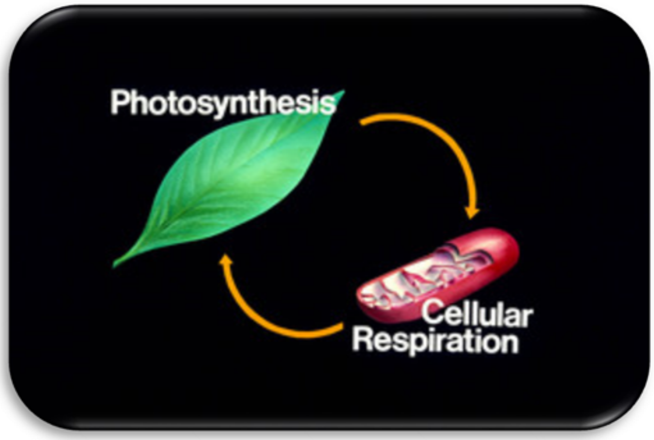
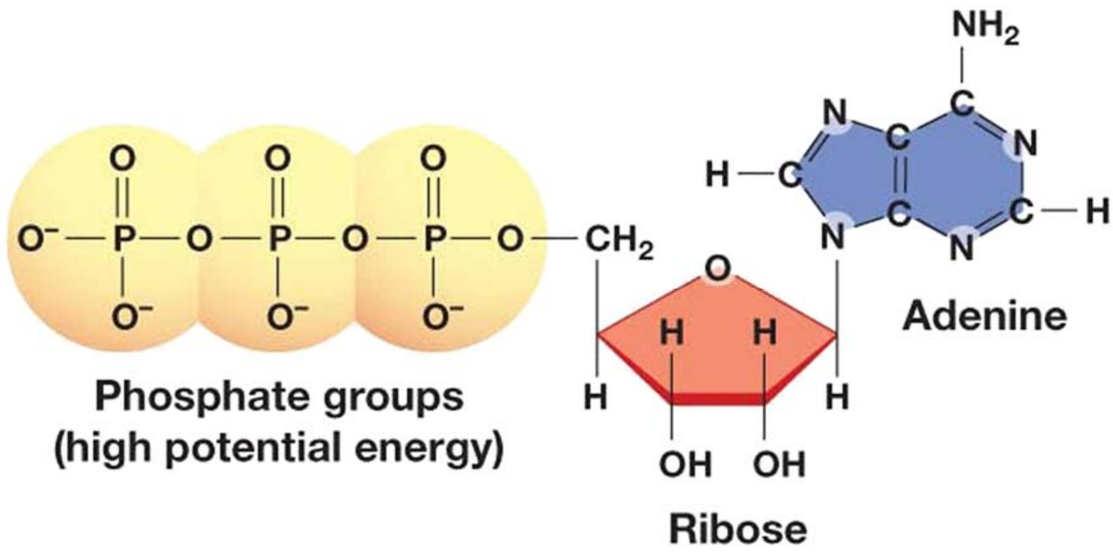


