Chapter 8

Topics in lectures 15 and 16

- **Metabolism**
  - Chemical foundations
  - Catabolism
  - Biosynthesis

Metabolism

- **Chemical Foundations**
  - Enzymes
  - REDOX
- Catabolism
  - Pathways
- Anabolism
  - Principles and pathways

Chemical Foundations: **Enzymes**

- **Function**
- Structure
- Enzyme-substrate interaction
- Action
- Regulation

Function

- Catalysts for chemical reactions

Reactants <-----------> Products

- Lower the energy needed for the reaction to occur (activation)
  - Endergonic or exergonic

===> Insight 8.1

Chemical Foundations: **Enzymes**

- Function
- **Structure**
- Enzyme-substrate interaction
- Action
- Regulation

Structure

- Simple enzyme
  - single protein
- Conjugated enzyme
  - single protein & cofactor
- Three-dimensional structure (conformation)
  - Enable specificity
    - Active or catalytic site
  - Enable regulation of activity

Cofactors

Cofactors bind to and activate the enzyme

- Ex. Metallic cofactors
  - Iron, copper, magnesium

- Coenzymes

Conjugated enzymes contain a metallic cofactor, coenzyme, or both in order for it to function as a catalyst.

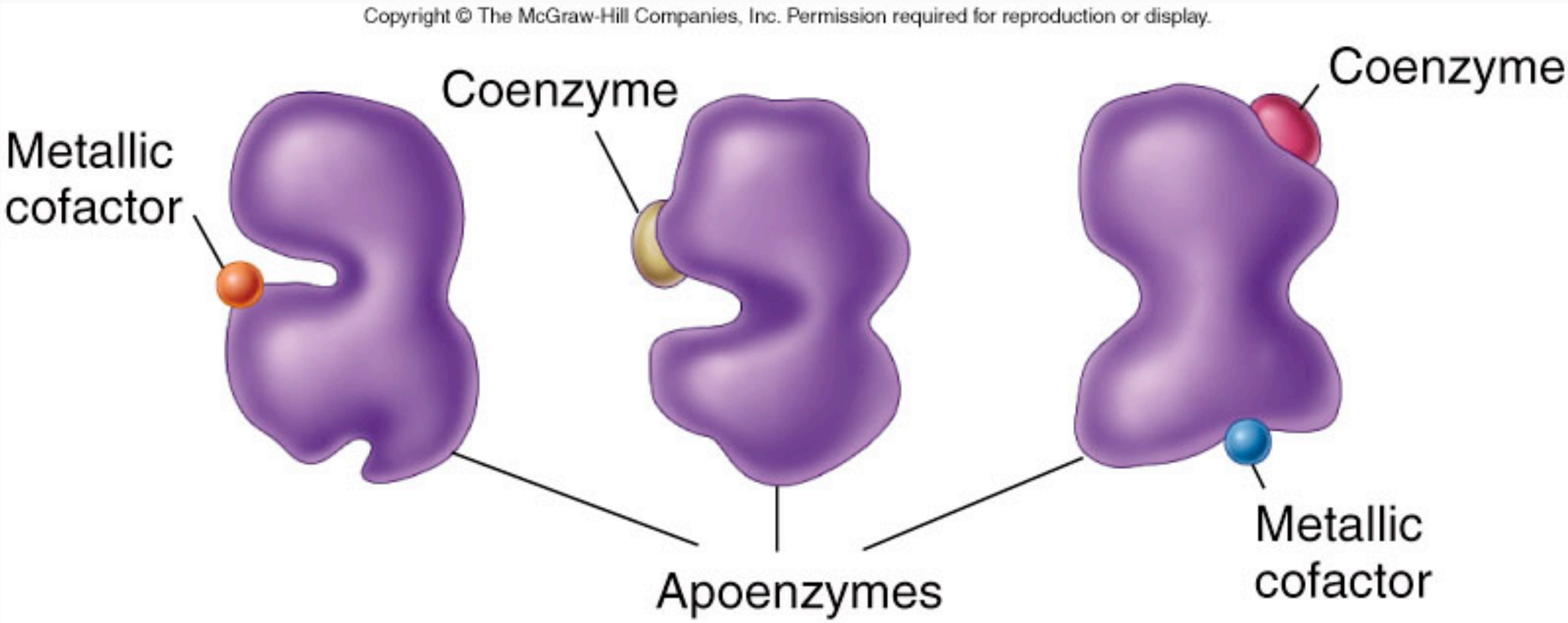


Fig. 8.2 Conjugated enzyme structure

Coenzyme

- Transient carrier - alter a substrate by removing a chemical group from one substrate and adding it to another substrate
  - Ex. Vitamins (nicotinamide, riboflavin)
    - NAD, FAD

An example of how a coenzyme transfers chemical groups from one substrate to another.

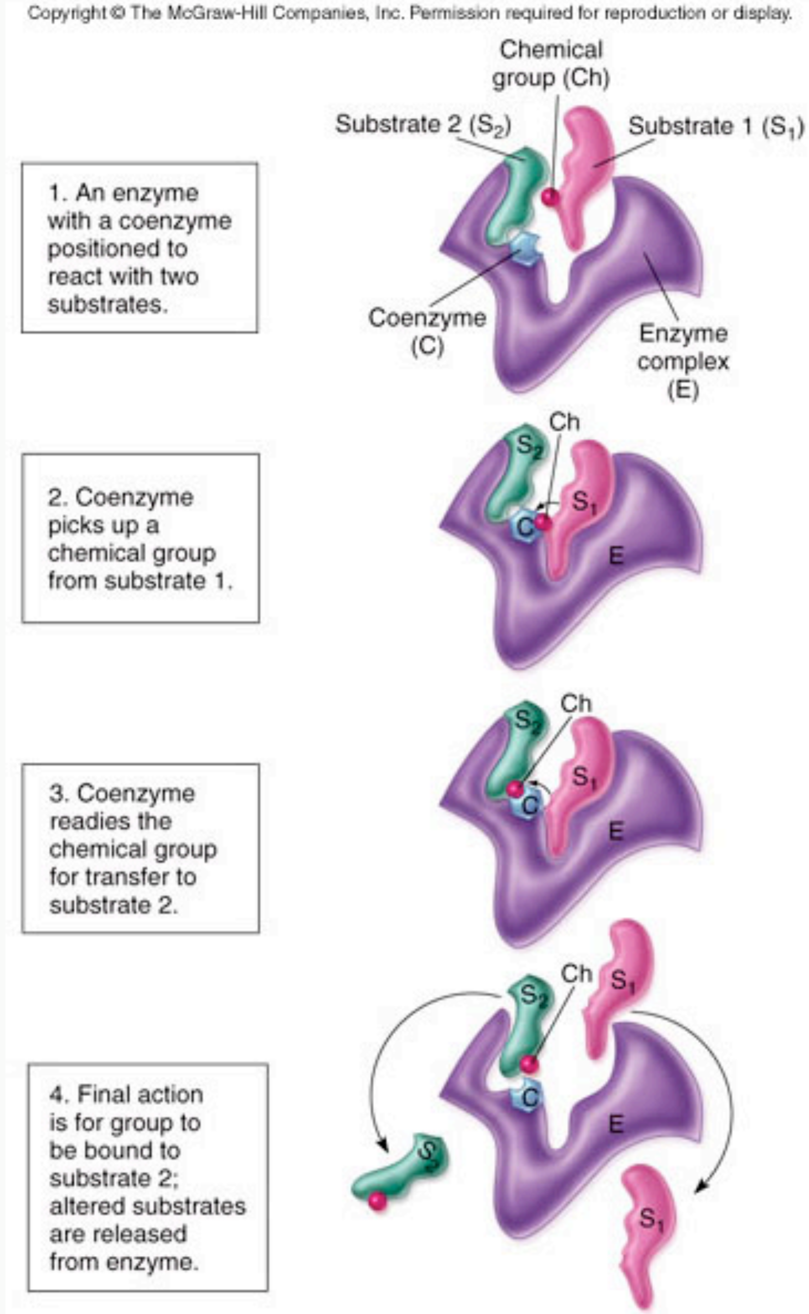


Fig. 8.5 The carrier functions of coenzymes

Specific active sites (amino acids) arise due to the folding of the protein into a specific three-dimensional structure (enzyme).

