

Chapter 8

An Introduction to Metabolism

PowerPoint® Lecture Presentations for

Biology

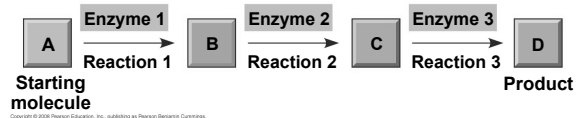
Eighth Edition

Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

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Fig. 8-UN1



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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
- Metabolism is an emergent property of life that arises from interactions between molecules within the cell

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- **Catabolic pathways** release energy by breaking down complex molecules into simpler compounds
 - Cellular respiration, the breakdown of glucose in the presence of oxygen, is an example of a pathway of catabolism

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Organization of the Chemistry of Life into Metabolic Pathways

- A **metabolic pathway** begins with a specific molecule and ends with a product
- Each step is catalyzed by a specific enzyme

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- **Anabolic pathways** consume energy to build complex molecules from simpler ones
 - The synthesis of protein from amino acids is an example of anabolism
 - **Bioenergetics** is the study of how organisms manage their energy resources

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Forms of Energy

- **Energy** is the capacity to cause change
- Energy exists in various forms, some of which can perform work

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The First Law of Thermodynamics

- According to the **first law of thermodynamics**, the energy of the universe is constant:
 - *Energy can be transferred and transformed, but it cannot be created or destroyed*
- The first law is also called the principle of conservation of energy

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- **Kinetic energy** is energy associated with motion
- **Heat (thermal energy)** is kinetic energy associated with random movement of atoms or molecules
- **Potential energy** is energy that matter possesses because of its location or structure
- **Chemical energy** is potential energy available for release in a chemical reaction
- Energy can be converted from one form to another

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The Second Law of Thermodynamics

- During every energy transfer or transformation, some energy is unusable, and is often lost as heat
- According to the **second law of thermodynamics**:
 - *Every energy transfer or transformation increases the **entropy** (disorder) of the universe*

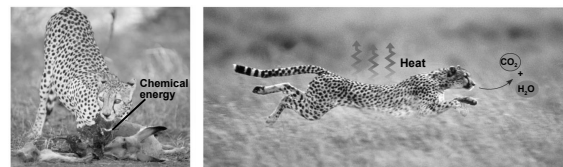
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The Laws of Energy Transformation

- **Thermodynamics** is the study of energy transformations
- A closed system, such as that approximated by liquid in a thermos, is isolated from its surroundings
- In an open system, energy and matter can be transferred between the system and its surroundings
- Organisms are open systems

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Fig. 8-3



(a) First law of thermodynamics (b) Second law of thermodynamics

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- Living cells unavoidably convert organized forms of energy to heat
 - Spontaneous processes occur without energy input; they can happen quickly or slowly
 - For a process to occur without energy input, it must increase the entropy of the universe
-

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Free-Energy Change, ΔG

- A living system's **free energy** is energy that can do work when temperature and pressure are uniform, as in a living cell
-

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Biological Order and Disorder

- Cells create ordered structures from less ordered materials
 - Organisms also replace ordered forms of matter and energy with less ordered forms
 - Energy flows into an ecosystem in the form of light and exits in the form of heat
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-
- The change in free energy (ΔG) during a process is related to the change in enthalpy, or change in total energy (ΔH), change in entropy (ΔS), and temperature in Kelvin (T):

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

- Only processes with a negative ΔG are spontaneous
 - Spontaneous processes can be harnessed to perform work
-

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Concept 8.2: The free-energy change of a reaction tells us whether or not the reaction occurs spontaneously

- Biologists want to know which reactions occur spontaneously and which require input of energy
 - To do so, they need to determine energy changes that occur in chemical reactions
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Free Energy, Stability, and Equilibrium

- Free energy is a measure of a system's instability, its tendency to change to a more stable state
 - During a spontaneous change, free energy decreases and the stability of a system increases
 - Equilibrium is a state of maximum stability
 - A process is spontaneous and can perform work only when it is moving toward equilibrium
-

