Metabolism: Energy and Enzymes

February 24th, 2012

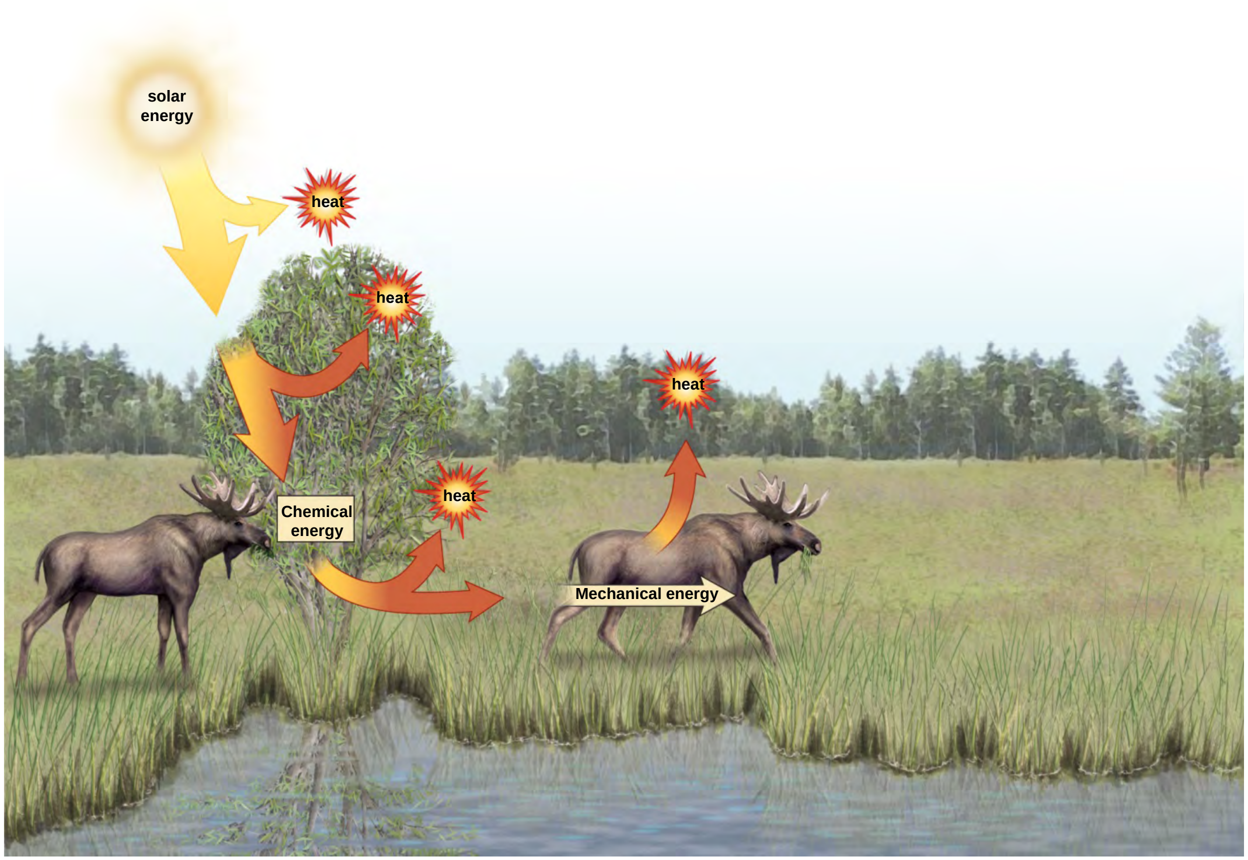
Outline

- 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

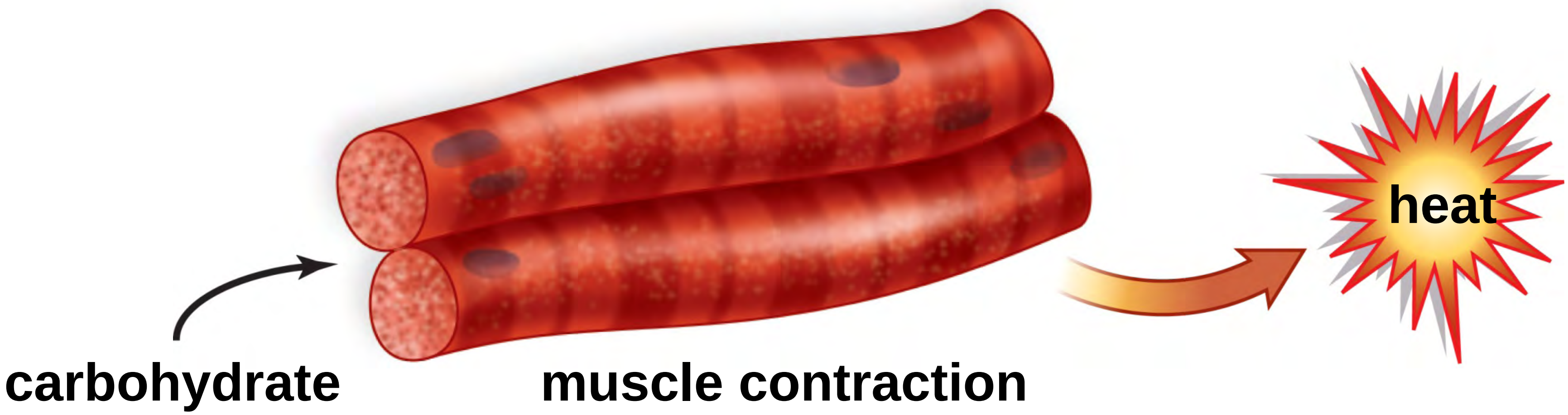
Flow of Energy



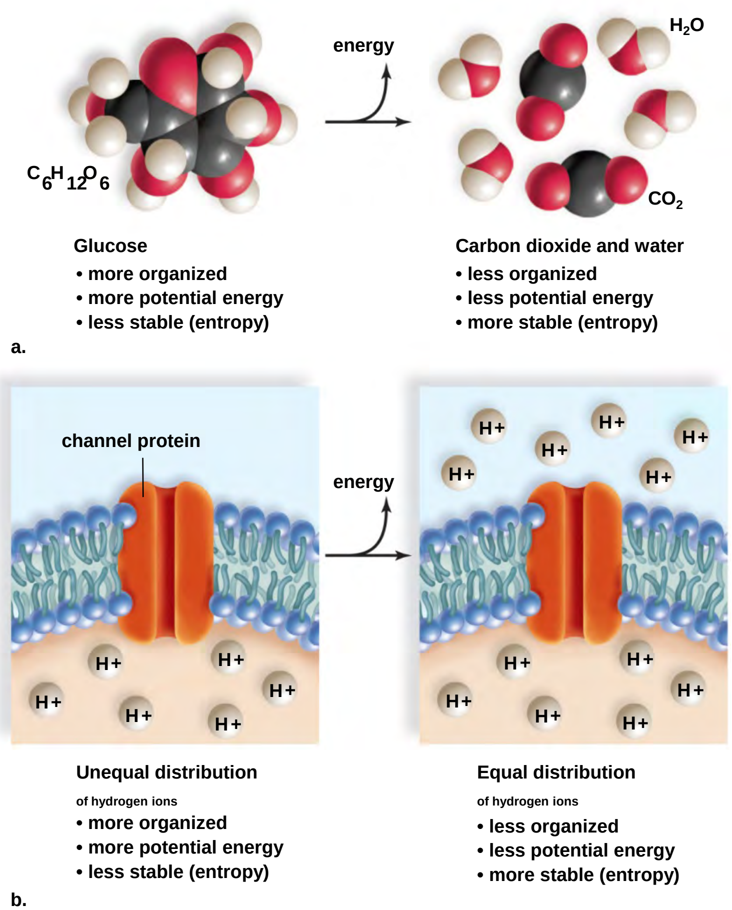
Laws of Thermodynamics

- 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



Cells and Energy



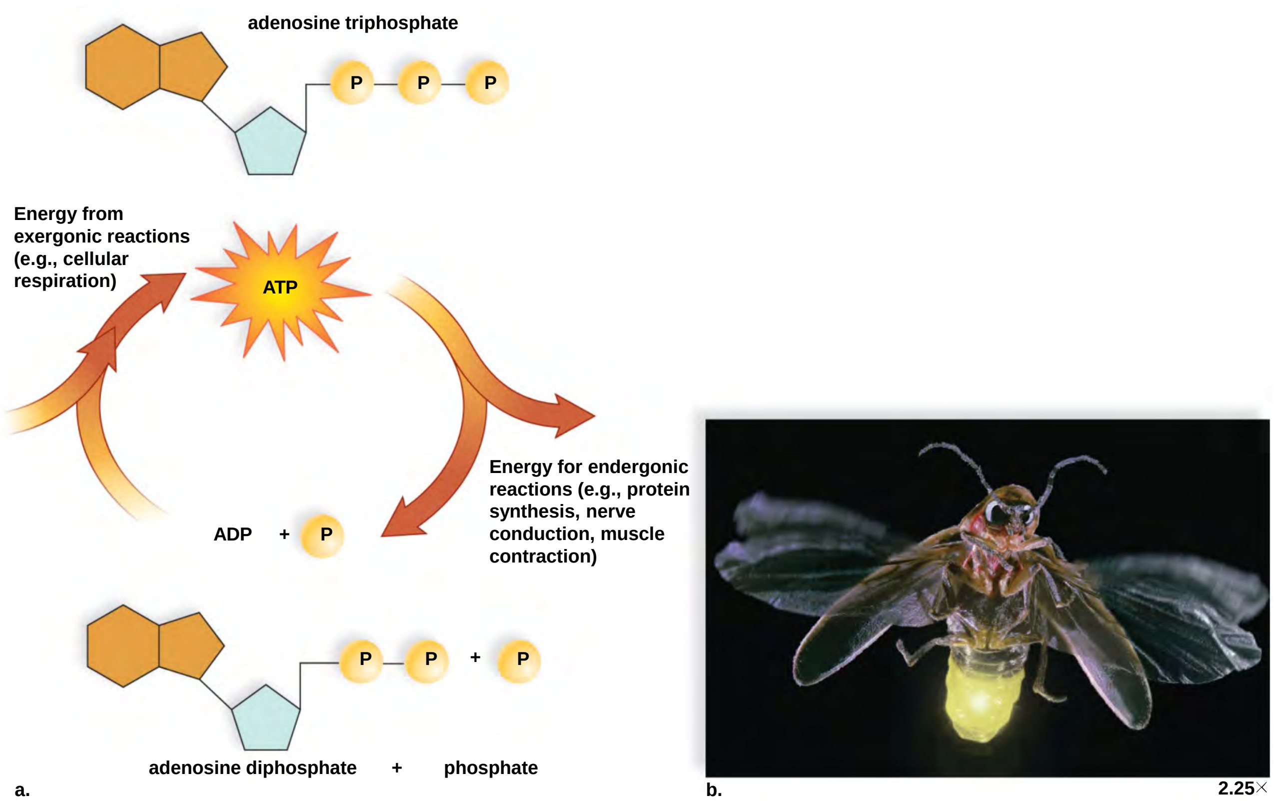
Metabolic Reactions and Energy Transformations

