Chapter 6

6.1 Cells and the Flow of Energy

A. Forms of Energy
1. **Energy** is capacity to do work; cells continually use *energy* to develop, grow, repair, reproduce, etc.
2. **Kinetic energy** is energy of *motion*; all moving objects have kinetic energy.
3. **Potential energy** is *stored* energy.
4. **Food** is **chemical energy**; it contains potential energy.
5. Chemical energy can be converted into **mechanical energy**, e.g., muscle movement.

B. Two Laws of Thermodynamics
1. First law of thermodynamics (also called the *law of conservation of energy*)
    a. Energy cannot be created or destroyed, but it can be changed from one form to another.
    b. In an ecosystem, solar energy is converted to chemical energy by the process of photosynthesis; some of the chemical energy in the plant is converted to chemical energy in an animal, which in turn can become mechanical energy or heat loss.
    c. Neither the plant nor the animal *create* energy, they *convert* it from one form to another.
    d. Likewise, energy is not destroyed; some becomes heat that dissipates into the environment.
2. Second law of thermodynamics
    a. Energy cannot be changed from one form into another without a loss of usable energy.
    b. Heat is a form of energy that dissipates into the environment; heat can never be converted back to another form of energy.

C. Cells and Entropy
1. Every energy transformation makes the universe less organized and more disordered; **entropy** is the term used to indicate the relative amount of disorganization.
2. When ions distribute randomly across a membrane, entropy has increased.
3. Organized/usable forms of energy (as in the glucose molecule) have relatively low entropy; unorganized/less stable forms have relatively high entropy.
4. Energy conversions result in heat; therefore, the entropy of the universe is always increasing.
5. Living things depend on a constant supply of energy from the sun, because the ultimate fate of all solar energy in the biosphere is to become randomized in the universe as heat; the living cell is a temporary repository of order purchased at the cost of a constant flow of energy.

6.2 Metabolic Reactions and Energy Transformations

1. **Metabolism** is the sum of all the biochemical reactions in a cell.
2. In the reaction A + B = C + D, A and B are **reactants** and C and D are **products**.
3. **Free energy** (ΔG) is the amount of energy that is free to do work after a chemical reaction.

   4. Change in free energy is noted as ΔG; a negative ΔG means that products have less free energy than reactants; the reaction occurs spontaneously.
   5. **Exergonic reactions** have a *negative* ΔG and energy is released.
   6. **Endergonic reactions** have a *positive* ΔG; products have more energy than reactants; such reactions can only occur with an input of energy.

A. ATP: Energy for Cells
   1. **Adenosine triphosphate** (ATP) is the energy currency of cells; when cells need energy, they "spend" ATP.
   2. ATP is an energy carrier for many different types of reactions.
   3. When ATP is converted into ADP + P, the energy released is sufficient for biological reactions with little wasted.
   4. ATP breakdown is coupled to endergonic reactions in a way that minimizes energy loss.
   5. ATP is a nucleotide composed of the base adenine and the 5-carbon sugar ribose and three phosphate groups.
   6. When one phosphate group is removed, about 7.3 kcal of energy is released per mole.

B. Coupled Reactions
   1. **Coupled reactions** are reactions that occur in the same place, at the same time, and in a way that an exergonic reaction is used to drive an endergonic reaction.
   2. ATP breakdown is often coupled to cellular reactions that require energy.
   3. ATP supply is maintained by breakdown of glucose during cellular respiration.

6.3 Metabolic Pathways and Enzymes
   1. **Enzymes** are catalysts that speed chemical reactions without the enzyme being affected by the reaction.
   2. Every enzyme is specific in its action and catalyzes only one reaction or one type of reaction.
   3. **Ribozymes** are made of RNA rather than proteins and also serve as catalysts.
   4. A **metabolic pathway** is an orderly sequence of linked reactions; each step is catalyzed by a specific enzyme.
   5. Metabolic pathways begin with a particular *reactant*, end with a particular *end product(s)*, and may have many intermediate steps.
   6. In many instances, one pathway leads to the next; since pathways often have one or more molecules in common, one pathway can lead to several others.
   7. Metabolic energy is captured more easily if it is released in small increments.
   8. A **reactant** is the substance that is converted into a **product** by the reaction; often many intermediate steps occur.

A. Energy of Activation
   1. Molecules often do not react with each other unless activated in some way.
   2. For metabolic reactions to occur in a cell, an enzyme must usually be present.
   3. The e**nergy of activation (E_a)** is the energy that must be added to cause molecules to react; without an enzyme (i.e., in a reaction vessel in the laboratory) this energy may be provided by heat, which causes an increase in the number of molecular collisions.

B. Enzyme-Substrate Complex
   1. A **substrate** is a reactant for an enzymatic reaction.
   2. Enzymes speed chemical reactions by lowering the energy of activation (E_a) by forming a complex with their substrate(s) at the *active site.*
      a. An **active site** is a small region on the surface of the enzyme where the substrate(s) bind.
      b. When a substrate binds to an enzyme, the active site undergoes a slight change in shape that facilitates the reaction. This is called the **induced fit model** of enzyme catalysis.
   3. Only a small amount of enzyme is needed in a cell because enzymes are not consumed during catalysis.
   4. Some enzymes (e.g., trypsin) actually participate in the reaction.
   5. A particular reactant(s) may produce more than one type of product(s).
      a. Presence or absence of enzyme determines which reaction takes place.
      b. If reactants can form more than one product, the enzymes present determine which product is formed.

