ENERGY PRODUCTION

ATP

The cells of all organisms—from the tiniest bacterium to the giant elephant—need energy to survive. They need energy to transport substances through the cell membrane, to make new cell parts and repair damaged ones, to grow, and to reproduce.

Where do organisms get all this energy? Directly or indirectly, almost all energy in living systems comes from the sun. Energy enters living systems when plants and a few other organisms absorb sunlight and use it to make organic compounds during the process of photosynthesis. These organic compounds store energy as chemical energy. Organisms that use energy from sunlight or inorganic substances to make organic compounds are called **autotrophs**. Most autotrophs are photosynthetic. Some autotrophs use chemical energy from inorganic substances to make organic compounds.

Other organisms, called **heterotrophs**, get their energy from food. The food contains energy trapped in the organic molecules manufactured by autotrophs. The energy is released in cells through the process of cellular respiration.

You may have heard that during cellular respiration your body cells "burn" food. This burning is different from the burning of wood. When wood burns, a lot of energy is given off quickly in the form of heat and light. In living cells, the energy stored in food is released gradually in a series of chemical reactions. The product in one reaction serves as a reactant in the next reaction.

When living cells break down food molecules, some of the energy in the molecules is released as heat. Other energy is stored in molecules of adenosine triphosphate, or **ATP**, which delivers energy wherever energy is needed in a cell. ATP contains three phosphate groups joined in a chain. When the bond between the two outer phosphate groups is broken, adenosine diphosphate, or **ADP**, forms and energy is released.

$$\text{ATP} \rightarrow \text{ADP} + \text{P} + \text{energy}$$

The energy released during this reaction is used as activation energy to power other chemical reactions needed to carry out life activities, such as those that build molecules.

Photosynthesis

Regardless of what you eat, if you trace the food back to its origin, you will nearly always end up with plants. Almost all living things depend on plants, or more specifically, on the products of an important process that takes place in plants—**photosynthesis**. This process can be summarized by the following equation:

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

The equation tells us that carbon dioxide and water in the presence of light react to form sugar and oxygen gas. However, the equation does not show how photosynthesis occurs. Let's look at the process in three stages.

Stage 1: Light energy is absorbed. The important chemical reactions that take place during photosynthesis occur in the plant cell's chloroplasts. As you can see in Figure 4-9, chloroplasts contain small disks called **thylakoids**. Each thylakoid contains a pigment called **chlorophyll**. Plants use chlorophyll to gather the sun's energy. Like all pigments, chlorophyll absorbs only certain wavelengths of light—mostly blue and red. It reflects green and yellow light, which is why most plants appear green. Light is a form of energy, and any substance that absorbs light also absorbs its energy.

