Photosynthesis

Dr. B. K. Jain

M. G. Science Institute
Ahmedabad

What is Photosynthesis

- Photosynthesis is the process by which plants, some bacteria, and some protistans use the energy from sunlight to produce sugar, which cellular respiration converts into ATP, the "fuel" used by all living things. The conversion of unusable sunlight energy into usable chemical energy, is associated with the actions of the green pigment chlorophyll. Most of the time, the photosynthetic process uses water and releases the oxygen.
- We can write the overall reaction of this process as:

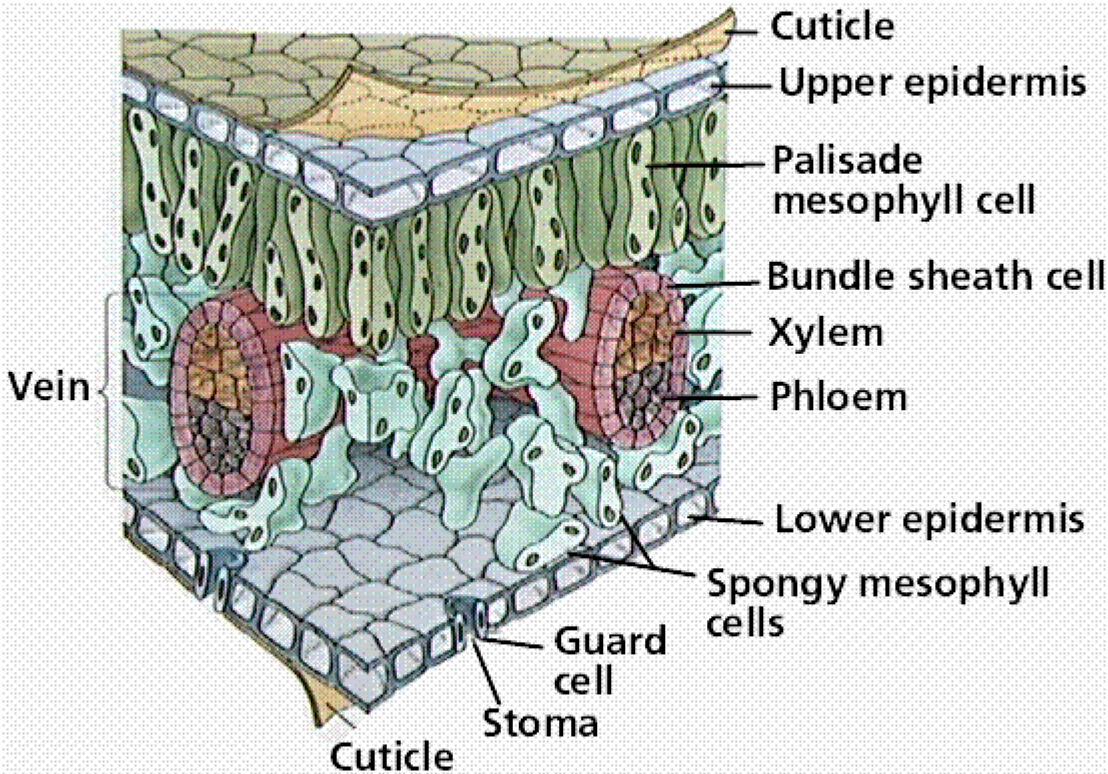
$$6H_2O + 6CO_2 \text{ ----------> } C_6H_{12}O_6 + 6O_2$$

