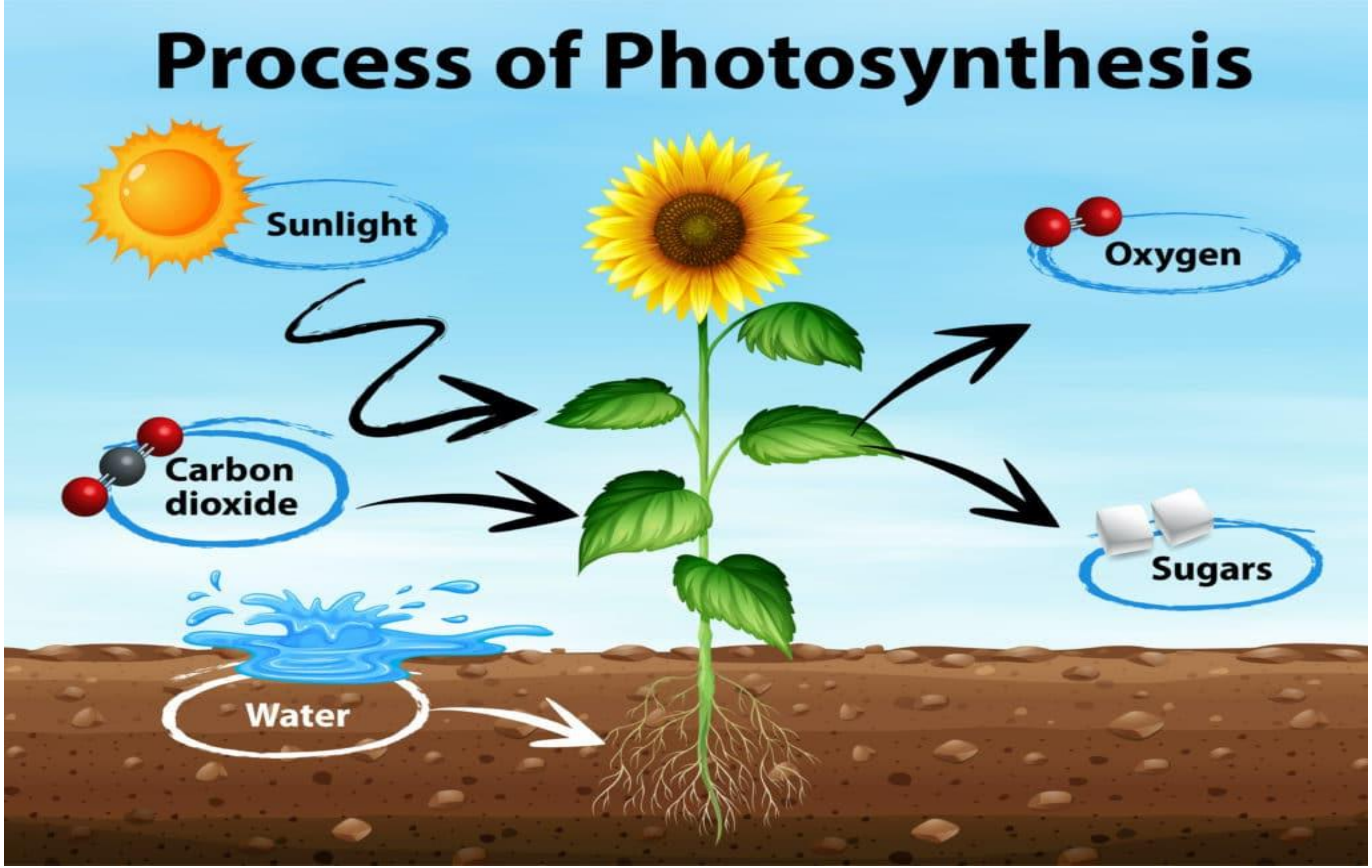
PHOTOSYNTHESIS



PHOTOSYNTHESIS

- **Photosynthesis** is the process in which green plants synthesize energy rich compound like carbohydrate from co_2 and H_2O in presence of **sunlight** and evolve **oxygen as byproduct.** Thus in this process **light energy** is converted in **chemical energy.**

$$2Co_2+2H_2O \xrightarrow[\text{chlorophyll}]{\text{Sunlight}} C_6H_{12}0_6+H_2O+60_2$$

Glucose

Note: During photosynthesis source of carbohydrate is co_2 and source of oxygen is H_2O