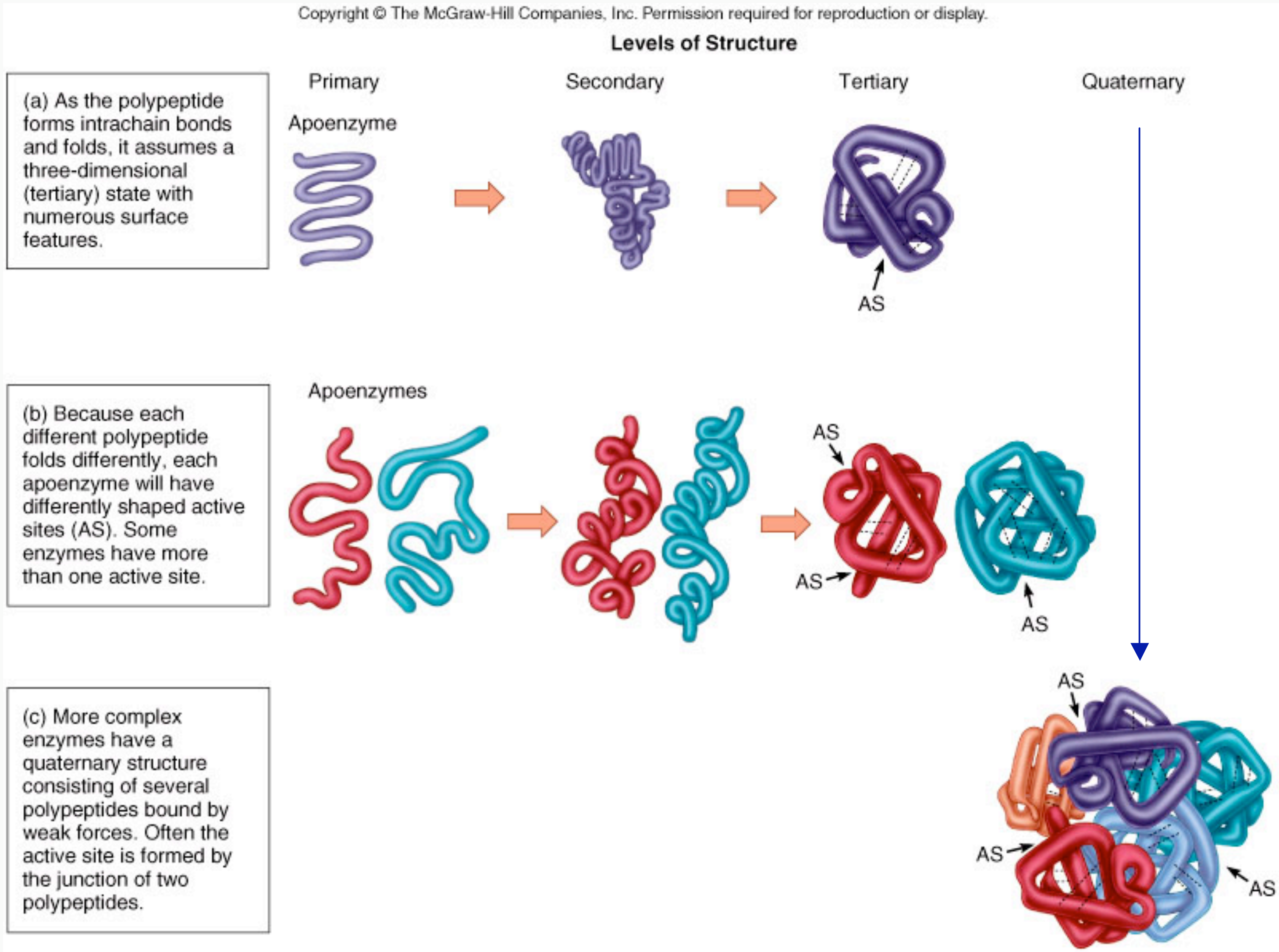


Fig. 8.3 How the active site and specificity of the apoenzyme arise.

Chemical Foundations: **Enzymes**

- Function
- Structure
- **Enzyme-substrate interaction**
- Action
- Regulation

Enzyme-substrate interactions

- Substrates specifically bind to the active sites on the enzyme
  - "lock-and-key"
  - induced fit
- Once the reaction is complete, the product is released and the enzyme reused

An example of the "lock-and-key" model, and the induced fit model.

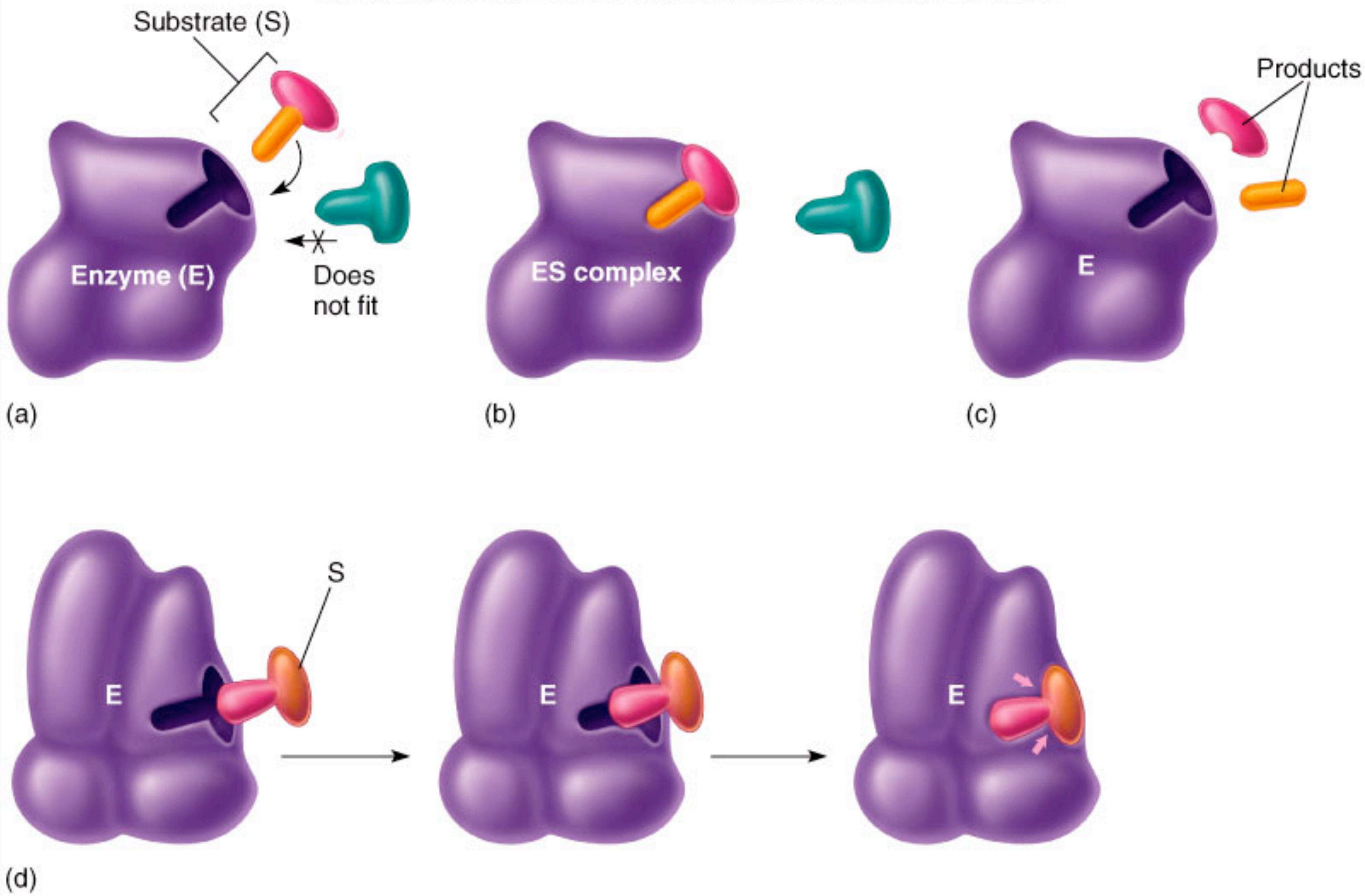


Fig. 8.4 Enzyme-substrate reactions

Chemical Foundations: **Enzymes**

- Function
- Structure
- Enzyme-substrate interaction
- **Action**
- Regulation

Action

- Exoenzymes
- Endoenzymes
- Constitutive
- Induction or repression
- Types of reactions

Exoenzymes are inactive while inside the cell, but upon release from the cell they become active. In contrast, endoenzymes remain in the cell and are active.

