Lecture 9-10: Energy of Life

Contents: *Cellular respiration, Enzymes and Photosynthesis*

1. Cellular respiration:

- **Cellular Respiration/Respiration:** The process by which living cells break down glucose molecules and release stored chemical potential energy. It occurs in the mitochondria.
  - **a.** You must not confuse respiration with breathing. **Breathing** is simply the exchange of gases between an organism and its environment. Cellular respiration is the "burning" of glucose in cells to release the energy required to support life process. The word "burning" is placed in quotation mark because the really does not burn. A better term to use is oxidation.
  - **b.** **Oxidation** is the loss or removal of electron(s) from a substance. In cellular respiration glucose is oxidized.

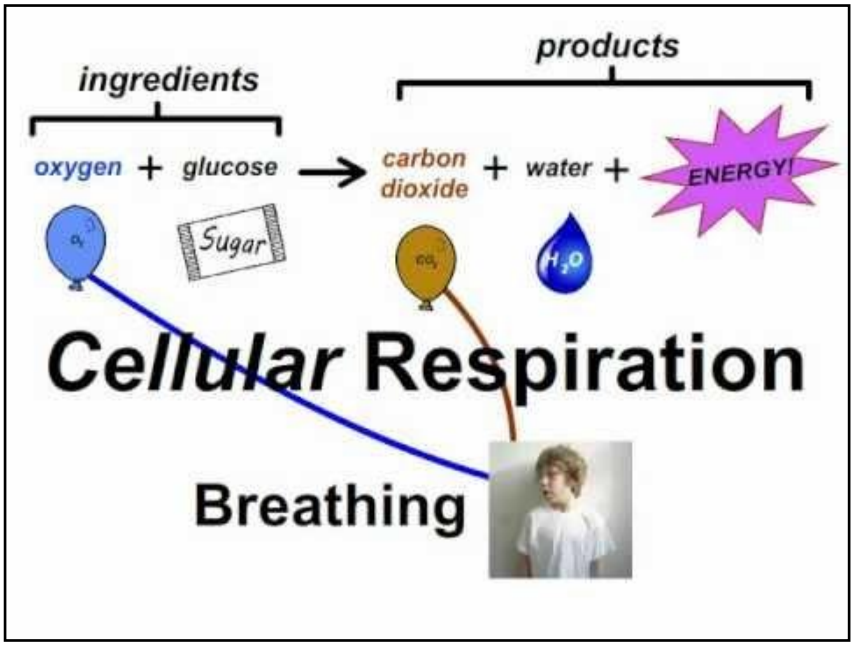

Figure 1: The difference between breathing and cellular respiration

- **Cellular Respiration vs. Oxidation**

  In some respects, oxidation in cell, or cellular respiration, is similar to oxidation, or burning, of fuels such as coal, wood, and oil. When a fuel is burned, chemical potential energy in the molecules of the fuel is released as heat and light energy.

  In a similar manner, when glucose is oxidized in cells, chemical potential energy in the glucose molecules is released partly as heat energy.

However, there is **one important difference** between the burning of fuel and the oxidation of glucose in living cells. The burning of fuel produces very high temperatures. Clearly, such high temperatures cannot occur in cells. The cells would be destroyed. Thus, during cellular respiration, the rate of oxidation must be controlled. As a result, it occurs in several small steps. Each step is assisted by an enzyme. The enzyme permits to take place that steps at the normal temperature of the organisms.
Enzymes are proteins that act as catalysts to regulate the **speed of the many chemical reactions** involved in the metabolism of living organisms.

- **The Summation Equation for Cellular Respiration**

Cellular respiration begins with two substances, glucose and oxygen. The process produces energy. Oxidation of most organic compounds produces carbon dioxide and water. Therefore, we will assume that they are formed in cellular respiration. We breathe out carbon dioxide and water vapour produced in our body by cellular respiration. The following are the **summation equations** for cellular respiration:

$$\text{Glucose} + \text{Oxygen} \xrightarrow{\textit{Enzymes}} \text{Carbon dioxide} + \text{Water} + \text{energy}$$

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

This summation equation only "*sums-up*" *what* happens during cellular respiration. It tells us *what* cellular respiration starts with and *what* it ends with. However, it does not tell us how this process occurs.

