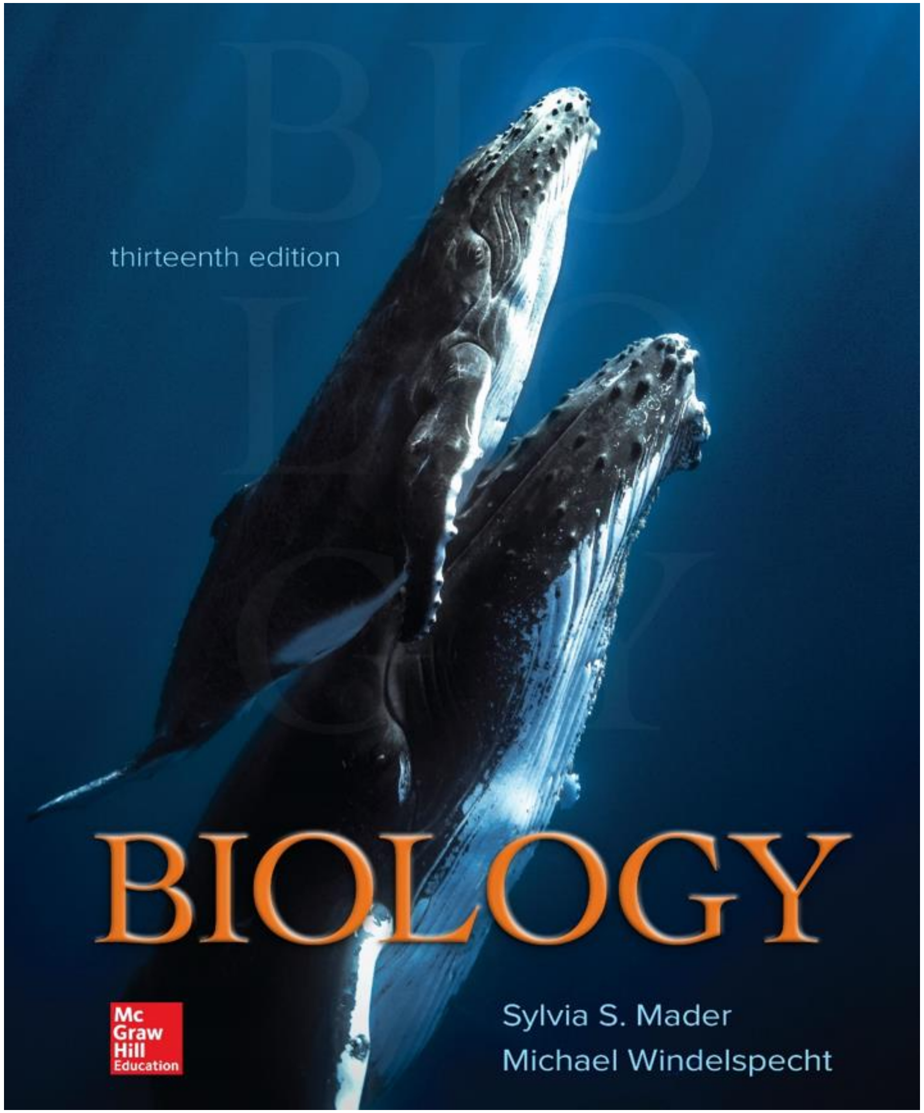

Biology

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Chapter 6
Metabolism:
Energy and Enzymes
Lecture Outline

See separate FlexArt PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.

Outline

6.1 Cells and the Flow of Energy

6.2 Metabolic Reactions and Energy Transformations

6.3 Metabolic Pathways and Enzymes

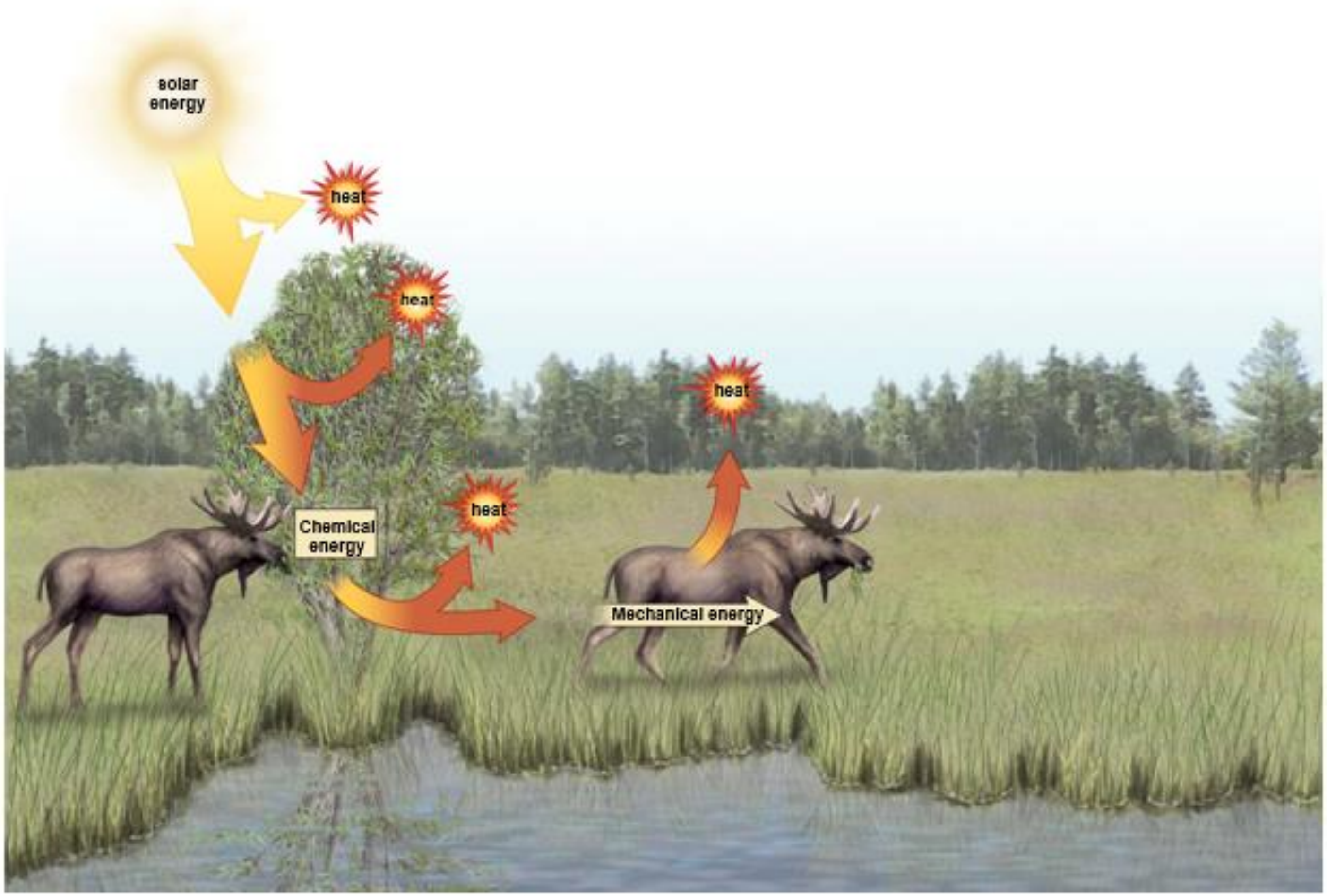
6.4 Oxidation-Reduction Reactions and Metabolism

6.1 Cells and the Flow of Energy

Energy is the ability to do work or bring about a change.

- **Kinetic energy**
  - Energy of motion
    - Water going over a waterfall
  - Mechanical
- **Potential energy**
  - Stored energy
  - **Chemical energy**
    - The food we eat

Flow of Energy



[Jump to Flow of Energy Long Description](#)

Two Laws of Thermodynamics (1)

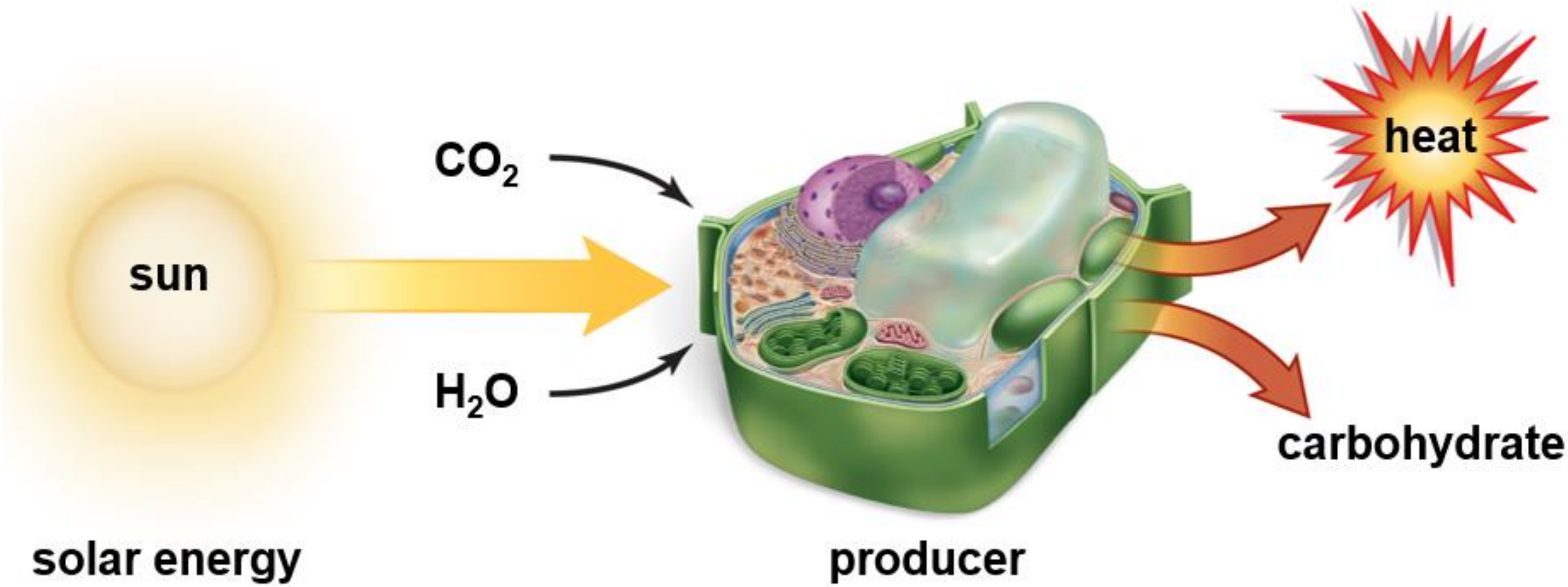
First law:

