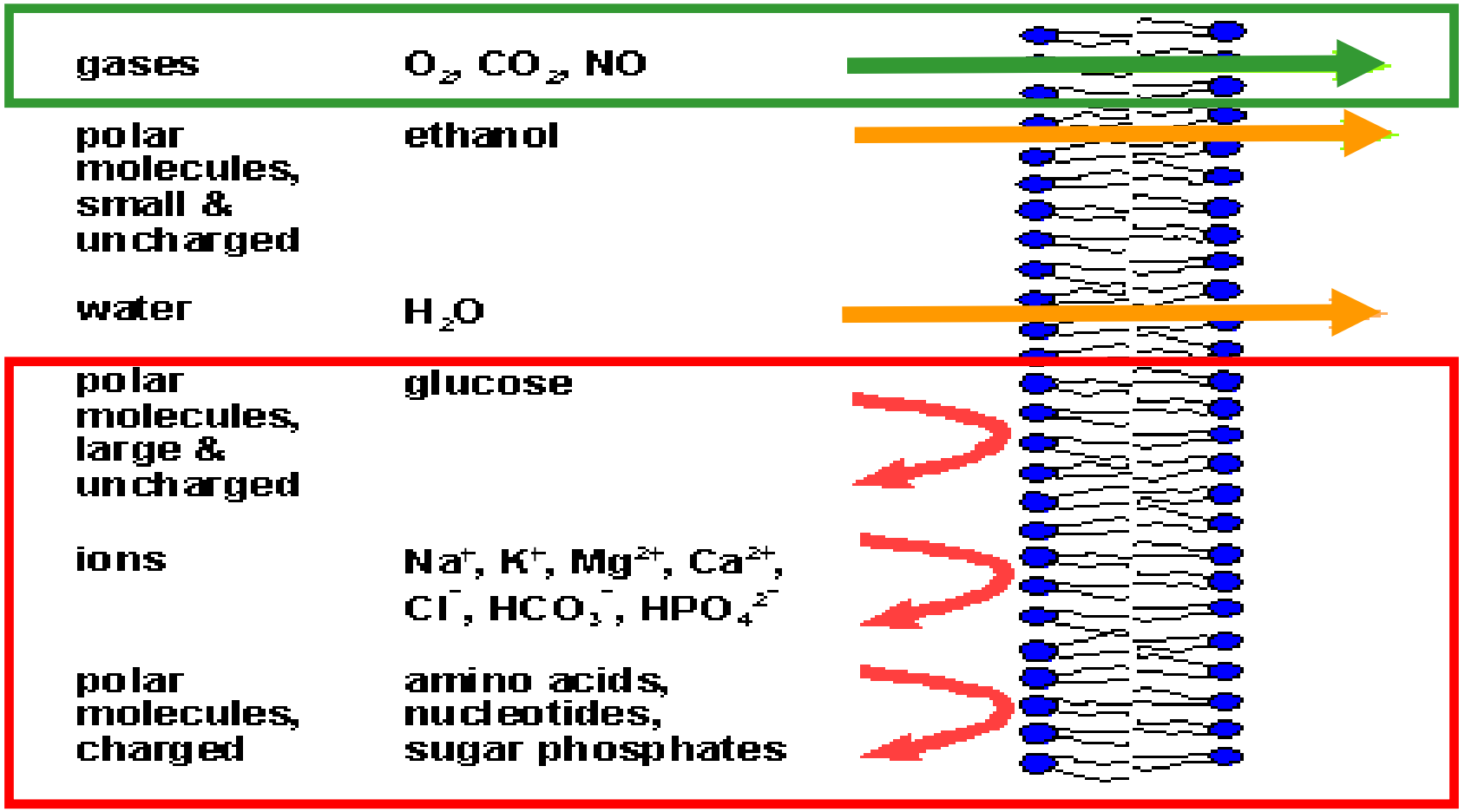
- Integral proteins -- embedded in the membrane
- Peripheral proteins -- loosely bound to the inner or outer surface
- Anchored proteins

Membrane Permeability



Membrane Permeability

High: Lipid-soluble (non-polar) molecules
Medium: Polar, small, uncharged molecules
Low: Polar, large molecules & Ions (charged)



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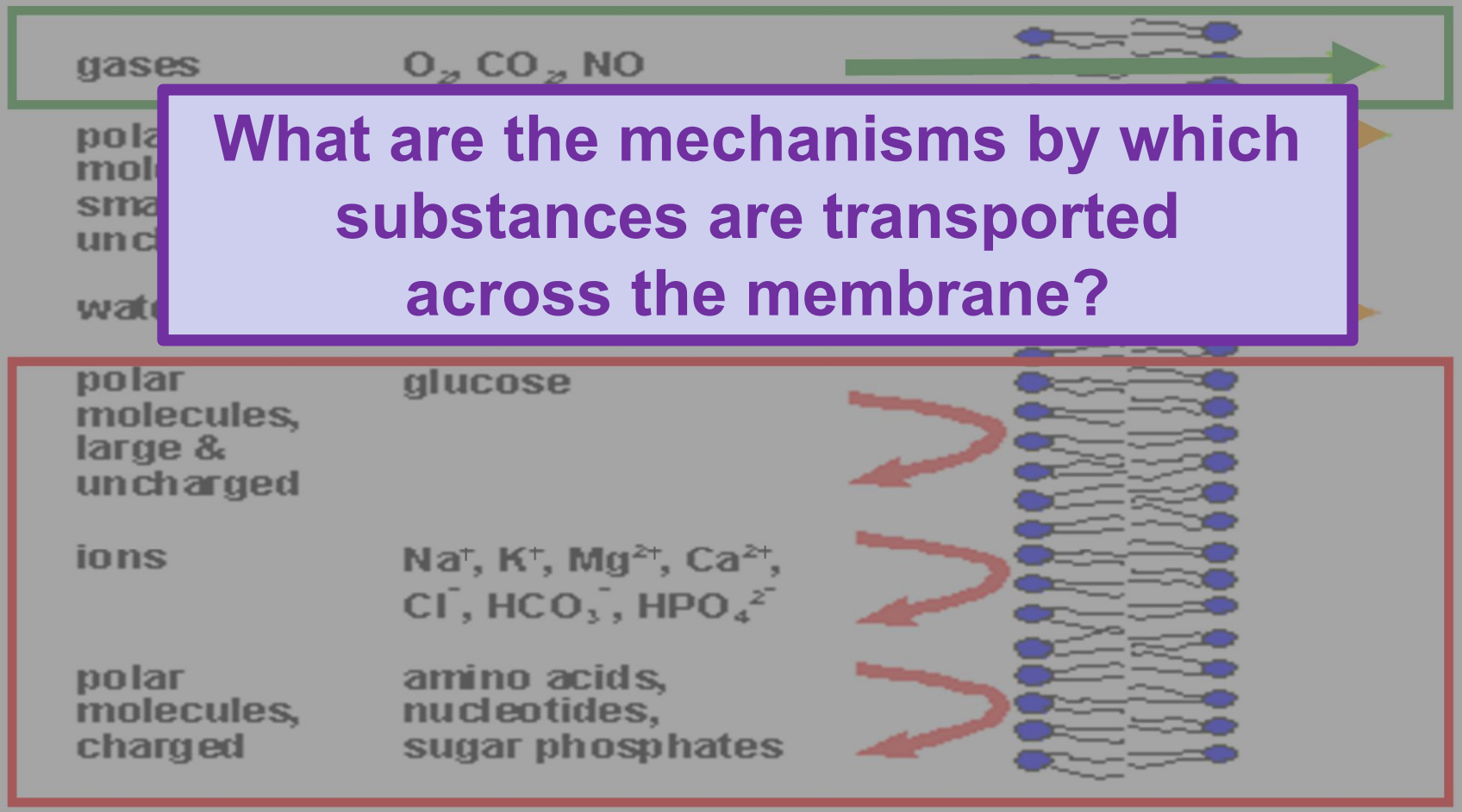


What are the mechanisms by which substances are transported across the membrane?