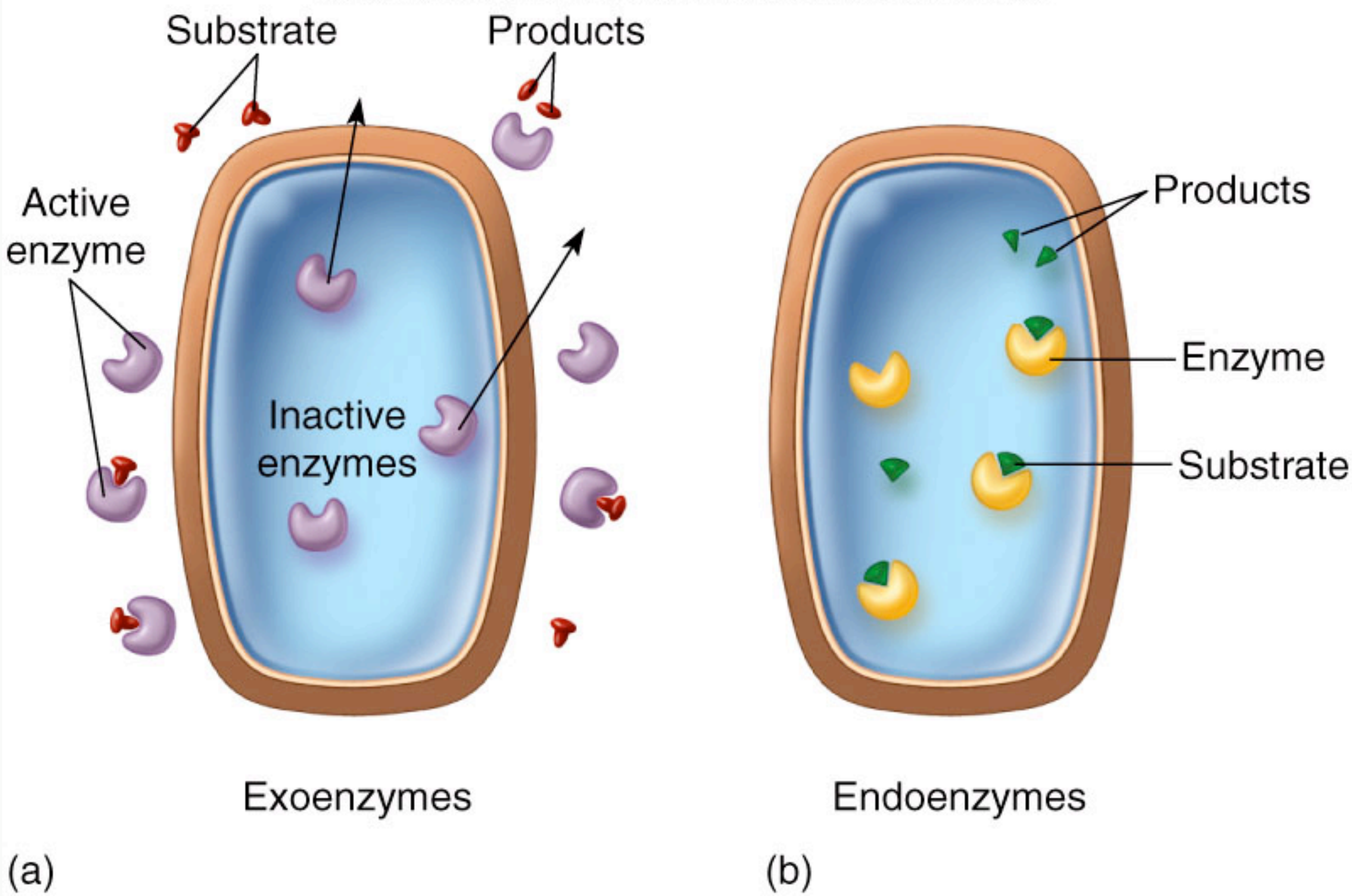
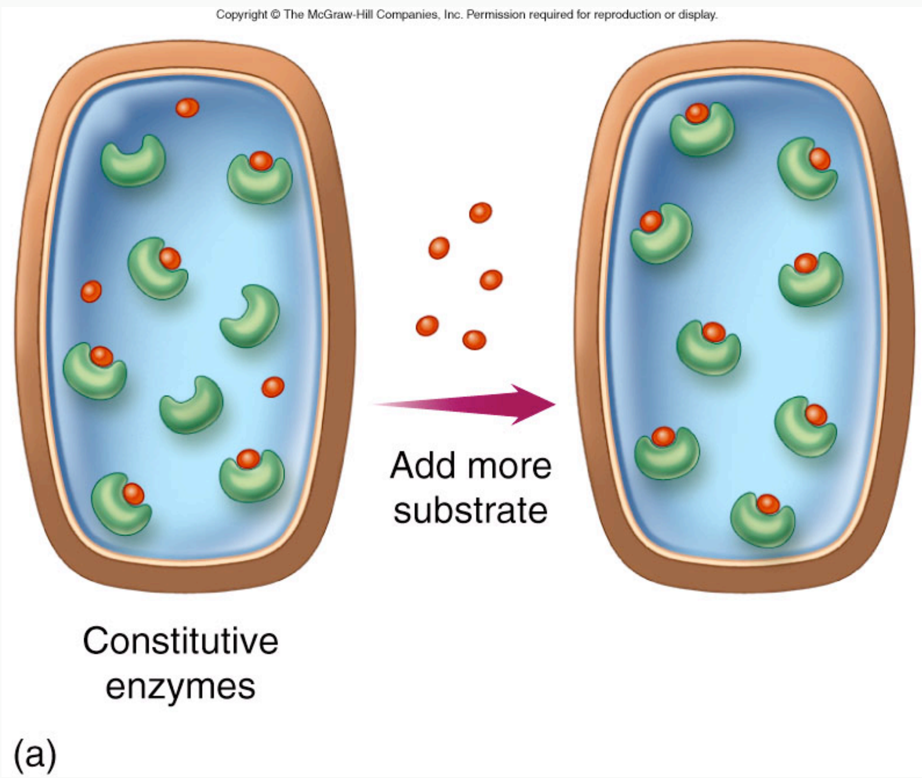


Fig. 8.6 Types of enzymes, as described by their location of action.

Constitutive enzymes are present in constant amounts, while regulated enzymes are either induced or repressed.



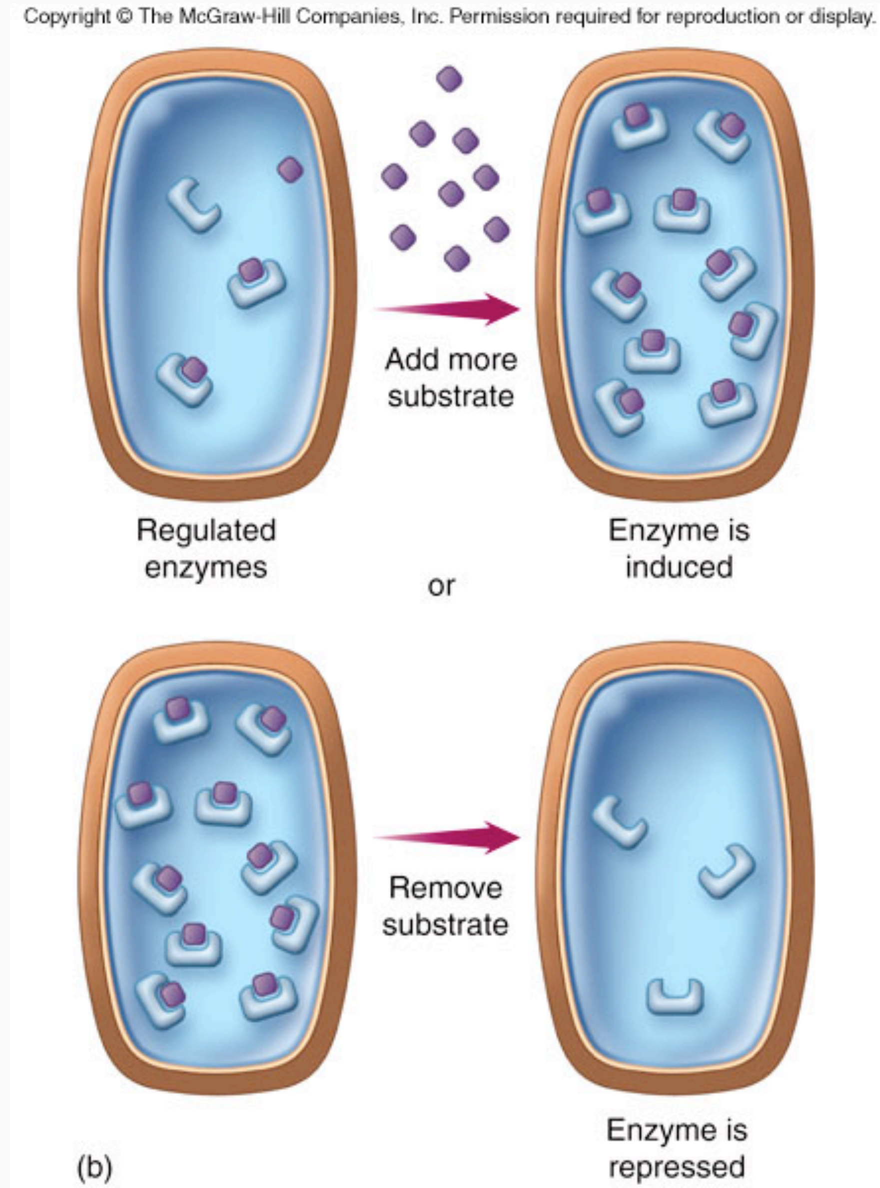
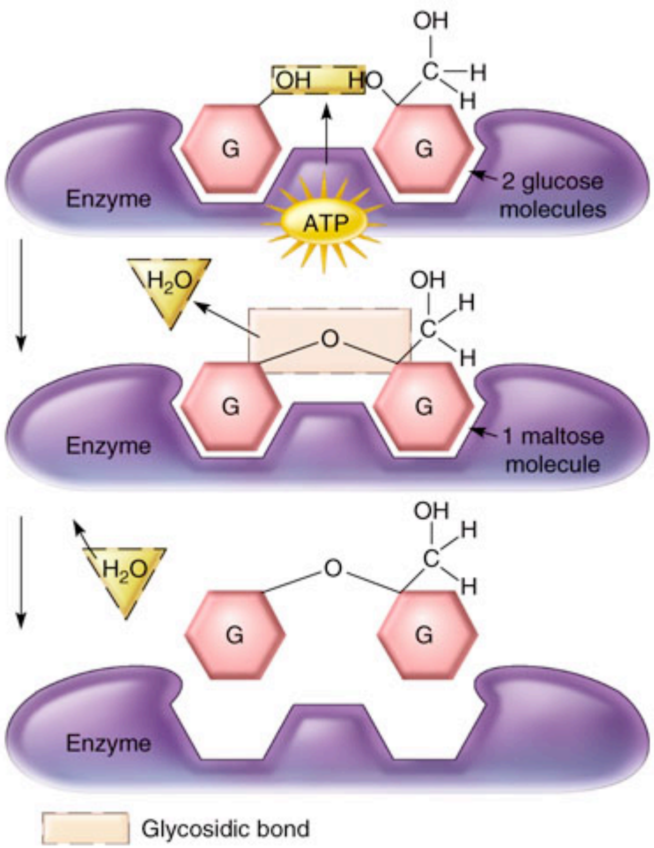


Fig. 8.7 Constitutive and regulated enzymes

Types of Reaction

- Condensation
- Hydrolysis
- Transfer reactions

Condensation reactions are associated with anabolic reactions, and hydrolysis reactions are associated with catabolic reactions.



