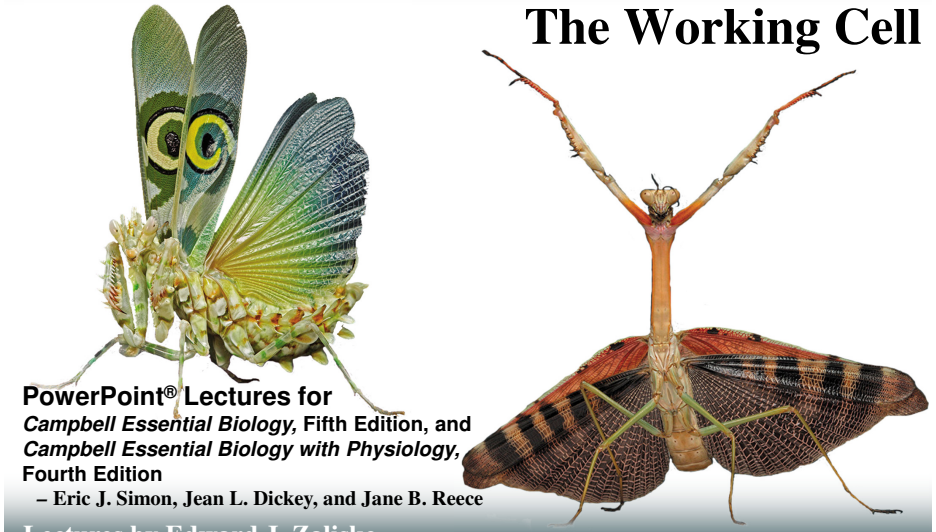
Chapter 5

The Working Cell



PowerPoint® Lectures for
***Campbell Essential Biology,* Fifth Edition, and**
Campbell Essential Biology with Physiology,
Fourth Edition
– Eric J. Simon, Jean L. Dickey, and Jane B. Reece

Lectures by Edward J. Zalisko

ALWAYS LEARNING PEARSON

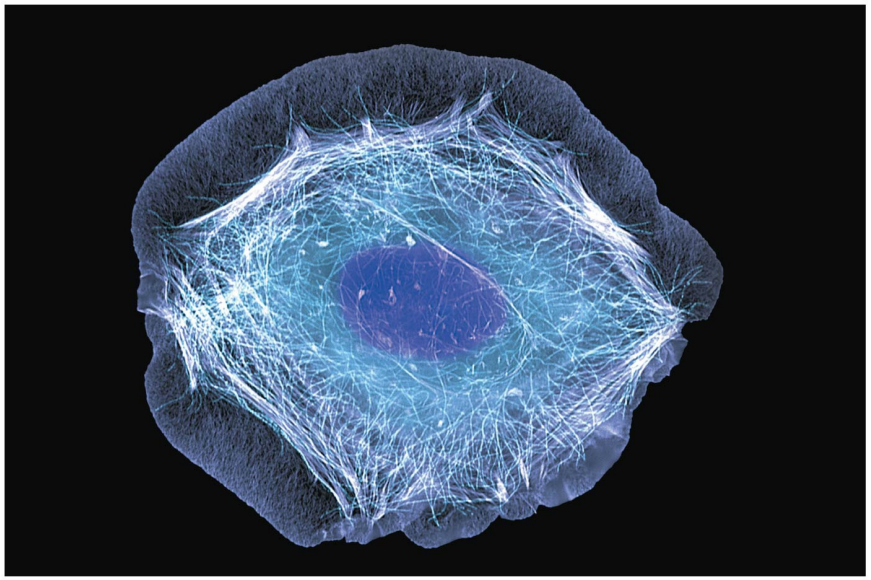
Chapter 5 Outline: The Working Cell

- Some Basic Energy Concepts
- ATP and Cellular Work
- Enzymes
- Membrane Function

Biology and Society: Harnessing Cellular Structures

- Cells control their chemical environment using
  - energy,
  - enzymes, and
  - the plasma membrane.
- Cell-based nanotechnology may be used to power microscopic robots.

Figure 5.0



Chapter 5 Outline: The Working Cell

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- **Some Basic Energy Concepts**
  - Conservation of Energy
  - Entropy
  - Chemical Energy
  - Food Calories
- ATP and Cellular Work
- Enzymes
- Membrane Function

SOME BASIC ENERGY CONCEPTS

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- Energy makes the world go around.
- But what is energy?

Conservation of Energy

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- **Energy** is defined as the capacity to cause change.
  - Some forms of energy are used to perform work.
  - Energy is the ability to rearrange a collection of matter.

Conservation of Energy

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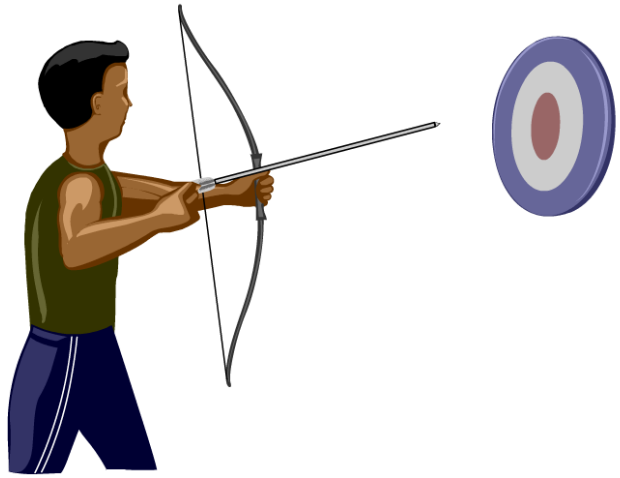
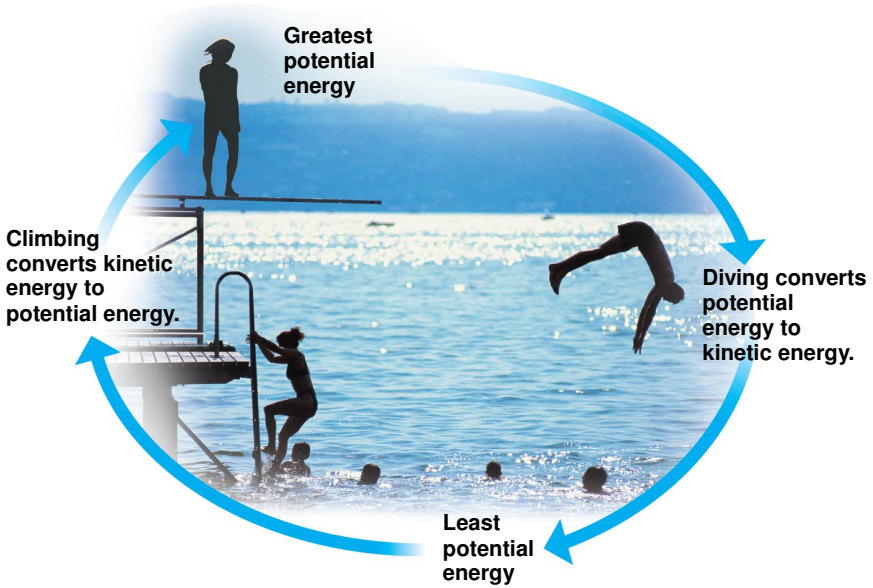
- **Kinetic energy** is the energy of motion.
- **Potential energy** is stored energy. It is energy that an object has because of its
  - location or
  - structure.



Animation: Energy Concepts

Right click slide / select “Play”

Figure 5.1



Conservation of Energy

- Machines and organisms can transform kinetic energy to potential energy and vice versa.
- In all such energy transformations, total energy is conserved.
  - Energy cannot be created or destroyed.
  - Energy can be converted from one form to another.
  - This is the principle of **conservation of energy**.

