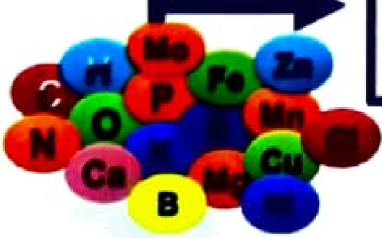
PLANT AND MINERAL NUTRITION

Contents to be covered in this topic

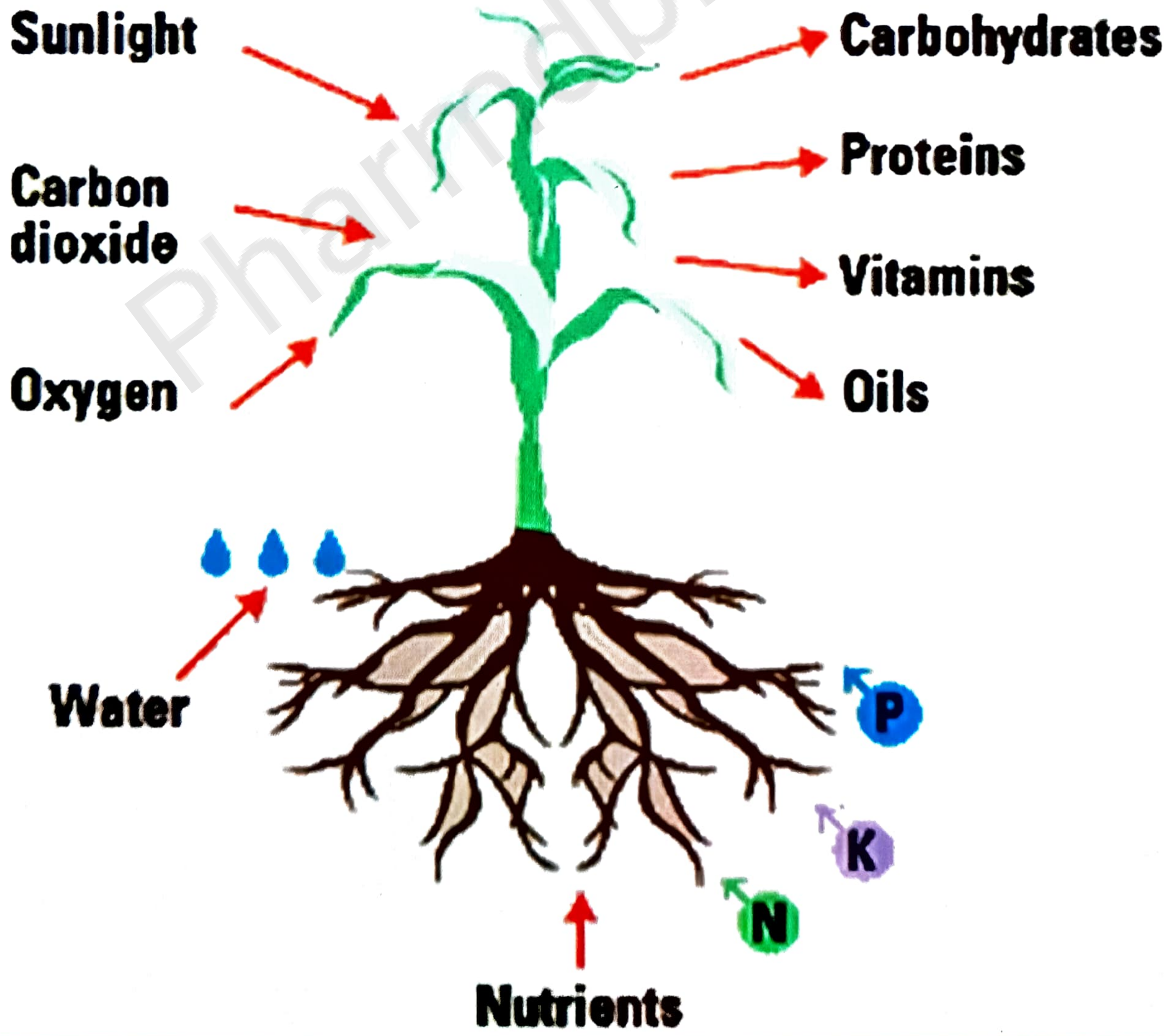
- MINERAL NUTRITION
- SOURCES OF DIFFERENT ESSENTIAL ELEMENTS
- ROLE OF MACRO-NUTRIENTS IN PLANTS AND THEIR DEFICIENCY SYMPTOMS
- ROLE OF MICRO-NUTRIENTS IN PLANTS AND THEIR DEFICIENCY SYMPTOMS
- ROLE OF MICRO-NUTRIENTS IN PLANTS AND THEIR DEFICIENCY SYMPTOMS
- MECHANISM OF ABSORPTION



❑ ESSENTIAL MINERAL , MACRO AND MICRONUTRIENTS

➢ Mineral nutrition

- All living organisms **require food** to **survive, grow and reproduce.**
- So every organism takes the food and utilizes the food constituents for its requirements of growth.
- **Nutrition** in plants may thus be defined as, 'a **process of synthesis of food**, its **breakdown and utilization** for various functions in the body'. The chemical substances in food are called nutrients e.g. **CO_2, water, minerals, carbohydrates, proteins, fats etc.**
- Carbohydrates in plants are synthesized by the process of **photosynthesis**
- **Carbon, hydrogen and oxygen** are the main elements in carbohydrates, fats and proteins. These are generally referred to as mineral elements. They are absorbed by the root system of plants in the form of their salts. The study of how plants get mineral elements and utilize them for their growth and development is called **mineral nutrition.**



a. **Based on their quantitative requirements,** essential elements are classified into two broad categories:

