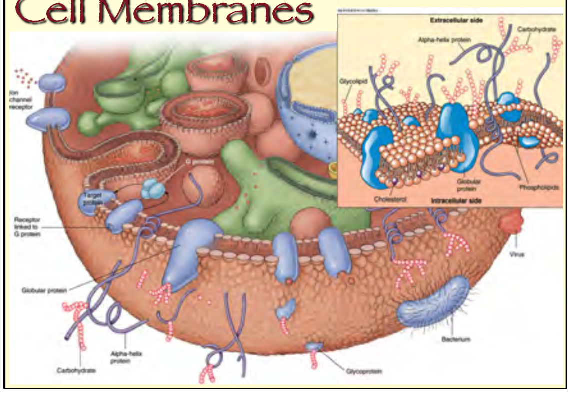
Cell Membranes



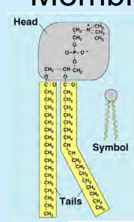
What does a cell need?

- **Selective isolation from environment (plasma membrane)**
- **Energy (ATP)** – **[to be discussed in future lecture]**
- Instructions (DNA)
- Machinery to carry out instructions and regulate processes (proteins)
- **Compartmentalization of incompatible or specialized activities (organelles)**

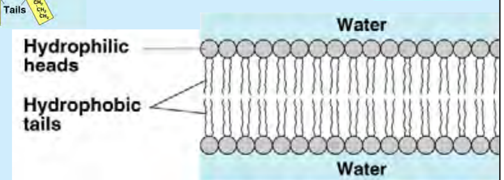
Cell Membrane Function

- Boundary between internal and external environments
- Selectively permeable - controls what goes in and out of cell or organelle
- Attachment to extracellular surfaces or to other cells (and organelles to cytoskeleton)
- Self or species recognition
- Cell to cell communication
- Lipid metabolism
- Localization of fixed or sequential processes

Membrane Phospholipid Bilayer

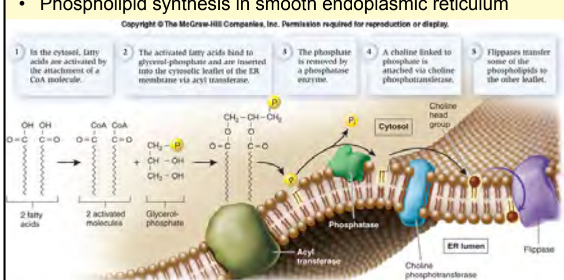


- Phospho-lipid bilayer forms the essential backbone of cellular membranes.



Synthesis of membrane lipids

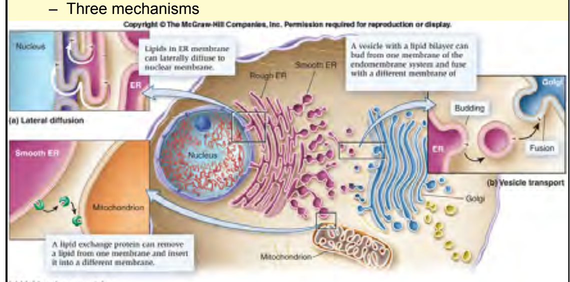
- Phospholipid synthesis in smooth endoplasmic reticulum



Denniston & Topping, *Foundations of General, Organic, and Biochemistry* ©2008, McGraw-Hill

Synthesis of membrane lipids

- Distribution of membrane lipids from sER to other organelles
  - Three mechanisms



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Synthesis of membrane lipids

Types of membrane lipids:
- **Phospholipids**
  - Major component of lipid bilayer
- **Cholesterol**
  - Contributes to rigidity / flexibility of membrane
- **Sphingolipids**
  - Two fatty acids condensed onto a serine, instead of a glycerol
  - Usually with longer fatty chains than on phospholipids
  - Polar head may be modified with a phosphate or carbohydrate (glycolipid)
  - Rafts of sphingolipids migrate along the membrane

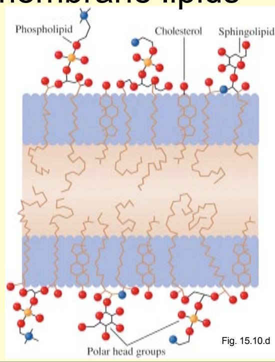
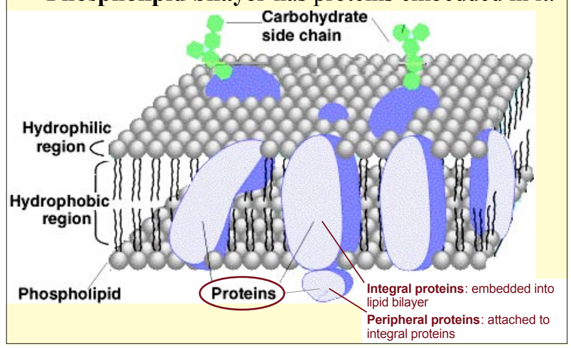