- Law of conservation of energy
- Energy cannot be created or destroyed, but can be changed from one form to another.
- Photosynthesizing leaves capture solar energy.
  - Some energy is used to form carbohydrates from carbon dioxide and water.
  - Much of the energy dissipates as heat.

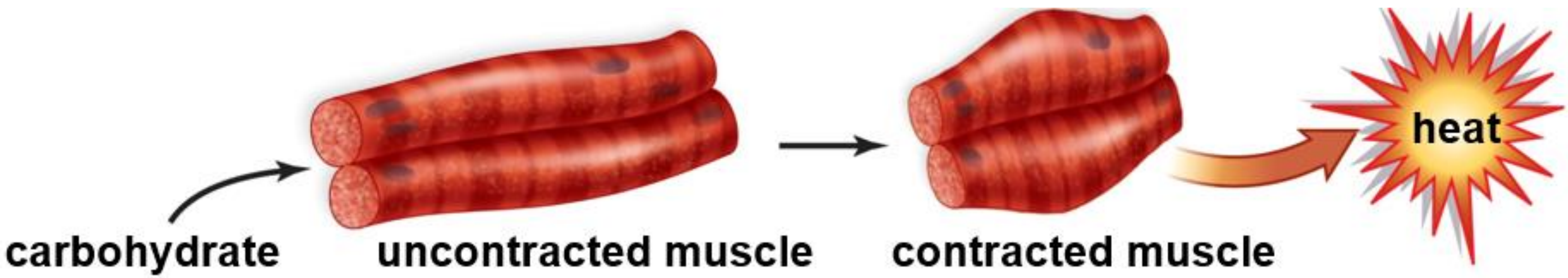
Second law:

- Law of entropy
- When energy is changed from one form to another, there is a loss of energy that is available to do work.
- No process requiring a conversion of energy is ever 100% efficient.
  - The majority of energy is lost as dissipated heat.

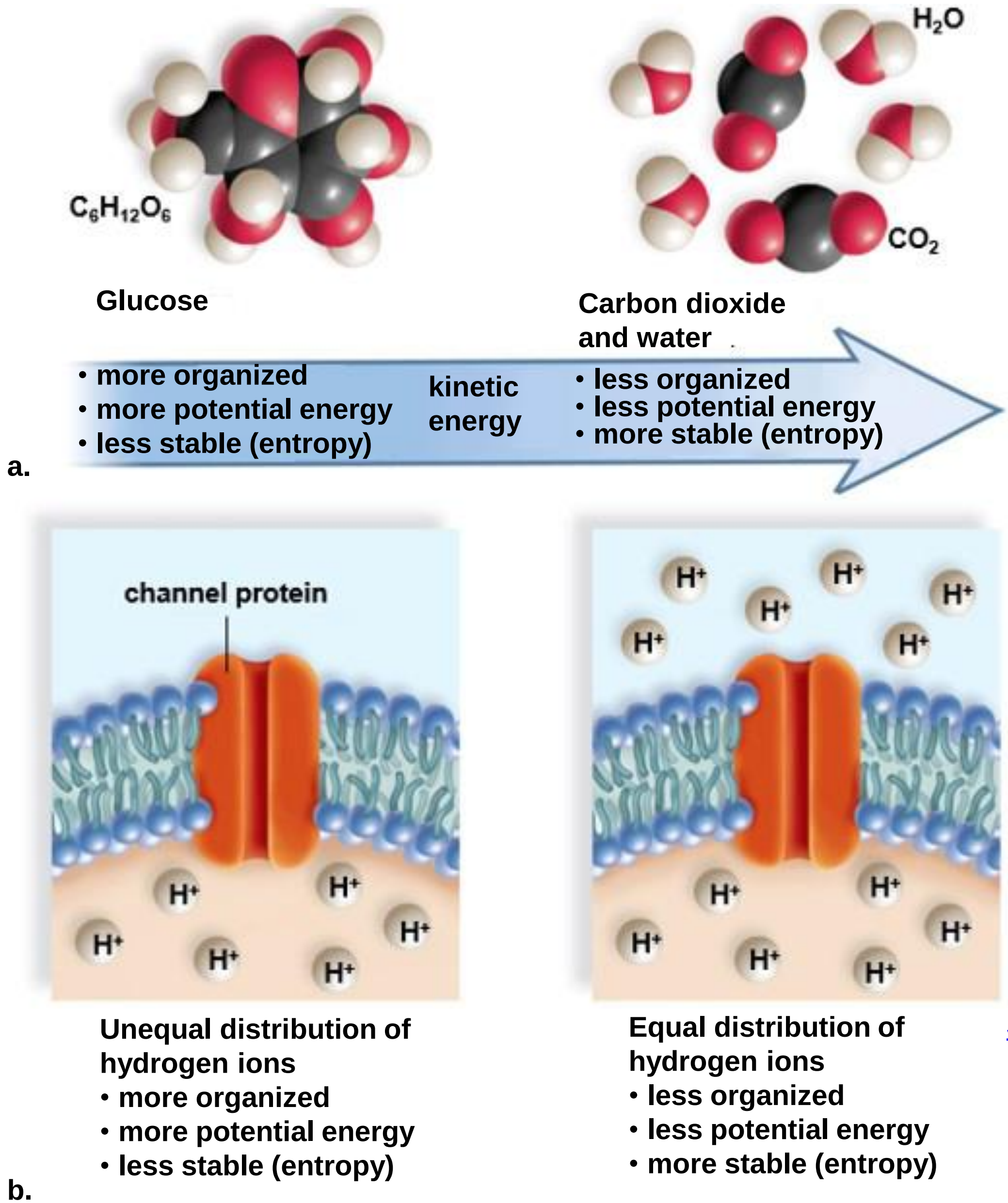
Two Laws of Thermodynamics (2)



Carbohydrate Metabolism



Cells and Entropy



Jump to Cells and Entropy Long Description

Cells and Entropy—The Second Law

The processes occurring in cells are energy transformations.

- Every process in cells increases the total entropy in the universe.
- Therefore, less energy is available to do useful work.
  - Example – Glucose tends to break apart into carbon dioxide and water over time.
    - Glucose is more organized and less stable than its breakdown products.
    - Compare this to a neat room, which is more organized but less stable than a messy room.
      - Energy is required to make a messy room more neat.
      - Similarly, the input of energy from photosynthesis (the sun) makes glucose from carbon dioxide and water.

Organisms called producers use energy to create organized structure in biological molecules.

Organisms that consume producers can use this potential energy to drive their own processes.

Living organisms depend on a constant supply of solar energy.

6.2 Metabolic Reactions and Energy Transformations

Metabolism

- Metabolism is the sum of cellular chemical reactions in a cell.
- **Reactants** participate in a reaction.
- **Products** form as result of a reaction.

Free energy is the amount of energy available to perform work.

- **Exergonic Reactions** – Products have ***less*** free energy than reactants (release energy).
  - These occur spontaneously.
- **Endergonic Reactions** – Products have ***more*** free energy than reactants (require energy input).
  - These are nonspontaneous.

ATP: Energy for Cells

Adenosine triphosphate (ATP)

- High-energy compound used to drive metabolic reactions
- ATP is not stored by cells.
  - Constantly being generated from **adenosine diphosphate (ADP)**
  - This is the ATP cycle.