Entropy

- Every energy conversion releases some randomized energy in the form of heat.
  - In other words, no energy conversion is 100% efficient
- **Heat** is a
  - type of kinetic energy and
  - product of all energy conversions.

Entropy

- Scientists use the term **entropy** as a measure of disorder, or randomness, in a system.
- All energy conversions increase the entropy of the universe.

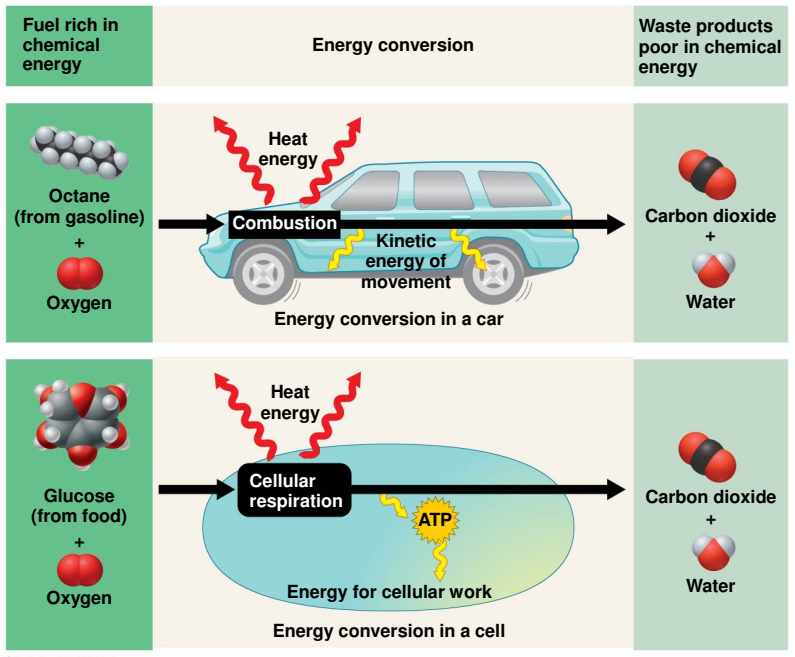
Chemical Energy

- Molecules store varying amounts of potential energy in the arrangement of their atoms.
- Organic compounds are relatively rich in such **chemical energy**.

Chemical Energy

- Chemical energy
  - arises from the arrangement of atoms and
  - can be released by a chemical reaction.
- Living cells and automobile engines use the same basic process to make chemical energy do work.

Figure 5.2



Chemical Energy

- Cellular respiration is
  - the energy-releasing chemical breakdown of fuel molecules and
  - the storage of that energy in a form the cell can use to perform work.

Chemical Energy

- Humans convert about 34% of the energy in food to useful work, such as the contraction of muscles.
- About 66% of the energy released by the breakdown of fuel molecules generates body heat.
- An average car converts about 25% of the energy in hydrocarbon fuels to move the car forward.

Food Calories

- A **calorie** is the amount of energy that can raise the temperature of one gram of water by 1 degree Celsius.
- Food Calories are kilocalories, equal to 1,000 calories.
- The energy of calories in food is burned off by many activities.

Chapter 5 Outline: The Working Cell

- Some Basic Energy Concepts
- **ATP and Cellular Work**
  - The Structure of ATP
  - Phosphate Transfer
  - The ATP Cycle
- Enzymes
- Membrane Function

ATP AND CELLULAR WORK

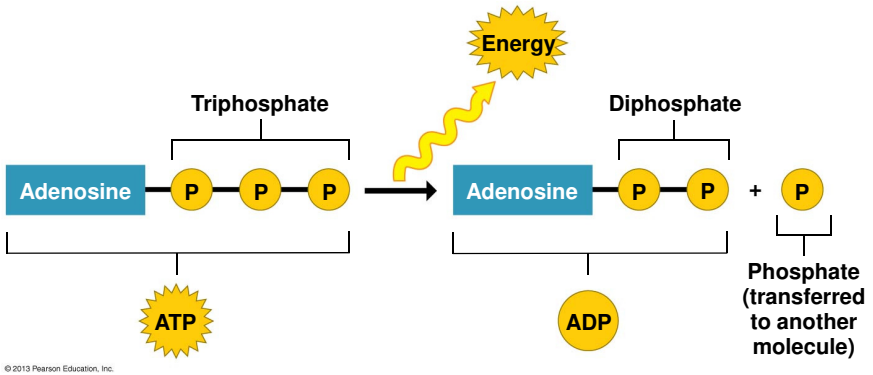
- Chemical energy is
  - released by the breakdown of organic molecules during cellular respiration and
  - used to generate molecules of ATP.
- **ATP**
  - acts like an energy shuttle,
  - stores energy obtained from food, and
  - releases it later as needed.

The Structure of ATP

- ATP (adenosine triphosphate)
  - consists of an organic molecule called adenosine plus a tail of three phosphate groups and
    - Each phosphate group is negatively charged
    - The negative charges repel each other
    - Potential energy stored in that last covalent bond
    - Energy is released when the 3rd phosphate is repelled by the negative charges causing it to move away (now kinetic energy)
    - $ATP + H_2O \rightarrow ADP + P_i$ $\Delta G^\circ = -7.3$ kcal/mol
    - $ATP + H_2O \rightarrow AMP + PP_i$ $\Delta G^\circ = -10.9$ kcal/mol
  - is broken down to ADP and a phosphate group, releasing energy

Blast Animation: Structure of ATP

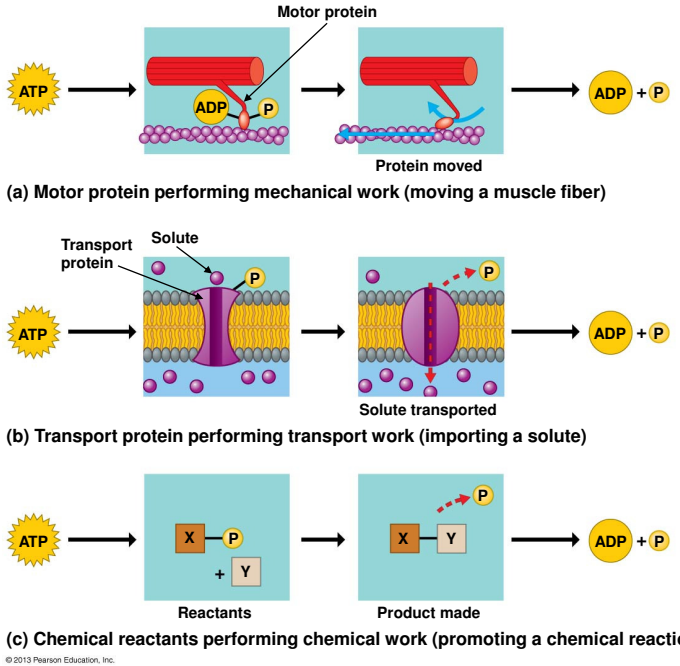
Figure 5.4



Phosphate Transfer

- ATP energizes other molecules by transferring phosphate groups.
- This energy helps cells perform
  - mechanical work,
  - transport work, and
  - chemical work.

Figure 5.5



(a) Motor protein performing mechanical work (moving a muscle fiber)

(b) Transport protein performing transport work (importing a solute)

(c) Chemical reactants performing chemical work (promoting a chemical reaction)

The ATP Cycle

- Cellular work spends ATP continuously.
- ATP is recycled from ADP and a phosphate group through cellular respiration.
- A working muscle cell spends and recycles up to 10 million ATP molecules per second.

