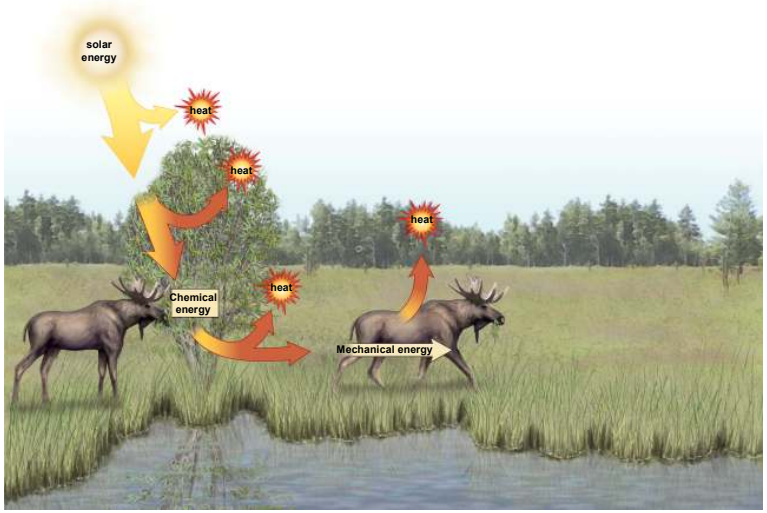
Chapter 6: pp. 103-116

Metabolism: Energy and Enzymes



BIOLOGY

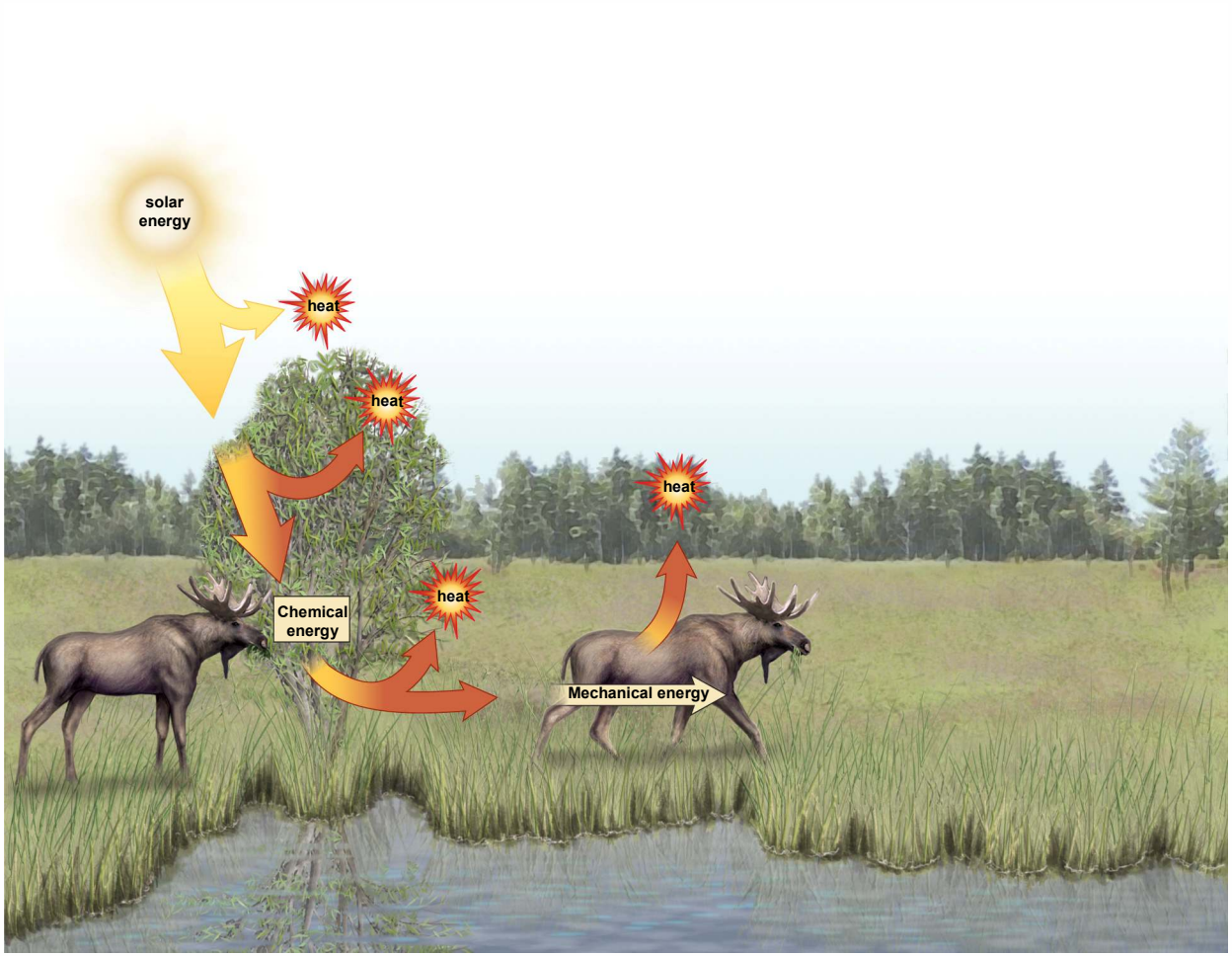
10th Edition

Sylvia S. Mader

Forms of Energy

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

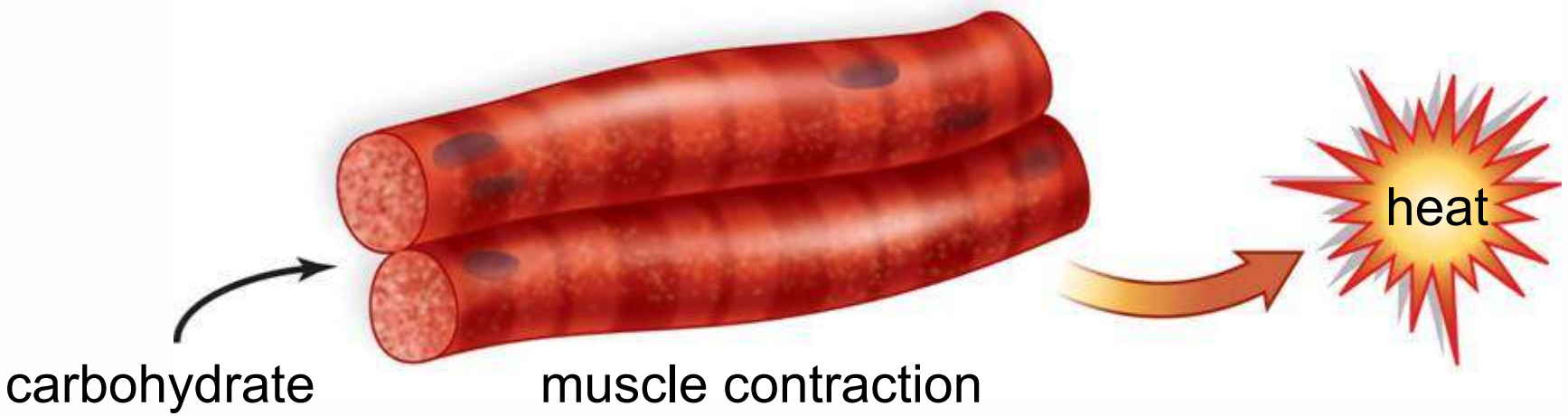
