Chapter 3–Part 1

10th ed.: pp. 87–105
11th ed.: pp. 90–107

Cellular Transport Mechanisms
The Cell Cycle

Transport Processes: Passive and Active (1 of 2)

1. Passive transport
   - Does not use ATP
   - Energy for transport provided by random molecular motion due to heat
   - Solute moves from higher to lower concentration i.e. down its concentration gradient
     \[ \text{[high]} \rightarrow \text{[low]} \]

Examples of passive transport:
   - Simple diffusion
   - Facilitated diffusion
   - Osmosis

   - Bulk flow
Active Transport (2 of 2)

2. **Active transport**
   - ATP required
   - Carrier molecule required
   - Solute moves from lower to higher concentration
     i.e. against its concentration gradient
     \[ \text{[low]} \rightarrow \text{[high]} \]

Examples of active transport:
- Primary active transport - Na\(^+\)/K\(^+\) ATPase pump
- Secondary active transport - cotransport, countertransport
- Vesicular transport*
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Simple Diffusion

All molecules are in *constant random motion* if environmental temperature is above *absolute zero*.

Movement of a substance from area of higher concentration to area of lower concentration

Net diffusion continues until concentration difference is eliminated (*equilibrium concentration* is reached).

**Absolute zero**

= COLD  
= 0  K
=  °C
=  °F

Simple Diffusion

Figure 3-14

1. Placing a colored sugar cube into a water-filled beaker establishes a steep concentration gradient.
2. As the cube begins to dissolve, many sugar and dye molecules are in one location, and none are elsewhere.
3. With time, the sugar and dye molecules spread through the water.
4. Eventually, the concentration gradient is eliminated and the molecules are evenly distributed throughout the solution.

Eventually reaches equilibrium concentration
### Factors Affecting Diffusion Rate (2 of 3)

**Diffusion rate** (*Flux*) is proportional (α) to:

- *Diffusion coefficient* (D) for the solute in a particular medium at a particular temperature
- *Surface area* (A) over which diffusion is occurring
- The *concentration difference* (∆C)
- *Length* (L) over which diffusion is occurring

**Fick’s equation:** \( \text{Flux} \propto \frac{D \cdot A \cdot \Delta C}{L} \)

But D is constant for a particular substance in a particular medium at constant temperature, so you can ignore it. *(But know what D is.)*
Factors Affecting Diffusion Rate (3 of 3)

\[ \text{Flux} \propto \frac{A \cdot \Delta C}{L} \]

Simple Diffusion Across Membranes

Permeability (P) refers to the ease with which substances can cross the cell membrane.
- Nothing passes through an impermeable barrier.
- Anything can pass through a freely permeable barrier.

Cell membranes are selectively permeable (semipermeable).
Simple Diffusion Rate Across a Membrane

Diffusion rate (\textit{Flux}) across a cell membrane depends upon:

- \textit{Permeability} (\(P\)) of the membrane to the solute
- The solute’s \textit{concentration difference} (\(\Delta C\)) across the membrane

So...

\[
\text{Flux} = P \cdot \Delta C
\]

Diffusion Across a Cell Membrane

Figure 3-15

EXTRACELLULAR FLUID

Lipid-soluble molecules diffuse through the plasma membrane

Plasma membrane

Channel protein

Large molecules that cannot diffuse through lipids cannot cross the plasma membrane unless they are transported by a carrier mechanism

Small water-soluble molecules and ions diffuse through membrane channels

Water?
Factors Affecting Permeability (P)

Permeability (P) is affected by:

- Solute size vs. protein channel (pore) size (e.g. aquaporins for water – see last slide in notes)
- Solute charge vs. local membrane charge
- Solubility in lipid
- Presence of specific carrier molecules (transporters)
- Temperature
- Concentration difference is NOT a factor that directly affects P.
Facilitated Diffusion

Diffusion that is *facilitated* by a *carrier molecule*

- Is a form of passive transport
  
  \([\text{High}] \rightarrow [\text{Low}]\)

- No ATP used

Characteristics of all carrier-mediated transport:

- Specific (carrier-mediated)
- Can be saturated
- Can be regulated
Transporters Can Be Saturated

Osmosis (This is what Osmosis Lab is about.)

