Mmmm…Energy
Energy & Enzymes

What is Energy?

- The transformation of energy is a hallmark of life.
- Energy is the capacity to do work, or the capacity to change.
- Energy transformations are linked to chemical transformations in cells.

All forms of energy can be placed in two categories:

- – Potential energy is stored energy—as chemical bonds, concentration gradient, charge imbalance, etc.
- – Kinetic energy is the energy of movement.

Metabolism

- Metabolism: sum total of all chemical reactions in an organism
- Anabolic reactions: complex molecules are made from simple molecules; energy input is required.
- Catabolic reactions: complex molecules are broken down to simpler ones and energy is released.

Laws of Thermodynamics

- First Law of Thermodynamics: Energy is neither created nor destroyed.
  - – When energy is converted from one form to another, the total energy before and after the conversion is the same.

- Second Law of Thermodynamics: When energy is converted from one form to another, some of that energy becomes unavailable to do work.
  - – No energy transformation is 100 percent efficient.

Energy Calculation

- In any system:
  Total Energy = usable energy + unusable energy
  Enthalpy (H) = Free Energy (G) + Entropy (S)
  or $H = G + TS$ (T = absolute temperature)
  $G = H - TS$

- Change in energy can be measured in calories or joules.
- Change in free energy (ΔG) in a reaction is the difference in free energy of the products and the reactants.

Gibbs Free Energy

$$\Delta G = \Delta H - T\Delta S$$

- If ΔG is negative, free energy is released.
- If ΔG is positive, free energy is consumed.
- If free energy is not available, the reaction does not occur.

- Magnitude of ΔG depends on:
- ΔH—total energy added ($\Delta H > 0$) or released ($\Delta H < 0$).
- ΔS—change in entropy. Large changes in entropy make ΔG more negative.

- If a chemical reaction increases entropy, the products will be more disordered.
- Example: hydrolysis of a protein into its component amino acids—ΔS is positive.

Second Law of Thermodynamics:
- Disorder tends to increase because of energy transformations.
- Living organisms must have a constant supply of energy to maintain order.

Exergonic vs. Endergonic

- Exergonic reactions release free energy ($-\Delta G$)—catabolism
- Endergonic reactions consume free energy ($+\Delta G$)—anabolism
- In principle, chemical reactions can run in both directions.
- Chemical equilibrium $\Delta G = 0$
- Forward and reverse reactions are balanced.
- Every reaction has a specific equilibrium point.
- ΔG is related to the point of equilibrium: the further towards completion the point of equilibrium is, the more free energy is released.
- ΔG values near zero—characteristic of readily reversible reactions.

ATP

- ATP (adenosine triphosphate) captures and transfers free energy.
- ATP releases a large amount of energy when hydrolyzed.
- ATP can phosphorylate or donate phosphate groups to other molecules.

What Is the Role of ATP in Biochemical Energetics?

- ATP is a nucleotide.
- Hydrolysis of ATP yields free energy.
  - $\Delta G = -7.3$ kcal/mole

Metabolism

- Metabolism is the sum of the chemical reactions in an organism.
- Catabolism is the energy-releasing processes.
- Anabolism is the energy-using processes.
- Catabolism provides the building blocks and energy for anabolism.
- A metabolic pathway is a sequence of enzymatically catalyzed chemical reactions in a cell.
- Metabolic pathways are determined by enzymes.

What Are Enzymes?

- Biological catalysts that speed up the rate of a reaction by lowering the activation energy.
- The catalyst is not altered by the reactions.
- Some reactions are slow because of an energy barrier = the amount of energy required to start the reaction—activation energy (Ea)

- Rate can be used to calculate enzyme efficiency: molecules of substrate converted to product per unit time—also called turnover.
- Ranges from 1 to 40 million molecules per second!

Enzymes

- Apoenzyme: protein
- Cofactor: Nonprotein component (include inorganic ions)
  - Coenzyme: Organic cofactor
- Holoenzyme: Apoenzyme + cofactor

Important Coenzymes

- NAD+
- NADP+
- FAD
- Coenzyme A

- Biological catalysts (enzymes and ribozymes) are highly specific.
- Reactants are called substrates.
- Substrate molecules bind to the active site of the enzyme.
- Three-dimensional shape of the enzyme determines the specificity.

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.

How Are Enzymes Regulated?

- Temperature and pH affect enzyme activity
  - enzymes function within an optimum temperature range
    - when temperature increases, the shape of the enzyme changes due to unfolding of the protein chains
  - enzymes function within an optimal pH range
    - the shape of enzymes is also affected by pH
    - most enzymes work best within a pH range of 6 - 8
      - exceptions are stomach enzymes that function in acidic ranges

- Cells can control enzymes by altering their shape
  - **allosteric enzymes** are affected by the binding of signal molecules
    - the signal molecules bind on a site on the enzyme called the **allosteric site**
    - some signals act as **repressors**
      - inhibit the enzyme when bound
    - other signals act as **activators**
      - change the shape of the enzyme so that it can bind substrate

- **Feedback inhibition** is a form of enzyme inhibition where the product of a reaction acts as a repressor
  - **competitive inhibition**
    - the inhibitor competes with the substrate for the active site
    - the inhibitor can block the active site so that it cannot bind substrate
  - **non-competitive inhibition**
    - the inhibitor binds to the allosteric site and changes the shape of the active site so that no substrate can bind

Ribozymes

- RNA that cuts and splices RNA.
- They can function as catalysts.
- They have active sites that substrates can bind to.

Oxidation-Reduction

- Oxidation is the removal of electrons.
- Reduction is the gain of electrons.
- Redox reaction is an oxidation reaction paired with a reduction reaction.
- In biological systems, the electrons are often associated with hydrogen atoms. Biological oxidations are often dehydrogenations.
- Energy released from the transfer of electrons (oxidation) of one compound to another (reduction) is used to generate ATP by chemiosmosis.

- In photosynthetic organisms, light causes chlorophyll to give up electrons. Energy released from the transfer of electrons (oxidation) of chlorophyll through a system of carrier molecules is used to generate ATP.

Enzyme Classification

- Oxidoreductase — Oxidation-reduction reactions
- Transferase — Transfer functional groups
- Hydrolase — Hydrolysis
- Lyase — Removal of atoms without hydrolysis
- Isomerase — Rearrangement of atoms
- Ligase — Joining of molecules, uses ATP