C. Factors Affecting Enzymatic Speed
   1. Substrate concentration.
      a. Because molecules must collide to react, enzyme activity increases as substrate concentration increases; as more substrate molecules fill active sites, more product is produced per unit time.
   2. Optimal pH
      a. Every enzyme has optimal pH at which its rate of reaction is optimal.
      b. A change in pH can alter the ionization of the *R* groups of the amino acids in the enzyme, thereby disrupting the enzyme's activity.
   3. Temperature
      a. As temperature rises, enzyme activity increases because there are more enzyme-substrate collisions.
      b. Enzyme activity declines rapidly when enzyme is **denatured** at a certain temperature, due to a change in shape of the enzyme.
   4. Enzyme cofactors
      a. Many enzymes require an inorganic ion or non-protein **cofactor** to function.
      b. Inorganic cofactors are ions of metals.
      c. A **coenzyme** is an organic cofactor, which assists the enzyme (i.e., it may actually contribute atoms to the reaction).
      d. **Vitamins** are small organic molecules required in trace amounts for synthesis of coenzymes; they become part of a coenzyme's molecular structure; vitamin deficiency causes a lack of a specific coenzyme and therefore a lack of its enzymatic action.
   5. Enzyme inhibition
      a. **Enzyme inhibition** occurs when a substance (called an *inhibitor*) binds to an enzyme and decreases its activity; normally, enzyme inhibition is *reversible*.

b. In **noncompetitive inhibition**, the inhibitor binds to the enzyme at a location other than the active site (the *allosteric* site), changing the shape of the enzyme and rendering it unable to bind to its substrate.
c. In **competitive inhibition**, the substrate and the inhibitor are both able to bind to the enzyme's active site.

D. Enzyme Inhibitors Can Spell Death (*Health Focus box*)
1. Cyanide
   a. Cyanide was used in human executions.
   b. Cyanide binds to the mitochondrial enzyme that is necessary for ATP production.
2. MPTP
   a. MPTP is an enzyme inhibitor that stops mitochondria from producing ATP.
   b. MPTP's toxic characteristics were discovered in the 1980s, after intravenous drug users developed syndromes of Parkinson disease.
   c. The drug users had injected a synthetic form of heroin contaminated with MPTP.
3. Sarin
   a. Sarin inhibits enzymes at neuromuscular junctions.
   b. The muscle contraction can't turn off, muscles do not relax and become paralyzed.
   c. In 1995, terrorists in Japan released sarin gas on a subway; 17 people died.
4. Warfarin
   a. Warfarin is a chemical produced by the spoiling of the plant sweet clover.
   b. Wafarin inhibits an enzyme for blood clotting.
   c. Used as a rat poison, pets and small children also can consume the poison.
5. Coumadin
   a. Coumadin is a medicine to prevent inappropriate blood clotting.
   b. Coumadin contains a nonlethal dose of warfanin.

6.4 Organelles and the Flow of Energy

A. Photosynthesis
1. Photosynthesis uses energy to combine carbon dioxide and water to produce glucose in the formula:
   $6\ CO_2 + 6\ H_2O + \text{energy} = C_6H_{12}O_6 + 6\ O_2$
2. **Oxidation** is the loss of electrons.
3. **Reduction** is the gain of electrons.
4. When hydrogen atoms are transferred to carbon dioxide from water, water has been oxidized and carbon dioxide has been reduced.
5. Input of energy is needed to produce the high-energy glucose molecule.
6. Chloroplasts capture solar energy and convert it by way of an electron transport system into the chemical energy of ATP.
7. ATP is used along with hydrogen atoms to reduce glucose; when **$NADP^+$ (nicotinamide adenine dinucleotide phosphate)** donates hydrogen atoms ($H^+ + e^-$) to a substrate during photosynthesis, the substrate has accepted electrons and is therefore reduced.
8. The reaction that reduces $NADP^+$ is:
   $NADP^+ + 2e^- + H^+ = NADPH$

B. Cellular Respiration

1. The overall equation for cellular respiration is opposite that of photosynthesis: $C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O$ + energy
2. When NAD removes hydrogen atoms ($H^+ + e^-$) during cellular respiration, the substrate has lost electrons and is therefore oxidized.
3. At the end of cellular respiration, glucose has been oxidized to carbon dioxide and water and ATP molecules have been produced.
4. In metabolic pathways, most oxidations involve the coenzyme **NAD^+ (nicotinamide adenine dinucleotide)**; the molecule accepts two electrons but only one hydrogen ion: $NAD^+ + 2e^- + H^+ = NADH$

C. Electron Transport Chain

1. Both photosynthesis and respiration use an **electron transport chain** consisting of membrane-bound carriers that pass electrons from one carrier to another.
2. High-energy electrons are delivered to the system and low-energy electrons leave it.
3. The overall effect is a series of redox reactions; every time electrons transfer to a new carrier, energy is released for the production of ATP.

D. ATP Production

1. ATP synthesis is coupled to the electron transport system.
2. Peter Mitchell received the 1978 Nobel Prize for his chemiosmotic theory of ATP production.
3. In both mitochondria and chloroplasts, carriers of electron transport systems are located within a membrane.
4. H^+ ions (protons) collect on one side of the membrane because they are pumped there by specific proteins.
5. The electrochemical gradient thus established across the membrane is used to provide energy for ATP production.
6. Enzymes and their carrier proteins, called **ATP synthase complexes,** span the membrane; each complex contains a channel that allows H^+ ions to flow down their electrochemical gradient.
7. In photosynthesis, energized electrons lead to the pumping of hydrogen ions across the thylakoid membrane; as hydrogen ions flow through the ATP synthase complex, ATP is formed.
8. During cellular respiration, glucose breakdown provides energy for a hydrogen ion gradient on the inner membrane of the mitochondria that also couples hydrogen ion flow with ATP formation.