Historical Accounts

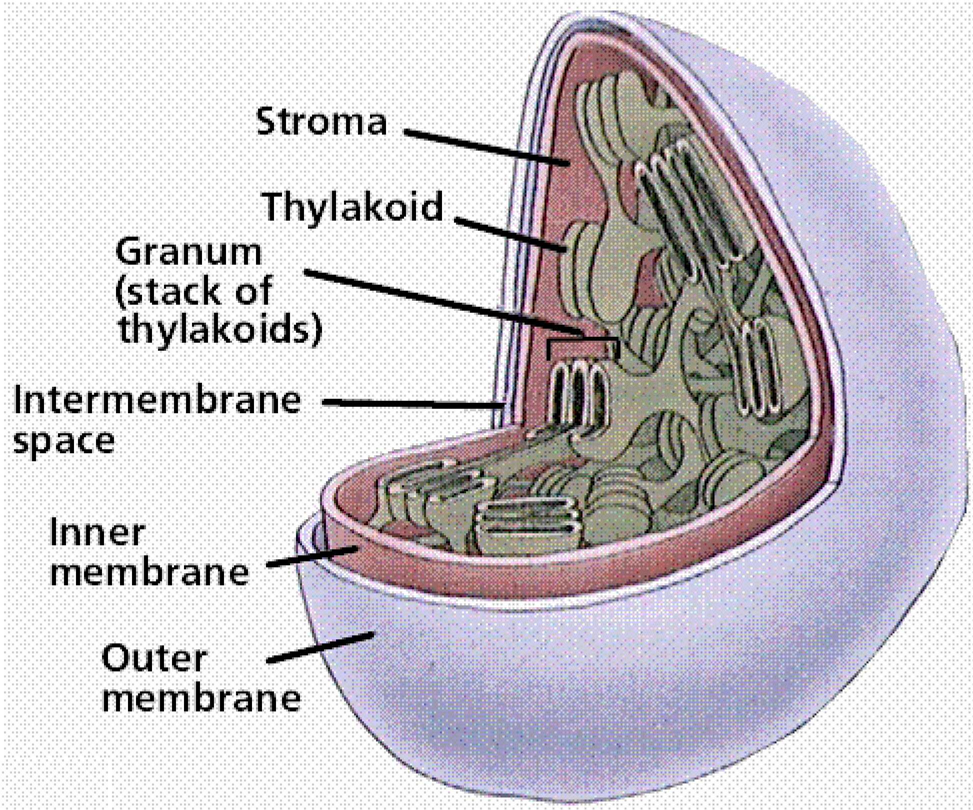
- Helmont : Demonstrated that for synthesis of the materials in their body plant obtain only water from the soil. Some salts are also absorbed in small amount.
- Priestley : Plant accepts CO_2 from the atmosphere and releases O_2 into the atmosphere.
- Ingenhouse : Only those organs of plants which possess chlorophyll release O_2 and that to only in presence of light.
- Hill : Showed that O_2 released into the atmoshere is from water

Site of Photosynthesis

- Anatomy of a Leaf:



Structure of Chloroplast



Ultrastructure of Chloroplast

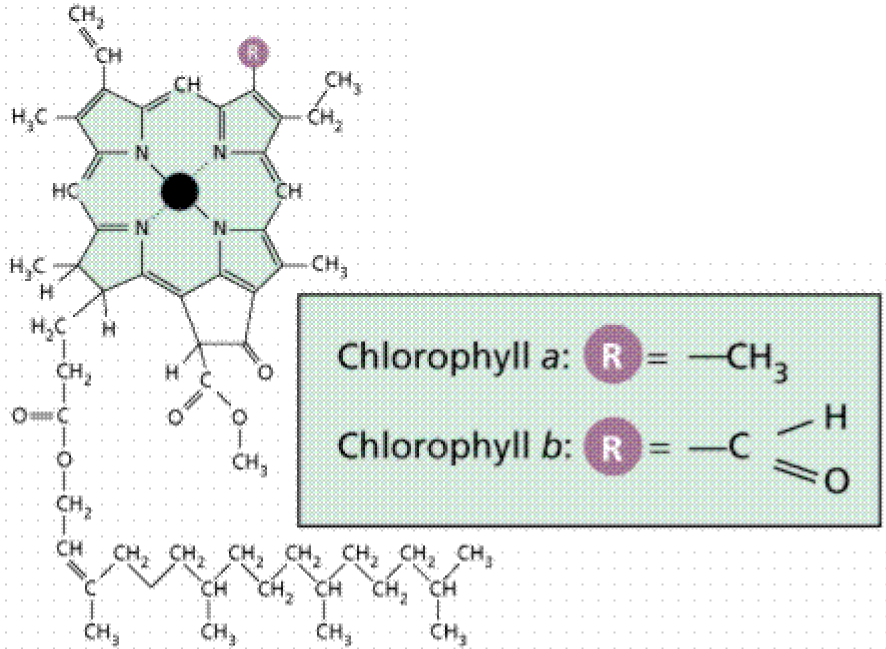
Each granum is made up of flat, lamellar structures called thylakoids which are arranged like stack-pile of coins.

Thylakoids contain chlorophyll pigments which are actually a mixture of four pigments viz. chlorophyll-a (blue-green in colour), chlorophyll-b (yellow-green in colour), catotene and xanthophyll (Yellow pigments).

