314en11

11

PHOTOSYNTHESIS

Photosynthesis (Photo = light; synthesis = to join) is the single most important process on earth on which depends the existence of human beings and almost all other living organisms. It is a process by which green plants, algae and chlorophyll containing bacteria utilize the energy of sunlight to synthesize their own food (organic matter) from simple inorganic molecules. Innumerable number of organic molecules which compose the living world are derived directly or indirectly from the photosynthetic organic matter. The oxidation of organic compounds releases stored energy to be utilized by the living organisms to carry out essential metabolic processes. It is important to note that photosynthesis is the only natural process which liberates oxygen to be used by all living forms for the process of aerobic respiration.

You have studied in lesson 4, that chloroplasts are the organelles that carry out photosynthesis or in other words they act as solar cells producing carbohydrates. In this lesson you will learn how green plants carry out photosynthesis.

OBJECTIVES

After completing this lesson, you will be able to :

- *define photosynthesis;*
- *name the different pigments found in chloroplasts;*
- *explain the main aspects of the process of photosynthesis;*
- *enumerate the steps involved in the light and dark reactions of photosynthesis;*
- *define the terms absorption spectrum, action spectrum, electron acceptor and photophosphorylation;*
- *distinguish between, absorption spectrum and action spectrum; light and dark reactions, cyclic and non-cyclic photo-phosphorylation,* C_3 *and* C_4 *photosynthesis;*
- *list the environmental variables and internal factors affecting photosynthesis;*
- *describe the principle of limiting factor giving suitable graphs.*

11.1 PHOTOSYNTHESIS

11.1 Let us look into the significance of the process

Significance

1. Green plants possess the green pigment, chlorophyll which can capture, transform, translocate and store energy which is readily available for all forms of life on this planet.
2. Photosynthesis is a process in which light energy is converted into chemical energy.
3. Except green plants, no other organism can directly utilise solar energy to synthesize food, hence they are dependent on green plants for their survival.
4. Green plants which can prepare organic food from simple inorganic elements are called autotrophic while all other organisms which cannot prepare their own food are called heterotrophic.
5. During photosynthesis, oxygen liberated into the atmosphere makes the environment livable for all aerobic organisms.
6. Simple carbohydrates produced in photosynthesis are transformed into lipids, proteins, nucleic acids and other organic molecules.
7. Plants and plant products are the major food sources of almost all organisms on the earth.
8. Fossil fuels like coal, gas, and oil represent the photosynthetic products of the plants belonging to early geological periods.

11.1.1 What is photosynthesis?

Photosynthesis is the process by which green plants, in the presence of light combine water and carbon dioxide to form carbohydrates. Oxygen is released as a by product of photosynthesis. Current knowledge of photosynthesis has resulted from discoveries made over 300 years of work. Some landmark experiments are given in the box below.

- Joseph Priestley (1772) and later Jan Ingenhousz (1779) showed that plants have the ability to take up CO_2 from the atmosphere and release O_2.
- Ingenhousz also discovered that release of O_2 by plants was possible only in presence of sunlight and by the green parts of the plant.
- Robert Hill (1939) demonstrated that isolated chloroplasts evolve O_2 when they are illuminated in the presence of electron acceptor which gets reduced. This reaction called Hill reaction accounts for the use of water as a source of electrons and protons for CO_2 fixation and release of O_2 as bye-product.

Photosynthesis is represented by the following overall chemical equation:

$$6CO_2 + 12H_2O \xrightarrow[\text{Sunlight}]{\text{Chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

In photosynthesis, CO_2 is fixed (or reduced) to carbohydrates (glucose $C_6H_{12}O_6$). Water is split in the presence of light (called photolysis of water) to release O_2. Note that O_2 released comes from the water molecule and not from CO_2.

11.1.2 Where does photosynthesis occur?

Photosynthesis occurs in green parts of the plant, mostly the leaves, sometimes the green stems and floral buds. The leaves contain specialised cells called mesophyll cells which contain the chloroplast– the pigment containing organelle. These are the actual sites for photosynthesis.

Look at the figure 11.1 that shows leaf Cell Structure and Function.

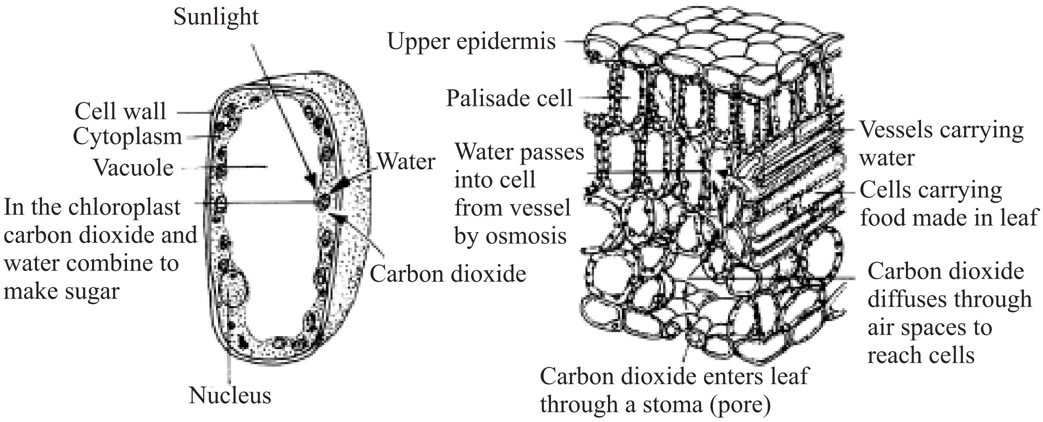


Fig. 11.1 Diagram to show structure of leaf cells

11.2 PHOTOSYNTHETIC PIGMENTS

The thylakoids of the chloroplast contain the pigments which absorb light of different wavelengths and carry out the photochemical reaction of photosynthesis.

