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Unit 5 Notes – Cellular Energy

B-3.1 Summarize the overall process by which photosynthesis converts solar energy into chemical energy and interpret the chemical equation for the process.

Key Concepts:

Photosynthesis: light-dependent reactions, dark (light-independent) reactions

All organisms need a constant source of energy to survive. *The ultimate source of energy for most life on Earth is the Sun.* *Photosynthesis* is the overall process by which sunlight (solar energy) chemically converts water and carbon dioxide into chemical energy stored in simple sugars (glucose). **This process occurs in two stages**.

- ✓ The first stage is called the *light-dependent reactions* because they require solar energy.
  - o During the light-dependent reactions, solar energy is absorbed by chloroplasts (see B-2.2) and two energy storing molecules (ATP and NADPH) are produced.
  - o The solar energy is used to split water molecules which results in the release of oxygen as a waste product, an essential step in the process of photosynthesis.
- ✓ The second stage is called the *dark (light-independent) reactions* because they do not require solar energy.
  - o During the dark (light-independent) reactions, **energy stored in ATP and NADPH is used to produce simple sugars (such as glucose) from carbon dioxide.** These simple sugars are used to store chemical energy for use by the cells at later times.
  - o Glucose can be used as an energy source through the process of cellular respiration or it can be converted to organic molecules (such as proteins, carbohydrates, fats/lipids, or cellulose) by various biologic processes.

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It is also essential for students to understand that the process photosynthesis is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of photosynthesis.

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

- ✓ In general, six carbon dioxide molecules and six water molecules are needed to produce one glucose molecule and six oxygen molecules.
- ✓ Each of the reactants (carbon dioxide and water) is broken down at different stages of the process.
- ✓ Each of the products (oxygen and glucose) is formed in different stages of the process.
- ✓ Solar energy is needed to break down the water molecules.

B-3.2 Summarize the basic aerobic and anaerobic processes of cellular respiration and interpret the chemical equation for cellular respiration.

Key Concepts:

Cellular respiration: adenosine triphosphate (ATP)
Glycolysis
Aerobic respiration: Krebs cycle (citric acid cycle), electron transport chain
Anaerobic respiration: fermentation, lactic acid fermentation, alcohol fermentation

The ultimate goal of *cellular respiration* is to convert the chemical energy in nutrients to chemical energy stored in *adenosine triphosphate (ATP).*

ATP can then release the energy for cellular metabolic processes, such as active transport across cell membranes, protein synthesis, and muscle contraction.

- ✓ Any food (organic) molecule, or nutrient, including carbohydrates, fats/lipids, and proteins can be processed and broken down as a source of energy to produce ATP molecules.

nutrients + oxygen → water + energy (ATP) + carbon dioxide

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To transfer the energy stored in glucose to the ATP molecule, a cell must break down glucose slowly and capture the energy in stages.

- ✓ The first stage is *glycolysis.*
  - ○ In the process of glycolysis a glucose molecule is broken down into pyruvic acid molecules and ATP molecules.
  - ○ Glycolysis is a series of reactions using enzymes that takes place in the cytoplasm.

- ✓ If oxygen is available, the next stage is the two-step process of *aerobic respiration*, which takes place primarily in the mitochondria of the cell.
  - ○ The first step of aerobic respiration is called the *citric acid* or *Krebs cycle.*
    - ♦ The pyruvic acid formed in glycolysis travels to the mitochondria where it is chemically transformed in a series of steps, releasing carbon dioxide, water, and energy (which is used to form 2 ATP molecules)

Pyruvic acid ⟶ carbon dioxide + water + energy (2 ATP)

  - ○ The second step of aerobic respiration is the *electron transport chain.*
    - ♦ Most of the energy storing ATP molecules is formed during this part of the cycle.
    - ♦ The electron transport chain is a series of chemical reactions ending with hydrogen combining with oxygen to form water. Carbon dioxide is released as a waste product as it is formed in several stages of the Krebs cycle.
    - ♦ Each reaction produces a small amount of energy, which by the end of the cycle produces many (up to 36) ATP molecules.
    - ♦ The ATP synthesized can be used by the cell for cellular metabolism

The process aerobic respiration is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of aerobic respiration.

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

- ✓ In general, one glucose molecule and six oxygen molecules are needed to produce six carbon dioxide molecules and six water molecules.
- ✓ Each of the reactants (glucose and oxygen) is used during different stages of aerobic respiration.
- ✓ Each of the products (carbon dioxide and water) is formed during different stages of the process.
- ✓ The energy that is released is primarily used to produce approximately 34 to 36 molecules of ATP per glucose molecule.

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If no oxygen is available, cells can obtain energy through the process of *anaerobic respiration*. A common anaerobic process is *fermentation.*

- ✓ Fermentation is not an efficient process and results in the formation of far fewer ATP molecules than aerobic respiration.
- ✓ There are two primary fermentation processes:
  - ○ *Lactic acid fermentation* occurs when oxygen is not available, for example, in muscle tissues during rapid and vigorous exercise when muscle cells may be depleted of oxygen.
    - ♦ The pyruvic acid formed during glycolysis is broken down to lactic acid, and in the process energy is released (which is used to form ATP).

Glucose → Pyruvic acid → Lactic acid + energy

    - ♦ The process of lactic acid fermentation replaces the process of aerobic respiration so that the cell can continue to have a continual source of energy even in the absence of oxygen, however this shift is only temporary and cells need oxygen for sustained activity.
    - ♦ Lactic acid that builds up in the tissue causes a burning, painful sensation.

  - ○ *Alcohol fermentation* occurs in yeasts and some bacteria.
    - ♦ In this process, pyruvic acid formed during glycolysis is broken down to produce alcohol and carbon dioxide, and in the process energy is released (which is used to form ATP).

Glucose → Pyruvic acid → alcohol + carbon dioxide + energy

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B-3.3 Recognize the overall structure of adenosine triphosphate (ATP)—namely, adenine, the sugar ribose, and three phosphate groups—and summarize its function (including the ATP-ADP [adenosine diphosphate] cycle).

Key Concepts:

ATP structure: nitrogenous base (adenine), ribose, phosphate group

ATP-ADP cycle

Adenosine triphosphate (ATP) is the most important biological molecule that supplies energy to the cell. A molecule of ATP is composed of three parts:

1. A *nitrogenous base (adenine)*
2. A sugar *(ribose)*
3. Three *phosphate groups* (therefore the name triphosphate) bonded together by "high energy" bonds

ATP-ADP cycle

- ✓ Cells break phosphate bonds as needed to supply energy for most cellular functions, leaving adenosine diphosphate (ADP) and a phosphate available for reuse.
    - When any of the phosphate bonds are broken or formed, energy is involved.
        - Energy is released each time a phosphate is removed from the molecule.
        - Energy is used each time a phosphate attaches to the molecule.
    - To constantly supply the cell with energy, the ADP is recycled creating more ATP which carries much more energy than ADP.
- ✓ **The steps in the ATP-ADP cycle are**
    - To supply cells with energy, a "high energy" bond in ATP is broken. ADP is formed and a phosphate is released back into the cytoplasm.

      ATP → ADP + phosphate + energy
    - As the cell requires more energy, ADP becomes ATP when a free phosphate attaches to the ADP molecule. The energy required to attach the phosphate to ADP is much less than the energy produced when the phosphate bond is broken.

      ADP + phosphate + energy → ATP