These pigments are associated with absorption of light energy. They absorb specific wavelength of light and obtain energy from them. This energy is first converted into energy of electrons and later into chemical energy.

Chlorophyll – a molecules are the main reactants in this process. The other kinds of molecules direct and focus the energy absorbed by them towards chlorophyll –a molecules.

Molecular Structure of Chlorophyll



Pigment System

- Chlorophyll molecules at the reaction centre and other accessory pigment molecules together constitute pigment systems.
- Each pigment system is made up of around 250 to 400 molecules

Pigment system -I	Pigment system -II
Chlorophyll-a molecules are stimulated by the wavelength of 700 nm	Chlorophyll-a molecules are stimulated by the wavelength of 680nm
It is also called as PS –I or P_{700}	It is also called as PS –II or P_{680}

Mechanism of Photosynthesis

- Photosynthesis takes place in two Phases:
- The first phase is the Light Dependent Process (Light Reactions or Photochemical phase), requires the direct energy of light to make energy carrier molecules that are used in the second process.
- The Light Independent Process (or Dark Reactions or biosynthetic phase) occurs when the products of the Light Reaction are used to form C-C covalent bonds of carbohydrates. The Dark Reactions can usually occur in the dark, if the energy carriers from the light process are present.
- The Light Reactions occur in the grana and the Dark Reactions take place in the stroma of the chloroplasts.

A. Photochemical Phase or Light reaction

During this process two main events occur:

1. Photolysis of water 2. Photophosphorylation

Photolysis of Water:

Spliting of water molecule using energy of light is called photolysis of water.

$$4H_2O \text{ ----------- } 4\,H^+ + 4\,OH^-$$

During this process 4 molecules are simultaneous split in presence of Mn^{++}, Cl^- and Ca^{++} . Thus 4 H^+ and 4 OH^- are released .

$$4H_2O \text{ ----------- } 4\,H^+ + 4\,OH^-$$

$$\mathbf{4\,H^+ + 2NADP = 2NADP.2H^+}$$

$$\mathbf{4\,OH^- \text{ --------- } 4\,e^- + 2\,H_2O + O_2}$$

2. Photophosphorylation

- In chlroplast, this reaction occurs in two ways.
- During this process ADP is phosphorylated and ATP is formed.
- Thus light energy is transformed into chemical energy.
- Phosphorylation occurs in two ways : 1. Cyclic and 2. Non cyclic phosphorylation.

Cyclic Photophosphorylation

- The electrons released by P700 of PS-I in the presence of light are taken up by the primary acceptor and are then passed on to ferredoxin (Fd), plastoquinone (PQ), cytochrome complex, plastocyanin (PC) and finally back to P700 i.e., electrons come back to the same molecule after cyclic movement.

The cyclic photophosphorylation also results in the formation of ATP molecules just like in non - cyclic photo phosphorylation.