The role of the pigments is to absorb light energy, thereby converting it to chemical energy. These pigments are located on the thylakoid membranes and the chloroplasts are usually so arranged within the cells that the membranes are at right angles to the light source for maximum absorption. The photosynthetic pigments of higher plants fall into two classes the chlorophyll and carotenoids.

The photosynthetic pigment **chlorophyll** is the principle pigment involved in photosynthesis. It is a large molecule and absorbs light maximally in the violet blue and in the red region of the visible spectrum and reflects green light and thus leaves appear green in colour. **Carotenoids** (carotene and xanthophyll) absorb light in the regions of the spectrum not absorbed by the chlorophylls and transfer that energy to chlorophyll to be used in photosynthesis.

Chlorophyll-a (a special type of chlorophyll) is the main pigment that traps solar energy and converts it into chemical energy. Chlorophyll-a is present in all autotrophic plants except photosynthetic bacteria. Thus Chl-a is called the essential photosynthetic pigment responsible for representing the **reaction centre.**

All other pigments such as chlorophyll b and carotenoids are collectively called accessory pigments since they pass on the absorbed light energy to chlorophyll a (Chl-a) molecule to be utilized for photosynthesis. These pigments, that is the reaction centres (Chl-a) and the accessory pigments (**harvesting centre**) are packed into functional clusters called **photosystems**. Photosystems are of two types **PSI** and **PSII**.

About 250-400 Chl-a molecules constitute a single photosystem. Two different photosystems contain different forms of chlorophyll a in their reaction centres. In photosystem I (PSI), chlorophyll– a with maximum absorption at 700 nm (P_{700}) and in photosystem II (PSII), chlorophyll– a with peak absorption at 680 nm (P_{680}), act as reaction centres. (P stands for pigment). The primary function of the two photosystems, which interact with each other is to trap the solar energy and convert it into the chemical energy also called **assimilatory power** (ATP and $NADPH_2$). The differences between them are given in the following Table 11.1.

Table 11.1 Differences between Photosystem I and Photosystem II

Photosystem I	Photosystem II
• PS I has a reaction centre of chlorophyll 'a' molecule with maximum light absorption at 700 nm wavelength. This reaction centre is referred to as P_{700}.	• PS II has a reaction centre of chlorophyll 'a' molecule with maximum light absorption at 680 nm. This reaction centre is also referred to to as P_{680}.
• Primary electron acceptor is an iron protein (Fe-S-protein)	• Primary electron acceptor, pheophytin, is a modified chlorophyll-a molecule with 2 hydrogen atoms in place of magnesium ion.
• A set of electron carriers are plastocyanin, ferredoxin and cytochrome	• A set of electron carriers are pheophytin plastoquinone, cytochromes.

11.3 ROLE OF SUNLIGHT IN PHOTOSYNTHESIS

Light consists of small particles or packages of energy called "photons". A single photon is also called **quantum.** What does the chlorophyll do? It absorbs light energy.

> Chlorophyll molecules absorb light energy and get into an excited state and lose an electron to the outer orbit. No substance can remain in an excited state for long, so the energised and excited chlorophyll molecule comes down to a low energy state known as **ground state** and releases the extra amount of energy. This energy can be lost as heat, or as light (fluorescence) or can do some work. In photosynthesis, it works by splitting water moelcule to produce H^+ and OH^- ions.

Carotene is orange-yellow pigment present along with chlorophylls in the thylakoid membrane. A carotene molecule breaks down into the vitamin A molecules. It is this pigment which gives carrot its colour.

Absorption and Action Spectra

For investigating a process such as photosynthesis that is activated by light, it is important to establish the action spectrum for the process and to use this to identify the pigments involved. An **action spectrum** is a graph showing the effectiveness of different wavelengths (VIBGYOR) of light in stimulating the process of photosynthesis, where the response could be measured in terms of oxygen produced at different wavelengths of light. An **absorption spectrum** is a graph representing the relative absorbance of different wavelengths of light by a pigment. An action spectrum for photosynthesis is shown in Fig. 11.2 together with an absorption spectrum for the combined photosynthetic pigments. Note the close similarity, which indicates that the pigments, chlorophyll-a in particular, are responsible for absorption of light used in photosynthesis.

All wavelengths of light are not equally effective in photosynthesis i.e. the rate of photosynthesis is more in some and less in others.

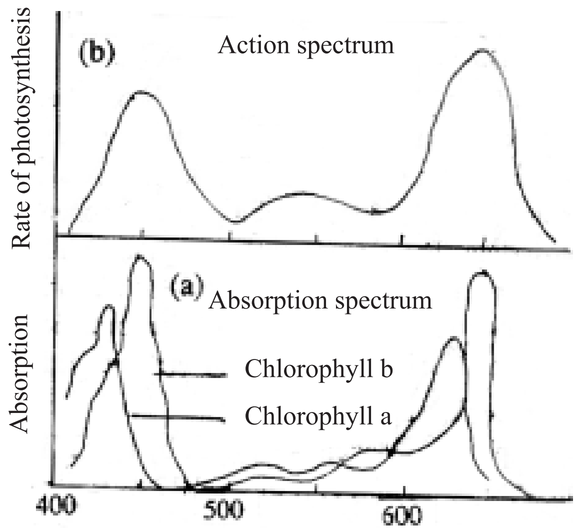


Fig. 11.2 Absorption Spectra of electromagnetic radiation B. Action Spectrum

Photosynthesis occurs maximum in blue and red region of spectra. Photosynthesis is very little in green and yellow light, because these rays are reflected back from the leaf.

INTEXT QUESTIONS 11.1

1. (i) Define photosynthesis

....

(ii) Give the overall general chemical equation of photosynthesis.

....