PHOTOSYNTHESIS AND CHEMOSYNTHESIS

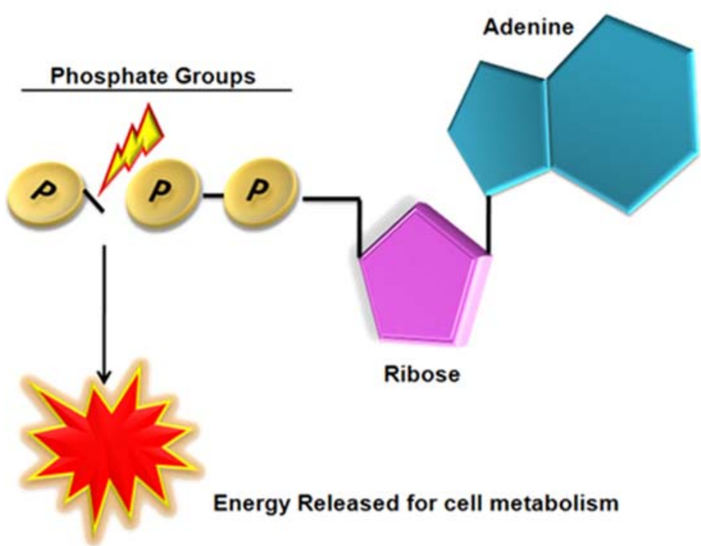
Continuing with our topic of the cell we will now look at how some cells produce and use energy. You should recall the characteristics of life (from unit 2) and one of those characteristics being metabolism. Metabolism is the sum of all chemical reactions carried out in an organism. These chemical reactions produce energy, by building organic molecules, or require energy, by breaking down organic molecules. Keep in mind, the energy, that is stored and used from these reactions, is found in the chemical bonds of the organic compounds. In this unit we will discuss the reactions which produce the energy needed to carry out metabolism in all organisms. The next unit will discuss the reaction which uses the energy that is produced or generated into a usable form the cell can use. Remember that organisms which generate or produce their own energy, or food, are autotrophs (self-feeder) and organisms which use the energy, or food, produced by other organisms to generate cellular energy are heterotrophs (other-feeder). The reactions we will discuss in this unit will involve autotrophic organisms because these reactions involve producing organic molecules that capture the energy from either the sun or inorganic molecules to produce “food”.

ATP (Adenosine Triphosphate)



The chemical nature of ATP was addressed in Unit 5. ATP is the energy “currency” of the cell. When cells break down the food that is consumed, some of the energy from the food is lost as heat. The energy not lost as heat is used to produce ATP, so the cell has a usable form of energy for all of its energy-required processes.

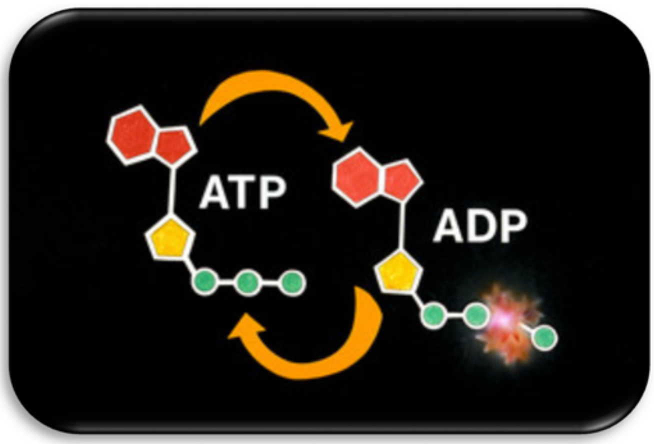
Hydrolysis of ATP



ATP ⟶ ADP + P + Energy

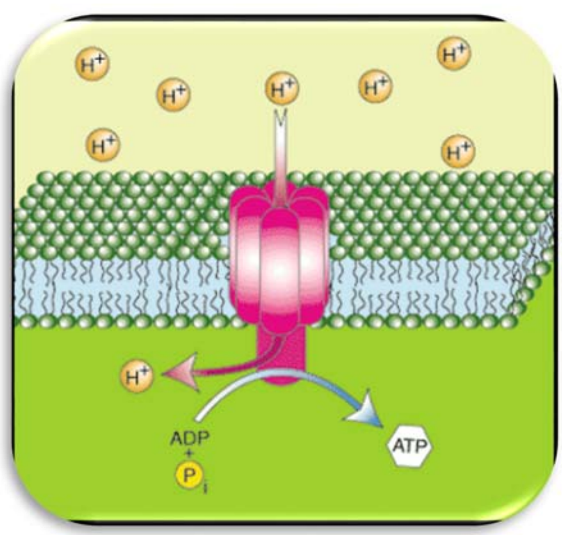
ATP has a large amount of potential energy (stored energy) within the chemical bond of the third phosphate group. In the hydrolysis decomposition reaction of ATP, the chemical bond of the third phosphate group is broken and energy is released. This energy will be used for any energy-required chemical process of the cell.