- 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

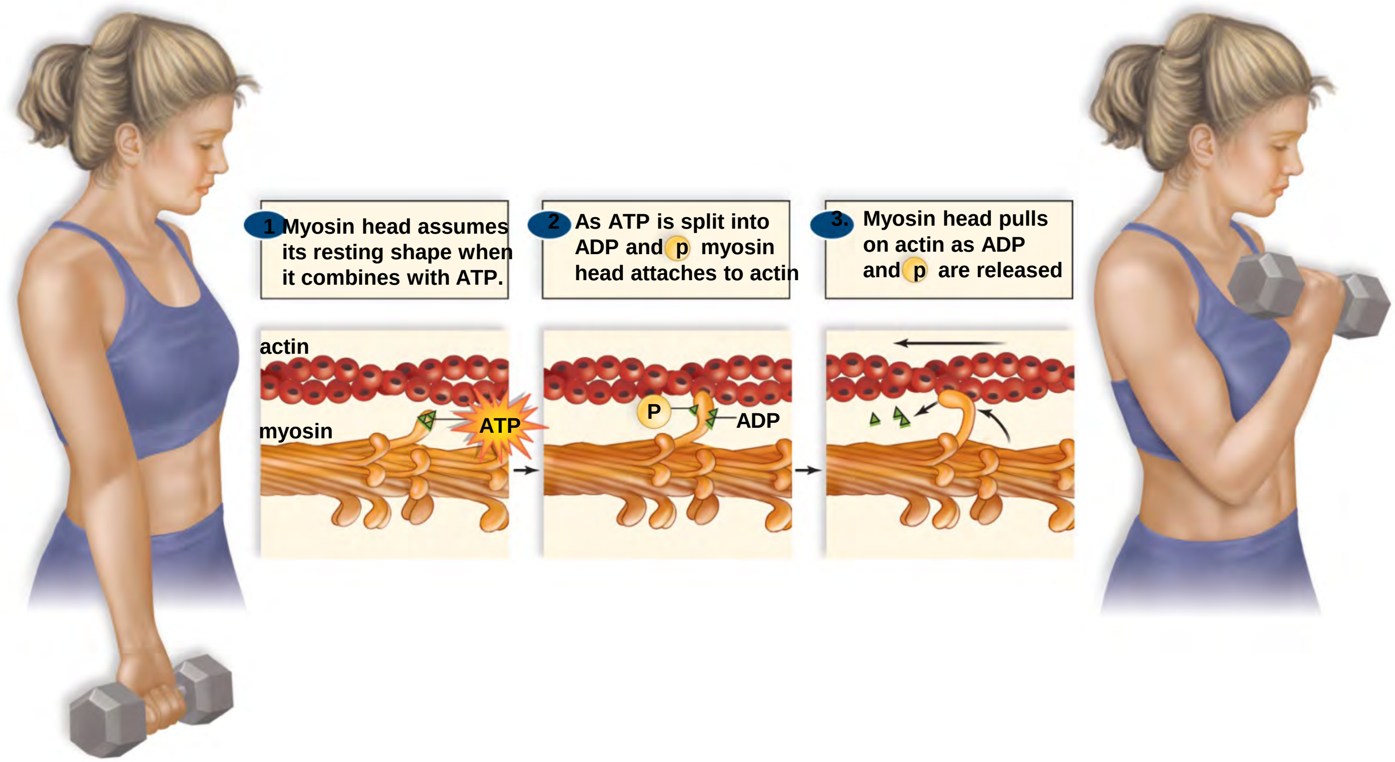
ATP and Coupled Reactions

- 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



Coupled Reactions



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

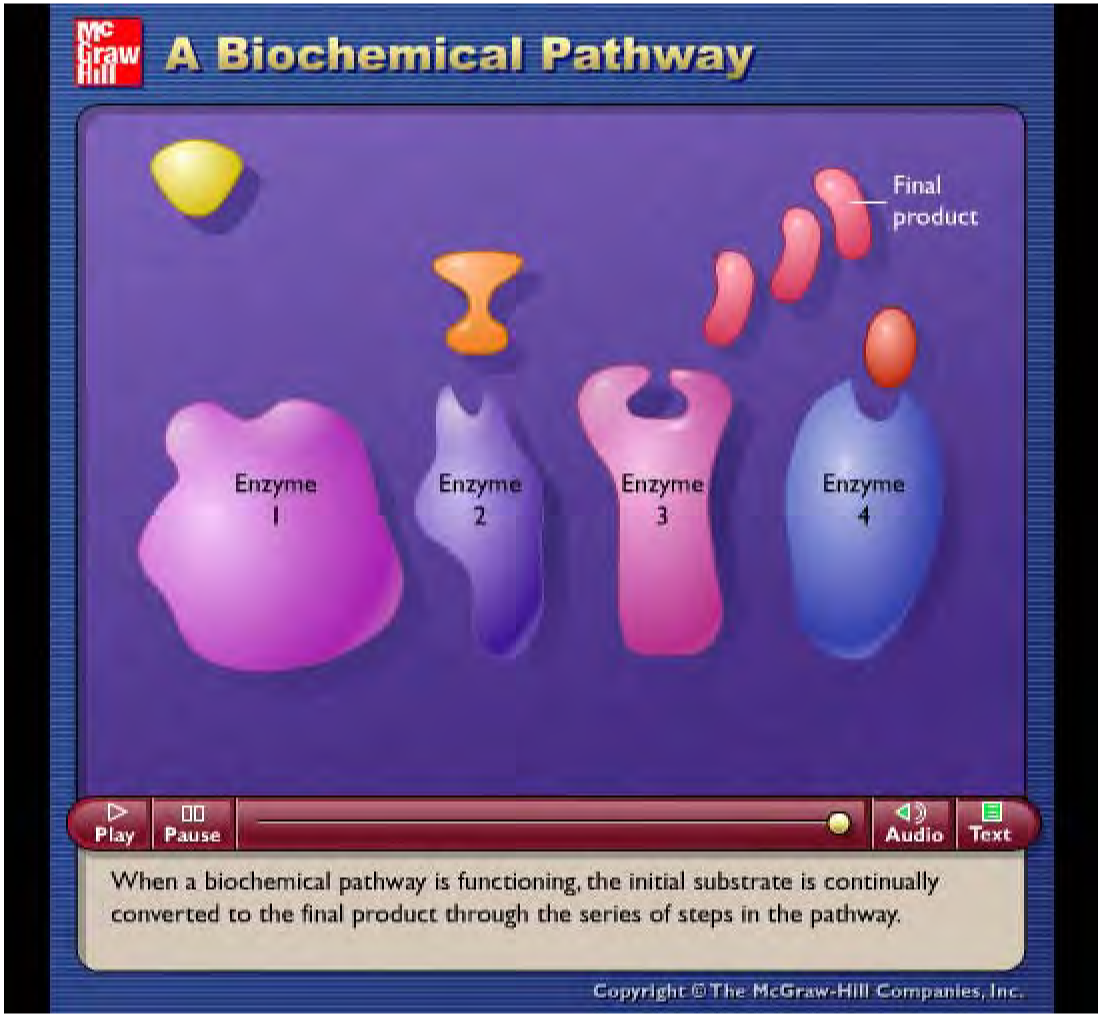
A ➔ B ➔ C ➔ D ➔ E ➔ F ➔ G

"A" is Initial Reactant

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

"G" is End Product

Animation



McGraw Hill
A Biochemical Pathway
Final product
Enzyme 1
Enzyme 2
Enzyme 3
Enzyme 4
Play
Pause
Audio
Text
When a biochemical pathway is functioning, the initial substrate is continually converted to the final product through the series of steps in the pathway.
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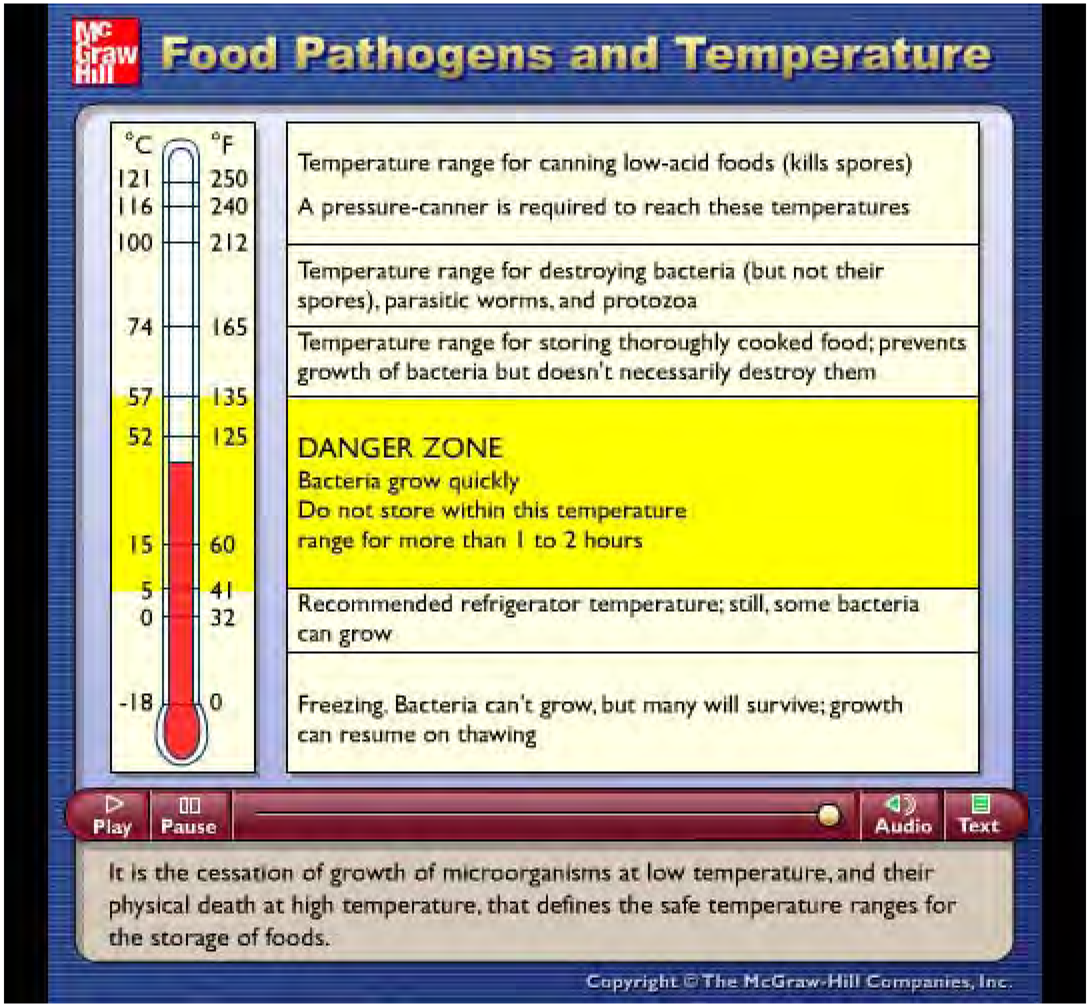
Enzymes

- 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

$$A \xrightarrow{E_1} B \xrightarrow{E_2} C \xrightarrow{E_3} D \xrightarrow{E_4} E \xrightarrow{E_5} F \xrightarrow{E_6} G$$