2. (i) List the two categories of photosynthetic pigments.

....

(ii) Which pigments are known as accessory pigments?

....

3. (i) What does chlorophyll do to the light falling on it?

....

(ii) Which pigment system absorbs maximally the red wavelength of light?

....

4. Answer the following

(i) In which colour of light, rate of photosynthesis is minimum and in which colour of light it is maximum?

....

(ii) Name the type of energy that is used in the process of photosynthesis. In which form does this energy get stored in plant body?

....

5. Which molecule is the source of evolution of oxygen in photosyntheisis— CO_2 or H_2O?

....

11.4 PHOTOCHEMICAL AND BIOSYNTHETIC PHASE

- The entire process of photosynthesis takes place inside the chloroplast. The structure of chloroplast is such that the light dependent (**light reaction**) and light independent (**Dark reaction**) reactions take place at different sites in the same organelle.
- The thylakoids have the pigments and other necessary components to absorb light and transfer electrons to carry out the light reaction or Electron Transport Chain (ETC). In ETC upon absorption of light, the electrons from PSII and PSI are excited to a higher energy level i.e. the electrons acquire excitation energy. As the electrons gain this energy, they are accepted by the electron acceptor which in turn is reduced, leaving the reaction centres of PSII and PSI i.e. P_{680} and P_{700} molecules in an oxidised state. This represents the conversion of light energy into chemical energy. The electrons then travel downhill in energy terms, from one electron acceptor to another in a series of oxidation-reduction reaction. This electron flow is 'coupled' to the formation of ATP. In addition, NADP is reduced to $NADPH_2$. The product of light reaction is called the reducing power or assimilatory power (ATP and $NADPH_2$) which move out of the thylakoid into the stroma of the chloroplast.
- In the stroma, the second step called as **dark reaction or biosynthetic pathway** occurs, where CO_2 is reduced by the reducing power generated in the first step and carbohydrates are produced.

Let us study these two steps in some more detail in the next part of the lesson.

11.4.1 Electron transport chain in photosynthesis

After receiving light PSII absorbs light energy and passes it on to its reaction centre, P_{680}. When P_{680} absorbs light, it is excited and its electrons are transferred to an electron acceptor molecule (Primary electron acceptor i.e. pheophytin) and it itself comes to the ground state. However by losing an electron P_{680} is oxidised and in turn it splits water molecule to release O_2. This light dependent spliting of water is called **photolysis**. With the breakdown of water electrons are generated, which are then passed on to the electron deficient P_{680} (which had transferred its electrons earlier). Thus the oxidised P_{680} regains its lost electrons from water molecules.

The reduced primary acceptor now donates electrons to the down stream components of the electron transport chain. The electrons are finally passed onto the reaction centre P_{700} or PSI. During this process, energy is released and stored in the form of ATP.

Similarly, PSI also gets excited when it absorbs light and P_{700} (Reaction centre of PSI) gets oxidised as it transfers its electrons to another primary acceptor molecule. While the oxidised P_{700} draws its electrons from PSII, the reduced primary acceptors molecule of PSI transfers its electrons via other electron carrier to NADP (Nicotinamide Adenine Dinucleotide Phosphate) to produce $NADPH_2$ a strong reducing agent. Thus we see that there is a continuous flow of electrons from the H_2O molecules to PSII to PSI, and finally to the NADP molecule which is reduced to $NADPH_2$. $NADPH_2$ is then utilised in reduction of CO_2 to carbohydrates in the biosynthetic pathway.

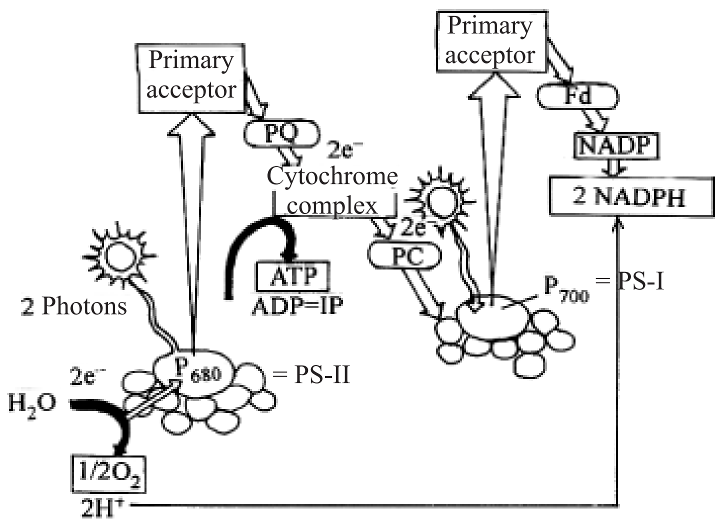


Fig. 11.3 Non-cyclic (z-scheme) photophosphorylation PQ = Plastoquinine, PC-Plastocyanin Fd = Ferredoxin

- Reduction of CO_2 to carbohydrate also requires ATP, which too are generated via electron transport chain. As the energy rich electrons pass down the electron transport system, it releases energy which is sufficient to bind inorganic phosphate (Pi) with ADP to form ATP. This process is called photophosphorylation. Since this takes place in presence of light it is called **Photo-phosphorylation.** It occurs in chloroplast in two ways:

(a) Non-cyclic photophosphorylation where electrons flow from water molecule to PSII and then to PSI and ultimately reduce NADP to $NADPH_2$. Since the electron flow is unidirectional and the electrons released from one molecule do not return to the same molecule, it is called non-cyclic photosphorylation (Fig. 11.3).

(b) Cyclic photophosphorylation occurs in photosynthetic bacteria which lack PS-II, and it involves PSI only. During this process electrons from PSI are not passed on to NADP. Instead the same electrons are returned to the oxidised P_{700} molecule. During this downhill movement of electrons ATP formation takes place. Thus this is termed as cyclic photophosphorylation (Fig. 11.4).