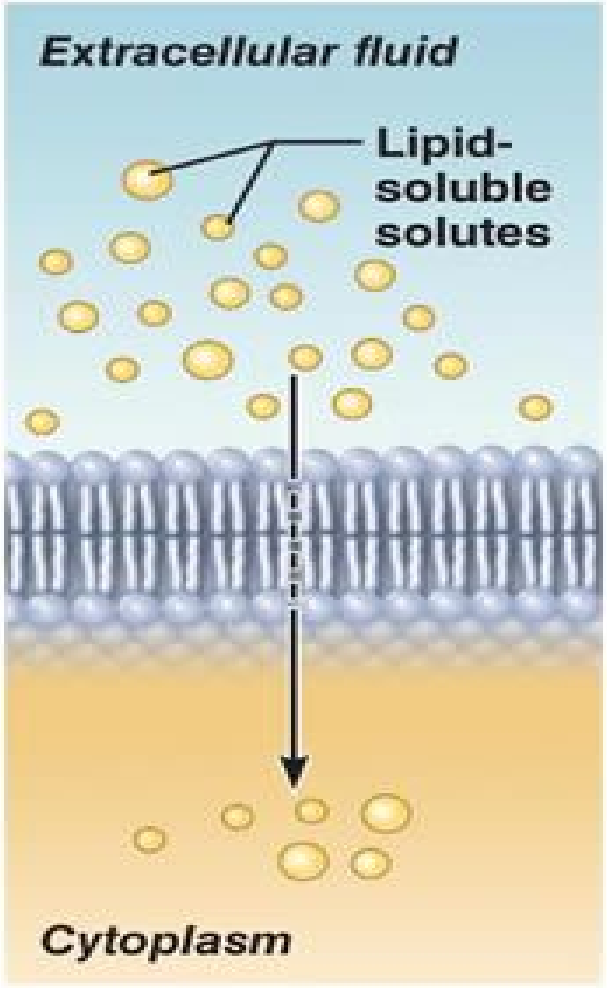
Passive Transport: Diffusion

- **Simple diffusion –**

  Lipid-soluble & nonpolar substances

  (e.g. gas molecules)

  diffuse directly through the lipid bilayer



Simple diffusion of fat-soluble molecules directly through the phospholipid bilayer

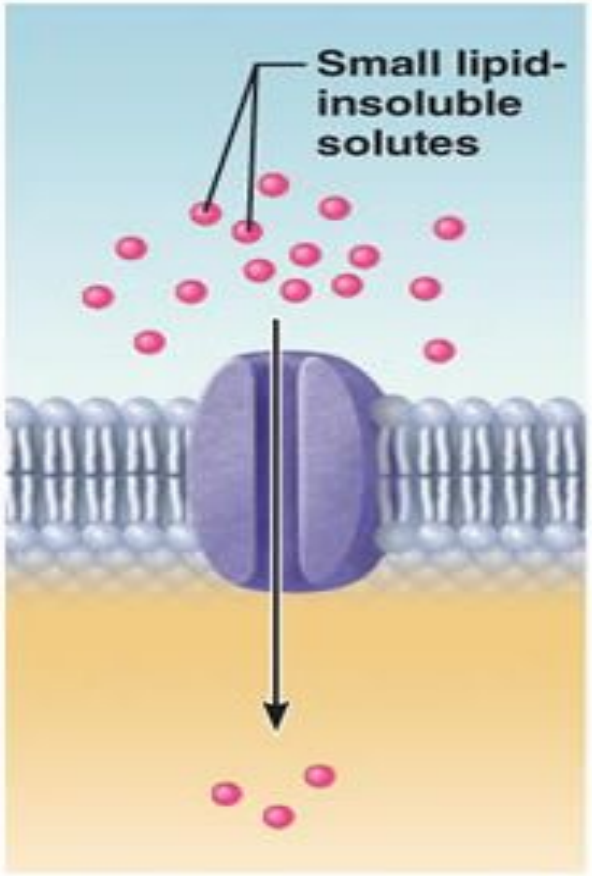
Passive Transport: Diffusion

- **Facilitated diffusion –**

  Lipid-insoluble & small substances

  (e.g. metal ions)

  diffuse through channel proteins



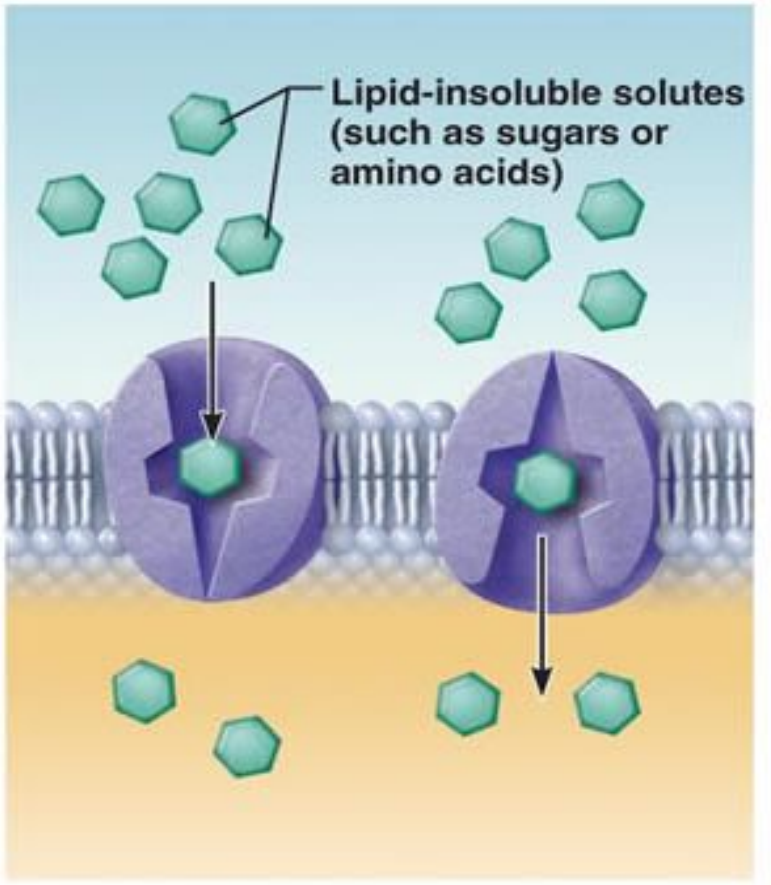
Channel-mediated facilitated diffusion through a channel protein; mostly ions selected on basis of size and charge

Passive Transport: Diffusion

- **Facilitated diffusion –**

  Large, polar molecules
  (e.g. simple sugars)

  combine with
  protein carriers



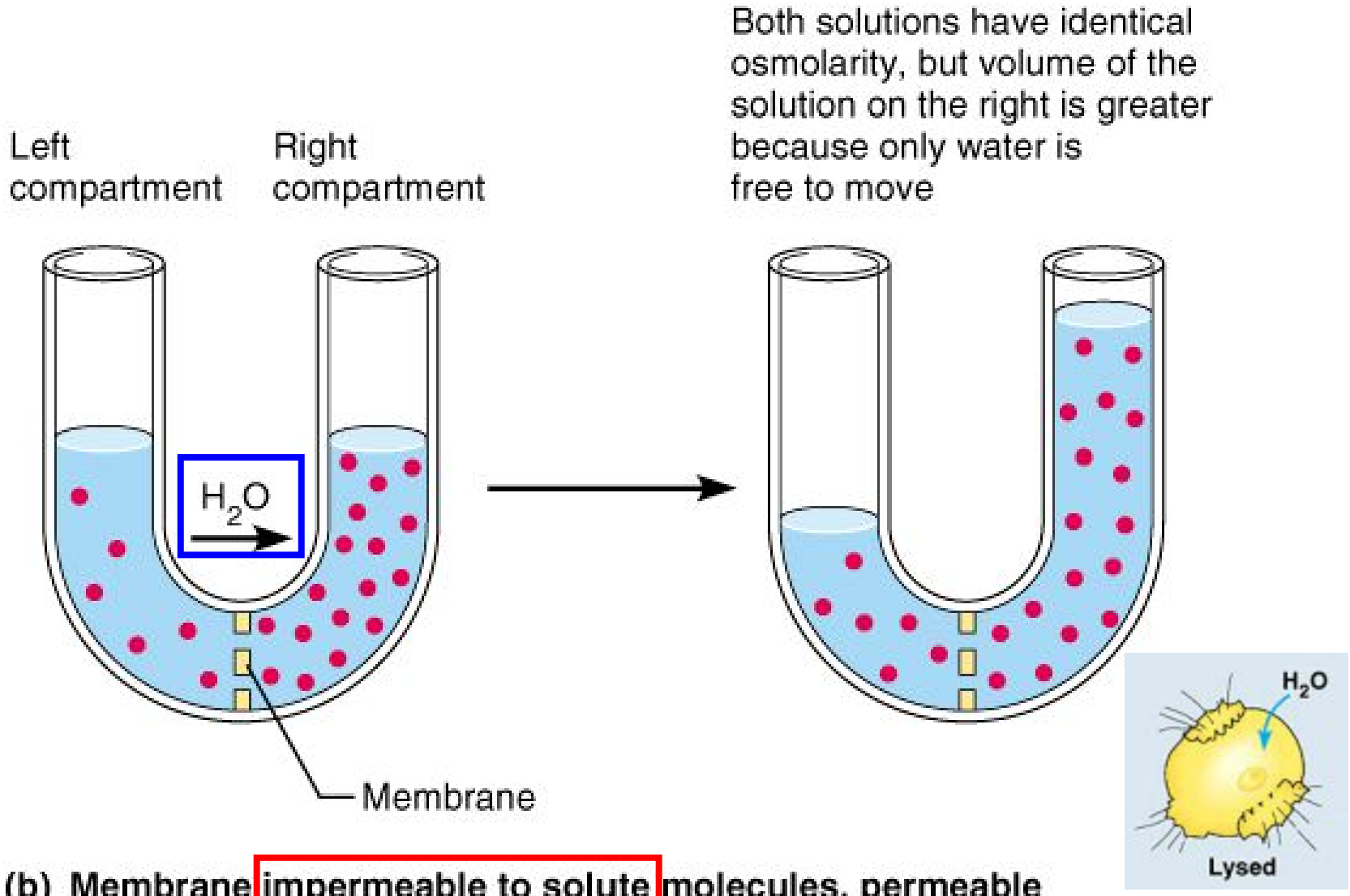
Carrier-mediated facilitated diffusion
via protein carrier specific for one chemical; binding of substrate causes transport protein to change shape

