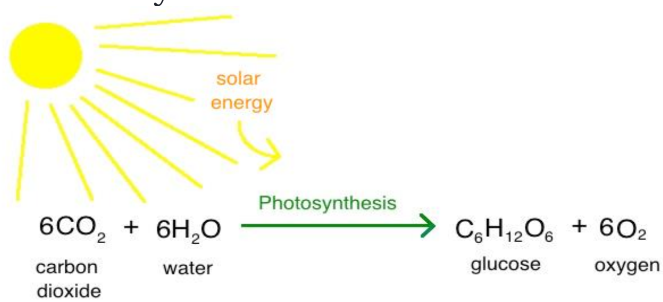
Leaf physiology

Photosynthesis and Respiration

All organisms, including humans, need energy to fuel the metabolic reactions of growth, development, and reproduction. But organisms can't use light energy directly for their metabolic needs. Instead, it must first be converted into chemical energy through the process of photosynthesis.

Photosynthesis is the process in which light energy is converted to chemical energy in the form of sugars. In a process driven by light energy, glucose molecules (or other sugars) are constructed from water and carbon dioxide, and oxygen is released as a byproduct. The glucose molecules provide organisms with two crucial resources: energy and fixed—organic—carbon.

- **Energy.** The glucose molecules serve as fuel for cells: their chemical energy can be harvested through processes like cellular respiration and fermentation, which generate adenosine triphosphate, a small, energy-carrying molecule—for the cell's immediate energy needs.
- **Fixed carbon.** Carbon from carbon dioxide—inorganic carbon—can be incorporated into organic molecules; this process is called **carbon fixation**, and the carbon in organic molecules is also known as **fixed carbon**. The carbon that's fixed and incorporated into sugars during photosynthesis can be used to build other types of organic molecules needed by cells.

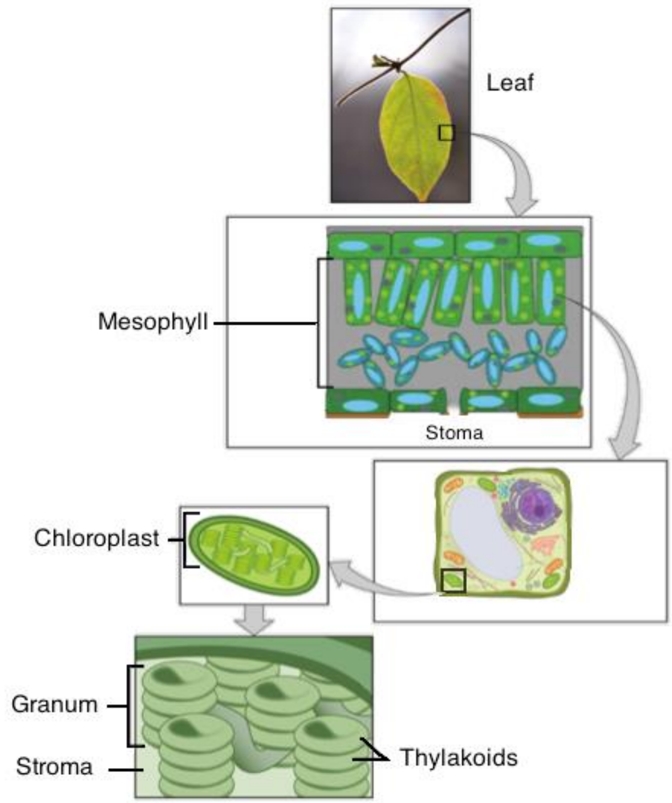


In photosynthesis, solar energy is harvested and converted to chemical energy in the form of glucose using water and carbon dioxide. Oxygen is released as a byproduct.

Leaves are sites of photosynthesis

Plants are the most common autotrophs in terrestrial—land—ecosystems. All green plant tissues can photosynthesize, but in most plants, but the majority of photosynthesis usually takes place in the leaves. The cells in a middle layer of leaf tissue called the **mesophyll** are the primary site of photosynthesis.

Small pores called **stomata**—singular, stoma—are found on the surface of leaves in most plants, and they let carbon dioxide diffuse into the mesophyll layer and oxygen diffuse out.



Each mesophyll cell contains organelles called chloroplasts, which are specialized to carry out the reactions of photosynthesis. Within each chloroplast, disc-like structures called **thylakoids** are arranged in piles like stacks of pancakes that are known as **grana**—singular, granum. The membrane of each thylakoid contains green-colored pigments called **chlorophylls** that absorb light. The fluid-filled space around the grana is called the **stroma**, and the space inside the thylakoid discs is known as the **thylakoid space**. Different chemical reactions occur in the different parts of the chloroplast.