Composed of:

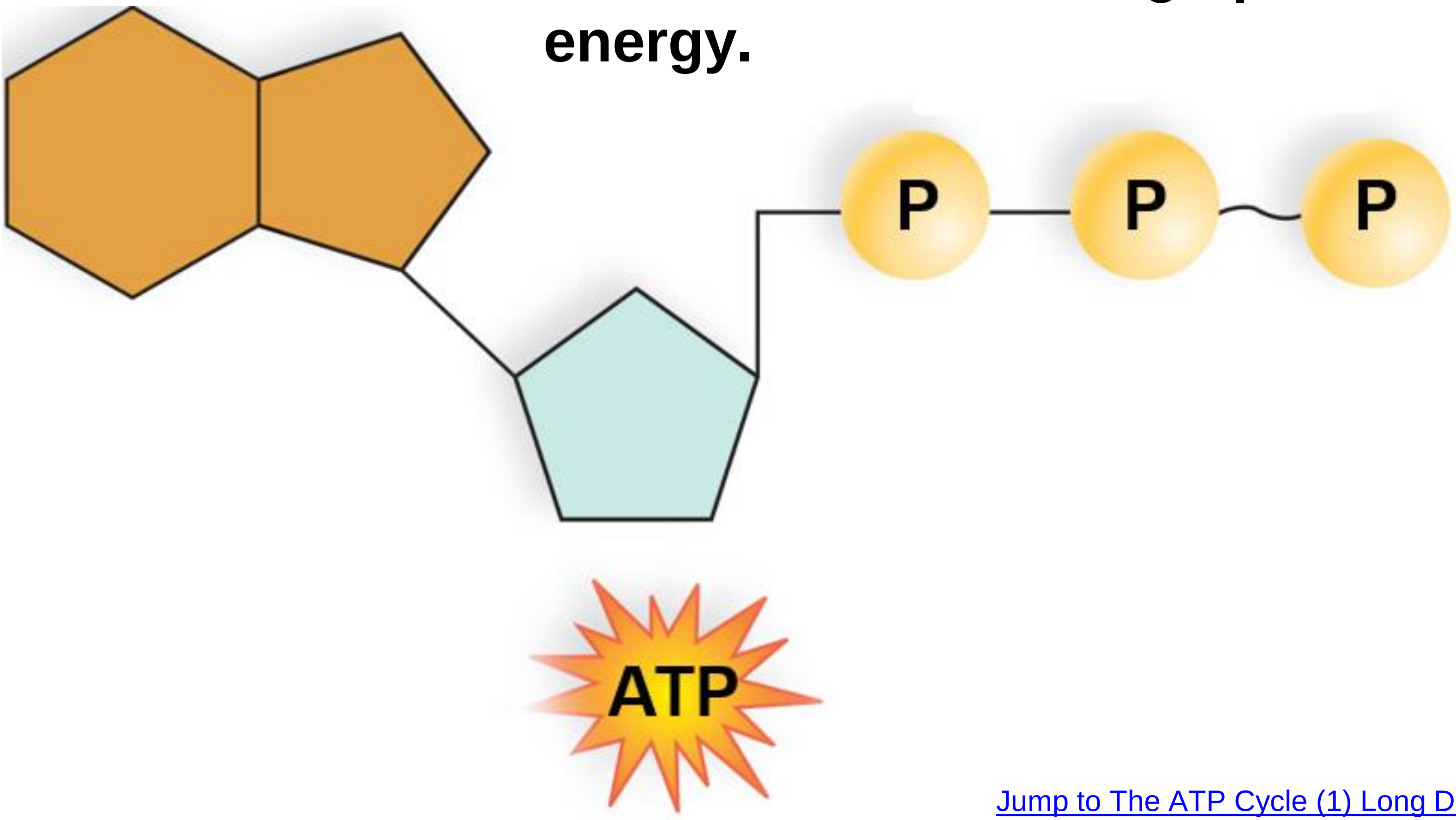
- Adenine, ribose (together = adenosine), and three phosphate groups

Coupled reactions

- Energy released by an exergonic reaction (or reactions) is captured in ATP.
- ATP is then used to drive an endergonic reaction.

The ATP Cycle (1)

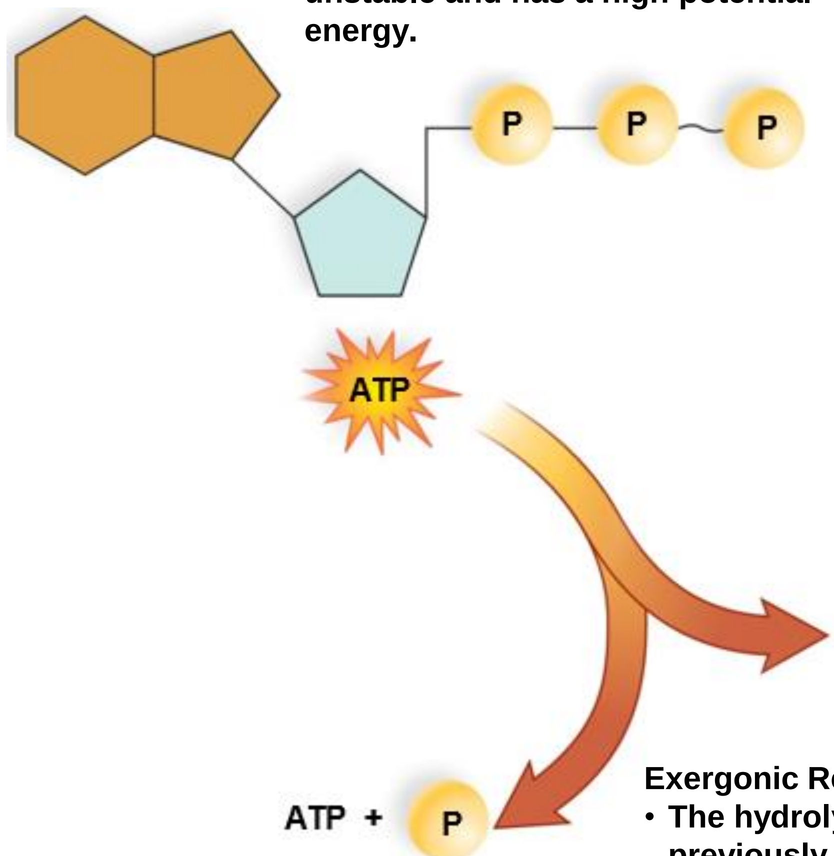
Adenosine triphosphate ATP is unstable and has a high potential energy.



Jump to The ATP Cycle (1) Long Description

The ATP Cycle (2)

Adenosine triphosphate ATP is unstable and has a high potential energy.



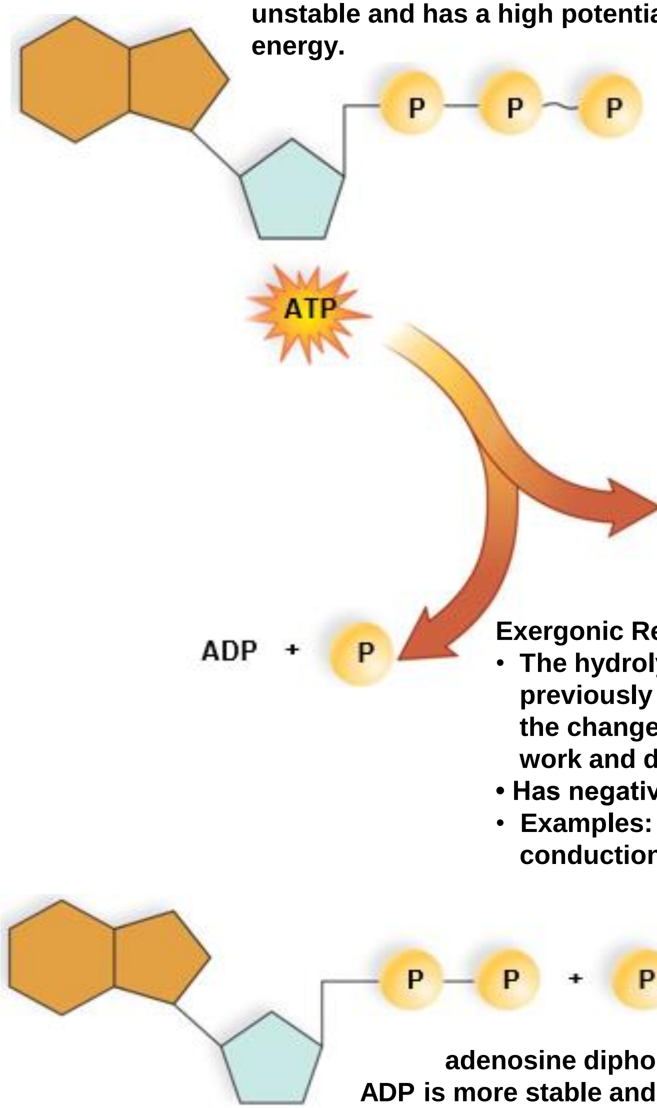
Exergonic Reaction:

- **The hydrolysis of ATP releases previously stored energy, allowing the change in free energy to do work and drive other processes.**
- **Has negative delta G.**
- **Examples: protein synthesis, nerve conduction, muscle contraction**

[Jump to The ATP Cycle (2) Long Description]

The ATP Cycle (3)

Adenosine triphosphate ATP is unstable and has a high potential energy.