Passive Transport: Osmosis

- Osmolarity – total concentration of solute particles in a solution

- **Osmosis** occurs when the concentration of a solvent is different on opposite sides of a membrane
- Osmosis in cells:
  - Diffusion of water across a semi-permeable membrane

Passive Transport: Osmosis



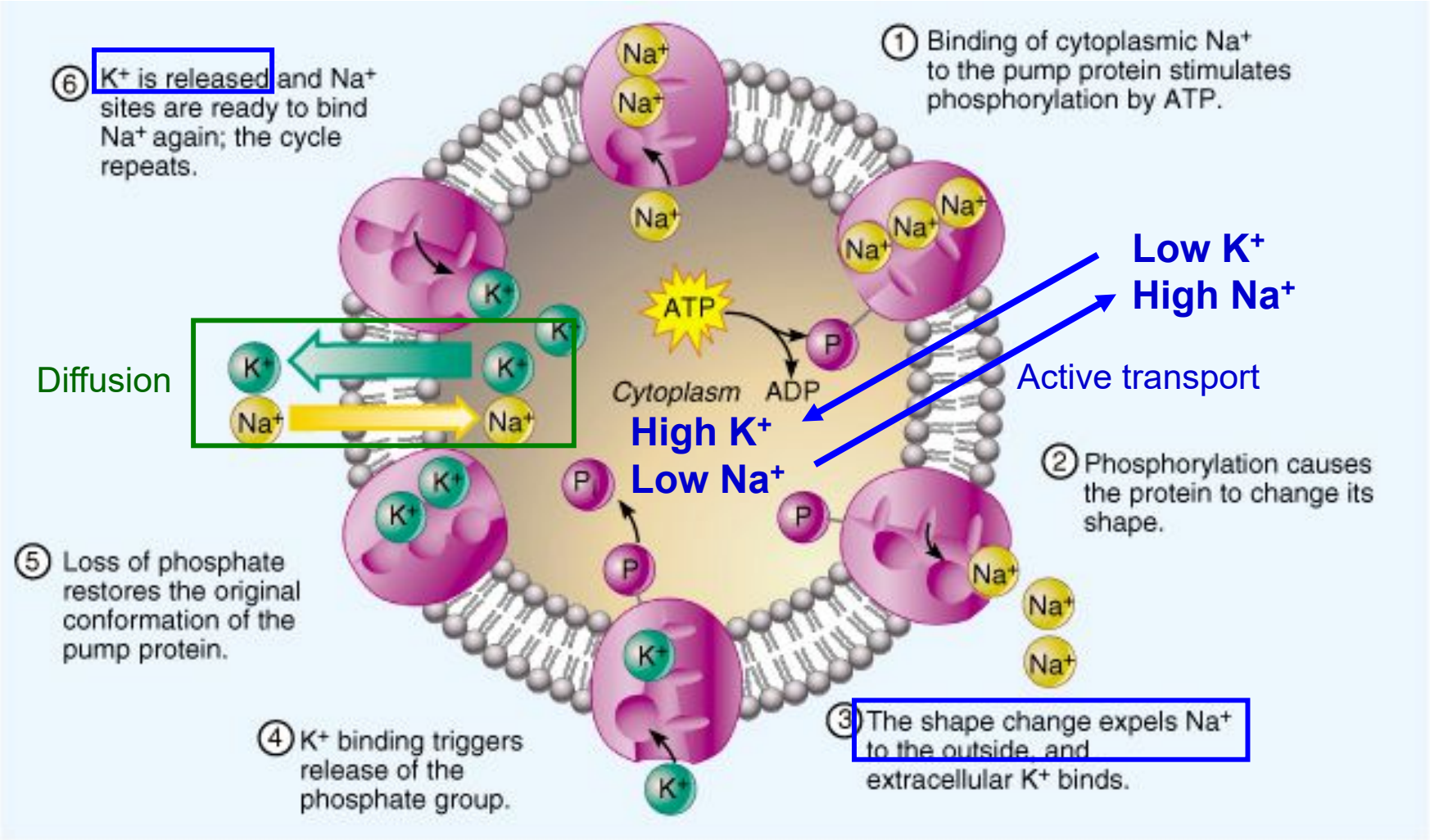
(b) Membrane impermeable to solute molecules, permeable to water

Passive Transport: Filtration

- Passage of water & solutes through a membrane by hydrostatic pressure
- Pressure gradient pushes solute-containing fluid from a higher-pressure area to a lower-pressure area

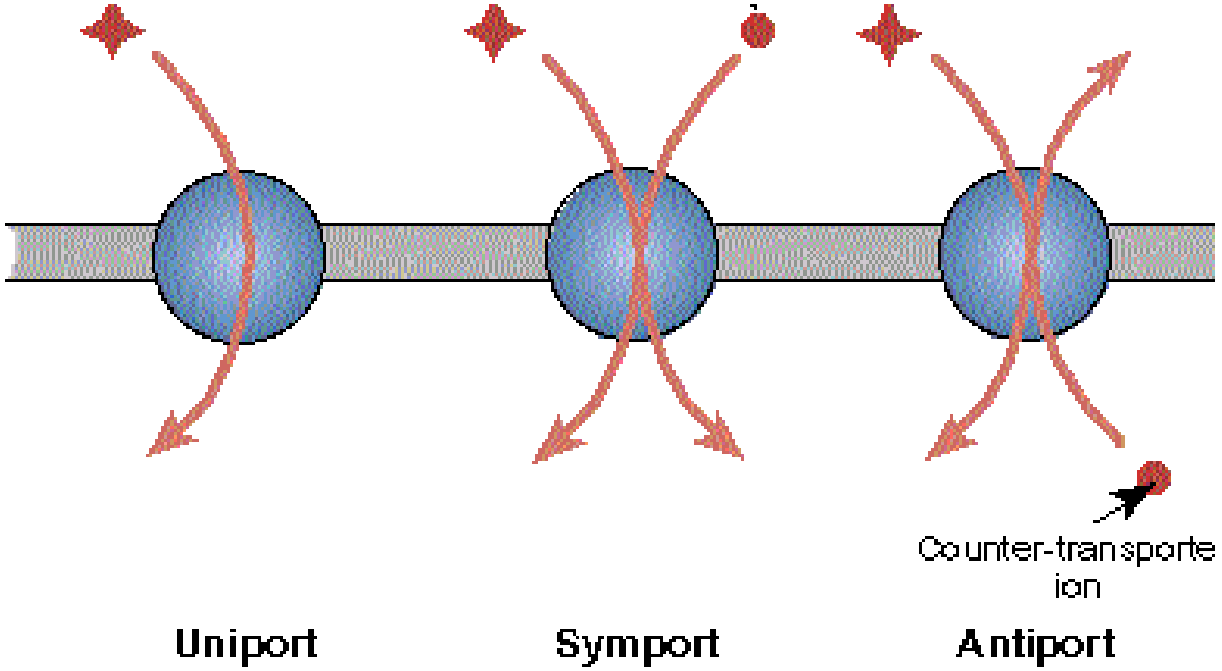
Active Transport

- Uses **ATP** to move solutes across a membrane
- Requires carrier proteins (e.g. sodium-potassium pump)