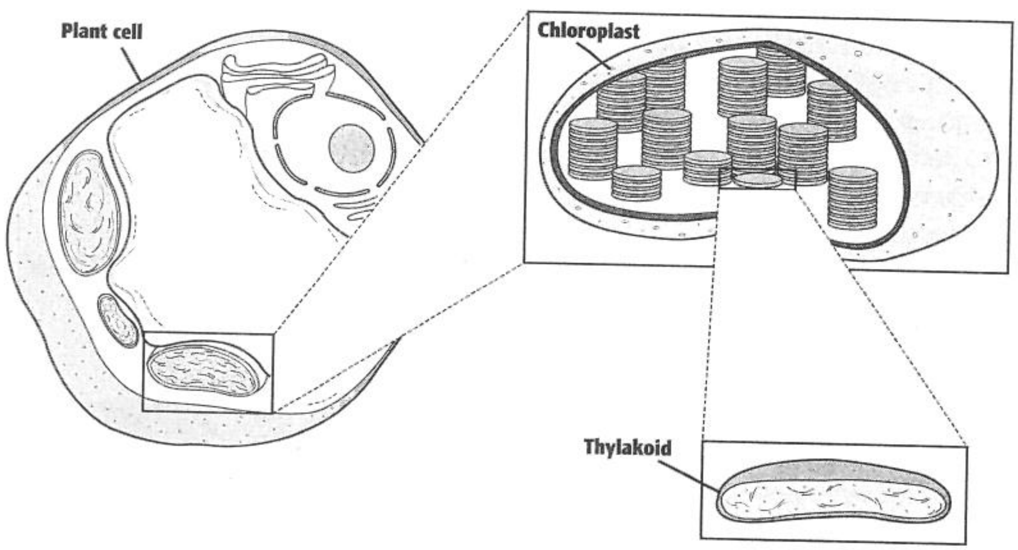

Figure 4-9

When light strikes a thylakoid, electrons in the chlorophyll molecules gain energy and they jump to a higher energy level. These "excited electrons" jump from chlorophyll to other molecules in the thylakoid membrane. In the process, oxygen is released.

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Photosynthesis, continued

Stage 2: Light energy is converted to chemical energy. After an excited electron jumps to a nearby molecule in the thylakoid membrane, it passes through a series of molecules called an **electron transport chain**. The energy passed through one type of electron transport chain is used to make ATP. The process is summarized in Figure 4-10.

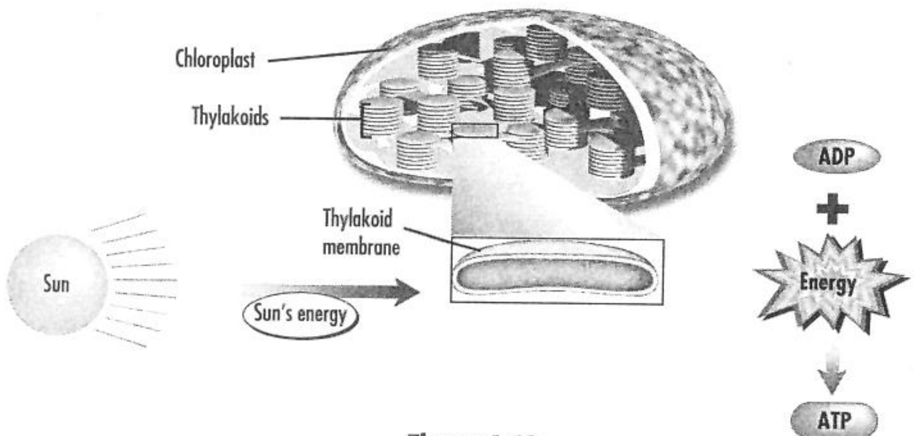

Figure 4-10

A second electron transport chain provides energy to make the compound NADPH, which carries the high-energy electrons to chemical reactions elsewhere in the cell. ATP and NADPH are used to power the last stage of photosynthesis, the building of energy-rich carbohydrate molecules.

The chemical reactions that occur in the first two stages of photosynthesis are often called the "light reactions" because these reactions can only occur in the presence of light energy. The third stage of photosynthesis can occur without sunlight.

Stage 3: Chemical energy is stored in organic compounds. The ATP and NADPH molecules formed during photosynthesis are not stable enough to store energy for more than a short time. In the third stage of photosynthesis, carbon atoms from carbon dioxide in the atmosphere are used to make organic compounds in which energy is stored. This transfer of carbon dioxide to organic compounds is called carbon dioxide fixation.

In one method of carbon dioxide fixation, the Calvin cycle, a three-carbon sugar is produced. The energy used in the Calvin cycle is supplied by ATP and NADPH, which are made during the second stage of photosynthesis. The steps of the Calvin cycle are summarized in Figure 4-11.