Animation



Food Pathogens and Temperature
°C
°F
121
250
116
240
100
212
74
165
57
135
52
125
15
60
5
41
0
32
-18
0
Temperature range for canning low-acid foods (kills spores)
A pressure-canner is required to reach these temperatures
Temperature range for destroying bacteria (but not their spores), parasitic worms, and protozoa
Temperature range for storing thoroughly cooked food; prevents growth of bacteria but doesn't necessarily destroy them
DANGER ZONE
Bacteria grow quickly
Do not store within this temperature range for more than 1 to 2 hours
Recommended refrigerator temperature; still, some bacteria can grow
Freezing. Bacteria can't grow, but many will survive; growth can resume on thawing
Play
Pause
Audio
Text
It is the cessation of growth of microorganisms at low temperature, and their physical death at high temperature, that defines the safe temperature ranges for the storage of foods.
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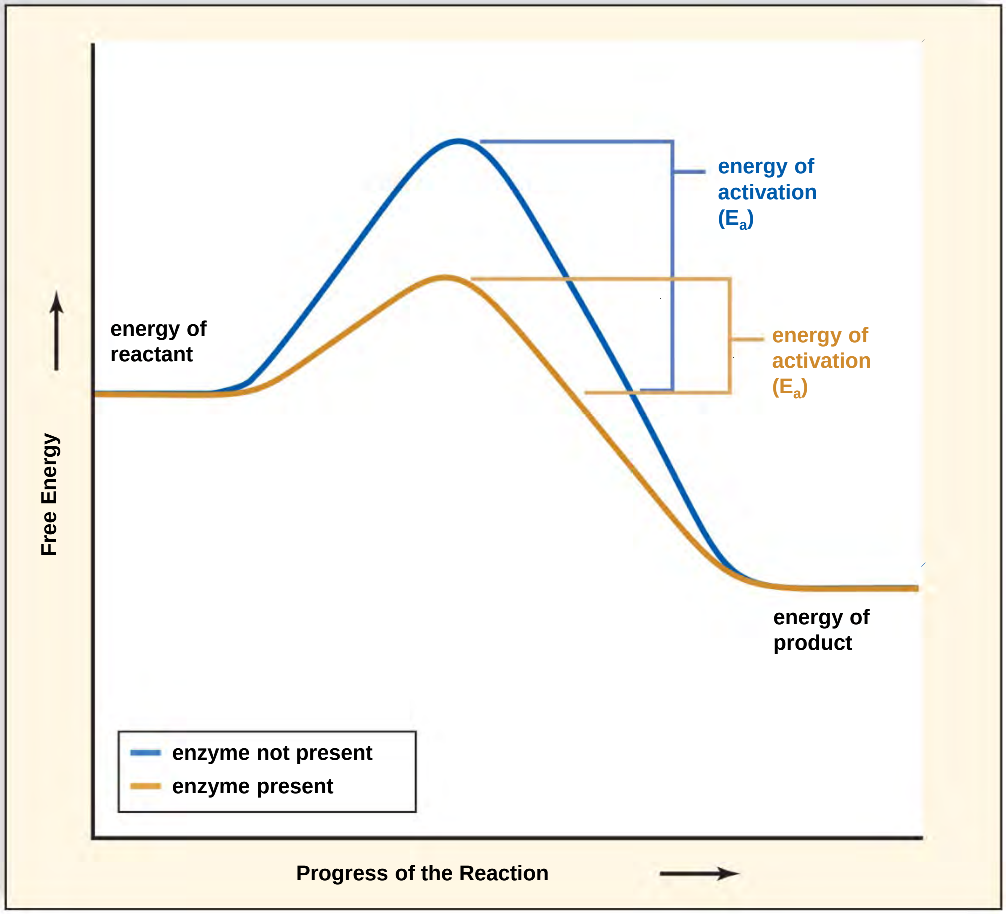
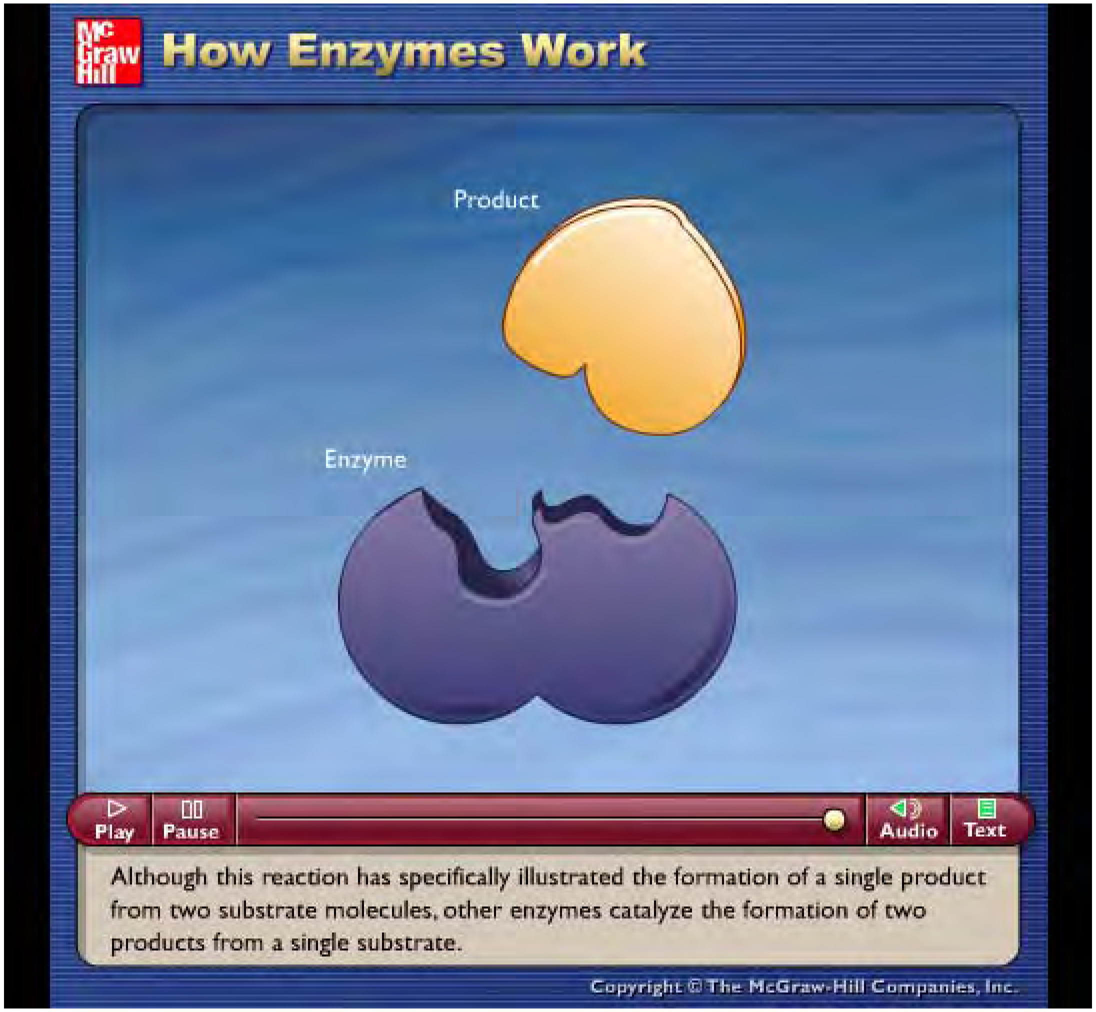
Enzymes: Energy of Activation

