

Chapter 6: pp. 103-116

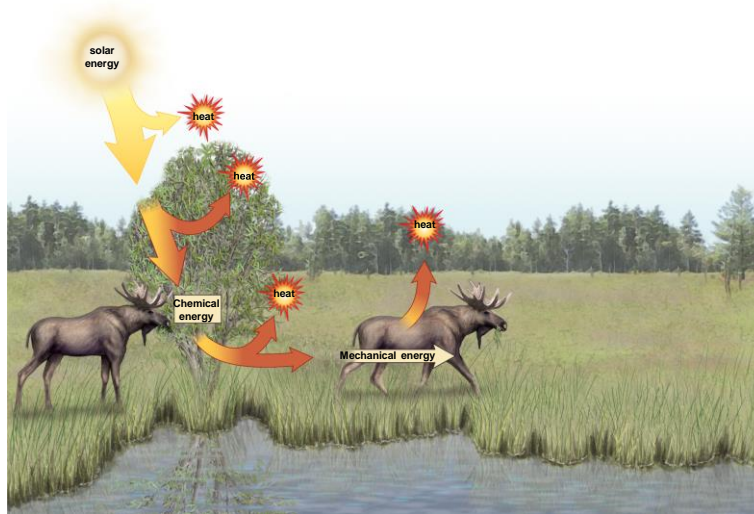
**BIOLOGY**

10th Edition

# Metabolism: Energy and Enzymes

Sylvia S. Mader

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Outline

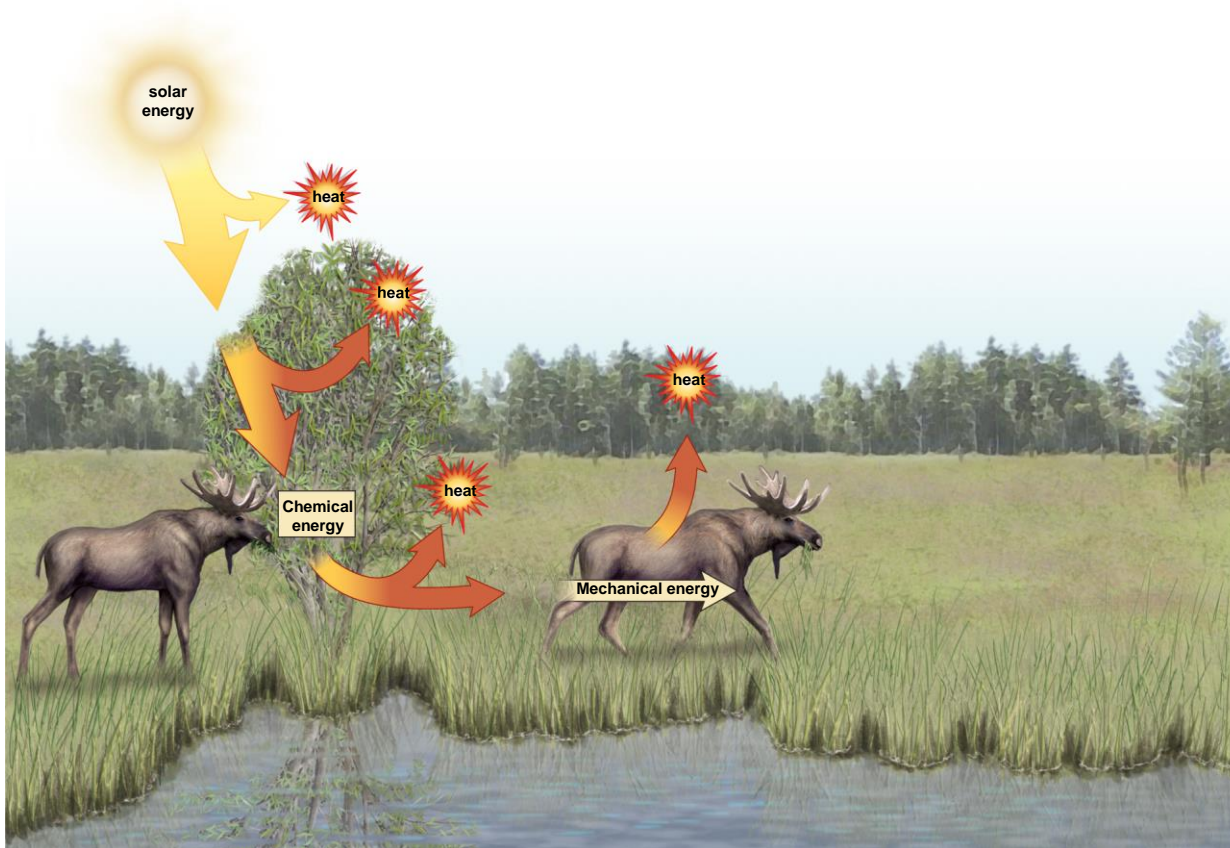
- Forms of Energy
  - Laws of Thermodynamics
- Metabolic Reactions
  - ATP
- Metabolic Pathways
  - Energy of Activation
  - Enzymes
  - Photosynthesis
  - Cellular Respiration

# Forms of Energy

- Kinetic:
  - Energy of motion
  - Mechanical
- Potential:
  - Stored energy
  - Chemical

# Flow of Energy

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Laws of Thermodynamics

- First law:

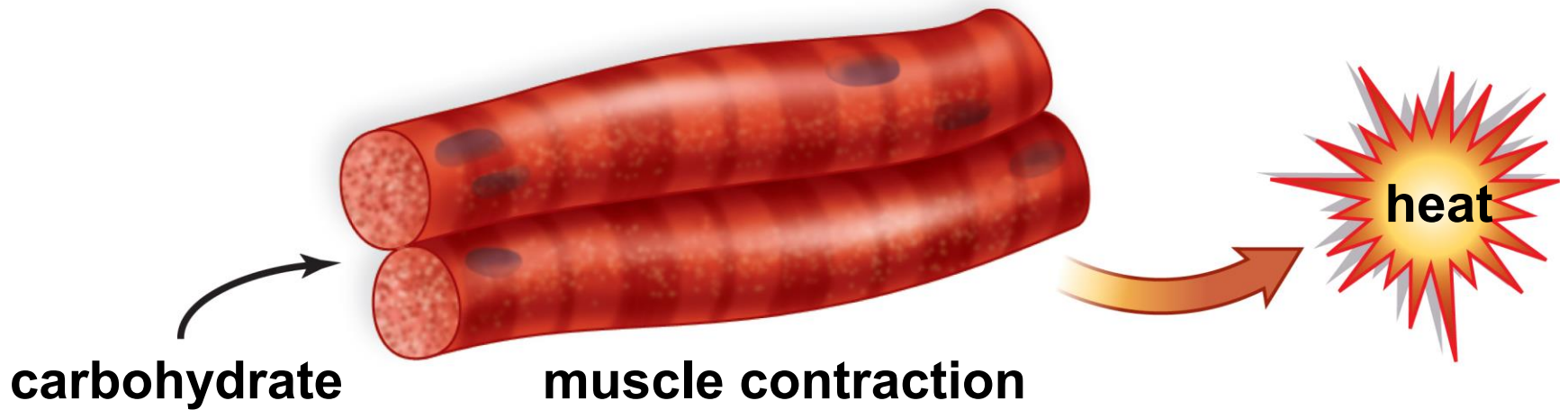
- Law of conservation of energy
- Energy cannot be created or destroyed, but
- Energy CAN be changed from one form to another