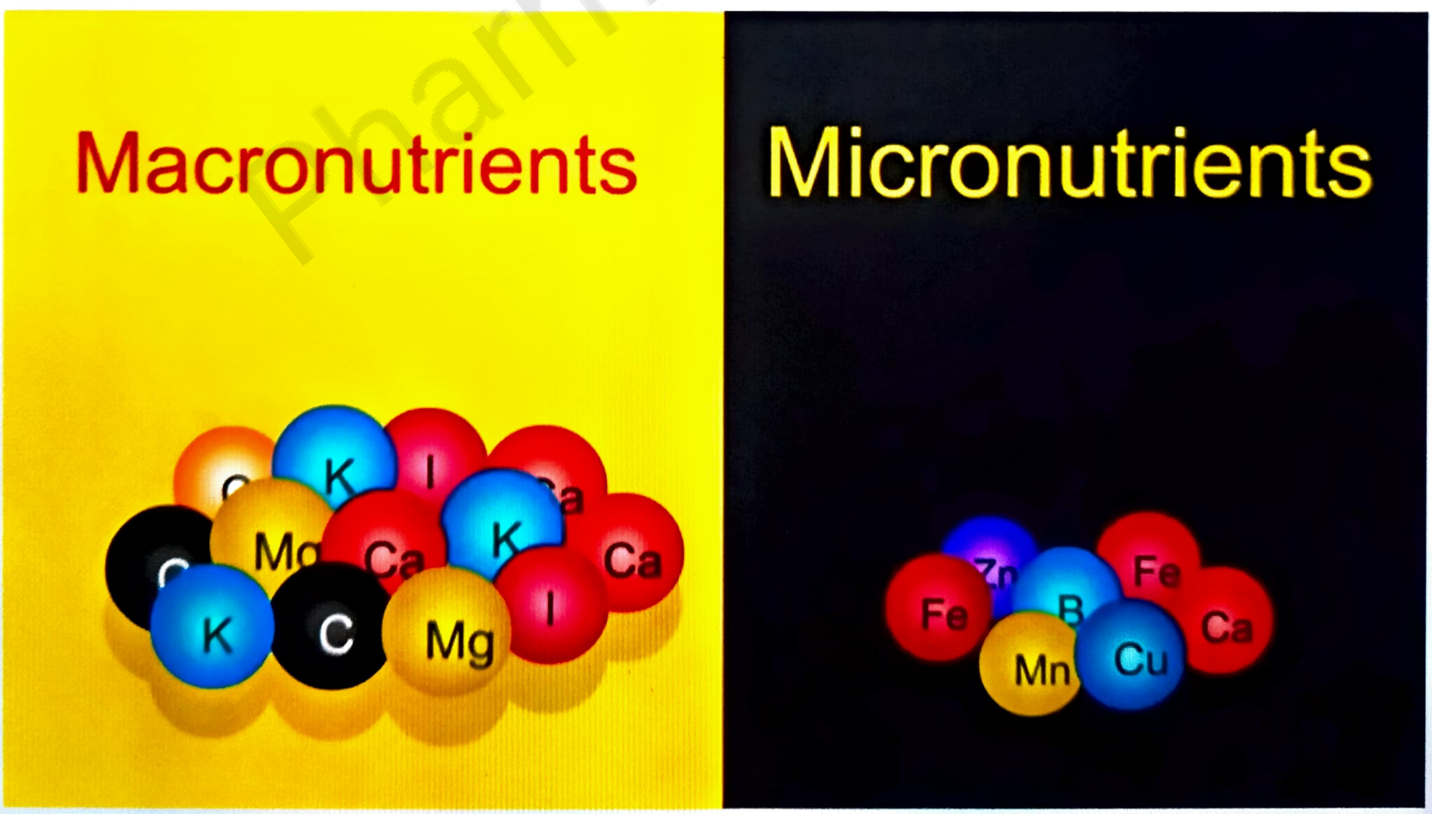
1. **Macronutrients**
2. **Micronutrients**

Macronutrients : generally present in large amounts in the plant tissues, i.e., in excess of 10 milli mole/kg or 1 to 10 mg per gram of dry matter. The macronutrients include nine elements that are **Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Sulphur, Potassium, Calcium and Magnesium.**

Micronutrients : Micronutrients or trace elements are those elements, which are needed in minute quantities, i.e, less than 10 milli mole/kg of dry matter or 0.1 mg or less than 0.1 mg per gram of dry matter. The micronutrients include eight elements that are Boron, Copper, Iron, Manganese, Molybdenum, Zinc, Nickel and Chlorine.

b. Based on their diverse functions, essential elements are classified into four categories:

1. As **components of biomolecules**, e.g. **carbon hydrogen, oxygen and nitrogen.**



2. As components of **energy related chemical compounds** e.g. **Phosphorus in ATP, Magnesium in chlorophyll**

3. As activator or inhibitor of enzymes e.g. **Mg is an activator of ribulose bisphosphate carboxylase** and **phosphoenol pyruvate carboxylase,** both of which are critical enzymes in photosynthetic carbon fixation.

- **Zn^{2+}** is an activator of **alcohol dehydrogenase and Mo** activates nitrogenase during nitrogen metabolism.

4. Elements that maintain the osmotic potential of a cell. e.g., **potassium** is involved in the **opening and closing of stomata. Chlorine** maintains the anion-cation **balance and the osmotic** potential of the cell

➢ Sources of Essential Elements for Plants :

Most of the essential elements are **taken from soil,** and some from the atmosphere

Sources of different essential elements

ELEMENTS	SOURCES OF ELEMENTS
CARBON	Taken as CO_2 from the atmosphere (air)
OXYGEN	Absorbed in the molecular form, from air or from water. It is also generated within a green plant during photosynthesis.
HYDROGEN	Released from water during **photosynthesis** in the green plant
NITROGEN	Absorbed by the **plants as nitrate ion (NO^-_3) or as ammonium ion (NH_4)** from the soil. Some organisms like **bacteria and cyanobacteria can fix nitrogen from air directly**
POTASSIUM, CALCIUM, IRON, PHOSPHORUS, SULPHUR, MAGNESIUM	Absorbed from the soil (are actually derived from the weathering of rocks. So they are called mineral elements). They are absorbed in the ionic forms e.g. K^+ ,Ca2+, Fe3+, H_2PO^{4-} / HPO_4^{2-} etc.

➤ Role of Macro-Nutrients in Plants and their Deficiency Symptoms:

MACRO-NUTRIENTS	REGIONS OF PLANTS WHERE REQUIRED	FUNCTION	DEFICIENCY SYMPTOMS
Nitrogen (N) Absorbed as NO_3^-, NO_2^- and NH_4^+ ions	All tissues, particularly in **meristematic tissues**	Major constituent of amino acids, proteins, nucleic acids, vitamins, etc.	(i) **Chlorosis,** in older leaves (ii) **Stunted growth** (iii) **Dormancy of lateral buds** (iv) Delayed flowering
Sulphur (S) Obtained as sulphates (SO_4^{2-}. ions).	Stem and root tips young leaves of the plant	• It is a constituent of **amino acids, methionine and cysteine** • It also forms parts of vitamins like thiamine, coenzyme-A	• **Chlorosis of younger leaves.** • **Stunted growth** of plants • Accumulation of **anthocyanin (purple colouration)**
Phosphorus (P) Absorbed by plants in the form of phosphate ions, either as **$H_2PO_4^-$ or HPO_4^{3-}**	**Young tissues**	• It is a constituent of **nucleotides and nucleic acids** • Present in cell **membranes as phospholipid** • It is involved in **phosphorylation reactions and energy metabolism as ATP**	i) Deficiency **causes purple or red spots on leaves.** ii) Leaves also become **dark (dull) green.** iii) **Delay in seed germination** iv) **Premature fall of leaves and flower buds also occurs**

Potassium (K) Potassium is taken as potassium ions (K^+)	Meristematic tissues, buds, leaves and root tips	(1) It controls the opening and closing of stomata (2) It **maintains turgidity** (osmotic balance) of cells (3) It activates a number of enzymes (4) Involved in protein synthesis	• Interveinal **chlorosis** • Loss of **apical dominance** and a **bushy appearance of plants,** • Loss of **cambial activity** • **Shorter internodes** • Increased rate of respiration
Magnesium (Mg) It is absorbed as Mg^{2+} ions by plants	Leaves of the plant	• It is a **constituent of chlorophyll** • It maintains the **ribosome structure for protein synthesis** • It activates the **enzymes of phosphate metabolism in respiration** and photosynthesis • Involved in the synthesis of **DNA and RNA** and **activation of enzyme**	• **Interveinal chlorosis** and **necrosis, first of older leaves.** • **Premature leaf fall**
Calcium (Ca) Calcium is obtained as calcium ions (Ca^{++}) from the soil	**Regions of plants where required:** Meristematic and differentiating tissues.	i) It occurs as **calcium pectate in the middle lamella of cell wall**	• Stunted growth • Necrosis of meristematic regions