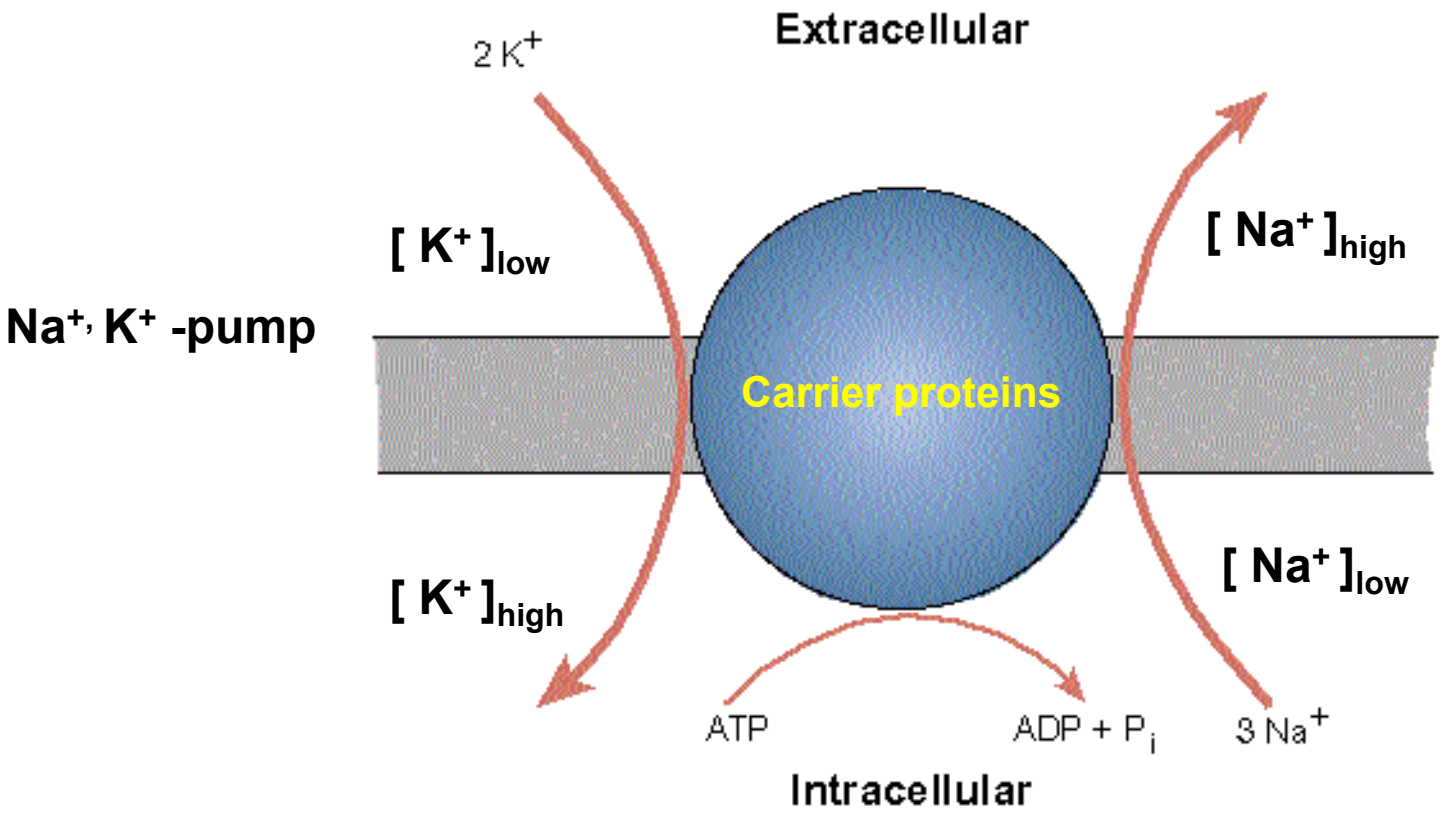
Types of Membrane Transport System

- Uniport system – 1 substance is moved across a membrane
- Symport system – 2 substances are moved across a membrane in the same direction
- Antiport system – 2 substances are moved across a membrane in opposite directions



Active Transport (primary)

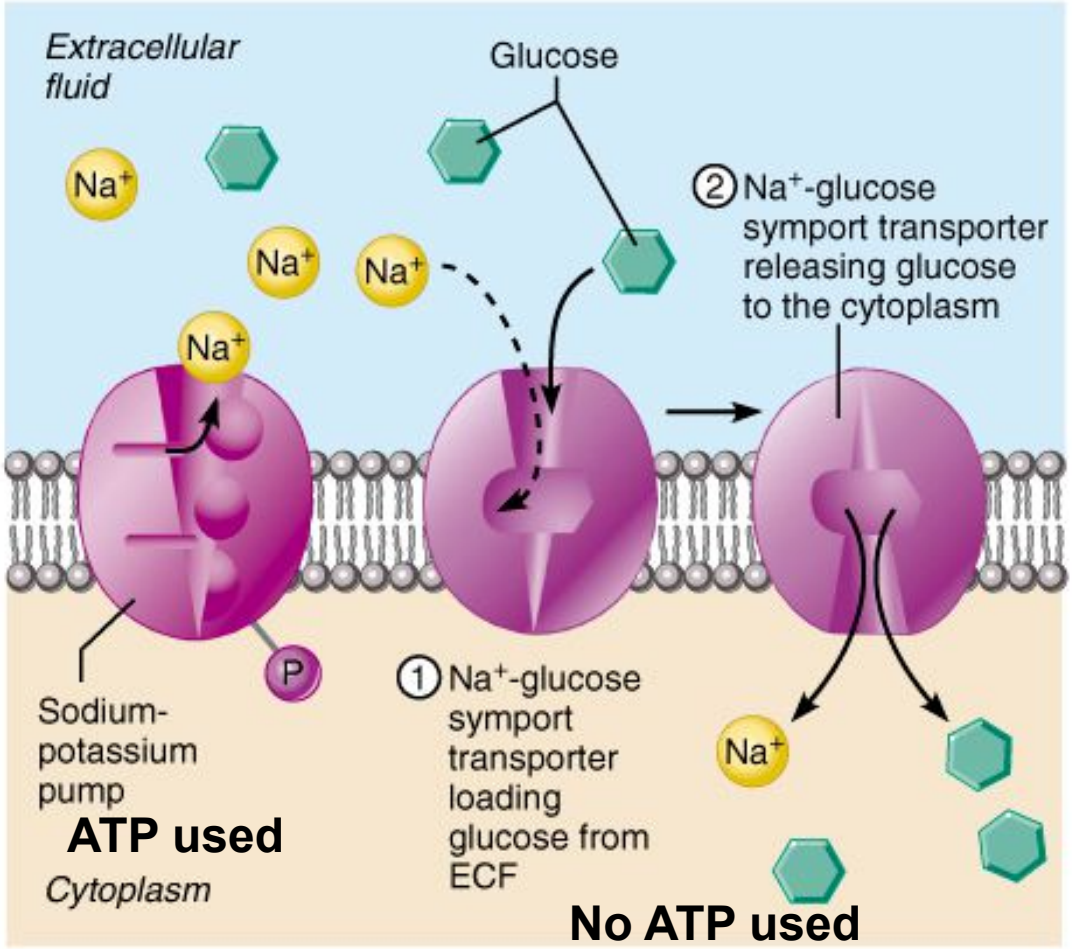
- Primary active transport – hydrolysis of ATP phosphorylates the transport protein causing conformational change



- **Carrier proteins allows transport of molecules against concentration gradient.**

Active Transport (secondary)

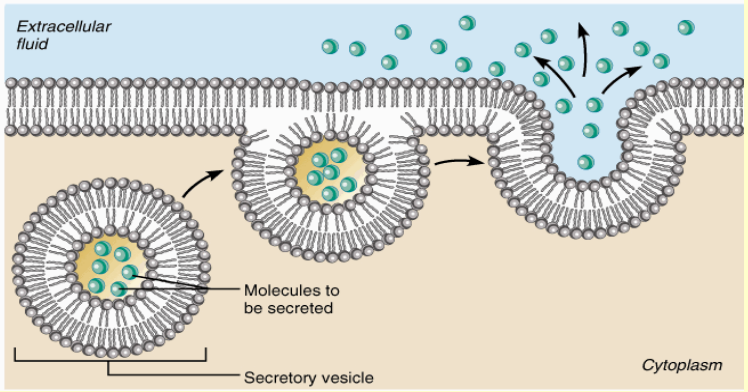
- Secondary active transport – use of an exchange pump (such as the Na^+-K^+ pump) **indirectly** to drive the transport of other solutes



Vesicular Transport

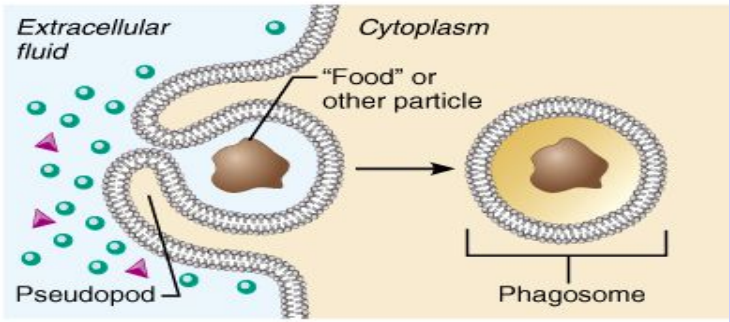
- Transport of large particles & macromolecules across plasma membranes
  - Exocytosis – moves substance from the cell interior to the extracellular space
  - Endocytosis – enables large particles and macromolecules to enter the cell
  - Receptor-mediated transport – uses clathrin-coated pits as the major mechanism for specific uptake of macromolecules

