Photosynthesis

How do plants harness light energy in photosynthesis?

What is photosynthesis?

Defination: Derived from photo- light synthesis – manufacture

- Is a process that nourishes almost all life in the biosphere by providing organic compound to eat and oxygen to breath**.**
- Is process of transducing light energy into chemical energy of organic molecules**.**
- Is process of converting inorganic molecules (water and carbodioxide) into range of organic molecule.
- Is process by which green plants, chlorophyll pigment, that absorbs light energy to transform into chemical energy stored in glucose.

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2 + Energy$$

List and explain phase of photosynthesis

Light dependent stage	**Light Independent stage**
Based on light energy for phosphorylation and photolysis of water.	Based on product of light energy ,not need light
Takes place in thylakoid(grana) membrane of chloroplast	Takes place in fluid stroma of chloroplast

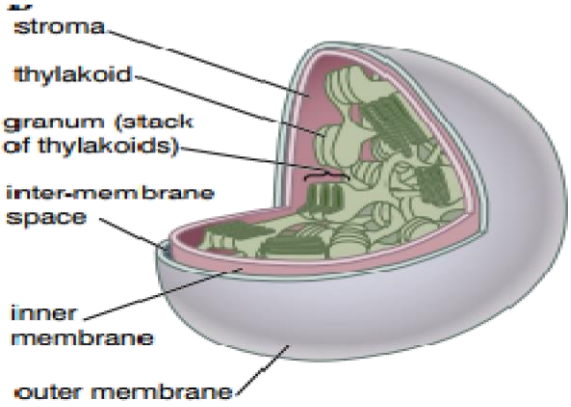
How structure of chloroplast suited to its function?

Is adapted for photosynthesis due to:-

- Presence of chlorophyll and photosensitive pigment arranged in photosystem that linked with ETC.
- Each photosystem and ETC is fixed in thylakoid membrane.
- Is disc-shaped with large surface area volume ratio to absorb more light. Has fluid –filled stroma that contains enzymes.

Structure of Chloroplast

Label each structure of chloroplast indicated below.



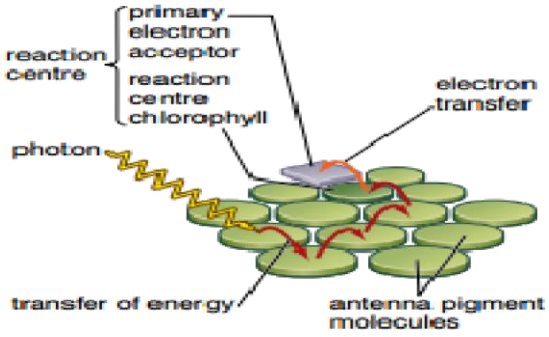
Photosystem

- Is a biochemical mechanism by which chlorophyll absorbs light energy.
- Sensitive to different light wavelength PsI (7**00λ**) and PsII (**680 λ**) and linked to different ETC.
- Is a site where light reaction begun.

What is the structure of a photosystem?

- A photosystem is complex proteins (pigment emended) in thylakoid membrane.
- It consists a number of pigment molecules clustered around one chlorophyll molecule called **Reaction centre molecule (**positioned next to ETC).
- This cluster of pigment molecules is called an **Antenna complex**.
- **Antenna complex** is an array of protein and chlorophyll light harvesting molecule in thylakoid membrane.
- Energy absorbed by other molecules in the photosystem is transferred to the **reaction centre molecule**, where the light-dependent reactions begin.
- Different pigment in the **antenna complex** can absorb different wavelengths of light, making the whole system more efficient.
- The pigments in the antenna complex include chlorophyll **a,** chlorophyll **b** and Carotenoids.
- Where **chlorophyll a** is always reaction centre molecule.