- Second law:

- Law of entropy
- When energy is changed from one form to another, there is a loss of usable energy
- Waste energy goes to increase disorder

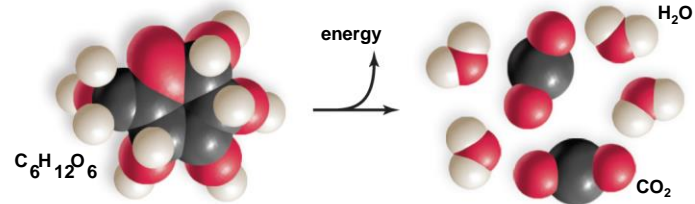
# Carbohydrate Metabolism

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Cells and Energy

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



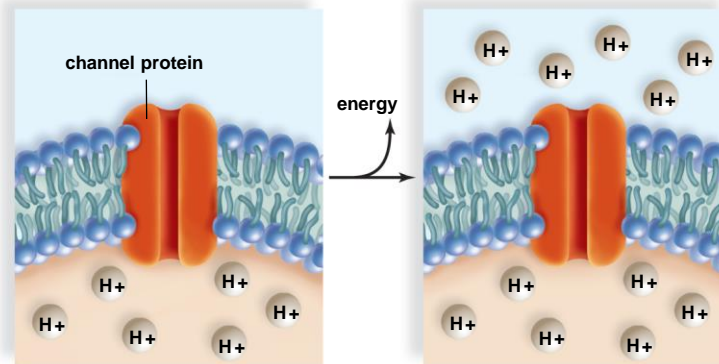
**Glucose**

- more organized
- more potential energy
- less stable (entropy)

**Carbon dioxide and water**

- less organized
- less potential energy
- more stable (entropy)

a.



**Unequal distribution  
of hydrogen ions**

- more organized
- more potential energy
- less stable (entropy)

**Equal distribution  
of hydrogen ions**

- less organized
- less potential energy
- more stable (entropy)

b.

# Metabolic Reactions and Energy Transformations

- Metabolism:
  - Sum of cellular chemical reactions in cell
  - Reactants participate in reaction
  - Products form as result of reaction
- Free energy is the amount of energy available to perform work
  - Exergonic Reactions - Products have *less* free energy than reactants
  - Endergonic Reactions - Products have *more* free energy than reactants

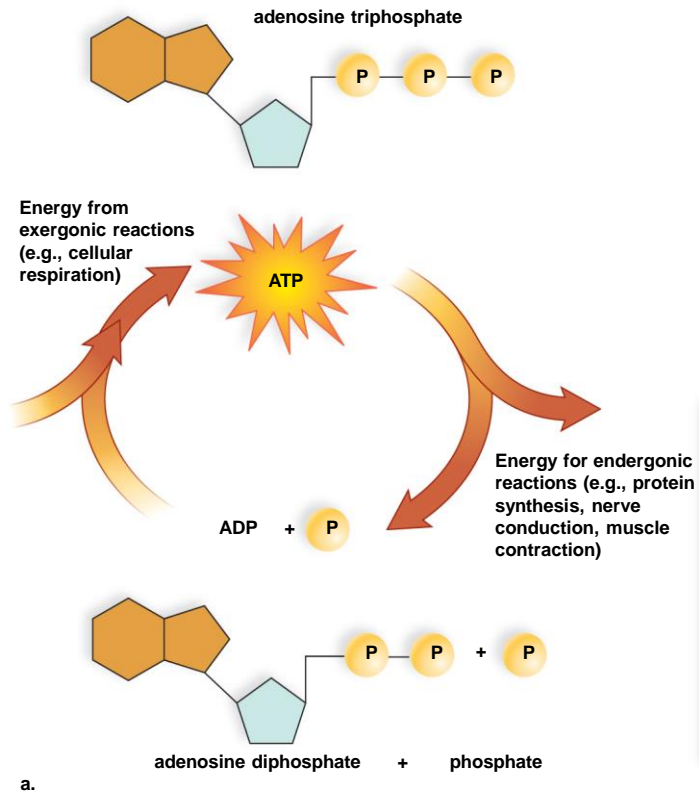


# ATP and Coupled Reactions

- Adenosine triphosphate (ATP)
  - High energy compound used to drive metabolic reactions
  - Constantly being generated from adenosine diphosphate (ADP)
- Composed of:
  - Adenine and ribose (together = adenosine), and
  - Three phosphate groups
- Coupled reactions
  - Energy released by an exergonic reaction captured in ATP
  - That ATP used to drive an endergonic reaction