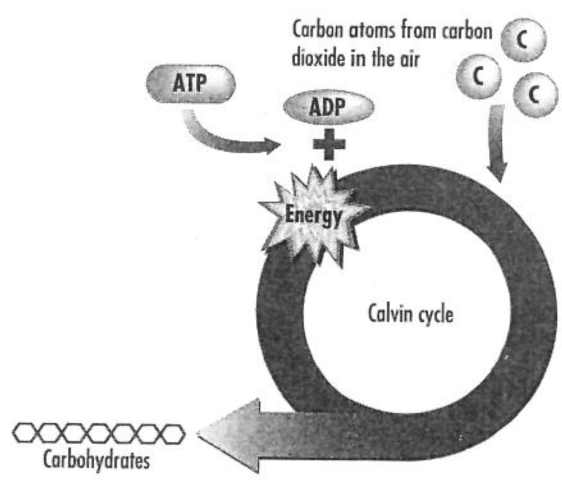

Figure 4-11

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Cellular respiration

The energy stored in the organic compounds that plants make is available for other organisms to use. But before that energy can be used, it must be transferred to ATP through a process called **cellular respiration**. The breakdown of one organic compound, glucose, can be summarized by the following equation:

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{enzymes}} 6CO_2 + 6H_2O + \text{energy (ATP)}$$

This equation tells us that sugar and oxygen react in the presence of enzymes to produce carbon dioxide, water, and energy, which is stored in ATP.

Cellular respiration occurs in two stages. As you can see in Figure 4-12, in the first stage, glucose is broken down in the cytoplasm in a process called **glycolysis**. During glycolysis, glucose is broken down into two smaller molecules of pyruvate. This reaction also produces small amounts of ATP and NADPH.

Glycolysis is followed by another set of reactions that use the energy temporarily stored in NADPH to make more ATP. When oxygen is present, pyruvate and NADPH are used to make a large amount of ATP in a process called **aerobic** respiration. This is the second stage of cellular respiration. Aerobic respiration occurs in the mitochondria of eukaryotic cells and in the cell membranes of prokaryotic cells. When oxygen is not present, pyruvate is converted to either lactate or ethanol and carbon dioxide. Figure 4-13 summarizes the process of aerobic respiration.

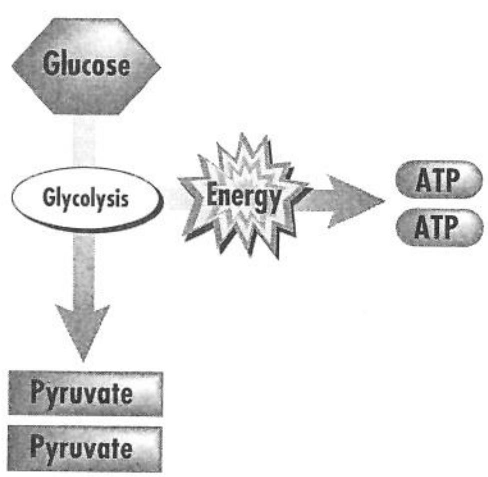

Figure 4-12

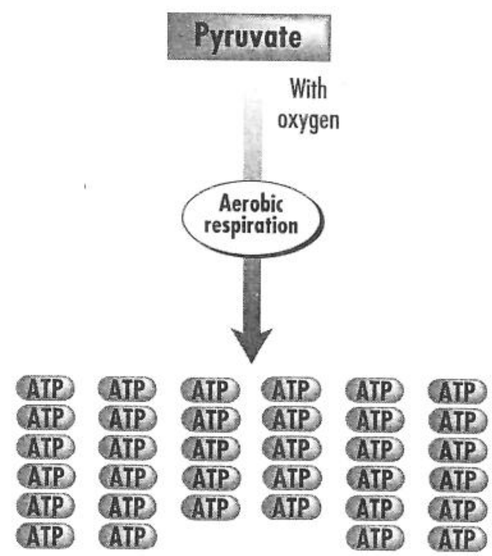

Figure 4-13

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TAKS Practice Questions, continued

4 Which of the following is an example of osmosis?

F The movement of ions from an area of high concentration to an area of lower concentration

G The movement of ions from an area of low concentration to an area of higher concentration

H The movement of water from an area of high concentration to an area of lower concentration

J The movement of water from an area of low concentration to an area of higher concentration

5 What happens to a cell when particles move out of the cell through facilitated diffusion?

A The cell gains energy.

B The cell uses energy.

C No energy change takes place.

D The cell produces energy.

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

6 Which process does the equation summarize?

F Glycolysis

G Calvin cycle

H Photosynthesis

J Cellular respiration