Blast Animation: ATP/ADP Cycle

Select “Play”

Figure 5.6

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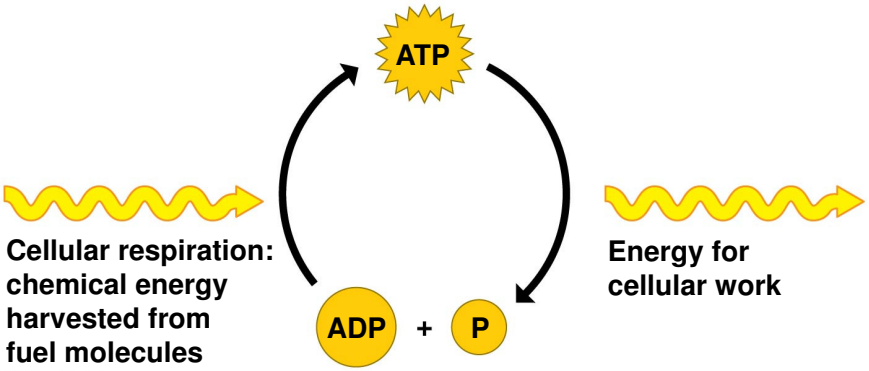

Figure 5.UN01

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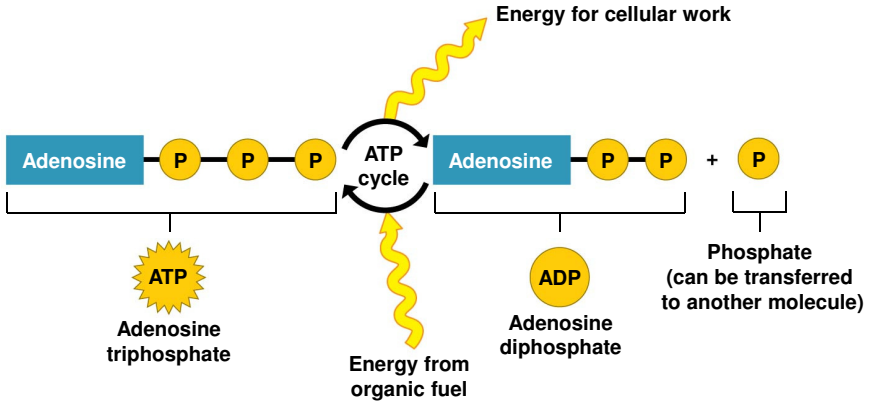

Chapter 5 Outline: The Working Cell

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- Some Basic Energy Concepts
- ATP and Cellular Work
- **Enzymes**
  - Activation Energy
  - Induced Fit
  - Enzyme Inhibitors
- Membrane Function

ENZYMES

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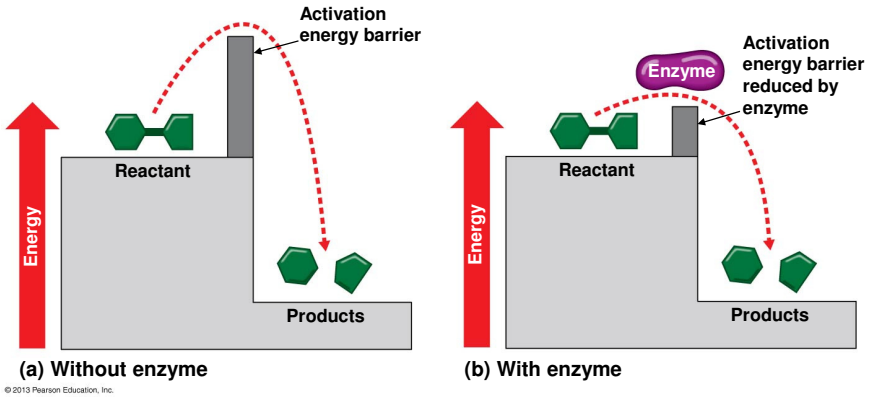
- **Metabolism** is the total of all chemical reactions in an organism.
- Most metabolic reactions require the assistance of **enzymes**, proteins that speed up chemical reactions.
  - Enzymes are catalysts which means they speed chemical reactions without being used up themselves
- All living cells contain thousands of different enzymes, each promoting a different chemical reaction.

Activation Energy

- **Activation energy**
  - activates the reactants and
  - triggers a chemical reaction.
- Enzymes reduce the amount of activation energy required to break bonds of reactant molecules.

Figure 5.7



The Process of Science: Can Enzymes Be Engineered?

- **Observation:** Genetic sequences suggest that many of [illegible] were formed through a type of molec[illegible]
- **Question:** [illegible] mimic this process thro[illegible]on?
- **Hypothesis:** [illegible]s could be used to modify the [illegible]tase into a new gene co[illegible]w function.

Induced Fit

- An enzyme is very selective in the reaction it catalyzes.
- Each enzyme recognizes a **substrate**, a specific reactant molecule.
  - The **active site** fits to the substrate, and the enzyme changes shape slightly.
  - This interaction is called **induced fit** because the entry of the substrate induces the enzyme to change shape slightly.

Induced Fit

- Enzymes can function over and over again, a key characteristic of enzymes (i.e. they are catalysts)
- Many enzymes are named for their substrates, but with an *–ase* ending.