Fig. 15.10.d

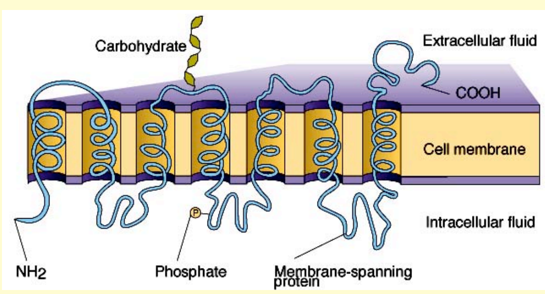
Plasma Membrane Proteins

- **Phospholipid bilayer** has proteins embedded in it.

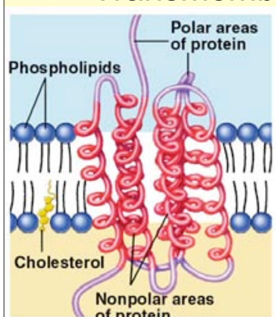


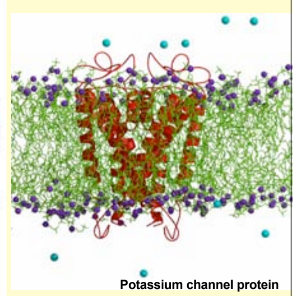
Proteins can insert into lipid bilayer

- Protein domains can be hydrophobic or hydrophilic

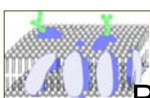


Transmembrane proteins



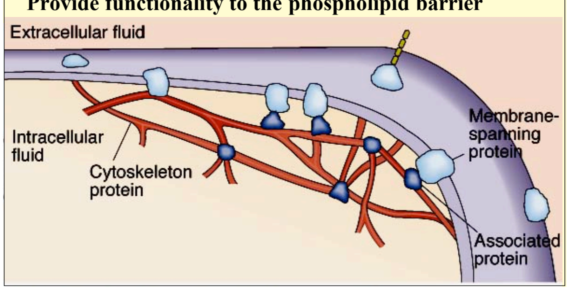


Multiple hydrophobic domains contribute to intramembrane function

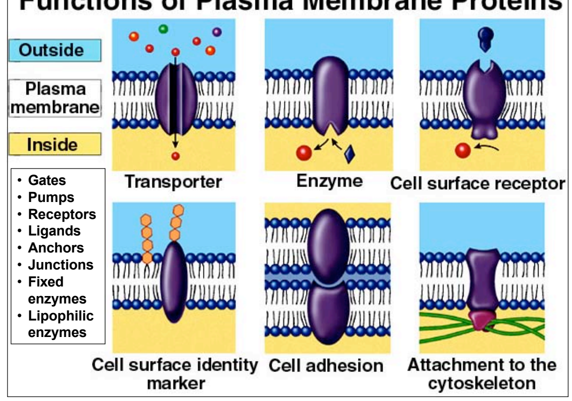


Plasma Membrane Proteins

Provide functionality to the phospholipid barrier



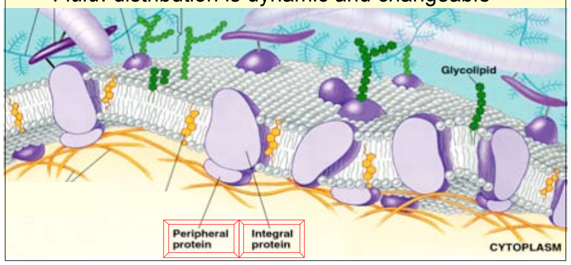
Functions of Plasma Membrane Proteins



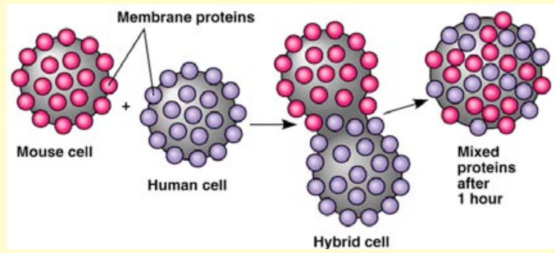
- Gates
- Pumps
- Receptors
- Ligands
- Anchors
- Junctions
- Fixed enzymes
- Lipophilic enzymes

Fluid Mosaic Model
of Membrane Structure

- *Mosaic*: patchy, non-uniform distribution of proteins
  - Different regions or sides of the same cell may have different functions
- *Fluid*: distribution is dynamic and changeable