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Fig. 8-5a

- More free energy (higher G)
- Less stable
- Greater work capacity

In a spontaneous change

- The free energy of the system decreases ($\Delta G < 0$)
- The system becomes more stable
- The released free energy can be harnessed to do work

- Less free energy (lower G)
- More stable
- Less work capacity

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Exergonic and Endergonic Reactions in Metabolism

- An **exergonic reaction** proceeds with a net release of free energy and is spontaneous
- An **endergonic reaction** absorbs free energy from its surroundings and is nonspontaneous

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Fig. 8-5b

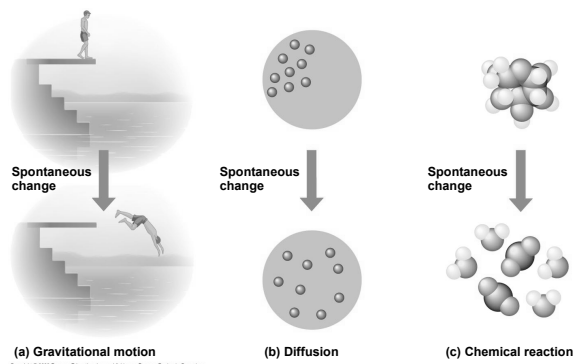
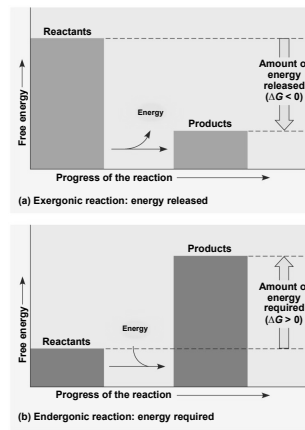


Fig. 8-6



Free Energy and Metabolism

- The concept of free energy can be applied to the chemistry of life's processes

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Equilibrium and Metabolism

- Reactions in a closed system eventually reach equilibrium and then do no work
- Cells are not in equilibrium; they are open systems experiencing a constant flow of materials
- A defining feature of life is that metabolism is never at equilibrium
- A catabolic pathway in a cell releases free energy in a series of reactions

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Concept 8.3: ATP powers cellular work by coupling exergonic reactions to endergonic reactions

- A cell does three main kinds of work:
 - Chemical
 - Transport
 - Mechanical
- To do work, cells manage energy resources by **energy coupling**, the use of an exergonic process to drive an endergonic one
- Most energy coupling in cells is mediated by ATP

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- The bonds between the phosphate groups of ATP's tail can be broken by hydrolysis
- Energy is released from ATP when the terminal phosphate bond is broken
- This release of energy comes from the chemical change to a state of lower free energy, not from the phosphate bonds themselves

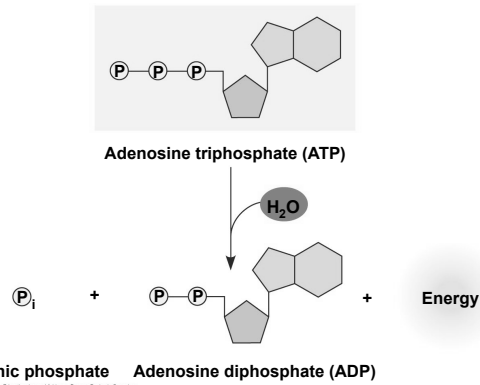
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The Structure and Hydrolysis of ATP

- **ATP (adenosine triphosphate)** is the cell's energy shuttle
- ATP is composed of ribose (a sugar), adenine (a nitrogenous base), and three phosphate groups

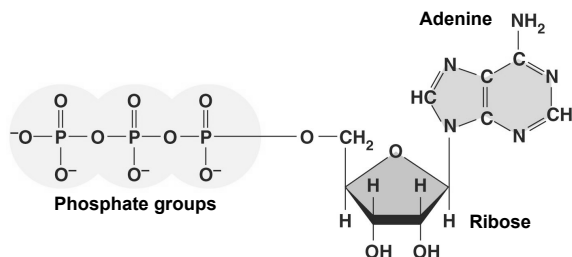
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Fig. 8-9