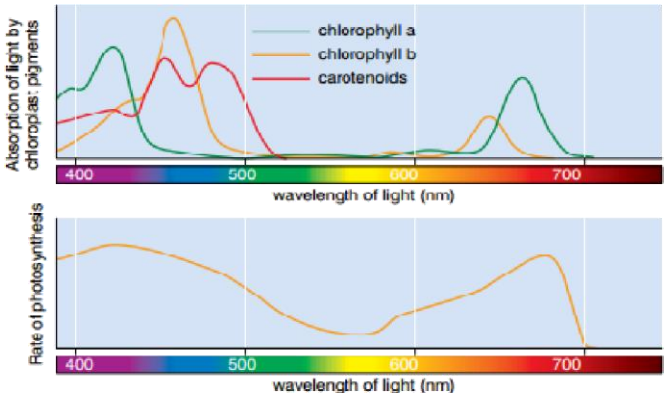
Structure of photosystem



Absorption spectrum to indicate which pigments absorbs what wavelength of light.

- Is measured by **spectrophotometer**.
- **Action spectrum** shows maximum peak at which photosynthetic electiveness at each wavelength.

Absorptive spectrum of chlorophyll a, chlorophyll b and Carotenoids.



Why plants appear green?

➢ Because they absorbs blue and red light wavelength, but reflects green light wavelength**.**

➢ There are two photosystem in light dependent reaction which have enormous pigments (**200-300**) associated with proteins and enzyme

Differentiate both types of photosystem

Photosystem I(PsI)	PhotosytemII(PsII)
Located at outer surface of thylakoid membrane	Located at inner surface of thylakoid membrane
Has 700 λ absorptive wavelength	Has 680 λ absorptive wavelength
Involved both cyclical and non-cyclical phosphorylation	Only involved in non-cyclical phosphorylation
Not associated with photolysis of water	Associated with photolysis of water

What happens in the light-dependent reactions?

- Light-dependent reactions use energy from light (photon) to drive synthesis of two molecules that drive the light independent reactions.

These reactions are:-

1. photolysis of water (light dependent spiliting of water

$$\mathbf{2H_2O \rightarrow O_2 + 4H^+ + 4e^-}$$

2. Phosphorylation reaction to synthesis ATP that provides the energy for er reactions, and

3. Produces reduced NADP which is similarly used to transporting hydrogen ions as NAD in respiration. It provides the hydrogen ions for later reduction reaction.

The following major reactions take place inside PsI and PsII respectively

1. Electrons in photosystem **II** are excited by the energy in photons and become more energetic as extra energy.

- They escape from the chlorophyll and pass to **primary electron acceptor**.

2. Energy from sunlight split water molecule in chloroplast, **photolysis**.

$2H2O \rightarrow O2 + 4H^+ + 4e^-$,

- Where electrons replace those lost from the chlorophyll molecule.

3. Primary electron acceptor passes electrons to the next first **ETC_1** (plastoquinone or '**Pq**'), Cytochrome and to last carrier plastocyanin (**Pc**) respectively.

- Electrons lose energy as they are pass from one carrier to the next, this empower the pump from outer stroma to inner thylakoid membrane.

4. In the cytochrome complex of ETC there is a proton pump between stroma and inner thylakoid.

- This creates protons accumulation inside the thylakoid, which drives the chemiosmotic synthesis of ATP.

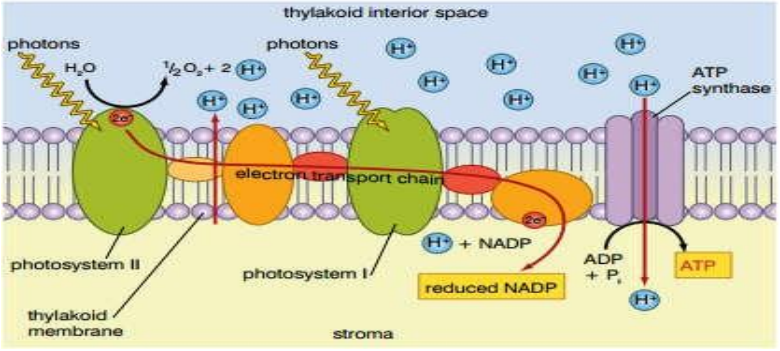
5. Electrons in photosystem **I** excited as absorbs photons and escape from chlorophyll molecule. They are replaced by the electrons that have passed down ETC from photosystem **II**.