(a) **Condensation Reaction.** Forming a glycosidic bond between two glucose molecules to generate maltose requires the removal of a water molecule and energy from ATP.

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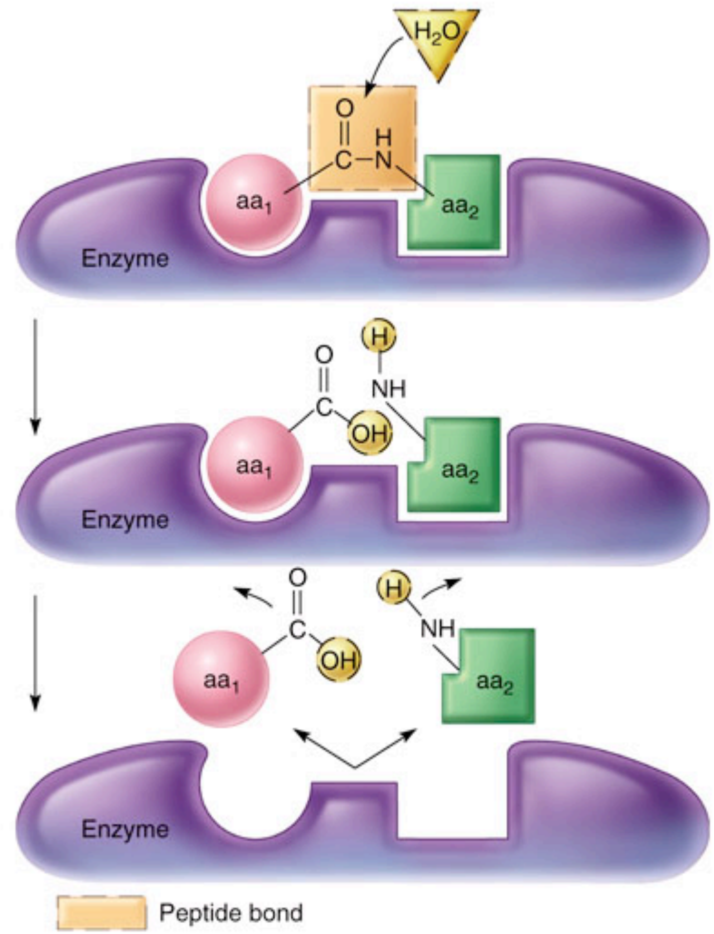


(b) **Hydrolysis Reaction.** Breaking a peptide bond between two amino acids requires a water molecule that adds an H and OH to the amino acids.

Fig. 8.8 Examples of enzyme-catalyzed condensation and hydrolysis reactions

Transfer reactions

- Transfer of **functional groups** from one molecule to another
  - Transferases
    - Aminotransferases
- Transfer of **electrons** from one substrate to another
  - Oxidation and reduction
    - Oxidoreductase

Examples of oxidoreductase, transferase, and hydrolytic enzymes.

TABLE 8.A A Sampling of Enzymes, Their Substrates, and Their Reactions

Common Name	Systematic Name	Enzyme Class	Substrates	Action
Lactase	β-D-galactosidase	Hydrolase	Lactose	Breaks lactose down into glucose and galactose
Penicillinase	Beta-lactamase	Hydrolase	Penicillin	Hydrolyzes beta-lactam ring
DNA polymerase	DNA nucleotidyl-transferase	Transferase	DNA nucleosides	Synthesizes a strand of DNA using the complementary strand as a model
Lactate dehydrogenase	Same as common name	Oxidoreductase	Pyruvic acid	Catalyzes the conversion of pyruvic acid to lactic acid
Oxidase	Cytochrome oxidase	Oxidoreductase	Molecular oxygen	Catalyzes the reduction (addition of electrons and hydrogen) to O_2

Table 8.A A sampling of enzymes, their substrates, and their reactions

Chemical Foundations: **Enzymes**

- Function
- Structure
- Enzyme-substrate interaction
- Action
- **Regulation**

Regulation

- Metabolic pathways
- Direct control (activity)
- Genetic control (concentration)

The different metabolic pathways are regulated by the enzymes that catalyze the reactions

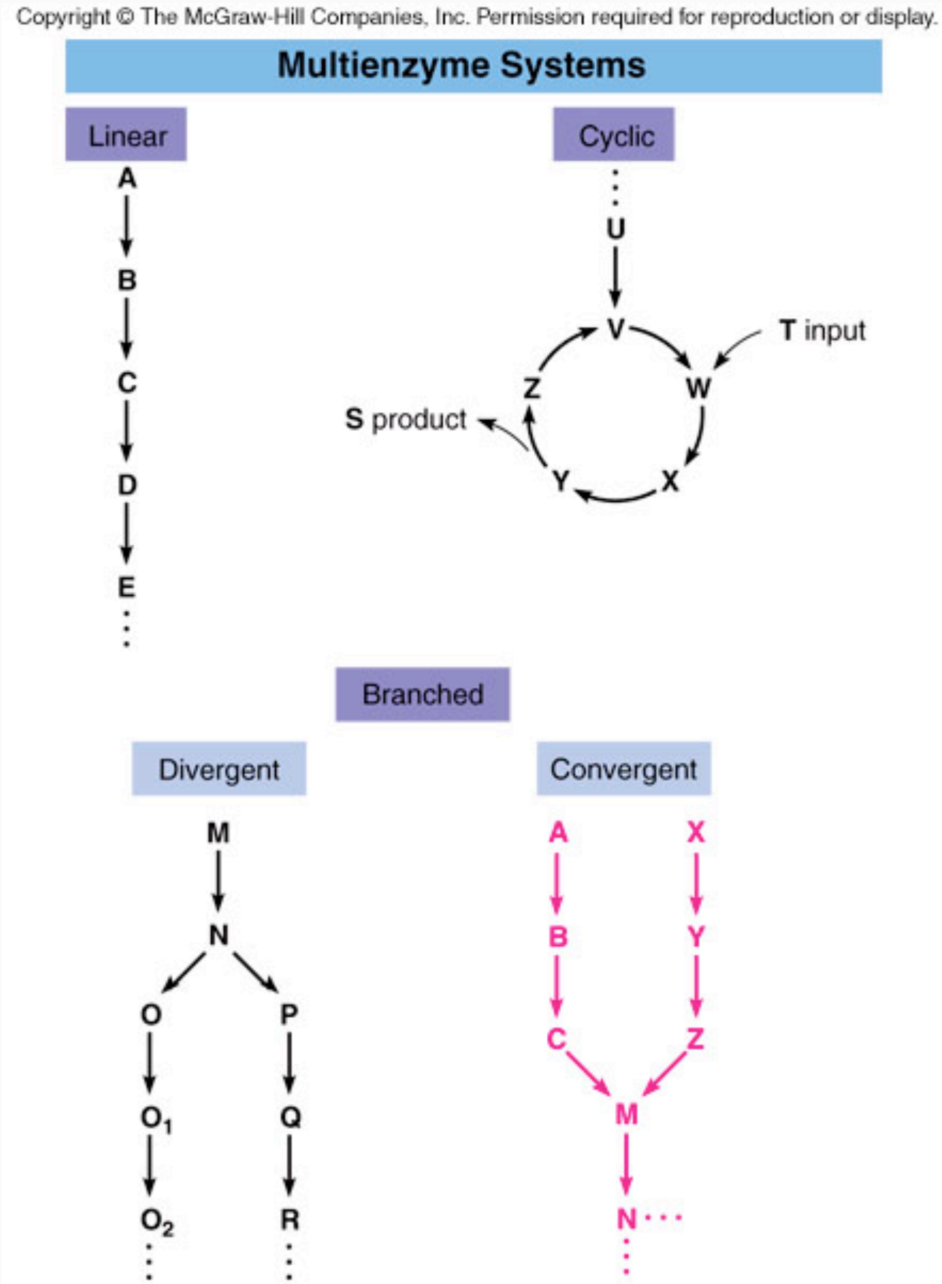


Fig.8.9 Patterns of metabolism

Competitive inhibition and noncompetitive inhibition are examples of direct control (regulation) of the activity of the enzymes.

