Cell Membrane Transport

Chapter Outline

I. Transport Across Membranes

- What membranes do?
  - Separate material: ICF / ECF
  - Allow exchange of material: ICF / ECF
- Why transport is important?
  - Obtaining O_2 and nutrients
  - Getting rid of waste products

Membranes Are Selective Permeable

- Property of a membrane: selective permeable.
  - Permeable = to pass through
  - Selective = restrictive

Membranes Are Selective Permeable

- Membrane permeability is affected by
  - The lipids solubility of the diffusing substance
  - The size and shape of the diffusing substance
  - Temperature
  - Membrane thickness

Membranes Are Selective Permeable

- Non-polar and small polar molecules are easily transported
  - **Examples**: O_2, CO_2, fatty acids, water
- Large polar molecules and ions are not transported
  - **Examples**: Glucose, proteins, Na^+

PLAY

TABLE 4.1 Millimolar Concentrations of Selected Solutes in Intracellular Fluid (ICF)* and Extracellular Fluid (ECF)

Solute	ICF (mM)	ECF (mM)
K^+	140.0	4.0
Na^+	15.0	145.0
Mg^{2+}	0.8	1.5
Ca^{2+}	<0.001†	1.8
Cl^-	4.0	115.0
HCO_3^-	10.0	25.0
P_i	40.0	2.0
Amino acids	8.0	2.0
Glucose	1.0	5.6
ATP	4.0	0.0
Protein	4.0	0.2

*Intracelluler fluid composition varies for different cell types.

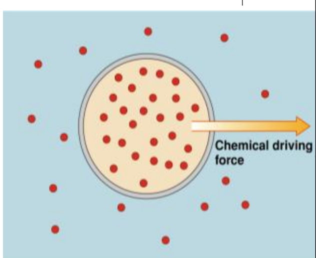
†Refers to calcium ions free in the cytosol. A significant quantity of intracellular calcium is sequestered in membrane-bounded organelles and/or bound to proteins.

Factors Affecting the Direction of Transport

- Molecules travel from high energy to lower energy
- Difference in energy across a membrane serves as a driving force. There are three types
  - Chemical
  - Electrical
  - Electrochemical

Chemical Driving Force

- Direction of chemical driving force
  - Down the chemical gradient (ΔC)
  - A molecule travels along its own ΔC



(a)

Electrical Driving Force

- Due to the uneven distribution of ion across the cell membrane, a cell has a difference in electrical potential or voltage called **membrane potential**

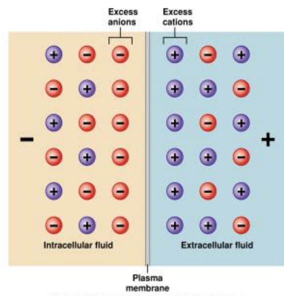
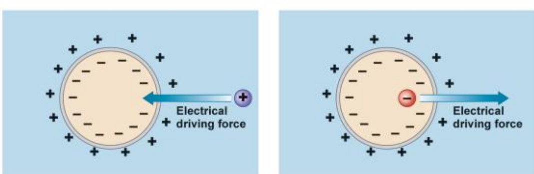


Figure 4.2

Electrical Driving Force

- Membrane potential = potential energy



(a) (b)

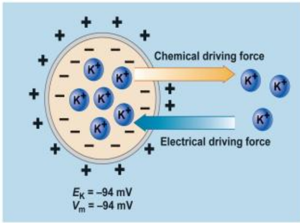
Figure 4.3

Electrochemical Force

- Electrochemical force= the combination of both chemical and electrical forces
- At equilibrium potential (*E*),
  - chemical driving force= electrical driving force
  - the electrochemical force is zero

Electrochemical Force on Potassium Movement

- When the electrochemical force= zero, K^+ will move to ______ direction.



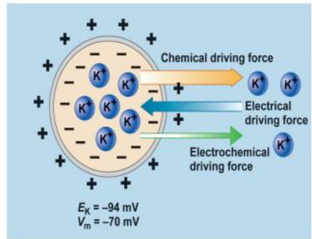
(a)

Figure 4.5
Figure 4.5

Equilibrium potential of potassium ion (E_k) = membrane potential (Vm),

Electrochemical Force on Potassium Movement

- When $V_m > E_k$, the electrochemical force is outward, K^+ moves_____.

