Chapter 8

An Introduction to Metabolism

PowerPoint Lectures for
Biology, Seventh Edition
Neil Campbell and Jane Reece

Lectures by Chris Romero

- Overview: The Energy of Life
- The living cell
  - Is a miniature factory where thousands of reactions occur
  - Converts energy in many ways

- Some organisms
  - Convert energy to light, as in bioluminescence

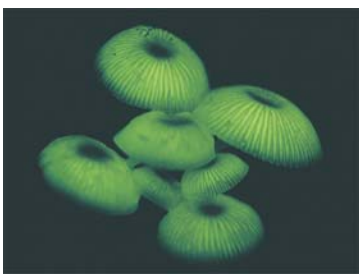


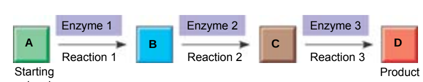
Figure 8.1

- Concept 8.1: An organism's metabolism transforms matter and energy, subject to the laws of thermodynamics

- Metabolism
  - Is the totality of an organism's chemical reactions
  - Arises from interactions between molecules

Organization of the Chemistry of Life into Metabolic Pathways

- A metabolic pathway has many steps
  - That begin with a specific molecule and end with a product
  - That are each catalyzed by a specific enzyme



- Catabolic pathways
  - Break down complex molecules into simpler compounds
  - Release energy

- Anabolic pathways
  - Build complicated molecules from simpler ones
  - Consume energy

Forms of Energy

- Energy
  - Is the capacity to cause change
  - Exists in various forms, of which some can perform work

- Kinetic energy
  - Is the energy associated with motion
- Potential energy
  - Is stored in the location of matter
  - Includes chemical energy stored in molecular structure

- Energy can be converted
  - From one form to another

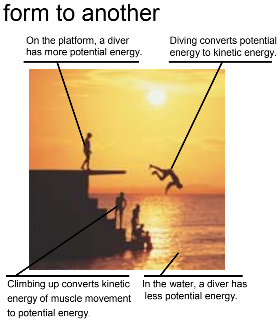


Figure 8.2

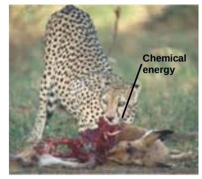
The Laws of Energy Transformation

- Thermodynamics
  - Is the study of energy transformations

The First Law of Thermodynamics

- According to the first law of thermodynamics
  - Energy can be transferred and transformed
  - Energy cannot be created or destroyed

- An example of energy conversion

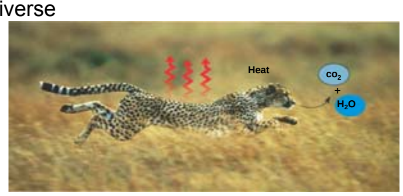


(a) First law of thermodynamics: Energy can be transferred or transformed but Neither created nor destroyed. For example, the chemical (potential) energy in food will be converted to the kinetic energy of the cheetah's movement in (b).

Figure 8.3

The Second Law of Thermodynamics

- According to the second law of thermodynamics
  - Spontaneous changes that do not require outside energy increase the entropy, or disorder, of the universe



(b) Second law of thermodynamics: Every energy transfer or transformation increases the disorder (entropy) of the universe. For example, disorder is added to the cheetah's surroundings in the form of heat and the small molecules that are the by-products of metabolism.

Figure 8.3

Biological Order and Disorder

- Living systems
  - Increase the entropy of the universe
  - Use energy to maintain order

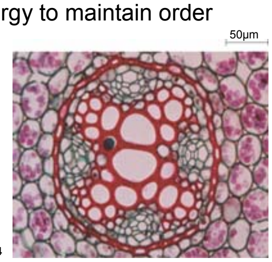


Figure 8.4

- Concept 8.2: The free-energy change of a reaction tells us whether the reaction occurs spontaneously

Free-Energy Change, ΔG

- A living system's free energy
  - Is energy that can do work under cellular conditions

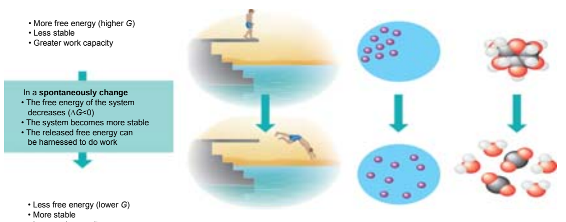
- The change in free energy, ΔG during a biological process
  - Is related directly to the enthalpy change (ΔH) and the change in entropy

$\Delta G = \Delta H - T\Delta S$

Free Energy, Stability, and Equilibrium

- Organisms live at the expense of free energy
- During a spontaneous change
  - Free energy decreases and the stability of a system increases

- At maximum stability
  - The system is at equilibrium



(a) **Gravitational motion.** Objects move spontaneously from a higher altitude to a lower one.
(b) **Diffusion.** Molecules in a drop of dye diffuse until they are randomly dispersed.
(c) **Chemical reaction.** In a cell, a sugar molecule is broken down into simpler molecules.