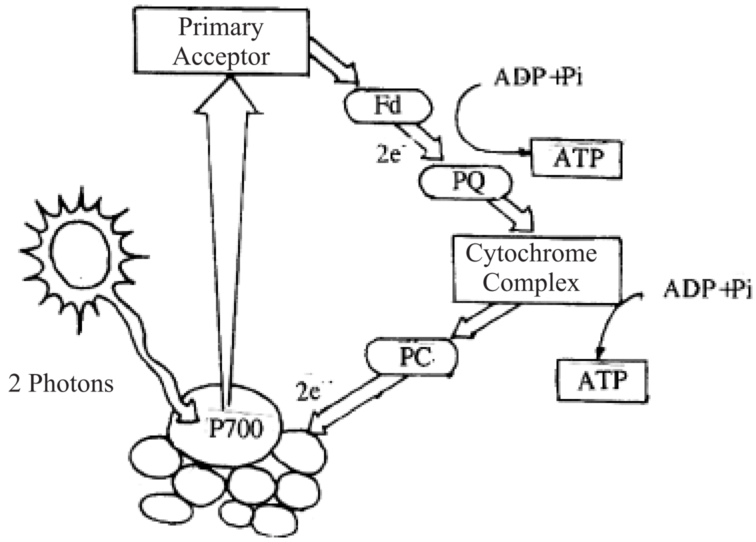


Fig. 11.4 Cyclic photophosphorylation

Table 11.2 Differences between cyclic and non-cyclic photophosphorylation

Cyclic photophosphorylation	Non-cyclic photophosphorylation
1. Only PSI is functional.	1. Both PSI and PSII are functional.
2. Electron comes from the chlorophyll P_{700} molecule and returns to the same chlorophyll P_{700}	2. Water is the primary source of the electrons and H^+. It gets photolysed through the process called **Photolysis;** NADP is the final acceptor of the electrons and H^+ ions.
4. Oxygen is not evolved because there is no photolysis of water	4. Oxygen is evolved as a bye product.
5. This process is found mainly in photosynthetic eubacteria e.g. purple sulphur bacteria.	5. This mainly takes place in all green plants, and cyanobacteria except photosynthetic eubacteria.

In higher photosynthetic plants, extra ATP can be made via cyclic photophosphorylation if cyclic and non-cyclic photophosphorylaiton occur side by side. The efficiency of energy conversion in the light reactions of photosynthesis is high and estimated at about 39%.

11.5 BIOSYNTHETIC PATHWAY (DARK REACTION)

- Both $NADPH_2$ and ATP produced during light reaction are essential requirements for synthesis of carbohydrates.
- These series of reactions which catalyse the reduction of CO_2 to carbohydrates (also called fixation of CO_2) take place in the **stroma** of the chloroplast.
- These reactions are independent of light i.e. light is not necessary but can continue in light as well if products of the light reaciton are available. Thus it is also called **dark reaction**.
- The carbon fixation reactions produce sugar in the leaves of the plant from where it is exported to other tissues of the plant as source of both organic molecule and energy for growth and metabolism.
- There are **two** major pathways by which CO_2 fixation (Dark reaction) takes place.

11.5.1 C_3 cycle (also called Calvin cycle after the name of its discoverer, Melvin Calvin)

In this cycle, initially the atmospheric CO_2 is accepted by a 5-carbon sugar ribulose bisphosphate (RuBP) resulting in the generation of two molecules of 3-carbon compound, 3-phosphoglyceric acid (PGA). This 3-carbon molecule is the first stable product of this pathway and hence the name C_3 cycle is given. Formation of PGA is called **carboxylation**. This reaction is catalysed by an enzyme called **ribulose bisphosphate carboxylase/oxygenase or Rubisco.** This enzyme is probably the most abundant protein on earth.

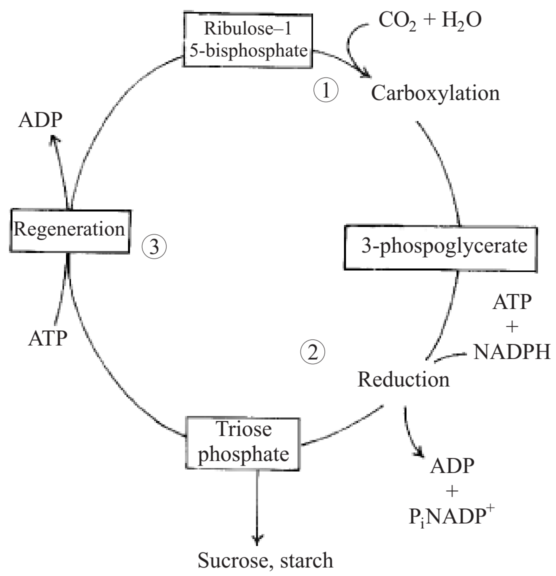


Fig. 11.5 The Calvin cycle

- In the next step, PGA is reduced to 3-carbon carbohydrate called **triose phosphate** using $NADPH_2$ and ATP (from light reaction). Much of these molecules are then diverted from the C_3 cycle and used for synthesis of other carbohydrates such as glucose and sucrose.
- To complete the cycle, the initial 5-carbon acceptor molecule, RuBP is regenerated from the triose phosphates using ATP molecule thus the C_3 cycle continues to regenerate the CO_2-acceptor (RuBP).

