

**Energy Transformations**

**Metabolism**

Substrate → Optimal pH

High energy bond

ATP

ATP → ADP + P<sub>i</sub>

ADP + P<sub>i</sub> → ATP

ATP → ADP + P<sub>i</sub> + Energy

ADP + P<sub>i</sub> → ATP + Energy

**I. Energy**

**A. Metabolism**- Sum of all biochemical pathways

**B. Anabolic Pathways**

1. Consume energy
2. Build complex molecules
3.  $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{glucose}$

**C. Catabolic Pathways**

1. Release energy
2. Break down complex molecules.
3.  $\text{Glucose} \rightarrow \text{CO}_2 + \text{H}_2\text{O}$

food molecules → the many molecules that form the cell

the many building blocks for biosynthesis

**I. Energy**

**D. Types of Energy**

1. **Kinetic energy** is energy of motion.
2. **Potential energy** is stored energy, or energy of position.
  - a. Water behind a dam
  - b. Position of electrons in atoms.
3. **Chemical Energy**
  - 1) Arrangement of the atoms within a molecule
  - 2) Glucose has more energy than its breakdown components, carbon dioxide and water.

Reservoir behind hydroelectric dam

Molecular Structure of Glucose

● Hydrogen  
● Carbon  
● Oxygen

**I. Energy**

**E. Two Laws of Thermodynamics**

**1. First Law of Thermodynamics (Principle of conservation of energy)**

- a. Energy cannot be created or destroyed; it can be changed from one form to another
- b. Energy in universe is constant
- c. Engine Flow: chemical energy of gas → heat → kinetic energy.
- d. Human body: chemical energy in food → chemical energy in ATP → kinetic energy of muscle contraction.

**Energy Transformations**

Chemical → Motion  
Nuclear → Chemical  
Chemical → Motion  
Biological → Thermal

**I. Energy**

**2. Second Law of Thermodynamics**

- a. Every energy transformation increases the entropy of the universe.
- b. 25% of chemical energy of gasoline is converted to move a car; rest is lost as heat.
- c. When muscles convert chemical energy in ATP to mechanical energy, some is lost as heat.
- d. Heat is a lowest form of energy (uncoordinated movement)

Lost Heat

Mechanical Energy

Heat Energy

2nd Law of Thermodynamic

Work 20%

Heat 80%

**I. Energy**

**F. Entropy(S)**

1. Measure of randomness or disorder
2. Organized/usable forms of energy = low entropy
3. Unorganized/less stable forms = high entropy.
4. Energy conversions result in heat and therefore the entropy of the universe is always increasing.

**Second Law of Thermodynamics**

ENTROPY (disorder) increases in closed system

**Nature's Heat Tax**

Work: Uniform change in motion of molecules in surroundings

Heat: Increase in chaotic motion of molecules in surroundings

### I. Energy

- As an individual you exhibit low entropy (violating 2<sup>nd</sup> law)
- Interactions with your surroundings makes you an open system.
- It takes a constant input of usable energy from the food you eat to keep you organized.
- Return simpler, low energy molecules (CO<sub>2</sub>, H<sub>2</sub>O, heat)

### I. Energy

**G. Free energy (G)**

- Amount of energy in a system that is free to do work
- Change in free energy is noted as ΔG
- Gibbs-Helmholtz Equation**
  - $\Delta G = \Delta H - T\Delta S$  (T=Temp in °K)
  - Gives the maximum amount of usable energy that can be harvested from a reaction.
  - Enthalpy(H)** is the systems total energy

### I. Energy

**H. Free Energy and Metabolism**

- Exergonic Reactions (-ΔG)**
  - Energy is released.
  - Cellular Respiration ΔG = -686 kcal/mol
- Endergonic Reactions(+ΔG)**
  - Products have more energy than reactants
  - Only occur with an input of energy.
  - Photosynthesis ΔG = +686 kcal/mol

Photosynthesis  
 $6CO_2 + 6H_2O \xrightarrow{\text{light energy}} C_6H_{12}O_6 + 6O_2$

Respiration  
 $C_6H_{12}O_6 + 6O_2 \rightarrow \text{energy} + 6CO_2 + 6H_2O$

### I. Energy

**I. Metabolic Equilibrium**

- ΔG = 0
- Reaction is at equilibrium.
- No work can be done
- Does a cell really want equilibrium?
- Cells release energy in series of reactions
  - A product of one reaction is used as a reactant in the second reaction
  - Reactions pull one another

### II. ATP

**A. Coupling Reactions**

- Energy released by an exergonic reaction is used to drive an endergonic reaction.
- Hydrolysis of ATP (**adenosine triphosphate**)
  - Energy from ATP → ADP + P<sub>i</sub> is used to fuel reactions.
  - P<sub>i</sub> phosphorylates an intermediate molecule making it less stable
  - In cells, about -13 kcal/mole is released when ATP is hydrolyzed to ADP + P (in lab only -7.3 kcal/mol)