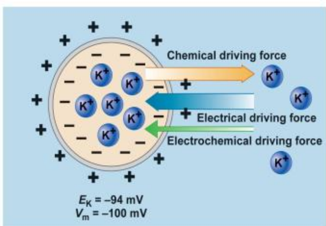


(b)

Figure 4.5

Electrochemical Force on Potassium Movement

- When $V_m < E_k$, the electrochemical force is inward, K^+ moves_____



(c)

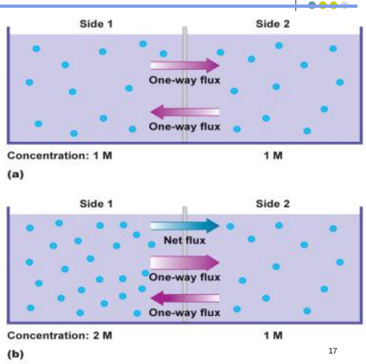
Figure 4.5

Rate of Transport

- The rate of transport of a certain substance is called **flux**.
- Flux is the number of molecules traveling through the membrane per unit time per unit surface area (mole/s/area)

Net Flux

- The net flux is the overall movement before achieving equilibrium.



II. Types of Transport

- Depending on the requirement of energy
  - Passive
    - Spontaneous
    - No cell energy is required
    - The direction of electrochemical force is downhill movement
  - Active
    - Require the consumption of energy
    - Uphill reaction

Types of Passive Transport

- Simple diffusion
- Facilitated diffusion
- Diffusion through channels
- Osmosis

19

Simple Diffusion

- No membrane proteins are needed
- Transport is through the bilipid layer
- Examples: fatty acids, O_2 and CO_2

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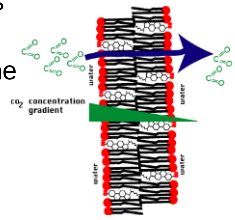


http://academic.brooklyn.cuny.edu/biology/bio4fv/page/simple.htm

20

Simple Diffusion Rate

- Is directly proportional to the lipid solubility, the magnitude of the driving force, surface area, and temperature

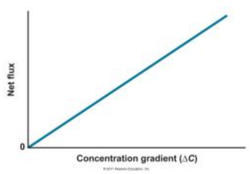


Figure 4.8

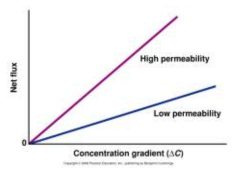


Figure 4.9

21

6-11

Simple Diffusion Rate

- Is inversely proportional to
  - membrane thickness,
  - diffusing molecule size and shape.

22

Facilitated Diffusion

- Passive transport through a carrier
- Characteristics of a carrier
  - Transmembrane protein
  - Has binding sites for specific particles
  - Binding occurs one side at a time
  - Random conformational changes
- Examples: organic molecules such as glucose

23

Facilitated Diffusion

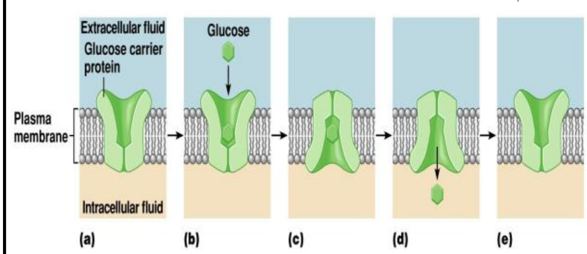


Figure 4.10

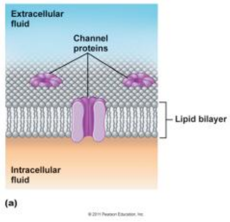
24

Factors Affecting the rate of Facilitated Diffusion

- Rate of transport of each carrier
- Number of carriers in membrane
  - Carriers demonstrate saturation
  - Cells can regulate the transport rate by modify number of carrier in membrane
- The magnitude of concentration (or electrochemical) gradient

Diffusion Through Channels

- Characteristics of a channel
  - Transmembrane protein
  - Functions like a passageway or pore
  - Substance specific
  - Accessible from only one side



Types of Channels

- Aquaporin
  - 13 classes of water transporter
- Ion Channels
  - Examples: inorganic ions (Na^+, K^+, Cl^-, Ca^{2+})
  - Leak channels
  - Gated channels

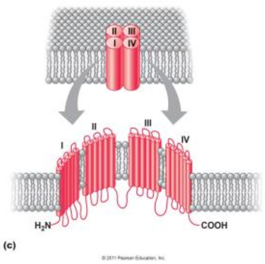


Figure 4.12 C Structure of a sodium channel

Osmosis: Passive transport of water across membranes

- Water moves from high concentration low concentration across the plasma membrane.