# The ATP Cycle

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

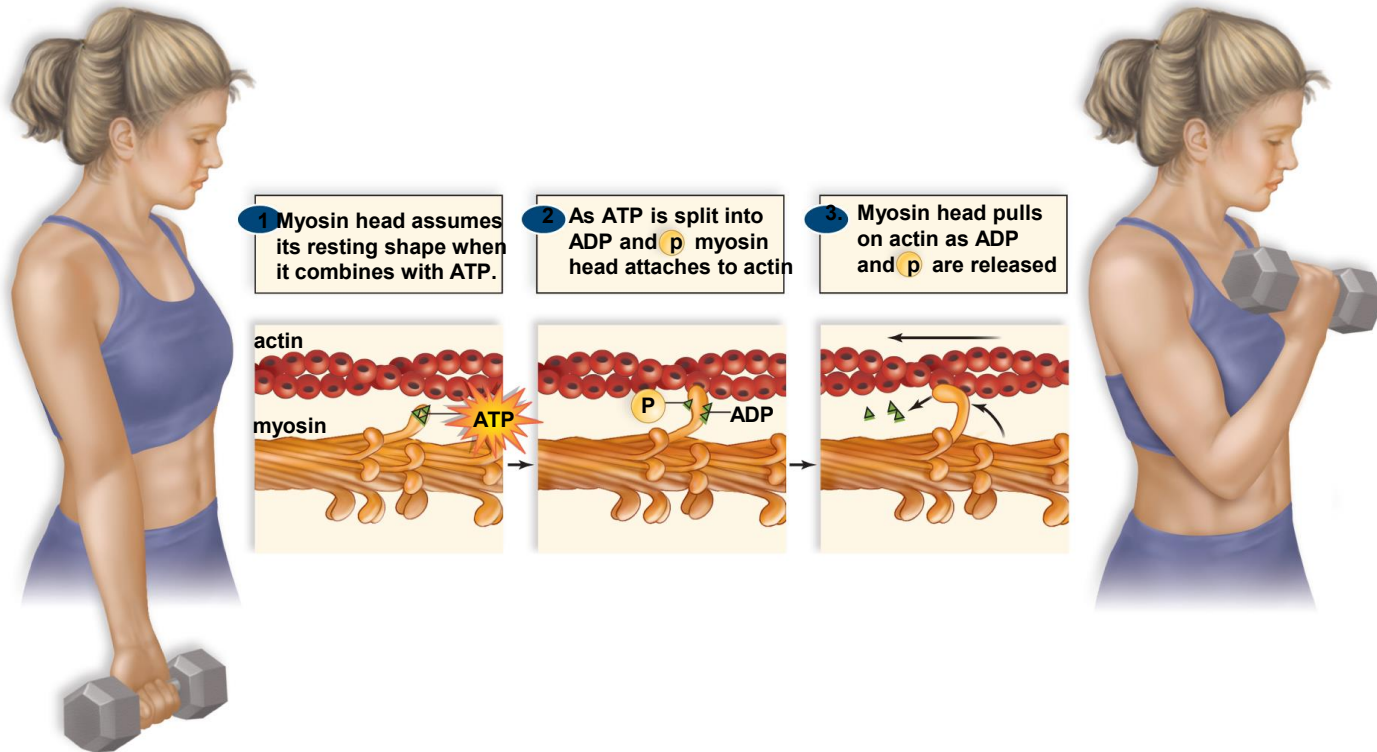


2.25×

b: © Darwin Dale/Photo Researchers, Inc.

# Coupled Reactions

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Metabolic Reactions and Energy Transformations

- Metabolism:
  - Sum of cellular chemical reactions in cell
  - Reactants participate in reaction
  - Products form as result of reaction
- Free energy is the amount of energy available to perform work
  - Exergonic Reactions - Products have *less* free energy than reactants
  - Endergonic Reactions - Products have *more* free energy than reactants

# Work-Related Functions of ATP

- Primarily to perform cellular work
  - Chemical Work - Energy needed to synthesize macromolecules
  - Transport Work - Energy needed to pump substances across plasma membrane
  - Mechanical Work - Energy needed to contract muscles, beat flagella, etc

# Metabolic Pathways

- Reactions are usually occur in a sequence
  - Products of an earlier reaction become reactants of a later reaction
  - Such linked reactions form a metabolic pathway
    - Begins with a particular reactant,
    - Proceeds through several intermediates, and
    - Terminates with a particular end product



“**A**” is Initial  
Reactant

**B, C, D, E, and F**  
are Intermediates

“**G**” is End  
Product

# Animation

**McGraw Hill** **A Biochemical Pathway**

Organisms contain many different kinds of enzymes that catalyze a variety of different reactions.

Copyright © The McGraw-Hill Companies, Inc.

# Enzymes

- Enzymes

- Protein molecules that function as catalysts
- The reactants of an enzymatically accelerated reaction are called substrates
- Each enzyme accelerates a specific reaction
- Each reaction in a metabolic pathway requires a unique and specific enzyme
- End product will not appear unless ALL enzymes present and functional





# Animation



The image shows a software interface for an animation titled "Food Pathogens and Temperature" by McGraw-Hill. The interface features a central video player window with a blue background and a single purple rod-shaped bacterium in the center. Below the video player is a control bar with buttons for "Play", "Pause", "Audio", and "Text", along with a progress slider. A text box at the bottom provides information about binary fission in microorganisms.

**McGraw Hill** **Food Pathogens and Temperature**

Microorganisms reproduce by fission; each parent cell increases in size, and then divides to form 2 daughter cells. The progression is swift; 2 become 4, 4 become 8, 8 become 16, 16 become 32, 32 become 64, and so on.

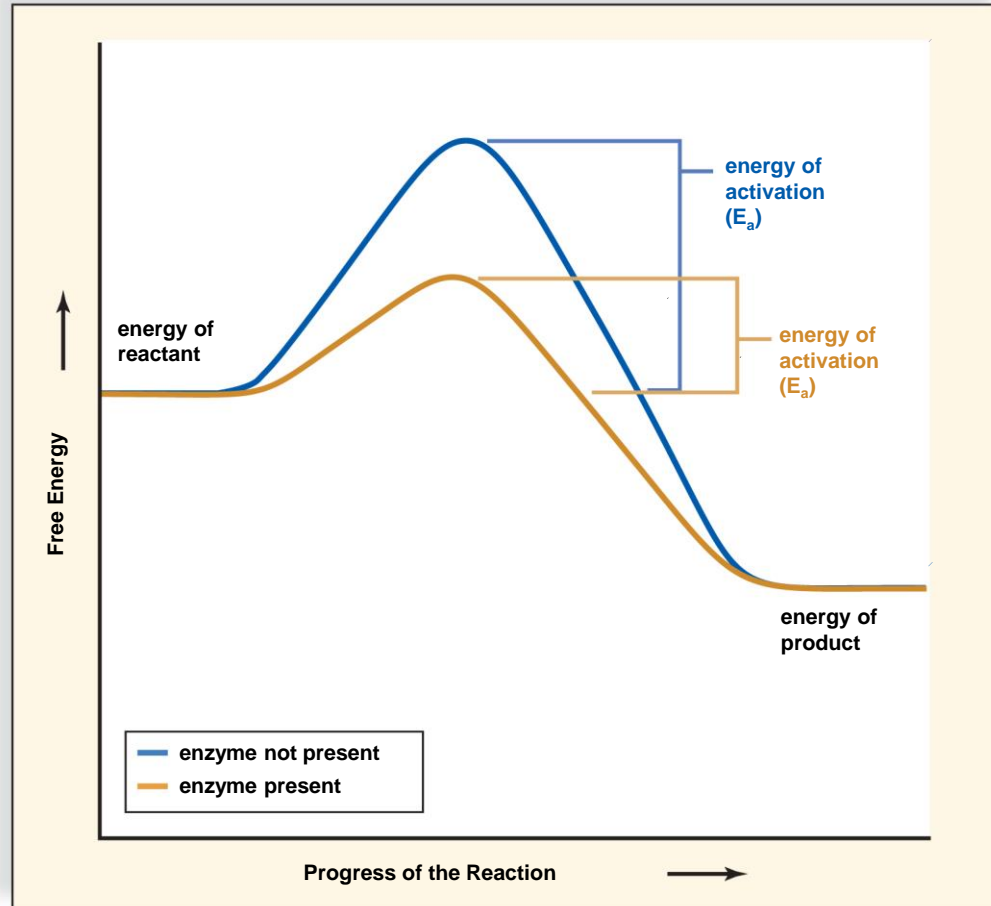
Copyright © The McGraw-Hill Companies, Inc.

