PHOTOSYNTHESIS

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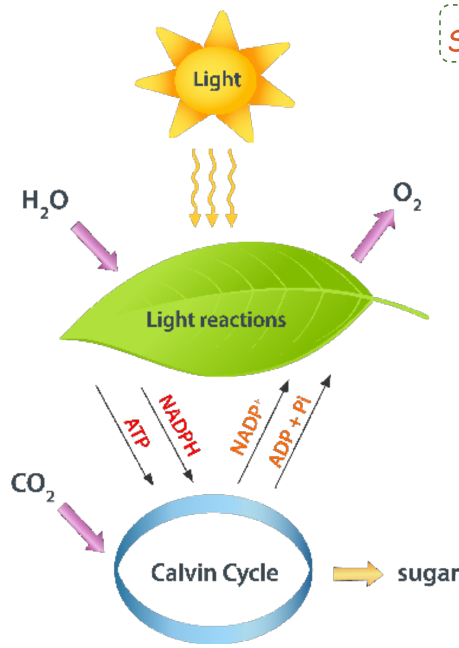
Biology

Big Picture

Photosynthesis is an important life process that provides more than 99% of the energy used by living things on Earth.

Photosynthesis is composed of two main processes: the light reactions and the Calvin cycle. In the light reactions, pigment molecules, which give leaves their green color, drive ATP and NADPH production when excited by photons. The Calvin cycle takes the products of the light reactions and uses them to form O_2 and sugar. Photosynthesis can thus be summarized as:

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



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Key Terms

Autotroph: Organisms that produce their own organic compounds (food). One way they do that is by undergoing photosynthesis.

Energy: The ability to do work. Photosynthetic organisms harness light energy from the sun to produce chemical energy stored in sugars.

Sugar: The organic compounds produced by photosynthesis are usually sugars. The immediate product of the Calvin cycle is a three carbon sugar (G3P) that can easily be converted to glucose, $C_6H_{12}O_6$, which is a major source of energy for all organisms.

ATP (adenosine triphosphate): An energy-rich molecule produced in the light reactions and used up in the Calvin cycle to drive sugar synthesis. When ATP is broken down, it releases energy and becomes ADP + a phosphate group (Pi).

NADPH: An electron carrier that transfers some of the energy absorbed from the sun in the light reactions to the Calvin cycle for sugar synthesis.

Chloroplast: Chloroplasts are the organelles in plant and algal cells where photosynthesis takes place.

- **Thylakoid Membranes:** Sac-like membranes that are organized into stacks called grana.
- **Stroma:** The fluid surrounding the thylakoid membranes within the chloroplast.

Light Reactions: Harness the energy in photons of sunlight to produce ATP and NADPH, molecules that store the energy from the sun for transfer to the Calvin cycle.

- **Photon:** A particle of light.

Photosystem: A protein complex involved in the light reactions. There are two photosystems involved in photosynthesis: photosystem II and photosystem I. The photosystems are primarily involved in the absorption of light and are composed of light harvesting complexes, where the pigment molecules are embedded, and a reaction center with a primary electron acceptor.

Electron Transport Chain (ETC): A series of molecules that pass high-energy electrons from molecule to molecule and capture their energy.

Proton Gradient: A separation of charge in the form of a high concentration of H^+ ions on one side of a membrane.

$NADP^+$ reductase: An enzyme that reduce $NADP^+$ to NADPH.

ATP Synthase: An enzyme and a channel protein that produces ATP by adding a phosphate group (Pi) to ADP.

Calvin Cycle: The Calvin cycle uses the NADPH and the ATP from the light reactions to synthesize sugars from molecules of CO_2.

Chemosynthesis: Another way autotrophs make food. In this case, the autotrophic organisms use chemical energy instead of light energy. Chemoautotrophs typically harness the energy from the oxidation of inorganic molecules, such as hydrogen sulfide, to produce organic compounds from inorganic carbon ones.

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Photosynthesis cont.

Photosynthesis Process

Plants and other **autotrophs** use photosynthesis to convert light **energy** into chemical energy, or *food*. Photosynthesis involves many chemical reactions, but the overall process can be described with a single chemical equation:

$$6\ CO_2 + 6\ H_2O + \text{Light Energy} \longrightarrow C_6H_{12}O_6 + 6\ CO_2$$

- $C_6H_{12}O_6$ is the chemical formula of **glucose**, a type of **sugar** used to store chemical energy.