In the reaction above you see **ATP** (adenosine triphosphate) being broken down into an **ADP** (adenosine diphosphate) and **P** (phosphate group broken off to release the **energy** from within the chemical bonds).



$$ADP + P \longrightarrow ATP$$

Synthesis of ATP



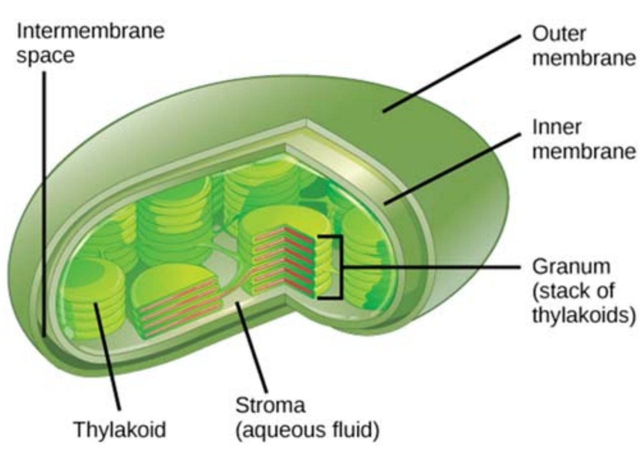
Many cells have an enzyme that catalyzes the synthesis of ATP. [*Catalyzes essentially means to bring about or cause and synthesis means to produce or make.*] The enzyme is called **ATP synthase**. ATP synthase works by recycling the ADP and P left over in the decomposition of ATP. ATP synthase chemically combines the ADP and P producing ATP thus restoring the large amount of potential energy. ATP synthase behaves as an enzyme and a channel protein. As hydrogen ions (H^+) move in or out of a cell through the ATP synthase in the membrane, the hydrogen ions then power the ATP synthase to add a phosphate group to the ADP producing ATP.

The following video examines the processes of photosynthesis and cell respiration. The video defines each process and describes how energy created during photosynthesis is transferred through ATP molecules.

ATP: The Energy Currency

CHLOROPLASTS

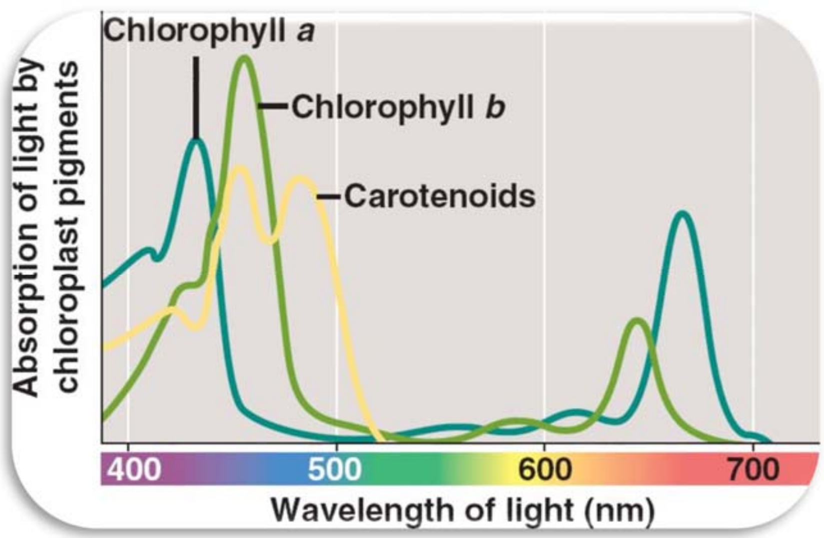
Chloroplasts are the organelles which undergo photosynthesis. This organelle is responsible for converting the energy from sunlight into an organic molecule (sugar) so it is said that chloroplasts convert light energy into chemical energy. Chloroplasts can be found in any photosynthetic autotroph such as plants, some bacteria, and some protists. A common misconception about photosynthesis is that it takes place only in plants. It is important to understand that it can take place in any cell that contains chloroplasts, such as those previously mentioned. Some bacteria undergo photosynthesis also, but remember they do not have organelles, so they have no chloroplasts. Bacteria will complete photosynthesis along their membrane.