# Enzymes: Energy of Activation

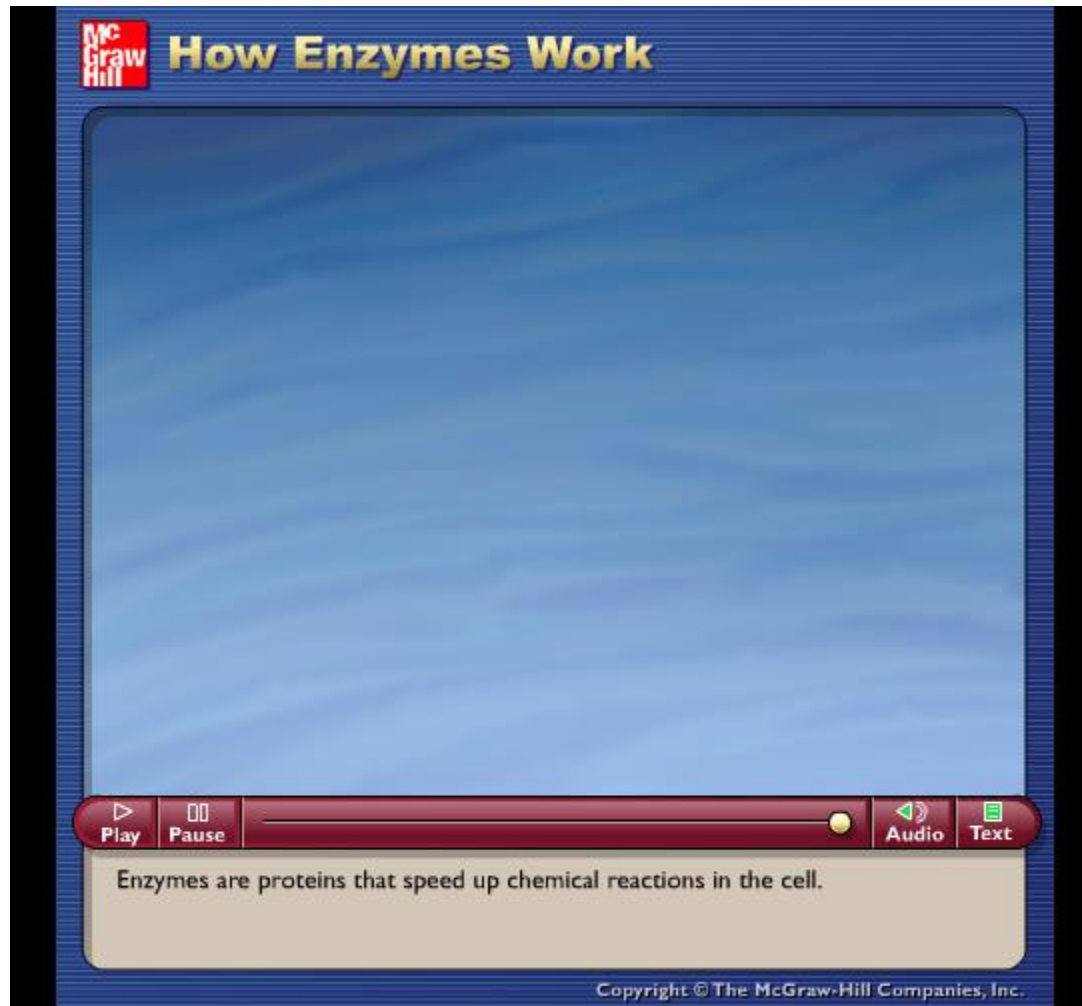
- Reactants often “reluctant” to participate in reaction
  - Energy must be added to at least one reactant to initiate the reaction
  - Energy of activation
- Enzyme Operation:
  - Enzymes operate by lowering the energy of activation
  - Accomplished by bringing the substrates into contact with one another

# Energy of Activation

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Animation




The image shows a video player interface with a blue background. At the top left is the McGraw-Hill logo. To its right, the title "How Enzymes Work" is displayed in a yellow, bold font. The main area of the player is a large, empty blue rectangle. Below this area is a red control bar containing a play button, a pause button, a progress slider with a yellow dot, an audio icon, and a text icon. At the bottom of the player, a white text box contains the sentence: "Enzymes are proteins that speed up chemical reactions in the cell." In the bottom right corner of the player, there is a small copyright notice: "Copyright © The McGraw-Hill Companies, Inc."

# Enzyme-Substrate Complex

- The active site complexes with the substrates
- Causes active site to change shape
- Shape change forces substrates together, initiating bond
- Induced fit model

# Animation

**McGraw Hill** **Enzyme Action and the Hydrolysis of Sucrose**



An example of how enzymes function in the body is from the enzyme sucrase. Sucrase resides on the surface of the microvilli on the intestinal epithelial (mucosal) cell surfaces.

Copyright © The McGraw-Hill Companies, Inc.

The image is a screenshot of an educational animation. At the top left is the McGraw Hill logo. The title 'Enzyme Action and the Hydrolysis of Sucrose' is displayed in yellow text on a blue background. The central part of the image is a detailed anatomical illustration of the human digestive system, including the liver, stomach, pancreas, and small and large intestines. Below the illustration is a control bar with 'Play', 'Pause', 'Audio', and 'Text' buttons, and a progress slider. A text box at the bottom provides an example of enzyme function, specifically mentioning sucrase on intestinal epithelial cells. The copyright notice 'Copyright © The McGraw-Hill Companies, Inc.' is located at the bottom right of the animation frame.

# Degradation vs. Synthesis

- Degradation:

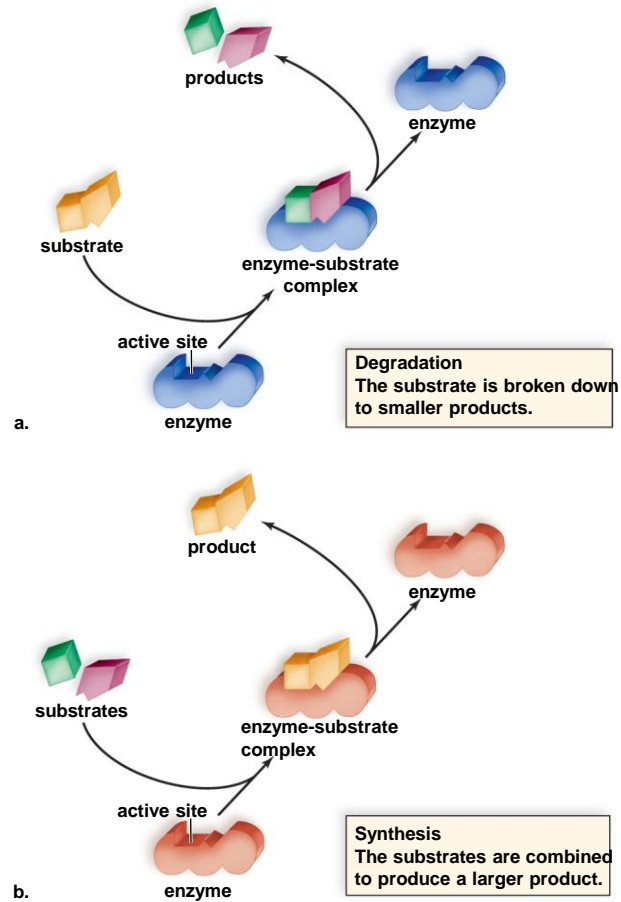
- Enzyme complexes with a single substrate molecule
- Substrate is broken apart into two product molecules

- Synthesis:

- Enzyme complexes with two substrate molecules
- Substrates are joined together and released as single product molecule

# Degradation vs. Synthesis

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.