- 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



Animation


How Enzymes Work
Product
Enzyme
Play
Pause
Audio
Text
Although this reaction has specifically illustrated the formation of a single product from two substrate molecules, other enzymes catalyze the formation of two products from a single substrate.
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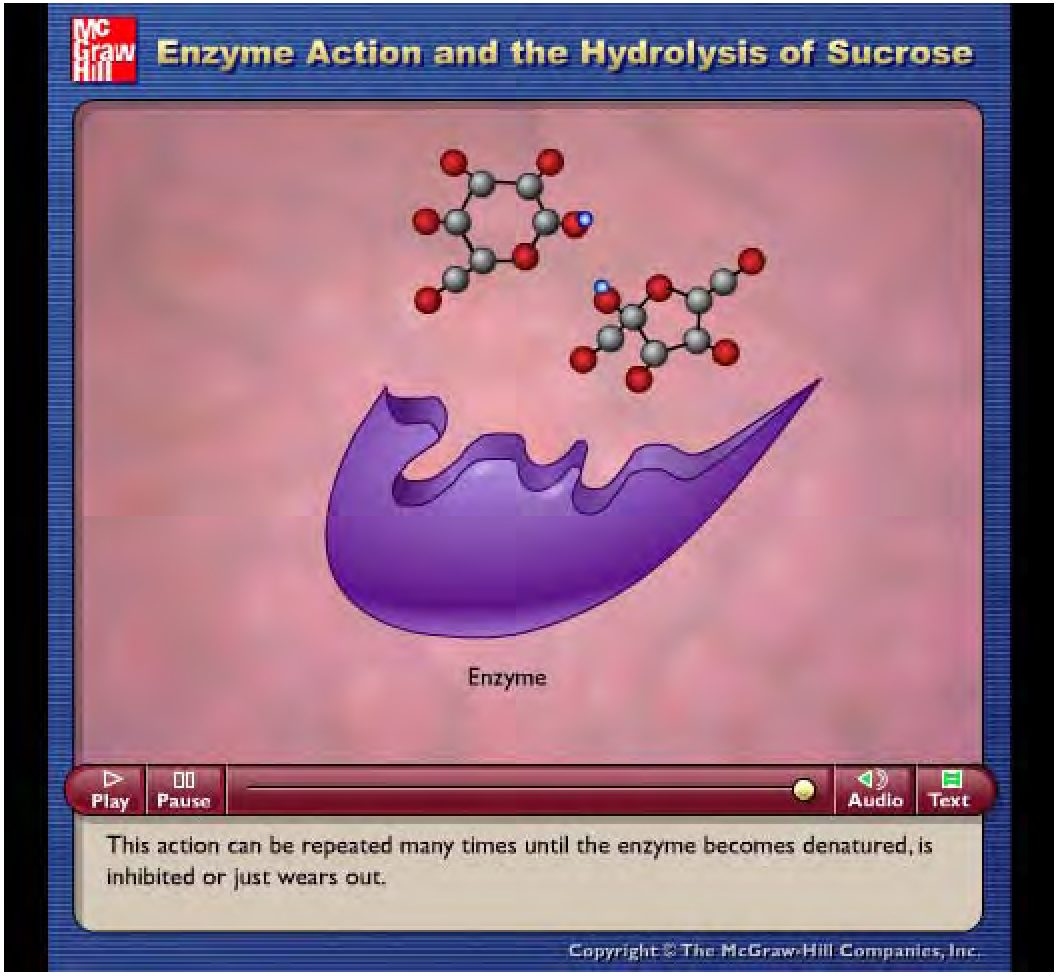
Enzyme-Substrate Complex

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

Animation



Enzyme Action and the Hydrolysis of Sucrose
Enzyme
Play
Pause
Audio
Text
This action can be repeated many times until the enzyme becomes denatured, is inhibited or just wears out.
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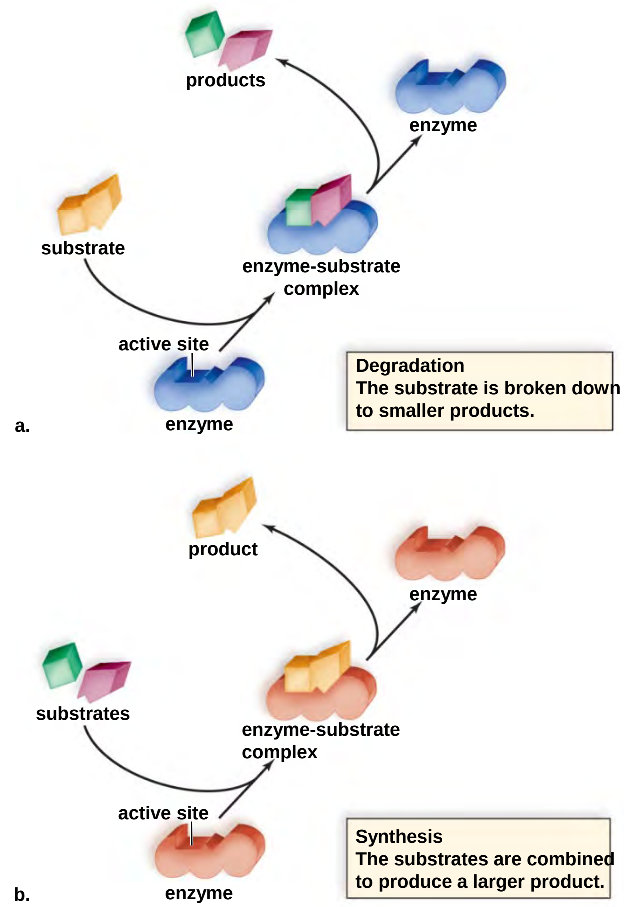
Degradation vs. Synthesis