➢ Role of Micro-Nutrients in Plants and their Deficiency Symptoms

Iron (Fe) absorbed mainly in the form of ferric ions(Fe^{3+}).	Leaves and seeds	1. It is an important constituent of cytochromes and ferredoxin, involved in electron transport 2. It **activates catalase** 3. It is involved in the **synthesis of chlorophyll**	Chlorosis starts with intravenous regions and results in chlorosis of complete leaf
Copper (Cu) **Absorbed as cupric ions (Cu^{++}).**	All tissues of the plant	1. It is associated with certain enzymes involved in the redox reactions 2. It is essential for the **overall metabolism**	(1) **Necrosis of young leaves** (2) Leaves fall off and bark becomes rough and splits **exuding gummy substances**
Boron (B) It is absorbed as BO_3^{3-} or B_4O_7,	Leaves and seeds	i) For **uptake and utilization of calcium ions** ii) It is needed for **pollen germination** iii) **Cell elongation** and cell differentiation	• Death of root and shoot tips • **Abscission of flowers** • **Loss of apical dominance** • Absence of root nodules in leguminous plants • **Small sized fruits.**

Zinc (Zn) obtained by plants as in Zn^{++}	**All tissues of the plant**	• **For the synthesis of auxins** • **Activates many enzymes, especially carboxylases**	• **Malformed (little) leaves** • **Interveinal chlorosis** • **Stunted growth**
Manganese (Mn) obtained by plants as Mn^{++} ions	All tissues, collects along the leaf veins	• It is necessary for photolysis of water in photosynthesis. • It activates many enzymes involved in photosynthesis, nitrogen metabolism and respiration	• Chlorosis • Grey spots on leaves
Molybdenum (Mo) Plants obtain molybdenum as molybdate ions (MoO_2^{2-})	All tissues, particularly in roots	• It is a **co-factor for enzyme nitrate reductase** • It is also necessary for nitrogenase	• Interveinal chiorosis
Chlorine (Cl) It is taken in the form of chloride ions.	All tissues of the plant	• It is necessary for **photolysis of water in photosynthesis**. • It may be required for **cell division** in leaves and roots.	• Stunted root growth • **Reduced fruit formation**

➤ Mechanism of Absorption:

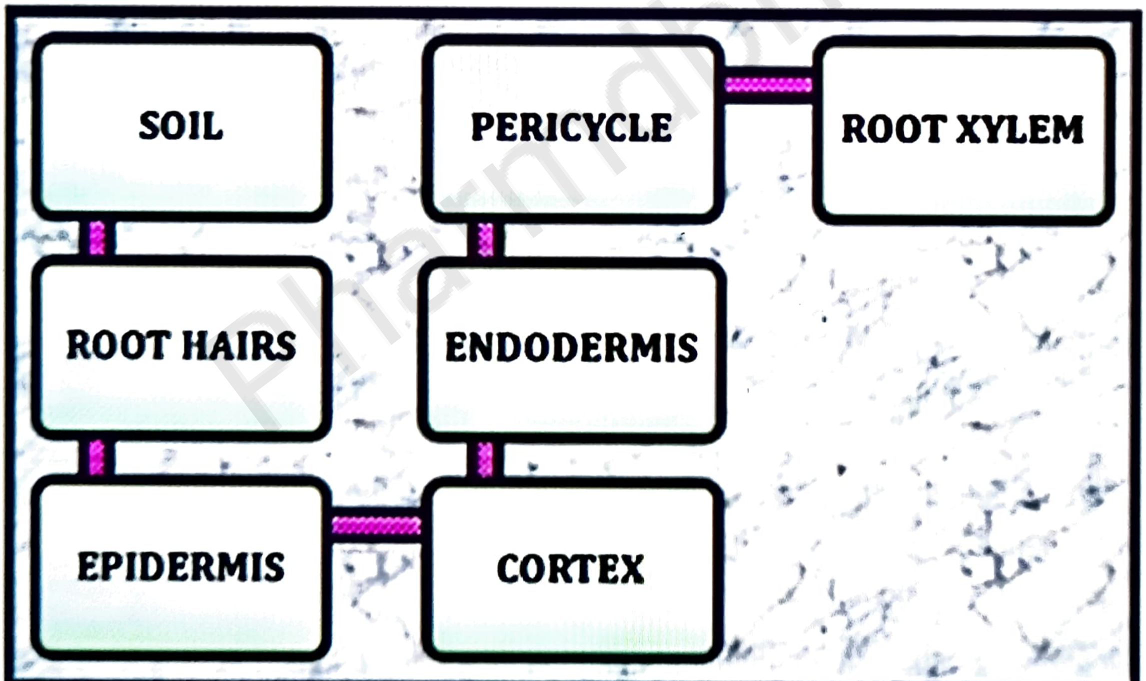
Passive Absorption:

(a) **Absorption by diffusion:** The mineral molecules move by the principle of diffusion. i.e. **from higher concentration to lower concentration** and does not involve any use of energy by root cells.

(b) **Ion exchange mechanism:** The process of exchanging negative ions (anions) and positive ions (cations) in the root cells by the ions of equivalent charge from the soil is known as **ion-exchange process** of passive absorption.

Active Absorption:

The ions find their **entry into the root cells** to accumulate in large concentration. These are then moved to the protoxylem by **plasmodesma with the help of respiratory energy.** The mechanism is explained by the presence of a **carrier compound.**

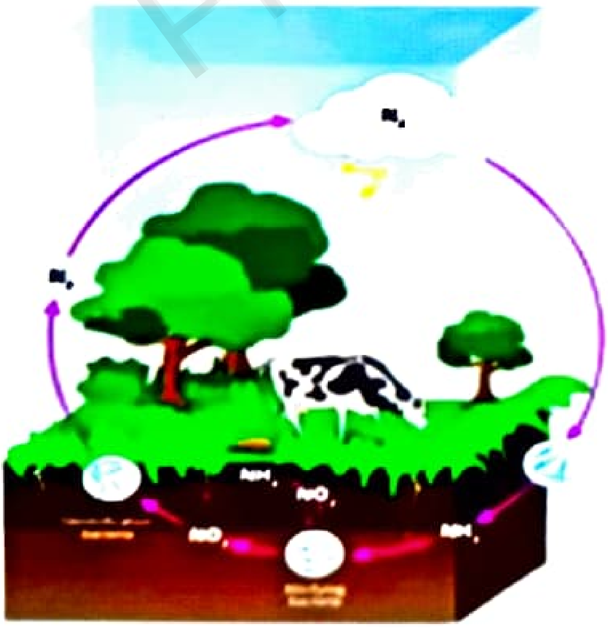


PATHWAY OF WATER ABSORPTION IN PLANTS

PLANT AND MINERAL NUTRITION

Contents to be covered in this topic

- NITROGEN CYCLE
- BIOLOGICAL NITROGEN FIXATION
- FORMATION OF ROOT NODULES IN LEGUMES
- SYNTHESIS OF AMINO ACIDS



❑ NITROGEN METABOLISM, NITROGEN CYCLE, BIOLOGICAL NITROGEN FIXATION

➢ Nitrogen Cycle

- Nitrogen is a limiting nutrient for both natural and agricultural ecosystems
- It exists as two nitrogen atoms held together by strong triple covalent bonds (N=N)

Nitrogen cycle involves the following steps:

(i) **Nitrogen fixation**

(ii) **Ammonification**

(iii) **Nitrification**

(iv) **Denitrification**

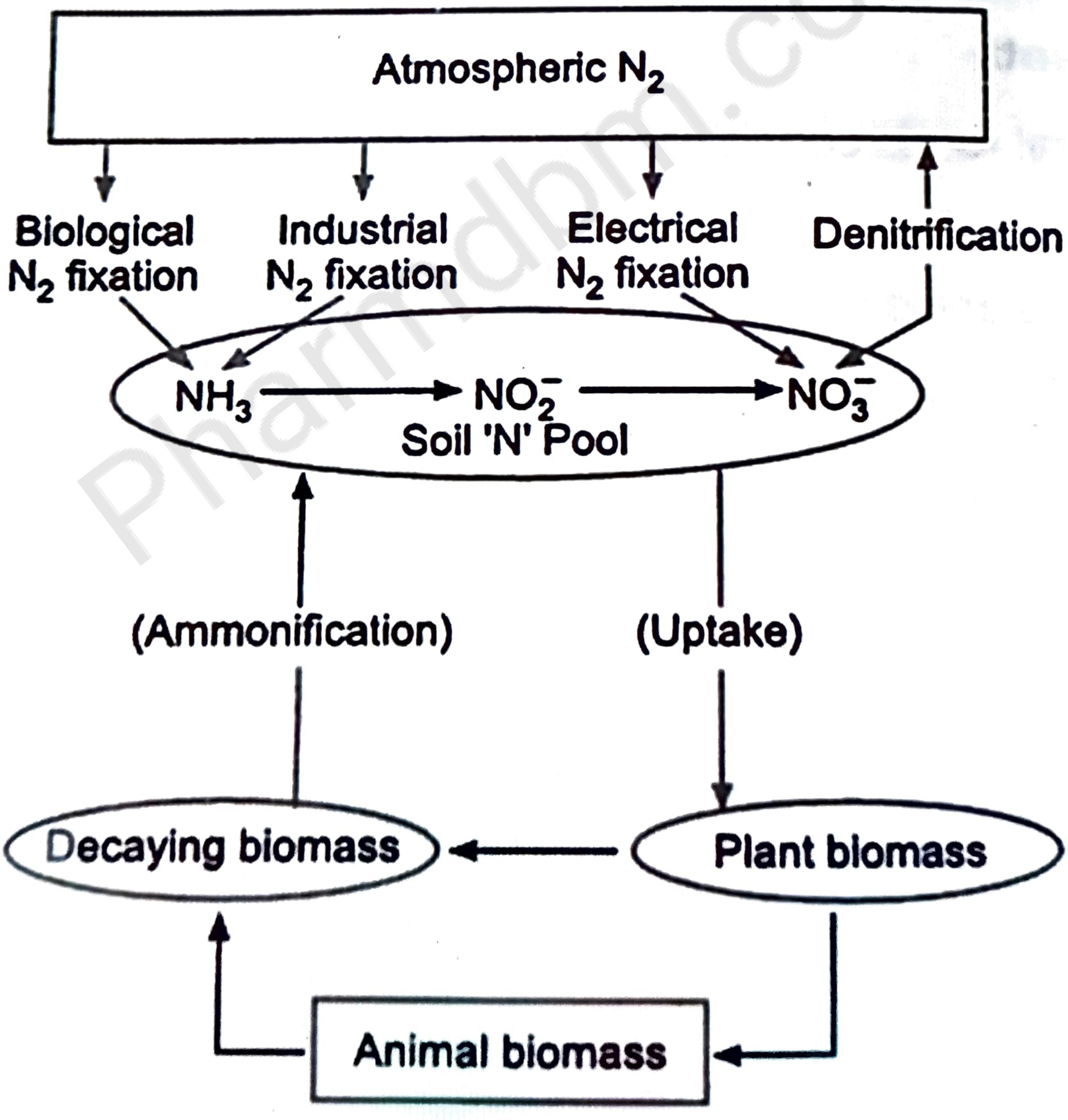


Fig. Nitrogen Cycle

(i) Nitrogen Fixation

- The process of **conversion of nitrogen into ammonia**
- In nature, lightning and ultraviolet radiation provide energy to convert nitrogen into nitrogen oxides like **N_2O, NO and NO_2**
- **Atmosphere** also gets some amount of **nitrogen oxides** from forest fires, automobile exhausts, industrial combustion and power generating stations

(ii) Ammonification

- The process by which **organic nitrogenous compounds are decomposed to produce ammonia,** is known as **ammonification.**
- Some ammonia volatilizes and re-enters the atmosphere
- Most of the ammonia is converted into nitrites and nitrates

(iii) Nitrification

- Nitrification is the process of **converting ammonia first into nitrite and then into nitrate**

$$2NH_3 + 3O_2 \longrightarrow 2NO_2 + 2H^+ + 2H_2O$$

$$2NO_2 + O_2 \longrightarrow 2NO_3$$

- These processes are carried out by **soil bacteria** that are **chemoautotrophs**
- Ammonia is oxidized into nitrite by **Nitrosomonas and Nitrococcus**
- Nitrite is oxidised to nitrate by **Nitrobacter**
- The nitrates are absorbed by the plants and reduced to nitrites.
- The nitrites are transported to the leaves and reduced to ammonia, which forms the amino group of amino acids

(iv) Denitrification

- It is the process of conversion or **reduction of the nitrates into nitrogen.**
- It is carried out by bacteria like **Pseudomonas and Thiobacillus**

➤ Biological Nitrogen Fixation

- Though nitrogen is abundant in the atmosphere, only a few living organisms, especially certain prokaryotes, are capable of using it.