Flow of Energy



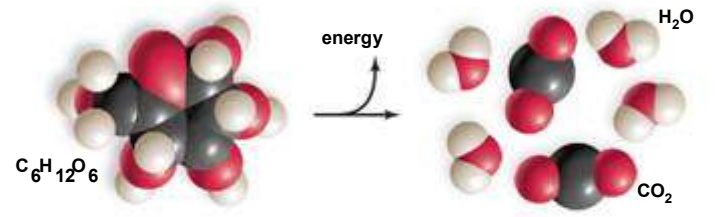
Laws of Thermodynamics

- 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



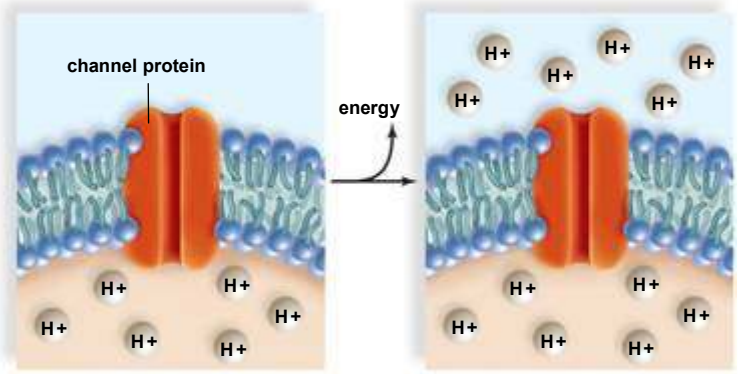
Cells and Energy



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.

