Semester – IV

Unit - III

Photosynthesis

Photosynthesis is the biochemical pathway which converts the energy of light into the bonds of glucose molecules. The process of photosynthesis occurs in two steps. In the first step, energy from light is stored in the bonds of *adenosine triphosphate* (ATP), and *nicotinamide adenine dinucleotide phosphate* (NADPH). These two energy-storing cofactors are then used in the second step of photosynthesis to produce organic molecules by combining carbon molecules derived from carbon dioxide (CO_2). The second step of photosynthesis is known as the Calvin Cycle. These organic molecules can then be used by mitochondria to produce ATP, or they can be combined to form glucose, sucrose, and other carbohydrates. The chemical equation for the entire process can be seen below.

Photosynthesis Equation

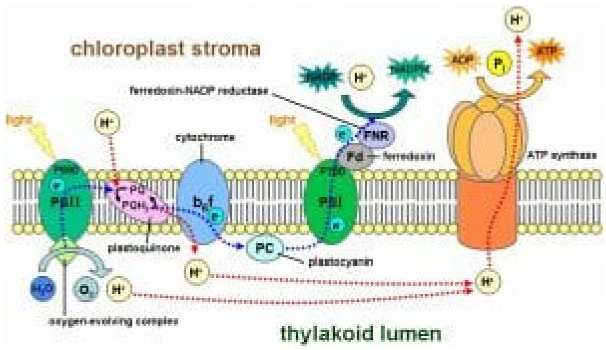
$6\ CO_2 + 6\ H_2O + Light \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$

Above is the overall reaction for photosynthesis. Using the energy from light and the hydrogens and electrons from water, the plant combines the carbons found in carbon dioxide into more complex molecules. While a 3-carbon molecule is the direct result of photosynthesis, glucose is simply two of these molecules combined and is often represented as the direct result of photosynthesis due to glucose being a foundational molecule in many cellular systems. You will also notice that 6 gaseous oxygen molecules are produced, as a by-produce. The plant can use this oxygen in its mitochondria during *oxidative phosphorylation*. While some of the oxygen is used for this purpose, a large portion is expelled into the atmosphere and allows us to breathe and undergo our own oxidative phosphorylation, on sugar molecules derived from plants. You will also notice that this equation shows water on both sides. That is because 12 water molecules are split during the light reactions, while 6 new molecules are produced during and after the Calvin cycle. While this is the general equation for the entire process, there are many individual reactions which contribute to this pathway.

Stages of Photosynthesis

The Light Reactions

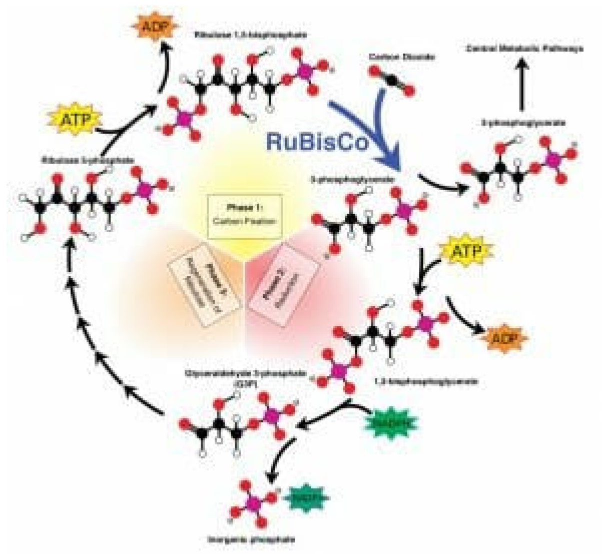
The light reactions happen in the *thylakoid membranes* of the chloroplasts of plant cells. The thylakoids have densely packed protein and enzyme clusters known as *photosystems*. There are two of these systems, which work in conjunction with each other to remove electrons and hydrogens from water and transfer them to the cofactors ADP and $NADP^+$. These photosystems were named in the order of which they were discovered, which is opposite of how electrons flow through them. As seen in the image below, electrons excited by light energy flow first through *photosystem II* (PSII), and then through *photosystem I* (PSI) as they create NADPH. ATP is created by the protein *ATP synthase*, which uses the build-up of hydrogen atoms to drive the addition of phosphate groups to ADP.



