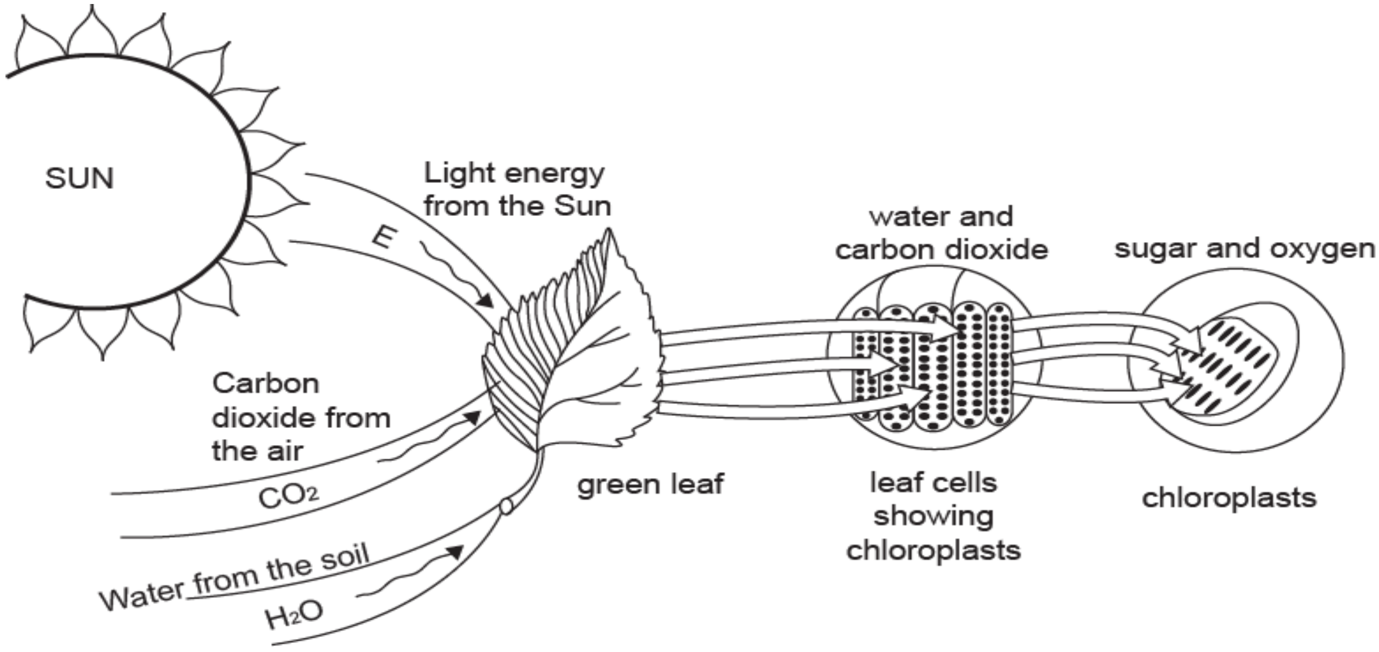
STUDENT REFERENCE SHEET

Photosynthesis Reference



Look at the diagram above to see that plant leaves absorb energy from the sun. The leaves take in carbon dioxide (CO_2) through small holes, called stomata, that are located on the bottom of the leaf. The plant gets water (H_2O) through its roots from the soil, as well as from water vapor in the air. Leaves contain structures called chloroplasts in their cells. These chloroplasts contain the green pigment chlorophyll.

When water and carbon dioxide combine in the presence of chlorophyll and light, is a sugar called glucose ($C_6H_{12}O_6$) is produced. The sugar remains in the plant while oxygen is released through the stomata. The water and carbon dioxide are the reactants, or the beginning substances of photosynthesis. The glucose and oxygen are the products, or the ending substances of photosynthesis.