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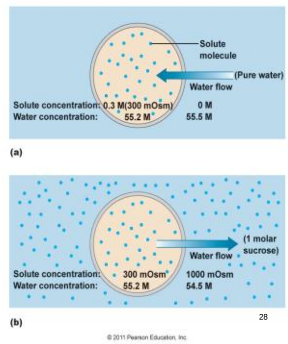


Figure 4.17

Molarity & Molality

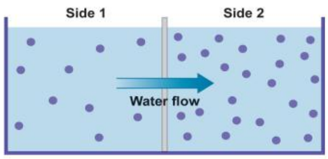
- 1 molar solution (1.0M) = 1mole of solute per liter solution
- 1 molal solution (1.0m) = 1 mole of solute per kg H_2O
  - May be more than one liter solution

Osmolarity

- Osmolarity (Osm) is total molarity of a solution
  - Permeant + impermeant solutes
  - E.g. 1.0m of NaCl yields a 2 Osm solution
    - Because NaCl dissociates into Na^+ + Cl^-
- Normal” osmolarity for most body fluids = 300 mOsm (milliosmoles)

Osmotic Pressure (π)

- π
  - Is force that would have to be exerted to stop osmosis
  - Is proportional to solute concentration
- Water moves from lower π to higher π



	Side 1	Side 2
Solute concentration:	300 mOsm (0.3 M)	500 mOsm (0.5 M)
Water concentration:	55.2 M	55.0 M
Osmotic pressure:	7.4 atm	12.3 atm

Fig 4.18 Osmotic pressure gradient ($\Delta\pi$): 12.3 atm – 7.4 atm = 4.9 atm

Tonicity

- Reflects the concentration of impermeant solutes relative to ICF
- Describe the effect of a solution on water movement

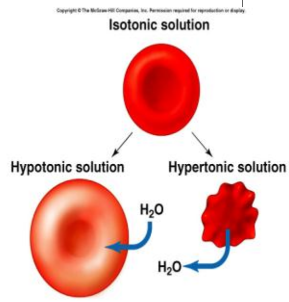


TABLE 4.3 Distinctions Between Osmolarity and Tonicity

Terms	Definitions and solute concentrations
Osmolarity	Total concentration of permeant and impermeant solutes
Iso-osmotic*	300 mOsm (permeant + impermeant)
Hypo-osmotic*	Less than 300 mOsm (permeant + impermeant)
Hyperosmotic*	Greater than 300 mOsm (permeant + impermeant)
Tonicity	Concentration of impermeant solutes relative to intracellular fluid
Isotonic*	300 mOsm (impermeant)†
Hypotonic*	Less than 300 mOsm (impermeant)†
Hypertonic*	Greater than 300 mOsm (impermeant)†

*These designations are relative to a cell containing 300 mOsm solutes, which are assumed to be impermeant.

†Permeant solutes may or may not be present.

Active Transport

- Non-spontaneous
- Requires cell energy
- Involves a pump (membrane protein)
- The net flux movement is uphill and against electrochemical gradient.

Characteristics of a Pump

- A pump
  - Is a type of membrane protein
  - Function as transporter and enzyme
  - Can harness energy to transport the molecules to a preferred direction
  - Have specific binding sites
  - Demonstrate saturation

Types of Active Transport

- Primary active transport
- Secondary active transport

Primary Active Transport

- Pump is both a transporter and an enzyme.
- Since energy is usually obtained from ATP hydrolysis, most of them are called ATP*ases.*
- For example sodium-potassium pump (also called the Na^+/K^+ ATPase)

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37

Sodium–Potassium Pump

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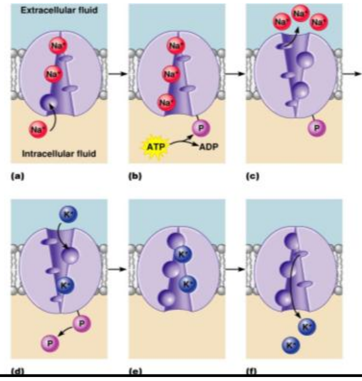