- As the electrons move downhill in the electron transport chain, they lose potential energy and ATP molecules are formed in the same way as in mitochondria during respiration.
- During cyclic photophosphorylation, electrons from photosystem - I are not passed to NADP from the electron acceptor. Instead the electrons are transferred back to P700. This downhill movement of electrons from an electron acceptor to P700 results in the formation of ATP and this is termed as cyclic photophosphorylation. It is very important to note that oxygen and NADPH2 are not formed during cycle photophosphorylation.
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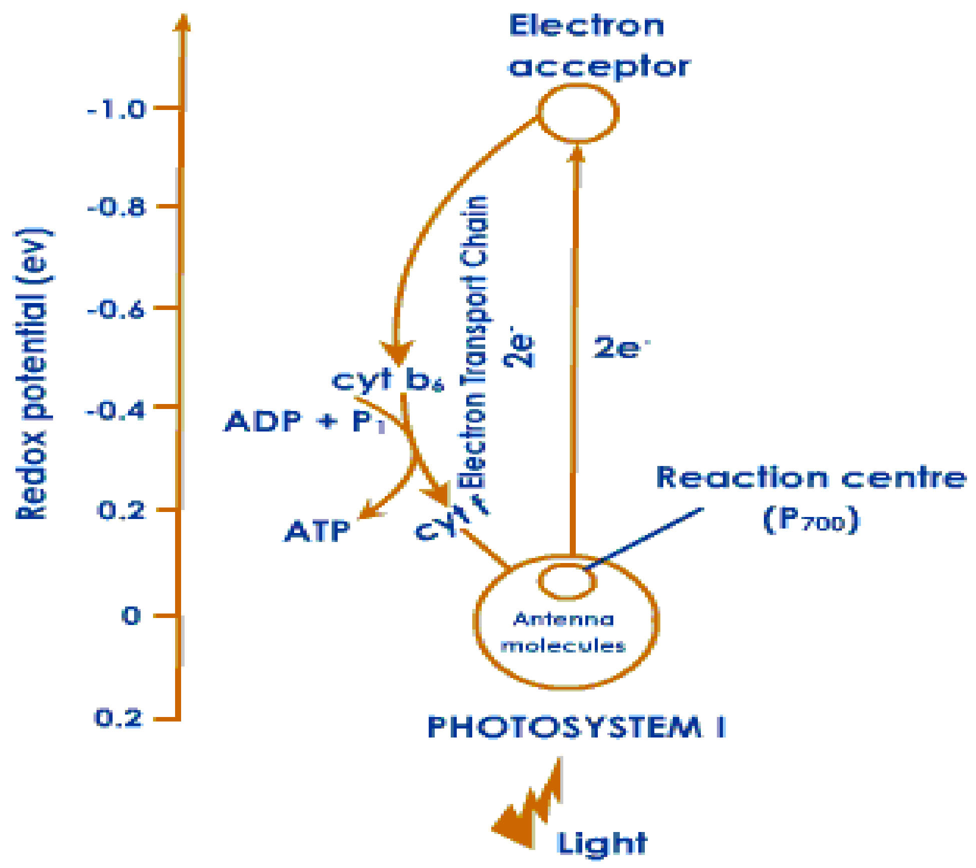
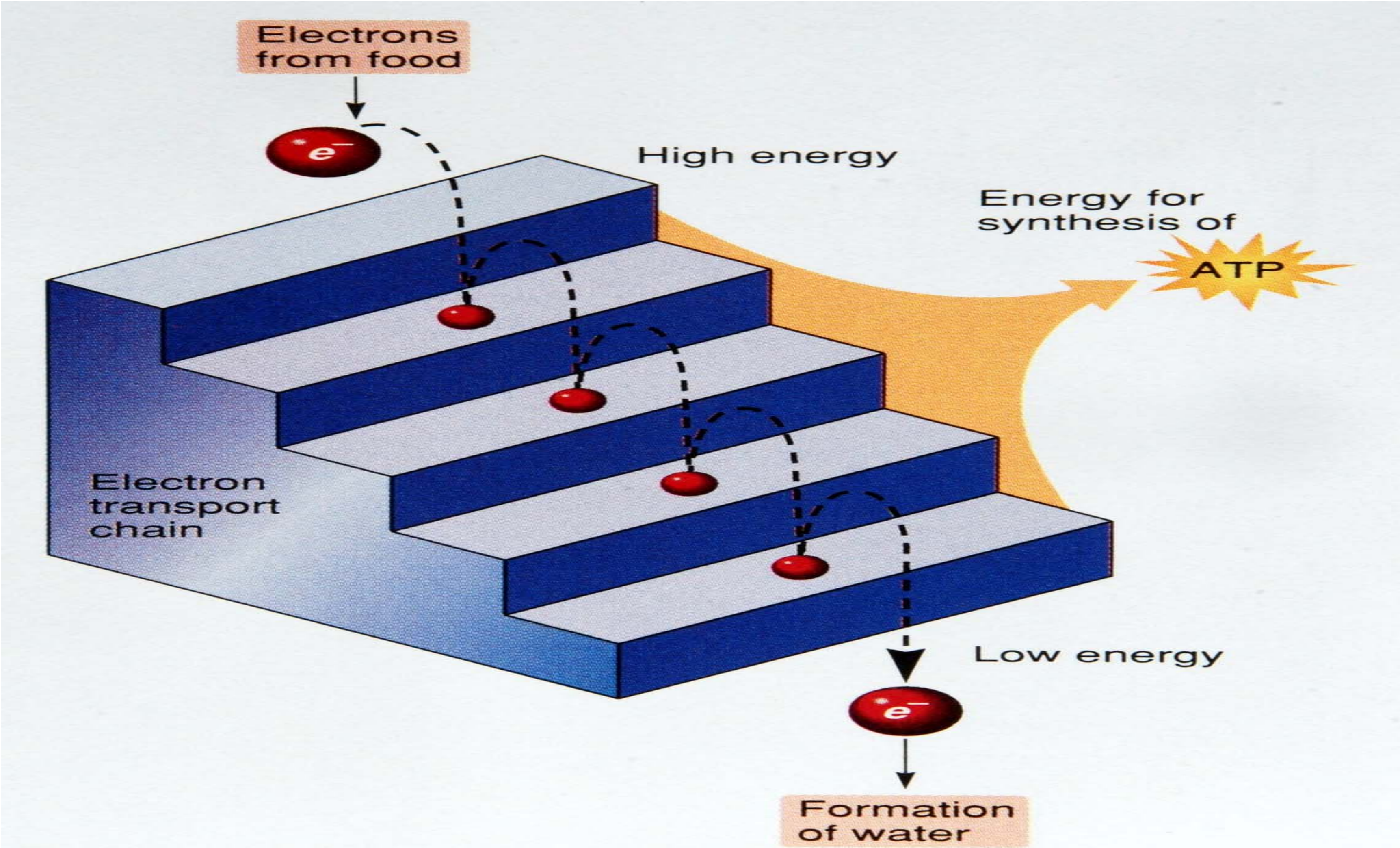
Cyclic Photophosphorylation