OR

Site of photosynthesis is **chloroplast**

➢ Site of photosynthesis -Chloroplast

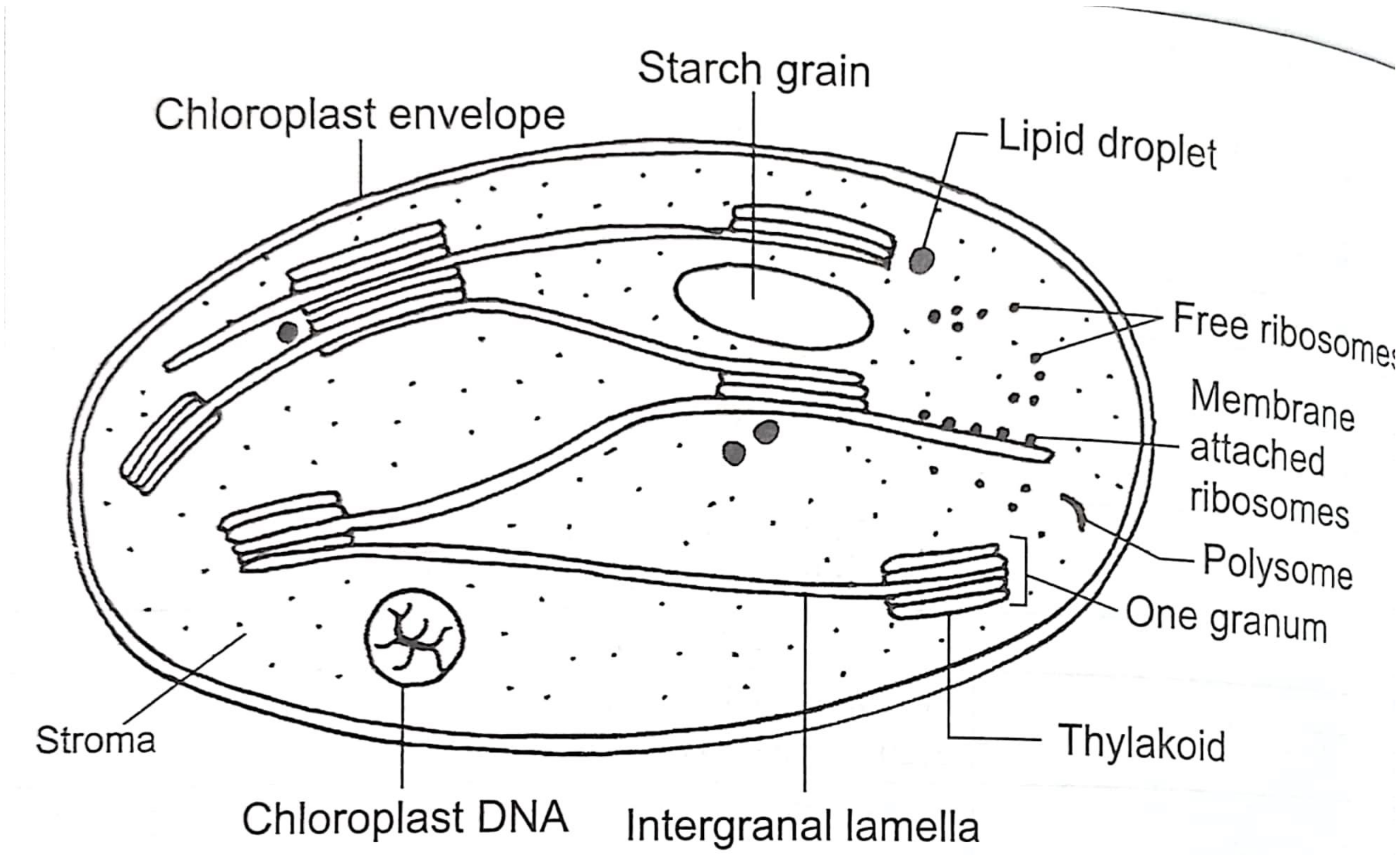


fig: Structure of Chloroplast

Photosynthetic units

- A photosynthetic unit is the smallest group of pigment molecules which take part in a photochemical act or conversion of light energy into chemical energy (ATP and NADPH).
- It has a photocentre or reaction centre which is filled by 200-300 harvesting pigment molecules.
- The photocentre contains a special chlorophyll-a molecule. It absorbs light energy having loner wavelengths. The harvesting molecules are if two types

a. **Antenna molecules-** they absorb the light of various wavelength but shorter than photocentre. On absorption of light energy, antenna molecules gets excited and an electron is pushed to an outer orbital. The excited antenna molecule handover their energy to core molecule by resonance and come to ground state.

b. **Core molecules:** the energy picked up by core molecules is supplied to the photocentre or reaction centre. Then the reaction centre gets excited and release an electron after which it comes to ground state to repeat the cycle. Photocentre cannot absorb the light of shorter wavelength. So, it requires the help of harvesting molecules for light absorption.