11.5.2 C_4 Cycle (or Hatch Slack Cycle)

- The C_4 cycle seems to be an adaptation for plants growing under dry hot environment. Such plants can photosynthesise even in the conditions of very low CO_2 concentration and under partial closure of stomata.
- Such plants can thus grow at low water content, high temperature and high light intensity. Sugarcane, and maize are some examples.
- Photorespiration (oxidation of RuBP in presence of O_2) is absent in these plants. So the photosynthetic rate is high. (For detail of photorespiration refer to lesson-12 Plant Respiration Section No. 12.5)
- The leaves of C_4 plants show presence of dimorphic chloroplasts, called **Kranz anatomy**.
  (a) In these plants, the vascular bundles have a sheath of large parenchyma cells around them in the form of a wreath, thus the name Kranz anatomy (Kranz : wreath)
  (b) Leaves possess two types of chloroplasts (dimorphic chloroplasts)
  (c) Chloroplasts in the mesophyll cells are smaller and have well developed grana (granal chloroplasts) but do not accumulate starch.
  (d) Chloroplasts in the bundle sheath cells are larger and lack grana (**agranal chloroplasts**) but contain numerous starch grains. (See Fig. 11.6).

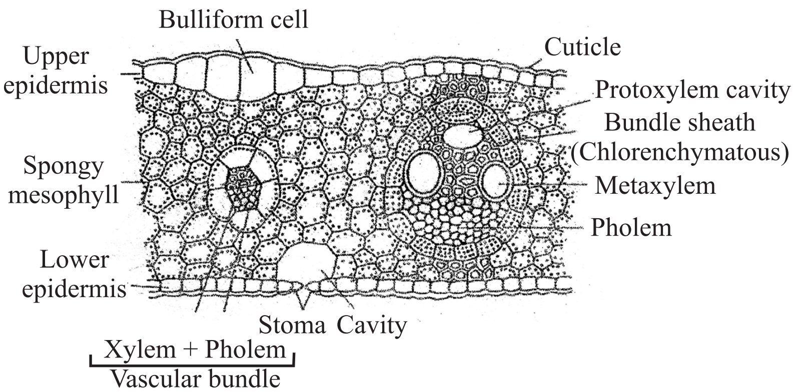


Fig. 11.6 Transverse section of maize leaf showing Kranz' anatomy

- In C_4 plants, the initial acceptor of CO_2 is **phosphoenol pyruvic acid or PEP**, a 3-carbon compound. It combines with CO_2 in presence of an enzyme **Phosphoenol pyruvate carboxylase (PEP carboxylase)** and forms a C_4 acid, oxaloacetic acid (OAA). This fixation of CO_2 occurs in the cytosol of the mesophyll cells of the leaf. OAA is the first stable product of this cycle which is 4 carbon compound and hence the name C_4 pathway is given.

- OAA then travels from mesophyll cells to the chloroplasts of bundle sheath cell where it releases the fixed CO_2. C_3 cycle operates within these cells and this CO_2 immediately combines with RuBP in C_3 cycle producing sugars. (See Fig. 11.7).

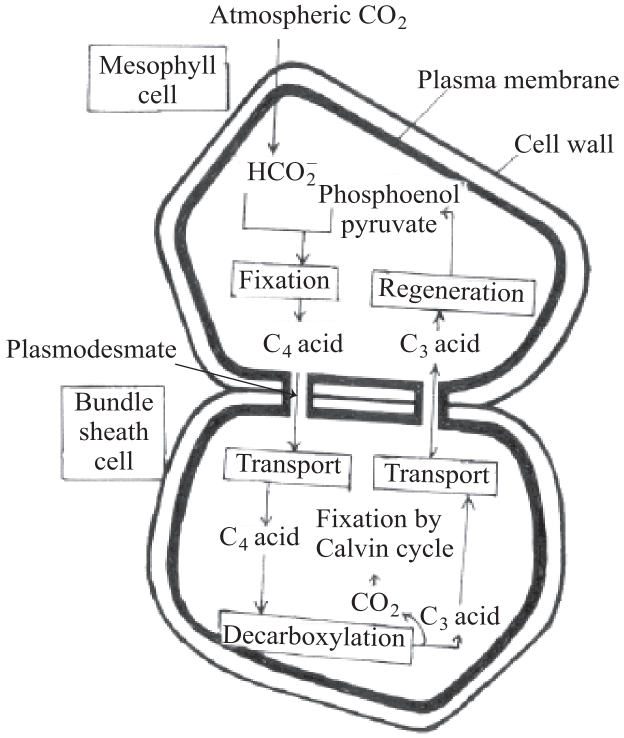


Fig. 11.7 The C4 photosynthetic carbon cycle

- Thus in C_4 pathway of dark reaction, there are two carboxylase enzymes that take part. PEP carboxylase (PEPCo) in the mesophyll cells and RUBP carboxylase (Rubisco) in the bundle sheath cells.
- The differences between C_3 and C_4 plants are tabulated below.

Table 11.3 Difference between C_3 and C_4 Plants

	C_3 Plants	C_4 Plants
Carbon dioxide fixation	Occurs once	Occurs twice, first in mesophyll cells, then in bundle sheath cells.
Carbon dioxide acceptor	Only one acceptor, RuBP which occurs in all green cells of the plant	In Mesophyll cells, PEP (Phosphoenol Pyruvic acid), 3-C, compound is CO_2 acceptor, but in the bundle sheath cells-RuBP, 5C, compound, is the CO_2^- acceptor
Carbon dioxide fixing enzymes	RuBP carboxylase, which is not efficient when CO_2 conc is low	PEP caboxylase which is very efficient, even if CO_2 conc. is low RuBP carboxylase, works efficiently because carbon dioxide concentration is high.
First product of photosynthesis	The first stable product is 3-C compound phosphoglyceric acid	The first product is 4-C compound oxaloacetic acid

Concentration of CO_2	Higher CO_2 conc. promotes photosynth]esis	Photosynthetic efficiency is high even if CO_2 conc. is low
Leaf anatomy	Only one type of chloroplast Kranz' anatomy is absent	Two types of chloroplasts (dimorphic) or Kranz' anatomy, i.e., two types of cells. each with its own type of chloroplasts are present.
Photorespiration	Occurs; excess of oxygen is an inhibitor of photosynthesis	Photorespiration is absent. The photo synthetic efficiency is further increased
Efficiency	Less efficient plotosynthesis than C_4 plants. Yields usually much lower.	More efficient photosynthesis as compared to that of the C_3 plants. Yields usually much higher.

