Water and Solute Transport

Homeostasis Requires Exchange of Materials

- Transportation of solutes in solution
  - Movement between external and internal environments
  - Movement between internal environment and cells
- Movement must be regulated

Cell Membranes

- Consist predominantly of phospholipids and protein
- Phospholipid bilayer (esp. hydrocarbon tails) limits ability of some substances to enter/leave the cell
  - Inhibits movement of larger and/or more hydrophilic solutes
- Selectively permeable

Cell Membranes

- Membrane proteins provide alternate routes for movement
- Highly specific in what substances are transported
- Transport activity is highly regulated

Equilibrium and Membrane Transport

- Equilibrium pertains to isolated systems
  - No input or output of energy or matter
- Equilibrium
  - State where no further net change is possible without system inputs or outputs
  - State of minimal capacity to do work under prevailing conditions
    - Minimum free energy

Passive and Active Transport

- Passive transport
  - Movement of materials in the direction of equilibrium
- Active transport
  - Capable of moving materials away from equilibrium
Simple Diffusion

- Particles in a fluid are in motion
  - Move randomly
- Statistically, particles tend to move in greater quantities from areas of high [ ] to areas of low [ ] than vice-versa

Fig. 3.2

Concentration Effects on Simple Diffusion

- Fick’s Law
  \[ J = D \times \frac{C_1 - C_2}{X} \]
  - \( J \) = net rate of diffusion between point 1 and point 2
  - \( D \) = diffusion coefficient (depends on medium permeability and temperature)
  - \( C_1 \) and \( C_2 \) = particle concentration at points 1 and 2
  - \( X \) = distance between points 1 and 2
  - \((C_1 - C_2)/X\) = concentration gradient

Diffusion rate increases with...

- Bigger differences in concentration
- Shorter diffusion differences
- Greater medium permeability
- Higher temperatures

Electrical Charges and Diffusion

- Movements of charged particles (ions) also influenced by electrical attraction/repulsion
- Charge differences are particularly important in areas immediately adjacent to cell membranes
- Combinatory effect of concentration and charge on diffusion (electrochemical gradient)

Membrane Permeability

- Lipid-soluble molecules can pass directly through the plasma membrane
- Inorganic ions often can pass through ion channel proteins
  - Specific for particular ions
  - May be gated
- Permeability of membrane depends on # of open channels available

Interactive Effects of Ion Diffusion

- Flow of particles along a concentration gradient normally does not affect concentration gradients of other particles
- Net diffusion of ions redistributes electrical charges
  - Affects electrochemical gradients for other ions
Facilitated Diffusion

- Passive movement of polar organic solutes through transporter proteins
- Defining features
  1. Transport is in direction of electrochemical equilibrium
  2. Solute moves faster through transporter protein than spontaneously through lipid bilayer
  3. Transport requires reversible binding of solutes to the transporter proteins
  4. Exhibit saturation kinetics

Problems with Passive Transport

- Net movement occurs ONLY in the direction towards equilibrium
- Animals generally need to maintain differences in solute concentrations with their surroundings

Active Transport

- Mechanisms capable of moving solutes away from electrochemical equilibrium
  - Requires use of metabolic energy (ATP)
    - Couples energetically unfavorable process with energetically favorable one
    - Typically rely on phosphorylation/dephosphorylation for function

Example: Na⁺/K⁺ ATPase

- Moves Na⁺ out of cells and K⁺ into cells
  - Both moved against their electrochemical gradients
- Pumps 3Na⁺ out for every 2K⁺ in
  - Enhances electrical gradients across cell membranes

Na⁺/K⁺ ATPase Function

- Na⁺ binds on cytosolic side
- ATP hydrolysis
  - phosphorylation of pump
- Shape/affinity change
  - transport and release of Na⁺
- K⁺ binds on extracellular side
  - dephosphorylation of pump
- Shape/affinity change
  - transport and release of K⁺

Ion pumping in freshwater fish gills

- Na⁺/K⁺ ATPase pumps Na⁺ into blood plasma
- Na⁺ drawn into the cell from surrounding water
- H⁺ pumped out of cell into water
- HCO₃ moves out into water in exchange for Cl moves into cell
Forms of Active Transport

- **Primary active transport**
  - Energy released from ATP hydrolysis used directly to transport ligands by the same protein
  - Transport inorganic ions against gradients
- **Secondary active transport (coupled transport)**
  - Electrochemical gradients are harnessed to drive ligand transport through a different transporter protein
  - Transport of organic molecules against their gradient

Coupled Transport: Intestinal Epithelial Cell

- Na+/K+ ATPase used to move Na+ out of cell
- Creates electrochemical gradient for Na+ to move into the cell

Coupled Transport: Intestinal Epithelial Cell

- Coupled transporter requires binding of both glucose and Na+ to apical surface to undergo conformation change
- Transporter loses affinity for glucose once Na+ dissociates

Water Transport

- Water is the primary solvent in biological solutions
- Water will diffuse along its concentration gradient (from low solute concentrations to high solute concentrations)
- Osmosis – passive transport across a membrane

Osmotic Pressure

- Amount of hydrostatic pressure that would need to be applied to a solution to prevent it from osmotically drawing water into itself across a semi-permeable membrane.
- A colligative property
  - Properties of solutions that depend on the total number of non-gaseous dissolved solute particles.
Osmotic Pressure

- Tendency of a solution to gain or lose water through osmosis when it undergoes exchange with another solution.
- Based upon concentration of total solutes in solution.
- Net osmosis between two solutions occurs from the lower osmotic pressure solution to the higher osmotic pressure solution.

Rates of Osmosis

- Derivation of Fick’s Law
  \[
  \text{Rate per unit area} = K \times \frac{\Pi_1 - \Pi_2}{X}
  \]
  - \( K \) = proportionality coefficient (depends on membrane osmotic permeability and temperature).
  - \( \Pi_1 \) and \( \Pi_2 \) = osmotic pressure on two respective sides of a membrane.
  - \( X \) = distance between the two sides of the membrane.
  - \( (\Pi_1 - \Pi_2)/X \) = osmotic gradient.

Osmotic Permeability

- Water can diffuse directly through phospholipid bilayers.
- Water channels (e.g., aquaporins) enhance permeability.
  - Transport through channels exceeds diffusion through channels.