The entire system works as follows. A photosystem is comprised of various proteins that surround and connect a series of *pigment molecules*. Pigments are molecules that absorb various photons, allowing their electrons to become excited. *Chlorophyll a* is the main pigment used in these systems, and collects the final energy transfer before releasing an electron. Photosystem II starts this process of electrons by using the light energy to split a water molecule, which releases the hydrogen while siphoning off the electrons. The electrons are then passed through plastoquinone, an enzyme complex that releases more hydrogens into the *thylakoid space*. The electrons then flow through a cytochrome complex and plastocyanin to reach photosystem I. These three complexes form an *electron transport chain*, much like the one seen in mitochondria. Photosystem I then uses these electrons to drive the reduction of $NADP^+$ to NADPH. The additional ATP made during the light reactions comes from ATP synthase, which uses the large gradient of hydrogen molecules to drive the formation of ATP.

The Calvin Cycle

With its *electron carriers* NADPH and ATP all loaded up with electrons, the plant is now ready to create storable energy. This happens during the *Calvin Cycle*, which is very similar to the citric acid cycle seen in mitochondria. However, the citric acid cycle creates ATP other electron carriers from 3-carbon molecules, while the Calvin cycle produces these products with the use of NADPH and ATP. The cycle has 3 phases, as seen in the graphic below.



During the first phase, a carbon is added to a 5-carbon sugar, creating an unstable 6-carbon sugar. In phase two, this sugar is reduced into two stable 3-carbon sugar molecules. Some of these molecules can be used in other metabolic pathways, and are exported. The rest remain to continue cycling through the Calvin cycle. During the third phase, the five-carbon sugar is regenerated to start the process over again. The Calvin cycle occurs in the *stroma* of a chloroplast. While not considered part of the Calvin cycle, these products can be used to create a variety of sugars and structural molecules.

Products of Photosynthesis

The direct products of the light reactions and the Calvin cycle are 3-phosphoglycerate and G3P, two different forms of a 3-carbon sugar molecule. Two of these molecules combined equals one glucose molecule, the product seen in the photosynthesis equation. While this is the main food source for plants and animals, these 3-carbon skeletons can be combined into many different forms. A structural form worth note is *cellulose*, and extremely strong fibrous material made essentially of strings of glucose. Besides sugars and sugar-based molecules, oxygen is the other main product of photosynthesis. Oxygen created from photosynthesis fuels every respiring organism on the planet.

Significance of photosynthesis

i. Helps in conversion of solar energy into organic matter.

ii. Consumes atmospheric carbon dioxide and yields carbohydrates and molecular oxygen.

iii. Evolves molecular oxygen for use by other living organisms and maintains the level of atmospheric oxygen which is continuously consumed by plants and animals during respiration.

iv. Produces carbohydrates and used by plants and animals to synthesize organic acids, proteins, fats, nucleic acids, pigments, hormones, vitamins, alkaloids and other metabolites

Chemosynthesis:
Such reactions in which reduction of carbon dioxide to carbohydrates does not require light and takes place in presence of energy obtained from oxidations of inorganic substances is called chemosynthesis e.g., Nitrifying bacteria (Nitrosomonas, Nitrosococcus) obtain energy by oxidising ammonia to nitrites), sulphur bacteria (e.g., Beggiatoa convert H,S to sulphur), Carbon monooxide bacteria (e.g., Carboxydomonas convert CO to CO_2), methane bacteria (e.g., Methanococcus oxidise methane into CO_2 and HzO) etc.

Photorespiration

We all know, photosynthesis is a biochemical process of producing carbohydrates using light energy. The whole process is carried in two phases.

1. Photochemical phase – In the photochemical phase, ATP and NADPH are produced
2. Biosynthetic phase – In this phase, the final product glucose is formed.

Based on, how plants proceed in the biosynthetic phase, plants are further classified as C_3 and C_4 plants. Another factor which differentiates a C_4 plant from C_3 is photorespiration.