- **Anabolism and Catabolism** (already discussed in first lecture, so provided in brief)

Anabolism is all of the metabolic processes that build bio-molecules. **E.g.** synthesis of an amino acid from simpler molecules and, the synthesis of a protein from amino acids;
Catabolism involves all of the metabolic processes that tear down bio-molecules.
E.g. cellular respiration, in which the sugar glucose is broken down in the presence of oxygen to carbon dioxide and water
The sum of anabolism and catabolism is called the **Metabolism.**

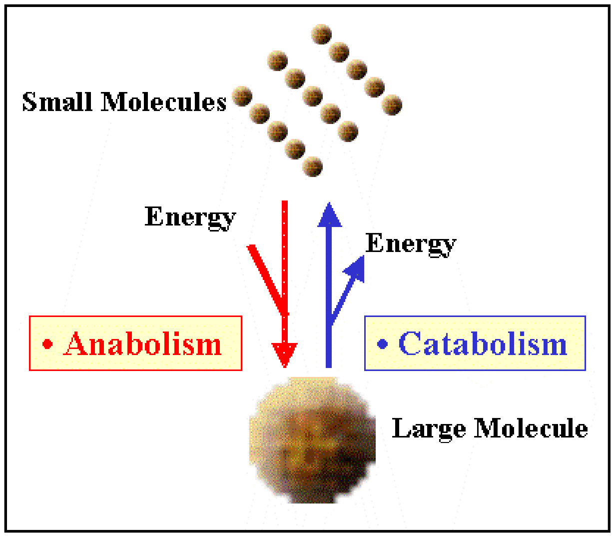

Figure 2: anabolism and catabolism at a glance

Table I-2. Comparison of Catabolism and Anabolism

		Catabolism	Anabolism
Descriptors of the Overall Process	Purpose	Energy generation	Formation of useful compounds
	Nature of the Process	Oxidative, degradative	Reductive, synthetic
	Energetics	Yields energy	Uses energy
Descriptors of the Chemical Participants	Types of Starting Materials	Highly variable, often complex	Relatively few, simple structures
	Types of Final Products	Relatively few, simple structures	Highly variable, often complex
	Typical Coenzyme/ Cosubstrate Transformations	ADP ----> ATP NAD+ ----> NADH	ATP---> ADP or AMP NADPH ---> $NADP^+$

- **ATP-The major energy currency**

  ATP is the molecule found in all living organisms that plays the key role in the storage, transfer, and release of energy in a cell. That is, it is the main immediate source of usable energy for the activities of the cells. ATP is the major **energy currency** molecule of the cell.

  ATP has a complex structural formula. We will write it simply as **A—Ⓟ~Ⓟ~Ⓟ**. The **A** stands for adenosine and each **Ⓟ** stands for one phosphate group. The wavy lines (~) represent high-energy phosphate bonds.

ATP is built up by the metabolism of foodstuffs in the cell in special compartments called mitochondria. It is then distributed to all parts of the cell. The two bonds between the three phosphate groups are **high-energy bonds**, that is, they are relatively weak and yield their energy readily when split by enzymes. These bonds play the key role in the storage, transfer, and release of energy in a cell. With the release of the end phosphate group, 7 kilocalories of energy become available for work, and the ATP molecule becomes **ADP** (**adenosine diphosphate**). Most of the energy-consuming reactions in cells are powered by the conversion of ATP to ADP; they include the transmission of nerve signals, the movement of muscles, the synthesis of protein, and cell division. Usually, ADP quickly regains the third phosphate unit by using food energy through the cellular respiration. The process can be summarized in this equation:

A—Ⓟ~Ⓟ~Ⓟ ⇆ A—Ⓟ~Ⓟ + Ⓟ + Energy

ATP ⇆ ADP + Ⓟ + Energy

In words the equation says: ATP produces ADP, a phosphate group, and energy. Also, ADP combines with a phosphate group and energy to produce ATP.

The change from ATP to ADP and from ADP to ATP occurs over and over again throughout the cell. The energy is stored in ATP and transported to where it is needed. There the ATP converts to ADP, releasing the needed energy.

- **The Role of ATP in Cellular Respiration**

The energy stored in ATP molecules is the only energy that is directly usable by cells. As a result, the energy released by glucose during cellular respiration must be stored in the bonds of ATP.