Vesicular Transport

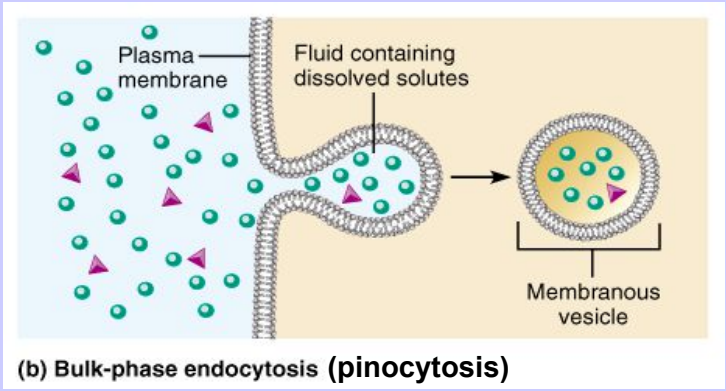


Exocytosis

Endocytosis

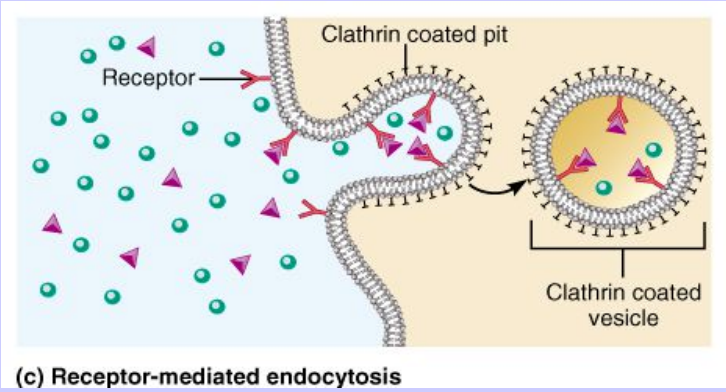


(a) Phagocytosis



(b) Bulk-phase endocytosis (pinocytosis)

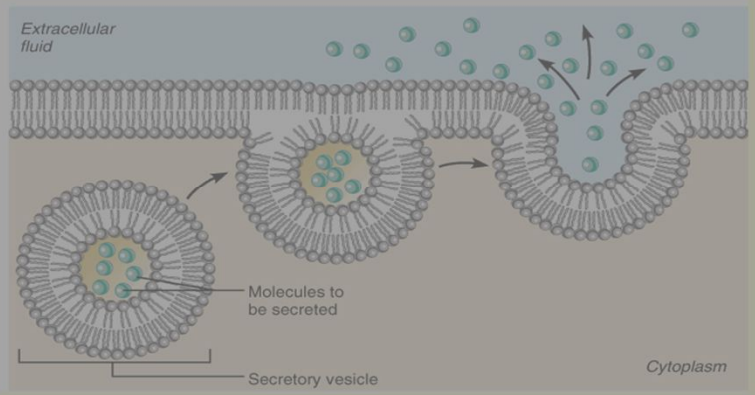
Non-Specific



(c) Receptor-mediated endocytosis

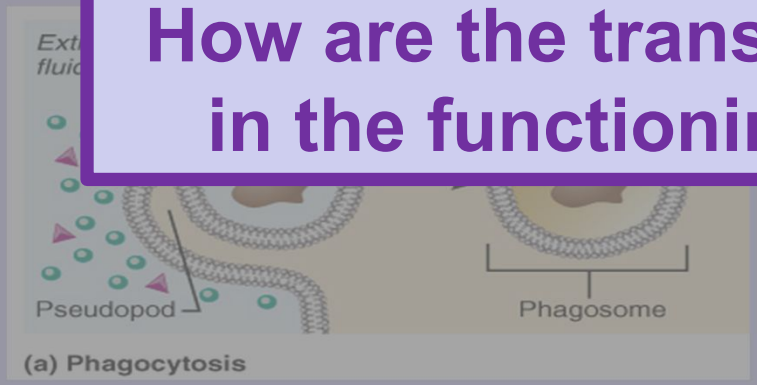
Molecular-Specific

Vesicular Transport



Exocytosis

How are the transport mechanisms involved in the functioning of our body systems ?



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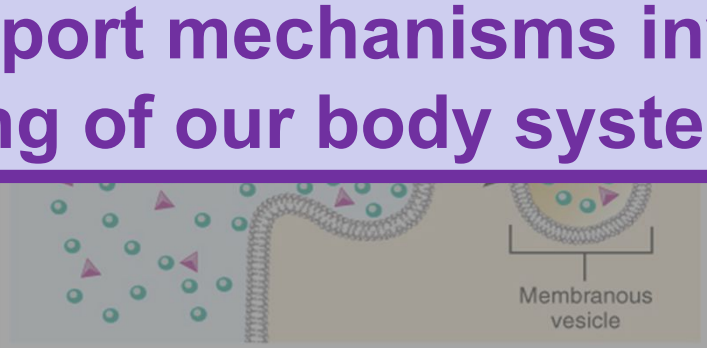
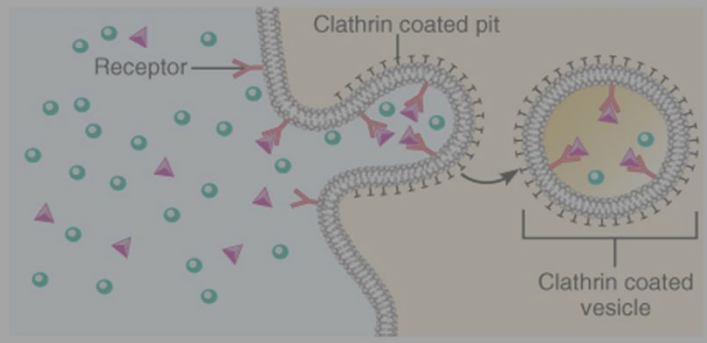


(b) Bulk-phase endocytosis (pinocytosis)

