BIOLOGY

Chapter 6 METABOLISM
Figure 6.2

- Energy from the sun.
- Plants \(\rightarrow\) photosynthesis
- Herbivores eat those plants
- Carnivores eat the herbivores
- Decomposers digest plant and animal matter
- Energy lost as heat
This tree shows the evolution of the various branches of life.

- The vertical dimension is time.
- Early life forms (blue) used anaerobic metabolism.
Metabolism & metabolic pathways

Anabolism
Catabolism

Metabolic pathways

Anabolic: Small molecules are assembled into large ones. *Energy is required.*

Catabolic: Large molecules are broken down into small ones. *Energy is released.*
Bioenergetics

- Energy transformations in living organisms

Energy = capacity to cause change
Catabolism

- Break down
- Complex → simple
- Exergonic
- Releases NRG

All of these monomers then participate in a reaction with Acetyl CoA through the Citric acid cycle, where NAD+ turns to NADH, and ADP turns into ATP via oxidative phosphorylation.

Catabolism is thus the breaking of large molecules into smaller molecules in order to create energy in the form of ATP and NADH for later use.
Anabolism

- Builds up
- Simple → Complex
- Endergonic
- Requires NRG
Energy Forms

1) Potential Energy

- Stored energy
  - Capacity to do work
- Due to:
  - Location
  - Bond arrangement
Energy Forms

2) Kinetic Energy
- Energy of motion
- Work energy
- Releases heat
A diver has more potential energy on the platform than in the water. Diving converts potential energy to kinetic energy.

Climbing up converts the kinetic energy of muscle movement to potential energy. A diver has less potential energy in the water than on the platform.

Energy Transformations

Potential ↔ Kinetic
Thermodynamics: Energy Transformations

- **Chemical energy** → **Kinetic energy** → **Light energy** → **Chemical energy**

**Figure 6.11**

(a) First law of thermodynamics

(b) Second law of thermodynamics
(a) First law of thermodynamics
Conservation of energy
(b) Second law of thermodynamics
Transformation inefficient
Increase in entropy
Entropy is a measure of randomness or disorder in a system.
Gases have higher entropy than liquids, and liquids have higher entropy than solids.
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Energy conversion</th>
<th>Waste products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>Heat energy</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>+</td>
<td>Combustion</td>
<td>+</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Kinetic energy of movement</td>
<td>Water</td>
</tr>
<tr>
<td></td>
<td>Energy conversion in a car</td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>Heat</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>+</td>
<td>Cellular respiration</td>
<td>+</td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td>Water</td>
</tr>
<tr>
<td></td>
<td>Energy conversion in a cell</td>
<td></td>
</tr>
</tbody>
</table>

Energy for cellular work

ATP

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Temperature & Entropy

- **solid**: Entropy increases with temperature.
- **melting**: Transition from solid to liquid.
- **liquid**: Entropy increases with temperature.
- **boiling**: Transition from liquid to gas.
- **gas**: Entropy increases with temperature.
Gibb’s Free Energy

\[ \Delta G = \Delta H - T\Delta S \]

- (\(\Delta G\)) = change in free energy during a process
- (\(\Delta H\)) = change in enthalpy, or change in total energy
- (\(\Delta S\)) = change in entropy
- (\(T\)) = temperature in Kelvin

- Only processes with a negative \(\Delta G\) are spontaneous
- Spontaneous processes can be harnessed to perform work
Free energy = energy capable of work
• Measure instability

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

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

• Less free energy (lower $G$)
• More stable
• Less work capacity

(a) Gravitational motion  (b) Diffusion  (c) Chemical reaction
Figure 6.9  
**Exergonic vs Endergonic Reactions**

<table>
<thead>
<tr>
<th>EXERGONIC REACTION: $\Delta G &lt; 0$</th>
<th>ENERGONIC REACTION: $\Delta G &gt; 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction is spontaneous</td>
<td>Reaction is not spontaneous</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gibbs Free Energy</th>
<th>Gibbs Free Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>reactants</td>
<td>reactants</td>
</tr>
<tr>
<td>$\Delta G &lt; 0$</td>
<td>$\Delta G &gt; 0$</td>
</tr>
<tr>
<td>Energy is released</td>
<td>Energy is added</td>
</tr>
<tr>
<td>products</td>
<td>products</td>
</tr>
<tr>
<td>Time</td>
<td>Time</td>
</tr>
</tbody>
</table>

**Endergonic ➔**

**Exergonic ➔**
- Activation energy is the energy required for a reaction to proceed, and it is lower if the reaction is catalyzed. This diagram’s horizontal axis describes the sequence of events in time.
Free Energy and Metabolism

(a) Exergonic reaction: energy released, spontaneous

Reactants

Energy

Products

Amount of energy released ($\Delta G < 0$)

Progress of the reaction
(b) Endergonic reaction: energy required, nonspontaneous

Free Energy and Metabolism

Reactants

Energy

Products

Amount of energy required ($\Delta G > 0$)

Progress of the reaction
Figure 8.7

Equilibrium and Metabolism

(a) An isolated hydroelectric system

(b) An open hydroelectric system

(c) A multistep open hydroelectric system
ATP powers cellular work

3 main kinds of cellular work:
Chemical/Transport/Mechanical
Lowers energy state
Figure 8.10

Phosphorylation

(a) Transport work: ATP phosphorylates transport proteins.