Enzymes permit the energy of glucose to be released in a slow, controlled manner. As it is released, it combines with a phosphate group, Ⓟ and ADP to form high-energy bonds in ATP. The ATP travels to places in the cell where energy is needed. It then loses a phosphate group and becomes ADP. The energy stored in the high-energy bond is released at this time. That energy powers all life processes.

Biologists have shown that, for every molecules of glucose that is oxidized, 38 molecules of ATP are formed. Therefore, the **summation equation** for cellular respiration showing the involvement of the ATP-ADP cycle could be written as:

$$C_6H_{12}O_6 + 6\,O_2 + \boxed{38\ ADP + 38\ P} \xrightarrow{\textit{Enzyme}} 6\,CO_2 + 6\,H_2O + \boxed{\begin{array}{l}38\ ATP \\ \text{Store Energy}\end{array}}$$

- **Anaerobic Respiration**

  The process of cellular respiration requires free oxygen, oxygen gas. As a result, it is called aerobic respiration. However many microorganisms, such as, yeast and some bacteria can respire without free oxygen. This type of respiration is called anaerobic respiration. **Anaerobic respiration** is the process by which certain microorganisms break down glucose molecules in the absence of molecular oxygen and release stored chemical potential energy.

  Anaerobic respiration may be two types: **alcohol fermentation**, and **lactic acid fermentation.**

a. Alcohol Fermentation

Bacteria and yeast that live in area where there is no oxygen must respire anaerobically. Since one of the end products is alcohol, this process is often called alcohol fermentation.

The summation equation for this type of anaerobic respiration is:

$$\text{Glucose} \xrightarrow{\text{Enzymes}} \text{Ethyl alcohol} + \text{Carbon dioxide} + \text{Energy}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2\,C_2H_5OH + 2\,CO_2 + \text{Energy}$$

b. Lactic Acid Fermentation

Anaerobic respiration does occur in some of our body cells from time to time. During periods of heavy physical activity, your muscle cells may not be able to get oxygen fast enough to carry out the usual aerobic cellular respiration. When this occurs, muscle cells begin to respire anaerobically. Glycogen, or animal starch, is stored in muscles. During anaerobic respiration, this glycogen changed to glucose. The glucose is then broken down anaerobically. No free oxygen is involved. Since the end product is lactic acid, this process is often called lactic acid fermentation.

The summation equation for this type of anaerobic respiration is:

$$\text{Glucose} \xrightarrow{\text{Enzyme}} \text{Lactic acid} + \text{Energy}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzyme}} 2\,C_3H_6O_3 + \text{Energy}$$

2. Enzymes:

- **Definition**
  Enzymes are complex chemicals that control reactions in living cells. They are biochemical catalysts speeding up reactions that would otherwise happen too slowly. The chemical which an enzyme works on is called its **substrate**. An enzyme combines with its substrate to form a short-lived **enzyme/substrate complex**. Once a reaction has occurred, the complex breaks up into **products and enzyme.**

$$E + S \rightarrow ES \rightarrow EP \rightarrow E + P$$

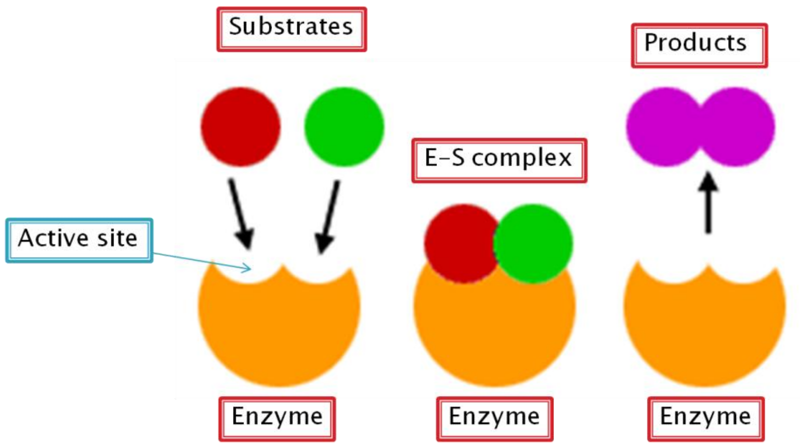

Figure 3: An enzyme catalyzed reaction

- **The chemical nature of enzymes**
  1. Enzymes are specific: each enzyme usually catalyses only one reaction.
  2. Enzymes combine with their substrates to form temporary enzyme-substrate complex.
  3. Enzymes are not altered or used up by the reactions they catalyze, so can be used again and again.
  4. Enzymes are sensitive to temperature and pH.
  5. Many enzymes need cofactors in order to function.
  6. Enzyme function may be slowed down or stopped by inhibitors.