Exergonic Reaction:

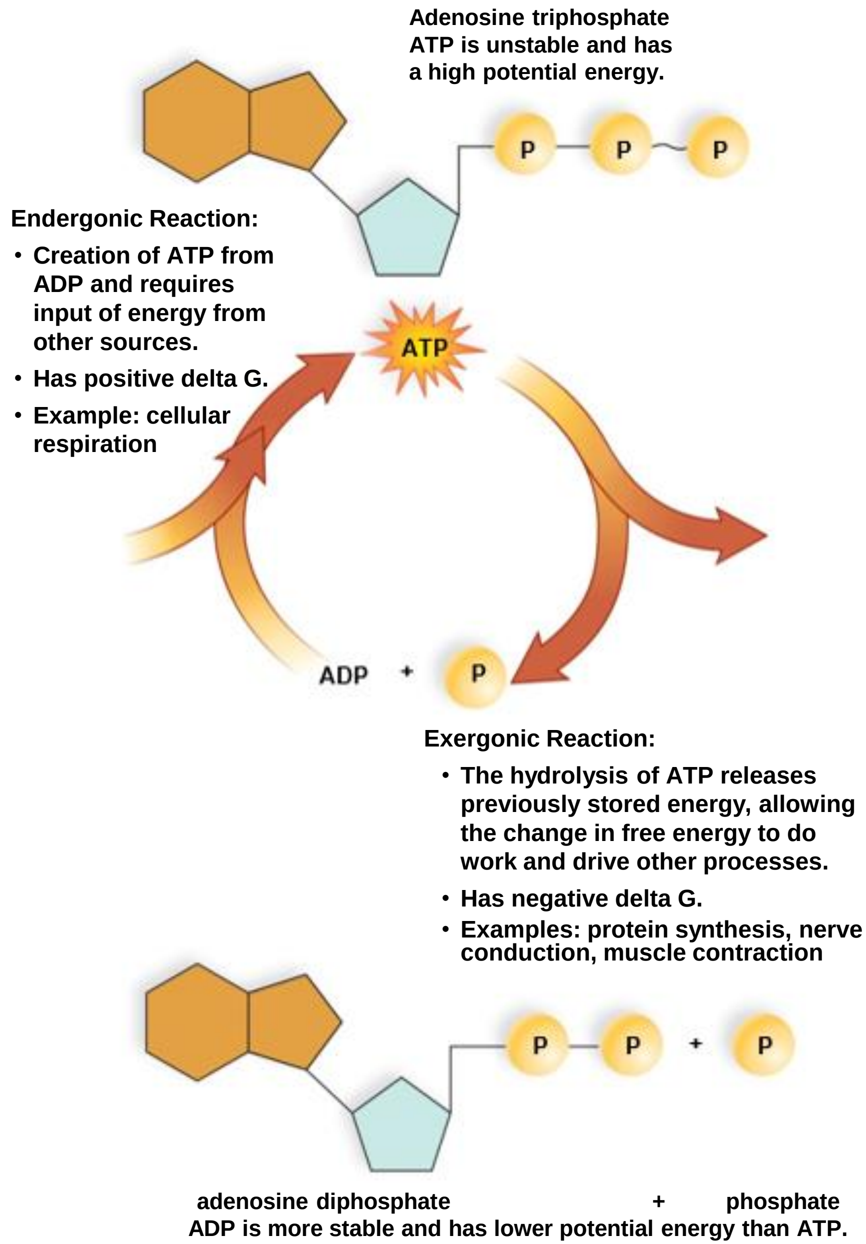
- The hydrolysis of ATP releases previously stored energy, allowing the change in free energy to do work and drive other processes.
- Has negative delta G.
- Examples: protein synthesis, nerve conduction, muscle contraction

[Jump to The ATP Cycle (3) Long Description]()

adenosine diphosphate + phosphate

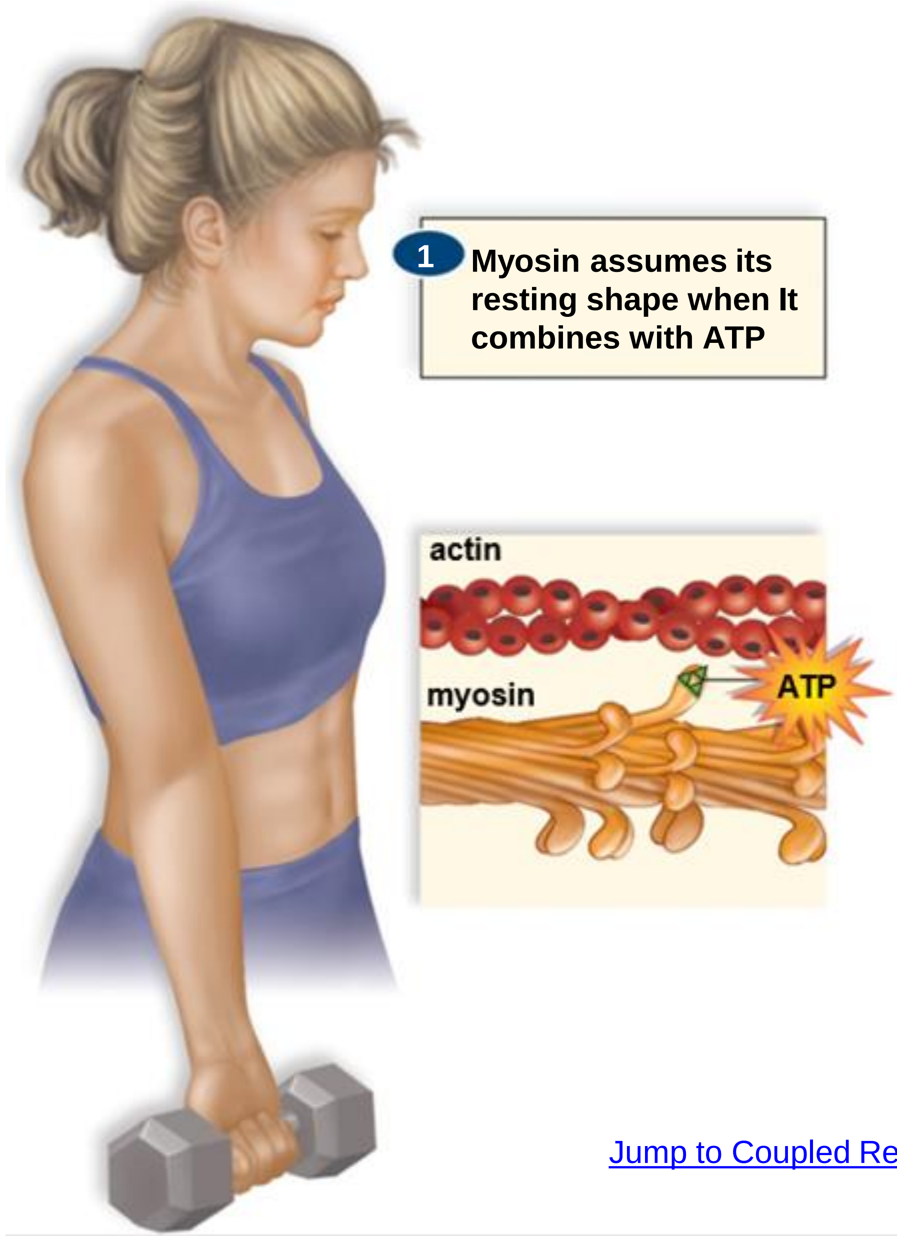
ADP is more stable and has lower potential energy than ATP.

The ATP Cycle (4)



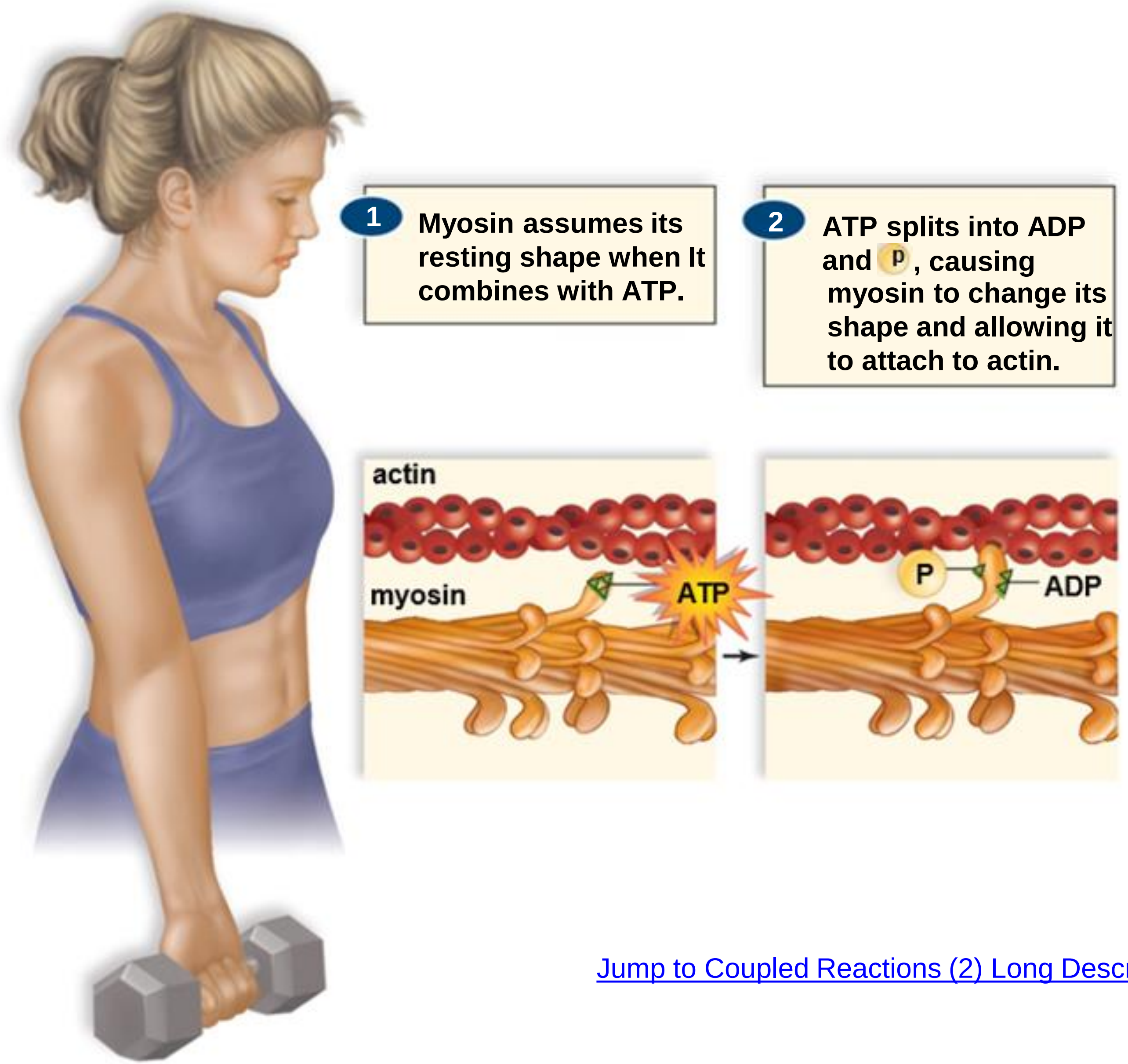
Jump to The ATP Cycle (4) Long Description