Fluid Mosaic Model
of Membrane Structure



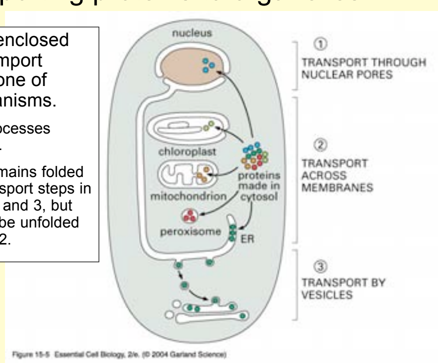
proteins can move laterally within membrane

Importing proteins to organelles

Membrane-enclosed organelles import proteins by one of three mechanisms.

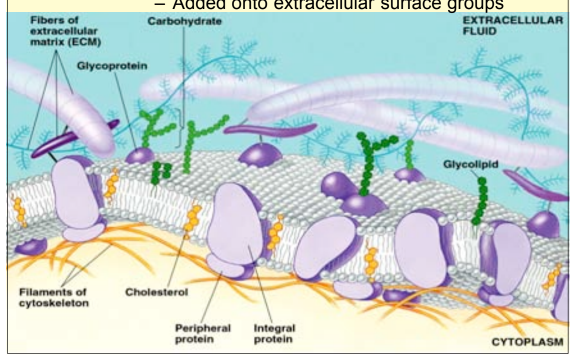
All of these processes require energy.

The protein remains folded during the transport steps in mechanisms 1 and 3, but usually has to be unfolded in mechanism 2.

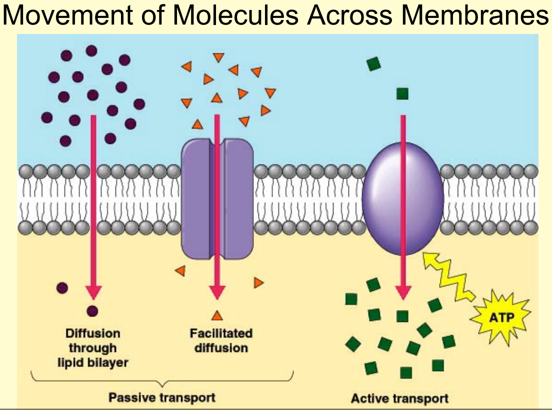


Membrane Carbohydrates

- As glycoprotein or glycolipid
- Added onto extracellular surface groups

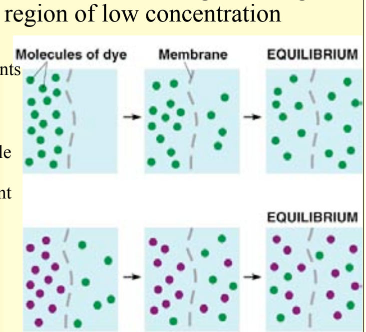


Movement of Molecules Across Membranes

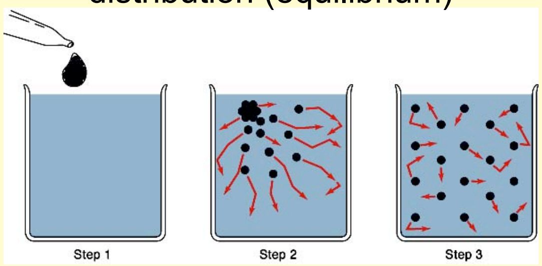


Passive Transport (Diffusion)

- Net movement of molecules from a region of high concentration to a region of low concentration
  - ✓ Caused by random (Brownian) movements of molecules
  - ✓ (Increase entropy)
  - ✓ Each type of molecule follows its own concentration gradient
  - ✓ At equilibrium, movement is equal in both directions

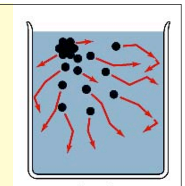


Random molecular motion eventually results in random distribution (equilibrium)



Gradient Equilibrium

Factors that affect
Rate of Diffusion



- Concentration gradient
  - Difference in concentration between two points
- Temperature (molecular movement)
- Permeability of the membrane / medium
- Available surface area of membrane
- Distance across which diffusion must occur
- Solvent state (gas > liquid > semisolid)

FICK'S LAW

Adolf Fick, 1858

Fick's law of diffusion of a gas across a fluid membrane:

$$\text{Rate of diffusion} = KA(P_2 - P_1)/D$$

Wherein:
- K = a *temperature-dependent* diffusion constant.
- A = the surface area available for diffusion.
- $(P_2 – P_1)$ = The difference in concentration (partial pressure) of the gas across the membrane.
- D = the distance over which diffusion must take place.

