Energy and Life

Plants and some other living things can use light energy from the sun to make food.

These organisms are called **autotrophs.** Many organisms cannot use the sun's energy directly. These organisms, called **heterotrophs**, get energy from their food.
Adenosine triphosphate, or ATP, is a compound cells use to store and release energy.

ATP is the basic energy source of all cells.

Cells use energy from ATP to carry out many activities. These include active transport, synthesis of proteins and nucleic acids, and responses to chemical signals at the cell surface. ATP is made up of adenine, a 5-carbon sugar called ribose, and three phosphate groups. Adenosine diphosphate (ADP) is a compound similar to ATP. Unlike ATP, ADP has only two phosphate groups. When energy is available, a cell can store small amounts of energy by adding a phosphate group to ADP to form ATP (ADP _ P→ATP). Energy stored in ATP is released by breaking the bond between the second and third phosphate groups (ATP →ADP _ P).

Photosynthesis: An Overview

Research into photosynthesis began centuries ago. **Scientists found that in the presence of light, plants change carbon dioxide and water into carbohydrates and give off oxygen.** This process is called **photosynthesis.** The overall equation for photosynthesis is:

$6\ CO_2 + 6\ H_2O +$ light energy $\rightarrow C_6H_{12}O_6 + 6\ O_2$

Photosynthesis uses the energy of sunlight to convert water and carbon dioxide into high-energy sugars and oxygen. Plants get the carbon dioxide needed for photosynthesis from the air or from the water in which they grow. Plants use the sugars produced during photosynthesis to make complex carbohydrates such as starches.

Photosynthesis also requires light and chlorophyll. Plants gather the sun's energy with light-absorbing molecules called **pigments.** The main pigment in plants is **chlorophyll.** A compound that absorbs light also absorbs the light's energy. When chlorophyll absorbs sunlight, much of the light energy is sent directly to electrons in the chlorophyll molecules. This raises the energy levels of the electrons. The visible spectrum is made up of wavelengths of light you can see. This spectrum contains all the colors. Chlorophyll absorbs light in the blue-violet and red regions of the visible spectrum well. Chlorophyll does not absorb light in the green region well. Plants look green because their leaves reflect this green light.

The Reactions of Photosynthesis

In plants and other photosynthetic prokaryotes, photosynthesis takes place inside the chloroplasts. Chloroplasts have saclike photosynthetic membranes called **thylakoids.** Proteins in the thylakoid membrane organize chlorophyll and other pigments into clusters known as **photosystems.** The photosystems are the light-collecting units of chlorophyll.

When sunlight excites electrons in chlorophyll, the electrons gain energy. The electron transfers its energy to another molecule. The energy continues to move from molecule to molecule until it gets to the end of the chain. The reactions of photosynthesis occur in two parts: lightdependent reactions and light-independent reactions.

1. **The light-dependent reactions produce oxygen gas and convert ADP and NADP_ into ATP and NADPH.**

These reactions need light and they occur in the thylakoid membranes. The light-dependent reactions can be divided into four processes: light absorption, oxygen production, electron transport, and ATP formation. The light-dependent reactions use water, ADP, and NADP_. They produce oxygen, ATP, and NADPH.

2. **The light-independent reactions are also called the Calvin cycle.**

These reactions do not need light. **The Calvin cycle uses ATP and NADPH from the light-dependent reactions to produce high-energy sugars.** The Calvin cycle takes place in the **stroma** of chloroplasts. The Calvin cycle uses carbon dioxide in its reactions. As photosynthesis proceeds, the Calvin cycle works steadily to remove carbon dioxide from the atmosphere and turn out energy-rich sugars. Six carbon dioxide molecules are needed to make a single 6-carbon sugar. Many factors affect the rate of photosynthesis. Such factors include water availability, temperature, and the intensity of light.

Cellular Respiration and Chemical Pathways

Food is the energy source for cells. The energy in food is measured in calories. A **calorie** is the amount of energy needed to raise the temperature of 1 gram of water 1 degree Celsius. The calorie (capital C) used on food labels is equal to 1000 calories. Cells do not burn glucose or other food compounds. They gradually release the energy. The process begins with a pathway
called **glycolysis.**

Glycolysis is the process in which a glucose molecule is split in half. This forms two molecules of pyruvic acid, a 3-carbon compound.

Glycolysis takes place in the cytoplasm of a cell. Through glycolysis, the cell gains 2 ATP molecules. In addition, the electron carrier NAD_ accepts a pair of high-energy electrons, producing NADH. By doing this, NAD_ helps pass energy from glucose to other pathways in the cell. When oxygen is not present, fermentation follows glycolysis. **Fermentation** releases energy from food molecules by forming ATP. Fermentation does not need oxygen, so it is said to be **anaerobic.** During fermentation, cells convert NADH back into the electron carrier NAD_ that is needed for glycolysis. This lets glycolysis continue to make a steady supply of ATP.
The two types of fermentation are alcoholic fermentation and lactic acid fermentation.

- Yeasts and a few other microorganisms carry out alcoholic fermentation.
- Lactic acid fermentation occurs in muscles during rapid exercise.

If oxygen is present, the Krebs cycle and electron transport chain follow glycolysis. Together, these pathways make up **cellular respiration.**

Cellular respiration is the process that releases energy by breaking down glucose and other food molecules in the presence of oxygen.

Cellular respiration takes place in mitochondria. The equation for cellular respiration is:

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

The Krebs Cycle and Electron Transport

Cellular respiration requires oxygen, so it is said to be **aerobic.** The **Krebs cycle** is the second stage of cellular respiration. **During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions.** The Krebs cycle is also known as the citric acid cycle, because citric acid is one of its first products. Here are the stages of the Krebs cycle.

- The Krebs cycle starts when pyruvic acid formed by glycolysis enters the mitochondrion.
- The pyruvic acid is broken down into carbon dioxide and a 2-carbon acetyl group.
- The two carbons of the acetyl group join a 4-carbon compound to produce citric acid.

The Krebs cycle continues in a series of reactions. In these reactions, two energy carriers accept high-energy electrons. NAD_ is changed to NADH, and FAD is changed to FADH2. These molecules carry the high-energy electrons to the electron transport chain. The carbon dioxide is released as a waste product.

The electron transport chain uses the high-energy electrons to change ADP into ATP.

In the electron transport chain, high energy electrons move from one carrier protein to the next. At the end of the chain, oxygen pulls electrons from the final carrier molecule. These electrons join with hydrogen ions, forming water. Each transfer along the chain releases a small amount of energy. ATP synthase uses the energy to produce ATP. Glycolysis produces 2 ATP molecules from one molecule of glucose. The Krebs cycle and the electron transport chain let the cell form 34 ATP molecules per glucose molecule. The total, then, for cellular respiration is 36 ATP molecules per glucose molecule. The energy flows in photosynthesis and cellular respiration occur in opposite directions. On a global level, photosynthesis and cellular respiration are also opposites. Photosynthesis removes carbon dioxide from the atmosphere and puts back oxygen. Cellular respiration removes oxygen from the atmosphere and puts back carbon dioxide.

Addition information and practice can be found at the following website:

www.explorelearning.com – use the photosynthesis lab, cell energy cycle gizmos to further your study.