Figure 5.9-1

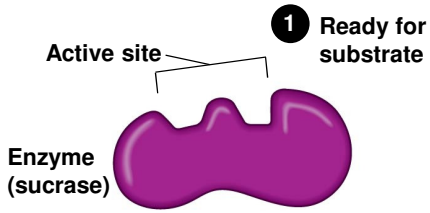


Figure 5.9-2

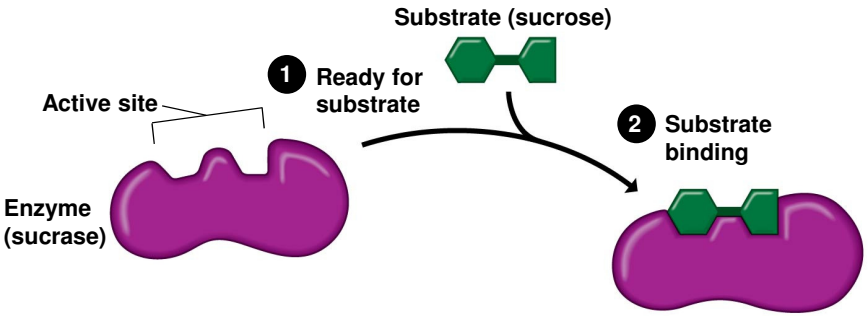


Figure 5.9-3

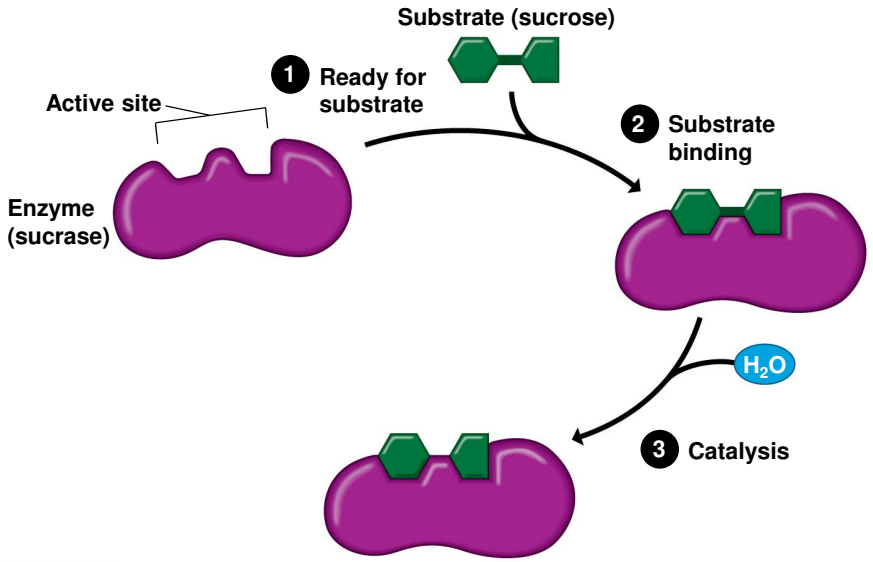


Figure 5.9-4

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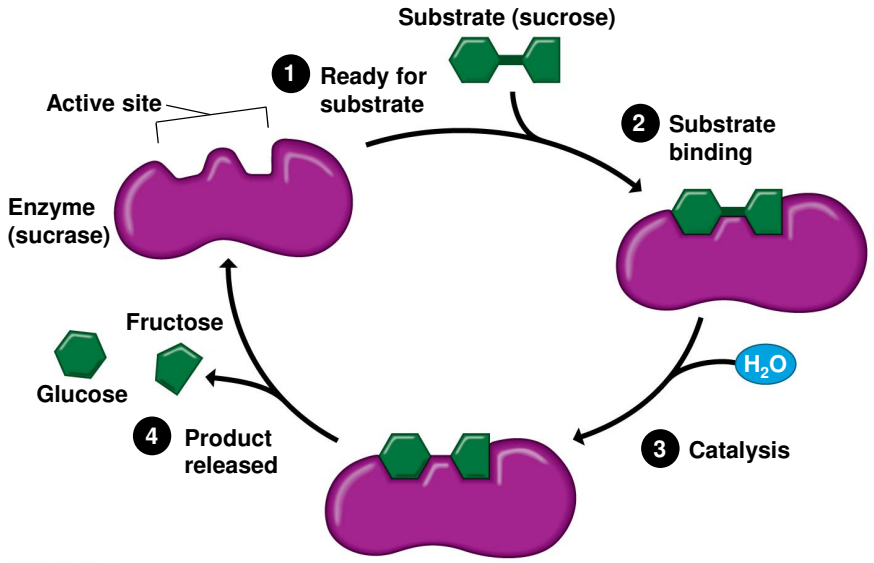

Enzyme Inhibitors

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- **Enzyme inhibitors** can prevent metabolic reactions by binding
  - to the active site or
  - near the active site, resulting in changes to the enzyme's shape so that the active site no longer accepts the substrate.

Figure 5.10

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(a) Enzyme and substrate binding normally

(b) Enzyme inhibition by a substrate imposter

(c) Inhibition of an enzyme by a molecule that causes the active site to change shape

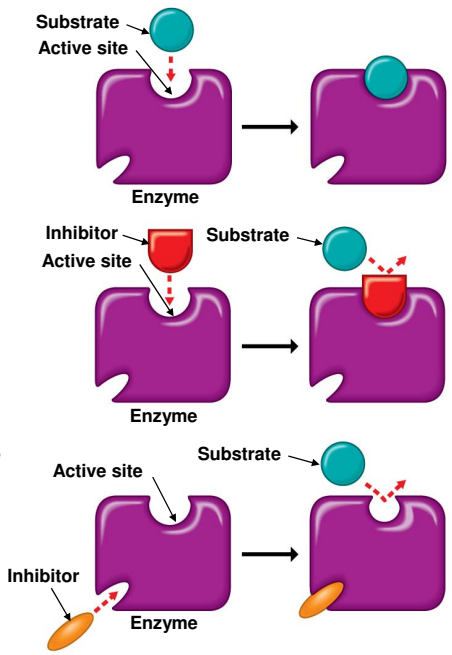

Figure 5.10a

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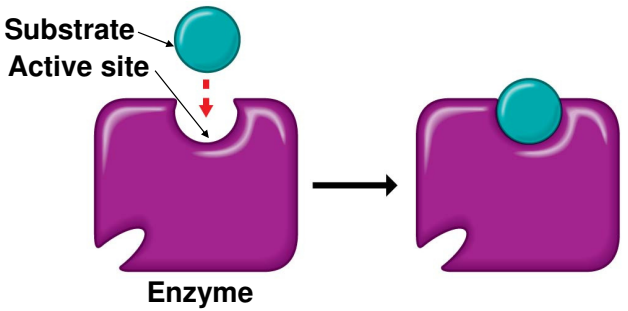
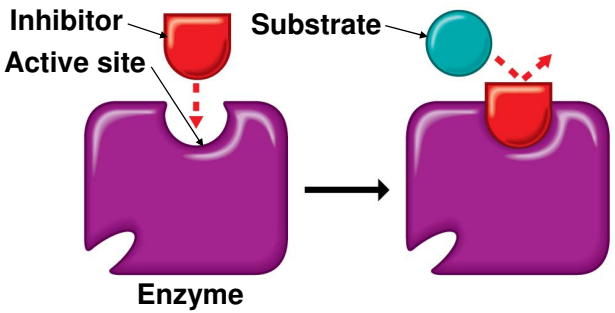


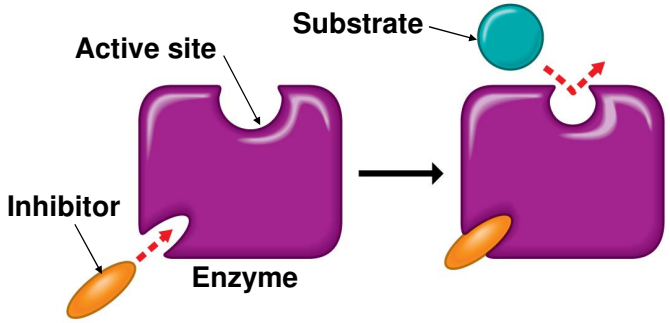
(a) Enzyme and substrate binding normally

Figure 5.10b



(b) Enzyme inhibition by a substrate imposter

Figure 5.10c



(c) Inhibition of an enzyme by a molecule that causes the active site to change shape

Enzyme Inhibitors

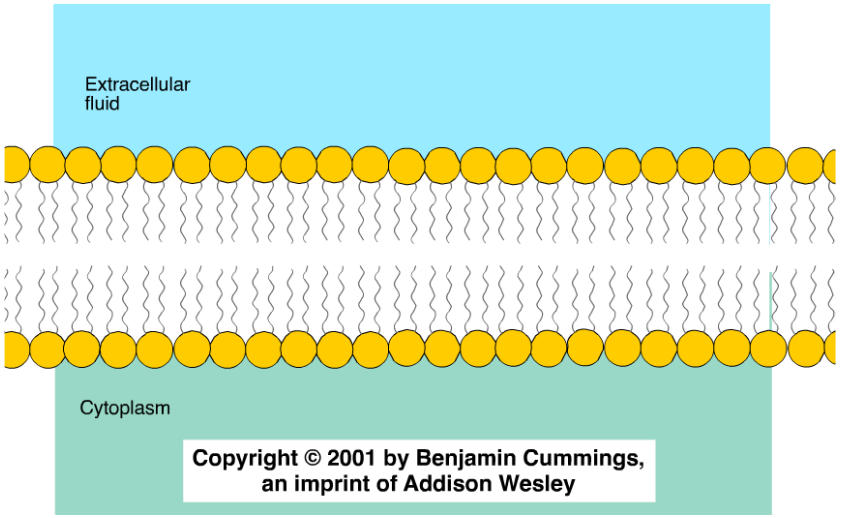
- Some products of a reaction may inhibit the enzyme required for its production.
  - This is called **feedback regulation**.
  - It prevents the cell from wasting resources.
- Many beneficial drugs work by inhibiting enzymes.
  - Penicillin blocks the active site of an enzyme that bacteria use in making cell walls.
  - Ibuprofen inhibits an enzyme involved in sending pain signals.
  - Many cancer drugs inhibit enzymes that promote cell division.