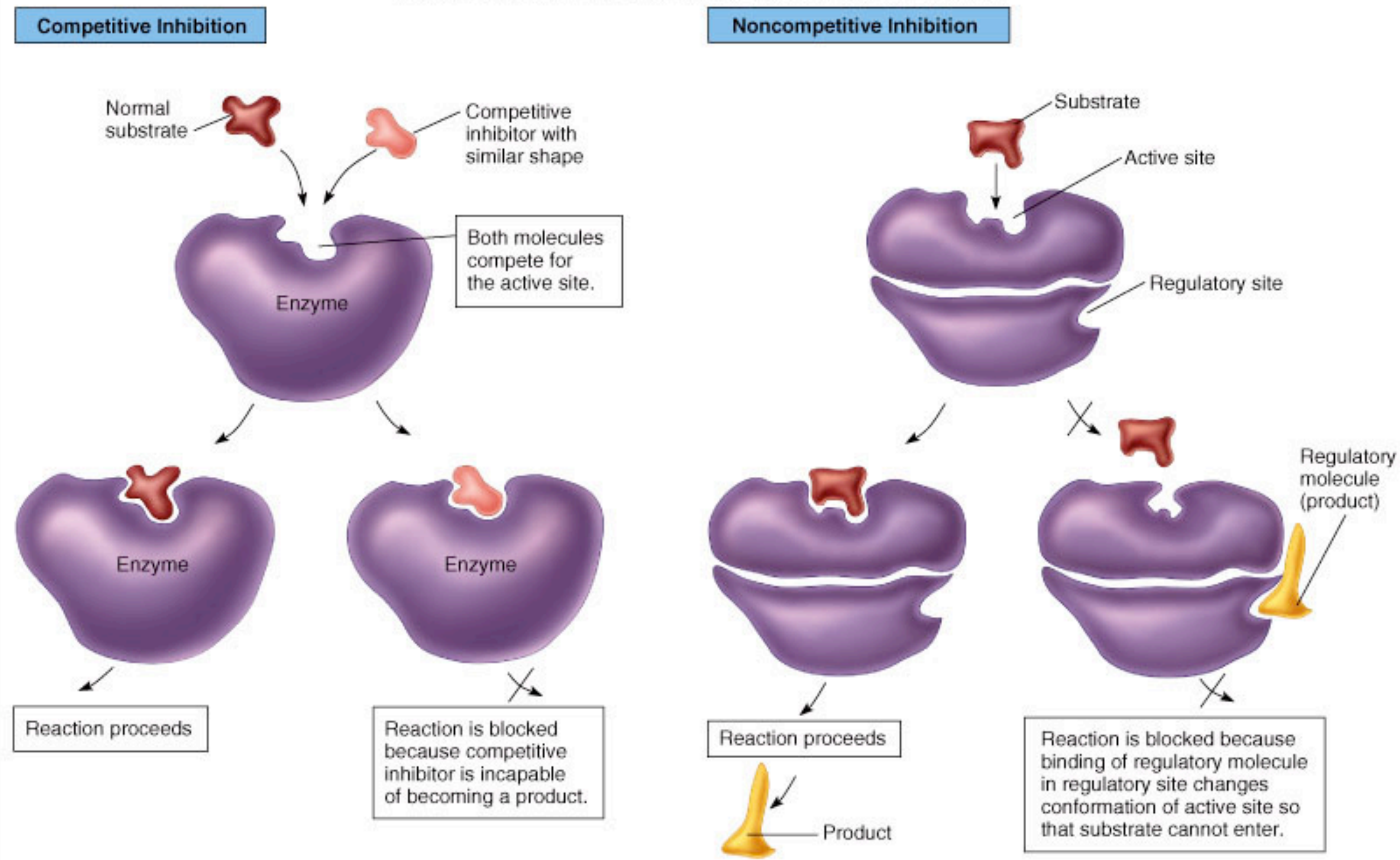


Fig. 8.10 Examples of two common control mechanisms for enzymes.

Genetic control

- Repression
- Induction (de-repression)

Repression is when proteins can stop the expression of genes that encode for enzymes, which involved metabolic reactions.

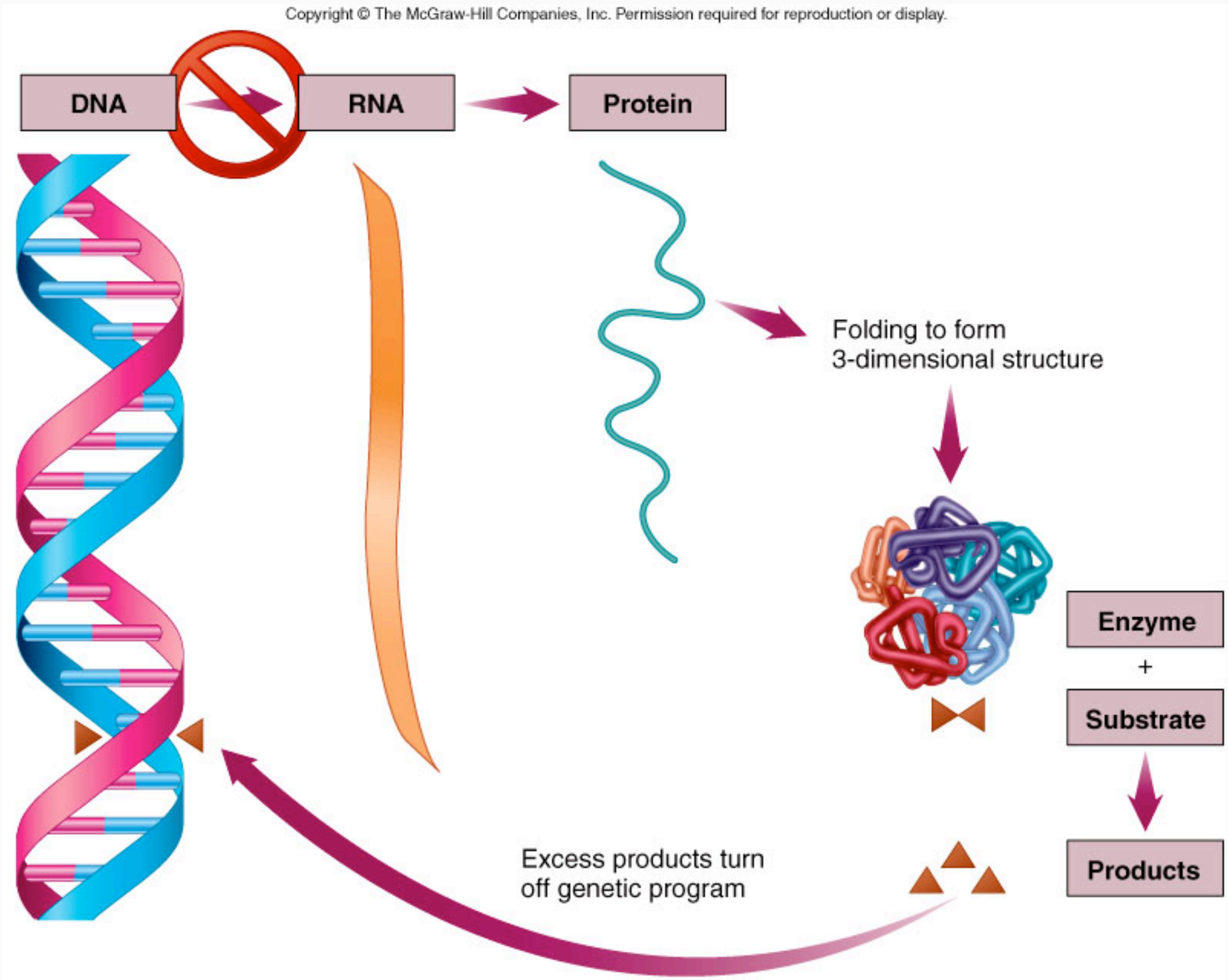


Fig. 8.11 One type of genetic control of enzyme synthesis

Summary of major enzyme characteristics.

TABLE 8.1 Checklist of Enzyme Characteristics

- Most are composed of protein; may require cofactors
- Act as organic catalysts to speed up the rate of cellular reactions
- Lower the activation energy required for a chemical reaction to proceed (Insight 8.1)
- Have unique characteristics such as shape, specificity, and function
- Enable metabolic reactions to proceed at a speed compatible with life
- Provide an active site for target molecules called substrates
- Are much larger in size than their substrates
- Associate closely with substrates but do not become integrated into the reaction products
- Are not used up or permanently changed by the reaction
- Can be recycled, thus function in extremely low concentrations
- Are greatly affected by temperature and pH
- Can be regulated by feedback and genetic mechanisms

Table 8.1 Checklist of enzyme characteristics

Chemical Foundations: **Redox reactions**

- **Red**uction and **ox**idation reaction
- Electron carriers transfer electrons and hydrogens
  - Electron donor
  - Electron acceptor
- Energy is also transferred and captured by the phosphate in form of ATP

REDOX

RED

OXIDANT + electron <==> REDUCTANT

OX

ELECTRON ACCEPTOR

ELECTRON DONOR

OIL --- RIG

Electron carriers

- Coenzymes
  - Nicotinamide adenine dinucleotide (NAD)
- Respiratory chain carriers
  - Cytochromes (protein)

Electron carriers, such as NAD, accept electrons and hydrogens from the substrate (organic molecule).