6. Electrons then pass along a second ETC_2 involving ferredoxin (**Fd)** and NADP reductases.

- Finally, electron reacts with protons and NADP in the stroma of the chloroplast to form reduced NADP.

Photosynthetic unit-

- Is an arrangement of pigment molecule, electron carrier molecules and ATP synthase capable of carrying out all reactions in the light-dependent stage of photosynthesis.
- Arrangement of all molecules to carryout light dependent reaction of photosynthesis. ***How photosynthetic unit arranged in thylakoid membrane***



Phosphorylation

There are two types phosphorylation in light dependent reaction.

These are **cyclical** and **Non-cyclical** phosphorylation.

Both process produces ATP because of:-

- There is an accumulation of protons in the interior of a thylakoid membrane.
  - This creates a concentration gradient between the thylakoid and the stroma of the chloroplast
  - Protons move through ATP synthase causing the rotor to spin for phosphorylation.

Non-cyclical phosphorylation

- Said non-cyclical as electron travel in non-cyclical manner.
- Involves one way of electron flow from water to NADP.
- First electron donor is water and final electron acceptor is NADP
- It end with net product of ATP,NADP and Oxygen
- Involves both PsII and PsI

Cyclical phosphorylation E.g. Bacteria

- Said cyclical as electron travel cyclical manner(Back-back)
- Is simple and rare process of phosphorylation.
- Involves only PsI
- Initial donor and final electron acceptor is chlorophyll molecule.
- The net product is only ATP molecules.

Plants rarely synthesis ATP by cyclical phosphorylation when:-

- No oxygen and reduced NADP availability.
- Sugar cannot synthesize as lack of carbodioxide.

Brief summary of the light-dependent reactions

Light energy is used to excite electrons. This cause: -

- Protons transfer to inside of the thylakoid membrane as they pass along ETC that leads to ATP synthesis.
- React with hydrogen ions and NADP at the end of the second ETC to form reduced NADP.
- Generally, ATP and reduced NADP are used to drive the synthesis of carbohydrates in the light-independent reactions of photosynthesis

Briefly compare and contrast photosynthesis and Respiration

Respiration	***Photosynthesis***
Is catabolic process Uses sugar as raw material and produces CO_2 and H_2O	Is anabolic process Uses CO_2 and H_20 to produce sugar
Is an oxidative process All organism respire to releases energy	Is reductive process to produce sugar. Only photoautrophic organism
Requires NAD and FAD as proton transfer	Requires NADP as proton transfer
Takes place in mitochondria	Takes place in chloroplast

How is carbohydrate synthesized in the light-independent reactions?

- Light-independent reactions uses product of light dependent reaction, ATP and NADP, to reduce carbon dioxide. .
  - It doesnt require light but based on product of light dependent reaction.
  - It takes place in the stroma of the chloroplasts.
  - Is called Calvin cycle after the work of Melvin Calvin on unicellular algae, chlorella (refer).
  - Is also referred to carbon fixation and reduction reaction.

- Is a complex cycle catalyzed by different enzyme.

This reaction involves three consecutive steps.

Stages of Calvin cycle

a. Carbon fixation stage

 Is a beginning stage of Calvin cycle when carbon dioxide react with pre-existing five carbon molecule ribulose biphosphate (**RuBP**) in stroma of chloroplast. Form an immediate carbon six molecule Phosphoglyceric acid (PGA) Is catalyzed by **Rubisco** enzyme (RuBP carboxylase/oxygenase).

b. Reduction carbon dioxide

- Is when carbon dioxide reduced to produce two carbon three molecule glycerdehyde3-phosphte (**G3P**).

This stage uses energy from ATP and proton from reduced NADP of light reaction

- Some G3P goes to synthesis glucose and other organic molecules, where else goes to regenerate RuBP.

c. Regeneration of RuBP from G3P

- Two G3P molecules needed to produce one glucose molecule.
- Regenerate original RuBP

➢ Calvin cycle needs six turns to produce two G3P (**TP**, *Triose phosphate*) which is enough to make one glucose molecule.

➢ One turn of Calvin cycle needs 3ATP and 2 NADP to produce one glucose molecule.

What factors affect the rate of photosynthesis?

