Chapter 8
An Introduction To Metabolism
Metabolism

- The totality of an organism’s chemical processes.
- Concerned with managing the material and energy resources of the cell.
Catabolic Pathways

- Pathways that break down complex molecules into smaller ones, releasing energy.
- Example: Cellular Respiration
Anabolic Pathways

- Pathways that consume energy, building complex molecules from smaller ones.
- Example: Photosynthesis
Energy

- Ability to do work.
- The ability to rearrange a collection of matter.
- Forms of energy:
  - Kinetic
  - Potential
  - Activation
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.
Kinetic Energy

- Energy of action or motion.
Potential Energy

- Stored energy or the capacity to do work.
Activation Energy

- Energy needed to convert potential energy into kinetic energy.
Energy Transformation

- Governed by the Laws of Thermodynamics.
Energy can be transferred and transformed, but it cannot be created or destroyed.

Also known as the law of “Conservation of Energy”
Each energy transfer or transformation increases the entropy of the universe.
Entropy

- Measure of disorder.
The *quantity* of energy in the universe is constant, but its *quality* is not.
How does Life go against Entropy?

By using energy from the environment or external sources (e.g. food, light).
Free Energy

- The portion of a system's energy that can perform work.
Free Energy

\[ G = H - TS \]

- \( G \) = free energy of a system
- \( H \) = total energy of a system
- \( T \) = temperature in K
- \( S \) = entropy of a system
Free Energy of a System

- If the system has:
  - more free energy
  - it is less stable

- It has greater work capacity
If the system is unstable, it has a greater tendency to change spontaneously to a more stable state.

This change provides free energy for work.
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
(a) Gravitational motion
(b) Diffusion
(c) Chemical reaction
Chemical Reactions

- Are the source of energy for living systems.
- Are based on free energy changes.
Reaction Types

- **Exergonic**: chemical reactions with a net release of free energy.
- **Endergonic**: chemical reactions that absorb free energy from the surroundings.
Exergonic/Endergonic

(a) Exergonic reaction (energy released; $\Delta G<0$).

(b) Endergonic reaction (energy required; $\Delta G>0$).
Biological Examples

- Exergonic – cellular respiration
- Endergonic – photosynthesis
Cell – Types of Work

- Mechanical – muscle contractions
- Transport – pumping across membranes
- Chemical – making polymers
Cell Energy

- Couples an exergonic process to drive an endergonic one.
- ATP is used to couple the reactions together.
(a) Transport work: ATP phosphorylates transport proteins

(b) Mechanical work: ATP binds noncovalently to motor proteins, then is hydrolyzed
**ATP**

- **Adenosine Triphosphate**
- **Made of:**
  - Adenine (nitrogenous base)
  - Ribose (pentose sugar)
  - 3 phosphate groups
(a) Structure of adenosine triphosphate (ATP)

(b) Hydrolysis of ATP

Adenosine triphosphate (ATP) + Water (H₂O) → Inorganic phosphate (Pᵢ) + Adenosine diphosphate (ADP) + Energy
Adenine

Ribose

Phosphates
Key to ATP

- Is in the three phosphate groups.
- Negative charges repel each other and makes the phosphates unstable.
ATP

- Works by energizing other molecules by transferring phosphate groups.
(a) Without ATP

\[
\text{Glu} + \text{NH}_3 \rightarrow \text{Glu} - \text{NH}_2 \quad \Delta G = +3.4 \text{ kcal/mol}
\]

\[
\text{∆G = +3.4 kcal/mol}
\]

(b) With ATP

1. \[
\text{Glu} + \text{ATP} \rightarrow \text{Glu}^\text{P} + \text{ADP}
\]

2. \[
\text{Glu}^\text{P} + \text{NH}_3 \rightarrow \text{Glu} + \text{P}_i
\]

\[
\text{∆G = −7.3 kcal/mol}
\]

