beings—directly for plants and indirectly for animals and humans who eat the plants or the plant-eating animals.

(2) ***Oxygen to breathe in*** : Photosynthesis is the only biological process which releases oxygen into the atmosphere. Oxygen supports all life on earth. No living being can remain alive without oxygen.

6.3 CHLOROPHYLL – THE VITAL PLANT PIGMENT

Chlorophyll (*chloro* : green, *phyll* : leaf) is the green pigment found in plants. It is contained in microscopic cell organelles called chloroplasts (Fig. 1.1 B).

Chloroplasts are minute oval bodies bounded by a double membrane, and their interior contains closely packed flattened sacs (**thylakoids**) arranged in piles (**grana**) lying in a colourless ground substance called **stroma** (Fig. 6.1). Ordinarily, there may be 40-50 chloroplasts in a cell. *The pigment **chlorophyll** is contained in the walls of **thylakoids**.* It is a highly complex substance, composed of carbon, hydrogen, oxygen, nitrogen and magnesium. Chloroplasts are mainly contained in the mesophyll cells, located between the upper epidermis and the lower epidermis (*i.e.* in palisade cells and spongy cells) of leaves. These are also found in the guard cells of stomata and in the outer layers of young green stems.

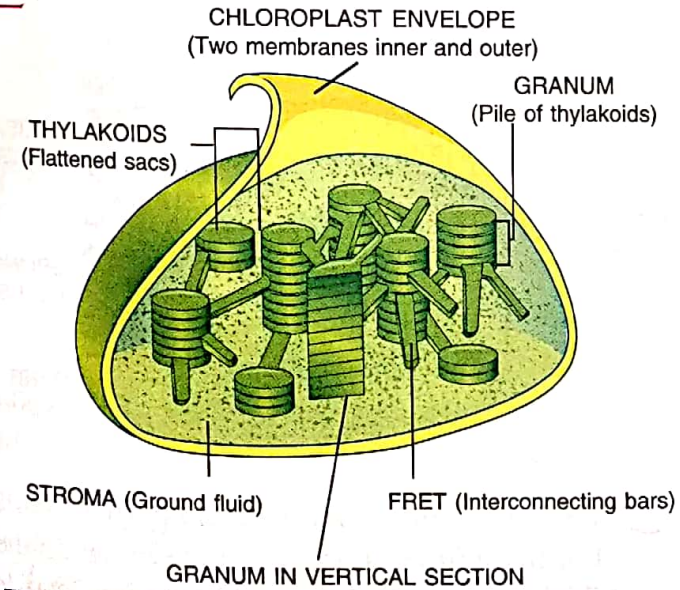


Fig. 6.1 : A chloroplast. Internal structure as revealed by electron microscope. (Highly diagrammatic)

There may be more than 500,000 chloroplasts per sq. mm. of leaf surface.

You will be surprised to know that there are nine types of chlorophyll. Two out of these, **chlorophyll-a** and **chlorophyll-b**, are best known and most abundant.

Chlorophylls absorb light at both ends of the visible spectrum - i.e. BLUE and RED light, and reflect away the green light. That is why, chlorophyll appears green. The absorbed blue and red lights are most effective for photosynthesis.

Too much light destroys chlorophyll

Chlorophyll is highly sensitive to light, so too much light may destroy it. However, the formation of chlorophyll itself depends on the exposure of the plant to light. The grass growing in the shade under a stone turns yellowish due to the non-formation of new chlorophyll and due to the disintegration of the older one in the absence of light.

6.4 REGULATION OF STOMATAL OPENING FOR LETTING IN CARBON DIOXIDE

Stomata are minute openings occurring in large numbers on the lower surface of a leaf. The main function of the stomata is to let in CO_2 from the atmosphere for photosynthesis. When stomata are not in use for photosynthesis, *i.e.* when it is dark, they tend to close their openings so that water loss is minimised from the leaves through transpiration. When there is light, as after sunrise, they reopen to allow CO_2 to diffuse in. Transpiration occurs along with photosynthesis. Due to this process, one can