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Fig. 8-8



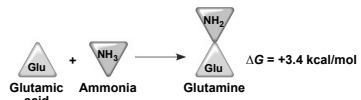
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How ATP Performs Work

- The three types of cellular work (mechanical, transport, and chemical) are powered by the hydrolysis of ATP
- In the cell, the energy from the exergonic reaction of ATP hydrolysis can be used to drive an endergonic reaction
- Overall, the coupled reactions are exergonic

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Fig. 8-10



(a) Endergonic reaction

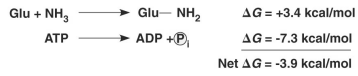
1 ATP phosphorylates glutamic acid, making the amino acid less stable.



2 Ammonia displaces the phosphate group, forming glutamine.



(b) Coupled with ATP hydrolysis, an exergonic reaction



(c) Overall free-energy change

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The Regeneration of ATP

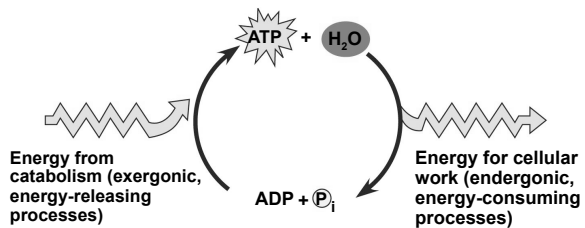
- ATP is a renewable resource that is regenerated by addition of a phosphate group to adenosine diphosphate (ADP)
- The energy to phosphorylate ADP comes from catabolic reactions in the cell
- The chemical potential energy temporarily stored in ATP drives most cellular work

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- ATP drives endergonic reactions by phosphorylation, transferring a phosphate group to some other molecule, such as a reactant
- The recipient molecule is now **phosphorylated**

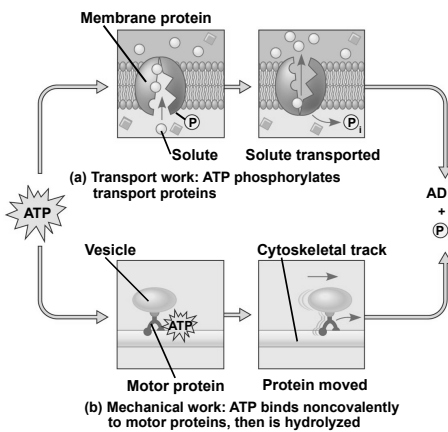
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Fig. 8-12



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Fig. 8-11



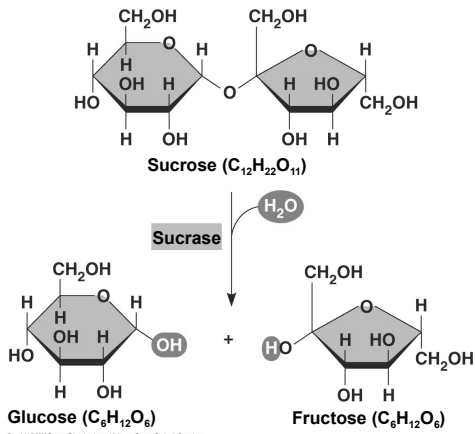
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Concept 8.4: Enzymes speed up metabolic reactions by lowering energy barriers

- A **catalyst** is a chemical agent that speeds up a reaction without being consumed by the reaction
- An **enzyme** is a catalytic protein
- Hydrolysis of sucrose by the enzyme sucrase is an example of an enzyme-catalyzed reaction

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Fig. 8-13



How Enzymes Lower the E_A Barrier

- Enzymes catalyze reactions by lowering the E_A barrier
- Enzymes do not affect the change in free energy (ΔG); instead, they hasten reactions that would occur eventually

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The Activation Energy Barrier

- Every chemical reaction between molecules involves bond breaking and bond forming
- The initial energy needed to start a chemical reaction is called the **free energy of activation**, or **activation energy (E_A)**
- Activation energy is often supplied in the form of heat from the surroundings