A chloroplast is an oval organelle consisting of two membranes. The outer membrane is more permeable than the inner membrane. Both membranes, however, allow light to pass through. The fluid-filled space inside a chloroplast is called the **stroma**. Within the stroma are flattened, disc-like sacs called **thylakoids**. The thylakoid's membrane contain molecules that absorb light energy and proteins for the chemical reactions involved in photosynthesis. A stack of these thylakoids, of which there are many, is called a **granum** or grana for plural.

The light absorbing substance within a chloroplast (thylakoid more specifically) is called a **pigment**. [Remember from physical science that the color you see is what is being reflected and the other colors of the spectrum that you do not see are being absorbed.] There are many different types of pigments within photosynthetic cells.

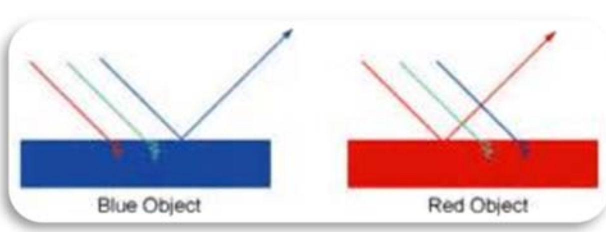
Chlorophylls - There are 3 different forms of chlorophyll: chlorophyll a, chlorophyll b, and chlorophyll c. Chlorophyll a is the most abundant pigment in all photosynthetic organisms and absorbs blue and red while reflecting mostly green and a little yellow. Chlorophyll b is similar to chlorophyll a, but is not as abundant as chlorophyll a, while still reflecting green. Chlorophyll b is found in plants and some protists. Chlorophyll c is found only in some protists.



Carotenoids - Carotenoids reflect red, orange, or yellow. Carotenoids are called an accessory pigment because they help the chlorophyll absorb light energy for photosynthesis.

Xanthophylls - Xanthophylls are similar to carotenoids, but do not absorb energy as well as carotenoids. Xanthophylls reflect red and yellow.

If you ever noticed how leaves in certain parts of the country change color in the fall it is due to these pigments and others. Chlorophyll is the primary pigment for photosynthesis to produce sugar during the spring and summer with warmer temperatures and longer days. With autumn, as the nights become longer the chlorophyll production slows down and eventually stops. At this time the other pigments begin to show their colors until their production also slows down and stops.



To learn more about this pigment change visit the link below:

http://na.fs.fed.us/fhp/pubs/leaves/leaves.shtm

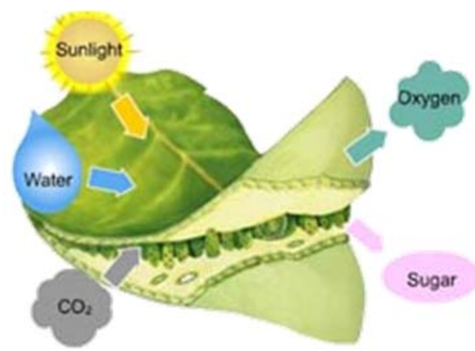
The following video examines the structure and function of chloroplasts by taking an in-depth look into how plants receive energy from sunlight.