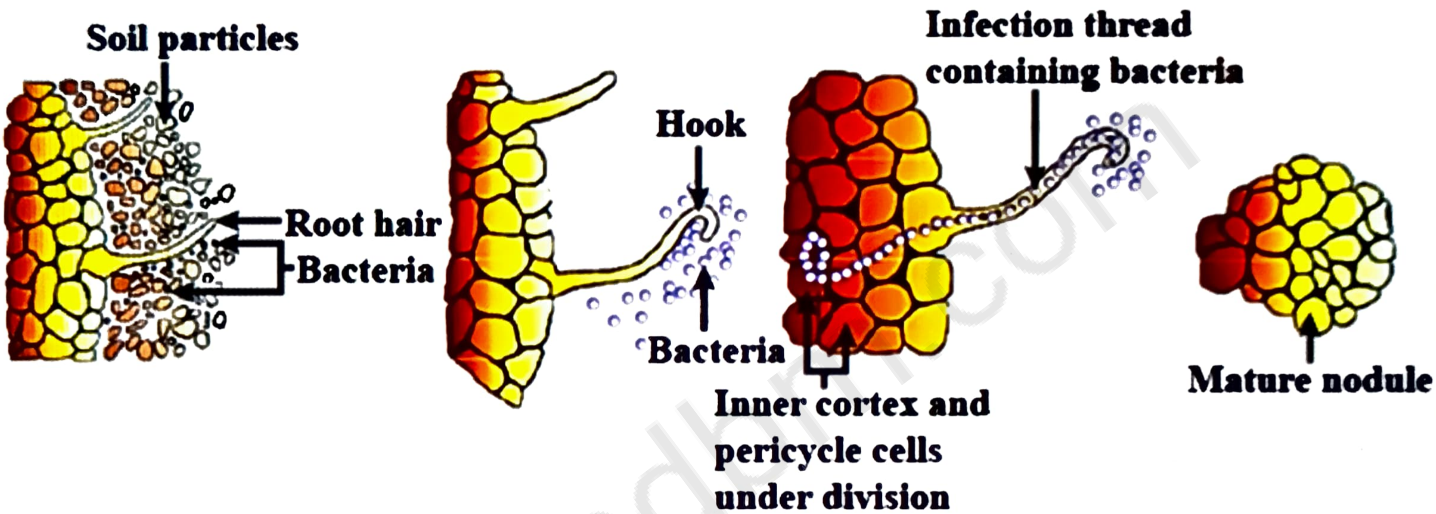
- The process by which **living organisms convert the free atmospheric nitrogen into ammonia,** is called **biological nitrogen fixation.**
- The nitrogen fixing **micro-organisms may be free living or symbionts.**
- Free living nitrogen fixers include: Azotobacter and Beljernickia (aerobes), Rhodospirillum and Clostridium (anaerobes) and Cyanobacteria like Nostoc and Aulosira
- **Symbiotic nitrogen fixers include:** Rhizobium in the roots of legumes, Frankia in non-legumes like Alnus and Casuarina, cyanobacteria like Nostoc and Anabaena (Cycas roots,Anthoceros, Azolla etc.)
- **Symbiotic nitrogen fixation** takes place in the **root nodules of legumes.**
- During this process, a dinitrogen molecule is reduced by the addition of hydrogen atoms into two molecules of ammonia catalyzed by the enzyme nitrogenase
- **Biological nitrogen fixation requires the following three biochemical components:**
  - ✓ A **reducing agent,** to transfer the hydrogen atoms to dinitrogen.
  - ✓ **ATP,** to provide energy.
  - ✓ **The enzyme system-nitrogenase,** a Mo-Fe protein and leghaemoglobin
- The **leghaemoglobin is a pink colour pigment** similar to haemoglobin of vertebrates and functions as an oxygen scavenger and protects the nitrogenase from oxygen.

$$N_2 + 8e^- + 8H^+ + 16\ ATP \longrightarrow 2NH_3 + 16\ ADP + 16\ Pi + H_2$$

➢ Formation of Root Nodules in Legumes

- When the **root hair of a leguminous plant** comes in contact with **Rhizobium**, it become scurled or deformed due to the chemicals secreted by the bacterium.
- The rhizobia enter these deformed root hair and proliferate within the root hair
- The plant responds by forming an infection thread, that grows inwards to deliver bacteria to the tissues

- It is believed that the **cytokinin produced by the bacteria and the auxin produced by the plant cells** stimulate cell division and enlargement to form a nodule
- The nodule establishes contact with the vascular tissues of the host for absorption of nutrients
- The formation of root nodules and nitrogen fixation occur under the control of **genes of legumes** and the nod genes of legumes and the **nod, nif and fix** genes of bacteria



➢ Synthesis of amino acids

- The **ammonia formed by nitrogen fixation** is used for the synthesis of amino acids
- The two processes by which amino acids are synthesized:

Reductive Amination:

- In this, ammonia reacts with alpha ketoglutaric acid and forms glutamic acid. α-ketoglutaric acid + NH_4^+ + NAD(P)H
- The reaction is catalyzed by **glutamate dehydrogenase**

Transamination:

- In this process, the **amino group is transferred from one amino acid to the keto group of α keto-acid.**
- Glutamic acid is the main amino acid which transfers its NI-12 group to seventeen other amino acids

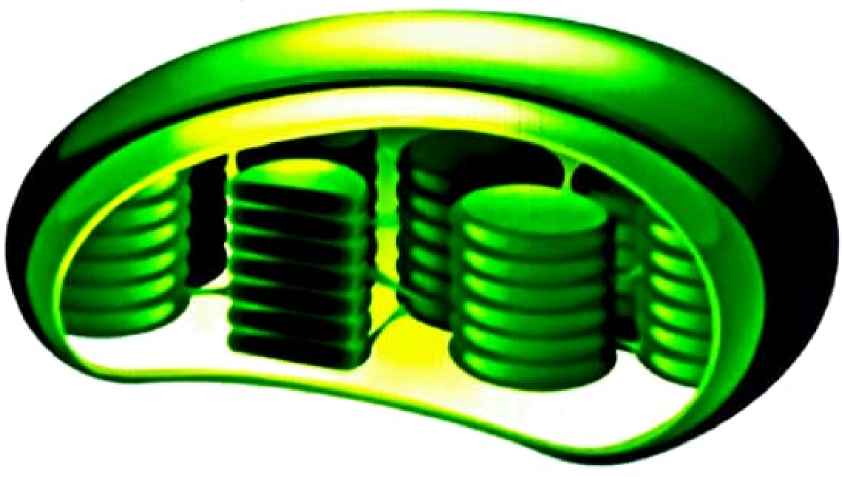
Amides :

- Amides are formed by the **replacement of hydroxyl ions of the amino** acid by NH_2^{1-} radical
- **Asparagine and glutamine** are the two major amides found in plants; they are formed by aspartic acid and glutamic acid in the presence of enzymes asparaginase synthetase and glutamine synthetase respectively
- **Amides have more nitrogen than amino acids**

PHOTOSYNTHESIS

Contents to be covered in this topic

- AUTOTROPHIC NUTRITION
- SITE OF PHOTOSYNTHESIS
- PIGMENTS INVOLVED IN PHOTOSYNTHESIS
- PHOTOSYSTEMS
- MECHANISM OF PHOTOSYNTHESIS



❑ AUTOTROPHIC NUTRITION

- It is a type of nutrition in which the **living organisms manufacture their own organic food** from simple inorganic raw materials.
- The green plants exhibit autotrophic mode of nutrition and hence called the autotrophs.
- The autotrophs **require external energy source** for the manufacture of organic substances.
- **Green plants obtain energy** from sunlight and therefore are called **photoautotrophs.**
- The process of synthesizing food in plant in the presence of sunlight is called **photosynthesis.**

➤ Photosynthesis

✓ Definition

Photosynthesis is 'a **physico-chemical process** by which **green plants use light energy to synthesize organic compounds**'.

Importance of Photosynthesis is due to mainly two reasons:

(i) It is the primary source of food for all living organisms.

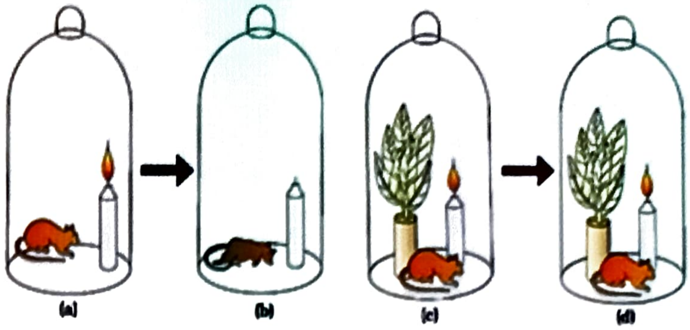
(ii) It is the only process responsible for the release of oxygen into the atmosphere by green plants

➤ Early Experiments to Show Important Factors for Growth and Photosynthesis of Plants

Joseph Priestley –

- In 1770 performed a series of experiments that revealed the essential role of air in the growth of green plants.
- Priestley observed that a candle burning in a closed space – a bell jar, soon gets extinguished .
- Similarly, a mouse would soon suffocate in a closed space. He concluded that a burning candle or an animal that breathe the air, both somehow, damage the air
- But when he placed a mint plant in the same bell jar, he found that the mouse stayed alive and the candle continued to burn.