Osmosis = diffusion of water down its concentration gradient across a semipermeable membrane

Osmotic pressure = pressure required to prevent osmosis

Hydrostatic pressure can oppose osmotic pressure.

- Water follows salt (solute).
- Water moves from higher $[\text{H}_2\text{O}]$ to lower $[\text{H}_2\text{O}]$. 
Chapter 3–Part 1–Transport processes

Osmosis Experiment

What will happen to the fluid levels on sides A and B?
What do you have to know to answer this question?.......

Flux = \( P \cdot \Delta C \)

Selectively permeable membrane

Osmosis - 1

Flux = \( P \cdot \Delta C \)

Required information:
- \( P_{H_2O} = \) High
- \( P_{glucose} = 0 \)
- \([glucose]\) on side A = 5%
- \([water]\) on side A = ?
- \([glucose]\) on side B = 10%
- \([water]\) on side B = ?

What is your prediction?
Chapter 3–Part 1–Transport processes

Osmosis - 2

Flux = P • ΔC

Osmotic Pressure

Osmotic pressure is the force necessary to prevent osmosis.
Osmotic Flow Across a Cell Membrane

**Isotonic solution**
- In an isotonic saline solution, no osmotic flow occurs, and the red blood cells appear normal.

**Hypotonic solution**
- In a hypotonic solution, the water flows into the cell. The swelling may continue until the plasma membrane ruptures, or lyses.

**Hypertonic solution**
- In a hypertonic solution, water moves out of the cell. The red blood cells shrink and become crenated.

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**Tonicity and the Effects of Osmosis on Cells**

The -tonic terms are based on the effects of osmotic solutions on cells

- **Isotonic** solution = no change in volume
- **Hypotonic** solution = cell swells
  - Hemolysis may occur
- **Hypertonic** solution = cell shrinks
  - Crenation occurs

**Note** that these terms:
- Refer to the **solution** (e.g. a hypotonic solution)
- Describe the **behavior of a cell** in that solution
Molarity, Osmolarity and Tonicity

- **Molarity** = concentration of a substance expressed in moles (mol) per liter of solution (M or mol/l)
  
  \[
  \text{MW of Na} \approx 23; \text{ 1 mol of Na} \approx 23 \text{ g}
  \]
  
  \[
  \text{MW of Cl} \approx 35; \text{ 1 mol of Cl} \approx 35 \text{ g}
  \]

- **Osmolarity** = concentration of osmotically active particles per liter of solution (Osm or mOsm)

  \[
  \text{1 mol/L NaCl} \rightarrow \text{1 mol/L Na}^+ + \text{1 mol/L Cl}^- = 2 \text{ Osm/L}
  \]

- **Tonicity** is based on the behavior of cells in a solution. The behavior depends upon the number of osmotically active particles, not their size.

- **tonic vs. –osmotic Terms – IMPORTANT!**

  Words ending in **–osmotic** (e.g. hypo-osmotic) simply state which solution is saltier or less salty. A membrane is not necessarily involved and these terms DO NOT describe the behavior of a cell in a particular solution. This is so simple that it’s hard to grasp! These terms could properly be applied to either a solution or a cell.

  Words ending in **–tonic** (e.g. hypotonic) describe the behavior of a cell (shrink, swell, stay the same size) in that particular solution. A membrane must be involved in order for some behavior to be observed. These terms are ONLY properly applied SOLUTIONS, not to cells.
E.g. #1 - Hypothetical Cell in 150 mM NaCl

Hypothetical cell:
- Cell’s total solute concentration = 300 mOsm/L
- Membrane is permeable to water ($P_{\text{H}_2\text{O}}$ = high)
- Membrane not permeable to salts ($P_{\text{NaCl}}$ = O)

Solution: $\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^-$
- 150 mM NaCl = 300 mOsm/L NaCl

Solution and cell are *iso-osmotic* to each other
Solution is *isotonic* to cell (cell stays same size)
Why?