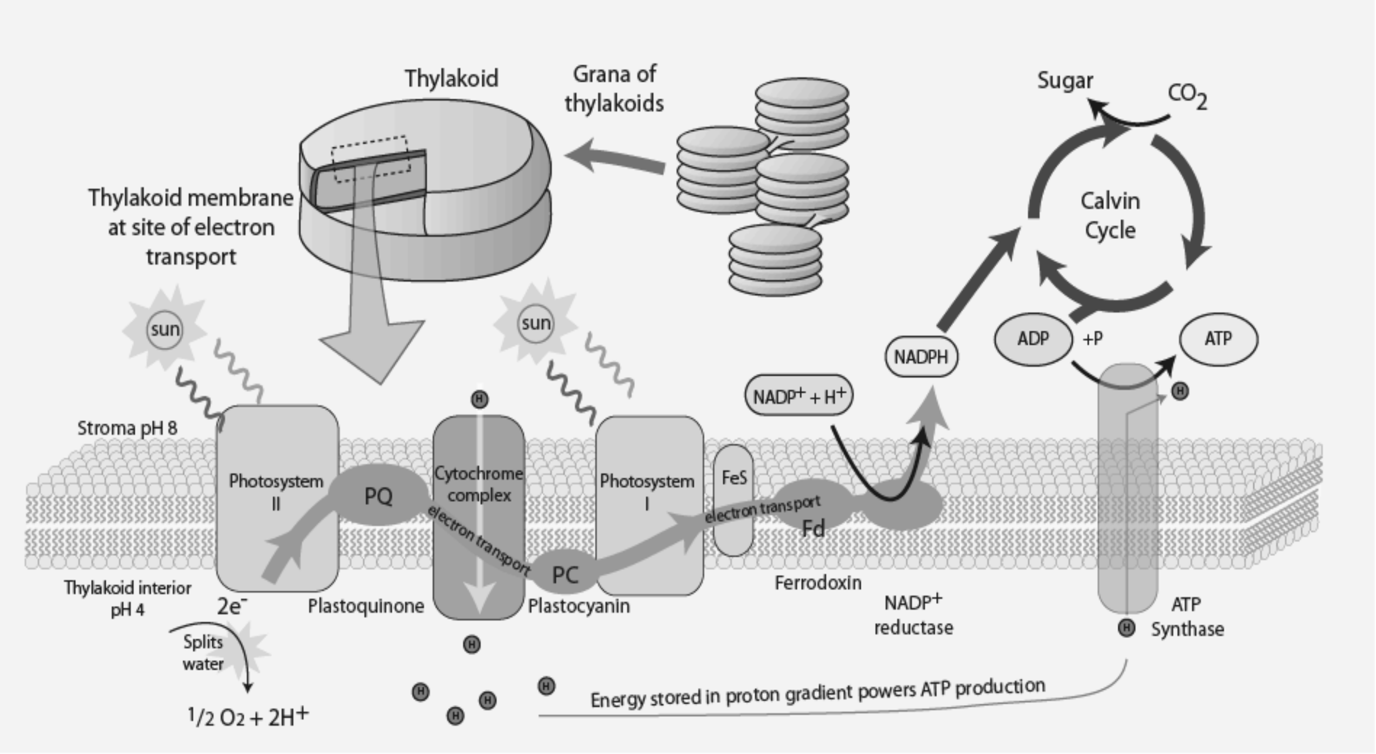
The process of photosynthesis is the beginning of many energy transformations. The radiant energy from the sun is transformed into chemical energy stored within the glucose.The glucose can be used by the cells of plants, and by the cells of organisms that eat plants, to make chemical energy for various life processes.

Light Reactions

When light energy from the sun hits a leaf, and enough water has been transported up from the roots, chloroplasts begin the photosynthetic process. Within each chloroplast is a set of compartments that are folded into cylinder shaped sheets called thylakoids. These thylakoids contain the pigment chlorophyll that is embedded in their membranes. The familiar chlorophyll molecule is what absorbs light energy.