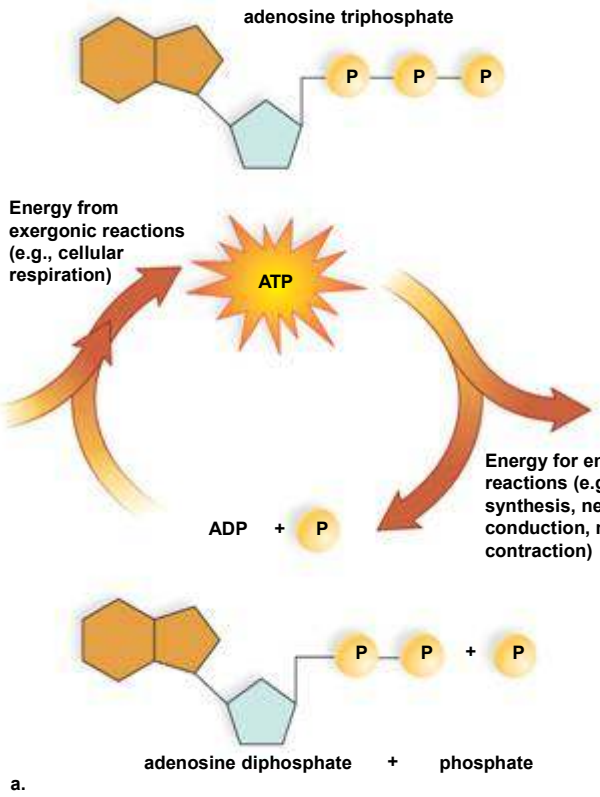
Metabolic Reactions and Energy Transformations