- Priestley hypothesised as follows: **Plants restore to the air whatever breathing animals and burning candles remove**



Jan Ingenhousz (1730-1799) -

- By placing it once in the dark and once in the sunlight, showed that sunlight is essential to the plant process that somehow purifies the air fouled by burning candles or breathing animals.
- Small bubbles were formed around the green parts while in the dark they did not. Later he identified these bubbles to be of oxygen. Hence he showed that it is only the green part of the plants that could release oxygen.

Julius von Sachs –

- Provided evidence for **production of glucose** when plants grow. Glucose is usually stored as starch.
- He found that the green parts in plants is where glucose is made, and that the glucose is usually stored as starch.

T.W Engelmann (1843 – 1909) -

- Using a prism he split light into its spectral components and then illuminated a green alga, Cladophora, placed in a suspension of aerobic bacteria.
- The bacteria were used to detect the sites of O_2 evolution.
- He observed that the bacteria accumulated mainly in the region of blue and red light of the split spectrum
- A first action spectrum of photosynthesis was thus described. It resembles roughly the absorption spectra of chlorophyll a and b
- **The empirical equation representing the total process of photosynthesis for oxygen evolving organisms was then understood as:**

$$CO_2 + H_2O \xrightarrow{\text{Light}} CH_2O + O_2$$

Where $[CH_2O]$ represented a carbohydrate (e.g., glucose, a six-carbon sugar)

Cornelius van Niel (1897-1985) -

- Based on his studies of **purple and green bacteria**, demonstrated that photosynthesis is essentially a light-dependent reaction in which hydrogen from a suitable oxidizable compound reduces **carbon dioxide to carbohydrates.**

This can be expressed by:

$$2H_2A + CO_2 \xrightarrow{Light} 2A + CH_2O + H_2O$$

- In green plants H_2O is the hydrogen donor and is oxidised to O_2
- O_2 evolved by the green plant comes from H2O, not from carbon dioxide. This was later proved by using radioisotopic techniques

$$6CO_2 + 12H_2O \xrightarrow{Light} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Where **$C_6H_{12}O_6$ represents glucose**. The O_2 released is from water; this was proved using radio isotope techniques

SITE OF PHOTOSYNTHESIS

- Photosynthesis does **take place in the green leaves** of plants but it does so also in other green parts of the plants.
- Mesophyll cells in the leaves, have a **large number of chloroplasts.** Usually the chloroplasts align themselves along the walls of the mesophyll cells, such that they get the optimum quantity of the incident light.
- Within the chloroplast there is membranous system consisting of **grana, the stroma lamellae, and the matrix stroma**
- The membrane system is responsible for **trapping the light energy and also for the synthesis of ATP and NADPH.**
- In stroma, enzymatic reactions synthesise sugar, which in turn forms starch.
- Since they are directly light driven are called **light reactions (photochemical reactions).** The latter are not directly light driven but are dependent on the products of light reactions (ATP and NADPH). Hence, to distinguish the latter they are called, by convention, as **dark reactions (carbon reactions).**

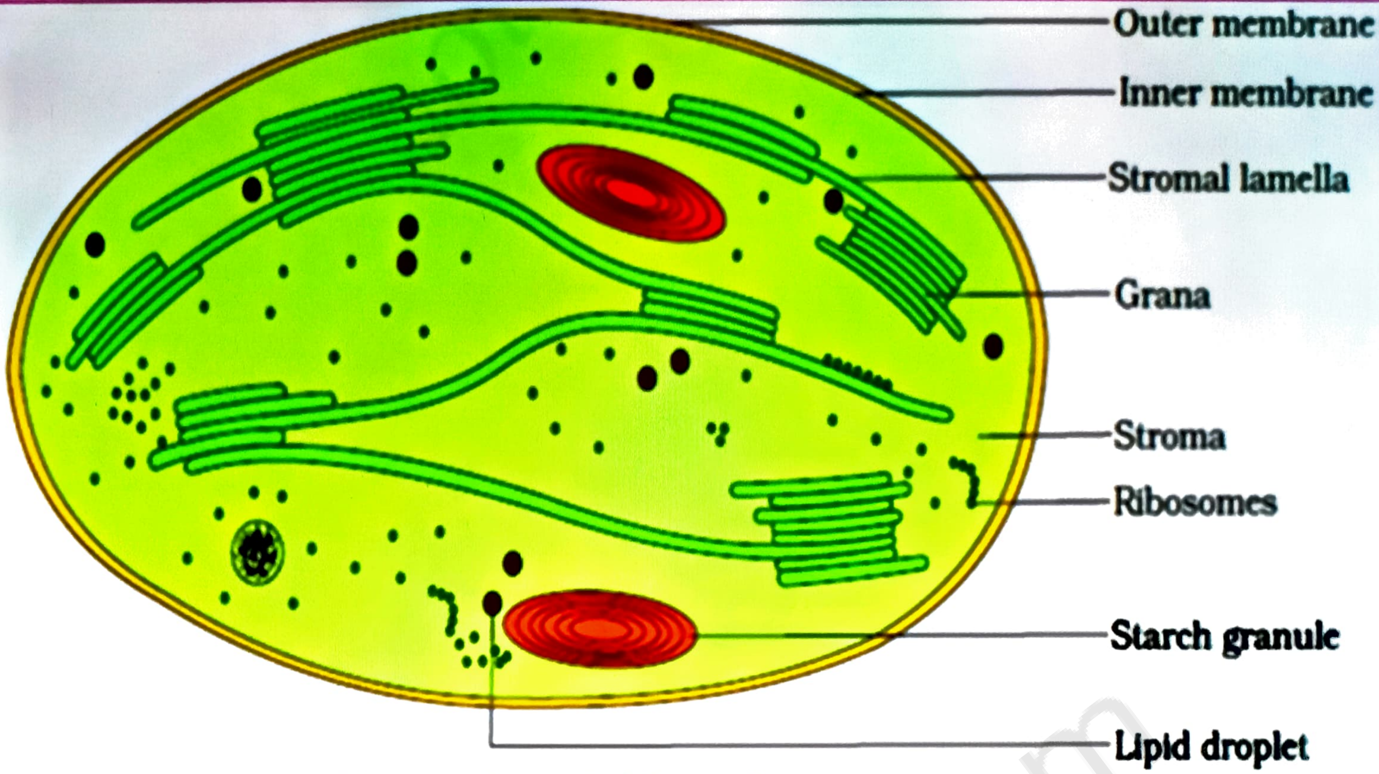


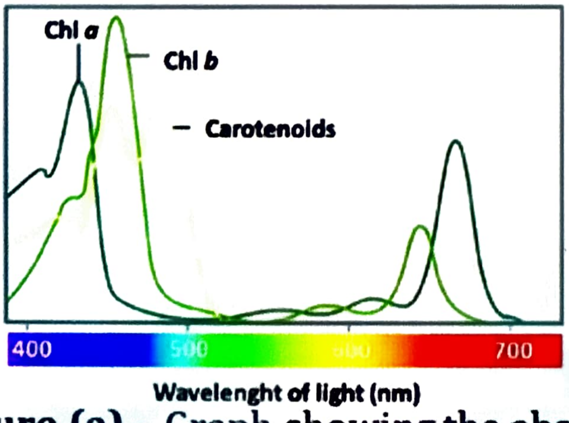
Fig. section of chloroplast

❑ PIGMENTS INVOLVED IN PHOTOSYNTHESIS

- A chromatographic separation of the leaf pigments shows that the colour that we see in leaves is not due to a single pigment but due to four pigments: **Chlorophyll a (bright or blue green in the chromatogram), chlorophyll b (yellow green), xanthophylls (yellow) and carotenoids (yellow to yellow-orange).**