Chapter 5 Outline: The Working Cell

- Some Basic Energy Concepts
- ATP and Cellular Work
- Enzymes
- **Membrane Function**
  - Passive Transport
  - Osmosis and Water Balance
  - Active Transport
  - Exocytosis and Endocytosis
  - The Role of Membranes in Cell Signaling

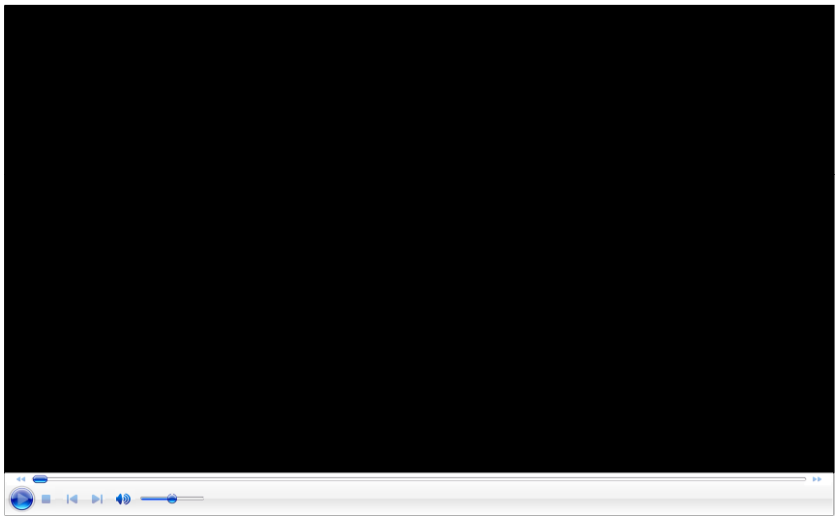
MEMBRANE FUNCTION

- Cells must control the flow of materials to and from the environment.
- Membrane proteins perform many functions.
- **Transport proteins**
  - are located in membranes and
  - help move substances across a cell membrane.



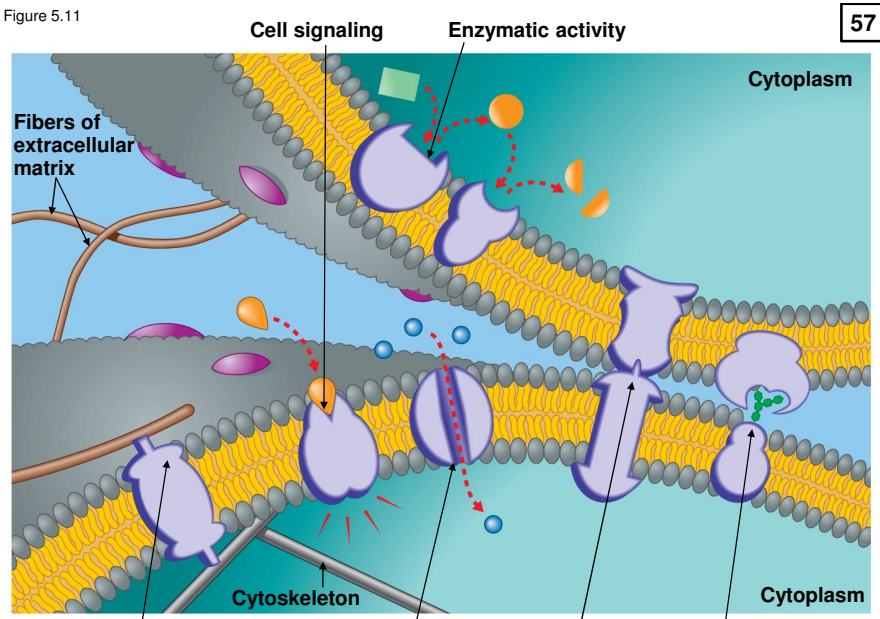
Animation: Membrane Selectivity

Right click slide / select "Play"



BioFlix Animation: Membrane Transport

Figure 5.11



Passive Transport: Diffusion across Membranes

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- Molecules contain heat energy that causes them to vibrate and wander randomly.
- **Diffusion** is the movement of molecules so that they spread out evenly into the available space.

Passive Transport: Diffusion across Membranes

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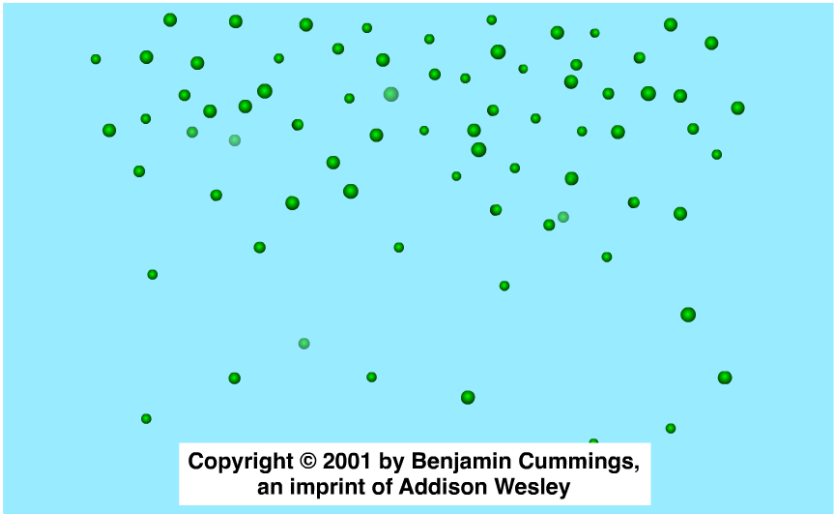
- **Passive transport** is the diffusion of a substance across a membrane without the input of energy.
- Cell membranes are selectively permeable, allowing only certain substances to pass.
- Substances diffuse down their **concentration gradient**, a region in which the substance's density changes
  - "Down the concentration gradient" means going from higher concentration to lower concentration
  - Concentration is equivalent to density of a particular substance in a liquid. Thus it is the amount of one substance in a particular volume

60



Blast Animation: Diffusion

Right click slide / select "Play"

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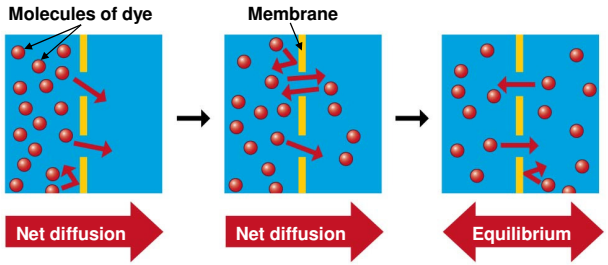
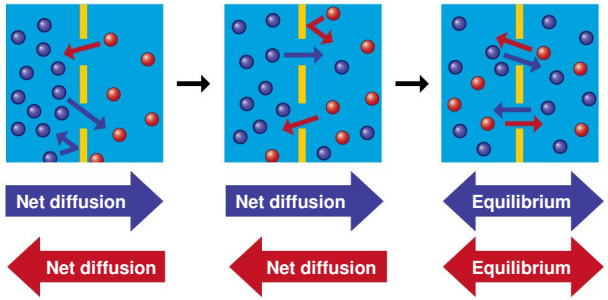
Blast Animation: Passive Diffusion Across a Membrane

Figure 5.12



(a) Passive transport of one type of molecule



(b) Passive transport of two types of molecules

Passive Transport: Diffusion across Membranes

- Some substances do not cross membranes spontaneously or cross slowly.
  - These substances can be transported via **facilitated diffusion**.
  - Specific transport proteins act as selective corridors.
  - No energy input is needed.