- **Classification of Enzyme:**

  Enzymes are protein. There are 6 types of reaction they can catalyze-

  1. **Oxidoreductases**: These catalyze oxidation and reduction reactions.
  2. **Transferases:** These catalyze the transfer of a chemical group from one compound to another.
  3. **Hydrolases:** These catalyze hydrolysis (splitting by use of water) reactions. Most digestive enzymes are hydrolases.
  4. **Lyases:** these catalyze the breakdown of molecules by reactions that do not involved hydrolysis.
  5. **Isomerases:** These catalyze the transformation of one isomer into another,
  6. **Ligases:** These catalyze the formation of bonds between compounds, often using the free energy made available from ATP hydrolysis.

     To remember from the acronym: **OTHLIL**

3. Photosynthesis

- **The Need for Energy**

  All living things need a continuous supply of energy. This energy is needed to support life profess such as movement, growth, and reproduction. Almost all energy used by living things originally comes from the sun. Green plants and many other organisms contain chlorophyll. These living things, through ***photosynthesis***, store some of the sun's energy in the bonds of glucose molecules. They do this by converting light energy into chemical potential energy. The glucose that is made during photosynthesis is the basic energy source for almost all organisms. Organisms break down glucose during the process of ***respiration***. This releases some of the energy that was stored in the bonds of the glucose molecules.

  Organisms that produce their own food are called ***autotrophs***. Therefore, organisms that contain chlorophyll are autotrophs. They use the glucose that they produce during photosynthesis as an energy source during reparation.

  Organisms that depend on other organisms for food are called ***heterotrophs***. All heterotrophs depend directly or indirectly on autotrophs food. The dependence is direct in the case of plant eaters, or ***herbivores***, such as rabbits, deer, and cow. They eat plants and convert stored carbohydrates in the plants into glucose. The glucose is then "***burned***" during respiration to release needed energy. The dependence is indirect in the case of flesh eaters, or carnivores, such as tiger, lion, and wolves. These animals feed on herbivores such as rabbits. The rabbits eat autotrophic organisms such as grass. Therefore, indirectly, the **carnivores** depend on autotrophs for glucose that is needed for energy.

- **Summary**

1. **Photosynthesis** is the process by which light energy is changed to chemical potential energy and stored in the bonds of glucose molecules.

2. **Respiration** is the process by which living cells break down glucose molecules and release the stored chemical potential energy.

Photosynthesis takes place **only in cells that contain chlorophyll**. Photosynthesis also requires light energy. In contrast, respiration takes place in **all cells**, **all the time**.

- **The Composition of Glucose**

Glucose belongs to a family of organic compounds called carbohydrates. Its molecular formula is $\mathbf{C_6H_{12}O_6}$. (We have already discussed in macromolecules section).

If we write its formula as $C_6(H_2O)$, we can see why it is called "*carbo...hydrate*". It contains carbon. It also contains hydrogen and oxygen in the same proportion as water.

- **The Summation Equation for Photosynthesis**

As the name implies, light energy (***photo***) is used in building complex substance from simple substances (***synthesis***). Photosynthesis process occurs only in organisms that contain chlorophyll. The simple substances used in photosynthesis are water and carbon dioxide. During photosynthesis light energy is changed to and stored as chemical potential energy in the bonds of glucose molecules.

Photosynthesis is the process by which green plants and certain other organisms use the energy of light to convert carbon dioxide and water into the simple sugar glucose. In so doing, photosynthesis provides the basic energy source for virtually all organisms. An extremely important by-product of photosynthesis is oxygen, on which most organisms depend.

$$\textit{Carbon dioxide + Water + Light Energy} \xrightarrow{\text{Chlorophy}} \textit{Glucose + Oxygen+ Water}$$

$$6\,CO_2 + 12\,H_2O + \text{Light Energy} \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6\,O_2 + 6H_2O$$

Theses equations are just **summation equations**. They simply "**sum up**" what happens during photosynthesis. They tell us what photosynthesis starts with and what it ends with. They indicate that chlorophyll must be present. However, these equations do not tell us how the process occurs.