The rate of Photosynthesis is dependent on a many environmental factor. This includes: -

1. Light intensity

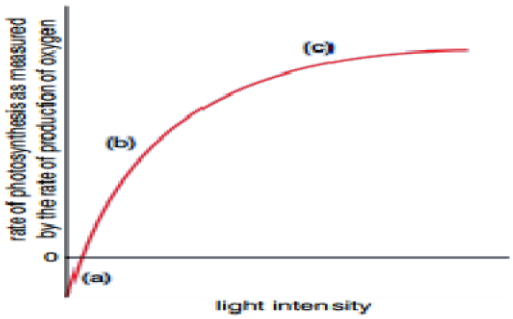
- It limits the rate of light dependent reaction directly by affecting number of electrons in reaction center molecule, **Photo-excitations**.

Explain how the effect of light on the following seasons where:

- On cold bright day (Arctic) – High light and low temperature.

- On warm cloudy day (summer) –Low light and high temperature
- On warm sunny day (summer)-Both light and temperature high

The rate of photosynthesis is limited by factor that is present in a limiting quantity (short supply), which is known as the **principle of limiting factors.**



The effect of light intensity on the rate of photosynthesis?

Based on the graph above:

a. Very low light intensities

Respiration is still occurring and is taking in oxygen faster than photosynthesis is producing it.

b. medium light intensities

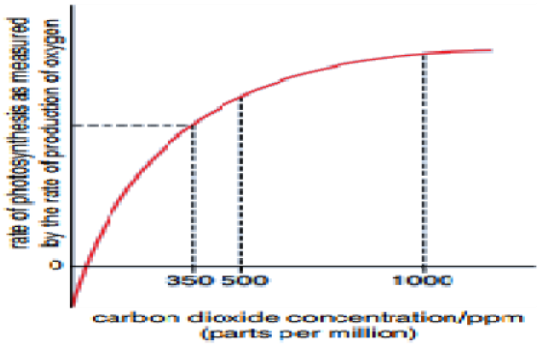
Photosynthesis is producing more oxygen than respiration uses, the rate of photosynthesis increases light intensity.

c. very high light intensities

The rate of photosynthesis is level out with light intensity; eventhoutgh other factor is probably limiting the rate.

2. **Carbon dioxide concentration**.

- It limits light independent reaction of photosynthesis by influencing initial reaction with RuBP.
- At low concentration of carbon dioxide little photosynthesis takes place, although respiration still uses oxygen. As [CO2] an increase so does rate of photosynthesis, until saturation of **Rubisco.**

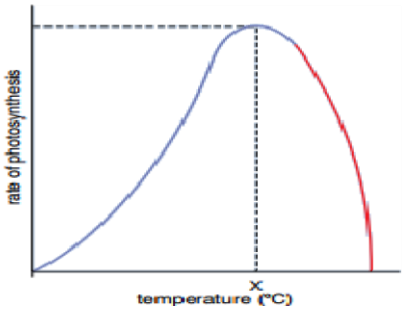


3. **Temperature**

- It limits the rate of both light dependent (ATP synthase) and independent (Rubisco) reaction of photosynthesis, as both reaction catalyzed by enzyme.
- But there is optimum temperature for photosynthesis enzyme which varies with geographical location.

Example:

- Enzymes of plants that live at arctic have lower optimum temperature than plants living in tropics.
- As temperature exceeds optimum, enzyme denatures and rate of photosynthesis decreases rapidly.



How all factors interact to influence the rate of photosynthesis?

Increasing the light intensity increase:-

- The rate at which electron exited from reaction center, photo – excitation
- The rate at which ATP and reduced NADP are produced in the light-dependent reactions.
- Increase the rate at which the Calvin cycle can take place.

However, the rate at which the Calvin cycle can 'turn' could be limited by:

- Low temperature (limiting the rate of Rubisco enzyme)
- Low carbon dioxide concentration, this limits the rate at which ATP AND NADP reused in light dependent reaction and the whole process limited, even though light intensity increases.

4. Wavelength of the light

- Rate of photosynthesis is faster in 'red' and 'blue' wavelengths than else, because these wavelengths are absorbed more efficiently than others. Leaves appear green as they reflects green wavelengths.