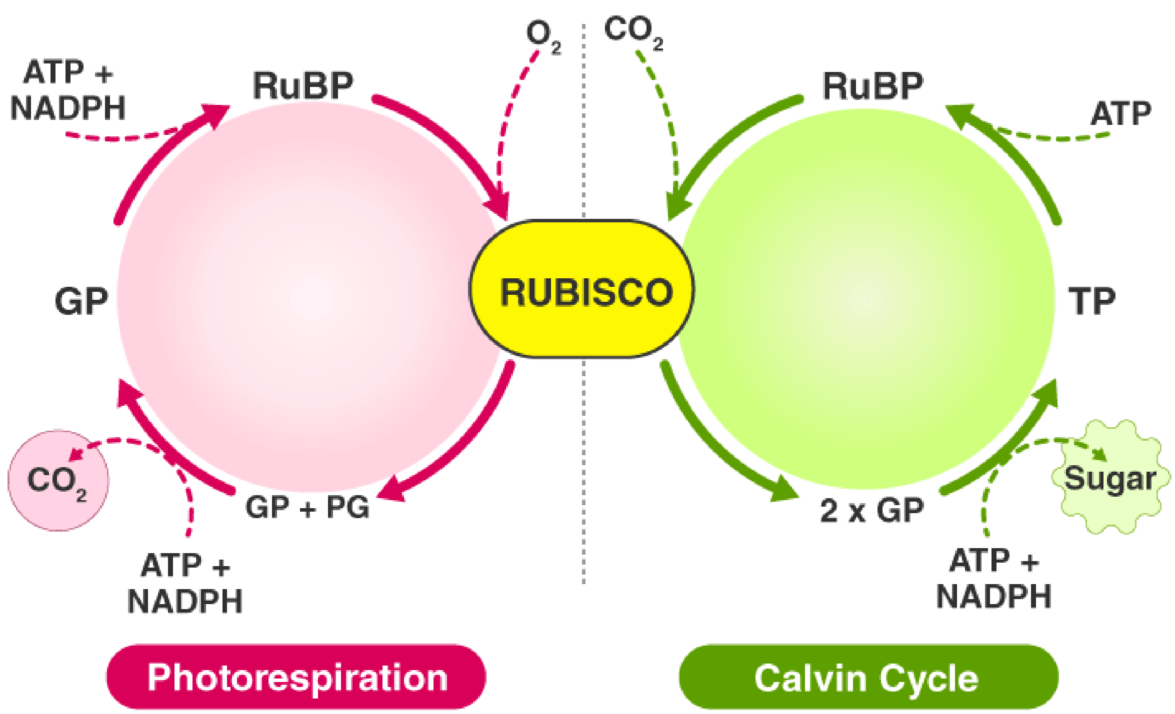
Photorespiration

Photorespiration is a respiratory process in many higher plants. This is also known as the oxidative photosynthetic, or C_2 photosynthesis or carbon cycle.

For a better understanding of photorespiration, let's recall the Calvin cycle, the first step of the biosynthetic phase in C_3 plants- Plants which use only the Calvin cycle for fixing the carbon dioxide.

The reaction in which carbon dioxide and water combine to give carbohydrates is termed as carbon fixation. Calvin cycle is the first step of carbon fixation where CO_2 combines with Ribulose-1 and 5-bisphosphate (RuBP) to form two molecules of 3 carbon acid called 3-phosphoglycericacid (PGA). The reaction is catalyzed by the most abundant enzyme in the world called RuBisCO (RuBP carboxylase-oxygenase). RuBisCO is the enzyme that has an affinity for both CO_2 and O_2 but has more affinity for CO_2. Hence, the binding of CO_2 and O_2 are competitive in nature and the concentration of the molecules in the atmosphere determines the winner. This is the basis for photorespiration in plants.

Sometimes in C_3 plants, RuBisCO binds to oxygen molecules and the reaction deviates from the regular metabolic pathway. The combination of RuBP and oxygen molecules leads to the formation of one molecule of phosphoglycerate and phosphoglycolate. This pathway is called photorespiration. During photorespiration, no sugar or ATP molecules are synthesized, but just CO_2 is released at the expense of ATP. And the whole process is futile.



However, C_4 plants do not undergo photorespiration due to their special mechanism to increase the CO_2 level for enzyme binding. During the Hatch and Slack Pathway, the C_4 acid, oxaloacetic acid (OAA) breaks down to release CO_2. This ensures the high concentration of intercellular CO_2. Thus, in C_4 plants, RuBisCO is more active as a carboxylase enzyme rather than as oxygenase.