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Fig. 8-15

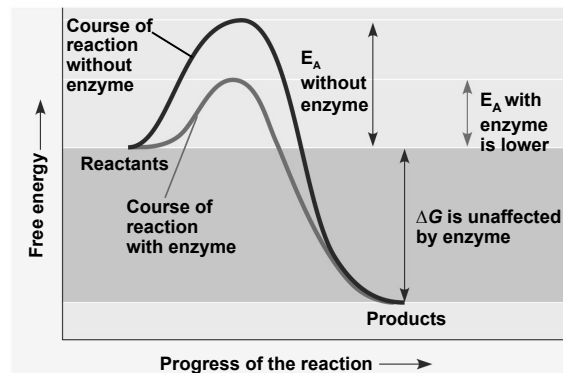
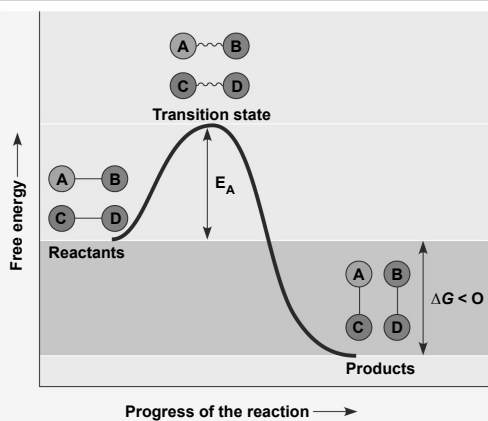


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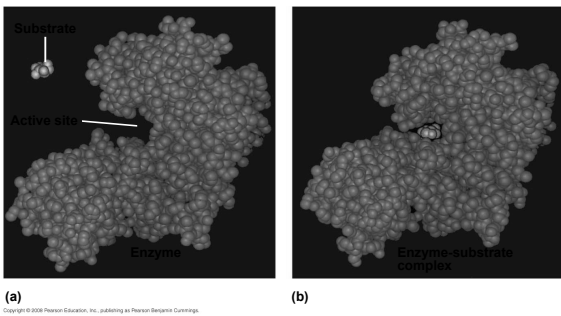


Substrate Specificity of Enzymes

- The reactant that an enzyme acts on is called the enzyme's **substrate**
- The enzyme binds to its substrate, forming an **enzyme-substrate complex**
- The **active site** is the region on the enzyme where the substrate binds
- Induced fit** of a substrate brings chemical groups of the active site into positions that enhance their ability to catalyze the reaction

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Fig. 8-16



(a)
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(b)

Effects of Local Conditions on Enzyme Activity

- An enzyme's activity can be affected by
 - General environmental factors, such as temperature and pH
 - Chemicals that specifically influence the enzyme

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Catalysis in the Enzyme's Active Site

- In an enzymatic reaction, the substrate binds to the active site of the enzyme
- 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

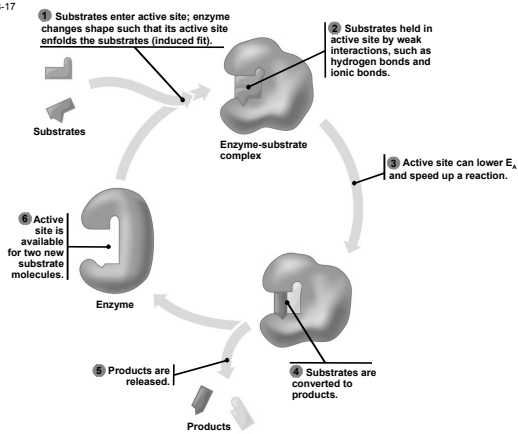
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Effects of Temperature and pH

- Each enzyme has an optimal temperature in which it can function
- Each enzyme has an optimal pH in which it can function

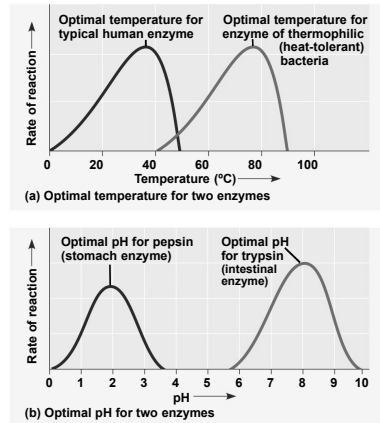
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Fig. 8-17