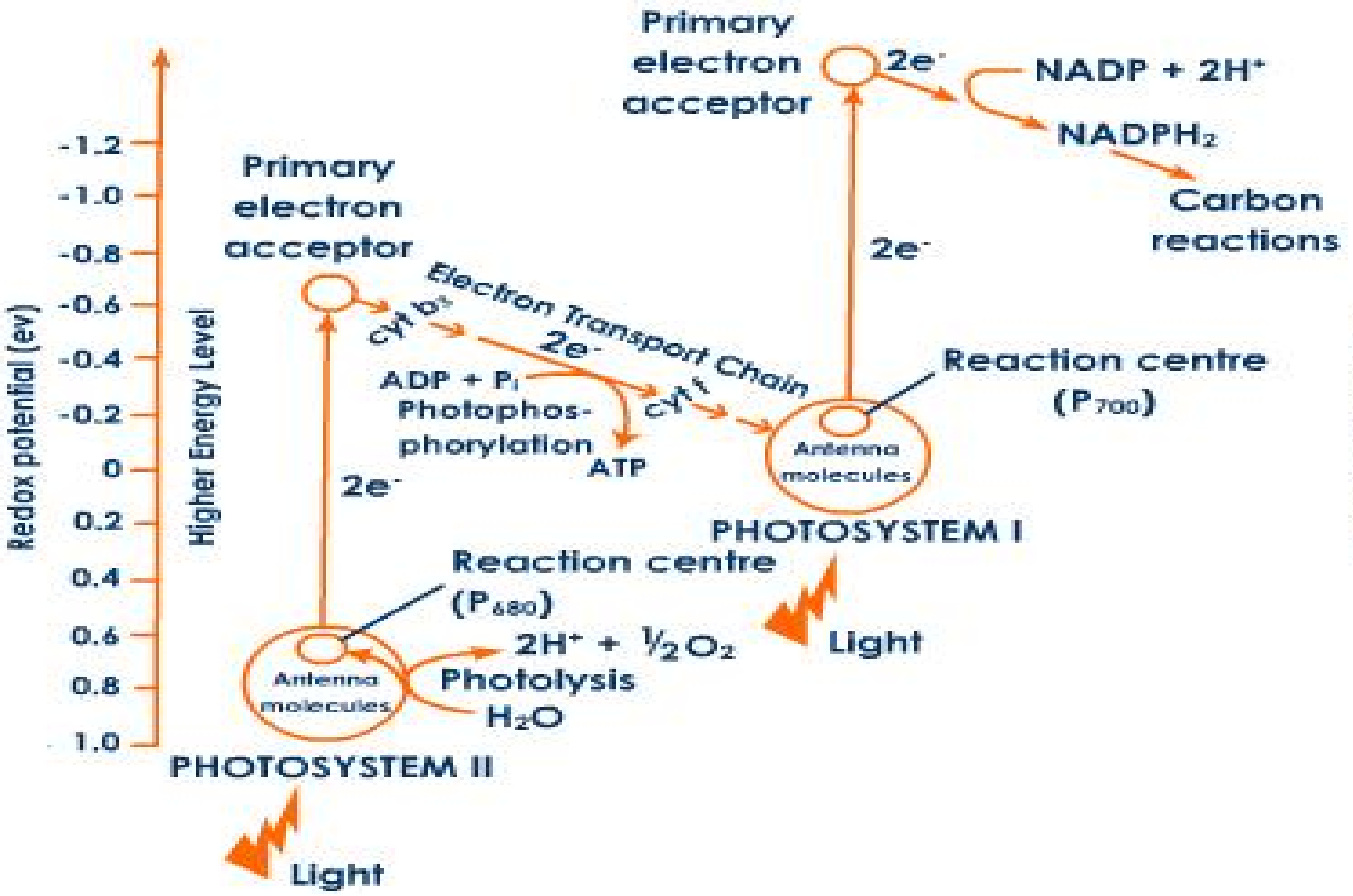
Electrons from food
e^-
High energy
Energy for synthesis of
ATP
Electron transport chain
Low energy
e^-
Formation of water