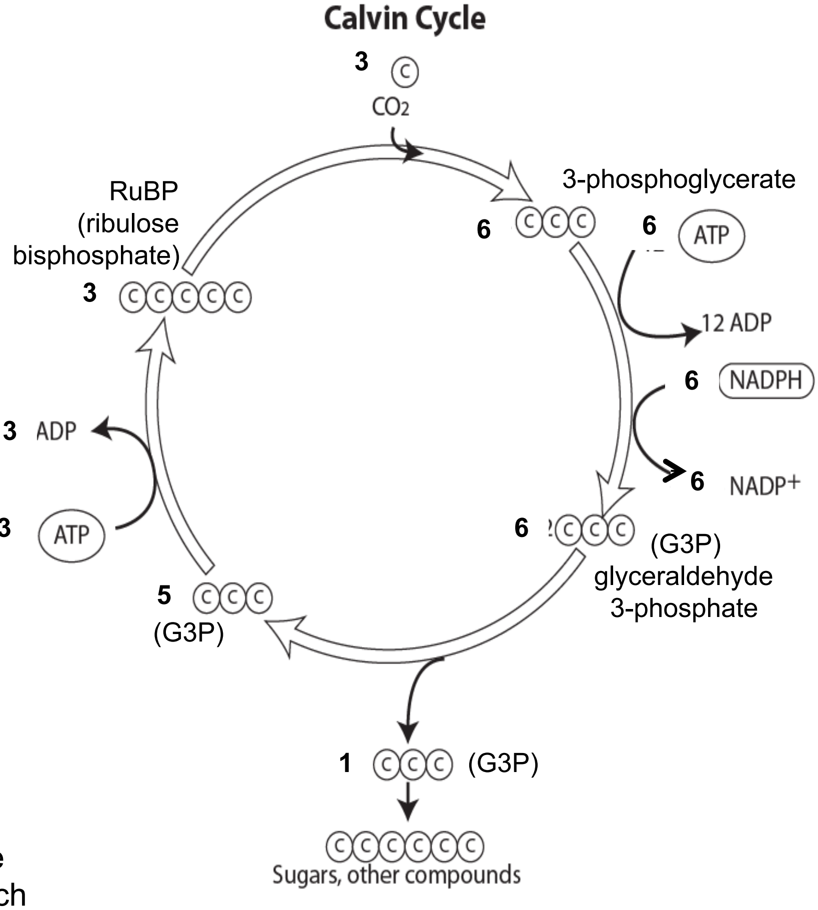
A single photon (particle) of light strikes a single chlorophyll molecule, giving off resonance energy, which is passed to nearby energy carrying molecules. As this light energy is absorbed, the energy is transferred to electrons, which are passed from the chlorophyll to a series of molecules that form an electron transport system. The energized electrons pass from one energy carrying photosystem to another, releasing small amounts of energy in the process.

A molecule called NADP$^+$, which carries electrons, binds with a hydrogen ion that is obtained by splitting a water molecule along with two of the excited electrons, forming NADPH. NADPH then transfers the excited electrons to the outside of the thylakoid membrane, an area called the stroma, where the dark reactions of photosynthesis take place.



Calvin Cycle (Dark Reactions)

The second stage of photosynthesis does not require light (sometimes called dark reactions), but it does require the products of the previous light reactions. Named after its discoverer, chemist Melvin Calvin, the Calvin Cycle uses energy to convert the carbon in CO_2 into sugars.
The Calvin Cycle occurs in a chloroplast's stroma, beginning with the process of carbon fixation. Carbon fixation is the transformation of CO_2 into an organic molecule by a living organism. Carbon dioxide captured from the atmosphere bonds with the 5-carbon sugar RuBP (ribulose bisphosphate), 'fixing' the carbon to this organic sugar.



The 6-carbon sugar created by fixing a carbon atom to RuBP (ribulose bisphosphate) immediately splits into two 3-carbon PGA (3-phosphoglycerate) molecules. Each PGA molecule is energized by the ATP created by the light-dependent reactions, and after another reaction with the NADPH, is converted to (G3P) glyceraldehyde 3-phosphate, a 3-carbon sugar with high energy bonds.

For every six molecules of G3P produced, only one is released into the cytoplasm for use in synthesizing other sugars. The remaining five G3P molecules (each with three carbon atoms) are used to replenish the RuBP that was used up at the beginning of the cycle.