- 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

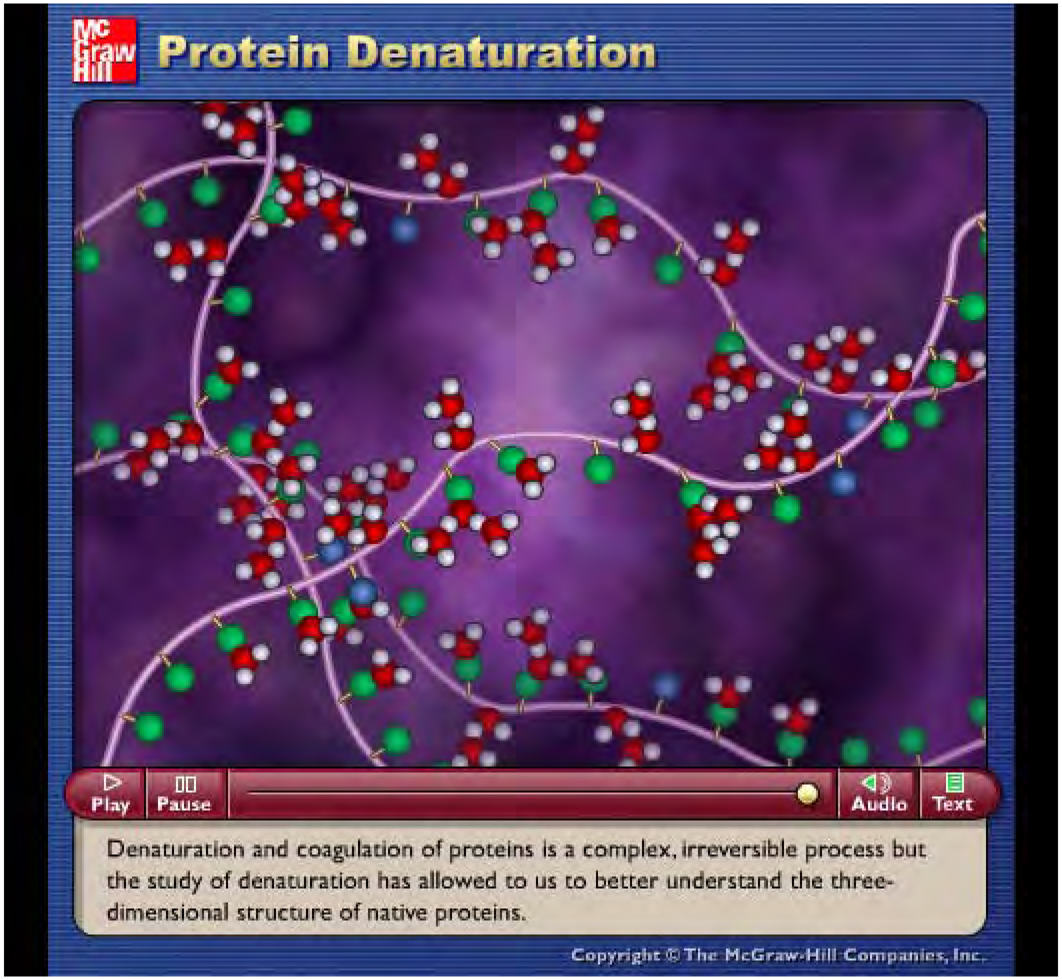
Degradation vs. Synthesis



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
Play
Pause
Audio
Text
Denaturation and coagulation of proteins is a complex, irreversible process but the study of denaturation has allowed to us to better understand the three-dimensional structure of native proteins.
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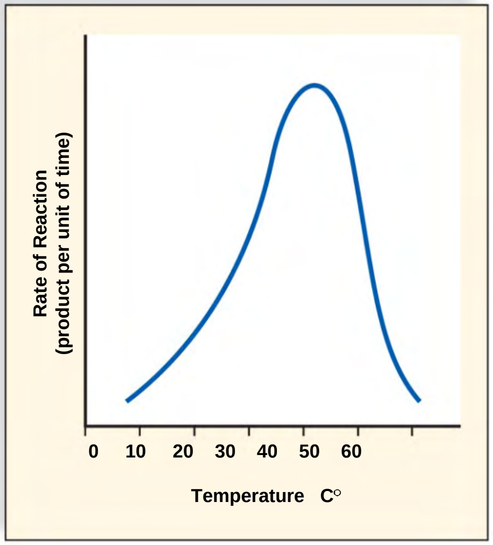
Factors Affecting Enzyme Activity: Temperature



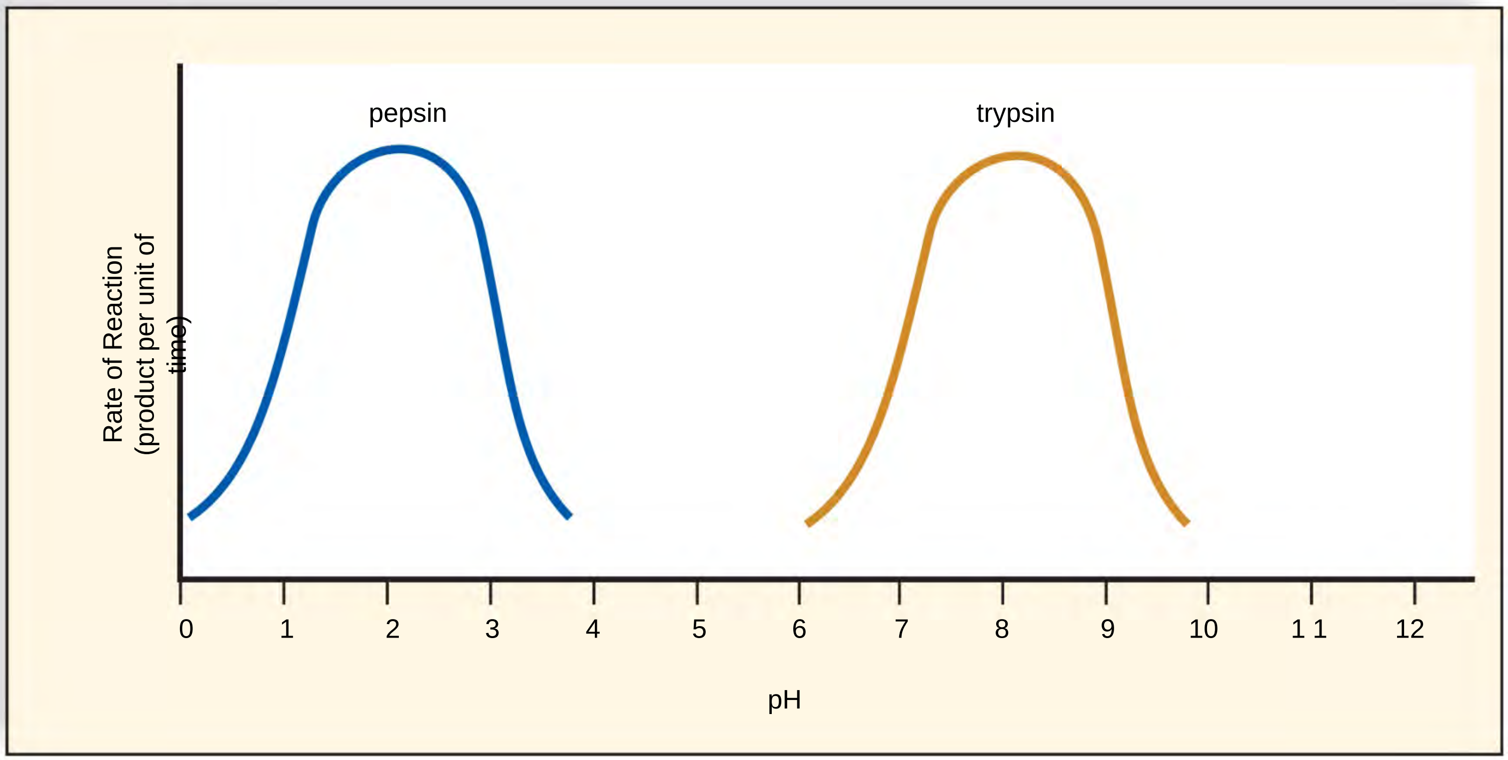
a. Rate of reaction as a function of temperature

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



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