Non-Specific

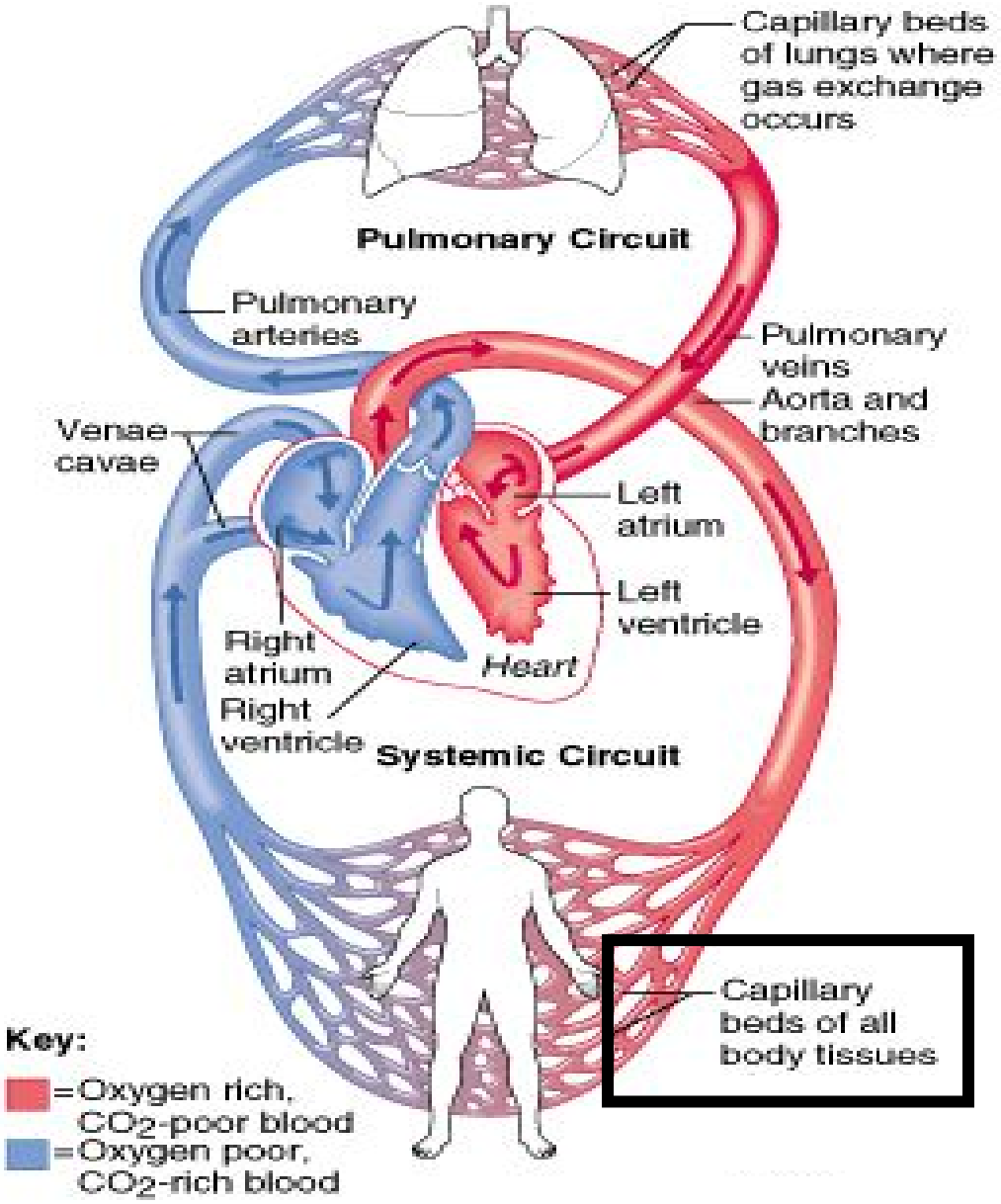
Endocytosis



(c) Receptor-mediated endocytosis

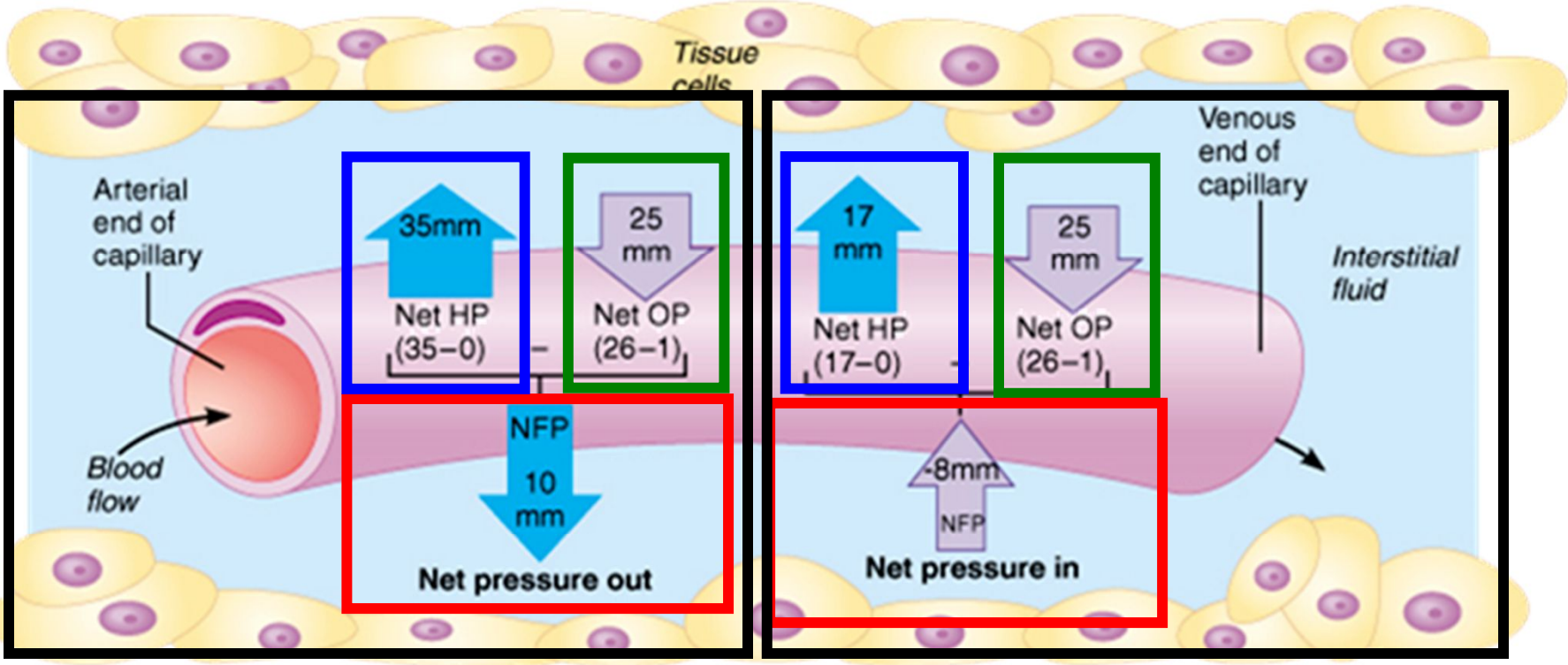
Molecular-Specific

Transport: Cardiovascular System



Transport: Cardiovascular System

Pressure dynamics across capillary beds



Key to pressure values:

HP_c at arterial end = 35 mm Hg HP_{if} = 0 mm Hg OP_{if} = 1 mm Hg

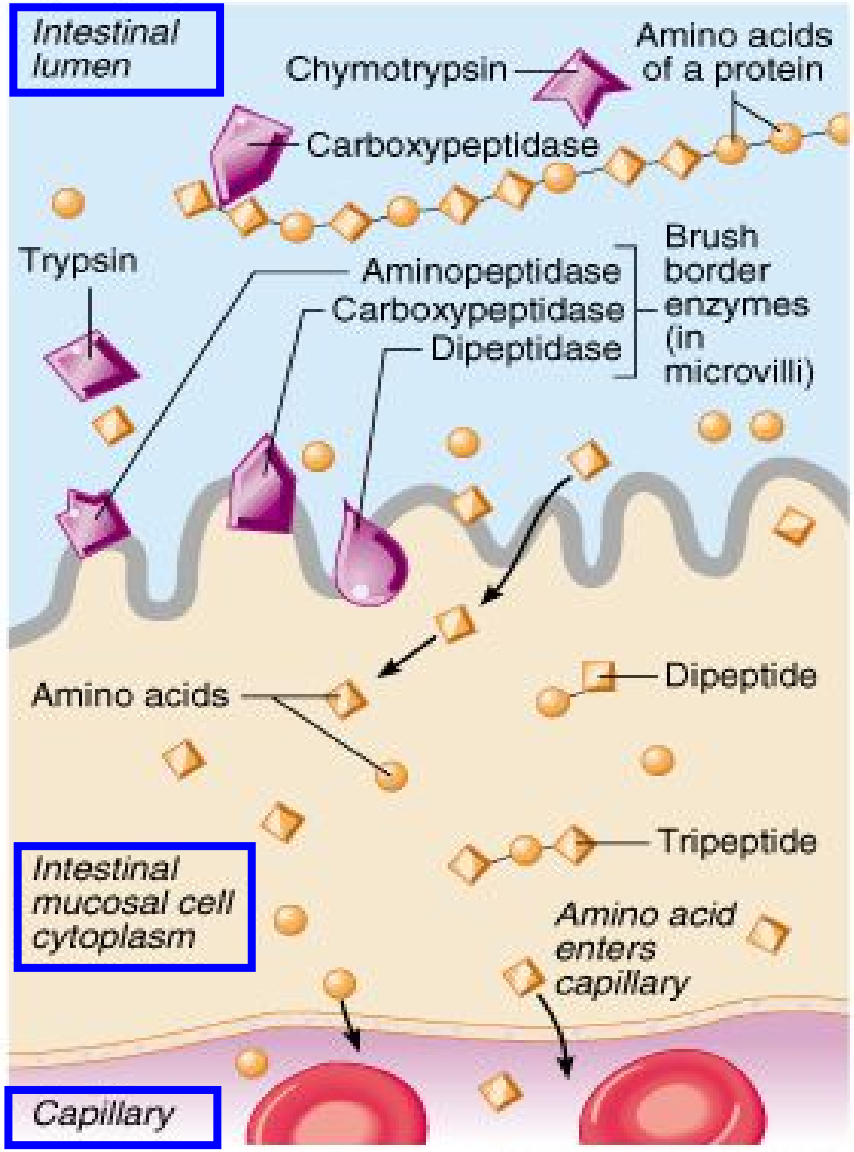
HP_c at venous end = 17 mm Hg OP_c = 26 mm Hg