# Factors Affecting Enzyme Activity

- Substrate concentration
  - Enzyme activity increases with substrate concentration
  - More collisions between substrate molecules and the enzyme
- Temperature
  - Enzyme activity increases with temperature
  - Warmer temperatures cause more effective collisions between enzyme and substrate
  - However, hot temperatures destroy enzyme
- pH
  - Most enzymes are optimized for a particular pH

# Animation

 **Protein Denaturation**



Protein denaturation changes the solubility of individual protein molecules, entrapping solvent water into a semisolid gel structure.

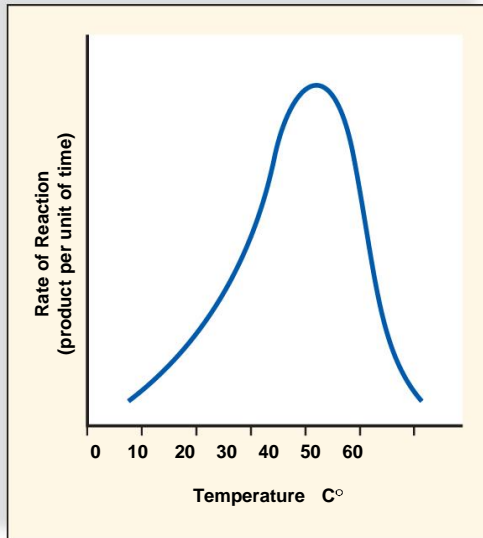
▶ Play    ⏸ Pause    ◀ Audio    📄 Text

This familiar gelatin dessert actually is a good example of the process of coagulation of proteins into a three dimensional latticework that entraps water molecules to produce a semisolid gel.

Copyright © The McGraw-Hill Companies, Inc.

# Factors Affecting Enzyme Activity: Temperature

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



a. Rate of reaction as a function of temperature



b. Body temperature of ectothermic animals often limits rates of reactions.

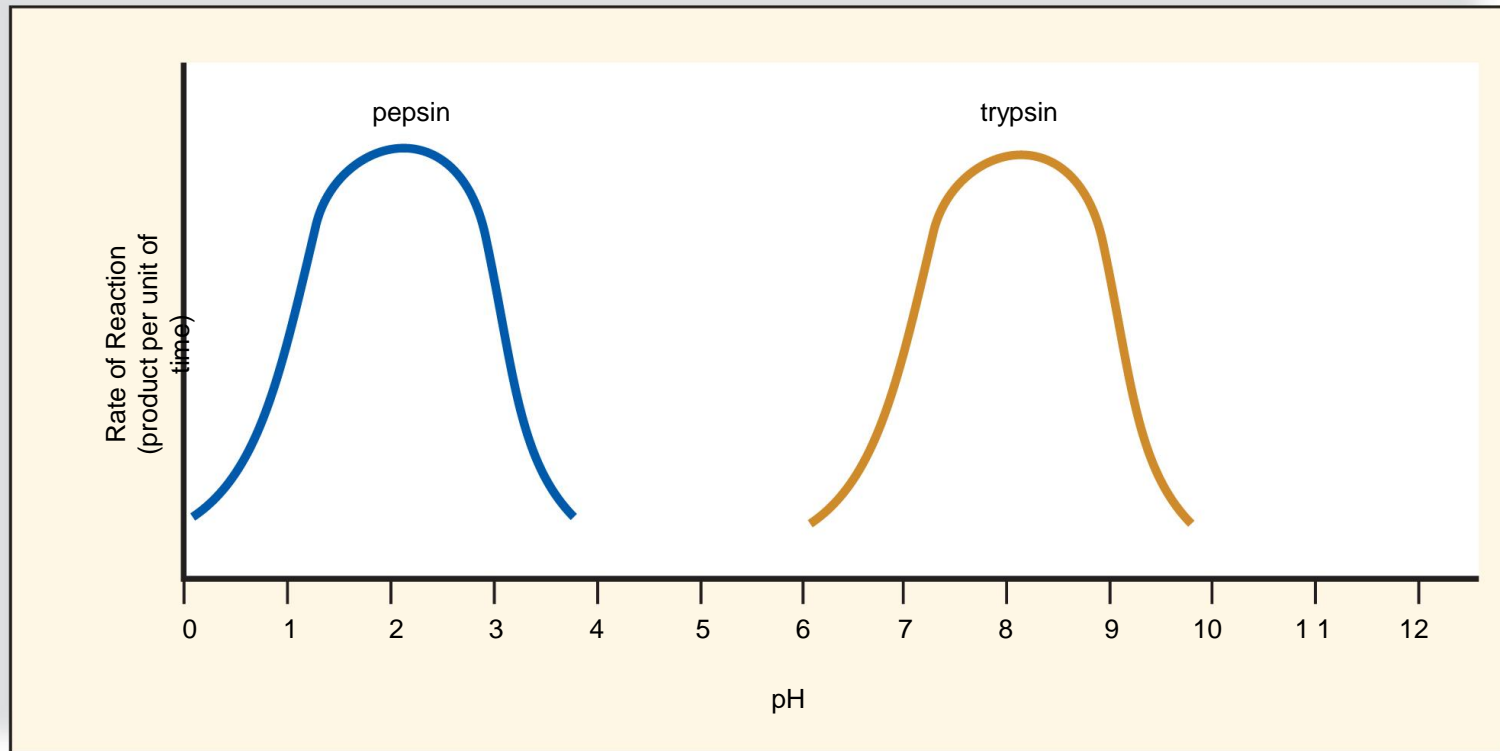


c. Body temperature of endothermic animals promotes rates of reactions.