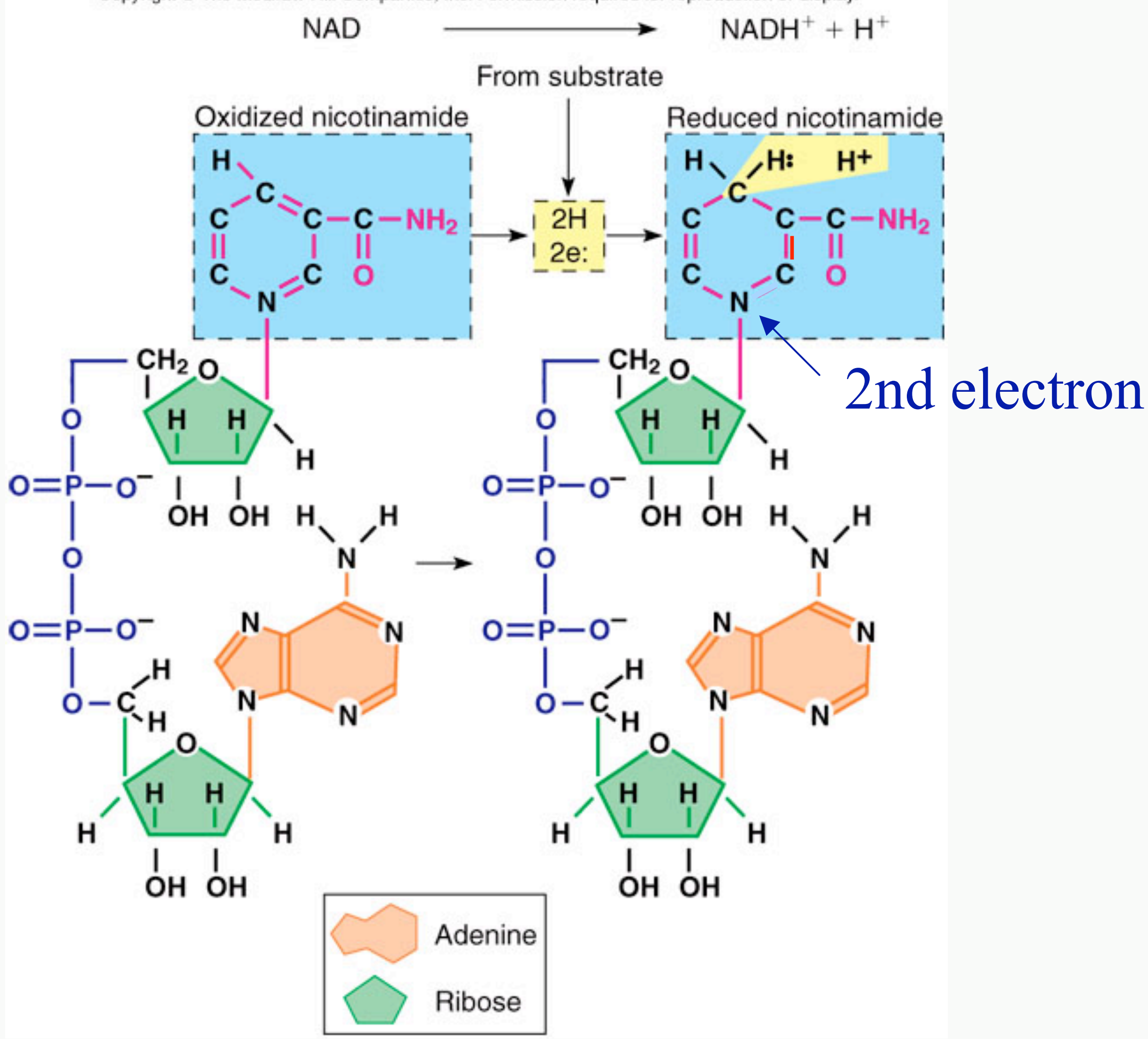


Fig. 8.13 Details of NAD reduction

Adenosine Triphosphate (ATP)

- Temporary energy repository
- Breaking of phosphates bonds will release free energy
- Three part molecule
  - Nitrogen base
  - 5-carbon sugar (ribose)
  - Chain of phosphates

The phosphates capture the energy and becomes part of the ATP molecule.

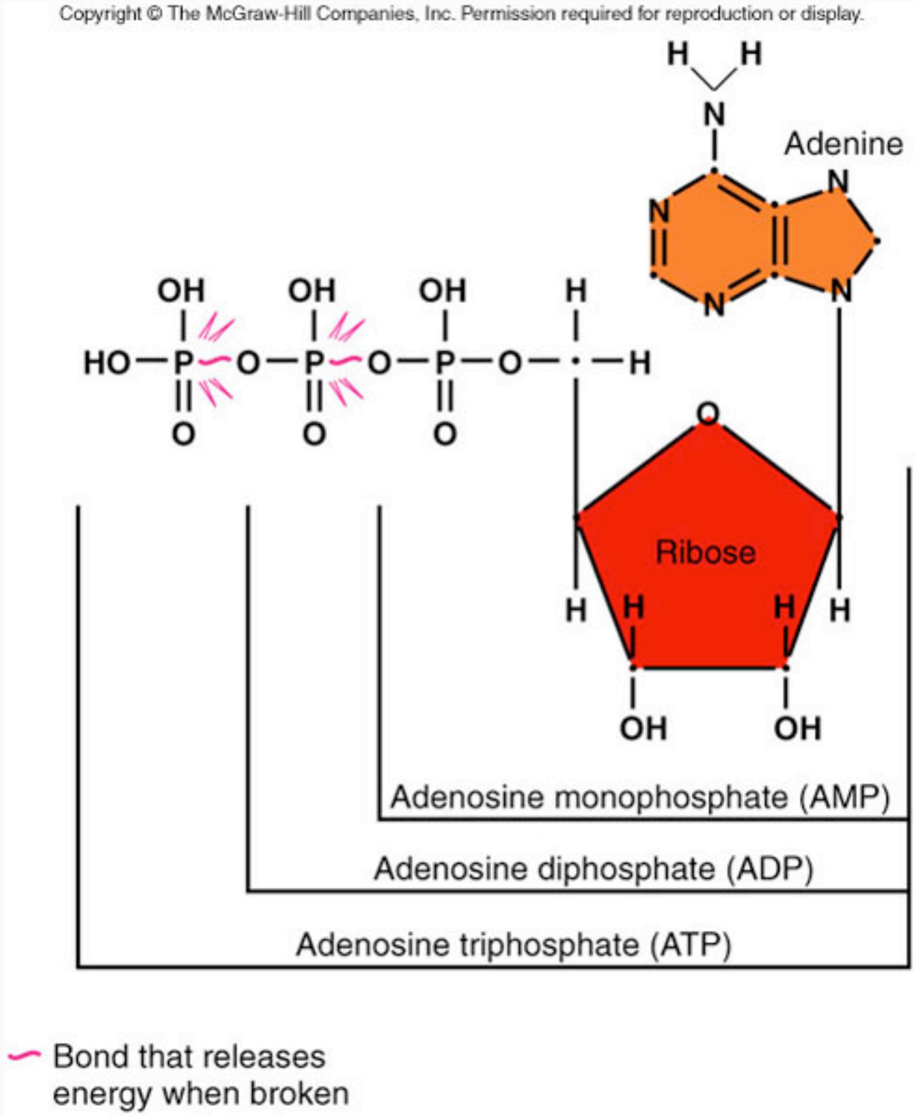


Fig. 8.14 The structure of adenosine triphosphate and its partner compounds, ADP and AMP.

ATP can be used to phosphorylate an organic molecule such as glucose during catabolism, thereby “passing on” bond energy.

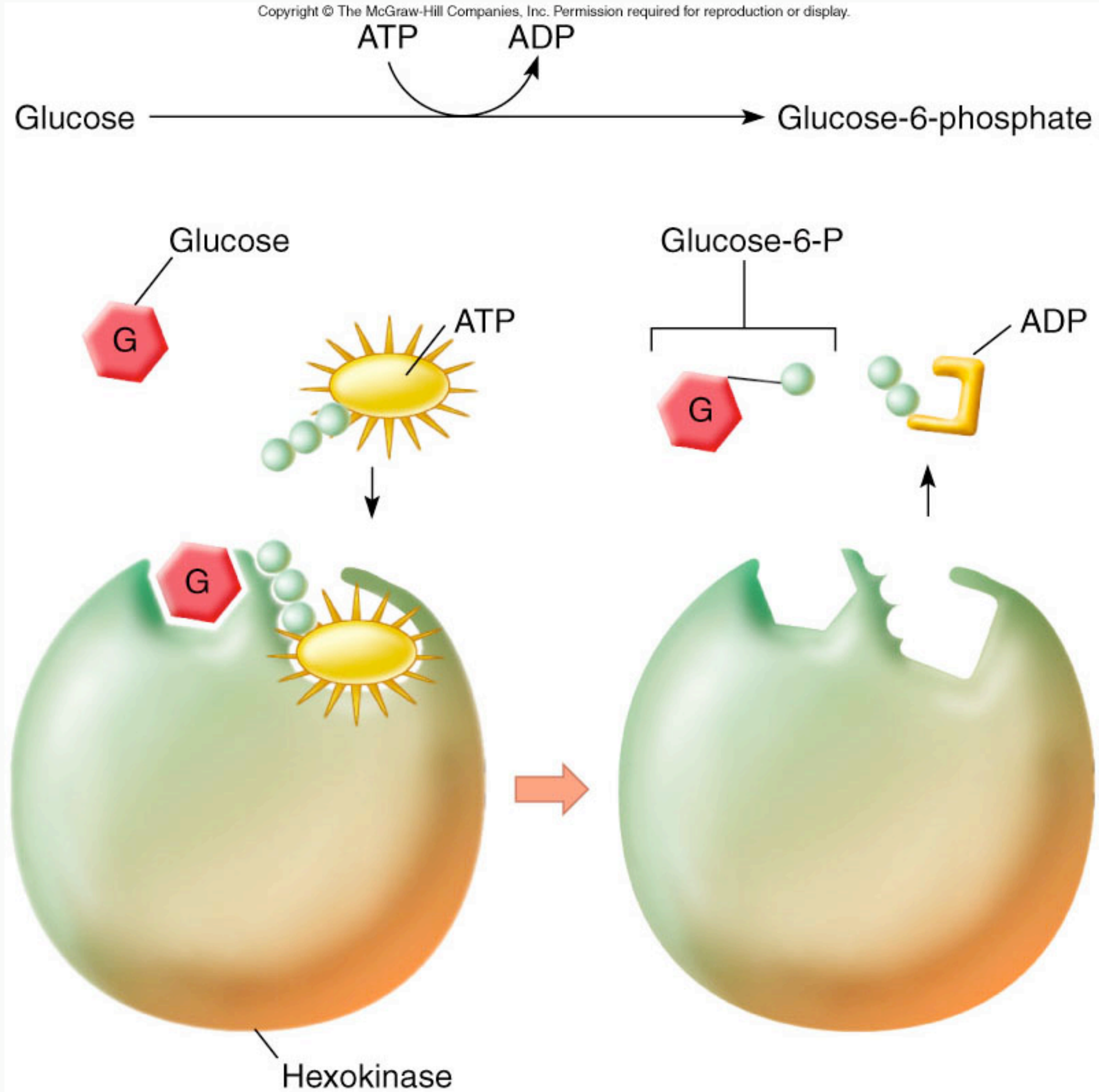
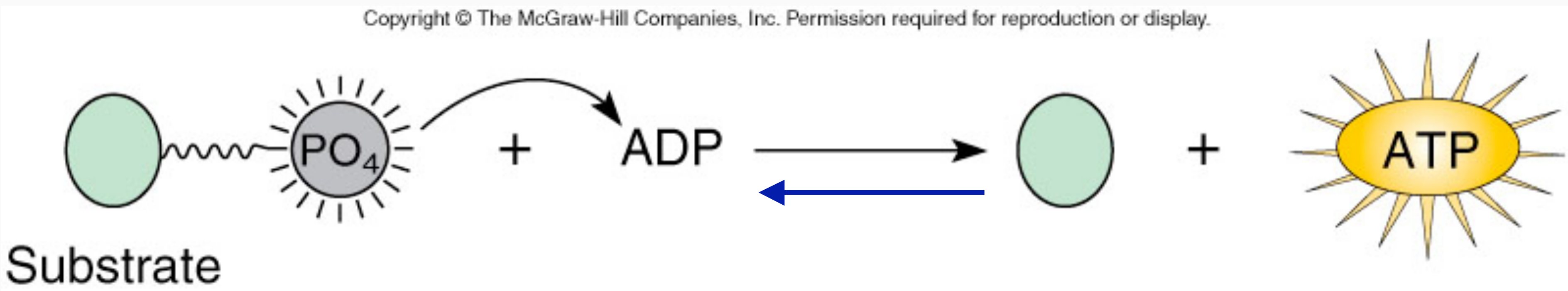