- 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

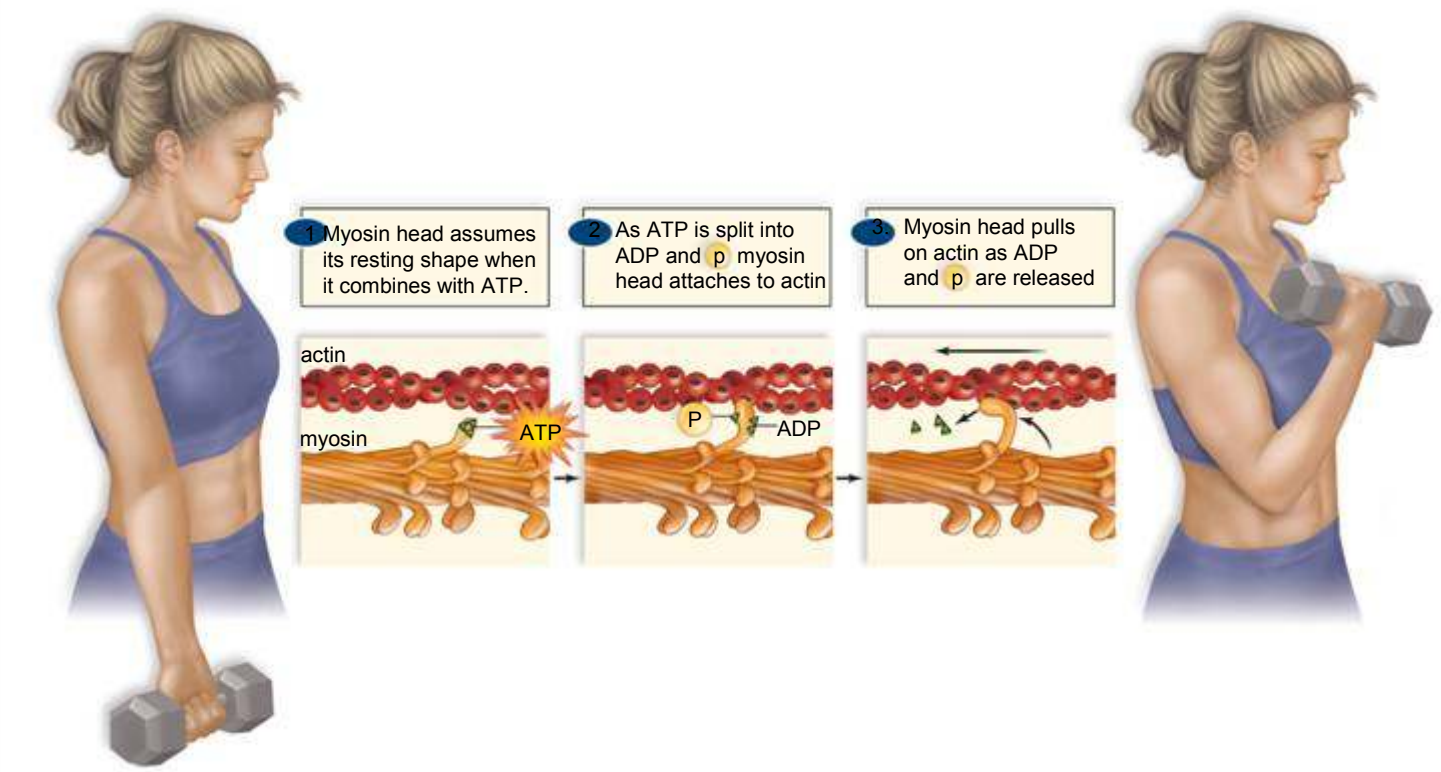
ATP and Coupled Reactions

- 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



Coupled Reactions



Metabolic Reactions and Energy Transformations

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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

Enzymes

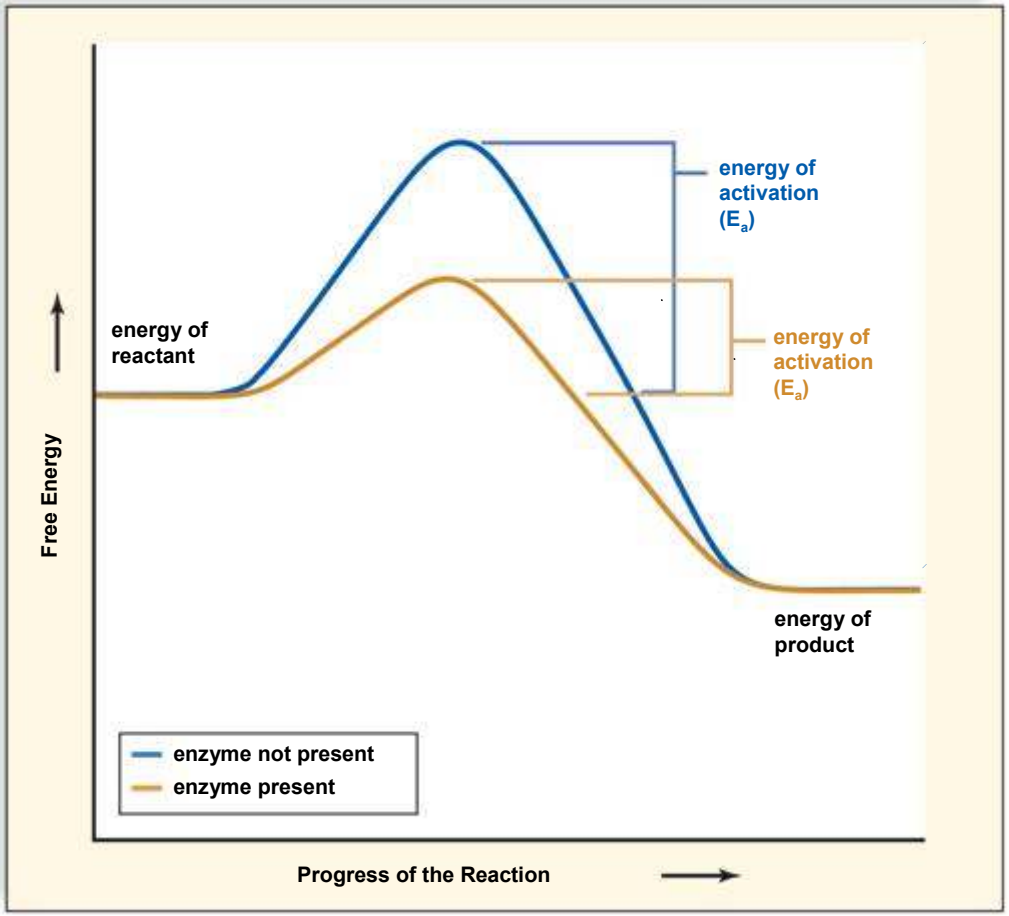
- Enzymes
  - Protein molecules that function as catalysts
  - The reactants of an enzymatically accelerated reaction are called substrates
  - Each enzyme accelerates a specific reaction
  - Each reaction in a metabolic pathway requires a unique and specific enzyme
  - End product will not appear unless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