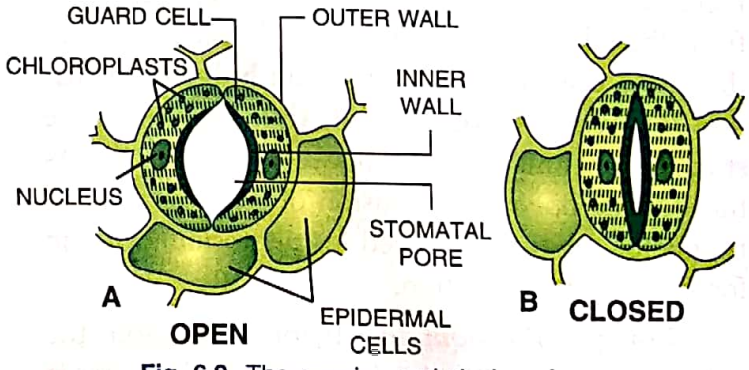


Fig. 6.2 The opening and closing of stomata.
A – Guard cells turgid, the stoma (mouth) opens,
B – Guard cells flaccid, the stoma closes.

say that ***transpiration is the price which the plant pays for photosynthesis.***

The closing and opening of the stomata are on account of the movement of water in and out of the guard cells. They have a **thick inner wall** facing the opening and a **thin outer wall** on the opposite side (Fig. 6.2); their cytoplasm contains chloroplasts.

Opening and Closing of Stomata

There are two theories about the opening and closing of stomata.

(1) Potassium ion concentration theory (recent)

(2) Sugar concentration theory (old)

(1) *K^+ ion concentration theory :*

According to the recent K^+ ion concentration theory, the stomatal opening and closing depend on the generation of potassium ion (K^+) gradient. During daytime, the chloroplasts in the guard cells photosynthesise which leads to the production of ATP. **This ATP is used to actively pump the potassium ions of the adjacent cells into the guard cells.** Increased K^+ concentration in the guard cells makes them hypertonic, so, more water from the adjacent cells is drawn in and the cells become more turgid and they move outwards to open out the stomatal pore. Reverse happens at night. The K^+ ions leak out thus reducing the turgor of guard cells and the stomatal pore closes.

(2) *Sugar concentration theory :*

According to the old sugar concentration theory, during daytime, the guard cells begin photosynthesis and the sugar (glucose) produced during the process increases the osmotic pressure which draws in water from the adjoining cells due to endosmosis. Hence, the guard cells **become turgid and bulge outwards** due to their thin outer wall, thus widening the stomatal opening lying in between (Fig. 6.2A). As the stomata open, the diffusion of gases in and out begins for fulfilling the need for photosynthesis and for allowing transpiration.

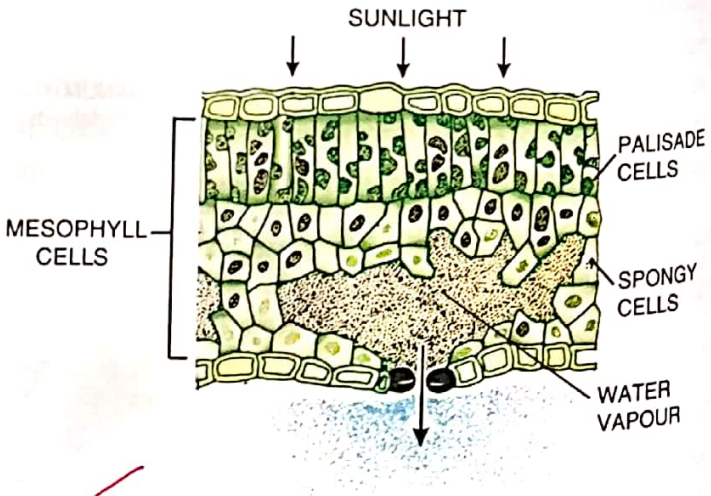
Closing of the stomata : If for any reason, the water content of the leaf is falling short, the water is drawn out of the guard cells due to exosmosis making them flaccid. As a result, their inner thick walls straighten to close the stomata.