B Vitamins

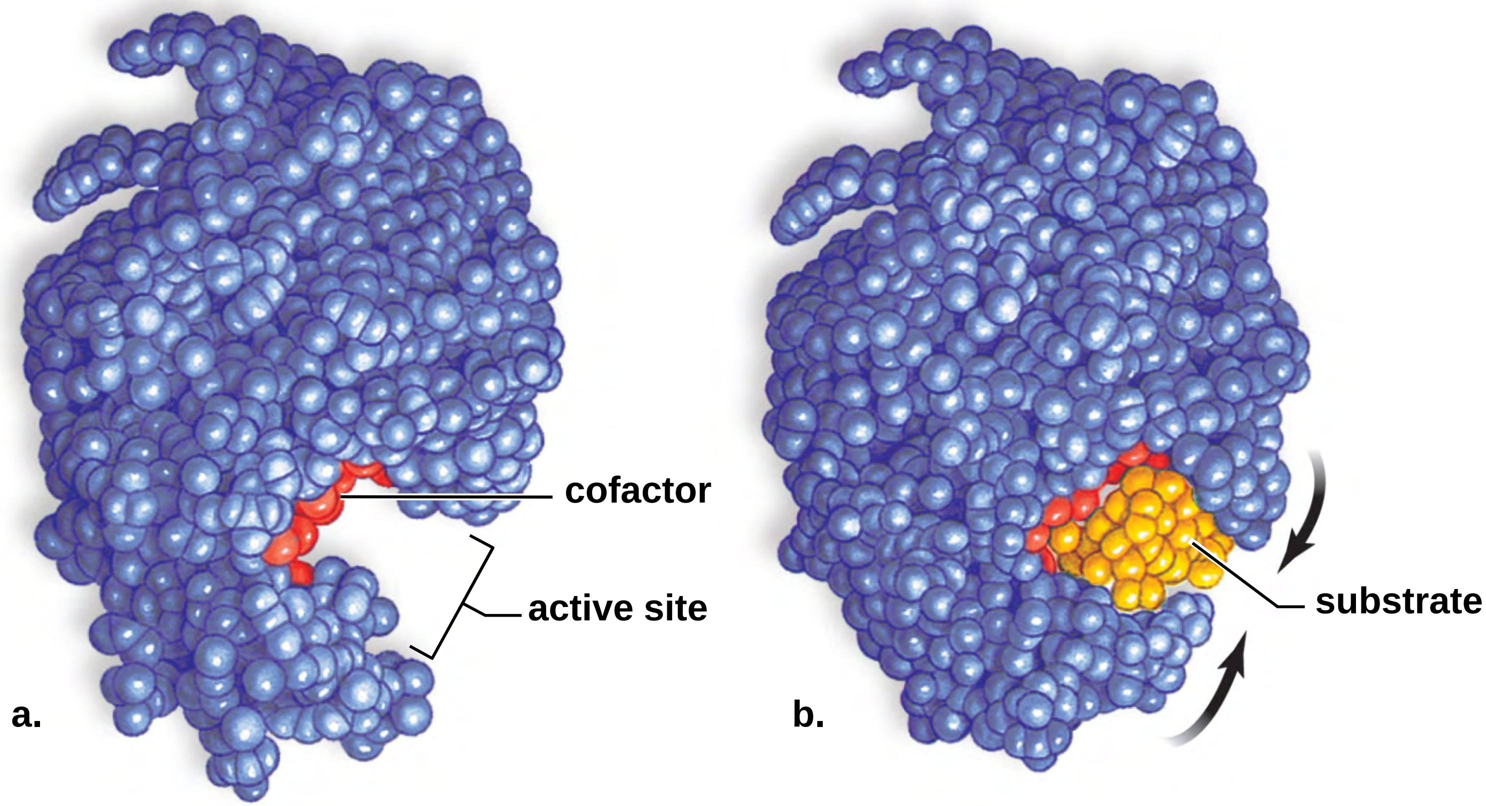
Vitamin	Source	Coenzyme and Function
Thiamine (Vitamin B1)	Meat, leafy green vegetables, grains, legumes	Thiamine pyrophosphate, coenzyme for enzymes involved in decarboxylation reactions
Riboflavin (Vitamin B2)	Milk, meat, grains	Serves as hydrogen carrier in important oxidation-reduction (respiration) reactions
Niacin (Nicotinamide)	Meat, peanuts	Hydrogen carrier in glycolysis, Kreb's cycle, oxidative phosphorylation
Pyridoxine (Vitamin B6)	Meat, fish, poultry	Reactions of protein metabolism
Pantothenic Acid	Meat, grain, legumes, egg yolk	Part of Coenzyme A
Biotin	Egg yolk, legumes, nuts, liver	Carboxylation, decarboxylation, deamination reactions