(b) Mechanical work: ATP binds noncovalently to motor proteins and then is hydrolyzed.
Figure 8.11

ATP cycle

Energy from catabolism (exergonic, energy-releasing processes)

ATP + \( \text{H}_2\text{O} \) → ADP + \( i\text{P} \)

Energy for cellular work (endergonic, energy-consuming processes)
General Enzyme Characteristics

- **Biological catalysts**
  - Increases chemical reactions

- **How enzymes work?**
  - Lower activation energy
  - Decrease amt of energy needed to get reaction going
Decreasing activation energy
Figure 6.15

Course of reaction without enzyme

Reactants

Course of reaction with enzyme

Products

Free energy

Progress of the reaction

$E_A$ without enzyme

$E_A$ with enzyme is lower

$\Delta G$ is unaffected by enzyme

Reactants

Products
Enzymes work on substrates at the active site.
Enzymes are specific (Specificity).
Enzymes \(\rightarrow\) reusable.
Figure 6.16

1. Substrates enter active site.

2. Substrates are held in active site by weak interactions.

Induced fit
Figure 6.16

1. Substrates enter active site.

2. Substrates are held in active site by weak interactions.

3. Active site can lower $E_A$ and speed up a reaction.

4. Substrates are converted to products.
Substrates enter active site.

Substrates are held in active site by weak interactions.

Active site can lower $E_A$ and speed up a reaction.

Active site is available for two new substrate molecules.

Products are released.

Substrates are converted to products.

Figure 6.16
Figure 6.16
Enzyme + substrate $\rightarrow$ ES complex $\rightarrow$ NZ + product(s)

- Induced fit
Factors Affect Enzyme Activity

1a. Environmental Conditions (Temperature)

- Optimal temperature for typical human enzyme (37°C)
- Optimal temperature for enzyme of thermophilic (heat-tolerant) bacteria (77°C)

Graph showing the rate of reaction over temperature.
Enzymes from different organisms may function best at different temperatures.

- Glucose-6-phosphate from bacterium that lives inside humans
- Glucose-6-phosphate from bacterium that lives in hot springs
Factors Affect Enzyme Activity

1b. Environmental Conditions (pH)

Optimal pH for pepsin (stomach enzyme)

Optimal pH for trypsin (intestinal enzyme)

Rate of reaction

(b) Optimal pH for two enzymes
Enzymes from different organisms may function best at different pHs.

- Chitinase from a bacterium that lives in acidic pools
- Chitinase from a soil-dwelling bacterium

![Graph showing the relative activity of chitinase at different pH levels.](Figure 3-27b Biological Science, 2/e © 2005 Pearson Prentice Hall, Inc.)
Factors Affect Enzyme Activity

1c. Environmental Conditions (Ionic concentration)
How can you use this to preserve your food items from microorganism that could spoil your meal?

- Temperature
  - Cooking?
  - Refrigeration?
- pH
- Ionic concentration
Factors Affect Enzyme Activity

2a. Cofactors
   - Inorganic
     • Zn/Fe/Cu

2b. Coenzymes
   - Organic
     • Vitamins ($B_{12}/B_6$)

• Binds to active site
• Stabilizes transition state
Factors Affect Enzyme Activity

3a. Competitive inhibitor

Ex. Aspirin, penicillin, nerve gases
- Sulfonamide $\rightarrow$ para-aminobenzoic acid (PABA)
  - Nucleic acid synthesis
Factors Affect Enzyme Activity

3b. Noncompetitive inhibitor

(a) Normal binding

(b) Competitive inhibition

(c) Noncompetitive inhibition

Substrate

Active site

Enzyme

Competitive inhibitor

Noncompetitive inhibitor

Ex. Aspirin, penicillin, nerve gases
- Sulfonamide $\rightarrow$ para-aminobenzoic acid (PABA)
- Nucleic acid synthesis

Ex. ATP
Figure 6.17 – Competitive & noncompetitive Inhibition
Ex. Anti-anxiety drugs (Valium, Xanax, Ativan)
- Increase the activity of gamma aminobutyric acid (GABA)
Ex. Na⁺ activation of thrombin
Ea. AMP
(a) **Allosteric activators and inhibitors**

Allosteric enzyme with four subunits

Regulatory site (one of four)

Active site (one of four)

Active form

Stabilized active form

Oscillation

Ex. Strychnine $\rightarrow$ glycine $\reg$ in CNS

Nonfunctional active site

Inactive form

Stabilized inactive form

Activator

Inhibitor
Figure 6.18 Allosteric Inhibitors
Competitive and noncompetitive inhibition affect the rate of reaction differently. Competitive inhibitors affect the initial rate but do not affect the maximal rate, whereas noncompetitive inhibitors affect the maximal rate.
(b) **Cooperativity**: another type of allosteric activation

Hemoglobin
An important regulatory mechanism in cells.
Feedback Inhibition

Active site of enzyme 1 is no longer able to catalyze the conversion of threonine to intermediate A; pathway is switched off.

Isoleucine binds to allosteric site.

Initial substrate (threonine)

Threonine in active site

Enzyme 1 (threonine deaminase)

Intermediate A

Enzyme 2

Intermediate B

Enzyme 3

Intermediate C

Enzyme 4

Intermediate D

Enzyme 5

End product (isoleucine)

Isoleucine used up by cell

Feedback inhibition

Active site available

Feedback inhibition