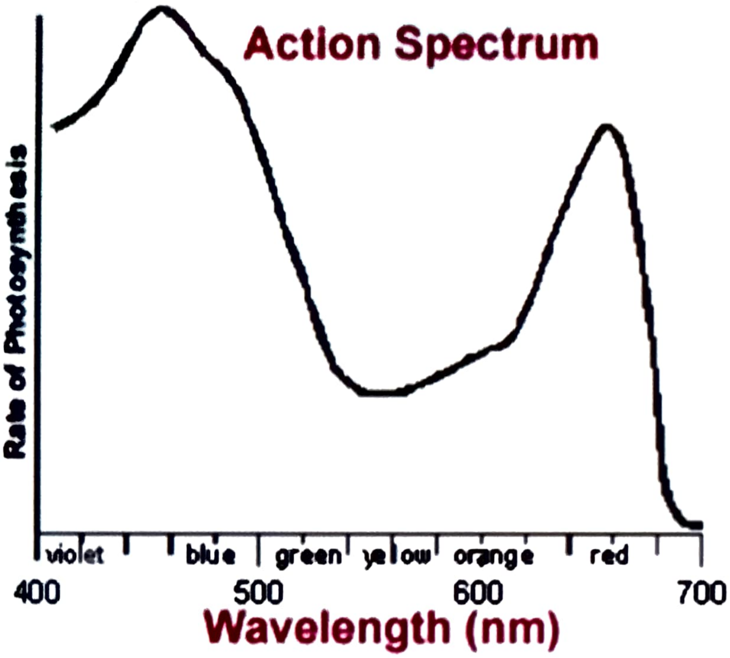
Roles various pigments play in photosynthesis-

- Pigments are substances that have an ability to absorb light, at specific wavelengths
- The graph showing the ability of chlorophyll a pigment to absorb lights of different wavelengths



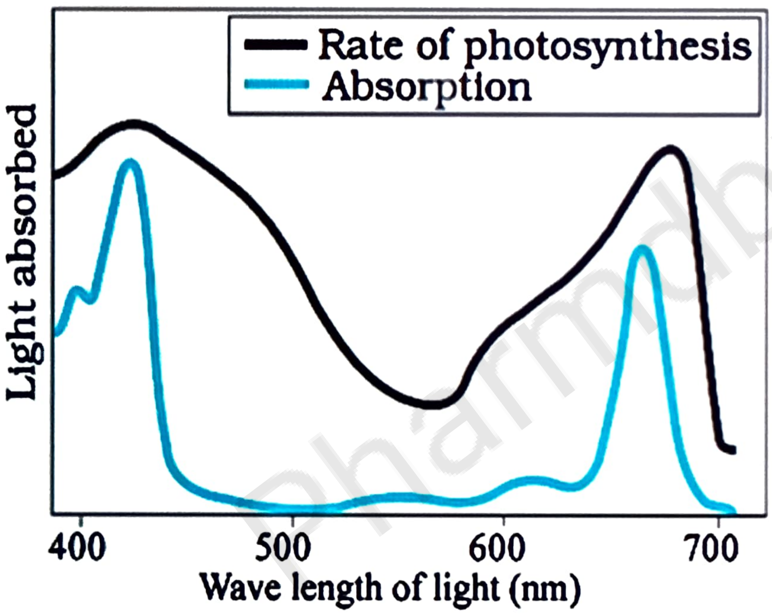
Determine the wavelength (colour of light) at which chlorophyll a shows the maximum absorption

Figure (a) - Graph showing the absorption spectrum of chlorophyll a, b and the carotenoids



Wavelengths at which **maximum photosynthesis occurs** in a plant. wavelengths at which there is maximum absorption by chlorophyll a, i.e., in the blue and the red regions,

Fig. Graph showing action spectrum of photosynthesis



A complete one-to-one overlap between the absorption spectrum of chlorophyll a and the action spectrum of photosynthesis

Fig. Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyll a

❑ PHOTOSYSTEMS

- A light reaction. The pigments are organized in the thylakoid membranes into two discrete photosystems: **photosystem I (PSI) and photosystem II (PSI)**
- Each photosystem has one specific **chlorophyll a** and many other pigments bound by proteins

- The chlorophyll a **forms the reaction centre**, where the actual reactions take place while the other pigment molecules form the light harvesting complex (LHC), also called as antennae.
- In PS I the reaction centre is **P_{700}**, which is a chlorophyll a molecule that absorb light 700 nm.
- In PS II, the reaction centre is P_{680} a chlorophyll a molecule that absorbs light at 680 nm.