Figure 8.5

Free Energy and Metabolism

Exergonic and Endergonic Reactions in Metabolism

- An exergonic reaction
  - Proceeds with a net release of free energy and is spontaneous

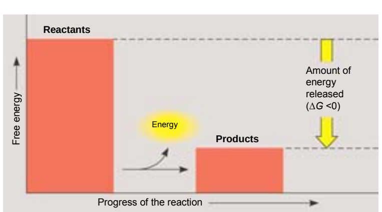


Figure 8.6 **(a) Exergonic reaction: energy released**

- An endergonic reaction
  - Is one that absorbs free energy from its surroundings and is nonspontaneous

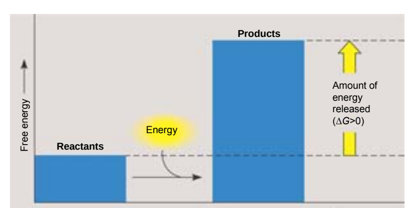


Figure 8.6 **(b) Endergonic reaction: energy required**

Equilibrium and Metabolism

- Reactions in a closed system
  - Eventually reach equilibrium

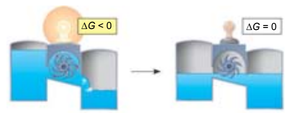


Figure 8.7 A (a) **A closed hydroelectric system.** Water flowing downhill turns a turbine that drives a generator providing electricity to a light bulb, but only until the system reaches equilibrium.

- Cells in our body
  - Experience a constant flow of materials in and out, preventing metabolic pathways from reaching equilibrium

(b) **An open hydroelectric system.** Flowing water keeps driving the generator because intake and outflow of water keep the system from reaching equilibrium.

Figure 8.7

- An analogy for cellular respiration

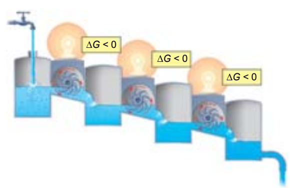


Figure 8.7 (c) **A multistep open hydroelectric system.** Cellular respiration is analogous to this system: Glucoce is brocken down in a series of exergonic reactions that power the work of the cell. The product of each reaction becomes the reactant for the next, so no reaction reaches equilibrium.

- Concept 8.3: ATP powers cellular work by coupling exergonic reactions to endergonic reactions
- A cell does three main kinds of work
  - Mechanical
  - Transport
  - Chemical

- Energy coupling
  - Is a key feature in the way cells manage their energy resources to do this work

The Structure and Hydrolysis of ATP

- ATP (adenosine triphosphate)
  - Is the cell's energy shuttle
  - Provides energy for cellular functions

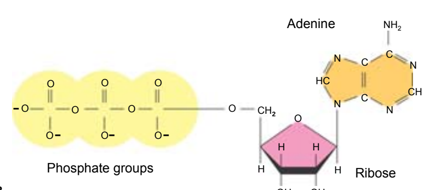


Figure 8.8

- Energy is released from ATP
  - When the terminal phosphate bond is broken

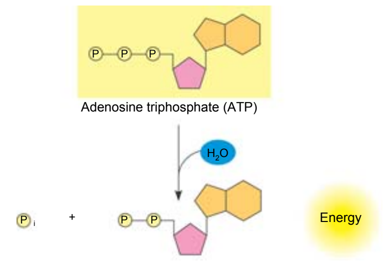


Figure 8.9

- ATP hydrolysis
  - Can be coupled to other reactions

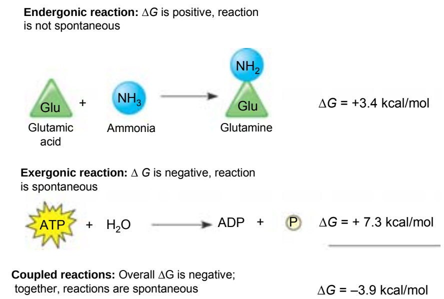


Figure 8.10

How ATP Performs Work

- ATP drives endergonic reactions
  - By phosphorylation, transferring a phosphate to other molecules