Coupled Reactions (1)



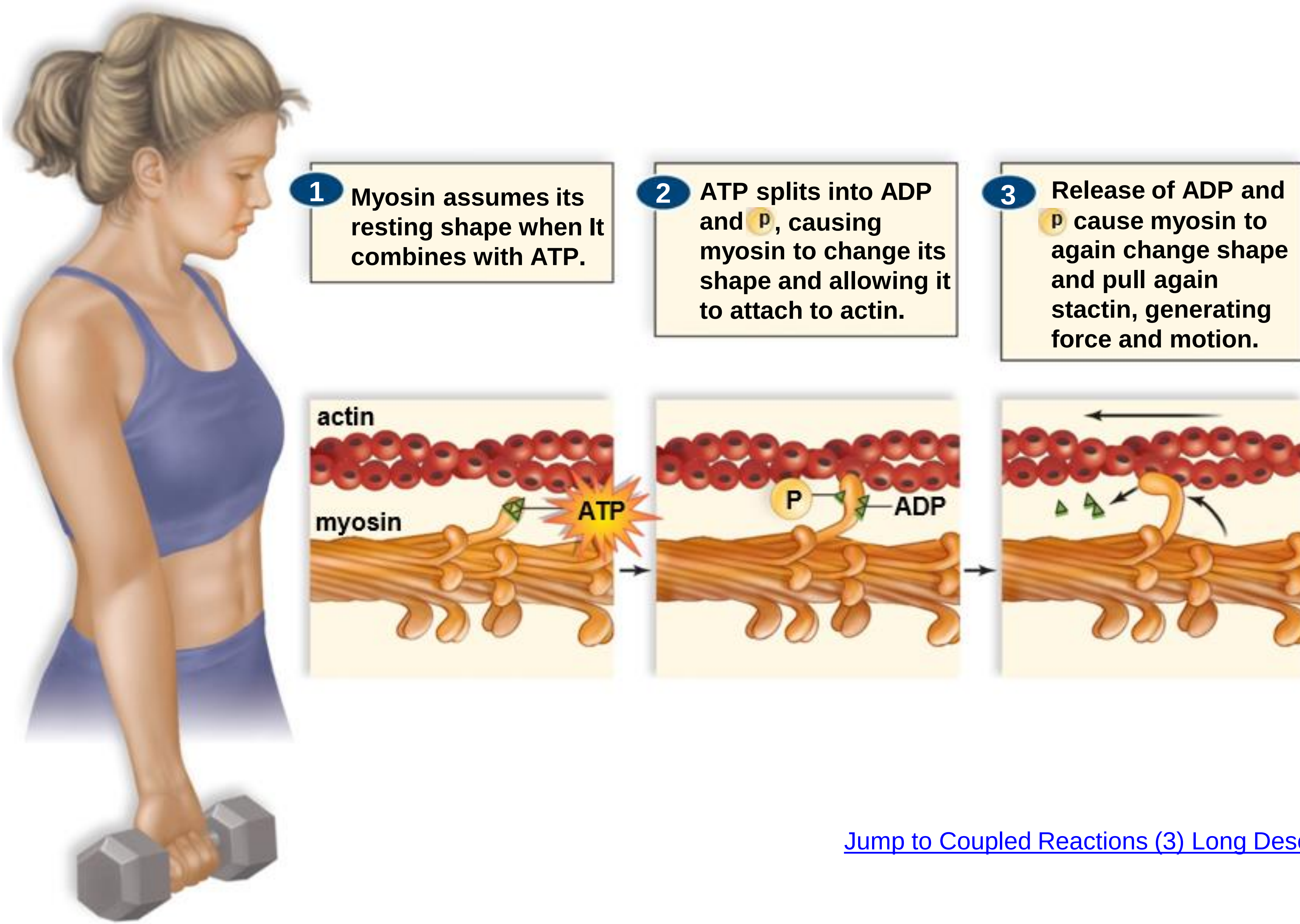
[Jump to Coupled Reactions (1) Long Description]

Coupled Reactions (2)



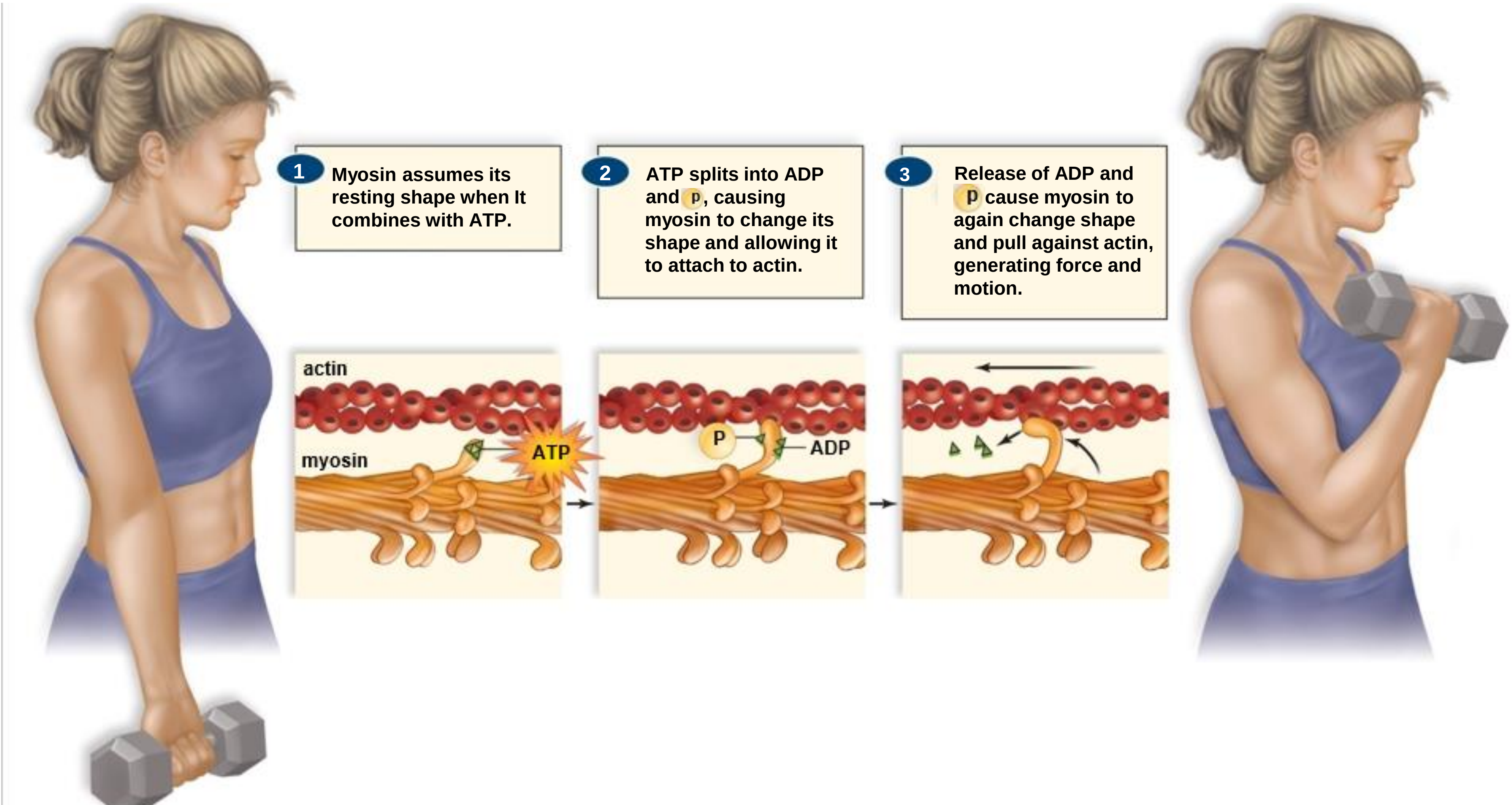
Jump to Coupled Reactions (2) Long Description

Coupled Reactions (3)



[Jump to Coupled Reactions (3) Long Description](#)

Coupled Reactions (4)



[Jump to Coupled Reactions (4) Long Description]

6.3 Metabolic Pathways and Enzymes (1)

Reactions normally occur in a sequence.