b: © James Watt/ Visuals Unlimited; c: © Creatas/ PunchStock

# Factors Affecting Enzyme Activity: pH

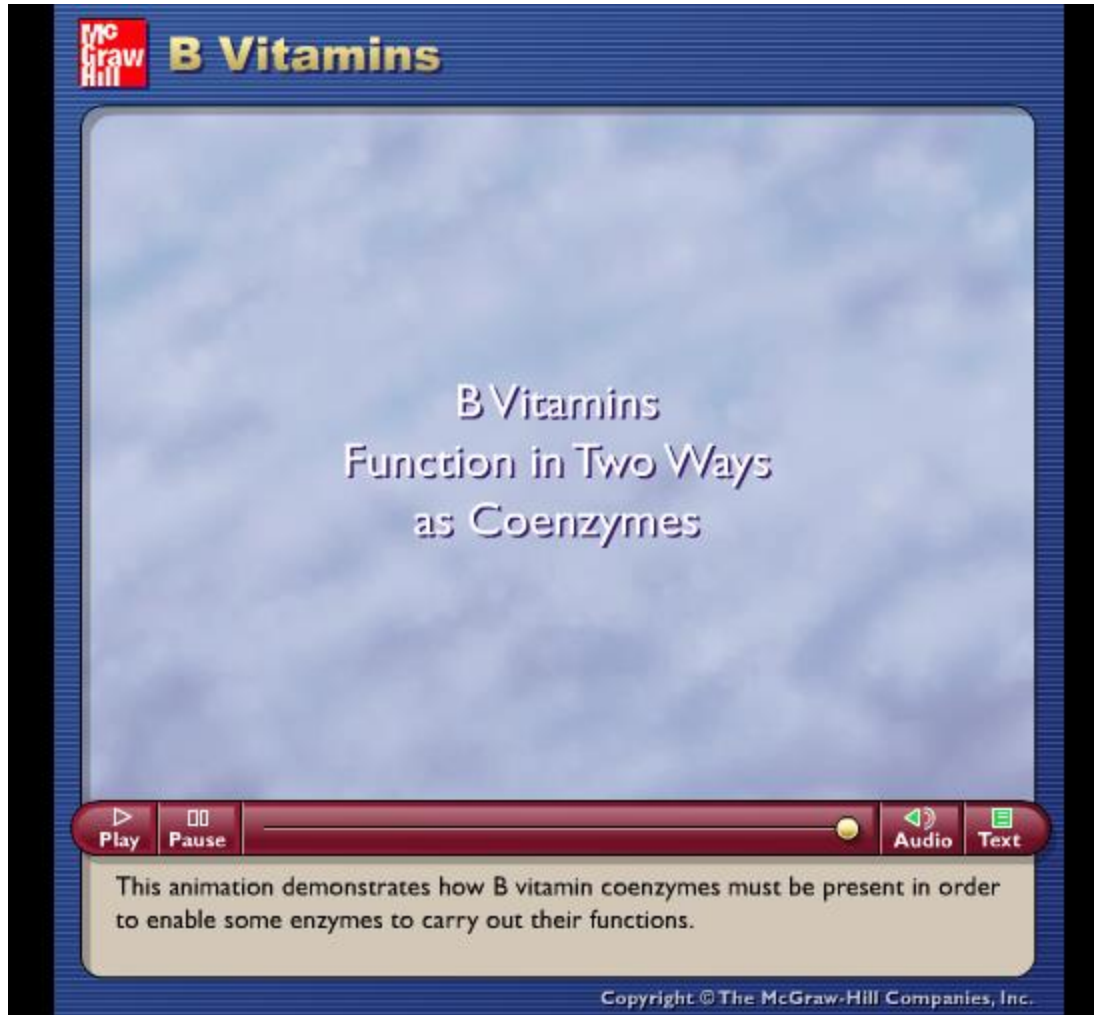
Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Factors Affecting Enzyme Activity

- Cells can affect presence/absence of enzyme
- Cells can affect concentration of enzyme
- Cells can activate or deactivate enzyme
  - Enzyme Cofactors
    - Molecules required to activate enzyme
      - Coenzymes are organic cofactors, like some vitamins
      - Phosphorylation – some require addition of a phosphate

# Animation



The image shows a software interface for an animation. At the top left is the McGraw Hill logo. To its right, the text "B Vitamins" is displayed in a bold, yellow font. The central area is a large, light blue square with a subtle, repeating pattern of the letters "B" and "V". In the center of this square, the text "B Vitamins Function in Two Ways as Coenzymes" is written in a white, serif font. Below the square is a dark red control bar containing icons for Play, Pause, a progress slider, Audio, and Text. At the bottom of the interface, a white text box contains the following text: "This animation demonstrates how B vitamin coenzymes must be present in order to enable some enzymes to carry out their functions." In the bottom right corner, there is a small copyright notice: "Copyright © The McGraw-Hill Companies, Inc."

**McGraw Hill** **B Vitamins**

B Vitamins  
Function in Two Ways  
as Coenzymes

▶ Play    ⏸ Pause        🔊 Audio    📄 Text

This animation demonstrates how B vitamin coenzymes must be present in order to enable some enzymes to carry out their functions.

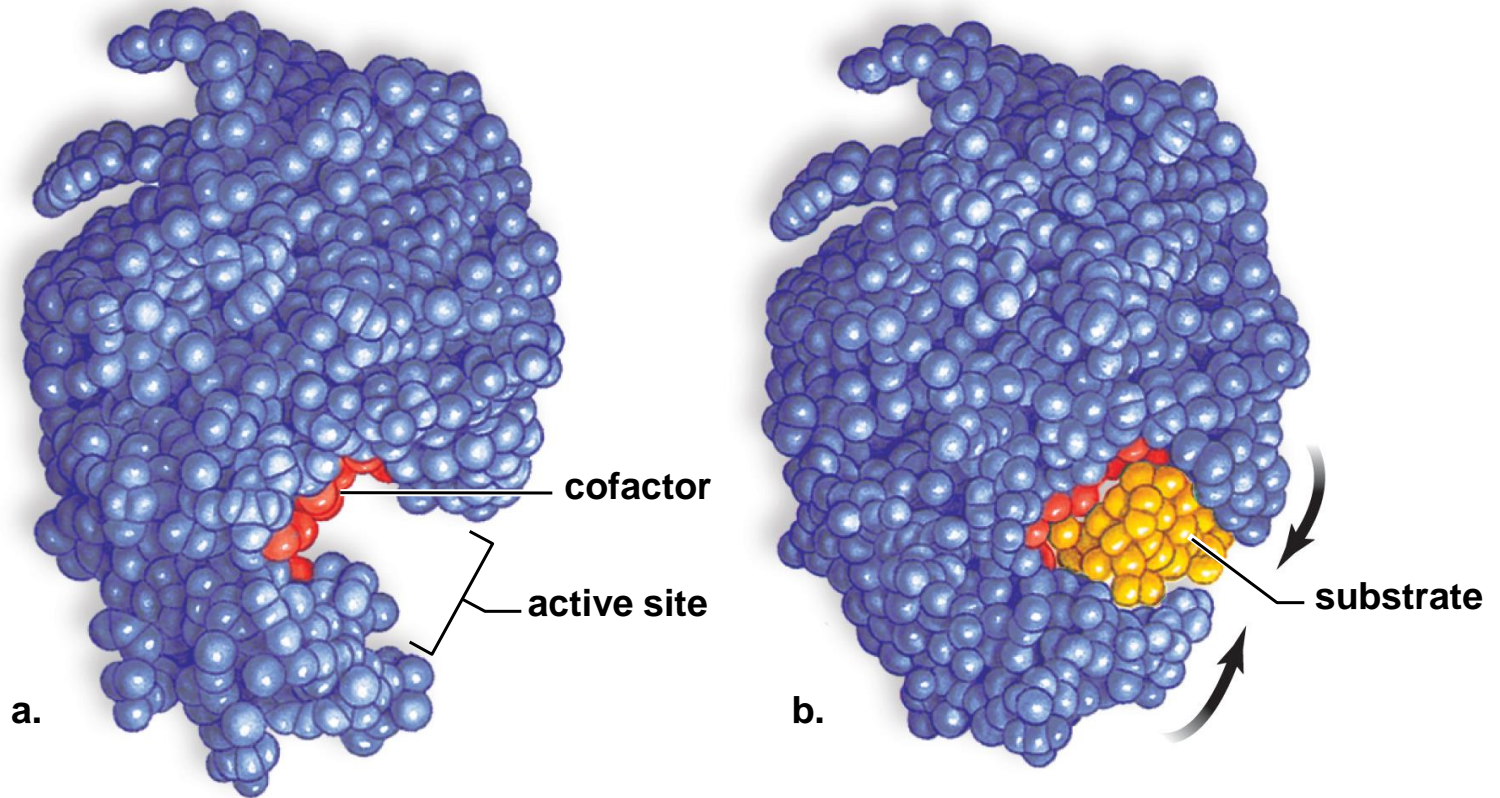
Copyright © The McGraw-Hill Companies, Inc.