INTEXT QUESTIONS 11.2

1. What is the role of NADP?

   ....

2. Why is dark reaction called so?

   ....

3. What is the role of the enzymes (i) rubisco and (ii) PEPCo and where are they present?

   ....

4. Explain Kranz anatomy.

   ....

5. Differentiate between the chloroplasts present in the mesophyll cells and in the bundle sheath cells of the leaf of a C_4 plant.

   ....

6. Why are C_4 plants more efficient than C_3 plants?

   ....

7. Name the two sets of reactions in photosynthesis in which light energy is required.

   ....

11.6 FACTORS AFFECTING RATE OF PHOTOSYNTHESIS

11.6.1 Factors affecting Photosynthesis

Factors affecting photosynthesis can be divided into two broad categories, the internal and external (environmental) factors.

(i) Internal Factors

1. **Chlorophyll :** The amount of chlorophyll present has a direct relationship with the rate of photosynthesis because this pigment is directly involved in trapping light energy responsible for the light reactions.
2. **Leaf age and anatomy :** Newly expanding leaves show gradual increase in rate of photosynthesis and the maximum is reached when the leaves achieve full size. Chloroplast functions decline as the leaves age. Rate of photosynthesis is influenced by variation in (i) number, structure and distribution of stomata, (ii) size and distribution of intercellular spaces (iii) relative proportion of palisade and spongy tissues and (iv) thickness of cuticle.
3. **Demand for photosynthate :** Rapidly growing plants show increased rate of photosynthesis in comparison to mature plants. When demand for photosynthesis is lowered due to poor meristematic activity, the photosynthetic rate declines.

(ii) External Factors

The major external factors which affect the rate of photosynthesis are temperature, light, carbondioxide, water, and mineral elements.

Concept of limiting factors : When a process is affected by various factors, the rate of the process depends upon the pace of the slowest factor. Let us consider three factors like light, carbon dioxide and temperature. It is seen that when all three factors are optimum, the rate of photosynthesis is maximum. However, of the three factors even if one of the factors becomes suboptimal and the other factors remain optimal, the rate of the photosynthetic process declines substantially. This is known as law of limiting factors shown by Blackman in 1905. It is defined as when a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the slowest factor which is known as the **limiting factor**.

Light : The rate of photosynthesis increases with increase of intensity of light within physiological limits or rate of photosynthesis is directly proportional to light intensity. Except on a cloudy day and at nights, light is never a limiting factor in photosynthesis in nature.

At a certain light intensity the amount of CO_2 used in photosynthesis and the amount of CO_2 produced in respiration are the same. This point of light intensity is known as **compensation point**.

Wavelength of light absorbed by photosynthetic pigments affects rate of photosynthesis. Red light and to some extent blue light has an enhancing influence on photosynthesis (See action spectrum).

The proportion of the total incident sunlight on earth, absorbed by green plants is generally a limiting factor. As per the estimates of the total incident light reaching the green plants, only about 1-2% is actually absorbed, because 70% is transmitted, and 28-29% is reflected back into the atmosphere.

Temperature : Very high and very low temperature affect the rate of photosynthesis adversely. Rate of photosynthesis will rise with temperature from 5°-37°C beyond which there is a rapid fall, as the enzymes involved in the process of the dark reaction are denatured at high temperature. Between 5°-35°C, with every 10°C rise in temperature rate of photosynthesis doubles or Q_{10} is 2 (Q = quotient), or slightly less than two.

Carbon dioxide : Since carbon dioxide being one of the raw materials for photosynthesis, its concentration affects the rate of photosynthesis markedly. Because of its very low concentration (0.03%) in the atmosphere, it acts as limiting factor in natural photosynthesis. At optimum temperature and light intensity, if carbon dioxide supply is increased the rate of photosynthesis increases markedly until CO_2 conc. is as high as 3.0%. Thus, CO_2 conc. in the atmosphere is always a limiting factor for photosynthesis.

Water : Water has an indirect effect on the rate of photosynthesis. Loss of water in the soil is immediately felt by the leaves, which get wilted and their stomata close down thus hampering the absorption of CO_2 from the atmosphere. This causes decline in photosynthesis.

Oxygen : Concentration of oxygen as an external factor, is never a limiting factor for photosynthesis because it is a by-product of photosynthesis, and it easily diffuses into the atmosphere from the photosynthesizng organ, **the leaf**. However, excesss of O_2 surrounding a green plant, reduces photosynthetic rate by promoting the rate of aerobic respiraiton.

Mineral elements : Some mineral elements like magnesium, copper, manganese and chloride ions, which are components of photosynthetic enzymes, and magnesium as a component of chlorophylls are important, and their deficiency would affect the rate of photosynthesis indirectly by affecting the synthesis of photosynthetic enzymes and chlorophyll, respectively.

11.7 CHEMOSYNTHESIS

Chemosynthesis

When plants utilise light energy to reduce carbon dioxide to carbohydrates, they are called photosynthetic autotrophs. There are some bacteria which can utilise chemical energy released during biological oxidation of certain inorganic substances to reduce carbon dioxide to carbohydrate. These bacteria are called **chemosynthetic autotrophs.**

This is found in many colourless bacteria and because they use chemical energy to reduce carbon dioxide, this process of carbohydrate synthesis is known as **chemosynthesis**.

Chemosynthesis may be defined as "the method of carbon assimilation when the reduction of CO_2 is carried out in darkness, utilising the energy obtained from oxidation of inorganic substances, such as H_2S and NH_3.