- Products of an earlier reaction become reactants (also known as substrates) of a later reaction.
- Such linked reactions form a **metabolic pathway.**
  - It begins with a particular reactant, proceeds through several intermediates, and terminates with a particular end product.
  - In other words, the product of the first reaction is the substrate of the second and so on, except in the case of G.

$$\mathbf{A} \rightarrow \mathbf{B} \rightarrow \mathbf{C} \rightarrow \mathbf{D} \rightarrow \mathbf{E} \rightarrow \mathbf{F} \rightarrow \mathbf{G}$$

"A" is Initial Reactant or Substrate	**B, C, D, E, and F are Intermediates**	**"G" is End Product**

6.3 Metabolic Pathways and Enzymes (2)

Enzyme

- Protein molecules function as catalysts.
- The reactants of an enzymatically catalyzed reaction are called **substrates.**
- Each enzyme accelerates a specific reaction.
- Each reaction in a metabolic pathway requires a unique and specific enzyme.
- The end product will not be formed unless ALL enzymes in the pathway are present and functional.

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

Enzyme-Substrate Complex (1)

The **active site** of an enzyme complexes with the substrates.

- It causes the active site to change shape.
- The shape change forces substrates together, initiating bond formation.
- **Induced fit model**
  - The enzyme is induced to undergo a slight alteration to achieve optimum fit for the substrates.

Enzyme-Substrate Complex (2)

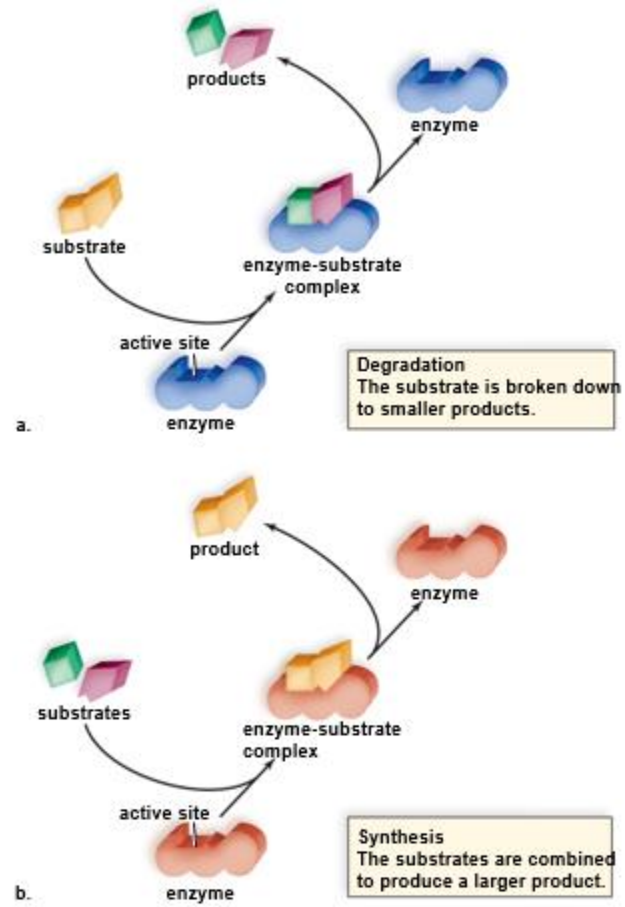
Degradation:

- Enzyme complexes with a single substrate molecule.
- Substrate is broken apart into two product molecules, which are released.

Synthesis:

- Enzyme complexes with two substrate molecules.
- Substrates are joined together and released as a single product molecule.

Enzymatic Actions



[Jump to Enzymatic Actions Long Description]

Energy of Activation (1)

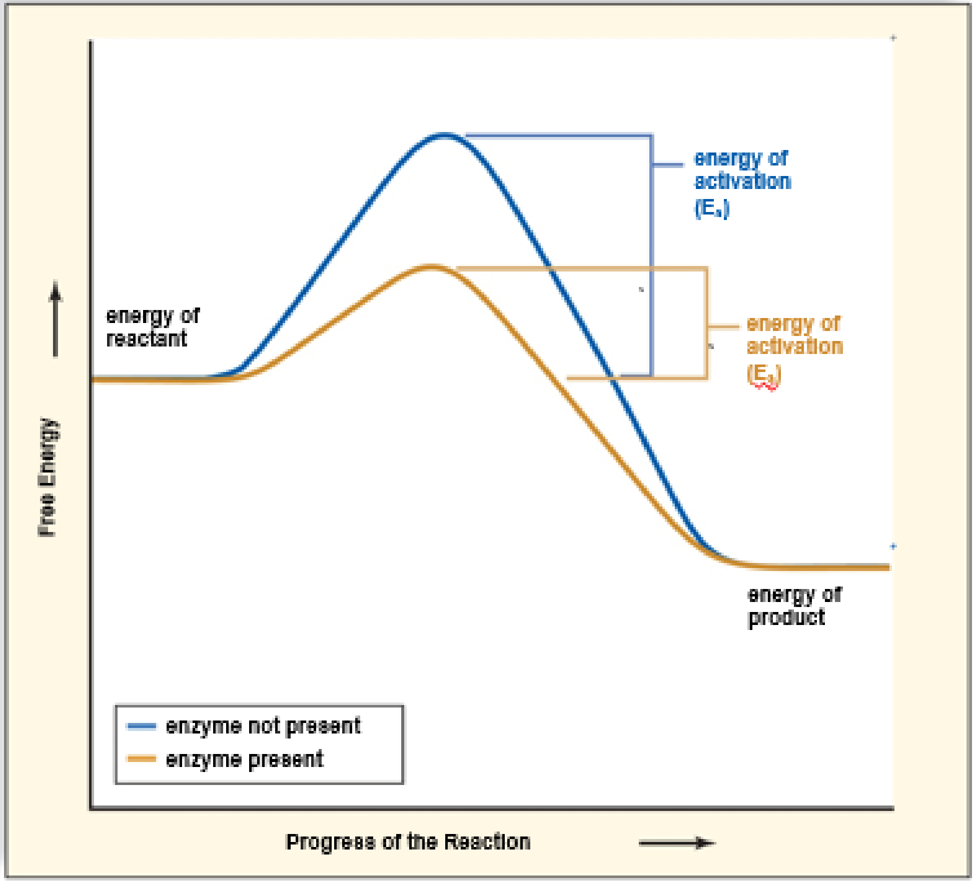
Molecules frequently do not react with one another unless they are activated in some way.

- Energy must be added to at least one reactant to initiate the reaction.
  - **Energy of activation**
    - E_A (the energy of activation) prevents molecules from spontaneously degrading in the cell.

Enzyme Operation:

- Enzymes operate by ***lowering*** the energy of activation.
- This is accomplished by bringing substrates into contact with one another.
  - This influences the rate of reaction and is why enzymes are catalysts of chemical reactions.

Energy of Activation (2)



[Jump to Energy of Activation (2) Long Description](#)

Factors Affecting Enzymatic Rate (1)

Substrate concentration

- Enzyme activity ***increases*** with substrate concentration due to more frequent collisions between substrate molecules and the enzyme.

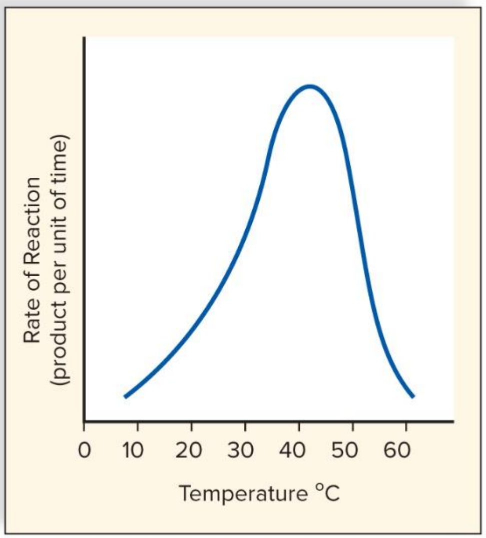
Temperature

- Enzyme activity ***increases*** with temperature.
- Warmer temperatures cause more effective collisions between enzyme and substrate.
- However, hot temperatures can **denature** and destroy enzymes.
  - Siamese cats have a mutation that causes enzymes to be active only at cooler body temperatures, affecting coloration.

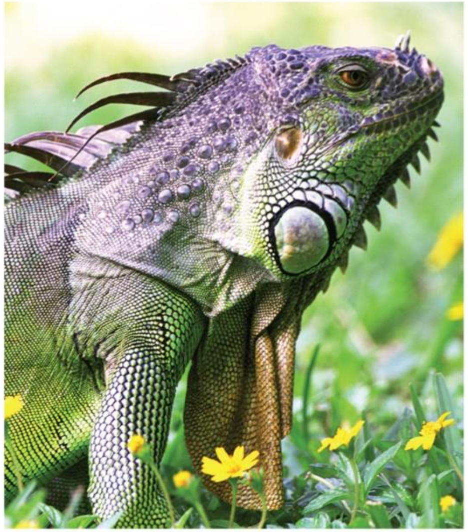
pH

- Most enzymes are optimized for a particular pH.
  - In the case of pepsin or trypsin, optimum protein digestion takes place at their respective pH optima.