Increased exchange rate by increased surface area

- **Microvilli**

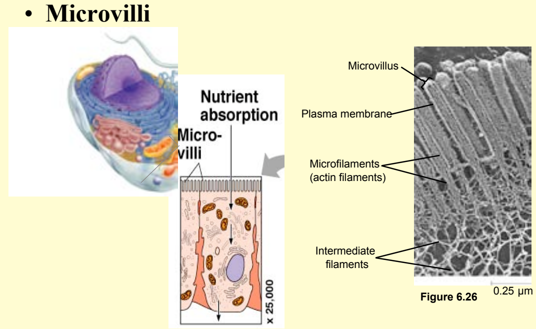
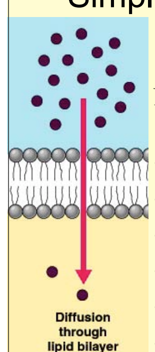


Figure 6.26

Concentration

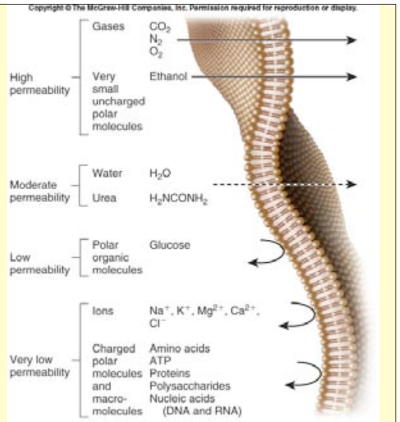
= Number of solutes in a given volume
- Examples
  - Moles per liter (molar = *M*)
  - Grams per 100ml (g%)
  - Nanogams per milliliter (ng/ml)
  - Parts per thousand (ppt)
- Osmolarity:
  the sum of **all** solutes in a given volume
  - in moles per liter (*Osm*)

Simple (non-selective) diffusion across cell membranes



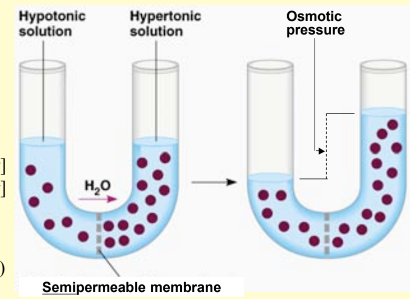
Nonpolar solutes dissolve through membrane
- O_2
- CO_2
- Fat soluble hormones (steroids)
- Urea
- Fat soluble vitamins
- Other small, fat soluble molecules

Relative permeability of a phospholipid bilayer



Osmosis: simple diffusion of the solvent (water)

- Water diffuses according to its concentration gradient
- ↑Osm □ □[water]
  □ Osm □ ↑[water]
- Osmosis can generate force (osmotic pressure)



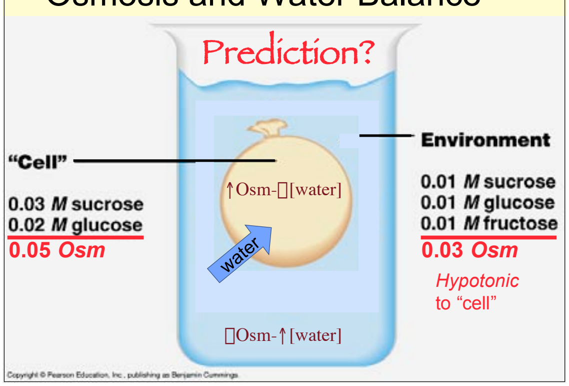
Osmolarity & Osmotic Pressure

- Osmolarity (Osm):
  the sum of **all** solutes in a given volume (moles per liter)
  - 1 *M* glucose solution = 1 *Osm*
  - 1 *M* glucose/1 *M* fructose/1 *M* ribose solution = 3 *Osm*
  - 1 *M* NaCl solution = 1 *M* Na^+/ 1 *M* Cl^- = 2 *Osm*
- Isosmotic: two solutions with the same Osm
- Hyposmotic: a solution with a lower Osm than another
- Hyperosmotic: a solution with a higher Osm than another
- *Remember*: ↑Osm □ □[water]
  □ Osm □ ↑[water]