5. Amount of chlorophyll

- Rate of photosynthesis increases with chlorophyll concentration.

Explain the role of principle of limiting factor in commercial plant grower?

Are there any other ways of photosynthesis?

C3 photosynthesis and photorespiration

- This type of photosynthesis takes place in plants growing in temperate environments, like Europe.
- They are vast majority of land plants (85%). E.g. Tomatoes, Potatoes, Spinach, Cassava, Rice, Barley .etc.
- Said **C3** because the first compound formed in LI reaction of Calvin cycle contains carbon three atoms (2G3P).

RuBP + CO_2 (Rubisco**)** $\xrightarrow{\text{Rubisco}}$ **2G3P**

Leaves of C3 plants have the following major adaptation for photosynthesis:

- Have broad leaves to capture more light
- Palisade cell has chloroplast at upper surface of leaves to absorb more light.
- Their stomata are mainly at lower surface.
- To minimize water loss (has waxy cuticle)
- They open their stomata mainly at day time, to allow entry of CO_2 and close if water loss is great on hot day.

- Spongy mesophyll has air space.

That allows easy diffusion of CO_2 and O_2 between palisade and stomata.

Bundle sheath cell lacks chloroplast and CO_2 fixed ones

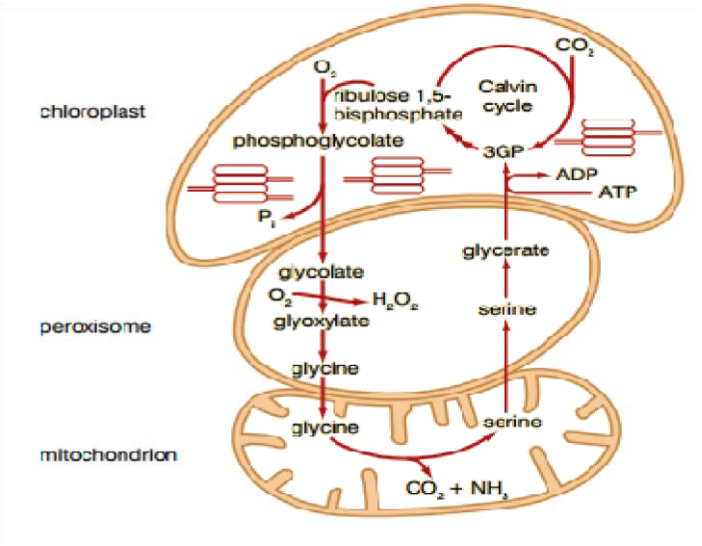
Photorespiration (C2 **photosynthesis**)

- It involves oxidation of carbon.
- Is catalyzed by Rubisc**o**/oxygenase (oxygenation) instead of carboxylase.
- In hot tropical conditions ,C3 plants do not yields enough carbon dioxide for photosynthesis ,this is because their stomata closed to prevent water loss that prevent entry of carbon dioxide . As a result, the concentration of carbon dioxide in the leaves falls.
- Rubisco behave in unusual way that RuBP binds with oxygen instead of carbon dioxide.
- Then RuBP is oxidized to one molecule of **GP** (not two) and one molecule of phosphoglycolate.

Ribulose biphosphate + oxygen $\xrightarrow{\text{Rubisco}}$ 1GP + 1phosphoglycolate

- Where 1GP formed in photorespiration re-enter the Calvin cycle and phosphoglycolate converted into GP for use in the Calvin cycle. These reactions (involves **chloroplas**t, **peroxisomes** and **a mitochondrion)** catalyzed by complex net work of enzymes**.**
- In addition, carbon dioxide is produced in the process.

The reactions of photorespiration



Photorespiration reduces efficiency of photosynthesis by **25%** than C3 plants .Because:

- Carbon is oxidized, which is the reverse of photosynthesis (reduction of carbon to carbohydrate).
- Ribulose biphosphate must be resynthesised and the phosphoglycolate removed.
- It also cost ATP and NADPH in the resynthesis of RuBP.