QuickTime **Chloroplast: Structure and Function**

PHOTOSYNTHESIS

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

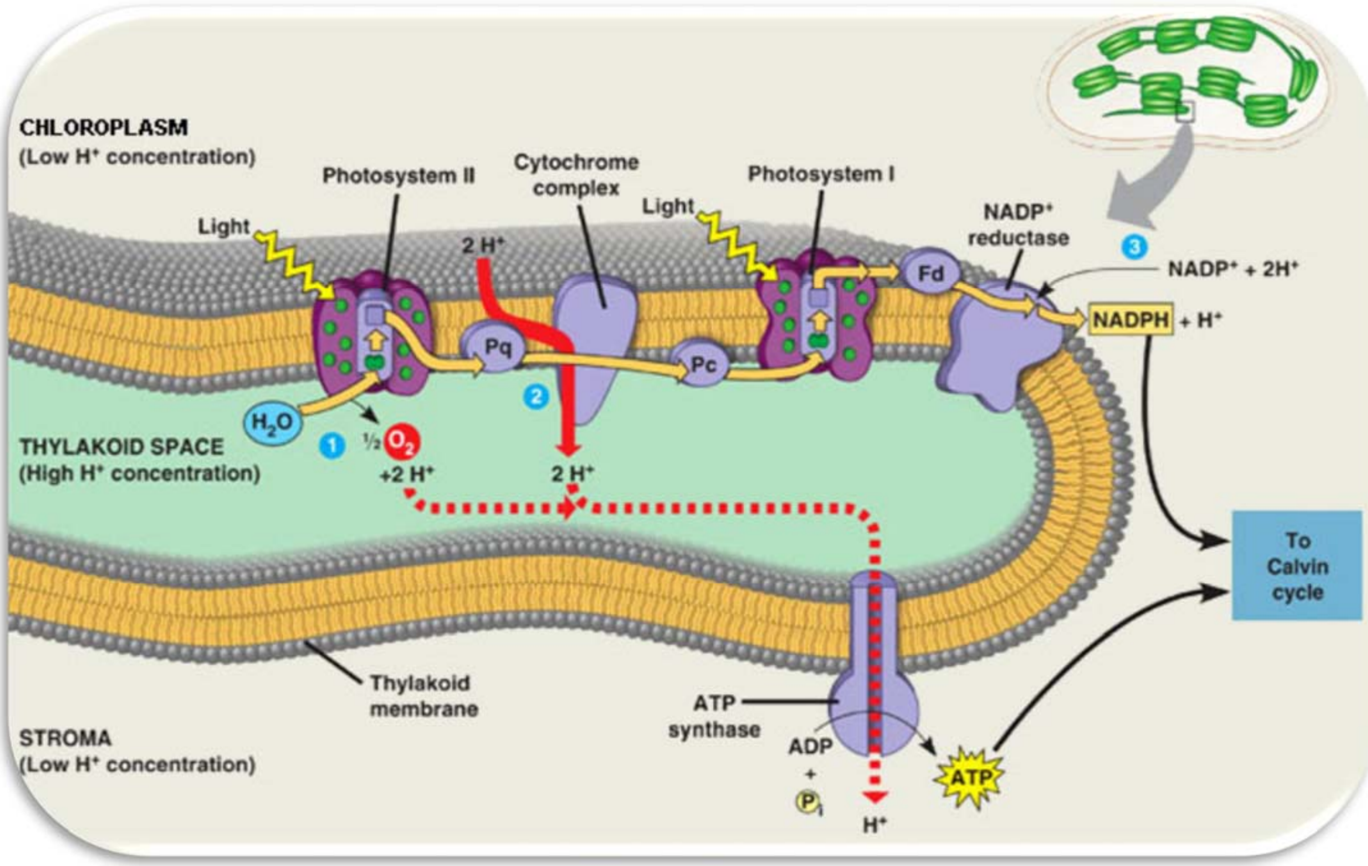
The chemical reaction for photosynthesis is carbon dioxide (CO_2) and water (H_2O) yielding oxygen (O_2) and sugar, specifically glucose, ($C_6H_{12}O_6$) with the help of sunlight and chlorophyll. Photosynthesis involves converting light energy into chemical energy. The goal of photosynthesis is to produce chemical energy in the form of an organic molecule, more specifically a carbohydrate or sugar (glucose).