(c) Free energy change with ATP

\[
\text{Glu} + \text{NH}_3 \rightarrow \text{Glu} - \text{NH}_2 \quad \Delta G = +3.4 \text{ kcal/mol}
\]

\[
\text{ATP} \rightarrow \text{ADP} + \text{P}_i \quad \Delta G = −7.3 \text{ kcal/mol}
\]

\[
\text{Net } \Delta G = −3.9 \text{ kcal/mol}
\]
ATP vs Food

- **ATP:**
  - Renewable energy resource.
  - Unstable bonds

- **Food:**
  - Long term energy storage
  - Stable bonds
ATP Cycles

- Energy released from ATP drives anabolic reactions.
- Energy from catabolic reactions “recharges” ATP.
ATP Cycle

Energy from catabolism (exergonic, energy-releasing processes)

\[ \text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{P}_i \]

Energy for cellular work (endergonic, energy-consuming processes)
ATP in Cells

- A cell's ATP content is recycled every minute.
- Humans use close to their body weight in ATP daily.
- No ATP production equals quick death.
Enzymes

- Biological catalysts made of protein.
- Cause the rate of a chemical reaction to increase.
Chemical Reaction

AB + CD → AC + BD

AB and CD are “reactants”
AC and BD are “products”
Enzymes

- Lower the activation energy for a chemical reaction to take place.
Enzyme Terms

- **Substrate** – the material an enzyme works on.

- Enzyme names: Ex. Sucrase
  - *ase* name of an enzyme
  - 1st part tells what the substrate is. (Sucrose)
Some older known enzymes don't fit this naming pattern.
Examples: pepsin, trypsin
Active Site

- The area of an enzyme that binds to the substrate.
- Structure is designed to fit the molecular shape of the substrate.
- Therefore, each enzyme is substrate specific.
1. Substrates enter active site; enzyme changes shape such that its active site enfolds the substrates (induced fit).

2. Substrates held in active site by weak interactions, such as hydrogen bonds and ionic bonds.

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

4. Substrates are converted to products.

5. Products are released.

6. Active site is available for two new substrate molecules.

Substrates

Enzyme-substrate complex

Enzyme

Products
Sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) is broken down by Sucrase into Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) and Fructose ($\text{C}_6\text{H}_{12}\text{O}_6$).
1. Substrate binds to enzyme.
2. Substrate is converted to products.
3. Products are released.
4. Active site is available for another molecule of substrate.
Models of How Enzymes Work

1. Lock and Key model
2. Induced Fit model
Substrate (key) fits to the active site (lock) which provides a microenvironment for the specific reaction.
Induced Fit Model

- Substrate “almost” fits into the active site, causing a strain on the chemical bonds, allowing the reaction.
Enzymes

- Usually specific to one substrate.
- Each chemical reaction in a cell requires its own enzyme.
Factors that Affect Enzymes

- Environment
- Cofactors
- Coenzymes
- Inhibitors
- Allosteric Sites
Factors that change protein structure will affect an enzyme.

Examples:
- pH shifts
- temperature
- salt concentrations
Cofactors: non-organic helpers to enzymes. Ex. Fe, Zn, Cu

Coenzymes: organic helpers to enzymes. Ex. vitamins
Enzyme Inhibitors

- **Competitive** – mimic the substrate and bind to the active site.
- **Noncompetitive** – bind to some other part of the enzyme.
(a) Normal binding  
(b) Competitive inhibition  
(c) Noncompetitive inhibition
The control of an enzyme complex by the binding of a regulatory molecule.

Regulatory molecule may stimulate or inhibit the enzyme complex.
Allosteric enzyme with four subunits

Active site (one of four)

Regulatory site (one of four)

Active form

Stabilized active form

Oscillation

Non-functional active site

Inactive form

Stabilized inactive form

(a) Allosteric activators and inhibitors
Control of Metabolism

- Is necessary if life is to function.
- Controlled by switching enzyme activity "off" or "on" or separating the enzymes in time or space.
Types of Control

- Feedback Inhibition
- Structural Order
When a metabolic pathway is switched off by its end–product.
End–product usually inhibits an enzyme earlier in the pathway.
Structural Order

- Separation of enzymes and metabolic pathways in time or space by the cell's organization.
- Example: enzymes of respiration
Summary

- Recognize that Life must follow the Laws of Thermodynamics.
- The role of ATP in cell energy.
- How enzymes work.