Each turn of the Calvin Cycle produces two G3P molecules. Each G3P molecule contains three carbon atoms, five of which are required to replenish RuBP. Therefore, in each turn of the Calvin Cycle, only a single net carbon atom is gained for producing other sugars. To create one molecule of glucose takes 6 turns of the cycle.

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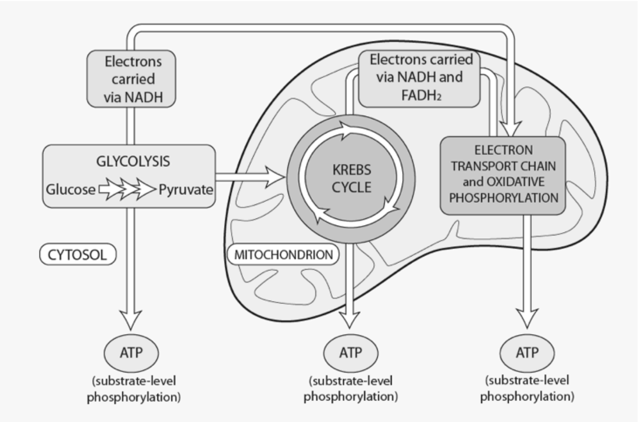
Cellular Respiration Reference

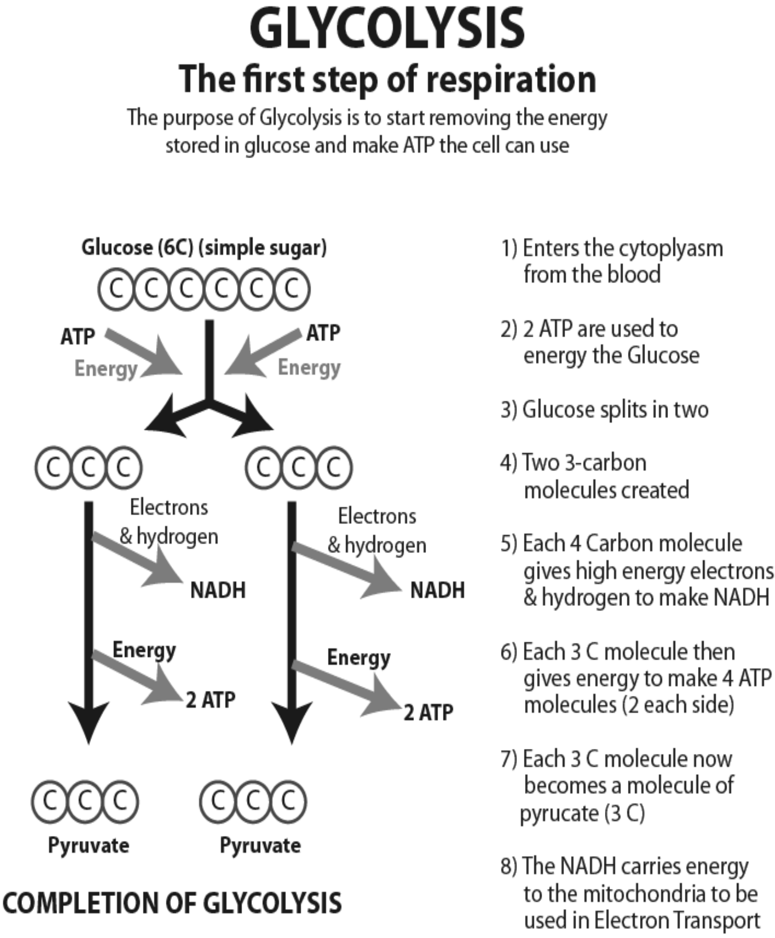
Cellular respiration is the series of chemical reactions that transform chemical energy in the form of sugars, into adenosine triphosphate (ATP), an energy form that cells can use. As the sugars produced from photosynthesis are broken down into carbon dioxide and water, energy is released. Cellular respiration occurs in three stages: glycolysis, the Krebs Cycle, and an electron transport chain.