The common chemosynthetic forms are :

(i) Nitrifying bacteria. *Nitrosomonas* and *Nitrobactor* oxidise NH_3 to NO_2

(ii) Sulphur bacteria

(iii) Iron bacteria

(iv) Hydrogen and methane producing bacteria

Differences between photosynthesis and chemosynthesis

Chemosynthesis	Photosynthesis
1. It occurs only in colourless anaerobic bacteria	1. This process occurs in all green plants including green bacteria.
2. During this process CO_2 is reduced to carbohydrates without light and chlorophyll.	2. CO_2 and H_2O are converted into carbohydrates in the presence of light and chlorophyll.
3. Here chemical energy released during oxidation of inorganic substances is used up to synthesise carbohydrates.	3. Light energy is converted into chemical energy and stored in the form of carbohydrates.
4. No pigment molecule is involved and oxygen is not evolved.	4. Several pigments are involved and oxygen is evolved as a by-product.
5. No photophosphorylation takes place.	5. Photophosphorytion takes place i.e. ATP is produced.

11.8 CHEMIOSMOTIC SYNTHESIS

This is a process in which energy stored as a hydrogen ion gradient across a membrane is used to synthesise ATP from ADP and Pi. The enzyme which uses the energy is ATP synthase and the energy or power source is the difference in the concentration of H^+ ions on opposite sides of the membrane. The membrane is the inner membrane of the mitochondrion or the chloroplast. The word 'osmosis' in Greek means 'push' and here the flow of H^+ ions across the membrane provides the energy or push to ATP synthase enzyme which then catalyses the synthesis of ATP.

Chloroplasts use chemiosmosis to generate ATP during photosynthesis. The prokaryotes lack the organelles mitochondria and chloroplast to generate H^+ gradients across plasma membranes and cannot use it for ATP synthesis. Peter Mitchell won the Nobel prize in 1978 for proposing the chemiosmotic model for syntheis of ATP.

INTEXT QUESTIONS 11.3

1. List the internal factors that influence the rate of photosynthesis?

   ....

2. State the principle of limiting factor.

   ....

3. Give an example of chemosynthetic bacteria.

   ....

4. Why are prokaryotes not able to produce ATP by chemiosmosis?

   ....

WHAT YOU HAVE LEARNT

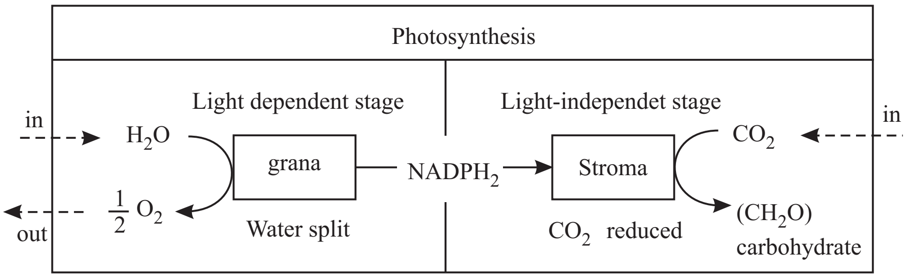
- Green plants are capable of synthesizing carbohydrates from CO_2 and H_2O in the presence of light, by the process of photosynthesis.
- During photosynthesis 'light energy', which is captured by the photosynthetic pigments (chlorophyll, carotenoids and xanthophylls) present in the chloroplasts, is converted into chemical energy.
- Photosynthesis in general is expressed by the following equation:

$$6CO_2 + 12H_2O \xrightarrow[\text{Light}]{\text{Chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

- Photosynthesis comprises two sets of reactions:
- Light reactions: which take place in grana or thylakoids of chloroplasts only in the presence of light.
- Dark reactions: Which occur in the stroma of chloroplast and are independent of light, if products of light reaction are provided.
- Light energy is used for splitting of water, and production of ATP and $NADPH_2$ and actual reduction of CO_2 takes place in the dark reaction.
- Light reaction occurs with the help of two functional units, photosystem-I and photosystem-II.
- During light reaction phosphorylation of ADP to ATP may occur in two ways, cyclic and non-cyclic.
- During dark reactions CO_2 is accepted by Ribulose biphosphate (RuBP) and the first stable product. 3-PGA (3 phosphoglyceric acid) is formed, which by further cyclic reactions (Calvin Cycle) leads to the formation of carbohydrates as well as in regeneration of RuBP.

- In C_4 plants like maize, jawar, bajra, the primary acceptor of CO_2 is in mesophyll cells and the first detectable product of dark reaction is oxaloacetic acid (OAA), whereas in the bundle sheath cells CO_2 fixation occurs through. Calvin cycle.
- Occurrence of dimorphic chloroplasts in C_4 plants is known as "Kranz anatomy" and is characterized by the presence of a sheath of parenchyma cells around a vascular bundle (bundle sheath). Cells of this sheath have larger chloroplasts which lack grana and are filled with starch grains. In contrast mesophyll cells contain chloroplasts which are smaller but have well developed grana.
- Rate of photosynthesis is influenced by (i) environmental factors such as light, temperature, carbon dioxide concentration and water, and (ii) internal factors which include age of leaf, chlorophyll content and leaf anatomy.