This table shows some details about several of the roles played by B vitamins as coenzymes.

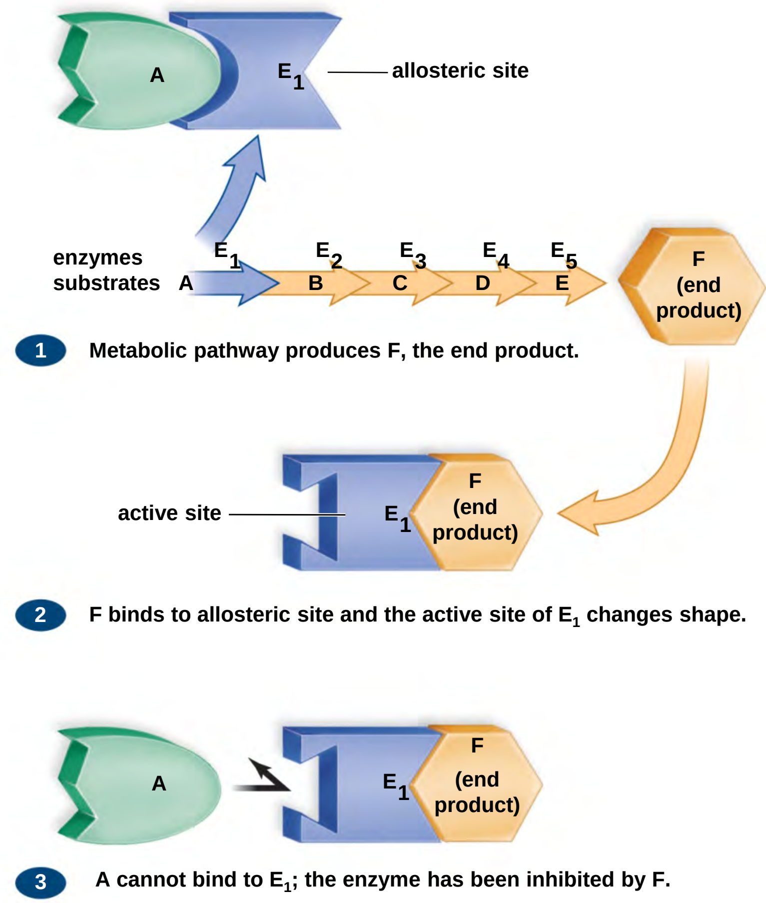
Factors Affecting Enzyme Activity

- 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

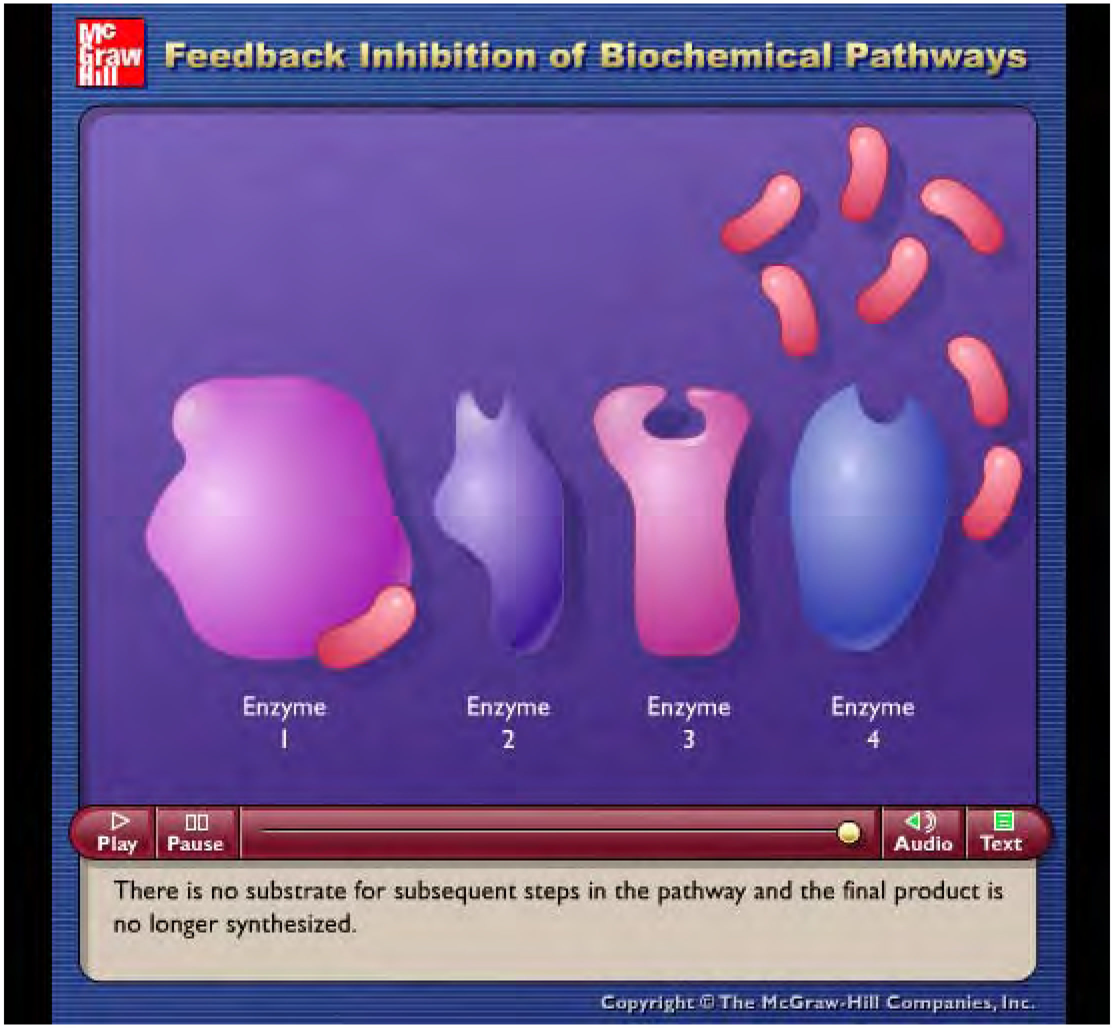
Cofactor at Active Site



Factors Affecting Enzyme Activity: Feedback Inhibition



Animation



Feedback Inhibition of Biochemical Pathways
Enzyme 1
Enzyme 2
Enzyme 3
Enzyme 4
Play
Pause
Audio
Text
There is no substrate for subsequent steps in the pathway and the final product is no longer synthesized.
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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

