Photosynthesis and Photosynthetic pigment

A process whereby plants, algae, and prokaryotes directly use light energy to synthesize organic compounds from CO₂ is called **photosynthesis**. The end products of photosynthesis are carbohydrates. In the presence of light, the green parts of plants produce organic compounds and oxygen from carbon dioxide and water. Using molecular formulas, we can summarize the complex series of chemical reactions in photosynthesis with this chemical equation:

\[ 6\text{CO}_2 + 12\text{H}_2\text{O} + \text{Light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O} \]

Photosynthetic process may be oxygenic (produces oxygen) or anoxygenic (don’t produce oxygen). Anoxygenic photosynthesis is found in four different bacterial groups: purple bacteria, green sulfur bacteria, green non-sulfur bacteria, and heliobacteria. O₂ comes from water, not from CO₂.

Oxygenic photosynthesis is found in cyanobacteria, seven groups of algae, and essentially all land plants. These two types of photosynthesis share similarities in the types of pigments they use to trap light energy, but they differ in the arrangement and action of these pigments.

The cells of plant leaves contain organelles called chloroplasts, which carry out the photosynthetic process. No other structure in a plant cell is able to carry out photosynthesis.

Photosynthesis takes place in three stages:

1. Capturing energy from sunlight
2. Using the energy to make ATP and to reduce the compound NADP+, an electron carrier, to NADPH
3. Using the ATP and NADPH to power the synthesis of organic molecules from CO₂ in the air.

The first two stages require light and are commonly called the **light-dependent reactions**. The third stage, the formation of organic molecules from CO₂, is called **carbon fixation**. This process takes place via a cyclic series of reactions. As long as ATP and NADPH are available,
the carbon fixation reactions can occur either in the presence or in the absence of light, and so these reactions are also called the **light-independent reactions**.

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**Chloroplast**

In plants, **chloroplasts** lie mainly inside the leaf in the cells of the **mesophyll**, a layer that includes many air spaces and a very high concentration of water vapor. The interior of the leaf exchanges gases with the outside through microscopic pores, called **stomata** (sing., **stoma**). Each mesophyll cell has 20 to 100 chloroplasts. The chloroplast, like the mitochondrion, is enclosed by outer and inner membranes. The inner membrane encloses a fluid-filled region called the **stroma**, which contains most of the enzymes required to produce carbohydrate molecules. Suspended in the stroma is a third system of membranes that forms an interconnected set of flat, disc-like sacs called **thylakoids**. In the thylakoid membrane, photosynthetic pigments are clustered together to form **photosystems**, which show distinct organization within the thylakoid.

The thylakoid membrane encloses a fluid-filled interior space, the **thylakoid lumen**. In some regions of the chloroplast, thylakoid sacs are arranged in stacks called **grana** (sing., **granum**). Each granum looks something like a stack of coins, with each “coin” being a thylakoid.

**Pigments:** Substances that absorb visible light are known as pigment. Thylakoid membranes contain several kinds of **pigments**, which are substances that absorb visible light. Different pigments absorb light of different wavelengths.

Physicists describe light’s behaviour as both wavelike and particle-like. To emphasize the particle-like nature of light, physicists point out that it exists in discrete packets called **photons**.
Each photon of light has a characteristic wavelength and energy level. Pigment molecules absorb the energy of some of these photons.

**Chlorophyll**

Chlorophyll, the main pigment of photosynthesis, absorbs light primarily in the blue and red regions of the visible spectrum. Green light is not appreciably absorbed by chlorophyll. Plants usually appear green because some of the green light that strikes them is scattered or reflected. Plants, algae, and cyanobacteria synthesize chlorophyll, whereas anaerobic photosynthetic bacteria produce a molecular variant called bacteriochlorophyll.

A chlorophyll molecule has two main parts, a complex ring and a long side chain. The ring structure, called a porphyrin ring, is made up of joined smaller rings composed of carbon and nitrogen atoms; the porphyrin ring absorbs light energy. The porphyrin ring of chlorophyll is strikingly similar to the heme portion of the red pigment haemoglobin in red blood cells. However, unlike heme, which contains an atom of iron in the center of the ring, chlorophyll contains an atom of magnesium in that position. Loss of the magnesium ion from chlorophyll results in the formation of a non-green product, pheophytin. Pheophytin is readily formed during extraction under acidic conditions, but small amounts are also found naturally in the chloroplast where it serves as an early electron acceptor. The chlorophyll molecule also contains a long, hydrocarbon side chain that makes the molecule extremely nonpolar and anchors the chlorophyll in the membrane. All chlorophyll molecules in the thylakoid membrane are associated with specific chlorophyll-binding proteins.