Non - Cyclic Photophosphorylation

- The electrons lost by P680 (PS-II) are taken up by P700 (PS-I) and do not get back to P680 i.e., unidirectional and hence it is called non- cyclic phosphorylation. The electrons pass through the primary acceptor, plastoquinone (PQ), cytochrome complex, plastocyanin (PC) and finally to P700.

- The electrons given out by P700 are taken up by primary acceptor and are ultimately passed on to NADP. The electrons combine with H^+ and reduce NADP to $NADPH_2$. The hydrogen ions also called protons are made available by splitting up of water. Non-cyclic photophosphorylation needs a constant supply of water molecules. The net result of non-cyclic phosphorylation is the formation of oxygen, NADPH and ATP molecules. Oxygen is produced as a waste product of photosynthesis.

Non Cyclic Photophosphorylation



Comparison of Non-cyclic PhotoPhosphorylation and Cyclic PhotoPhosphorylation

Non-cyclic photophosphorylation	Cyclic photophosphorylation
Electrons do not come back to the same molecule.	Electrons come back to the same molecule
First electron donor is water	First electron donor is P_{700} (PSI)
Involves both PSI & PSII	Involves PSI only
Last electron acceptor is NADP	Last electron acceptor is P_{700} (PSI)
The net products are ATP, NADPH and O_2	The product is ATP only

Dark Phase or Biosynthetic Phase

- **Atm. CO_2 + Ribulose-di-phosphate = 6-C unstable compound**

Carboxylation

- **6-C unstable compound--- 2 Mol. of Phosphoglyceric acid (3 C)**

(As the first stable product is 3 C Compond, it is known as C_3 pathway)

- **Phosphoglyceric acid + NADP H_2 + ATP = PGAL + NADP +ADP**

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Means :

6 CO_2 + 6 RUDP = 6 Mol. of unstable compound

6 Mol of Unstable compound give 12 Mol. of PGAL

Out of 12 PGAL, 10 PGAL are utilized in the reformation of 6 Mol of RuBP

Dark Phase or Biosynthetic Phase

- Out of the remaining 2 Mol. of PGAL

  1 Mol is converted in to DHAP

DHAP + PGAL = Fructose di phosphate (1 Mol.)