E.g. #2 - Hypothetical Cell in 300 mOsm Urea

Cell membrane is permeable to both water *and* urea
- [Urea] inside cell is initially zero
- Urea diffuses down its concentration gradient into cell
- Osmotic concentration of cell increases
- *Water follows solute and cell swells*

300 mOsm/L urea is:
- *Iso-osmotic* to the cell
- *Hypotonic* to the cell (because the cell swells)
Bulk Flow (add this to slide #2)

- Movement of large numbers of particles in a fluid (air or liquid)
- Movement is in response to a pressure gradient
- More solute movement than would occur due to simple diffusion or osmosis
- ATP is not used at the site of transport
  - E.g. filtration of blood in kidney
  - E.g. movement of air and suspended particles into and out of lungs

SECTION 3-6
Carrier-mediated and vesicular transport mechanisms facilitate membrane passage

Both facilitated diffusion and active transport are carrier-mediated processes. BUT...

Facilitated diffusion is a passive transport process; active and vesicular transport are active processes.
Facilitated Diffusion is **PASSIVE**

Diffusion that is *facilitated* by a *carrier molecule*

- Is a form of **passive** transport
  
  \([\text{High}] \rightarrow [\text{Low}]\)

- No ATP used

Characteristics of all carrier-mediated transport:

- Specific (carrier-mediated)
- Can be saturated
- Can be regulated

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**Facilitated Diffusion of Glucose**

![Facilitated Diffusion of Glucose](image)
Chapter 3–Part 1–Transport processes

### Active Transport

**Active transport:**
- Consumes ATP
- Is *independent* of (does not depend upon) concentration gradients
- Is carrier-mediated transport

**Types of active transport include:**
- Primary active transport
- Secondary active transport (cotransport)
- Vesicular transport ✔

### Primary Active Transport

**Example = Na⁺/K⁺ ATPase pump**
- ATP used *at the site of transport*
- Both Na⁺ and K⁺ pumped against their concentration gradients

This pump is *electrogenic*
- Pumps 3 Na⁺ out of and 2 K⁺ into the cell
- Net loss of cations (+) from the cell
- Helps make inside of cell membrane negatively charged compared to outside of membrane
Sodium Potassium ATPase Pump

An *electrogenic* pump

![Diagram of Sodium Potassium ATPase Pump]

$[\text{Na}^+]$ high
$[\text{K}^+]$ low

$[\text{Na}^+]$ low
$[\text{K}^+]$ high

Secondary Active Transport

ATP **not** used *at the site of transport*

- Concentration gradient for one solute is established by primary active transport
- This concentration gradient provides the energy to drive movement of a second solute
- Can move second solute against its concentration gradient

Types:

- Symporter (*cotransporter*) - transported solutes move in same direction
- Antiporter (*countertransporter* or *exchanger*) - transported solutes move in opposite directions
Secondary Active Transport  
Figure 3-20, part 1

(Without transporter, $P_{\text{glucose}}$ is very low)

High [Na$^+$]

Low [Na$^+$]

Requires maintaining a high extracellular [Na$^+$]

Secondary Active Transport  
Figure 3-20, part 2

- Martini prefers the term COTRANSPORT
- Concentration difference maintained with Na$^+$/K$^+$ ATPase pump
Vesicular Transport Requires ATP

Material moves into or out of cells in membranous vesicles

**Endocytosis** is movement into the cell

(Listed from most specific to least specific)
- Receptor-mediated endocytosis (coated vesicles)
- Phagocytosis (pseudopodia)
- Pinocytosis (a.k.a. bulk-phase endocytosis)

**Exocytosis** is ejection of materials out of the cell

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Receptor-Mediated Endocytosis

Figure 3-21

![Diagram of Receptor-Mediated Endocytosis](http://academic.brooklyn.cuny.edu/biology/bio4fv/page/rectpr.htm)

- e.g.
  - Iron
  - Cholesterol

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RME animation

http://academic.brooklyn.cuny.edu/biology/bio4fv/page/rectpr.htm
Pinocytosis and Phagocytosis Figure 3-22 (9th ed.)