The Effect of Temperature on Rate of Reaction



a. Rate of reaction as a function of temperature



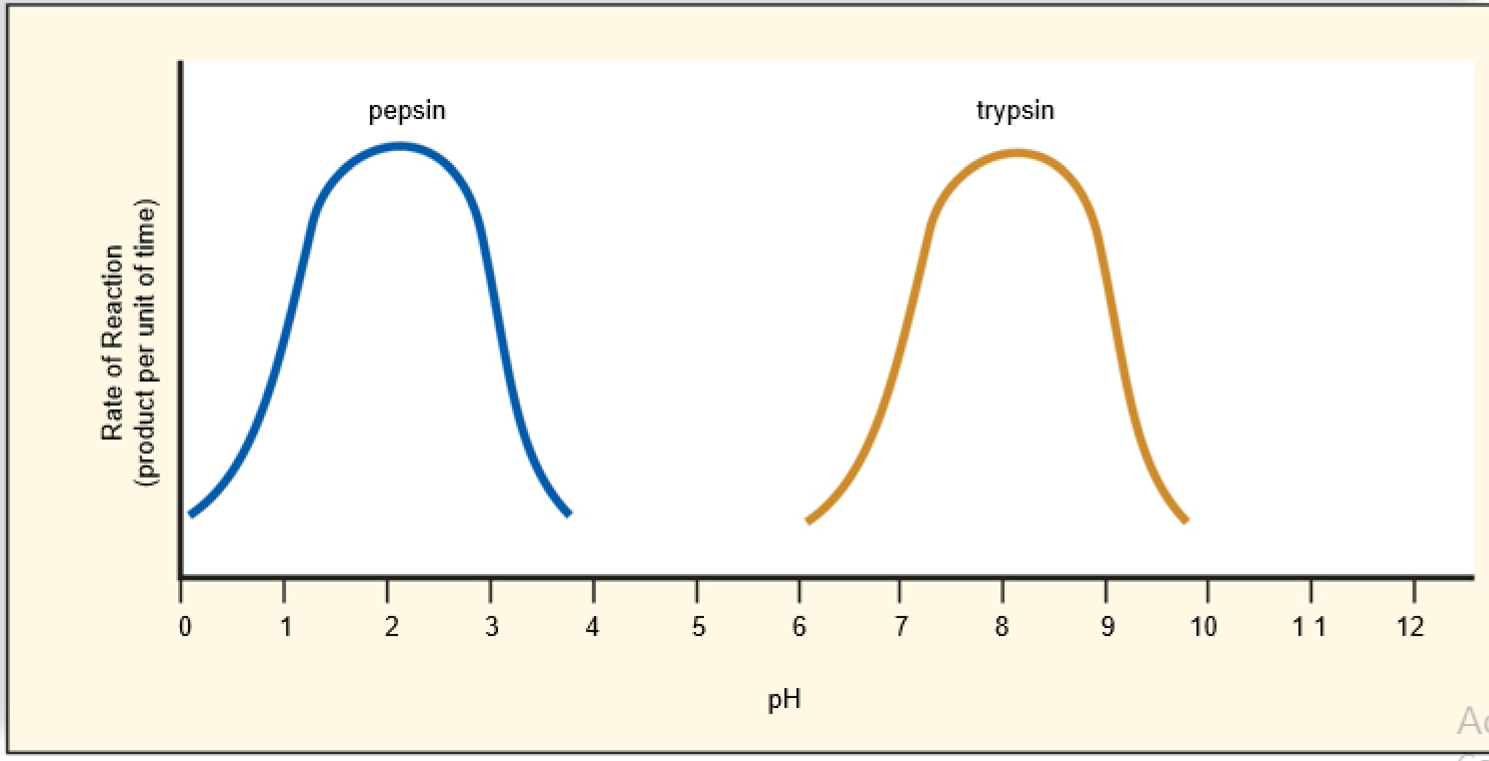
b. Body temperature of ectothermic animals often limits rates of reactions.

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

(b): ©MedioImages/SuperStock RF; (c): ©Moodboard/Glow Images RF

Jump to The Effect of Temperature on Rate of Reaction Long Description

The Effect of pH on Rate of Reaction



[Jump to The Effect of pH on Rate of Reaction Long Description](#)

Factors Affecting Enzymatic Rate (2)

Cells can regulate the presence/absence of an enzyme.

Cells can regulate the concentration of an enzyme.

Cells can activate or deactivate some enzymes.

- Enzyme **cofactors**
  - Molecules required to activate enzyme
    - FAD and NAD^+ and $NADP^+$ are cofactors, the first two in cellular respiration, the third in photosynthesis.
  - **Coenzymes** are nonprotein organic molecules.
    - **Vitamins** are small organic compounds required in the diet for the synthesis of coenzymes.

Factors Affecting Enzymatic Rate (3)

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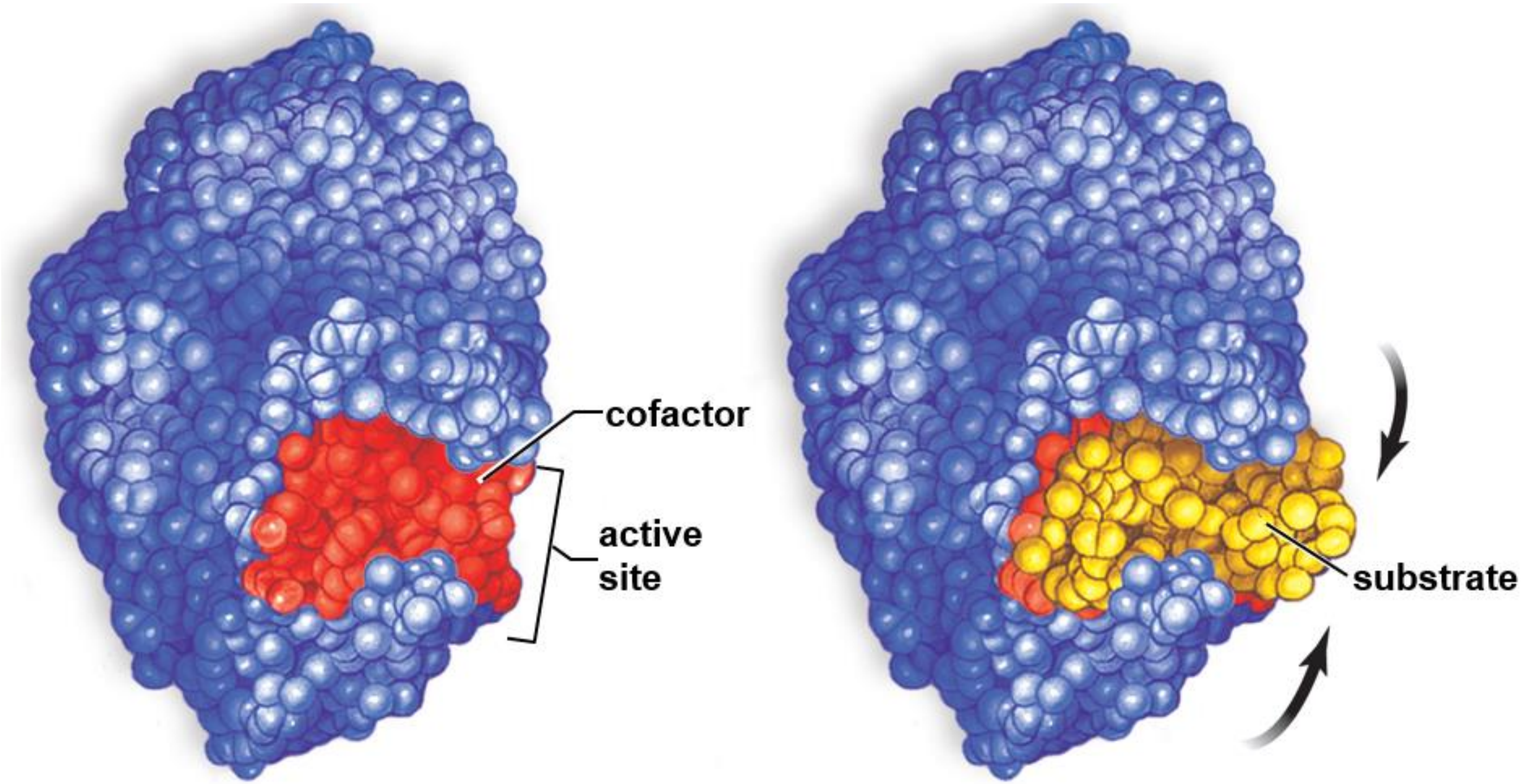
Jump to Factors Affecting Enzymatic Rate (3) Long Description

Cofactors at Active Site



a. b.