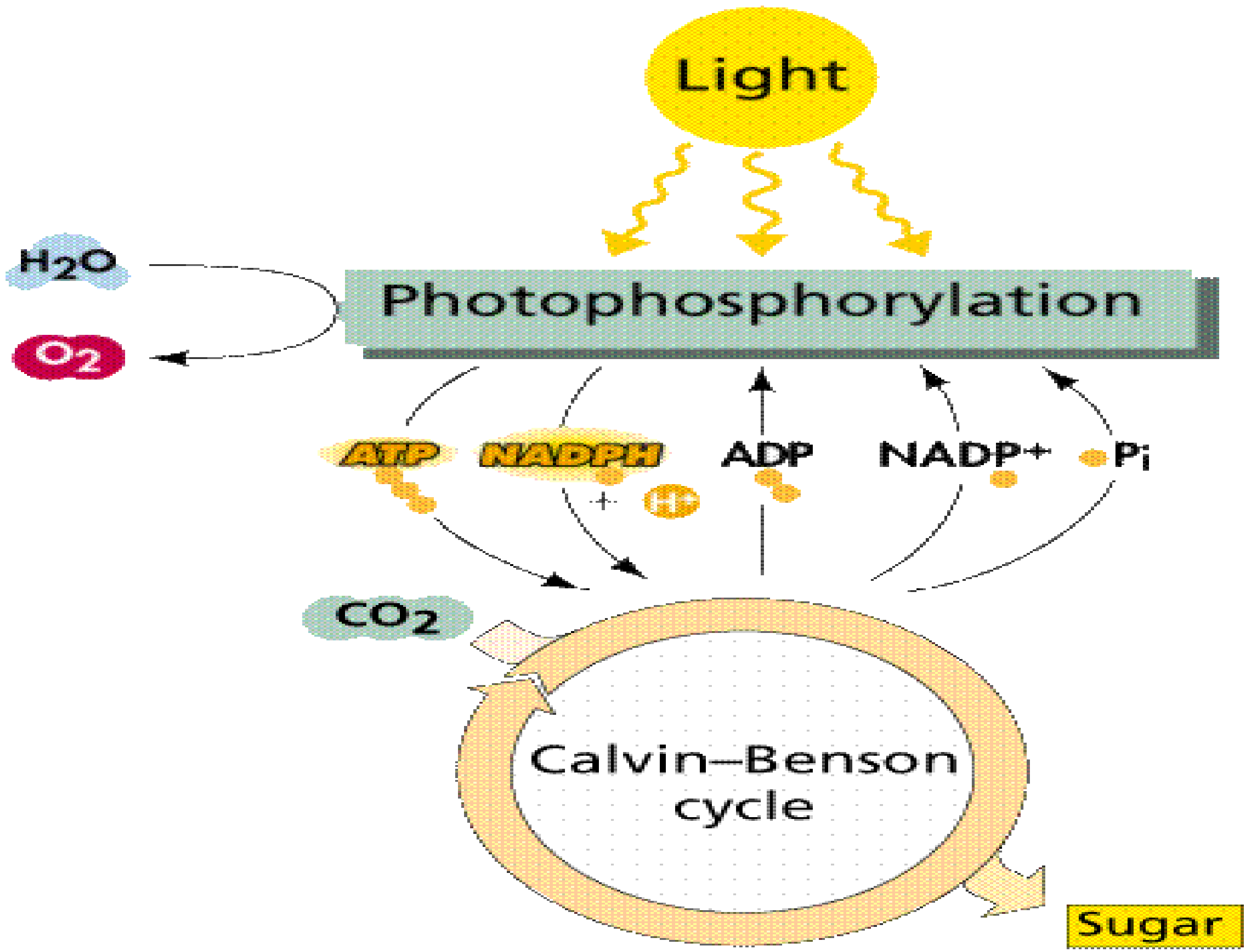
ADP--ATP

Fructose di phosphate------------------ Fructose phosphate

ADP--ATP

Fructose phosphate ------------------- Glucose

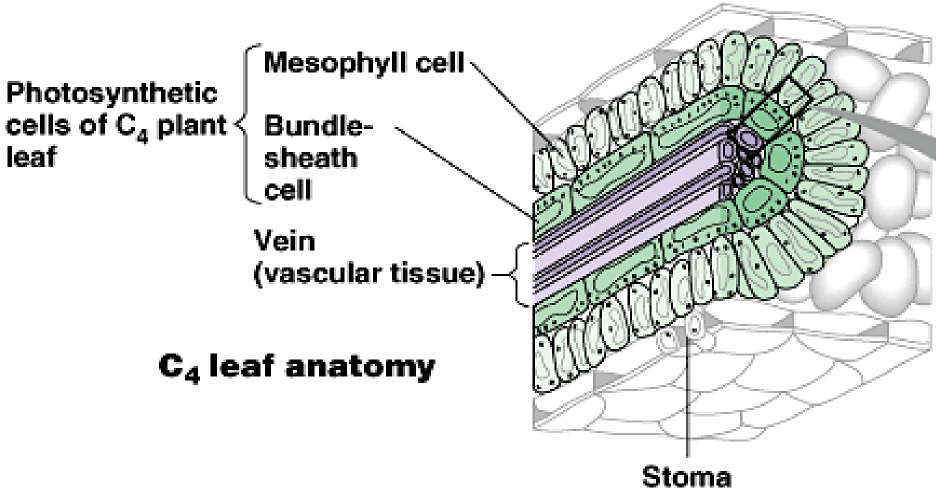
Overview of the two phases in the photosynthesis process