- The three types of cellular work
  - Are powered by the hydrolysis of ATP

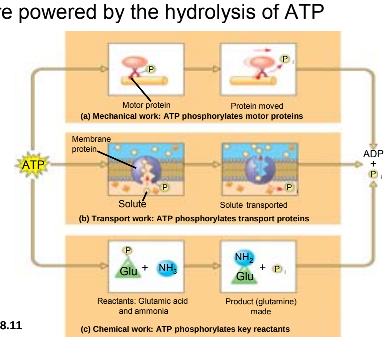


Figure 8.11

The Regeneration of ATP

- Catabolic pathways
  - Drive the regeneration of ATP from ADP and phosphate

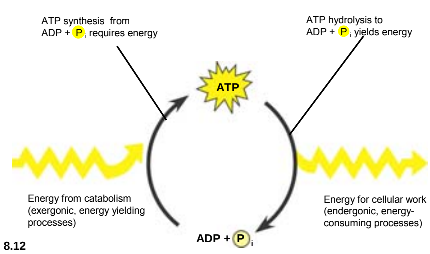


Figure 8.12

- Concept 8.4: Enzymes speed up metabolic reactions by lowering energy barriers
- A catalyst
  - Is a chemical agent that speeds up a reaction without being consumed by the reaction

- An enzyme
  - Is a catalytic protein

The Activation Barrier

- Every chemical reaction between molecules
  - Involves both bond breaking and bond forming

- The hydrolysis
  - Is an example of a chemical reaction

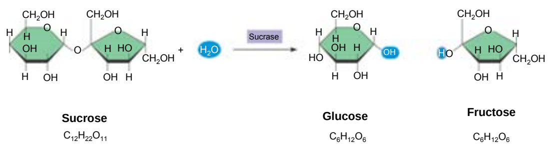


Figure 8.13

- The activation energy, E_A
  - Is the initial amount of energy needed to start a chemical reaction
  - Is often supplied in the form of heat from the surroundings in a system

- The energy profile for an exergonic reaction

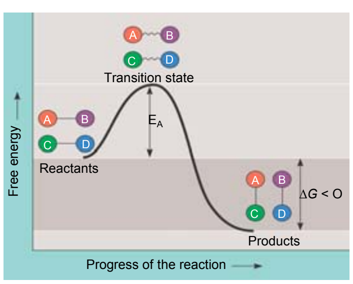


Figure 8.14

How Enzymes Lower the E_A Barrier

- An enzyme catalyzes reactions
  - By lowering the E_A barrier

- The effect of enzymes on reaction rate

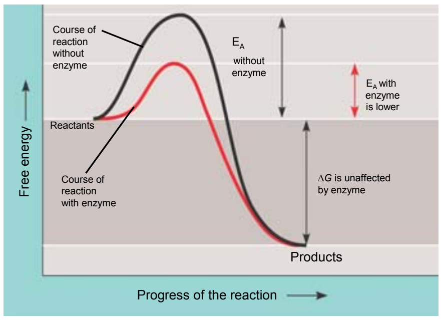


Figure 8.15

Substrate Specificity of Enzymes

- The substrate
  - Is the reactant an enzyme acts on
- The enzyme
  - Binds to its substrate, forming an enzyme-substrate complex

- The active site
  - Is the region on the enzyme where the substrate binds

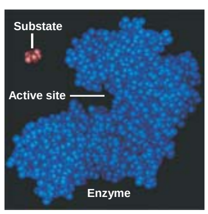


Figure 8.16 (a)

- Induced fit of a substrate
  - Brings chemical groups of the active site into positions that enhance their ability to catalyze the chemical reaction

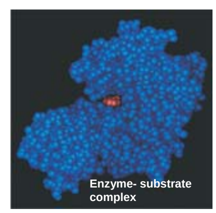


Figure 8.16 (b)

Catalysis in the Enzyme's Active Site

- In an enzymatic reaction
  - The substrate binds to the active site

- The catalytic cycle of an enzyme

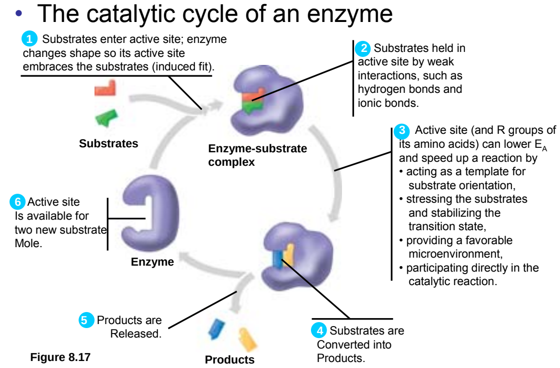


Figure 8.17

- The active site can lower an E_A barrier by
  - Orienting substrates correctly
  - Straining substrate bonds
  - Providing a favorable microenvironment
  - Covalently bonding to the substrate