C4 photosynthesis

- This pathway gets round the problem of photorespiration that reduces efficiency of photosynthesis.
- Takes place in plants that grow in tropical and sub tropical enviroment like Ethiopia. Examples of C4 plants include; maize, crabgrass, sorghum and sugarcane.
- Named C4, because the first compound formed in the light independent reactions of photosynthesis contain carbon four (oxaloacetate), not GP that of C3 plants.
- The light-dependent reactions are the same as in the C3 plants, but differ in how glucose is synthesized in the light-independent reactions.

➢ The structure of the leaf of C4 is essentially similar to that of a C3 plant, but differ in that: Cells of the bundle sheath contain chloroplasts that C3 plants lacks.

- No thylakoid means that the light-dependent reactions cannot occur here and oxygen is not produced in these chloroplasts.
- This helps to prevent photorespiration and allows Calvin cycle to take place.

➢ The light-dependent reactions in C4 pathway take place in the mesophyll cells, which have chloroplasts with thylakoid.

The following reactions take place:

1. CO_2 reacts with a C3 compound called PEP (Phosphoenol pyruvate) to form the C4 compound **oxaloacetate** in mesophyll cell.

➢ Catalyzed by the enzyme PEP carboxylase (**Pepco**).

PEP + CO2 $\xrightarrow{\textbf{PEP carboxylase}}$ **Oxaloacetate**

2. Oxaloacetate is converted into another C4 compound (**malate** in bundle sheath cell. $\longrightarrow$

Oxaloacetate Malate

3. In the bundle sheath cell, malate is converted to pyruvate with the release of a molecule of CO_2 that starts Calvin cycle by binding with RuBP.

Malate $\xrightarrow{CO2}$ Pyruvate

4. The pyruvate is back converted to PEP that enters Calvin cycle to synthesis sugar; this reaction requires ATP.

- C4 cycle uses two more molecules of ATP to deliver a molecule of CO_2 to Rubisco than does the C3 cycle.
- This is not a problem in tropic, as the high light intensity that generates much ATP from the light dependent reactions.

- C4 photosynthesis is most efficient under the following conditions:
- Low carbon dioxide concentration High light intensity High temperature.
- Plants grow in Ethiopia are C4plants and well adapted to hot and bright days. So, produce high yield when compared to C3 plants.

- Why C4 plants experience low carbon dioxide concentration?

- This is not due to composition air in tropics is different from other regions.
- But, C4 plants (grass, maize ...etc) grow very close together and compete for CO_2 in the air reduces

Comparison of C3 and C4 plants

Features	**C3 Plants**	**C4Plants**
Bundle sheath cells	Lack chloroplasts	Have chloroplasts with no thylakoid
Enzyme used to fix CO_2	Rubisco	Pepco (PEP carboxylase)
Optimum temperature	15–25 oC	30–40 oC
optimum CO_2 concentration	700 ppm	400 ppm
Fixation of CO_2	Mesophyll cells	Mesophyll cells
Calvin cycle	Mesophyll cells	Bundle sheath cells

Crassulacean acid metabolism (**CAM photosynthesis)**

•This carbon fixation pathway experienced in s plants adapted to desert conditions.

Example: Succulent, xerophytes cacti.Agaphe...etc

•In this area their stomata closed during day time when temperature is high to reduce rate of evapotranspiration. So, if they don't open their stomata how they can obtain CO_2 needed for photosynthesis? They have temporal adaptation.

•By opening stomata at night for carbon fixation the mesophyll cells.

•They experiences the same set of reactions with C4 plants, but differ in carrying reactions at times (seasonal isolation).

1. At night plants opens their stomata to allow carbon fixation that reacts with PEP in mesophyll cell forming oxaloacetate and malate as C4plants.

PEP $\xrightarrow{CO_2}$ **Pepco Oxaloacetate** $\longrightarrow$ **Malate**

2. Malate stored in vacuole overnight.
3. During day, light dependent reaction generates **ATP** and **NADP**, so that Calvin cycle continues.
4. Malate released from vacuole and breakdown into glycerate, releasing CO_2 for Calvin cycle to produce sugar.

Malate $\xrightarrow{CO_2 + RuBP}$ **Glycerate**