$$6\,CO_2 + 6\,H_2O + \text{energy} \longrightarrow C_6H_{12}O_6 + 6\,O_2$$

carbon dioxide + water + energy → glucose + oxygen

Cellular Respiration

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

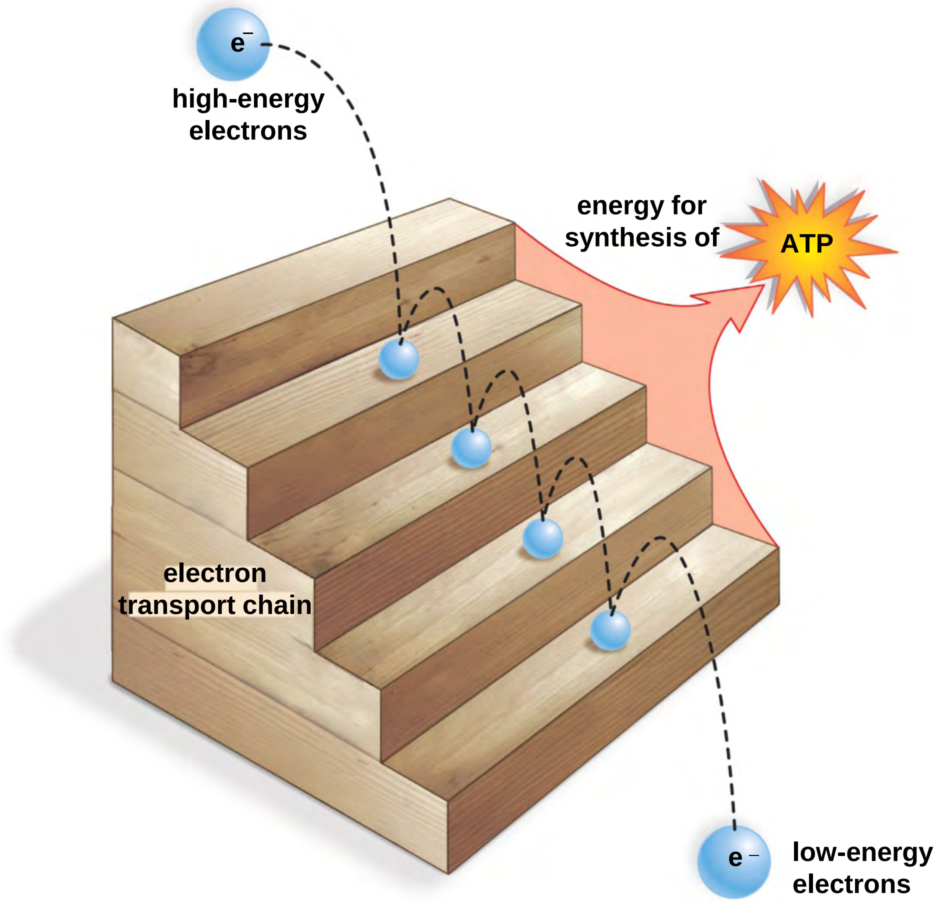
$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + \text{energy}$$

glucose + oxygen → carbon dioxide + water + energy

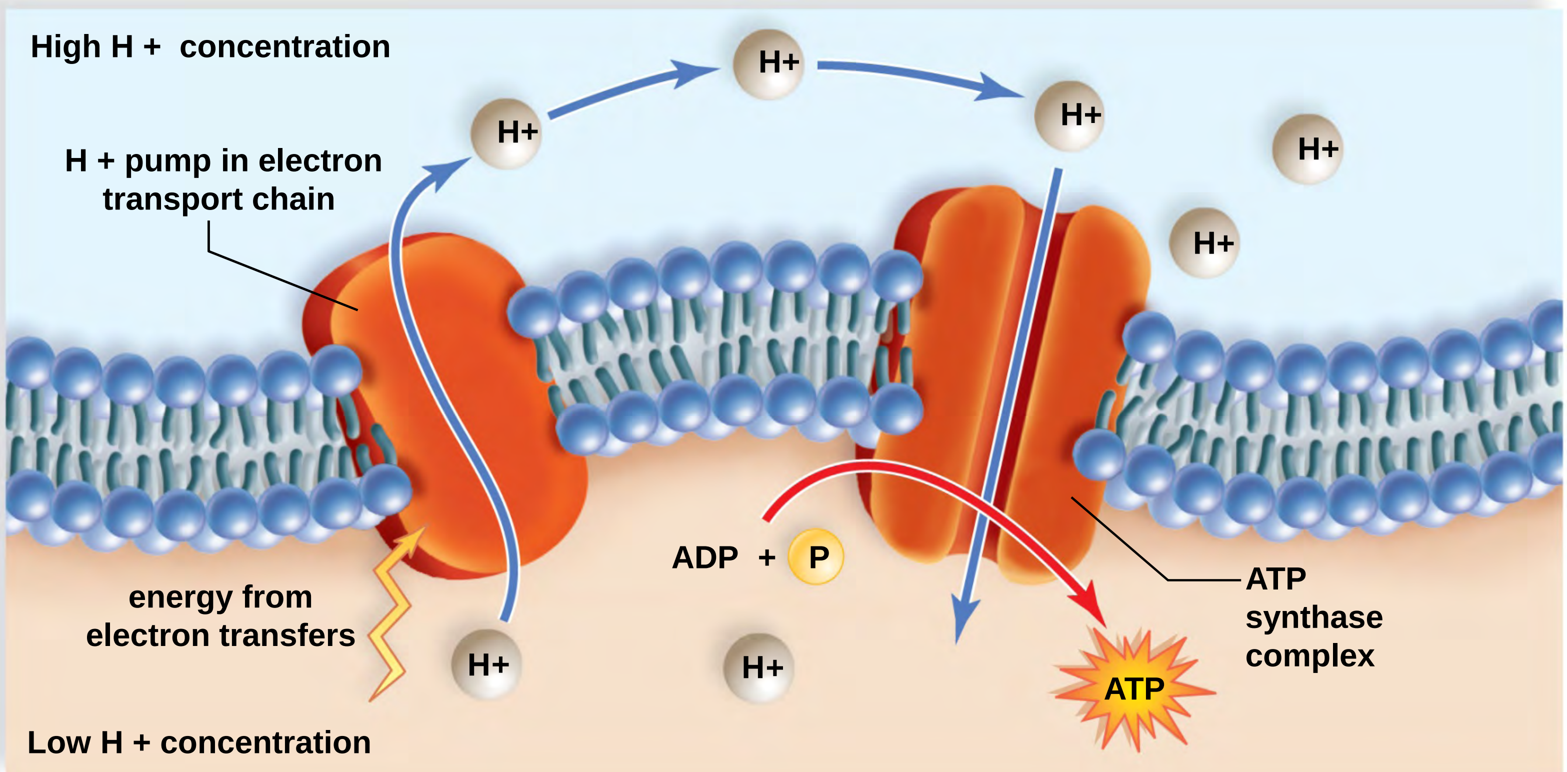
Electron Transport Chain

- 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



Chemiosmosis



Review

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