This is an electron micrograph showing pinocytosis at the surface of a cell in contact with the bloodstream.

In phagocytosis, material is brought into the cell enclosed in a phagosome that is subsequently exposed to lysosomal enzymes. After nutrients are absorbed from the vesicle, the residue is discharged by exocytosis.

Transport Summary – Spotlight Figure 3-22

Read this excellent summary
SECTION 3-7
The transmembrane potential results from the unequal distribution of ions across the plasma membrane

Difference in electrical potential between inside and outside a cell (measured in mV)
Inside of membrane is negatively charged with respect to outside
Undisturbed cell has a resting potential

Chapter 12 at the end of this term…

SECTION 3-8
Stages of a cell’s life cycle include interphase, mitosis and cytokinesis
Cell Division

Cell division is the reproduction of cells

- **Mitosis** is the nuclear division of somatic cells
- **Meiosis** produces sex cells (Chapter 28)

**Apoptosis** is the genetically controlled death of cells
Interphase Has Four Parts

Most somatic cells spend the majority of their lives in **interphase**

- **G₁ phase** - first “gap” after mitosis
  - Growth, metabolism, everyday activities

- **S phase** - synthesis
  - Synthesis of DNA, histone synthesis

- **G₂ phase** - second “gap” after mitosis
  - Growth, prepare for mitosis

- **G₀ phase** - withdraw from cell cycle
  - E.g. nerve cells, heart muscle cells

DNA Replication

**A = T**

**G = C**
Mitosis

a.k.a. Nuclear division or M phase:

- Prophase
- Metaphase
- Anaphase
- Telophase

Interphase, Mitosis, and Cytokinesis
SECTION 3-9
Several growth factors affect the cell life cycle
Some Growth Factors

M-phase promoting factor (MPF)
- AKA maturation-promoting factor
- Composition:
  a) Cdc2 (cell division cycle protein 2)
  b) Cyclin
- Over time → ↑ cyclin → ↑ MPF → mitosis

Other growth factors
- Growth hormone, prolactin, nerve growth factor (NGF), epidermal growth factor (EGF), fibroblast growth factor (FGF), erythropoietin (EPO) (Pretty obvious names, eh?)

<table>
<thead>
<tr>
<th>Table 3-2</th>
<th>Chemical Factors Affecting Cell Division</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>Sources</td>
</tr>
<tr>
<td>M-phase promoting factor (MPF)</td>
<td>Forms within cytoplasm from Cdc2 and cyclin</td>
</tr>
<tr>
<td>Growth hormone</td>
<td>Anterior lobe of the pituitary gland</td>
</tr>
<tr>
<td>Prolactin</td>
<td>Anterior lobe of the pituitary gland</td>
</tr>
<tr>
<td>Nerve growth factor (NGF)</td>
<td>Salivary glands; other sources suspected</td>
</tr>
<tr>
<td>Epidermal growth factor (EGF)</td>
<td>Ductal glands; other sources suspected</td>
</tr>
<tr>
<td>Fibroblast growth factor (FGF)</td>
<td>Wide range of cells</td>
</tr>
<tr>
<td>Erythropoietin (EPO)</td>
<td>Kidneys (primary source)</td>
</tr>
<tr>
<td>Thymagens and related compounds</td>
<td>Thymus</td>
</tr>
<tr>
<td>Cholones</td>
<td>Many tissues</td>
</tr>
</tbody>
</table>

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Number of Mitotic Divisions

May be regulated by *telomeres*

- DNA + proteins at ends of chromosomes
- Formed by *telomerase* (not DNA polymerase) early in life, becomes inactive by adulthood
- Contain multiple copies of TTAGGG
- Bend to form caps on chromosome ends
- Attach chromosomes to nuclear matrix
- Protect chromosome ends during mitosis
- Telomeres apparently wear out

This is thought to signal a repressor gene and stops cell division (and may prevent cancer)

Read sections 3-10 and 3-11 for your own edification.

No test questions on these.