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

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



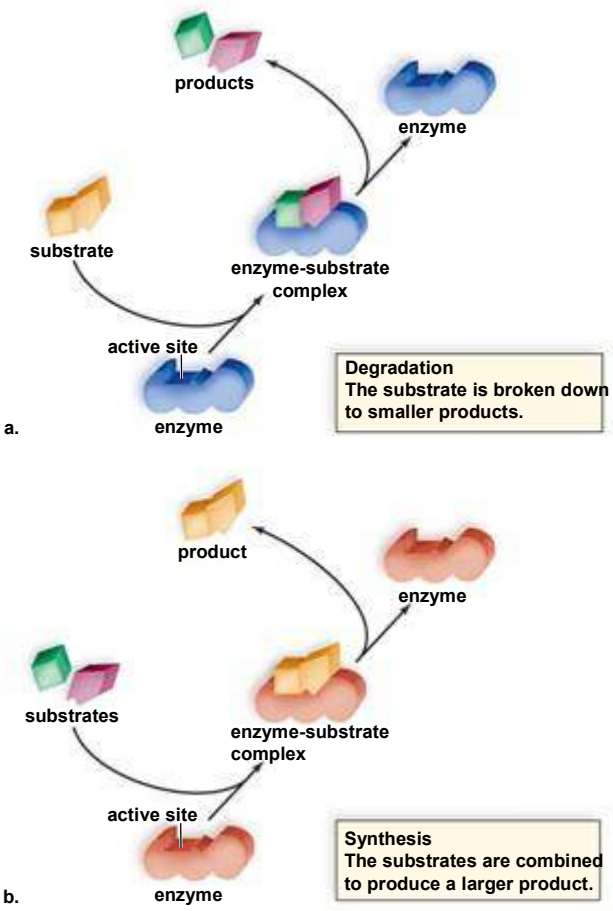
Enzyme-Substrate Complex

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

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

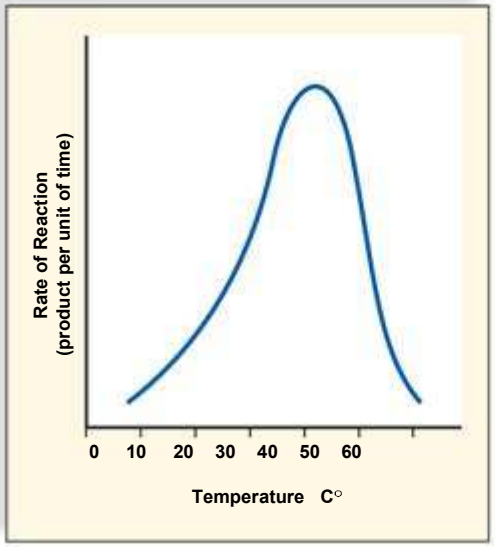
Degradation vs. Synthesis