? Progress Check

1. Answer the following in "Yes" or "No"
   (i) All parts of a green plant carry out photosynthesis. Yes/No
   (ii) All green parts of a plant carry out photosynthesis. Yes/No
   (iii) Photosynthesis is the only biological process that releases oxygen into the air. Yes/No
   (iv) Out of nine types of chlorophyll, chlorophyll a and b are the most abundant. Yes/No
   (v) Too much light destroys chlorophyll. Yes/No
   (vi) No transpiration occurs during photosynthesis. Yes/No
   (vii) During sunlight, the guard cells turn flaccid to open the stomata. Yes/No

6.5 PROCESS OF PHOTOSYNTHESIS

Mesophyll cells (both **palisade** and **spongy**) in a leaf are the principal centres of this activity. During daytime, when sunlight falls on the leaf, the **light energy** is trapped by the chlorophyll of the upper layers of mesophyll, especially the palisade cells. This energy is utilized in chemical processes involved in the manufacture of food, where the raw materials used are carbon dioxide and water.



- **Carbon dioxide** from the atmosphere enters the leaf by diffusion down a concentration gradient (higher concentration outside the leaf, and less concentration inside) through the stomata.

Water from the soil is taken up by the roots, sent up through the stem and finally to the leaves where it is distributed in the mesophyll tissue.

The chemical equation to represent this process is as follows :

$$6CO_2 + 12H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6H_2O + 6O_2\uparrow$$

The glucose molecule $C_6H_{12}O_6$ is a simple sugar readily soluble in water.

The 6 molecules of H_2O liberated at the end of the process are those that are **re-formed** during a chain of reactions and not out of the original ones.

6.6 TWO MAIN PHASES OF PHOTOSYNTHESIS — (A) LIGHT-DEPENDENT PHASE AND (B) LIGHT-INDEPENDENT (DARK) PHASE

(A) LIGHT-DEPENDENT PHASE (PHOTOCHEMICAL PHASE)

In this phase, light plays the key role. A series of chemical reactions occur in very quick succession, initiated by light and therefore, the phase is called the photochemical phase. The light reaction takes place in **thylakoids** (containing chlorophyll) of the chloroplasts.

The light reaction (photochemical phase) occurs in two main steps.

Step I. *Activation of chlorophyll.* The chlorophyll on exposure to light energy becomes activated by absorbing **photons** (photon is the smallest unit of light energy).

Step II. *Splitting of water.* The absorbed energy is used in splitting the water molecule (H_2O) into its two components (Hydrogen and Oxygen) and releasing electrons.

$$2H_2O \xrightarrow{\text{energy of 4 photons}} 4H^+ + 4e^- + O_2$$

The reaction is known as **photolysis**, which means ***splitting by light*** (*photo* = light, *lysis* = breaking).

Photolysis occurs in the grana of a chloroplast and is defined as the splitting of H_2O molecules into hydrogen ions and oxygen in the presence of **light**.

End result of the products of photolysis

(1) The **hydrogen** ions (H^+) are picked up by a compound **NADP** (Nicotinamide adenine dinucleotide phosphate) to form **NADPH.**

$$NADP^+ + e^- + H^+ \xrightarrow{\text{enzyme}} NADPH$$

(2) The **oxygen** (O) component is given out as molecular oxygen (O_2).

$$2O \rightarrow O_2$$

(3) The **electrons** (e^-) are used in converting ADP (adenosine diphosphate) into energy-rich compound ATP (adenosine triphosphate) by adding one phosphate group P_i (inorganic phosphate).

$$ADP + P_i \text{ (inorganic phosphate)} \rightarrow ATP$$

[This process is called **phosphorylation** (addition of phosphate) and since the energy used in the process comes from light (photons), the process is termed as **photophosphorylation**].

(B) LIGHT-INDEPENDENT (DARK) PHASE [also called Biosynthetic phase] *

The new term Light Independent Phase

The old term "dark phase" did not mean that it occurs when it is dark i.e. at night. It only meant that the reactions are not dependent on light. That is why, it is now better to call it "light independent phase."

The reactions in this phase do not require light energy, and occur simultaneously with the light reaction (time gap between the two being less than even one-thousandth of a second).

Conversion of glucose into starch and other chemicals : Most green plants convert glucose into **starch** as soon as it is formed during photosynthesis. Several glucose molecules are transformed to produce one molecule of starch; this process is called **polymerisation.** Some plants change glucose to sucrose (cane sugar, which chemically is called disaccharide or double sugar), or some into oils, etc.

$$* CO_2 + NADPH + ATP \xrightarrow{\text{enzyme}} C_6H_{12}O_6 + NADP + P_i + ADP$$