Osmosis and Water Balance

- The diffusion of water across a selectively permeable membrane is **osmosis**.

Figure 5.13-1

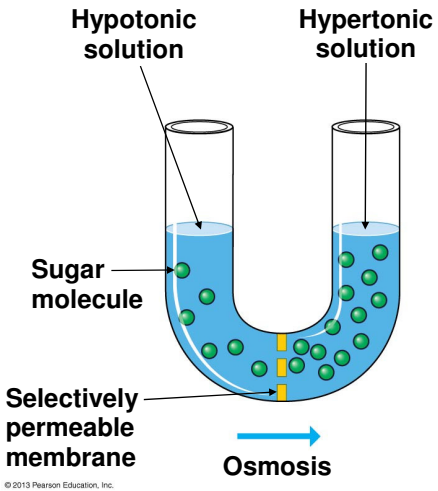
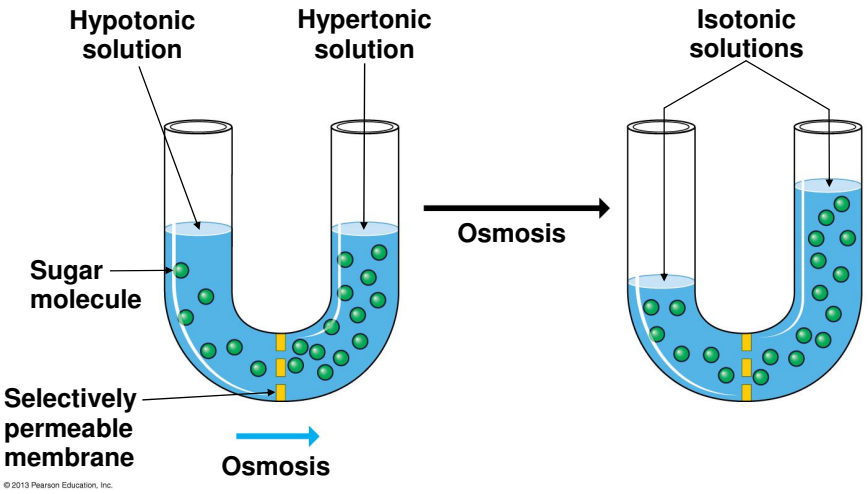


Figure 5.13-2



Osmosis and Water Balance

- Compared to another solution,
  - a **hypertonic** solution has a higher concentration of solute,
  - a **hypotonic** solution has a lower concentration of solute, and
  - an **isotonic** solution has an equal concentration of solute.
- While not entirely correct, you can think of tonicity as "saltiness"

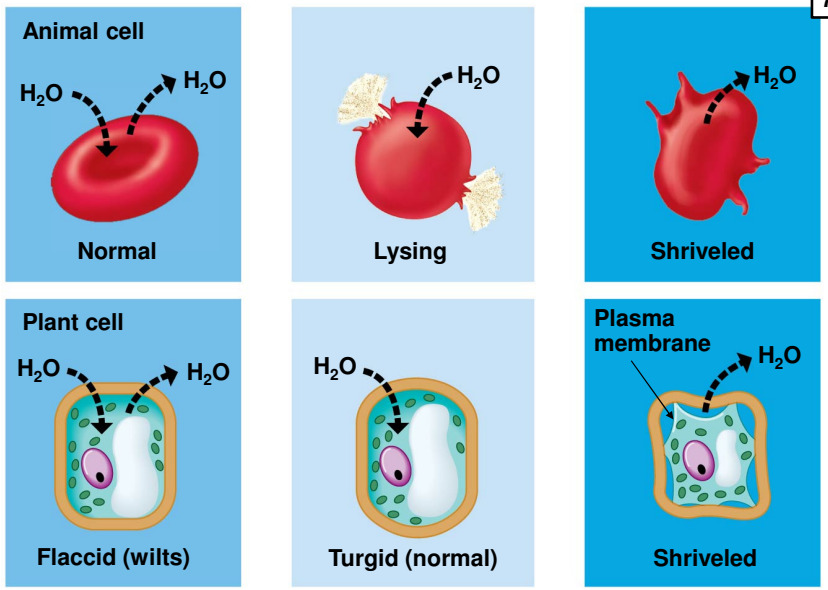
Water Balance in Animal Cells

- **Osmoregulation** is the control of water balance within a cell or organism.

Water Balance in Plant Cells

- Plants have rigid cell walls.
- Plant cells are healthiest in a hypotonic environment, which keeps their walled cells turgid.

Figure 5.14



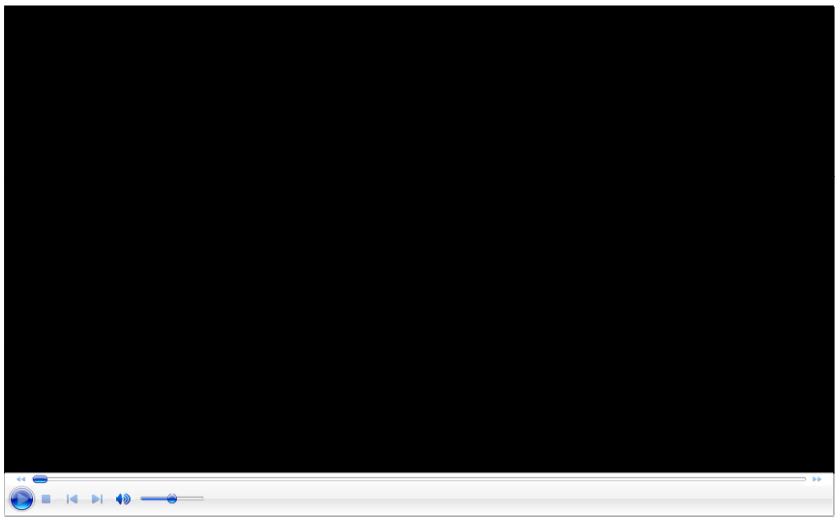
(a) Isotonic solution

(b) Hypotonic solution

(c) Hypertonic solution

Water Balance in Plant Cells

- As a plant cell loses water,
  - it shrivels and
  - its plasma membrane may pull away from the cell wall in the process of **plasmolysis**, which usually kills the cell.



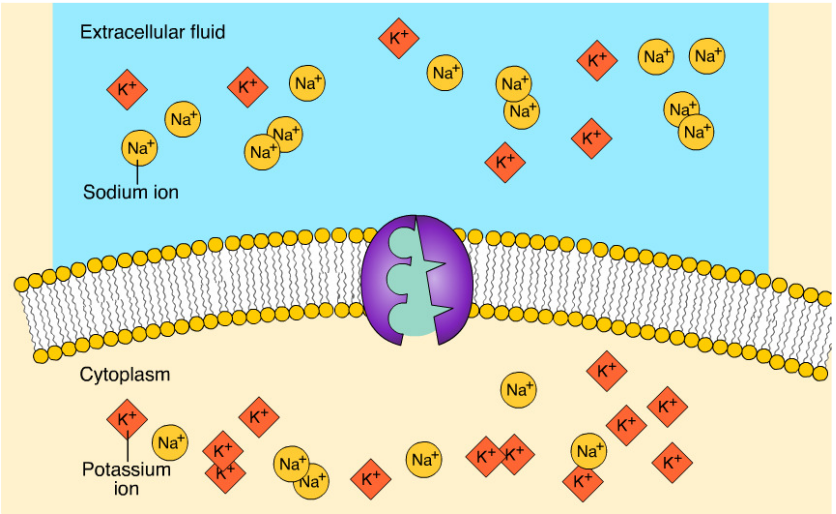
Video: Turgid Elodea

Figure 5.15

Active Transport: The Pumping of Molecules across Membranes

- **Active transport** requires that a cell expend energy to move molecules across a membrane.
  - Where does this energy come from?