# Factors Affecting Enzyme Activity

- Reversible enzyme inhibition
  - When a substance known as an inhibitor binds to an enzyme and decreases its activity
    - Competitive inhibition – substrate and the inhibitor are both able to bind to active site
    - Noncompetitive inhibition – the inhibitor binds not at the active site, but at the allosteric site
  - Feedback inhibition – The end product of a pathway inhibits the pathway's first enzyme

# Cofactor at Active Site

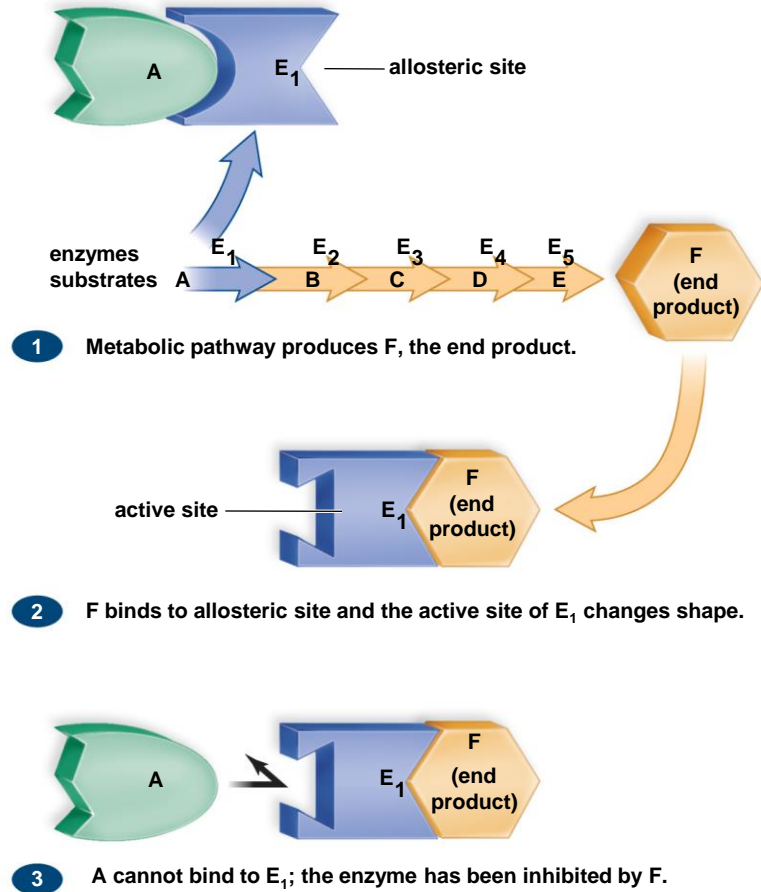
Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.






# Factors Affecting Enzyme Activity: Feedback Inhibition

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Animation

 **Feedback Inhibition of Biochemical Pathways**



▶ Play    ⏸ Pause    ◀ Audio    📄 Text

Many of the enzyme-catalyzed reactions that occur in a cell, such as those involved in the biosynthesis of an amino acid, are carried out in a specific sequence called a biochemical pathway.

Copyright © The McGraw-Hill Companies, Inc.

# Irreversible Inhibition

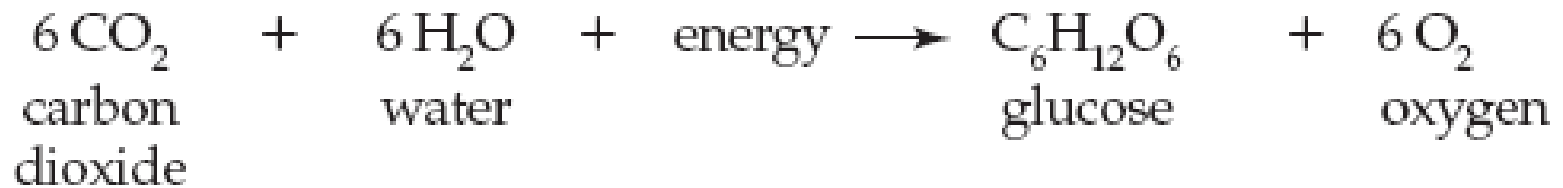
- Materials that irreversibly inhibit an enzyme are known as poisons
- Cyanides inhibit enzymes resulting in all ATP production
- Penicillin inhibits an enzyme unique to certain bacteria
- Heavy metals irreversibly bind with many enzymes
- Nerve gas irreversibly inhibits enzymes required by nervous system

# Oxidation-Reduction

- Oxidation-reduction (redox) reactions:
  - Electrons pass from one molecule to another
    - The molecule that loses an electron is oxidized
    - The molecule that gains an electron is reduced
  - Both take place at same time
  - One molecule accepts the electron given up by the other

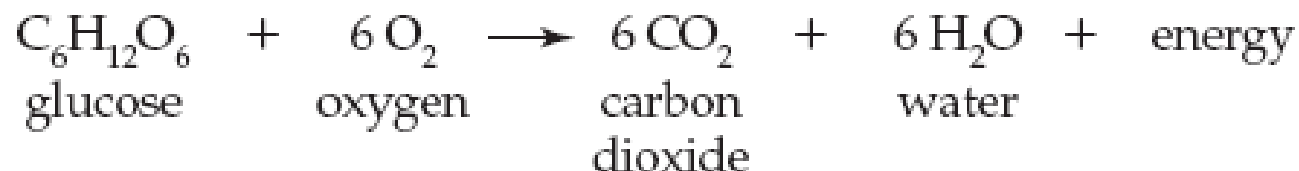
# Photosynthesis and Cellular Respiration

## Photosynthesis



## Cellular Respiration

The overall equation for cellular respiration is opposite to that for photosynthesis:

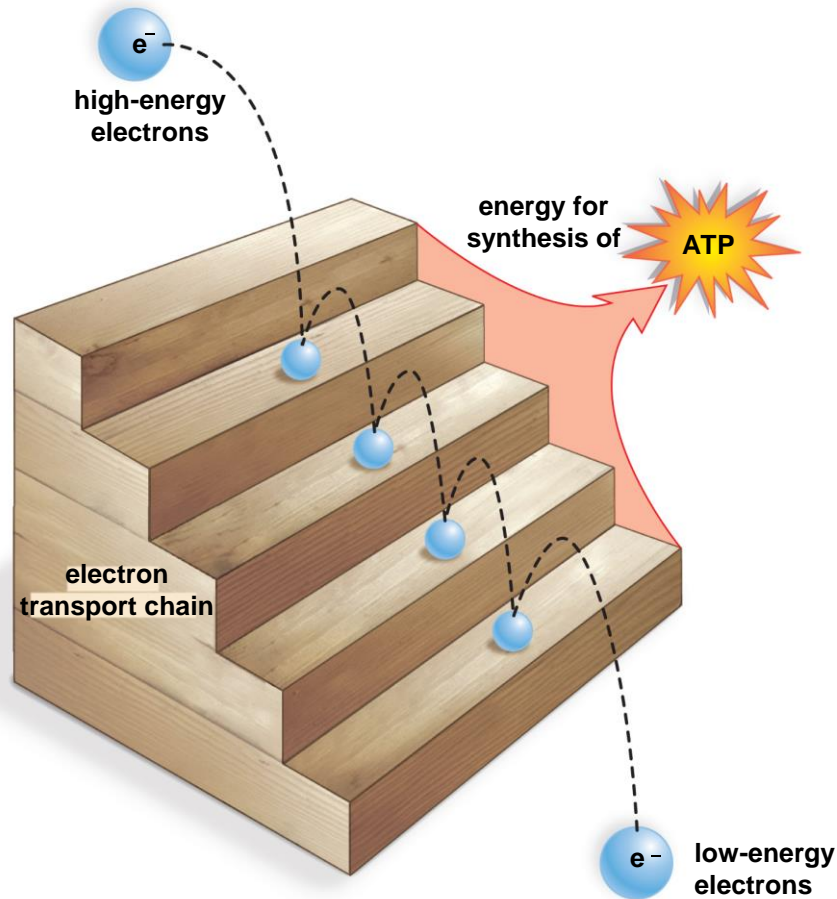


# Electron Transport Chain

- Membrane-bound carrier proteins found in mitochondria and chloroplasts
- Physically arranged in an ordered series
  - Starts with high-energy electrons and low-energy ADP
  - Pass electrons from one carrier to another
    - Electron energy used to pump hydrogen ions ( $H^+$ ) to one side of membrane
    - Establishes electrical gradient across membrane
    - Electrical gradient used to make ATP from ADP – Chemiosmosis
  - Ends with low-energy electrons and high-energy ATP

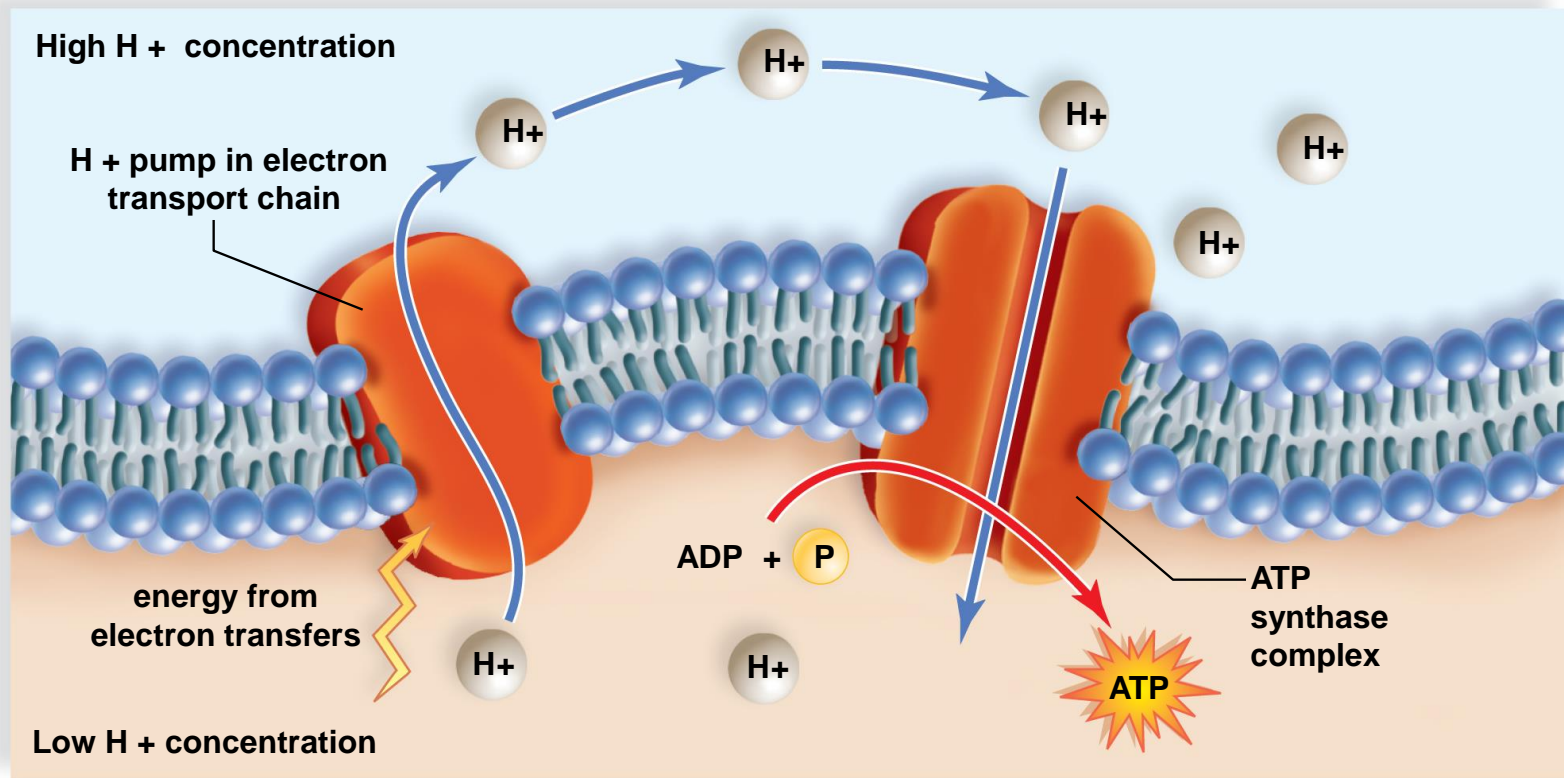
# A Metaphor for the Electron Transport Chain

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# Chemiosmosis

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.





# Review

- Forms of Energy
  - Laws of Thermodynamics
- Metabolic Reactions
  - ATP
- Metabolic Pathways
  - Energy of Activation
  - Enzymes
  - Photosynthesis
  - Cellular Respiration

Chapter 6: pp. 103-116

**BIOLOGY**

10th Edition

# Metabolism: Energy and Enzymes

Sylvia S. Mader

Insert figure 6.1 here