Glycolysis

Recall that the Calvin Cycle resulted with sugars being released into the cytoplasm to form glucose. Respiration begins with the sugars created at the end of photosynthesis. In the cytoplasm of a plant cell, glucose (a 6-carbon sugar) is broken down into a substance called pyruvic acid, a 3-carbon molecule. For each molecule of glucose that is split apart during glycolysis, two molecules of pyruvic acid, two units of ATP, two molecules of water, and two molecules of an electron carrier called NADH are produced.

The pyruvic acid moves to the mitochondria, where it loses electrons, releasing CO_2. The remaining two carbons (from the pyruvic acid) bond with another molecule called coenzyme A, forming acetyl-CoA. This new molecule is needed to begin the next stage of respiration: the Krebs Cycle.



The purpose of Glycolysis is to start removing the energy stored in glucose and make ATP the cell can use

1) Enters the cytoplyasm from the blood
2) 2 ATP are used to energy the Glucose
3) Glucose splits in two
4) Two 3-carbon molecules created
5) Each 4 Carbon molecule gives high energy electrons & hydrogen to make NADH
6) Each 3 C molecule then gives energy to make 4 ATP molecules (2 each side)
7) Each 3 C molecule now becomes a molecule of pyrucate (3 C)
8) The NADH carries energy to the mitochondria to be used in Electron Transport

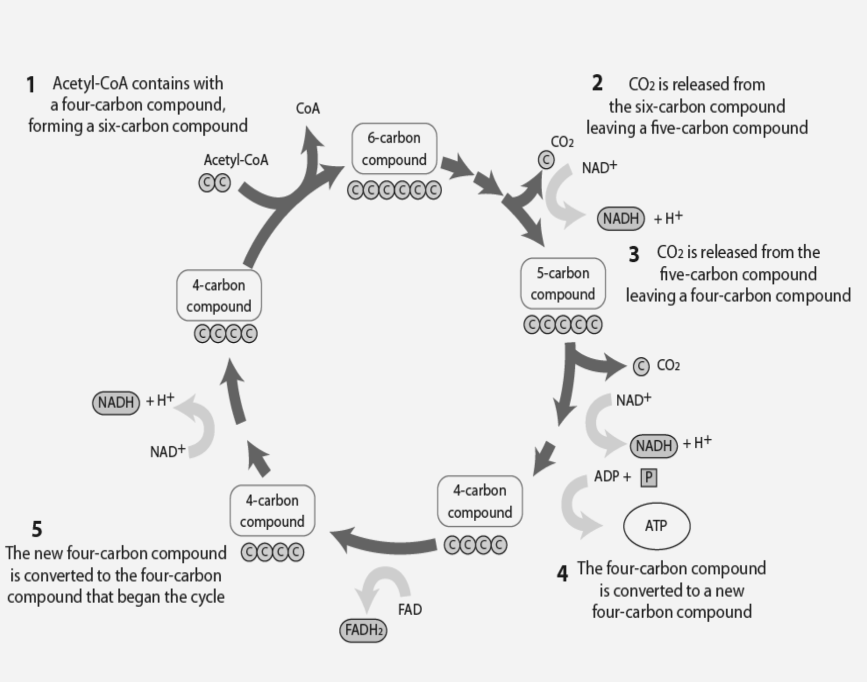
The Krebs Cycle

After glycolysis, the 2-carbon molecule acetyl-CoA binds with other molecules and gradually gets broken down inside the mitochondria to form ATP and CO_2. This process is called the Krebs Cycle, or the citric acid cycle, and requires the presence of oxygen.

The Krebs Cycle begins when acetyl-CoA, which contains two carbon atoms, reacts with oxaloacetic acid, which has four carbon atoms. The result is a 6-carbon molecule called citric acid. Next, an electron transport molecule NAD^+ binds to a hydrogen atom (and removes electrons), forming NADH while the citric acid molecule (six carbons) releases a molecule of CO_2, leaving a 5-carbon compound remaining.