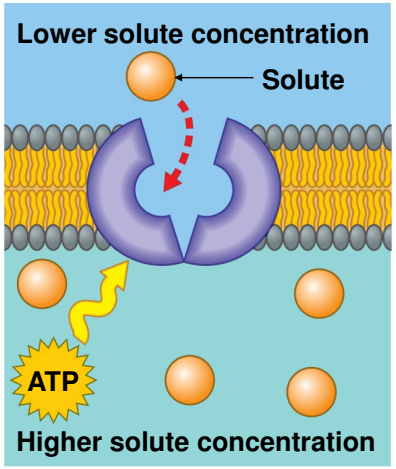
Blast Animation: Active Transport: Sodium-Potassium Pump



Animation: Active Transport

Right click slide / select "Play"

Figure 5.16-1



Active transport

Figure 5.16-2

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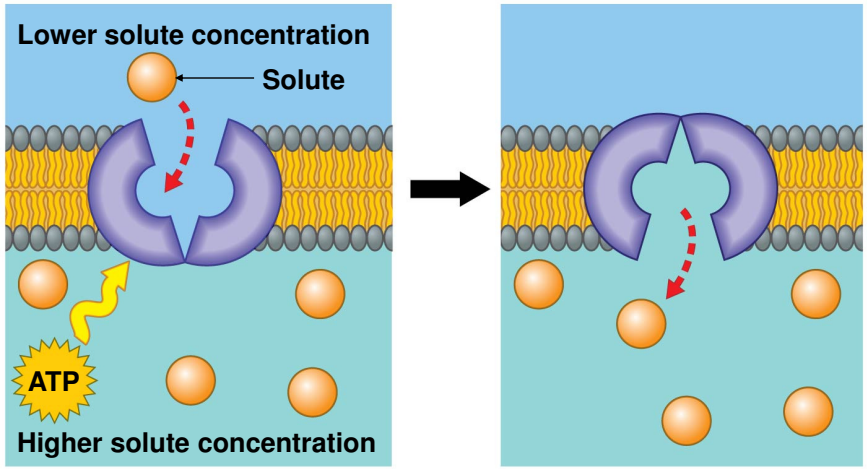
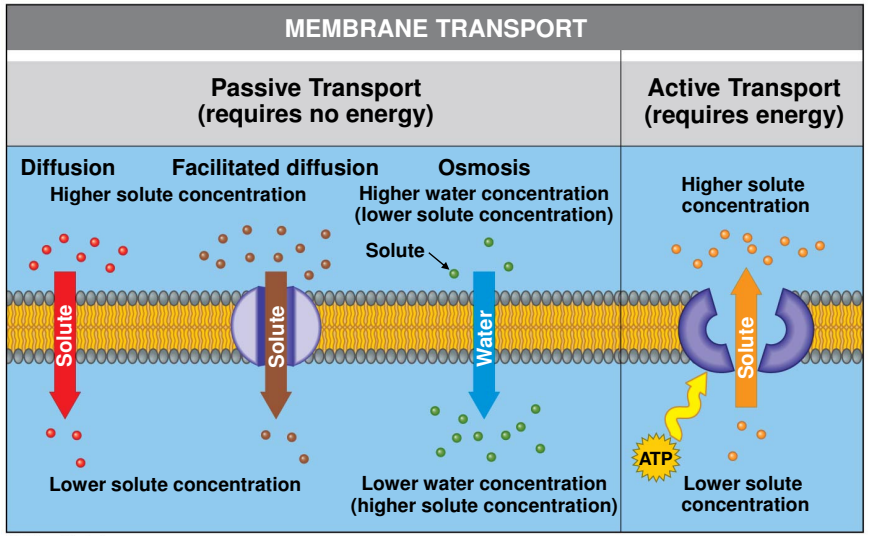


Active transport

Figure 5.UN03

98



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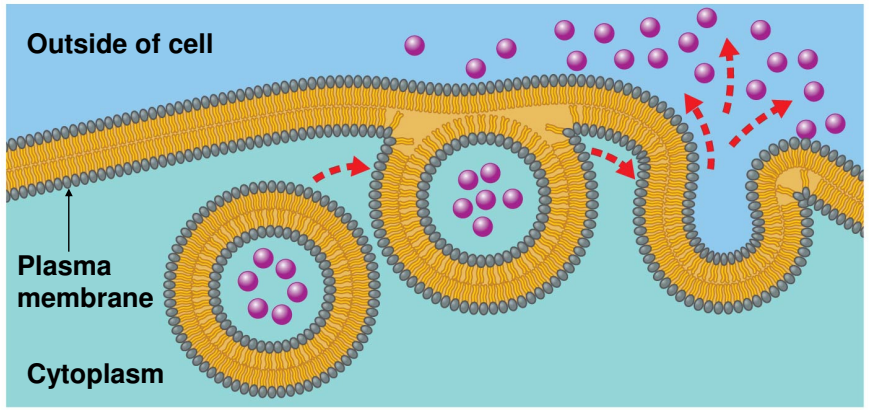
Exocytosis and Endocytosis: Traffic of Large Molecules

- **Exocytosis** is the secretion of large molecules within transport vesicles.

Figure 5.17

83



Exocytosis

Exocytosis and Endocytosis: Traffic of Large Molecules

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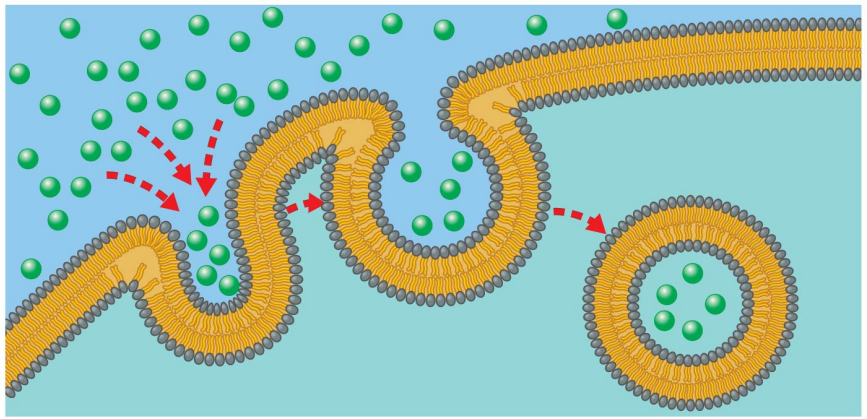
- **Endocytosis** takes material in via vesicles that bud inward from the plasma membrane.