A SUMMARY OF PHOTOSYNTHESIS



Light-dependent stage	Light independent stage
• occurs in the thylakoid membranes of the grana	• occurs in the stroma
• largely a photochemical change, requiring light energy	• a series of biochemical changes, each reaction catalysed by an enzyme
• light energy is converted to chemical energy in the form of ATP and NADPH$_2$; water is split into hydrogen and oxygen; hydrogen is combined in NADPH$_2$; oxygen gas is released as a byproduct	• carbon dioxide is converted to compounds such as carbohydrates (with the help of chemical energy of ATP and NADPH$_2$); the reactions of the light-independent stage are known as the Calvin cycle and C_4-pathway
• chlorophylls are grouped together in units of about 300 molecules (known as photosystems); two types exist, photosystems I and II	• carbon dioxide is combined with ribulose bisphosphate (the acceptor substance) and the product splits instantly into two molecules of glycerate 3-phosphate (GP, the first product of photosynthesis) in C_3-plants
• light energy absorbed by the photo-systems causes electrons from chlorophyll to be raised to a high energy level and to pass to NADPH$_2$; ATP is generated; water is split and provides the electrons	• CO_2 is reduced with the help of RuBP and Rubisco to a three-carbon sugar, triose phosphate; then, in a series of reactions, the acceptor molecule is regenerated and sugars, starch and other substances are formed from

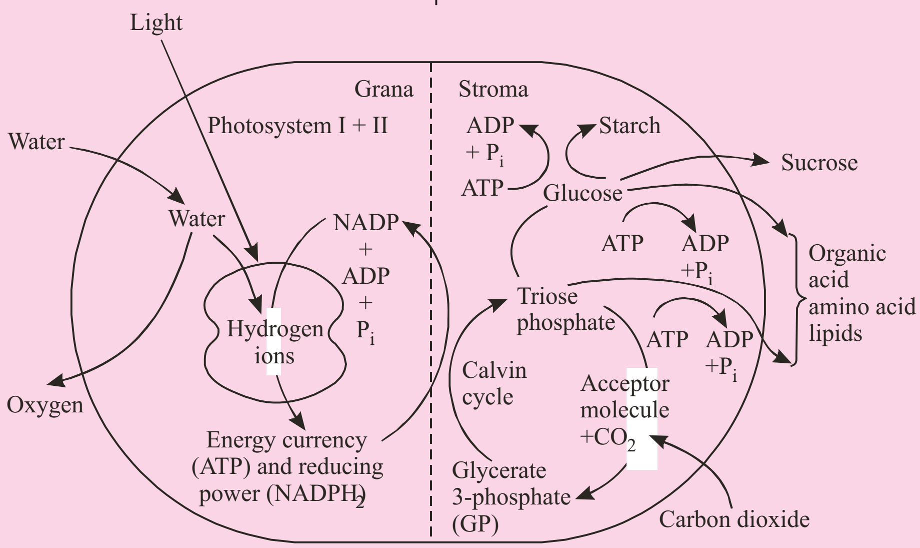
to the photosystem and the hydrogen for $NADPH_2$ production:

$$2H_2O + 2NADP \xrightarrow[\text{Chlorophyll}]{\text{Light}} O_2 + 2NADPH_2$$

$$ADP + P_i \xrightarrow[\text{Chlorophyll}]{\text{Light}} \text{ATP (considerable, but variable amount)}$$

triose phosphate:

$$3ATP + CO_2 + 2NADPH_2 \longrightarrow (CH_2O) + H_2O + 3ADP + 3P_i + 2NADP$$



TERMINAL EXERCISES

1. Describe briefly the process of photosynthesis.
2. Write short notes on (i) Ultrastructure of chloroplast and (ii) Pigments involved in photosynthesis.
3. What are accessory pigments? Why they are called so?
4. Mention path of electrons in the light reaction of photosynthesis.
5. What do you understand by photophosphorylation.
6. Discuss photolysis of water and its significance.
7. Describe the reactions occurring during dark reaction of photosynthesis.
8. Differentiate between C_3 and C_4 plants.
9. Differentiate between PSI and PSII.
10. What are the products of light reactions. What is the fate of these products?

11. Why is cyclic photophosphorylation called so?

12. What is Kranz anatomy?

13. Name the two carboxylase enzymes in C_4 cycle.

14. What are chemosynthetic autotrophs?

15. How does CO_2 concentration affect the rate of photosynthesis?

16. What is the effect of excess of oxyygen on the rate of photosynthesis?

17. Whether light absorbed by green plants, on global basis is limiting factor for photosynthesis or not! Explain

ANSWERS TO INTEXT QUESTIONS

11.1 1. (i) It is the process by which green plants produce food (carbohydrates) from simple substances like CO_2 and water in presence of sun light and chlorophyll.

(ii) $6CO_2 + 12H_2O \xrightarrow[\text{Sunlight}]{\text{Chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2$

2. (i) Chlorophylls and carotenoids.

(ii) Carotenoids and chlorophyll b

3. (i) Absorb it and then convert it into chemical energy.

(ii) Chlorophyll a and b

4. (i) Minimum in green and yellow light and maximum in blue and red light.

(ii) light energy; chemical energy

5. From photolysis of water in PSII

11.2 1. NADP acts as an electron acceptor and H^+ acceptor and finally, it gets reduced to $NADPH_2$.

2. It is called dark reaction because it can occur independent of light i.e. can occur both in light and in dark.

3. (i) Rubisco is a part of C_3 cycle and combines with CO_2 to produce a C_3 compound called PGA.

(ii) PEPCo is a part of C_4 path way and combines with CO_2 to form a C_4 compound called OAA.

Rubisco is present in the mesophyll cells of C_3 plants and in the bundle sheath cells of C_4 plants.

PEPCo is found only in mesophyll cells of C_4 plants.

4. See text
5. See text
6. C_4 plants have no photorespiration and thus there is no loss of additional carbon dioxide, due to breakdown of RuBP to Glycolate and CO_2.
7. (i) Photolysis of water

11.3

1. leaf age, chlorophyll content, leaf anatomy (size, internal structure, stomatal distribution)
2. See text
3. *Nitrosomonass* and *Nitrobacter*.
4. Because they are not able to maintain H^+ gradient across a membrane in the absence of membrane bound organelles in their cytoplasm.