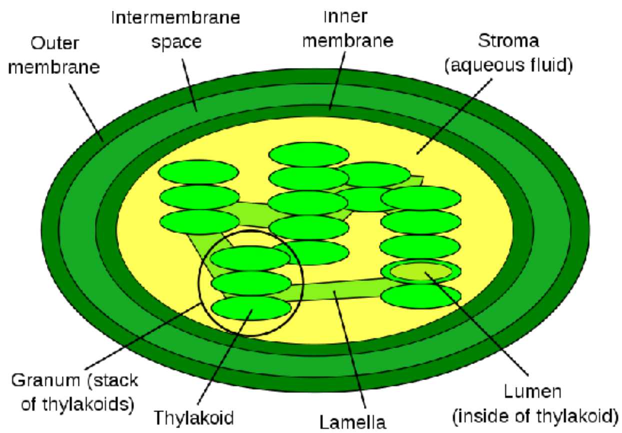


Image Credit: Example, Public Domain

Photosynthesis occurs in two main stages:

1. Light reactions

Water and light energy are converted into chemical energy stored in **ATP** and **NADPH**.

2. Calvin cycle

Carbon dioxide and the energy stored in ATP and NADPH are used to make glucose.

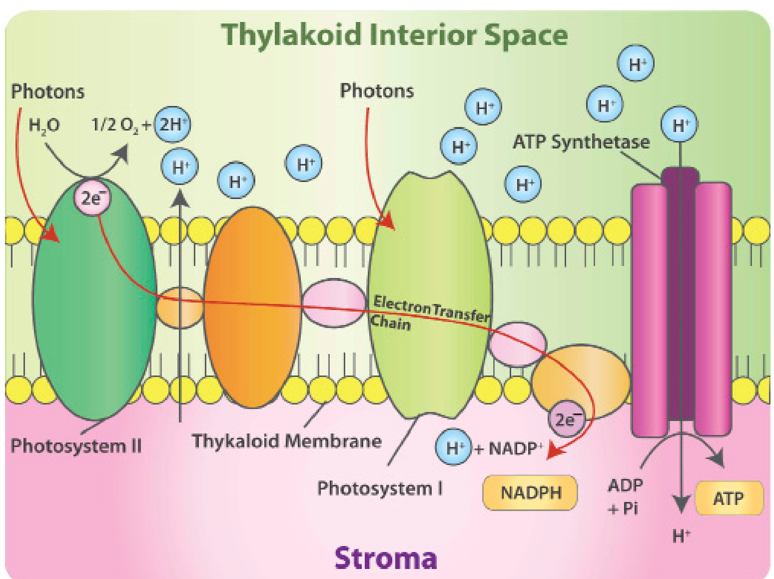
Photosynthesis takes place in the **chloroplast**

- The **thylakoid membranes** are where the light reactions take place. The pigment molecules, which give leaves and chloroplasts their green color and directly absorb energy from the sun, are embedded in the thylakoid membranes.
- The **stroma** is where the Calvin cycle takes place.

Light Reactions

1. The light reactions begin when a **photon** hits a chlorophyll molecule in **photosystem** II, exciting its electrons.
2. At the same time, a water is split by enzymes in the thylakoid membrane into 2 H^+ ions, one oxygen atom, and a pair of electrons.

   The hydrogen ions are released inside the membrane. The oxygen atom will combine with another atom to produce the waste product O_2. The two electrons replace the electrons lost from the chlorophyll in photosystem II.
3. The pair of excited electrons from the chlorophyll molecules travel down an **electron transport chain (ETC)**. The energy from the electrons is used to pump hydrogen ions into the thylakoid space, generating a **proton (H^+) gradient** across the thylakoid membrane.



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4. The electrons, no longer excited, reach photosystem I. They are re-energized by the light energy absorbed by a chlorophyll molecule in photosystem I.
5. The electrons now travel down another shorter ETC and onto **$NADP^+$ reductase**, which uses the electrons and a H^+ ion to produce NADPH.
6. H^+ ions move down the proton gradient and travel across the thylakoid membrane by flowing through **ATP synthase**. The energy from the flowing hydrogen ions is used to produce ATP by phosphorylating (adding a phophate group to) ADP.

Summary: Light energy and water are consumed, oxygen (released as waste), NADPH, and ATP are produced.

Photosynthesis cont.