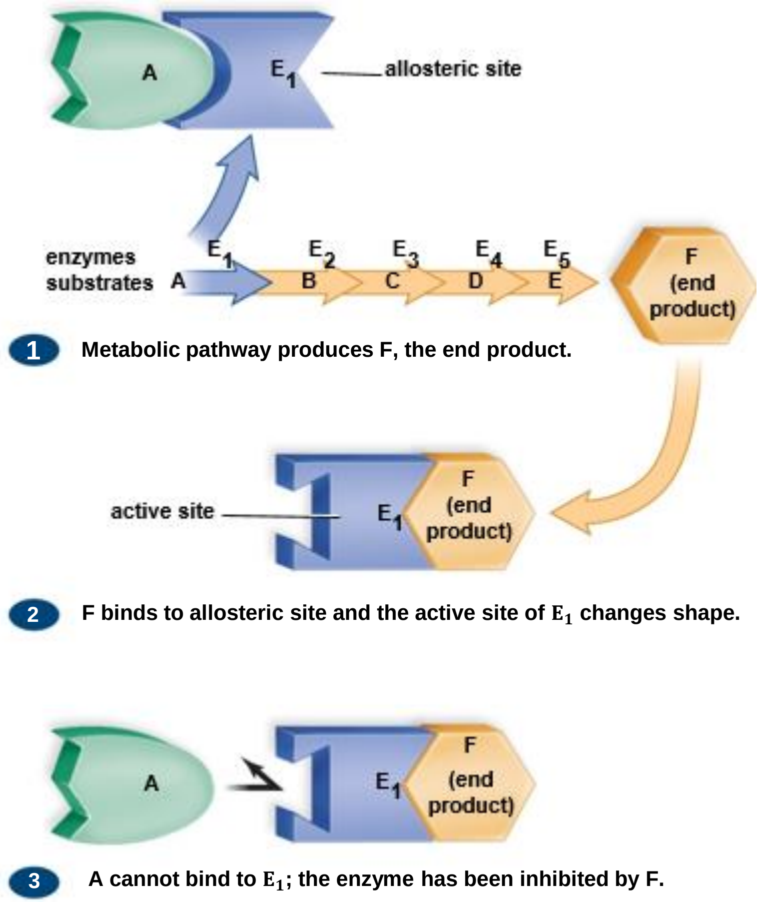
Jump to Cofactors at Active Site Long Description

Enzyme Inhibition

Reversible enzyme inhibition

- A substance known as an inhibitor binds to an enzyme and decreases its activity.
  - **Competitive inhibition** – The substrate and the inhibitor are both able to bind to the active site and they compete with one another.
    - The product forms only when the substrate binds to the active site.
  - **Noncompetitive inhibition** – The inhibitor does not bind at the active site, but at an allosteric (allo means other) site.
    - A change in shape initiated by an inhibitor binding to the allosteric site changes the shape of the active site, making it unable to bind to its substrate.

Noncompetitive Inhibition of an Enzyme



[Jump to Noncompetitive Inhibition of an Enzyme Long Description]

Enzyme Inhibitors Can Spell Death

Materials that irreversibly inhibit an enzyme are known as poisons.

Cyanide inhibits enzymes required for ATP production.

Sarin inhibits an enzyme located at the neuromuscular junction.

Warfarin inhibits an enzyme responsible for the blood-clotting process.

6.4 Oxidation-Reduction Reactions and Metabolism

Oxidation-reduction (redox) reactions

- Electrons pass from one molecule to another.
  - **Oxidation** – loss of an electron
  - **Reduction** – gain of an electron
- Both take place at the same time.
- One molecule (or atom) accepts the electron given up by the other.
  - Example: In the production of NaCl, sodium is oxidized and chlorine is reduced; OILRIG (oxidation is loss, reduction is gain).

Photosynthesis and Cellular Respiration (1)

Photosynthesis

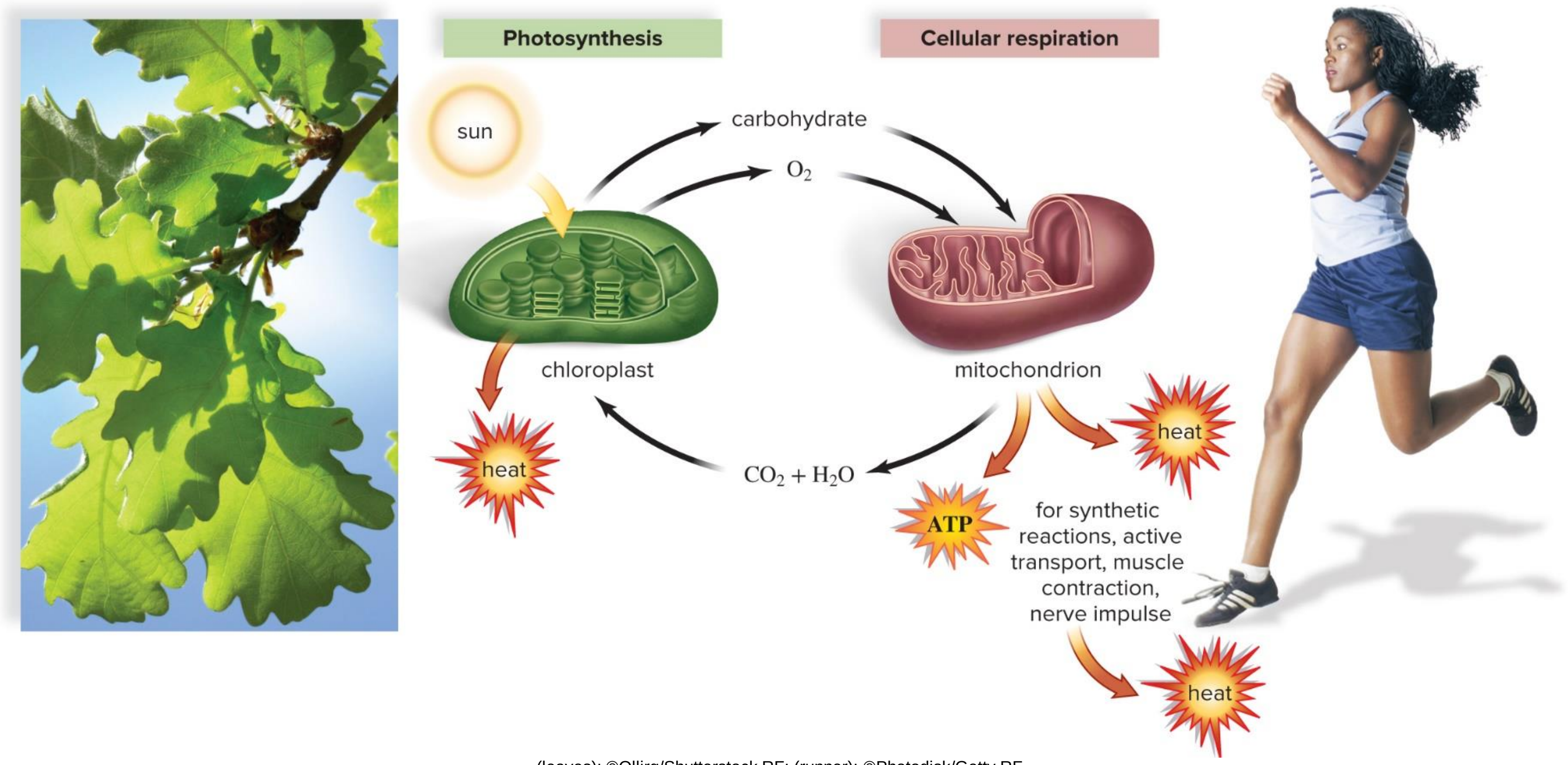
$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy} \rightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

Cellular Respiration

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

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

Photosynthesis and Cellular Respiration (2)



(leaves): ©Ollirg/Shutterstock RF; (runner): ©Photodisk/Getty RF

Jump to Photosynthesis and Cellular Respiration (2) Long Description

Chloroplasts and Photosynthesis

Chloroplasts capture solar energy and use it to convert water and carbon dioxide to a carbohydrate.

Hydrogen atoms are transferred from water to carbon dioxide as glucose forms.

- Carbon dioxide has been reduced and water oxidized.
- The energy is provided by solar energy.
  - The reduction of carbon dioxide to form a mole of glucose stores 686 kilocalorie of energy in the chemical bonds of glucose.
  - Living organisms can oxidize glucose in mitochondria.

Mitochondria and Cellular Respiration

Mitochondria oxidize carbohydrates and use the released energy to build ATP.

Cellular respiration consumes oxygen and produces carbon dioxide.

- The equation is the opposite of the photosynthesis equation.
- Glucose has been oxidized (lost hydrogen atoms) and oxygen has been reduced (gained hydrogen atoms).
  - When oxygen gains hydrogen atoms, it becomes water.
- Cells oxidize glucose step by step.
  - The energy is stored and converted to ATP molecules.

Photosynthesis and Cellular Respiration Form a Cycle

Carbohydrate produced in chloroplasts becomes a substrate for cellular respiration in mitochondria.

Carbon dioxide released by mitochondria becomes a substrate for photosynthesis in chloroplasts.

- Both organelles are involved in a redox cycle.
  - Carbon dioxide is reduced in photosynthesis and carbohydrate is oxidized in cellular respiration.
- Energy does not cycle between the two organelles; it flows from the sun through each step of photosynthesis and cellular respiration.
  - Eventually, it becomes unusable heat when ATP is used by the cell.