Figure 5.18

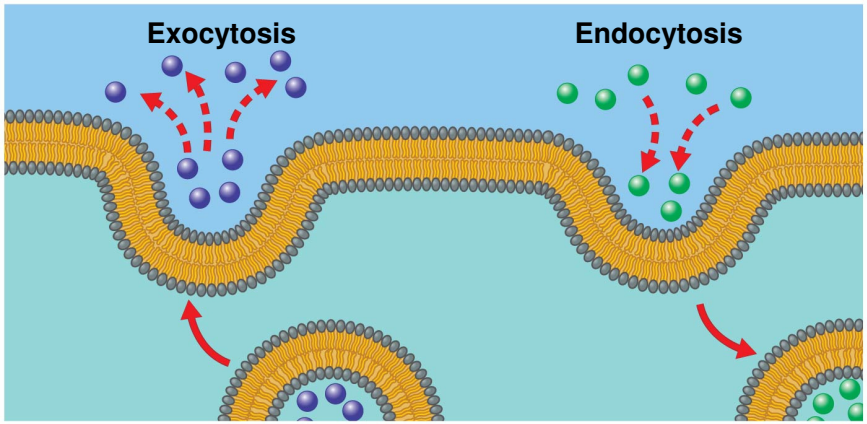
88



Endocytosis

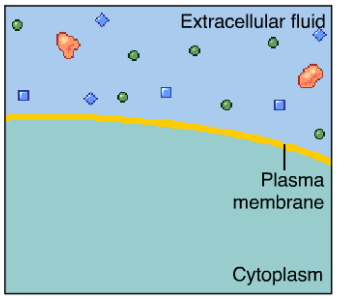
Figure 5.UN04

99



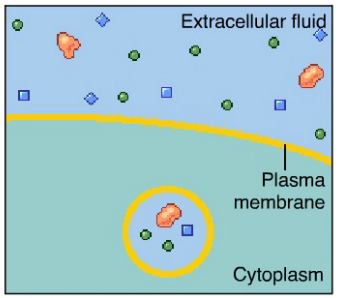
80

Blast Animation: Endocytosis and Exocytosis



Animation: Exocytosis and Endocytosis Introduction

Right click slide / select "Play"



Animation: Exocytosis

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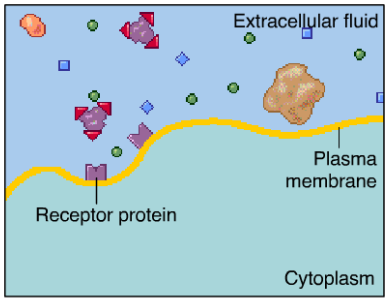
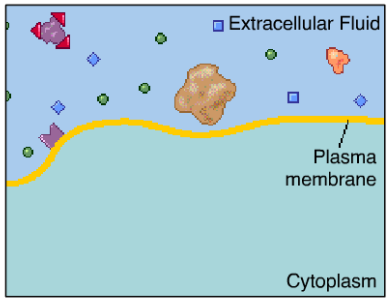


Animation: Receptor-Mediated Endocytosis

Right click slide / select "Play"

Exocytosis and Endocytosis: Traffic of Large Molecules

- In the process of **phagocytosis** ("cellular eating"), a cell engulfs a particle and packages it within a food vacuole.

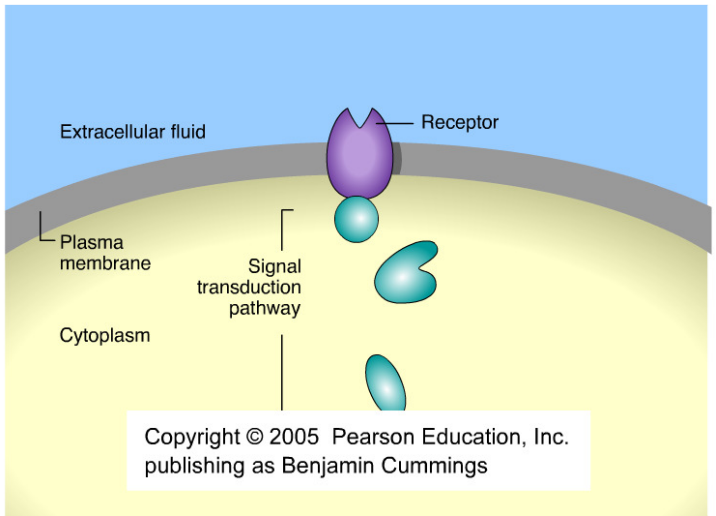


Animation: Phagocytosis

Right click slide / select "Play"

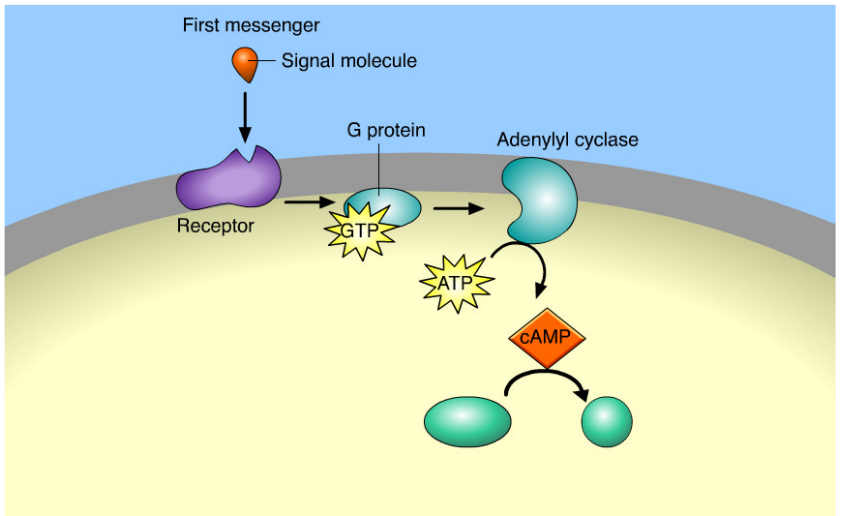
The Role of Membranes in Cell Signaling

- The plasma membrane helps convey signals
  - between cells and
  - between cells and their environment.
- Receptors on a cell surface trigger **signal transduction pathways** that
  - relay the signal and
  - convert it to chemical forms that can function within the cell.



Animation: Overview of Cell Signaling

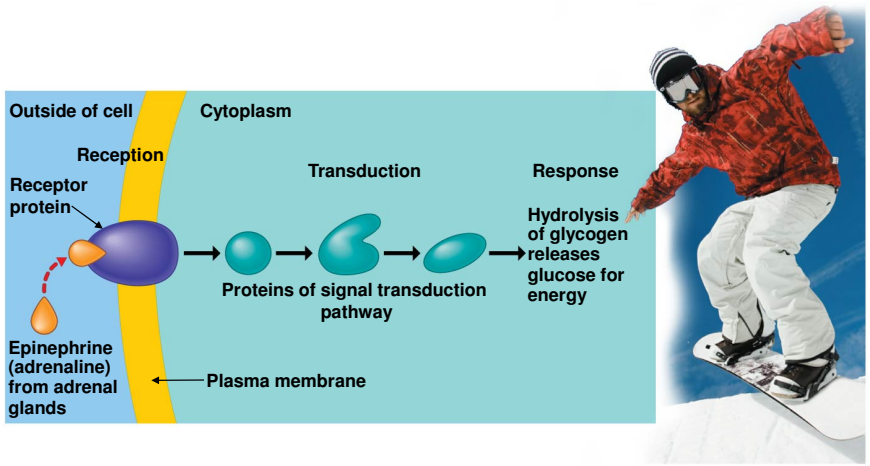
Right click slide / select "Play"



Animation: Signal Transduction Pathways

Right click slide / select "Play"

Figure 5.19



Evolution Connection: The Origin of Membranes

- Phospholipids
  - are key ingredients of membranes,
  - were probably among the first organic compounds that formed from chemical reactions on early Earth, and
  - self-assemble into simple membranes.

Figure 5.20