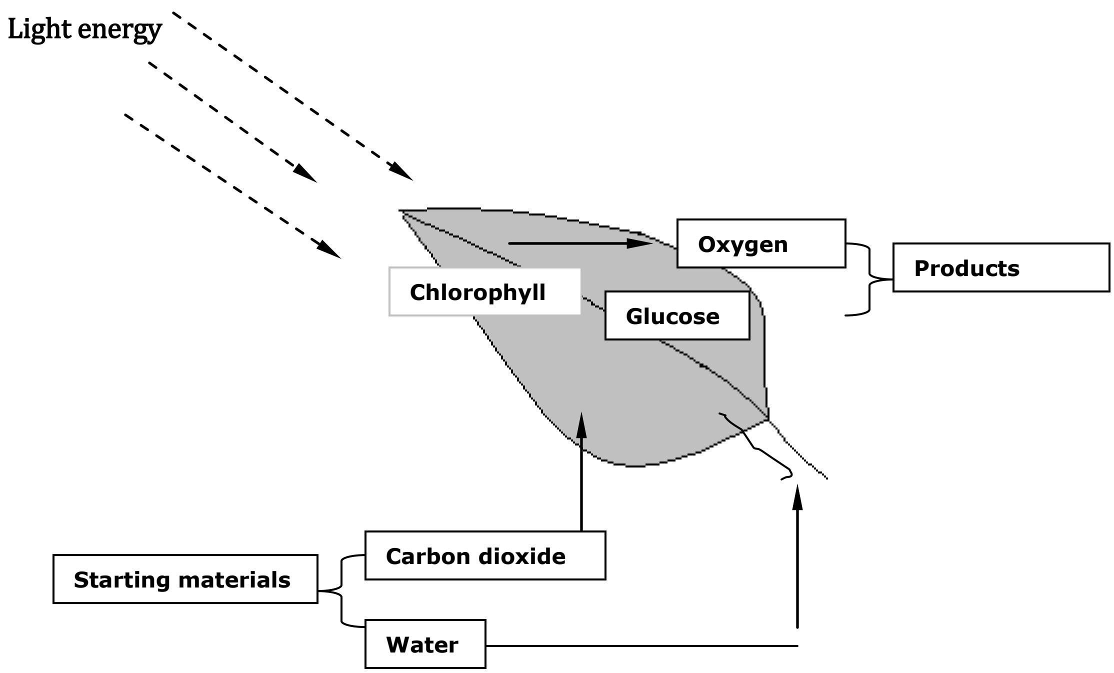

Figure 4: The diagram sums up what happens during photosynthesis. Water and carbon dioxide enter the leaf. Glucose and oxygen are produced.

- **The Role of Chlorophyll**
  A green leaf appears green in white light. Therefore, it must contain pigments that absorb the red and blue wave lengths of the spectrum but reflect green wave length. Of course these pigments are **chlorophyll**. Nearly all the blue light is absorbed by the chlorophyll. Also, much of the orange and red light is absorbed. However, little green and yellow light is absorbed. Therefore, plants that contain chlorophyll as their main pigment appear green because chlorophyll reflects mainly green and yellow light.

- **Chlorophyll**

  Chlorophyll, the pigment found in plants, some algae, and some bacteria that gives them their green colour and that absorbs the light necessary for photosynthesis. Chlorophyll absorbs mainly violet-blue and orange-red light. There are at least five chlorophyll molecules. All are somewhat alike in structure and properties. The two most common types are chlorophyll a and chlorophyll b. Chlorophyll is found in cell organelles called **chloroplasts**. The chlorophyll functions as a catalyst in the process of photosynthesis. A catalyst is a substance that affects the rate of a chemical reaction without being permanently changed itself. Thus chlorophyll speeds up the process of photosynthesis, but is not used up in the process.

  Apparently other pigments, the **carotenes** and the **xanthophylls**, also assist in photosynthesis. It is believed that that they aid chlorophyll in absorbing the light energy needed for photosynthesis.

________________Good Luck Students_________________