Photosystem (Two pigment system) and reaction Centre

- Light energy is trapped by photosynthetic pigments arranged in centers called **Photosystems (PS).**
- The discovery of **Emerson effect** indicated that, in each chloroplast, chlorophyll and accessory pigments are arranged in two types of photosystems called **Photosystem I (PSI) and photosystem II (PSII).**
- In each photosystem, a molecule of Chl.a is called primary pigment called reaction centre and other chlorophyll molecules are known as accessory pigment.
- These photosystems are visible as a particle in the thylakoid.
- In each PS, several hundred chlorophyll molecules and accessory pigments (carotene, xanthophyll) harvest light energy.
- **Pigment System I or photosystem I (PSI):** It absorbs light having wavelength (distance between two points in the waves of light) shorter as well as longer than 680 nm. The important pigments of this system are Chlorophyll-a 670, Chlorophyll-a 680, Chlorophyll-a 695, P-700 and carotenoids. Among them, P700 acts as the reaction centre of PSI and involved in cyclic electron transport.

- **Pigment System II or photosystem II (PSII):** It absorbs light having wavelength shorter than 680 nm. The important pigments of this system are Chlorophyll-a 670, P-680, Chl-b and phycobilins. Among them, P680 acts as the reaction centre of PSI and involved in non-cyclic electron transport.
- PSI and PS II are interrelated and produce ATP (energy carrier) and NADPH. The reaction centre for PS I is P700 and PSII is P680. The reaction center uses this energy to start the chemical reaction.

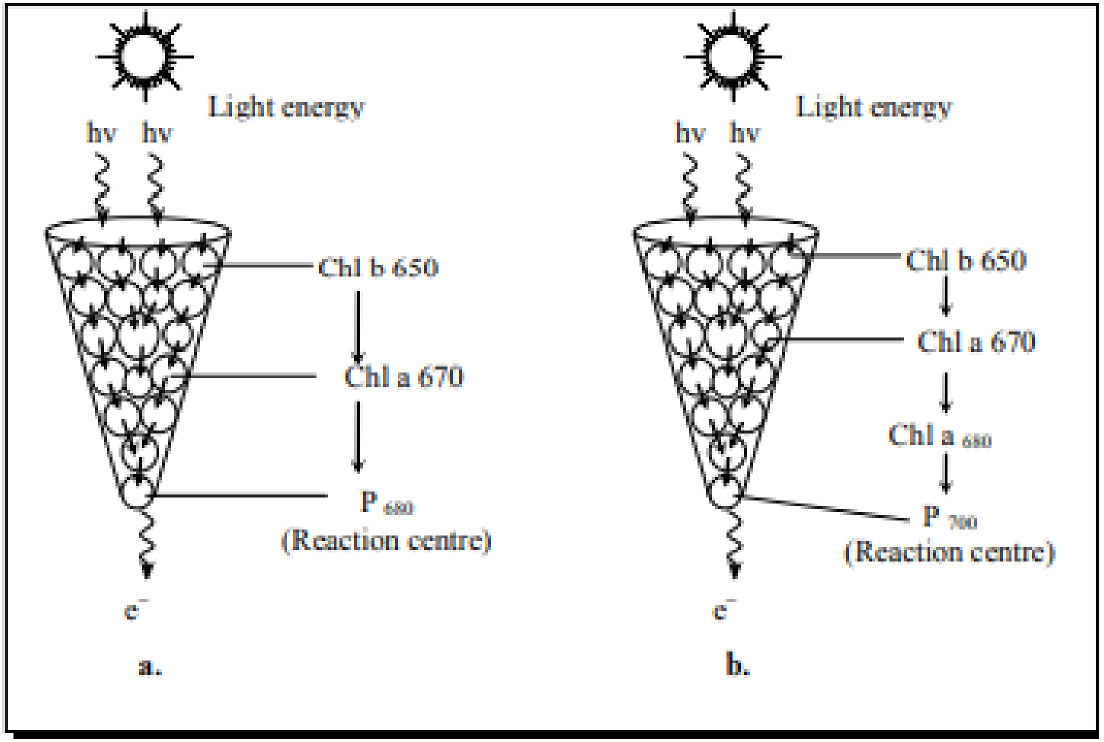


Fig. 3.2: Photosystem (PS): a. PS II; b. PS I

Write difference between PSI and PSII from book

Mechanism of Photosynthesis

- Photosynthesis is complex oxidation and reduction process in which oxidation (loss of electron) of water and reduction (gain of electron) of carbon-dioxide takes place. Photosynthesis is completed in two main stages.