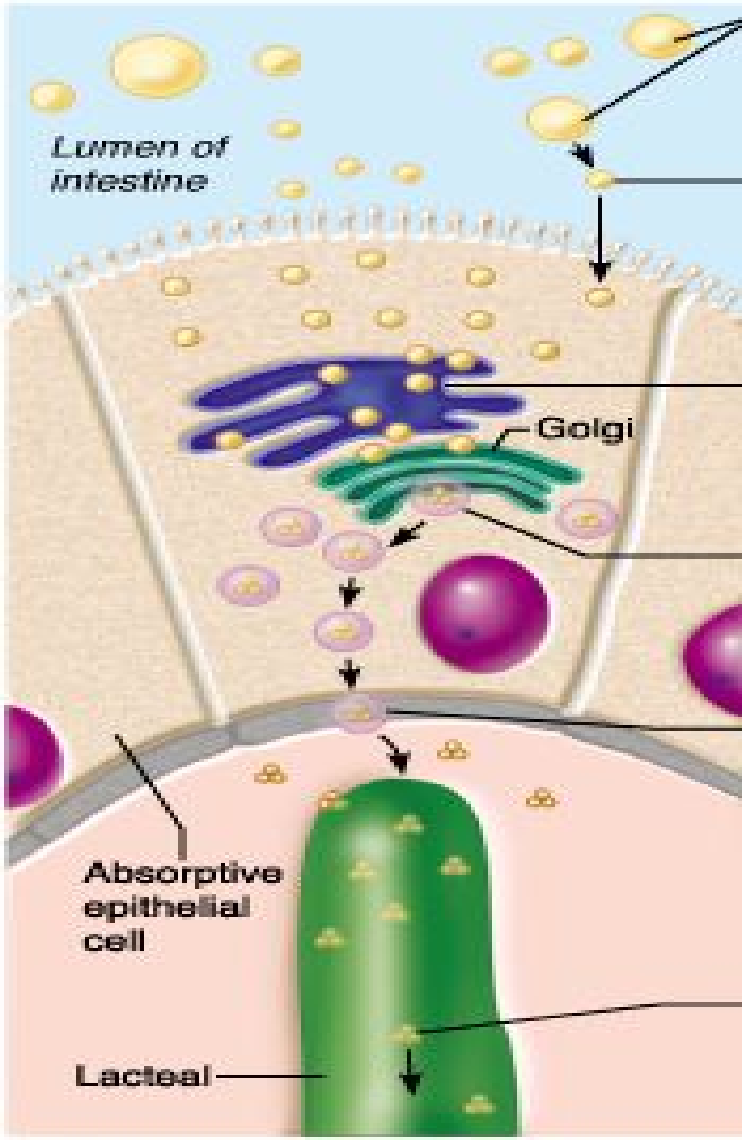
- **At the arterial end of a bed, hydrostatic forces dominate (fluids flow out)**
- **At the venous end of a bed, osmotic forces dominate (fluids flow in)**

- Fluids enter tissue beds > Fluid return to blood
- Excess fluid returns to blood via **lymphatic system**