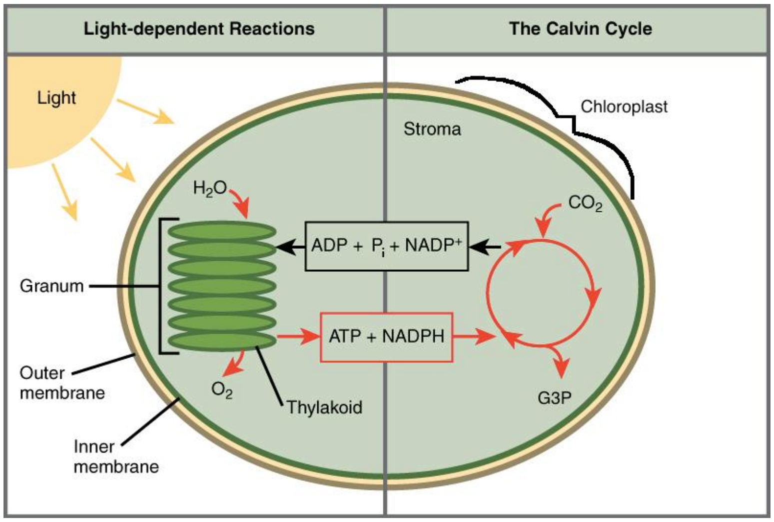
The light-dependent reactions and the Calvin cycle

Photosynthesis in the leaves of plants involves many steps, but it can be divided into two stages: the **light-dependent reactions** and the **Calvin cycle**.

- The **light-dependent reactions** take place in the thylakoid membrane and require a continuous supply of light energy. Chlorophylls absorb this light energy, which is converted into chemical energy through the formation of two compounds ATP an energy storage molecule—and NADPH- a reduced (electron-bearing) electron carrier. In this process, water molecules are also converted to oxygen gas—the oxygen we breathe! The light-dependent reactions take place in the thylakoid membrane. They require light, and their net effect is to convert water molecules into oxygen, while producing ATP molecules—from ADP and Pi—and NADPH molecules—via reduction of NADP+. ATP and NADPH are produced on the stroma side of the thylakoid membrane, where they can be used by the Calvin cycle.

- The **Calvin cycle**, also called the **light-independent reactions**, takes place in the stroma and does not directly require light. Instead, the Calvin cycle uses ATP and NADPH from the light-dependent reactions to fix carbon dioxide and produce

three-carbon sugars—glyceraldehyde-3-phosphate, or G3P, molecules—which join up to form glucose.
The Calvin cycle takes place in the stroma and uses the ATP and NADPH from the light-dependent reactions to fix carbon dioxide, producing three-carbon sugars—glyceraldehyde-3-phosphate, or G3P, molecules. The Calvin cycle converts ATP to ADP and Pi, and it converts NADPH to NADP+. The ADP, Pi, and NADP+ can be reused as substrates in the light reactions.



Schematic of the light-dependent reactions and Calvin cycle and how they're connected.

Overall, the light-dependent reactions capture light energy and store it temporarily in the chemical forms of ATP and NADPH. There, ATP is broken down to release energy, and NADPH donates its electrons to convert carbon dioxide molecules into sugars. In the end, the energy that started out as light winds up trapped in the bonds of the sugars.

Production of organic molecules

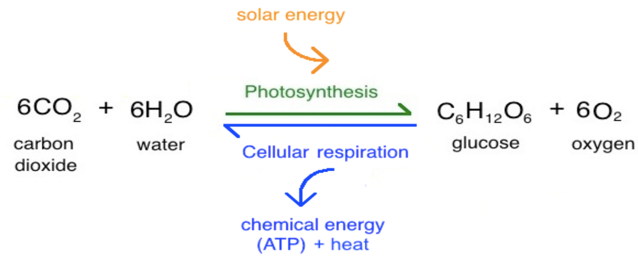
Glyceraldehyde phosphate is used to make glucose ($C6H_{12}O_6$). Glucose can be stored in the plant as starch. Other enzymes convert carbohydrates into lipids. Plants can make proteins if they have nitrate (absorbed into roots from fertilizer) and nucleic acids if they have phosphate.

Three different types of plants:

1. C3 plants: typical plants that open their stomata during the day, and close their stomata at night. Common plants in cool areas e.g., Canada.
2. C4 plants: open their stomata only briefly during the day. They store CO2 as the 4-carbon sugar: oxaloacetate. Mainly tropical plants eg sugarcane.
3. CAM plants: only open their stomata at night, to conserve water. These are desert plants like cactus.