Four species of chlorophyll, designated chlorophyll *a*, *b*, *c*, and *d*, are known. Chlorophyll *a* is the primary photosynthetic pigment in all higher plants, algae, and the cyanobacteria. **Chlorophyll b** is an accessory pigment that also participates in photosynthesis. It differs from chlorophyll *a* only in a functional group on the porphyrin ring: the methyl group (—CH)₃ in chlorophyll *a* is replaced in chlorophyll *b* by a terminal carbonyl group (—CHO). This difference shifts the wavelengths of light absorbed and reflected by chlorophyll *b*, making it appear yellow-green, whereas chlorophyll *a* appears bright green. Chlorophyll *c* found in the diatoms, dinoflagellates, and brown algae and it lacks the phytol tail. Chlorophyll *d*, found only in the red algae, is similar to chlorophyll *a* except that a —O—CHO group replaces the (—CHCH₂) group on ring I. Chlorophylls absorb strongly in the blue and red regions of the visible spectrum. The presence of chlorophylls makes plants look green because they reflect green light, which they do not absorb.
**Carotenoids**

A second group of pigment molecules found in all photosynthetic organisms is the **carotenoids** which are yellow and orange and also called accessory pigment. Carotenoids absorb in the blue and green parts of the visible spectrum. Thus, carotenoids appear yellow, orange, or red. The carotenoids found in plants belong to two classes, called carotenes and xanthophylls. When a carotenoid molecule is excited, its energy can be transferred to chlorophyll $a$. In addition, carotenoids are antioxidants that inactivate highly reactive forms of oxygen generated in the chloroplasts.

The carotenoid family of pigments includes **carotenes** and **xanthophylls**. Carotenes are predominantly orange or red-orange pigments. $\beta$-carotene is the major carotenoid in algae and higher plants. Note that in $\beta$-carotene and $\alpha$-carotene (a minor form), both ends of the molecule are cyclized. Lycopene, the principal pigment of tomato fruit, has both ends open. The yellow carotenoids, xanthophylls, are oxygenated carotenes. $\beta$-carotene, which absorbs strongly in the blue region of the visible spectrum, is known to quench both the triplet excited chlorophyll as well as the highly reactive singlet excited oxygen, which can be generated by the reaction of triplet chlorophyll with ground state oxygen. Thus, $\beta$-carotene protects chlorophyll from photooxidation.

**Phycobilins** are straight-chain or open-chain tetrapyrrole pigment molecules present in the eukaryotic red algae and the prokaryotic cyanobacteria. The prefix, *phyco*, designates pigments of algal origin. Four phycobilins are known. Three of these are involved in photosynthesis and the fourth, phytochromobilin, is an important photoreceptor that regulates various aspects of growth and development.

In the thylakoid membrane, 200–300 chlorophyll molecules and accessory pigments are organized by an array of proteins to form structures called the **antenna complex** and the reaction center. These complexes, along with the molecules that capture and process excited electrons, form a **photosystem**.

**Each pigment has a characteristic absorption spectrum**

When a photon strikes a molecule with the amount of energy needed to excite an electron, then the molecule will absorb the photon raising the electron to a higher energy level. Whether the photon’s energy is absorbed depends on how much energy it carries (defined by its wavelength), and also on the chemical nature of the molecule it hits.
A specific atom, therefore, can absorb only certain photons of light—namely, those that correspond to the atom’s available energy levels. As a result, each molecule has a characteristic absorption spectrum, the range and efficiency of photons it is capable of absorbing.

**Fig.** Schematic picture of the overall organization of the membranes in the chloroplast. The chloroplast of higher plants is surrounded by the inner and outer membranes (envelope). The region of the chloroplast that is inside the inner membrane and surrounds the thylakoid membranes is known as the stroma. It contains the enzymes that catalyzes carbon fixation and other biosynthetic pathways. (Source: Taiz and Ziger)