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

Factors Affecting Enzyme Activity: Temperature

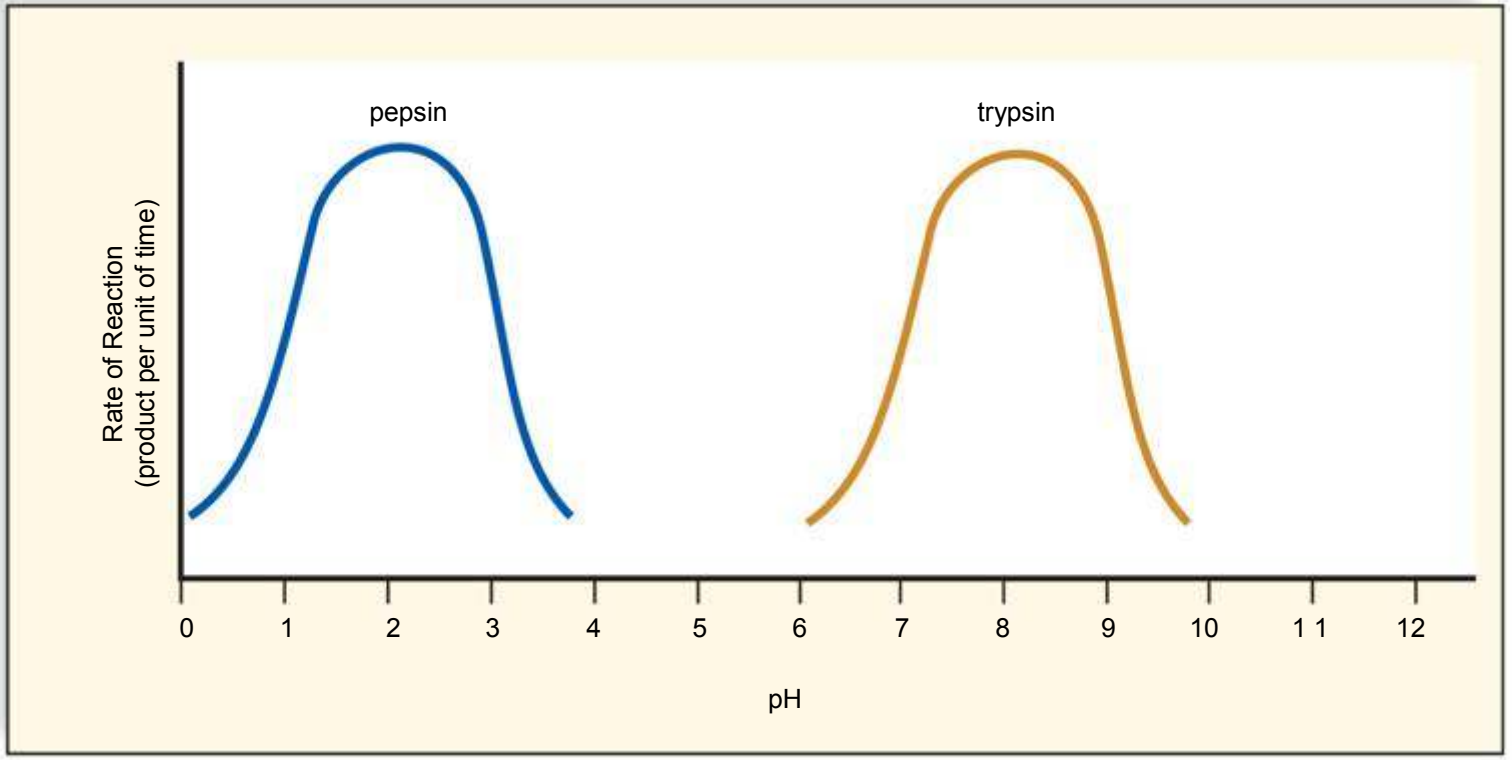


a. Rate of reaction as a function of temperature

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

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

Factors Affecting Enzyme Activity: pH



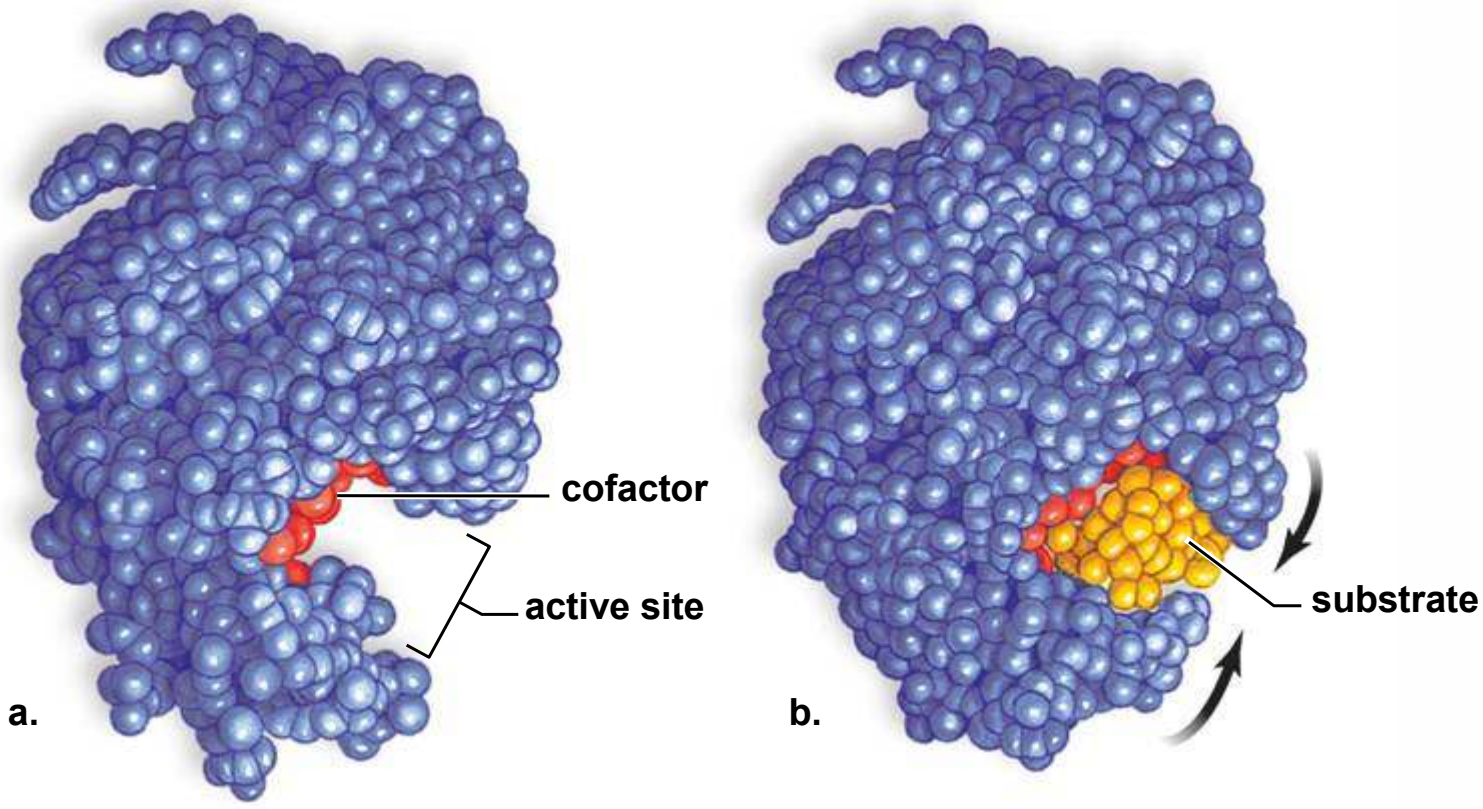