Fig. 8.15 An example of phosphorylation of glucose by ATP

ATP can be synthesized by substrate-level phosphorylation.



ATP can phosphorylate by substrate-level phosphorylation.

Fig. 8.16 ATP formation by substrate-level phosphorylation

Metabolism

- Chemical Foundations
  - Enzymes
  - REDOX
- **Catabolism**
  - Pathways
- **Anabolism**
  - Principles and pathways

Catabolism

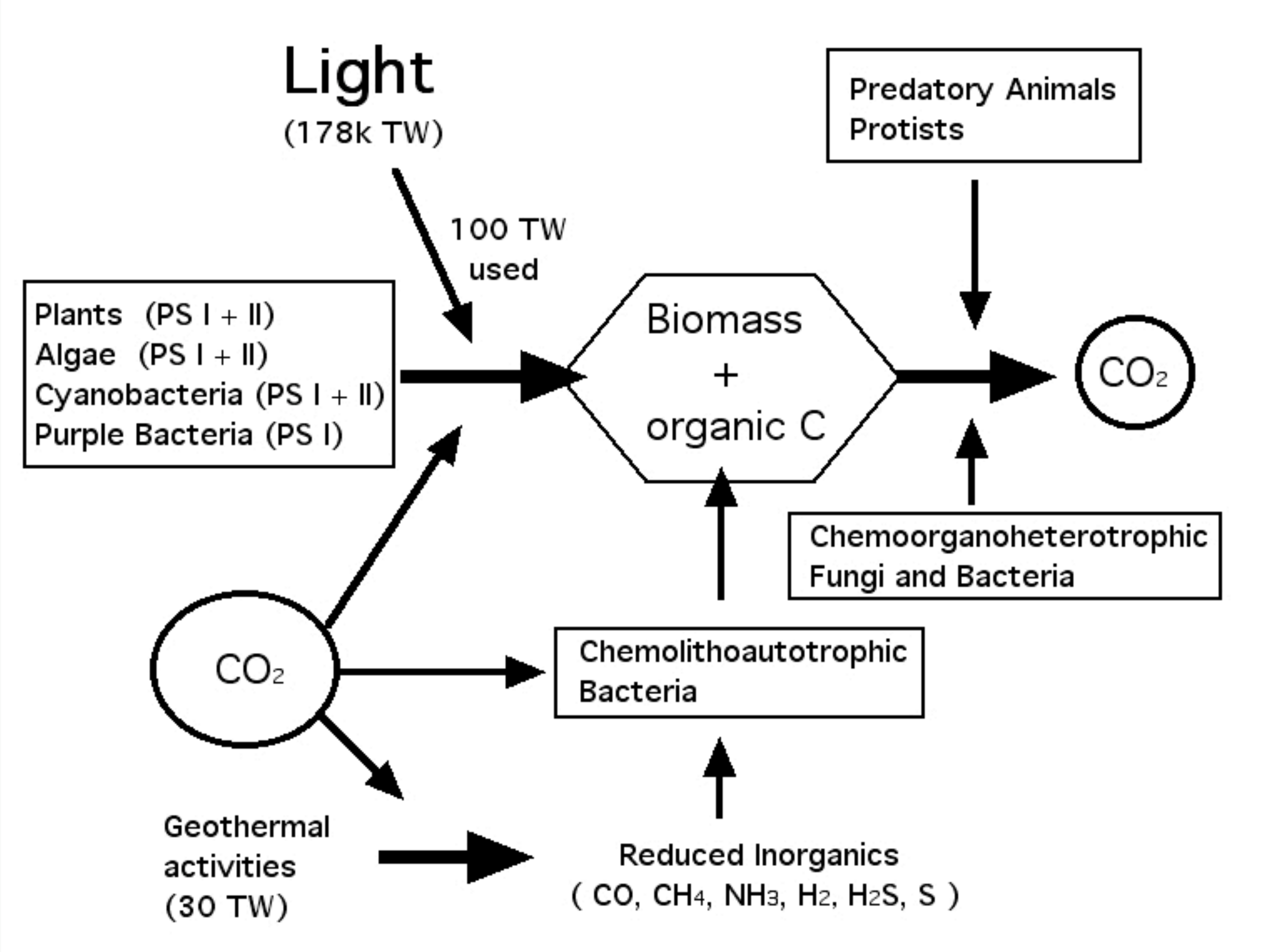
- Enzymes are involved in the **harvest of energy** from the environment and their transformation into cell-own, useable energy. Some of this energy needs to be spent in the process on the accession of energy and nutrients (e.g., chemotaxis, transport).

Anabolism

- Enzymes are involved in the **use of energy** from catabolism in order to synthesize simple and complex compounds, macromolecules and cell structures from simpler compounds).

Energy

- **Cell energetics**
  - **Exergonic**
  - **Endergonic**
- **Redox reaction**
- **Electron carrier**
- **Adenosine Triphosphate (ATP)**



Integrated model of energy and carbon flow

The relationship between catabolism and anabolism.