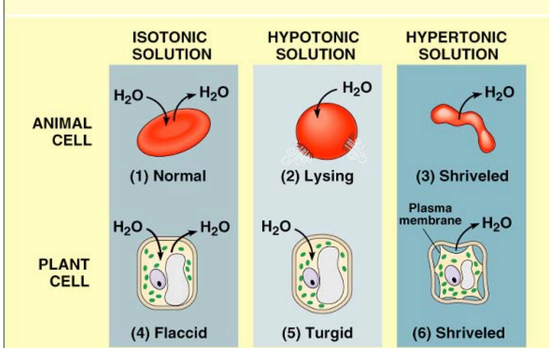
Osmolarity & Osmotic Pressure

- Osmolarity (Osm):
  the sum of **all** solutes in a given volume (moles per liter)
- Osmotic Pressure (P_{Osm}):
  - Force generated by osmosis
  - Measure of the tendency to take on water by osmosis
- Isotonic: two solutions with the same P_{Osm}
- Hypotonic: a solution with a lower P_{Osm} than another
  - I.e., loses water to the other solution
- Hypertonic: a solution with a higher P_{Osm} than another
  - I.e., takes water from the other solution
- *For an isosmotic solution to be isotonic, the membrane must be equally permeable (or equally impermeable) to all solutes*
  - *All isotonic solutions are isosmotic.*
  - *But not all isosmotic solutions are isotonic.*

Osmosis and Water Balance



Osmosis and Water Balance



Osmotic Swelling

- Mechanisms to resist excessive swelling in hypotonic environments

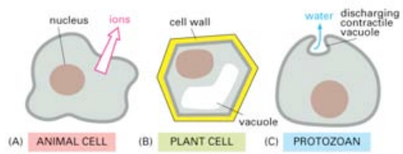
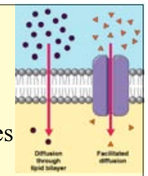


Figure 12-17 Essential Cell Biology, 2/e. (© 2004 Garland Science)

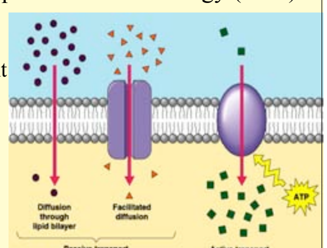
Selective permeability



- Except for water and small nonpolar solutes, permeability of cell membranes is **selective** and **regulated**.
- Permeability determined by **transporter proteins**.
  - Channels and carriers are <u>solute specific</u>
  - If no transporter, than that solute cannot cross membrane
- *(Artificial membranes are only semipermeable —i.e., only discriminate based upon molecular <u>size</u>.)*

Types of cellular transport

- **Passive transport**: driven by Brownian motion
  - Simple diffusion & osmosis
  - Facilitated diffusion (carrier mediated passive transport)
- **Active transport**: requires chemical energy (ATP)
  - Carrier mediated
  - Can transport <u>against</u> concentration gradient

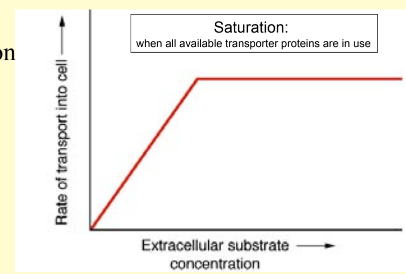


Carrier mediated transport

- Transporters are *binding proteins*

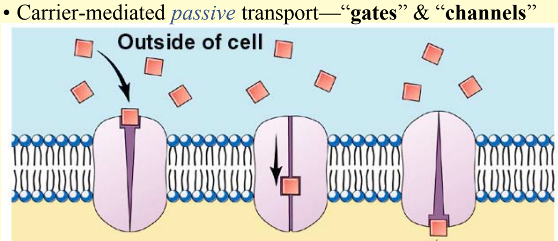
 subject to

- Specificity
- Competition
- Saturation



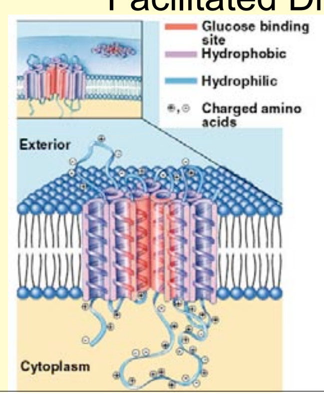
Facilitated Diffusion

- Carrier-mediated *passive* transport—"**gates**" & "**channels**"



- Movement from high to low concentration, only when gate is open
- Gate may open/close in response to
  - Chemical signal
  - Cell voltage
  - Mechanical distortion

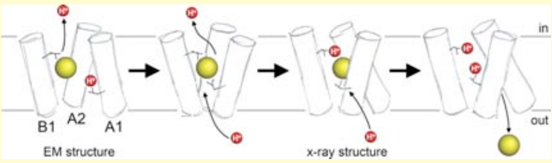
Facilitated Diffusion



Glucose channel

- May be gated
  - Most tissues
  - Opens in response to insulin
- Or ungated
  - Brain tissue