Factors Affecting Enzyme Activity

- 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

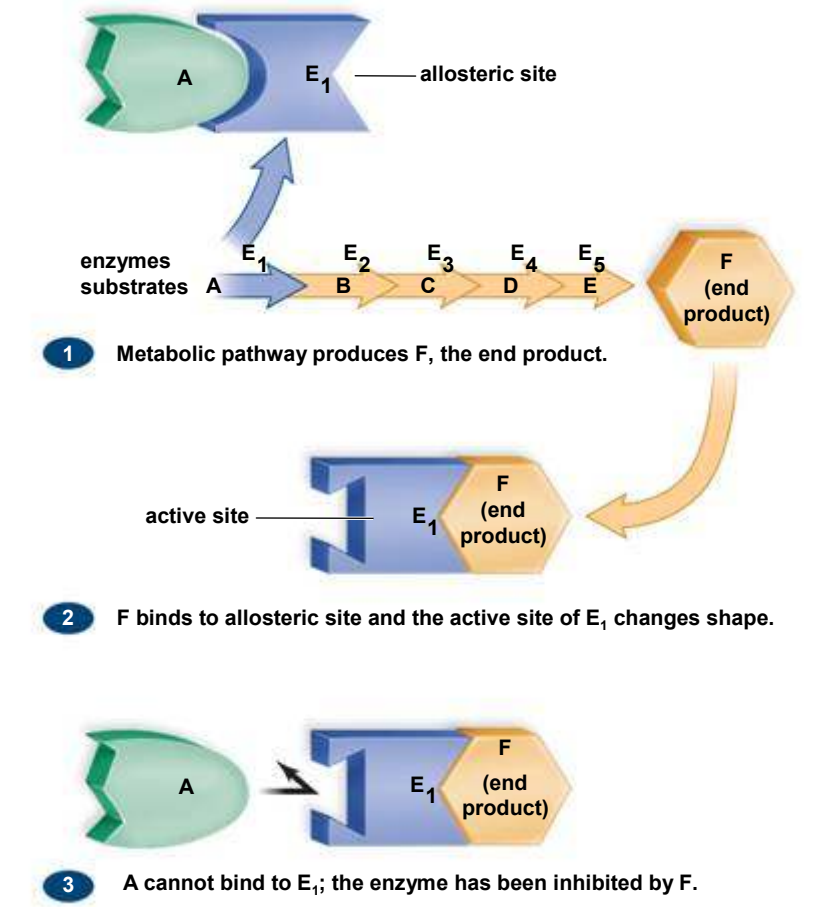
Factors Affecting Enzyme Activity

- 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



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

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} + \text{energy} \longrightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2}$$