There are three overall stages to photosynthesis:

- **Stage 1**: Light energy is captured.
- **Stage 2**: The captured light energy is temporarily stored as chemical energy.
- **Stage 3**: The temporarily stored energy is used in carbon dioxide fixation to produce an organic molecule (glucose).

Stage 1: *Light energy is captured.*



Splitting of Water

When sunlight strikes a thylakoid membrane the energy from the sunlight is absorbed by the pigment molecules in the thylakoid membrane. The electrons in the pigment molecule are then "excited" by the energy of the sunlight and move to a higher energy level. These excited electrons then move to nearby molecules and to what are called electron carriers. When the "excited" electrons leave the pigment molecule and travel down the membrane they must be replaced. An enzyme in the thylakoid membrane will then split a molecule of water and replace the "excited" electron with an electron from the hydrogen atoms (H) in water (H_2O). The resulting hydrogen ions (H^+) from the splitting of water will be released into the thylakoid. The left over oxygen atoms from the splitting of water will combine and form oxygen gas (O_2) and be released from the cell into the atmosphere. We, as animals, are thankful for that because that is the oxygen that we breathe.

Hydrogen Ion Pump

The "excited" electrons travel to nearby molecules releasing their energy to pump hydrogen ions (H^+) into the thylakoid in the first of what is called **Electron Transport Chains**. By pumping hydrogen ions into the thylakoid a concentration gradient is created. There is a higher concentration of hydrogen inside the thylakoid and a lower concentration of hydrogen outside the thylakoid. When this occurs hydrogen will naturally and passively diffuse out of the thylakoid through the channel protein and enzyme known as ATP synthase. As you have read earlier in this unit, every time hydrogen ions pass through an ATP synthase channel protein/enzyme ATP is produced.

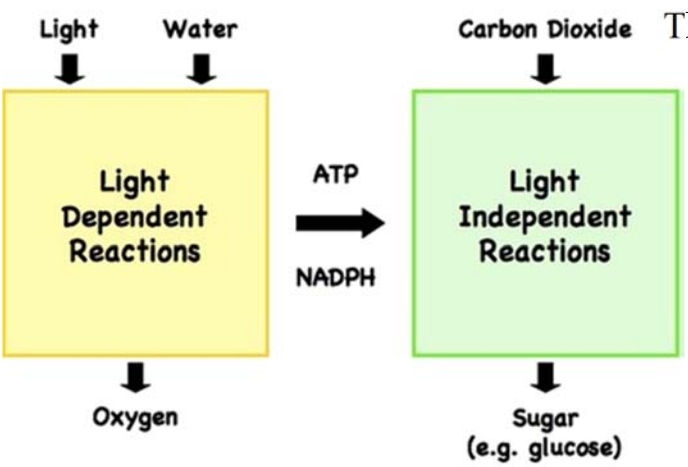
Producing NADPH

The "excited" electron used in the first electron transport chain, for pumping hydrogen ions into the thylakoid, uses up all of its energy and is absorbed into another chlorophyll molecule down the membrane. The sunlight also "excites" electrons in this chlorophyll molecule to go into the second **electron transport chain**. As these "excited" electrons leave the chlorophyll molecule, they are replaced by the de-energized electrons from the first electron transport chain. These new "excited" electrons chemically combine hydrogen ions (H^+) with an electron acceptor known as $NADP^+$ to produce NADPH. NADPH (Nicotinamide adenine dinucleotide phosphate) is an electron carrier which is responsible for carrying the high energy electrons needed to store energy in the organic molecules (sugar) in the third step of photosynthesis.