### II. ATP

**B. Structure of ATP**

- Nucleotides**
  - Nitrogen base adenine
  - Ribose
  - Three phosphates.
- ATP is called a "high-energy" molecule
  - Three negative phosphates repel
  - ADP is more stable
  - Some energy is lost as heat
  - Overall reaction is exergonic.
  - ATP is constantly recycled from ADP + P<sub>i</sub>
  - Muscle Cell= 10 million used and recycled per second

## II. ATP

**C. Function of ATP**

1. Chemical work: ATP supplies energy to synthesize macromolecules that make up the cell. (polymerization)
2. Transport work: ATP supplies energy needed to pump substances across the plasma membrane.
3. Mechanical work: ATP supplies energy to move muscles, cilia and flagella, chromosomes, etc.

**Polymerization**

## III. Metabolic Pathways

- Orderly sequence of chemical reaction
- Begin with particular reactant, end with an end product, and have many intermediate steps.
- Can be catabolic or anabolic
- Since pathways use the same molecules, a pathway can lead to several others.
- Energy is captured more easily if it is released in small increments.
- Each step in a series of chemical reactions is assisted by an enzyme.

## IV. Enzymes

- Enzymes are **catalytic** proteins
- Speed chemical reactions without being changed
- Every enzyme catalyzes only one reaction or one type of reaction.
- Enzymes lower the Energy of Activation
  1. **Energy of activation ( $E_A$ )** is energy that must be added to cause molecules to react
  2. Heat speeds a reaction, but denatures proteins
  3. Enzymes allow reactions to proceed at moderate temps

## IV. Enzymes

**E. Enzyme-Substrate Complexes**

1. Substrates are reactants in an enzymatic reaction.
2. Enzymes lowering the energy of activation ( $E_A$ ) by forming a complex with their substrate(s) at the active site.
  - a. **Active site**- small region on surface of enzyme where the substrate(s) bind.
  - b. **Induced-fit model**
    - i. Slight change in enzyme shape when substrate binds
    - ii. Facilitates the reaction

## IV. Enzymes

3. Substrates are held in place by weak bonds from functional groups
4. Active site is a microenvironment
5. When all enzymes are filled (saturated) reaction can't go faster
6. Most enzymes named adding the ending "-ase." to substrate name

## IV. Enzymes

**F. Factors That Affect Enzymatic Speed**

1. Enzymatic reactions are rapid
  - a. Most occur 1000 times/sec
  - b.  $2H_2O_2 \rightarrow 2H_2O + O_2$  (600,000 times/sec with catalase)
2. Temperature
  - a. Increase temp  $\rightarrow$  increase molecular collisions  $\rightarrow$  increase enzyme activity
  - b. Too high (or low?) denatures enzyme
  - c. Optimal temp for human enzymes is 35 $^{\circ}$ -40 $^{\circ}$ C

### IV. Enzymes

3. pH
  - a. Each enzyme has optimal pH that maintains its normal configuration.
  - b. A change in pH alters ionization of side chains, eventually resulting in denaturation.
  - c. Optimal in humans is pH 6-8
4. Concentration of enzyme

Substrate

Optimal pH

Maximum velocity,  $V_m$

$V_i$  initial reaction rate ( $\text{mol L}^{-1} \text{s}^{-1}$ )

[S], concentration of substrate ( $\text{mol L}^{-1}$ )

Enzyme is saturated: far more substrate than it can deal with

### IV. Enzymes

5. Cofactors Help Enzymes
  - a. Many enzymes require an inorganic ion or nonprotein cofactor to function
  - b. They accept or contribute atoms to the reaction.
  - c. Cofactors- inorganic ions (iron, zinc, copper)
  - d. **Coenzymes**- Organic cofactors (vitamins)

### IV. Enzymes

G. Controlling Metabolism

1. **Competitive Inhibition**
  - a. Another molecule is similar to enzyme's substrate
  - b. Competes with substrate for enzyme's active site
  - c. Decreases product formation.

(a)

(b)

### IV. Enzymes

2. **Allosteric Interactions**
  - a. **Noncompetitive Inhibition**
    - a. A molecule binds to an allosteric site (a site other than active site)
    - b. Changes the three-dimensional structure of the enzyme
    - c. Cannot bind to its substrate.
  - b. **Allosteric Activation**

### IV. Enzymes

4. **Feedback Inhibition**
  - a. Regulates activity of most enzymes
  - b. Product binds to enzyme's active or allosteric site
  - c. Concentrations of products can be kept within narrow ranges.
  - d. Pathways can be regulated by feedback inhibition

The First Law of Thermodynamics

(a) Energy transformation

The Second Law of Thermodynamics

(b) Energy transformation

Free energy

Energy transformations

LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 6.3 The Law of Thermodynamics  
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