Cellular Respiration

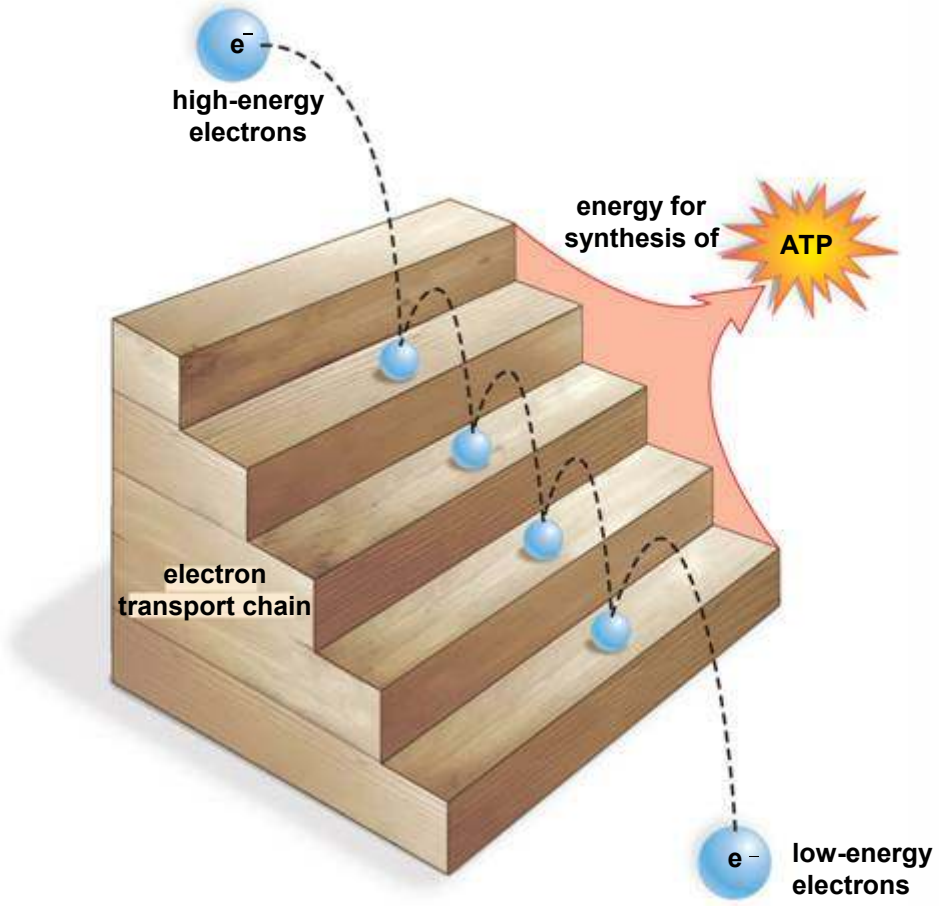
The overall equation for cellular respiration is opposite to that for photosynthesis:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2} \longrightarrow \underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} + \text{energy}$$

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