Stage 2: *The captured light energy is temporarily stored as chemical energy.*

The end of Stage 1 provides us with ATP from the first electron transport chain and NADPH from the second electron transport chain. The ATP and NADPH produced is where the light energy is temporarily stored as chemical energy. Both ATP and NADPH will be needed and used to power the third step of producing the energy-rich organic molecule which will be used as food for heterotrophs.

Stage 3: *The temporarily stored energy is used in carbon dioxide fixation to produce an organic molecule.*



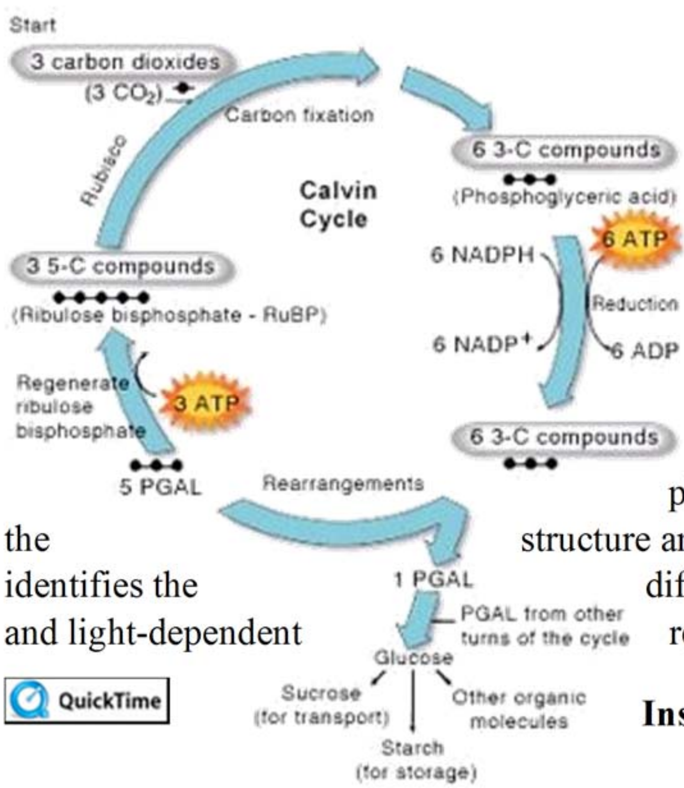
The first two stages of photosynthesis rely completely on sunlight in order to happen. Because of the need for sunlight, stage 1 and stage 2 are referred to as the **light dependent** or light reactions. The third stage is referred to as the **light independent** or dark reactions, because the energy needed from sunlight was already used and chemically stored in stages 1 and 2, now stage 3 can occur without the need for sunlight.

The ATP and NADPH produced in stage 2 will now be used to produce energy-storing organic molecules known as carbohydrates or sugars (glucose) from the carbon atom in carbon dioxide

(CO_2). Using the carbon atom in carbon dioxide to produce organic molecules is known as **carbon dioxide fixation**. There are many ways photosynthetic organisms perform carbon dioxide fixation, but the most common method or process is known as the **Calvin Cycle**. The Calvin Cycle occurs in 4 basic steps.

CALVIN CYCLE SUMMARY

- **Step 1**: An enzyme adds a molecule of carbon dioxide to a five-carbon compound. This process will occur three times to produce three six-carbon compounds.
- **Step 2**: Each of the three six-carbon compounds split into two three-carbon compounds. A phosphate group from the ATP (from stage 2) and electrons from NADPH (from stage 2) are added to the three-carbon compounds to produce three-carbon sugars.
- **Step 3**: One of the three-carbon sugars leaves the Calvin Cycle and is used to make organic compounds (energy).
- **Step 4**: Using energy from ATP and the remaining five three-carbon sugars, enzymes recreate three of the original five-carbon compound that began the cycle.