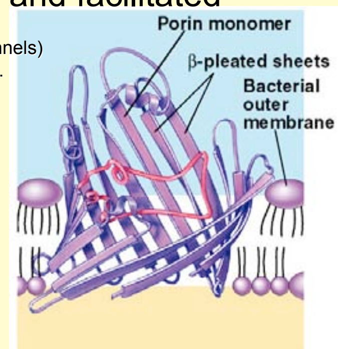
Facilitated Diffusion



- Multidrug Transporter Mechanism

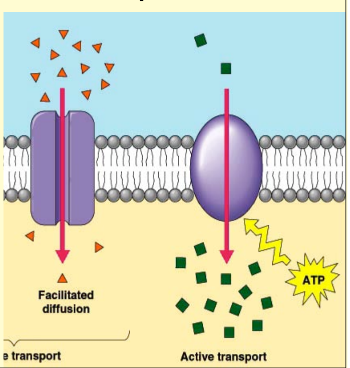
Osmosis may be both simple and facilitated

Aquaporins (water channels) speed water movement.



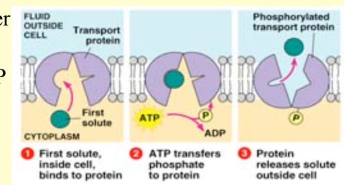
Active Transport

- Carrier mediated
  - "**pumps**"
- *Active*: requires **ATP**
- Can force movement <u>against</u> concentration gradient
- <u>Creates</u> concentration gradient
- (creates order/ decreases entropy)



Active Transport

1. Solute binds to carrier protein
2. Binding triggers ATP hydrolysis, transfers phosphate to carrier
3. Phosphorylation produces change in shape of carrier
4. Change in shape causes carrier to move solute



Difference in concentration is maintained by selective permeability of membrane

- Cytosol relatively high in K^+, protein, organic-phosphates
- Low in Na^+, Ca^{++}, Cl^-

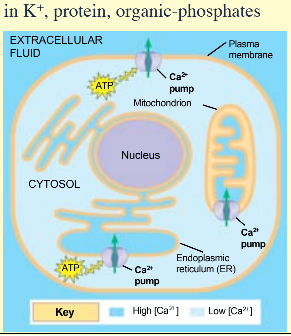
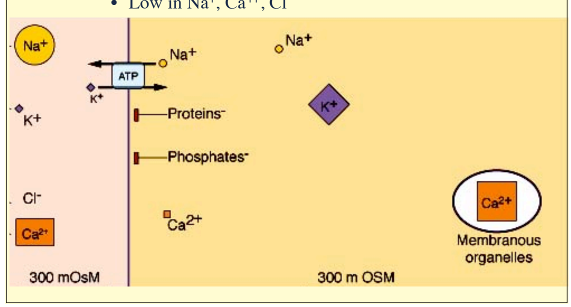


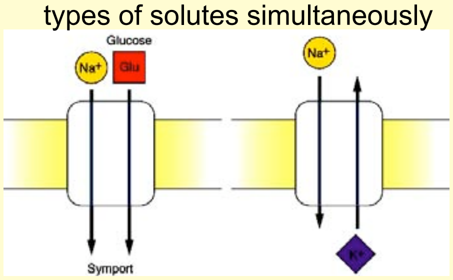
Figure 11.11

Difference in concentration is maintained by selective permeability of membrane

- Cytosol relatively high in K^+, protein, organic-phosphates
- Low in Na^+, Ca^{++}, Cl^-



Some carriers can transport two different types of solutes simultaneously



Symport: same direction

Antiport: different directions

Na^+/K^+ ATPase:
very important active transporter

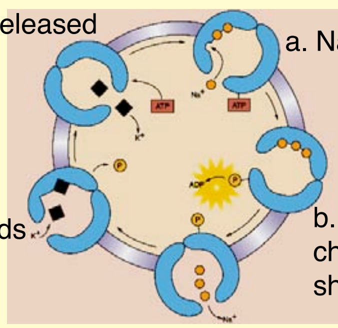
- Antiport
  - Pumps 3 Na^+ out
  - Pumps 2 K^+ in

  } per each ATP used
- Na^+/K^+ ATPase used to:
  - Maintain ion gradients
  - Create electrical potential (inside of cell negatively charged relative to outside).

How Na^+/K^+ ATPase works

e. K^+ is released

a. Na^+ binds



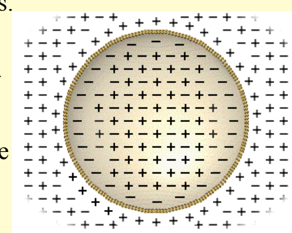
d. K^+ binds

b. ATPase changes shape

c. Na^+ is released

Cells as Electrical Batteries

- **Electrogenic pumps:** Active transport □ chemical gradients of ions □ <u>electrical</u> gradients.
- Electrical gradient produces a <u>membrane potential</u>.
- Inside of the cell is negative relative to the outside of the cell.