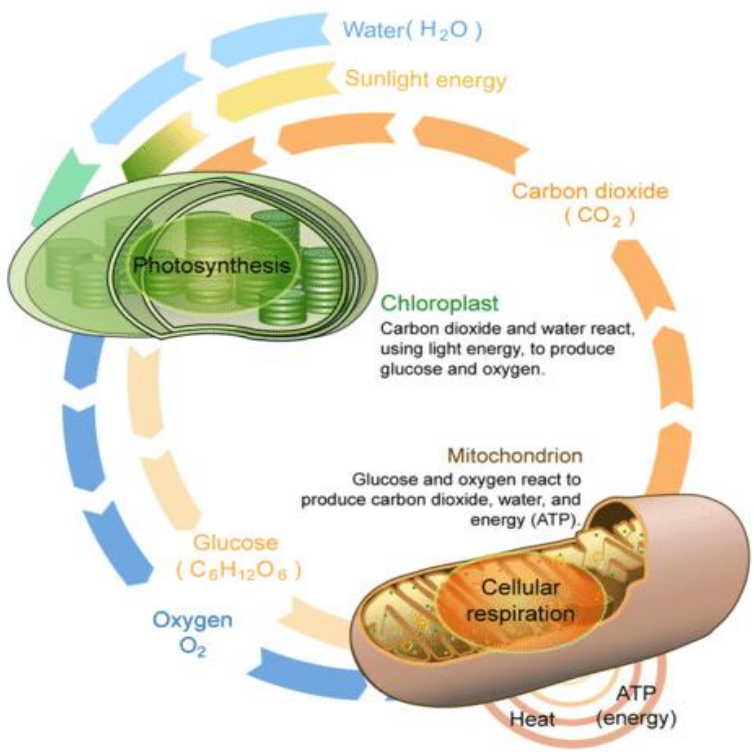
Photosynthesis vs. cellular respiration

At the level of the overall reactions, photosynthesis and cellular respiration are near-opposite processes. They differ only in the form of energy absorbed or released, as shown in the diagram below.



On a simplified level, photosynthesis and cellular respiration are opposite reactions of each other. In photosynthesis, solar energy is harvested as chemical energy in a process that converts water and carbon dioxide to glucose. Oxygen is released as a byproduct. In cellular respiration, oxygen is used to break down glucose, releasing chemical energy and heat in the process. Carbon dioxide and water are products of this reaction.

For instance, photosynthesis and cellular respiration both involve a series of **redox** reactions (reactions involving electron transfers). In cellular respiration, electrons flow from glucose to oxygen, forming water and releasing energy. In photosynthesis, they go in the opposite direction, starting in water and winding up in glucose—an energy-requiring process powered by light. Like cellular respiration, photosynthesis also uses an electron transport chain to make a H+ concentration gradient, which drives ATP synthesis by chemiosmosis.



TRANSPIRATION

Although large quantities of water are absorbed by plant from the soil but only a small amount of it is utilized. The excess of water is lost from the aerial parts of plants in the form of water vapors. This is called as transpiration. Transpiration is of three types:

1. **Stomatal transpiration**: Most of the transpiration takes place through stomata. Stomata are usually confined in more numbers on the lower sides of the leaves. In

monocots. Eg. Grasses they are equally distributed on both sides. While in aquatic plants with floating leaves they are present on the upper surface.

2. **Cuticular transpiration**: Cuticle is impervious to water, even though, some water may be lost through it. It may contribute a maximum of about 10% of the total transpiration.
3. **Lenticular transpiration:** Some water may be lost by woody stems through lenticels. Major part of water loss by deciduous trees during leafless stage.

Mechanism of stomatal transpiration

The mechanism of stomatal transpiration which takes place during the day time can be studied in three steps

1. Osmotic diffusion of water in the leaf from xylem to intercellular space above the stomata through the mesophyll cells.
2. Opening and closing of stomata (stomatal movement)
3. Simple diffusion of water vapors from intercellular spaces to other atmosphere through stomata.

Factor affecting rate of Transpiration

1. Atmospheric Humidity is inversely proportional to rate of transpiration.
2. Temperature is directly proportional to rate of transpiration.
3. Light intensity is directly proportional to rate of transpiration.
4. Wind velocity is directly proportional to rate of transpiration.
5. Carbon dioxide concentration is inversely proportional to rate of transpiration.
6. The factors like structure of leaf area of transpiring surface, number of stomata, orientation of leaf is included in the category.

Significance of transpiration:

- As transpiration helps in the movement of xylem sap, it increases the absorption of mineral nutrients by the roots from the soil.
- It causes cooling effect on leaf and plant surface.
- It produces suction pressure for absorption, ascent of sap, mineral translocation and distribution if minerals.
- Transpiration decreases heating of leaves by solar radiations.
- It maintains turgidity as well as aids in hydrological cycle.