Krebs Cycle

The Krebs cycle produces electron carries that temporarily store chemical energy



This 5-carbon compound releases another CO_2, and another molecule of NADH is formed. A unit of ATP is also produced at this time, and a 4-carbon compound remains.

The 4-carbon compound undergoes additional reactions where NAD^+ and FAD (another electron carrier) each remove hydrogen atoms and two energized electrons. NAD^+ becomes NADH, and FAD becomes $FADH_2$; these molecules will pass their electrons on to the membrane of the mitochondrion for the final stage of respiration.

The remaining 4-carbon compound is recycled into oxaloacetic acid to begin the Krebs Cycle again. For every one molecule of glucose that enters the respiration process, two ATP are formed during glycolysis, and two ATP form during the Krebs Cycle (one ATP for each pyruvate). The majority of the ATP generated during respiration comes from the final stage, the electron transport chain.

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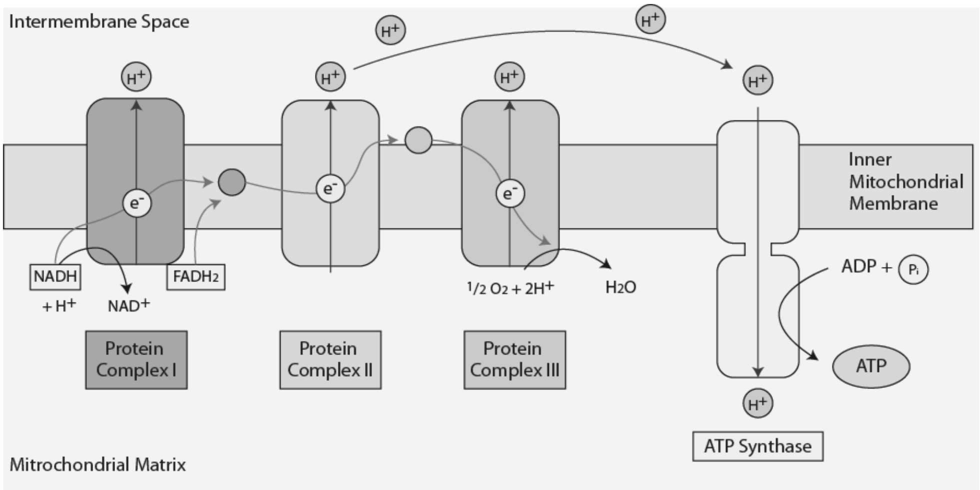
Electron Transport Chain (ETC)

In this final stage of cellular respiration, 32 ATP molecules are formed within the membrane of the mitochondrion. At the end of the Krebs Cycle, electron carrier molecules NADH and $FADH_2$ each deliver two energized electrons to the first protein complex in the electron transport chain. For each electron that a protein complex accepts, it pumps out one hydrogen ion across the mitochondrial membrane. The transmembrane electrochemical gradient of these hydrogen ions provides energy for the formation of ATP.



The second protein complex in the electron transport chain can only accept one electron at a time. One electron is transferred from Protein Complex I to Protein Complex II. As the electrons move over, they release hydrogen ions to the outside of the mitochondrial membrane.

The third protein complex requires four electrons to complete its chemical reaction. These four electrons, along with four hydrogen ions, bind with two oxygen atoms to form two molecules of water. The four electrons are taken from Protein Complex I and II.

A single unit of ATP can be produced by ATP synthase with a sufficient amount of energy from the electrochemical gradient of hydrogen ions across the mitrochondrial membrane. To produce one unit of ATP, three hydrogen ions are transported across the mitochondrial membrane back into the mitochondria, “down” the electrochemical gradient.

The energy from the hydrogen ions carried by NADH and $FADH_2$ from glycolysis and the Krebs Cycle to the electron transport chain is used to produce a net of 36 ATP molecules per initial glucose molecule. In other words, 4 ATP are produced during glycolysis, but 2 ATP are required to fuel the process. This net of 2 ATP, plus the 2 ATP produced from the Krebs Cycle and the 32 created from the ETC, yield a net ATP production of 36, or

$$\mathbf{(4-2) + 2 + 32 = 36}.$$