Effects of Local Conditions on Enzyme Activity

- The activity of an enzyme
  - Is affected by general environmental factors

Effects of Temperature and pH

- Each enzyme
  - Has an optimal temperature in which it can function

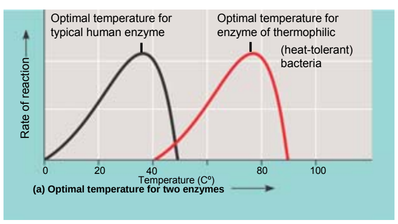


Figure 8.18

- Has an optimal pH in which it can function

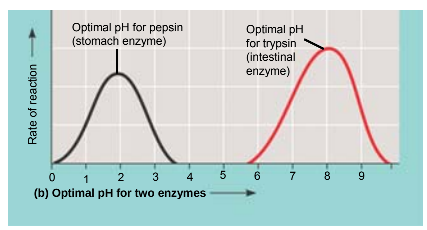


Figure 8.18

Cofactors

- Cofactors
  - Are nonprotein enzyme helpers
- Coenzymes
  - Are organic cofactors

Enzyme Inhibitors

- Competitive inhibitors
  - Bind to the active site of an enzyme, competing with the substrate

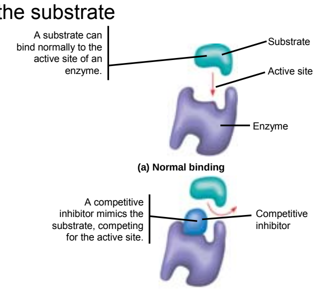


Figure 8.19

- Noncompetitive inhibitors
  - Bind to another part of an enzyme, changing the function

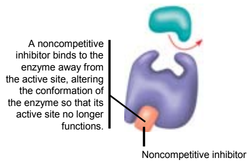


Figure 8.19 (c) Noncompetitive inhibition

- Concept 8.5: Regulation of enzyme activity helps control metabolism
- A cell's metabolic pathways
  - Must be tightly regulated

Allosteric Regulation of Enzymes

- Allosteric regulation
  - Is the term used to describe any case in which a protein's function at one site is affected by binding of a regulatory molecule at another site

Allosteric Activation and Inhibition

- Many enzymes are allosterically regulated

  - They change shape when regulatory molecules bind to specific sites, affecting function

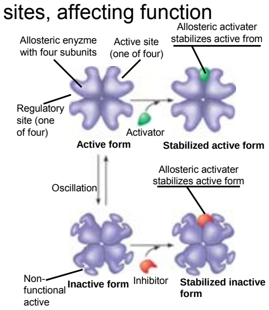


Figure 8.20 **(a) Allosteric activators and inhibitors.** In the cell, activators and inhibitors dissociate when at low concentrations. The enzyme can then oscillate again.

- Cooperativity
  - Is a form of allosteric regulation that can amplify enzyme activity

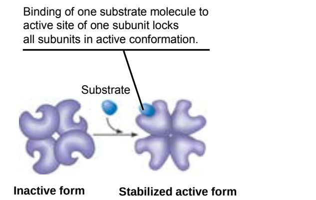


Figure 8.20 **(b) Cooperativity: another type of allosteric activation.** Note that the inactive form shown on the left oscillates back and forth with the active form when the active form is not stabilized by substrate.

Feedback Inhibition

- In feedback inhibition
  - The end product of a metabolic pathway shuts down the pathway

- Feedback inhibition

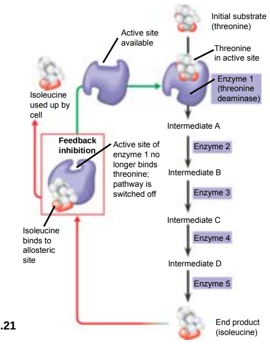


Figure 8.21

Specific Localization of Enzymes Within the Cell

- Within the cell, enzymes may be
  - Grouped into complexes
  - Incorporated into membranes

- Contained inside organelles

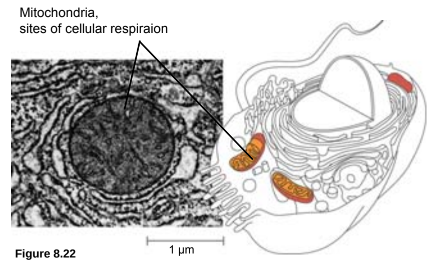


Figure 8.22