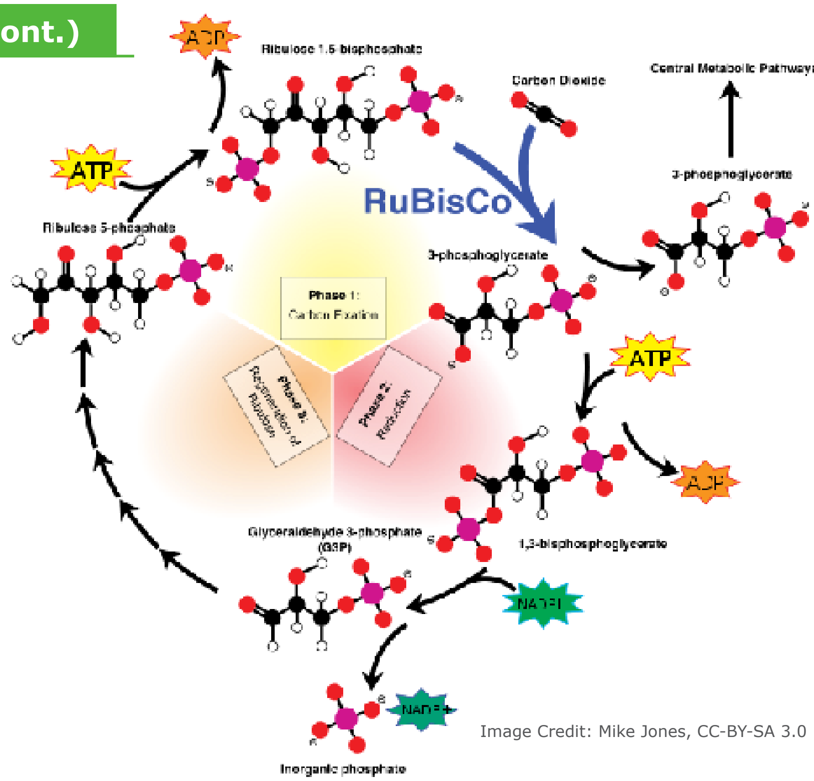
Photosynthesis Process (cont.)

Calvin Cycle

Carbon fixation: RuBP, a five carbon compound, combines with CO_2 to form 3PG, a three carbon compound. This reaction is facilitated by an enzyme called RuBisCo.

- Reduction: The energy stored in ATP and NADPH is used to rearrange 3PG into G3P, another three carbon compound. At this point, one molecule of G3P exits the cycle and goes on to form glucose.
- Regeneration: Molecules of G3P are used to regenerate RuBP with the help of ATP molecules.

Summary: carbon dioxide is consumed, G3P (can be used to form glucose) is produced.



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Common Misconceptions

All plants are photosynthetic.

Reality: Photosynthesis is just one means by which plant species acquire nutrients. **Chemosynthesis** is an example of another process that some autotrophs use to produce food.

Only green plants undergo photosynthesis.

Reality: Chlorophyll molecules, which give green plants their color, are only one type of pigment molecule in photosystems I and II. There are other pigment molecules that allow brown plants, red plants, and some species of seaweed to undergo photosynthesis.

Photosynthesis is a simple process.

Reality: Even though photosynthesis is broken down into two main processes (the light reactions and the Calvin cycle), photosynthesis is really very complex, requiring almost 100 different chemical reactions.

Plants breathe in carbon dioxide and exhale oxygen.

Reality: Although plants do take in carbon dioxide and release oxygen, plants do not respire or breathe like humans. Carbon dioxide is required to build the organic compounds produced by photosynthesis and oxygen is produced as a by-product of the light reactions. Plants do not release oxygen by breathing.

Photosynthesis only takes place in the leaves of plants.

Reality: Although photosynthesis does primarily take place in the leaves of many plants, photosynthesis can also take place in the stems and petioles of certain plant species.

The light reactions occur during the day and the Calvin cycle occurs during the night.

Reality: Although the Calvin cycle, sometimes referred to as the light-independent or dark reactions, does not directly depend on light as a source of energy, the Calvin cycle and the light reactions occur simultaneously. The Calvin cycle does depend on the ATP and NADPH produced by the transfer of light energy in the light reactions.

Plants only undergo photosynthesis and not cellular respiration.

Reality: Plants undergo both photosynthesis and cellular respiration. Plants need to undergo cellular respiration in order to harness the energy stored in the sugars that were synthesized in photosynthesis.

Notes