Cells as Electrical Batteries

Electrogenic pumps:
- In animal cells, primarily the Na^+/K^+ pumps.
- In plants, fungi, & bacteria, primarily **proton pumps**.

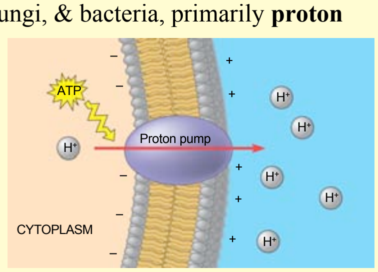
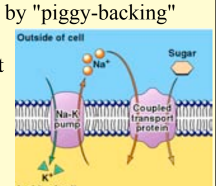


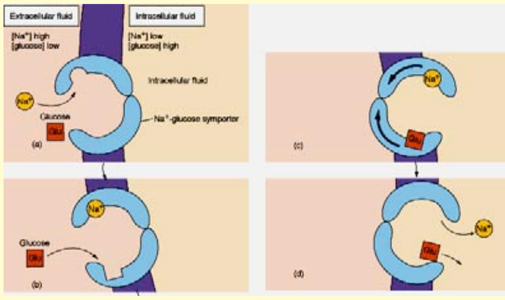
Figure 7.18

Cotransport, or secondary active transport

- Carrier protein does not <u>directly</u> use ATP
- But ATP required to create the gradient by other pumps
- Solute "A" transported by diffusion with the created gradient
- Solute "B" moved against gradient by "piggy-backing" with outside "A"
- Example: Na^+ and glucose symport
  - Na^+ diffuses
  - Glucose actively transported

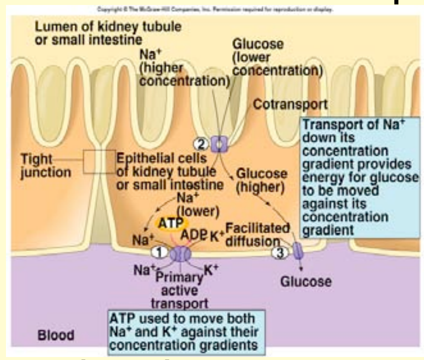


Cotransport of Na^+ and glucose



- Both solutes required for transport

Active Transcellular Cotransport



Aka, **Secondary Active Transport**, or **Symport**

H^+/Sucrose symport

- Essential in plants
  - Sucrose is their primary circulating energy substrate

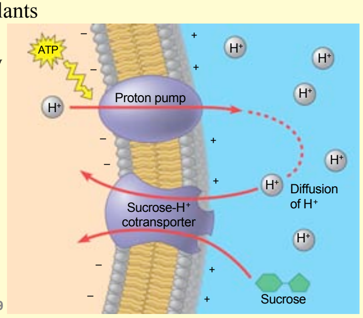
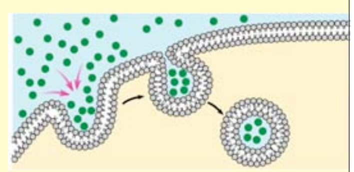


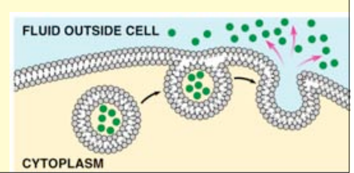
Figure 7.19

Bulk (vesicular) transport

- **Endocytosis**

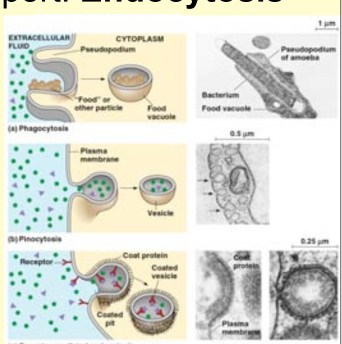


- **Exocytosis**



Bulk Transport: **Endocytosis**

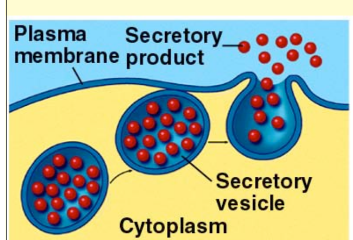
- **Endocytosis**: Transport of molecules or large particles <u>into</u> a cell using a vesicle
  - **Phagocytosis**: cell eating
  - **Pinocytosis**: nonspecific cell drinking
  - **Receptor mediated endocytosis**: transport of specific molecules (ligands)

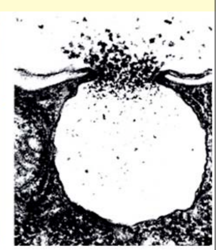


Active Transport (Requires energy)