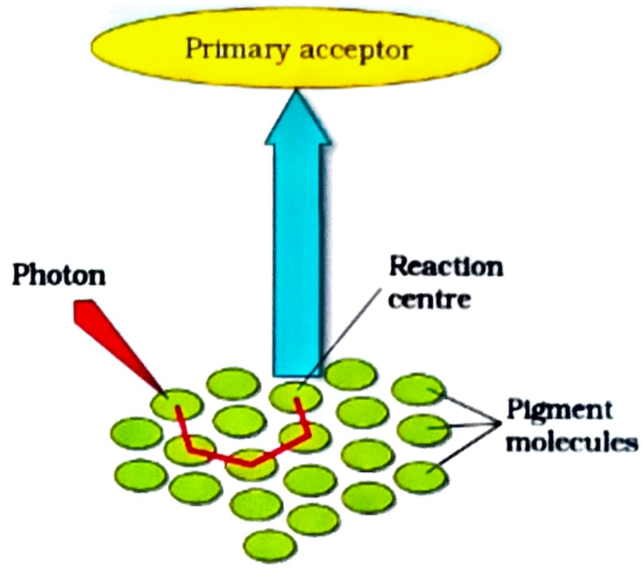


Fig. The light harvesting complex

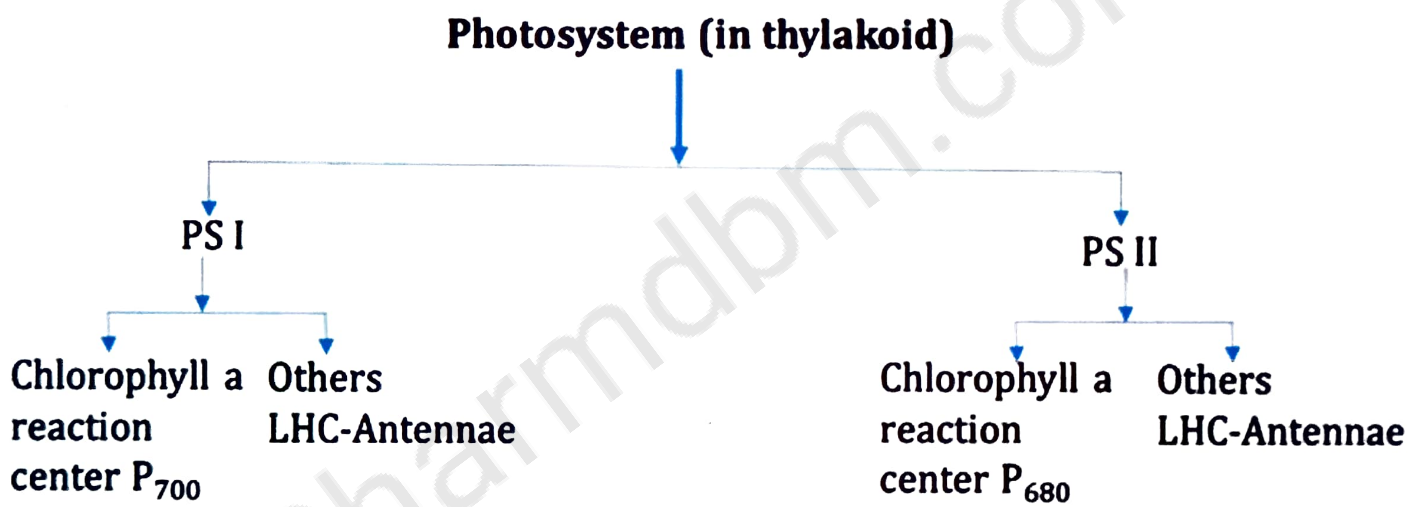


Fig. Photosynthesis

❑ MECHANISM OF PHOTOSYNTHESIS

The process of photosynthesis consists of two stages:

(1) Light reaction (Taking place in grana)

(2) Dark reaction (Taking place in stroma of chloroplast)

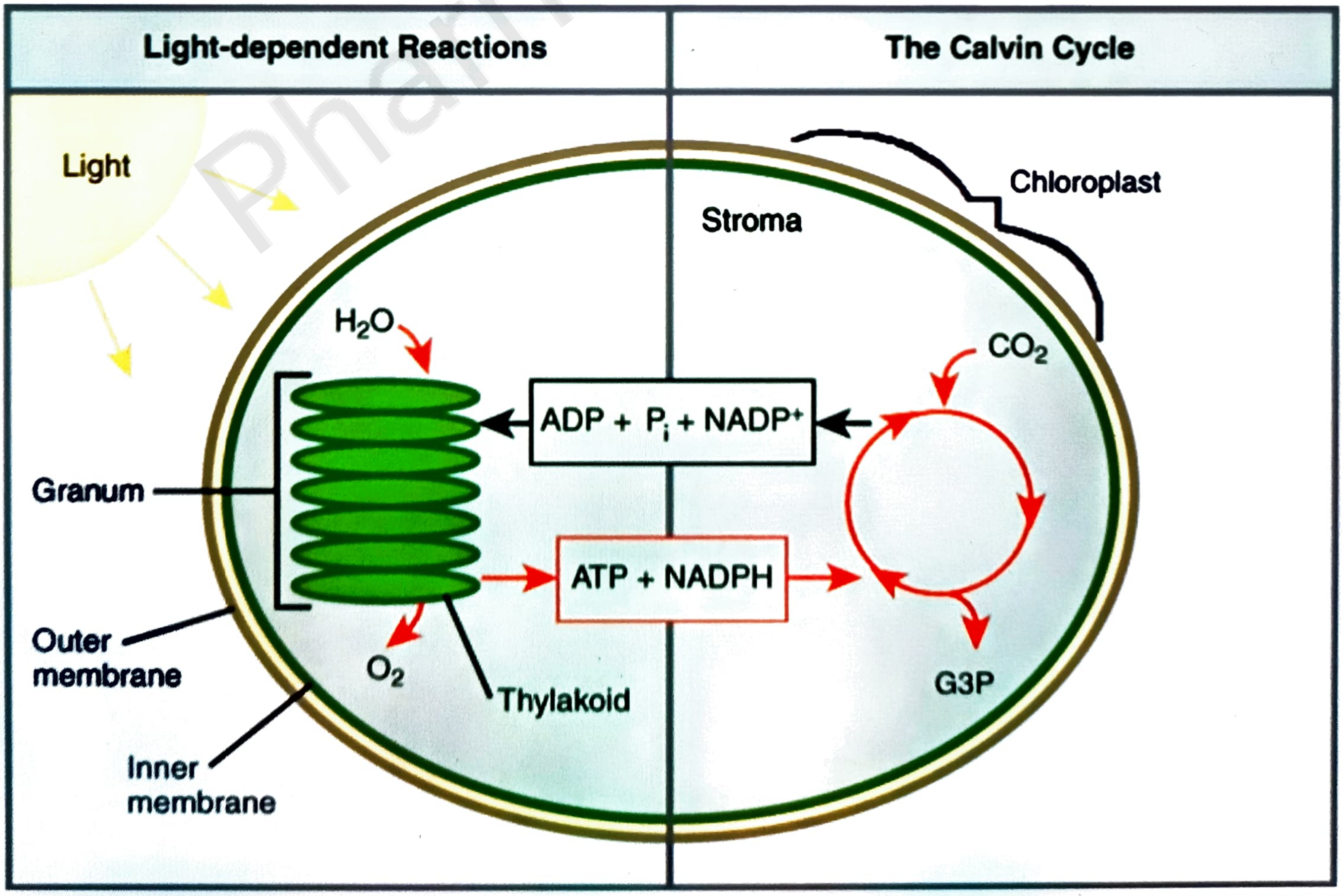
(1) Light Reaction: As the name indicates, it takes place in the **presence of sunlight.** Various pigments as mentioned earlier get involved in the process along with carriers like **ferredoxin, plastocyanin, cytochromes** and others. During this reaction chlorophyll-a absorbs solar energy and gets excited and as a result of which an energy rich electron is tossed from chlorophyll-a.

While passing through the cyclic as well as non-cyclic paths energy is stepped down for the formation of ATP and electron gets back to its normal level. The formation of ATP in the presence of sunlight is known as photophosphorylation. While **photolysis of water** is its splitting into H and OH- ions in the presence of light. This is non-cyclic electron transfer. During the process, **electrons from the excited chlorophyll-a do not return to chlorophyll-a**, but, are transferred to ferredoxin and then converted to NADP that gets ionized. H^+ ion liberated gets combined with NADP to form $NADPH_2$. The OH gives electron to chlorophyll-a and forms water and oxygen. The electron obtained from OH^- produces adenosine triphosphate (ATP).

(2) Dark Reaction (Calvin-cycle):

This reaction takes place in the **absence of light** and hence is called dark reaction. It takes place in stroma of the chloroplast. As the reaction gets carried in the absence of light it is not a photochemical but it is an **enzymic process.**

Dark reaction consists of fixing the carbon-dioxide to form the carbohydrate with the help of Adenosine-tri-phosphate (ATP) and Nicotinamide adenine dinucleotide diphosphate (NADPH) formed in the light reaction earlier.



The mechanism of this reaction was studied by a scientist **Malvin Calvin** in 1953 and hence named as Calvin Cycle. The details of Calvin cycle are as under: Most of the plants follow **Calvin cycle of C_3** pathway of fixing carbon-dioxide to carbohydrates. But certain plants of tropical area follow another pathway, which fix up carbon-dioxide even of lower concentration and is explained by Hatch and Slack pathway also known as C_4 pathway since the first intermediate product is C_4 acid.