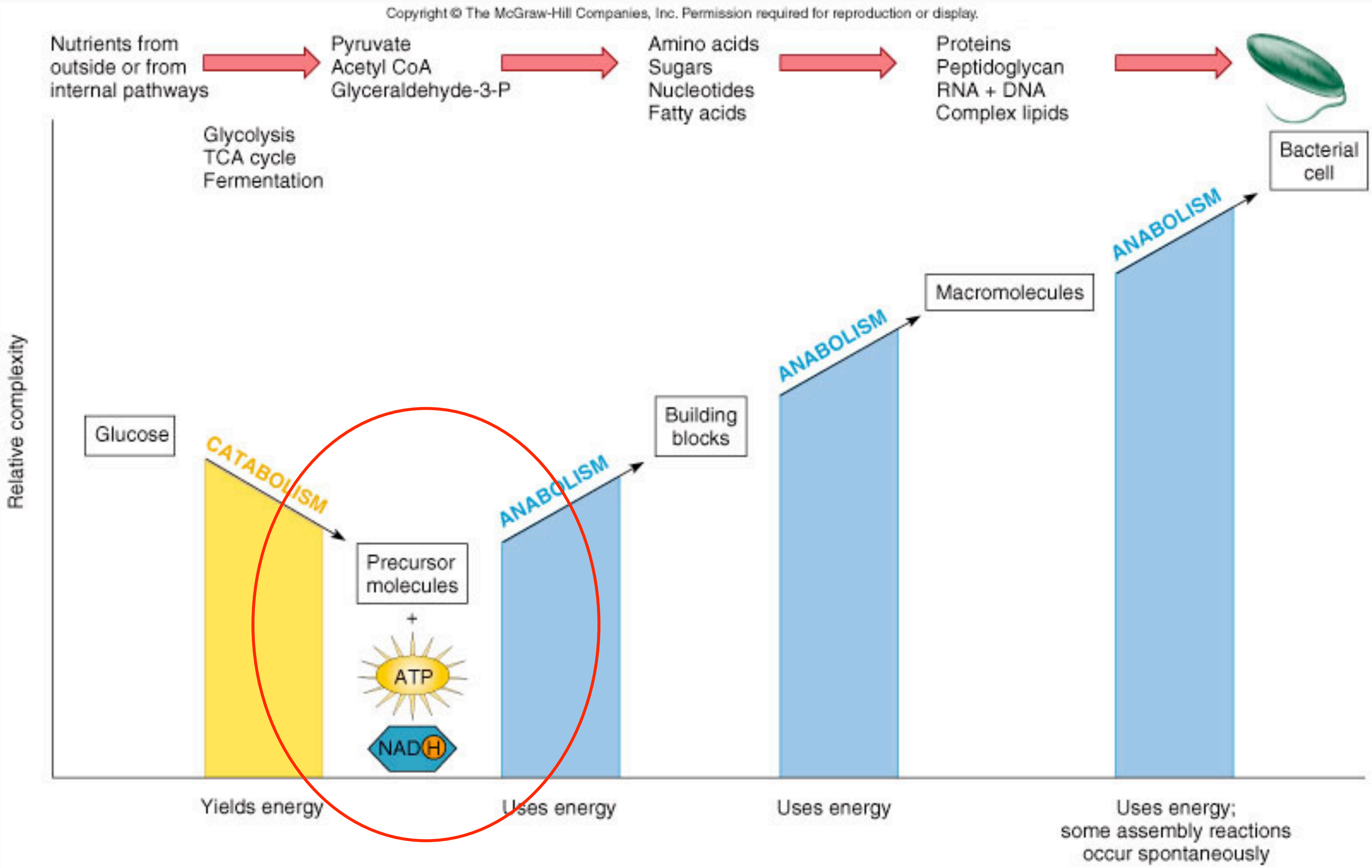


Fig. 8.1 Simplified model of metabolism

Pathways leading to the 12 precursors

- Central Pathways
  - Mostly catabolism
    - Embden-Meyerhof-Parnas (EMP) pathway [glycolysis]
      - 5 precursors: G6P, 3PG, DHAP,PEP,pyruvate
    - Tricarboxylic acid cycle (TCA)
      - 3 precursors: OAA, alpha-KG, succinyl~CoA
  - Mostly anabolism
    - Pentose phosphate pathway
      - 2 precursors: R5P, E4P
  - Acetyl~CoA,
- Alternate pathways
  - G1P

The general scheme associated with metabolism of organic molecules, the redox reaction, and the capture of energy in the form of ATP.

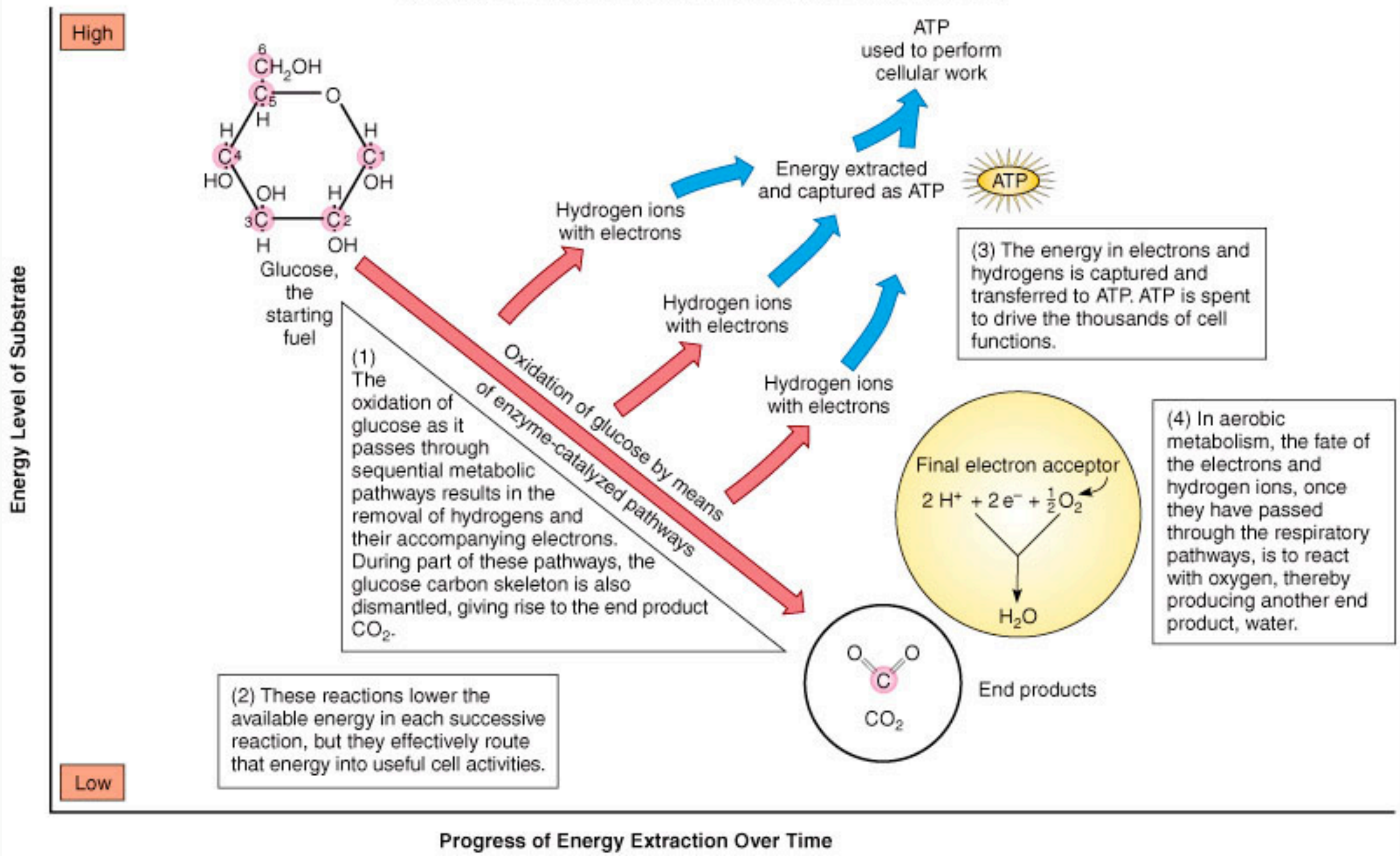


Fig. 8.12 A simplified model that summarizes the cell's energy machine.

Catabolism: Summary of the complete oxidation of glucose and the transformation of its bond energy into useable energy (a total of 38 ATP).

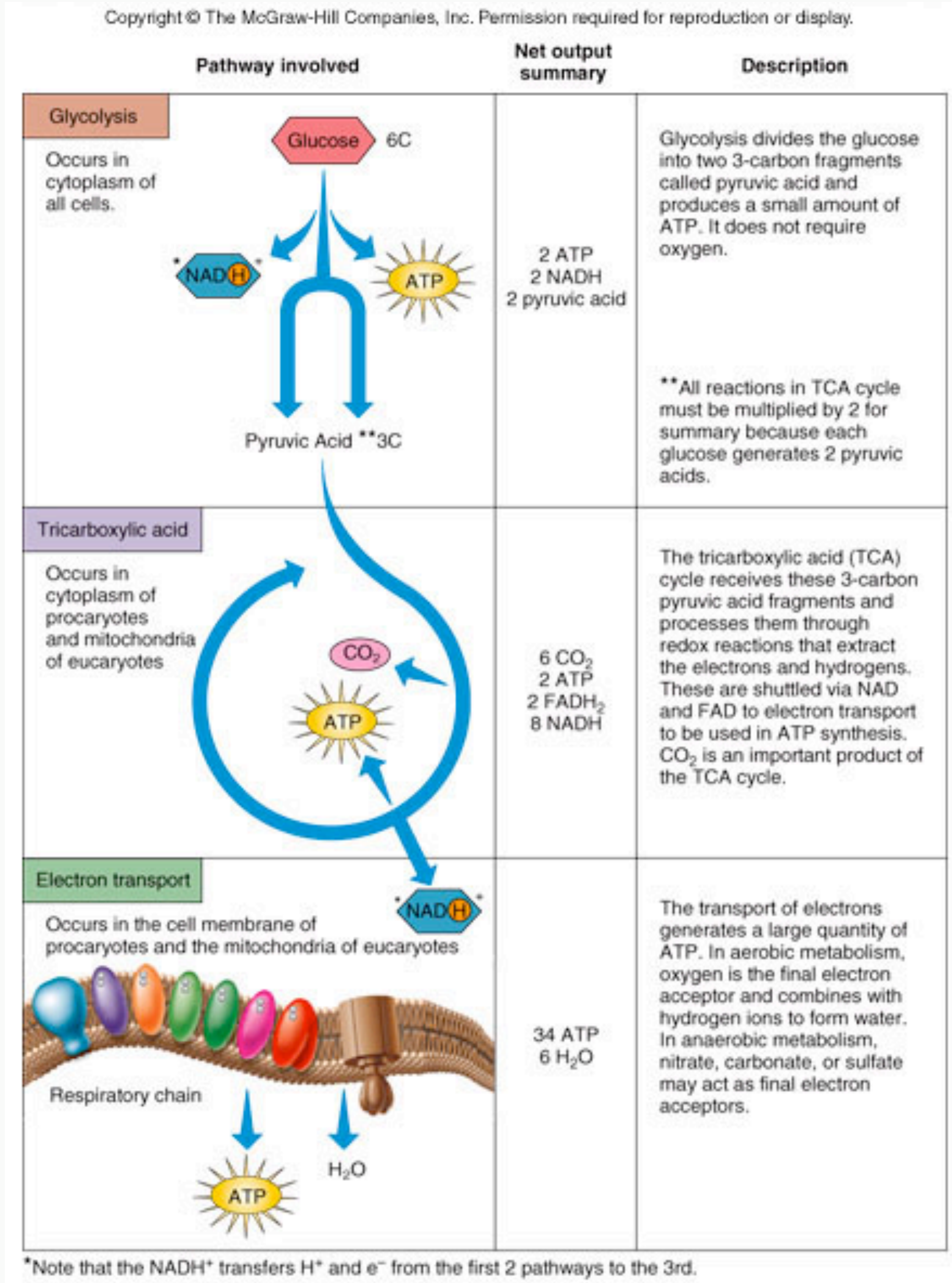


Fig. 8.17
Overview of the flow, location, and outcomes of pathways in aerobic **respiration**.