Figure 4.14

38

Secondary Active Transport

- Primary active transport of ion creates ion gradients
- Energy released from electrochemical gradient of another solute drives a pump

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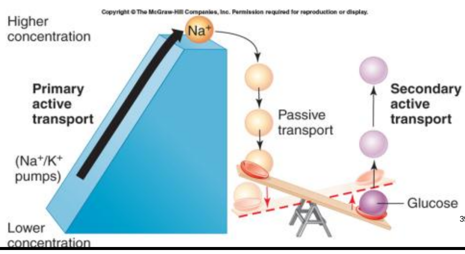

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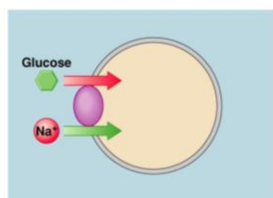
Secondary Active Transport

- Cotransport (symport) The transport of two substances in the same direction.
  - Diffusion of Na^+ provides energy to actively transports glucose



(a) Cotransport

Figure 4.15a

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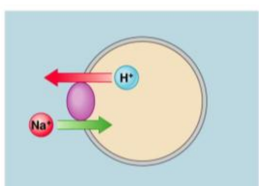
Secondary Active Transport

- Counter transport (antiport): The transport of two substances in opposite direction.
  - Diffusion of Na^+ provides energy to actively transport H^+



(b) Countertransport

Figure 4.15b

41

Active and Passive Transport Coexist in Cells

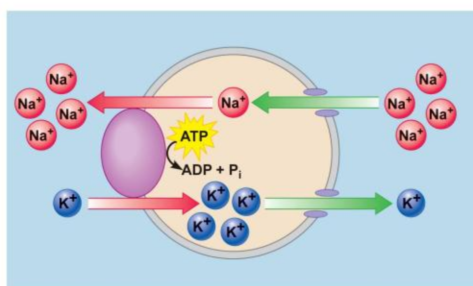


Figure 4.16

42

Table 4.2 Characteristics of Transport Processes

	SIMPLE DIFFUSION	MEDIATED TRANSPORT			
		Passive transport		Active transport	
		Channel	Facilitated diffusion	Primary	Secondary
Direction of net flux	Down electrochemical gradient	Down electrochemical gradient	Down electrochemical gradient	Up electrochemical gradient	Up electrochemical gradient
Transport protein required?	No	Yes, ion channel	Yes, carrier	Yes, pump	Yes, pump
Requires energy?	No	No	No	Yes	Yes
Energy source	(Not applicable)	(Not applicable)	(Not applicable)	ATP or other chemical energy source	Electrochemical gradient of another solute
Saturation?	No	Sometimes	Yes	Yes	Yes
Specificity?	No	Yes	Yes	Yes	Yes
Character of transported substance	Hydrophobic (nonpolar)	Hydrophilic (ionized or polar)	Hydrophilic (ionized or polar)	Hydrophilic (ionized or polar)	Hydrophilic (ionized or polar)
Examples	Fatty acids, O_2, CO_2	Inorganic ions (Na^+, K^+, Cl^-, Ca^{2+})	Organic molecules (glucose)	Inorganic ions (Na^+, K^+, H^+, Ca^{2+})	Organic molecules and inorganic ions (glucose, amino acids, H^+, Ca^{2+})

Transport of Material Via Membrane-Bound Compartments

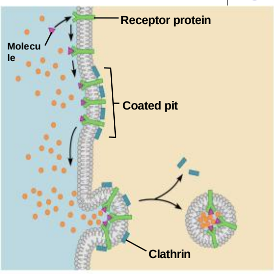
- Bulk transport of macromolecules
- Consume energy
- Uses membrane compartments
  - Endocytosis
  - Exocytosis

Endocytosis

- Molecules enter the cell through the formation of vesicles (endosomes)
  - Phagocytosis
    - Cell eating
    - A cell uses amoeboid movement to engulf particles. Example WBC
  - Pinocytosis
    - Cell - drinking
  - Receptor-mediated transport

Receptor-Mediated Transport

- Specific transport
- Cholesterol
- Familial hypercholesterolemia, FH (type II) patients have defect membrane surface receptors that help to remove LDLs from circulation