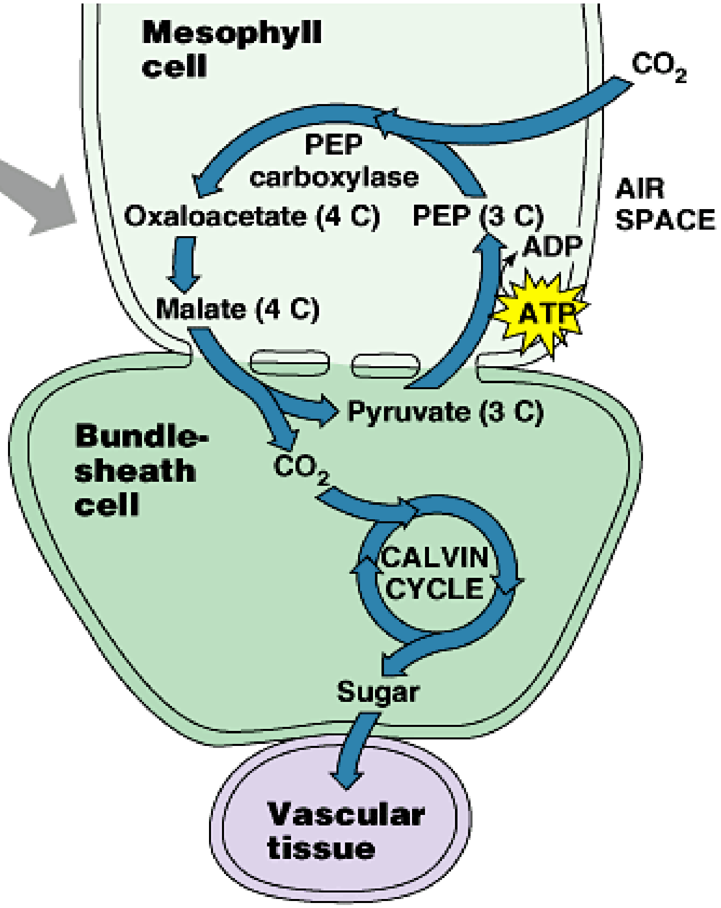
The Hatch-Slack pathway or"C_4 Plants"

- In C_4 plants(Monocot plants), CO_2 is bound into **phosphenol pyruvate** (pep), (recall glycolysis) in cells in the leaf known as "mesophyll cells". As CO_2-pep and the CO_2 is released into the bundle sheath cells, which surround the vascular bundle. In these bundle sheath cells the CO_2 enters the Calvin cycle as usual.
- In effect the mesophyll cells of a C_4 plant pump CO_2 into the bundle sheath cells, keeping the CO_2 concentration in the bundle sheath cells high enough for RUBISCO to fix CO_2 rather than Oxygen. In this way C_4 plants can minimise photorespiration and maximise sugar production.
- As the first product is a 4-C molecule (Oxalo acetic acid),this path is called C_4 path.

"C_4 Pathway"



C_4 leaf anatomy



The C_4 pathway

Kranz Anatomy

- It is seen in monocot plants
- C_4 pathway operates in two kinds of photosynthetic cells- mesophyll cells and bundle sheath cells.
- The bundle sheath cells are arranged surrounding vascular bundles. Such an arrangement is called Kranz anatomy.
- The chloroplast in bundle sheath cells does not show grana organization.
- The light reaction takes place in mesophyll cells and process of CO_2 fixation occurs in bundle sheath cells.
- This arrangement prevents the O_2, evolved during light reaction, from entering the bundle sheath cells, thus there is no possibility of photorespiration.

Difference between C_3 and C_4 path

No.	Character	C_3 path	C_4 path	
1	Type of cell	One (mesophyll)	Two(Mesophyll and Bundle sheath cells)	
2	Kranz Anatomy	Does not occur	occurs	
3	Chloroplast	With grana	With and without grana	
4	First CO_2 acceptor	RuBP	PEP	
5	First product	PGA (C_3)	Oxalo acetic acid (C_4)	
6.	Productivity	Normal	High	

Factors affecting photosynthesis

- Light
- Temperature
- CO_2 concentration
- Soil water
- Availability of nutrients

Thank you