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Fig. 8-18



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Cofactors

- **Cofactors** are nonprotein enzyme helpers
- Cofactors may be inorganic (such as a metal in ionic form) or organic
- An organic cofactor is called a **coenzyme**
- Coenzymes include vitamins

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Concept 8.5: Regulation of enzyme activity helps control metabolism

- Chemical chaos would result if a cell's metabolic pathways were not tightly regulated
- A cell does this by switching on or off the genes that encode specific enzymes or by regulating the activity of enzymes

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Enzyme Inhibitors

- **Competitive inhibitors** bind to the active site of an enzyme, competing with the substrate
- **Noncompetitive inhibitors** bind to another part of an enzyme, causing the enzyme to change shape and making the active site less effective
- Examples of inhibitors include toxins, poisons, pesticides, and antibiotics

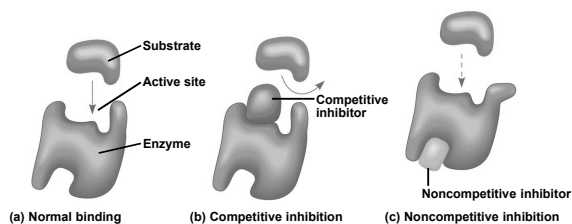
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Allosteric Regulation of Enzymes

- **Allosteric regulation** may either inhibit or stimulate an enzyme's activity
- Allosteric regulation occurs when a regulatory molecule binds to a protein at one site and affects the protein's function at another site

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Fig. 8-19



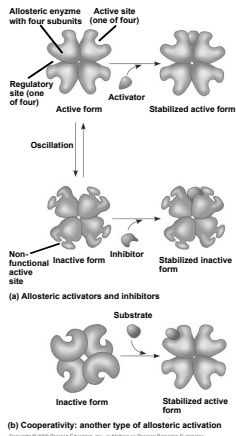
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Allosteric Activation and Inhibition

- Most allosterically regulated enzymes are made from polypeptide subunits
- Each enzyme has active and inactive forms
- The binding of an activator stabilizes the active form of the enzyme
- The binding of an inhibitor stabilizes the inactive form of the enzyme

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Fig. 8-20

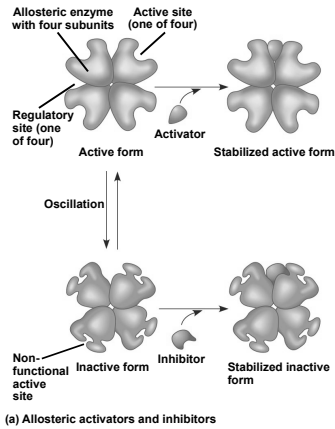


Feedback Inhibition

- In **feedback inhibition**, the end product of a metabolic pathway shuts down the pathway
- Feedback inhibition prevents a cell from wasting chemical resources by synthesizing more product than is needed

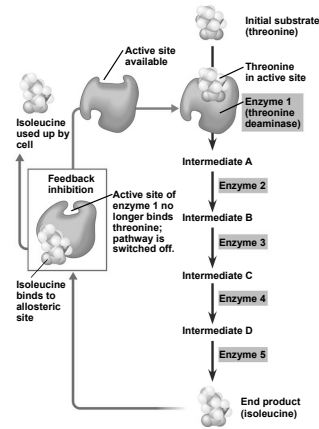
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Fig. 8-20a



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Fig. 8-22



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- **Cooperativity** is a form of allosteric regulation that can amplify enzyme activity
- In cooperativity, binding by a substrate to one active site stabilizes favorable conformational changes at all other subunits

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Specific Localization of Enzymes Within the Cell

- Structures within the cell help bring order to metabolic pathways
- Some enzymes act as structural components of membranes
- In eukaryotic cells, some enzymes reside in specific organelles; for example, enzymes for cellular respiration are located in mitochondria. This is called compartmentalization.

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