(c) Receptor-mediated endocytosis

Figure 4.21c

Exocytosis

The reverse of endocytosis

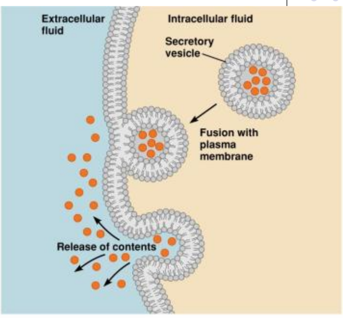


Figure 4.22

Exocytosis

Three Functions of Exocytosis

- To add components to the plasma membrane.
- To replace the membrane that is lost during endocytosis
- To secrete molecules

Epithelial Transport: Movement of Molecules Across Two Membranes

- Apical membrane is lumen facing
- Basolateral membrane is blood facing
- Tight junctions limit materials transport

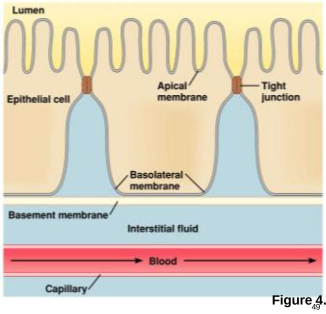


Figure 4.23

49

Epithelium: Absorption of Sodium

- Apical membrane
  - Na^+ channel (passive)
- Basolateral membrane
  - Na^+ / K^+ pump (active)
  - K^+ Channel
- Overall transport of sodium is passive or active?

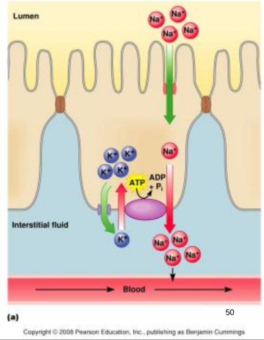


Figure 4.24

50

Epithelium: Absorption of Glucose and Sodium Ions

- Apical membrane
  - Sodium-linked cotransport system
- Basolateral membrane
  - Na^+ / K^+ pump
  - K^+ channel
  - Glucose carrier
- Overall transport of glucose is passive or active?

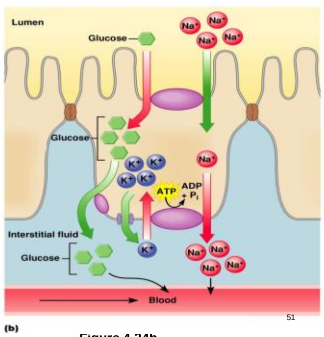
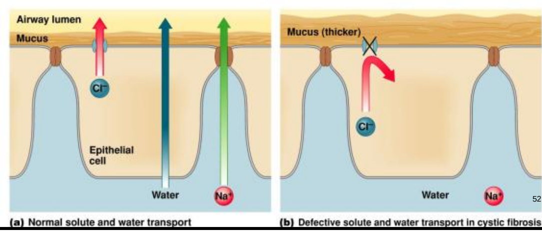


Figure 4.24b

51

Cystic Fibrosis

- Defected chloride transporter
- Thick respiratory mucus clogs airway and promotes bacteria growth
- Defect in chloride channel proteins in membrane causes the inability of water secretion



52

Epithelia Water Transport

- By actively pump solutes to create an osmotic gradient, osmosis follows.

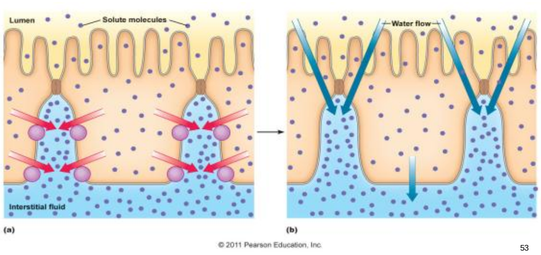


Figure 4.25

53

Transcytosis

- Transport of macromolecules across epithelial cells which involve both endocytosis and exocytosis

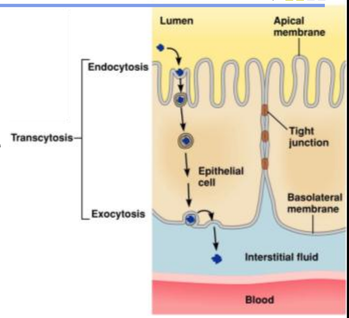


Figure 4.26

54