Transport: Digestive System

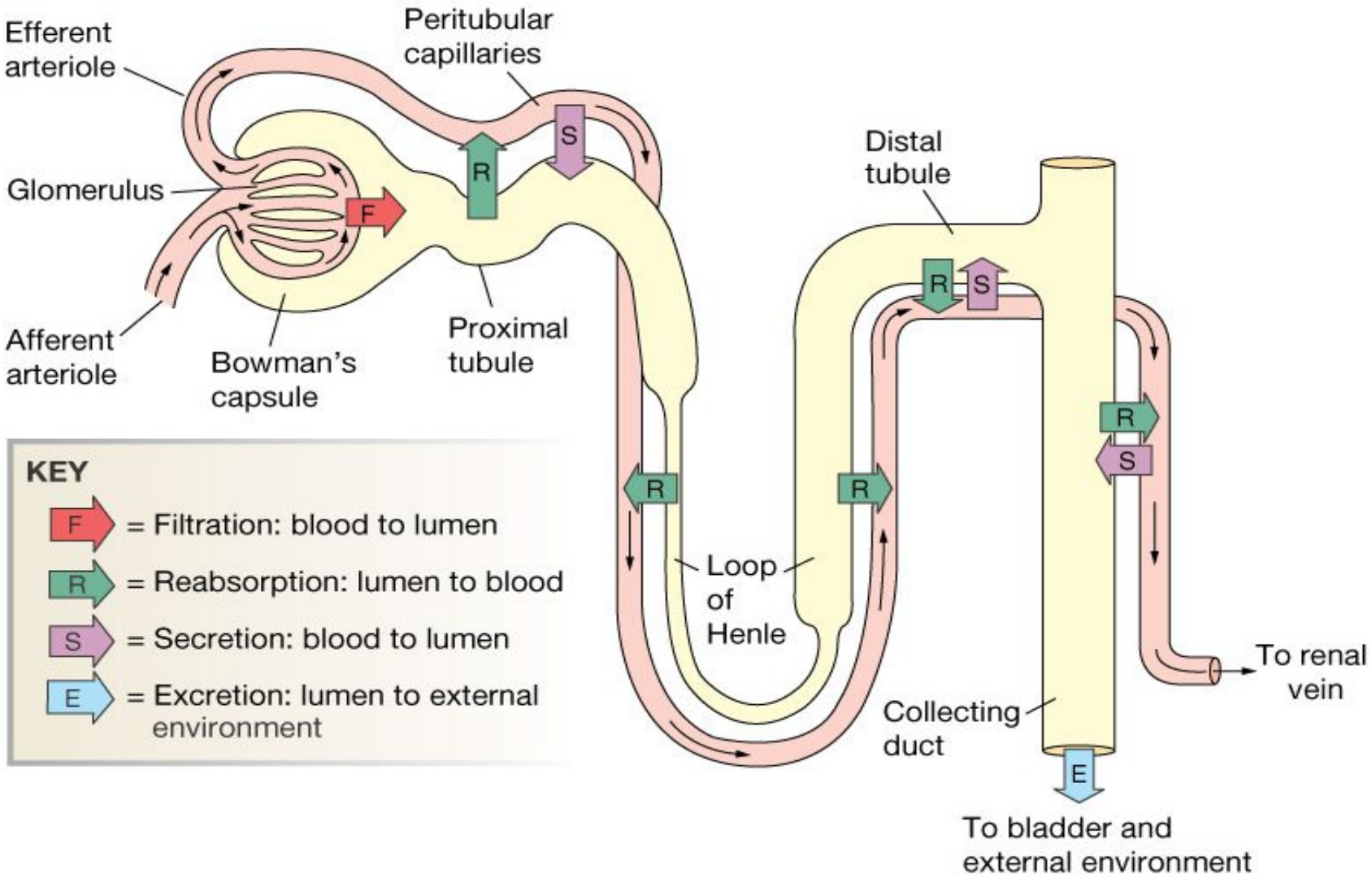
Across Intestinal Wall





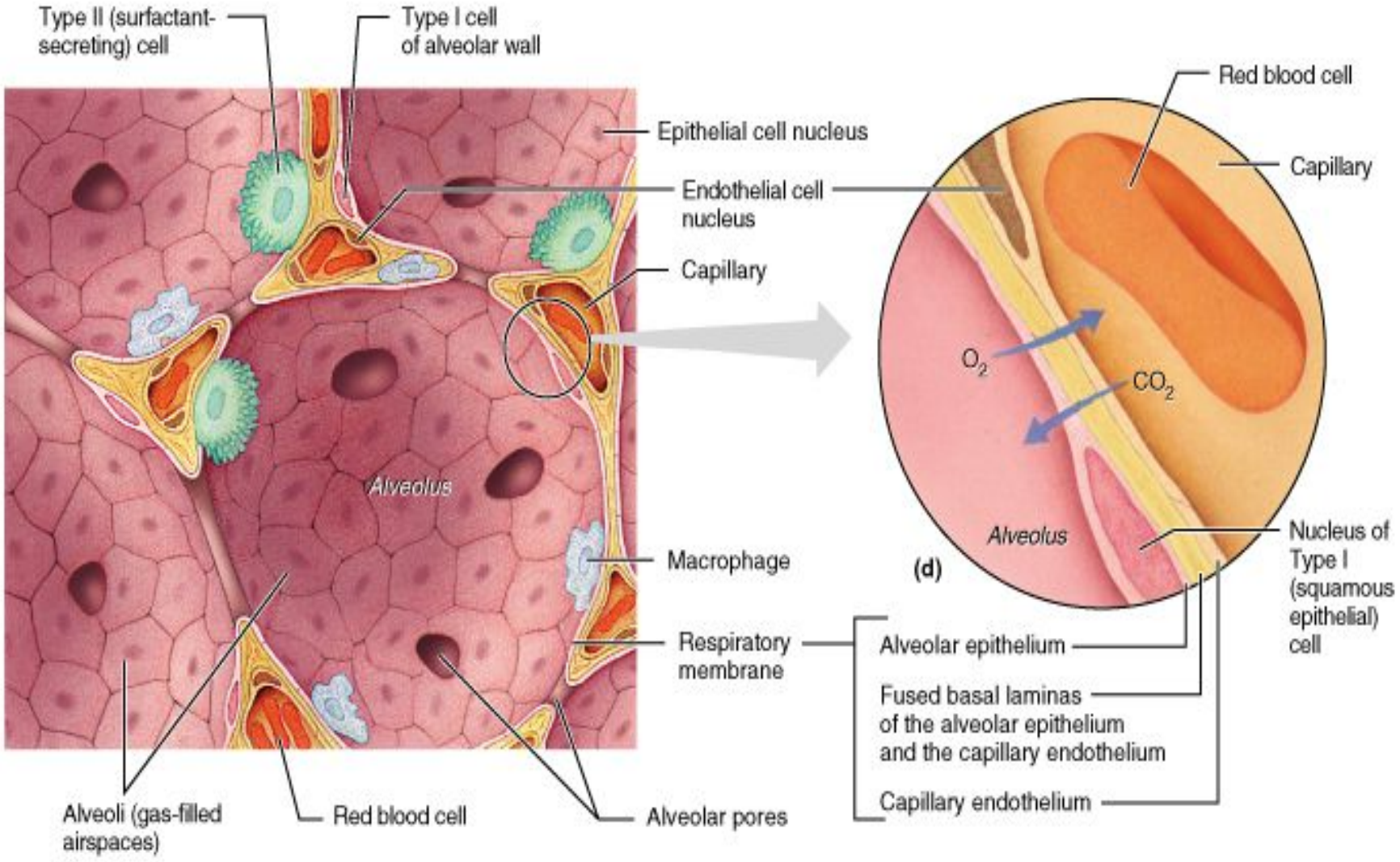
Transport: Renal System

Across Wall of the Renal Tubule



Transport: Respiratory System

Across Alveolar Wall



Clinical Relevance

Cystic Fibrosis

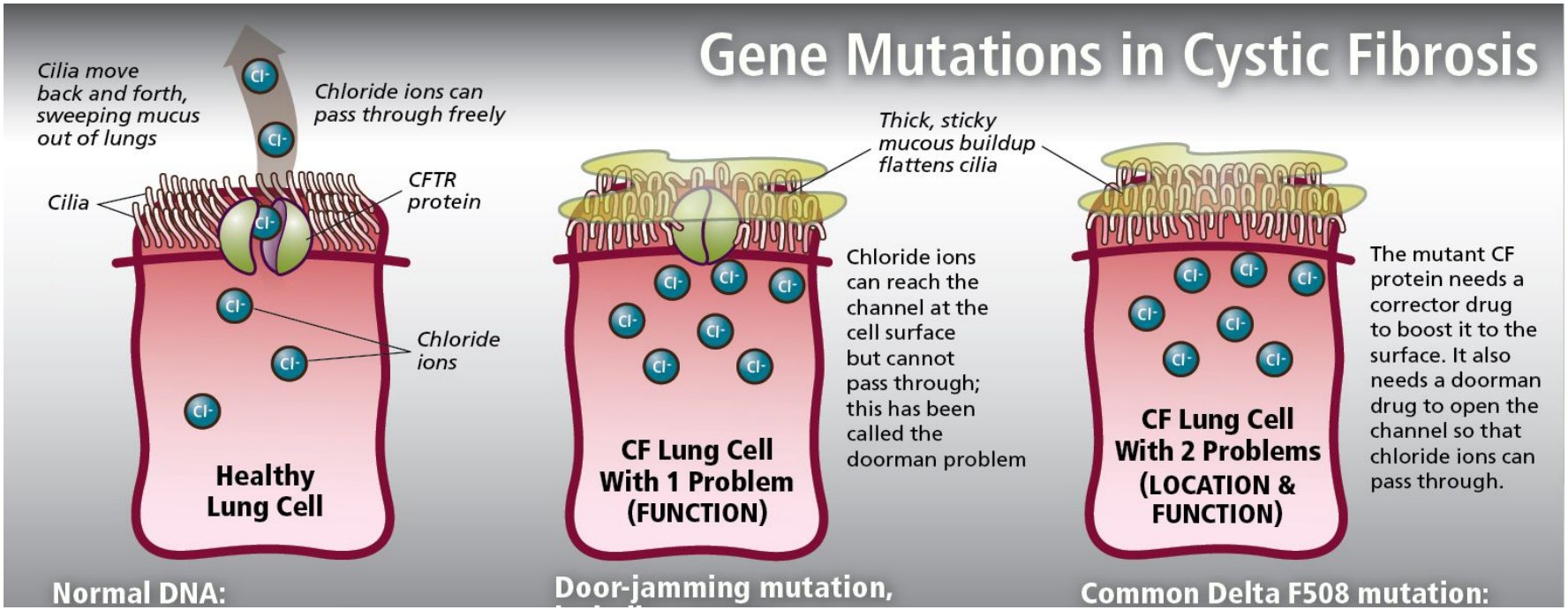
Mutation in the gene of cystic fibrosis transmembrane conductance regulator (CFTR)

→ Abnormal regulation of chloride transport in epithelium (particularly in lungs)

→ Disruption of salt & water transport across cell membrane

→ Build-up of thick mucus in lungs & decreased mucociliary clearance

→ Breathing difficulties



Key Points

Water Content of the Body

Plasma Membrane

- Membrane proteins
- Membrane permeability

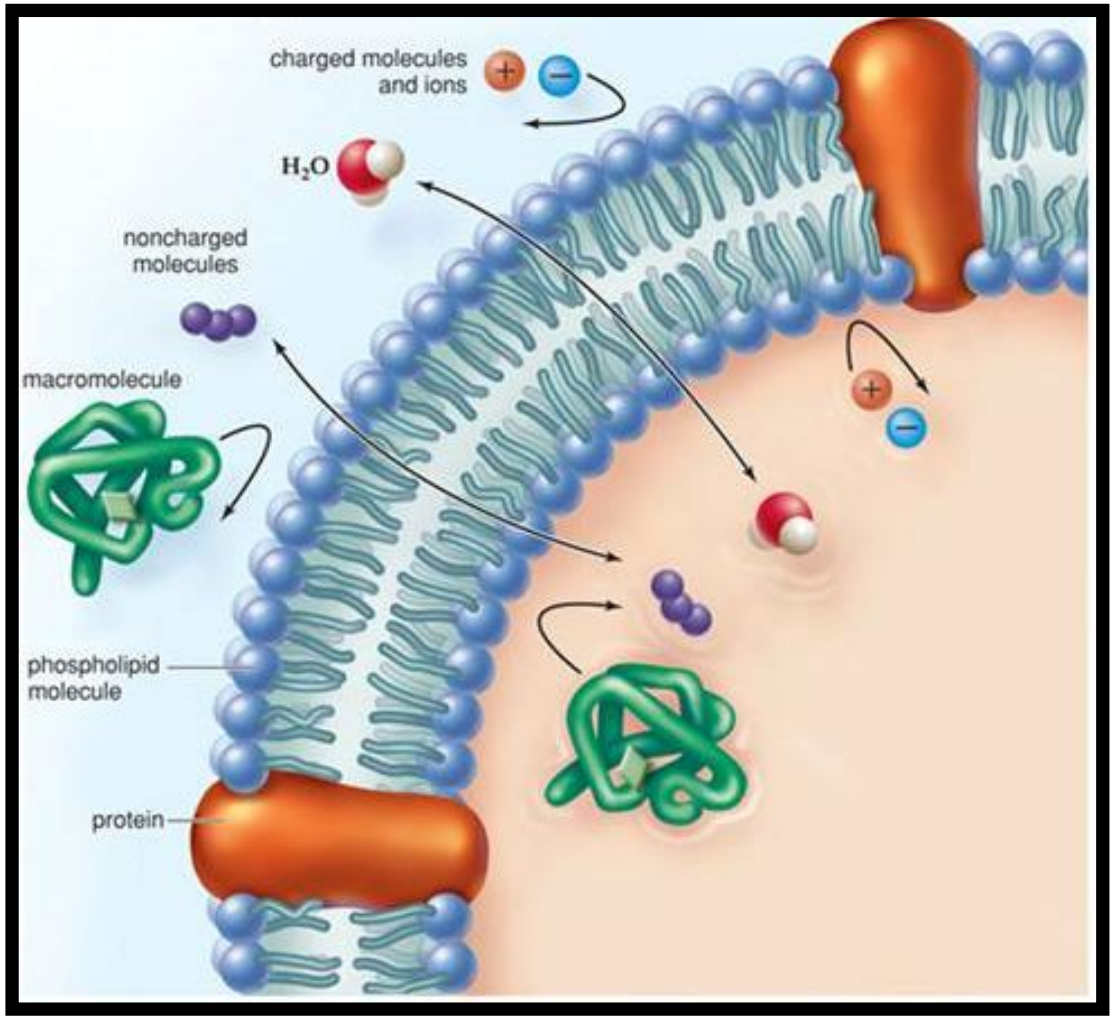
Passive Transport

- Diffusion
- Osmosis
- Filtration

Active Transport

- Primary
- Secondary

Vesicular Transport



Transport of Substances in Different Systems