Bulk Transport: **Exocytosis**

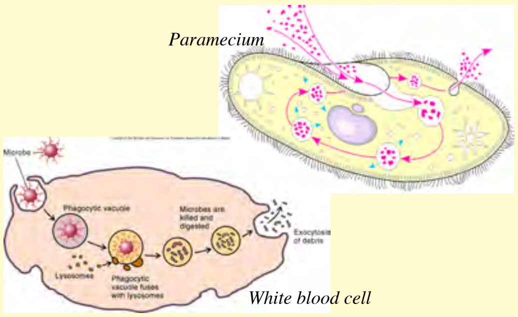
- **Exocytosis** — excretion / secretion





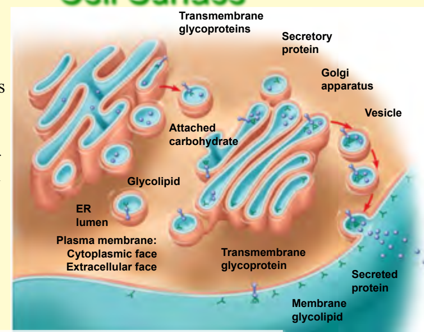
Active Transport (Requires energy)

Cells Eat and Spit Out:
Endo- and **Exocytosis**



Cell Surface

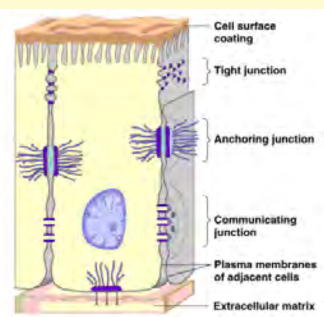
- Carbohydrates (on glycoproteins and glycolipids) give membranes **"sidedness"**
  - Membrane-bound carbs for cell recognition
  - Secreted glycoproteins coat outer surface of cell



- Organelle cytoplasmic (outer) face → plasma membrane cytoplasmic (inner) face
- Organelle lumen (inner) face → plasma membrane extracellular (outer) face

Figure 7.9

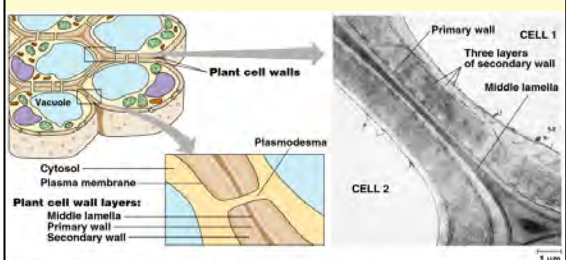
Cell Surface Junctions



Junctions

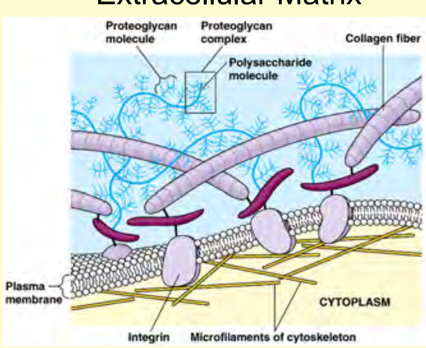
- Tight
  - Restrict fluid passing around cells
- Anchoring
  - (desmosomes)
  - Join adjacent cytoskeletons
- Communicating (gap)
  - Allow passage of small molecules
  - Esp. in
    - Plants
    - Embryos
    - Electrochemically coupled cells

Cell Surface Junctions & Walls



- Walls of secreted extracellular polysaccharide (cellulose or chitin)
- Plasmodesmata form gap (communicating) junctions between cells

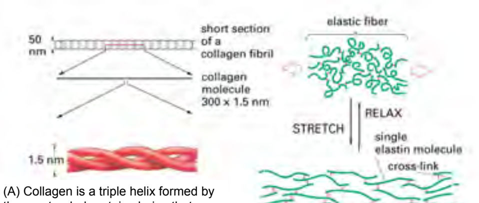
Extracellular Matrix



- No walls (animal cells)
- Matrix or basement membrane of secreted proteins/glycoproteins.

Extracellular Matrix

- Major matrix proteins: **Collagen** and **Elastin**



(A) Collagen is a triple helix formed by three extended protein chains that wrap around one another. Many rodlike collagen molecules are cross-linked together in the extracellular space to form collagen fibrils that have the tensile strength of steel.

(B) Elastin polypeptide chains are cross-linked together to form rubberlike, elastic fibers. Each elastin molecule uncoils into a more extended conformation when the fiber is stretched and will recoil spontaneously as soon as the stretching force is relaxed.

Figure 4-25 Essential Cell Biology, 2/e. (© 2004 Garland Science)