The following video introduces the complex biochemical processes that occur during photosynthesis. The program looks specifically at the structure and function of chloroplasts and chlorophyll, and identifies the difference between the light-independent reactions and light-dependent reactions of photosynthesis.

QuickTime

Inside Plants: Photosynthesis in Detail

FACTORS THAT AFFECT PHOTOSYNTHESIS

There are three factors that affect photosynthesis: light intensity, carbon dioxide concentration, and temperature.

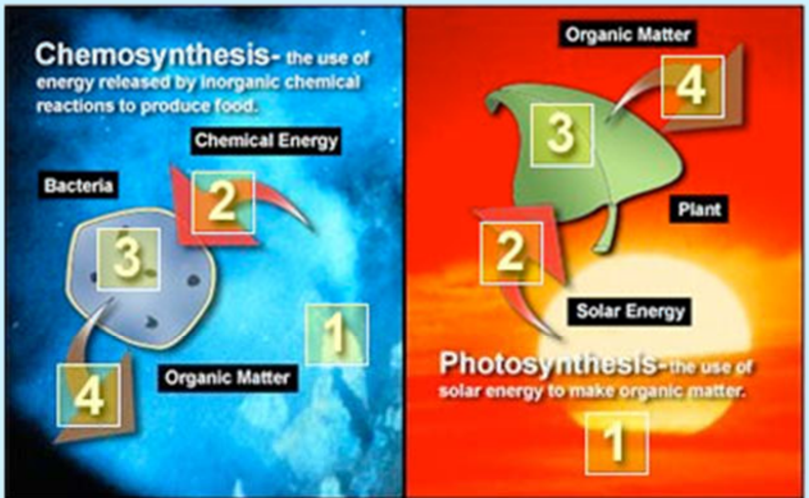
- **Light Intensity**: The rate of photosynthesis increases as light intensity increases until all of the pigments in a chloroplast are being used. Once all of the pigments are being used there is nothing left to absorb the light energy.

- **Carbon Dioxide Concentration**: Carbon dioxide concentration is similar to light intensity because once a saturation point is reached, the rate of photosynthesis cannot be increased or, in other words, go any faster.

- **Temperature**: Photosynthesis involves many chemical reactions which require enzymes. Enzymes, being proteins, require a certain temperature range in order to function properly. If the temperature increases or decreases too much the enzyme will not function properly, therefore, the chemical reaction will not occur.

$$CO_2 + 4\,H_2S + O_2 \longrightarrow CH_2O + 4\,S + 3\,H_2O$$

CHEMOSYNTHESIS



Hot water gushing from hydrothermal vents is saturated with dissolved chemicals.	1	The sun gives off energy in the form of light.
Bacteria absorb hydrogen sulfide and carbon dioxide from vent water and oxygen from seawater.	2	Plants absorb sunlight, and take up water from the soil and carbon dioxide from the air.
The bacteria use energy released by oxidizing sulfur to make organic molecules.	3	The plants use solar energy to make organic molecules.
The bacteria grow and reproduce, and are eaten or hosted as internal symbionts by other animals.	4	The plants grow and reproduce, and are eaten or hosted as internal symbionts by animals.

Chemosynthesis is another type of reaction that creates chemical energy. This type of reaction requires inorganic molecules to produce the chemical energy, not sunlight. This type of reaction is a rare reaction as it is only done by bacteria found deep in the ocean near hydrothermal vents or oceanic crust ridges. Since bacteria are prokaryotes with no nucleus or more importantly no organelles, there is no organelle to perform chemosynthesis. Instead, chemosynthesis occurs on their cell membrane. As was already stated, chemosynthesis does not require or use sunlight, instead it uses the inorganic molecule hydrogen sulfide (H_2S) or in some cases methane (CH_4). The hydrogen sulfide along with oxygen (O_2) and carbon dioxide (CO_2) will produce the high energy molecule sugar (CH_2O) for the organisms deep in the ocean to feed on for energy.

Now answer questions 1 through 20.