a. Light reaction or Hill reaction or Primary photochemical reaction (Light dependent phase)

b. Dark reaction or Blackman's reaction (Light independent phase)

1. Light reaction or Hill reaction

- It takes place in the **grana of chloroplast** in presence of light. Light reaction is also called Hill reaction after the name of scientist Robin Hill.
- It cannot take place in the absence of light.
- Chemical energy like ATP and $NADPH_2$ are produced in this phase, which are further useful in the dark phase.
- In **light reaction** solar energy trapped by chlorophyll is used to split **H_20 into H^+ and OH^- ion**.
- The H^+ is used to reduce NADP (co-enzyme which accepts electrons and hydrogen ions) into $NADPH_{2,}$ which is used to reduce **co_2 in dark reaction**. **O_2** is also evolved in light reaction.
- It is completed into following steps:

a. **Photo-excitation of chl. a**

b. Photolysis of water

c. Reduction of NADP

c. Photophosphorylation

a. **Photo-excitation of Chlorophyll a.**

- In each pigment system, all the **accessory pigment absorb light energy** and transfer to **chl.a, known as reaction centre.**
- **On the absorption of energy, the reaction centre gets excited and** expels electron which travel to different electron acceptors during photophosphorylation. This process is called the photo-excitation of Chl-a. In photosystem I, chl.a is P_{700} which absorb light at a wavelength of 700 nm and in photosystem II, chl. a is P_{680} absorb light at a wavelength of 680nm.
- In both the system all pigments absorb light energy

b. Photolysis of water

- The light energy trapped by chlorophyll molecules is used to split water into hydrogen ion (H^+)and oxygen atoms (OH^-) using a splitting enzyme. This process is known as photolysis of water.
- $4H_2O \longrightarrow 4H^+ + 4OH^-$
- $4OH^- \longrightarrow 2H_2O + 4e^- + O_2$ OR
- $2H_2O \longrightarrow 2H^+ + 2e^- + 1/2O_2$
- During photolysis of water, molecular oxygen, water, electron and proton are produced. The electron and proton are accepted by ADP and NADP to produce ATP and $NADPH_2$.
- Note: **NADP**-Nicotinamide adenine dinucleotide phosphate.
- **ATP-** Adenosine triphosphate
- **ADP-** Adenosine diphosphate

C. **Reduction of NADP:**

In chloroplast, naturally occurring electron acceptor $NADP^+$. With the addition of hydrogen ion (H^+) from photolysis, NADP is reduced to $NADPH_{2.}$

Oxidised NADP + $2H^+$ + $2e^-$ $\longrightarrow$ Reduced $NADPH_2$

D. Photophosphorylation

- The process of formation of higher energy phosphate (ATP) by using light energy is called photophosphorylation. The process is catalyzed by an enzyme ATP synthase. (ATPase).
- The formation of ATP occurs in both photosystem I and Photosystem II.
- ADP + Pi $\longrightarrow$ ATP
- It is of two types.
- 1. **Noncyclic photophosphorylation**
- **2. Cyclic photophosphorylation**

1. Noncyclic Photophosphorylation

- In this photophosphorylation both PSI and PSII are involved in production of **ATP, $NADPH_2$ and O_2.**
- The P_{680} of PSII absorb sufficient quantum of energy and expels electron.

- The electron are accepted by primary acceptor, from primary acceptor electrons are transferred in series of enzymes such as **plastoquinone (PQ), Cytochrome complex, Plastocyanin (PC)**. During this process **ATP** are synthesized when electron passed over the **cytochrome complex.**
- The electron is then passed downhill to p700 of PSI.
- The electrons are again accepted by primary acceptor which are ultimately pass onto NADP through ferredoxin (Fd).
- The electron along with H^+ (produced during photolysis of water) combined with NADP and form $NADPH_2$.
- Hence, in non-cyclic photophosphorylation two $NADPH_2$ and one ATP are produced with the evolution of oxygen. It is common method of photophosphorylation of higher plants including cyanobacteria.
- In conclusion, the high energy electrons are moved on from P680 of PSII to P700 of PSI but they do not get back to P680 and hence this phase is called non-cyclic photophosphorylation.

Noncyclic Photophosphorylation

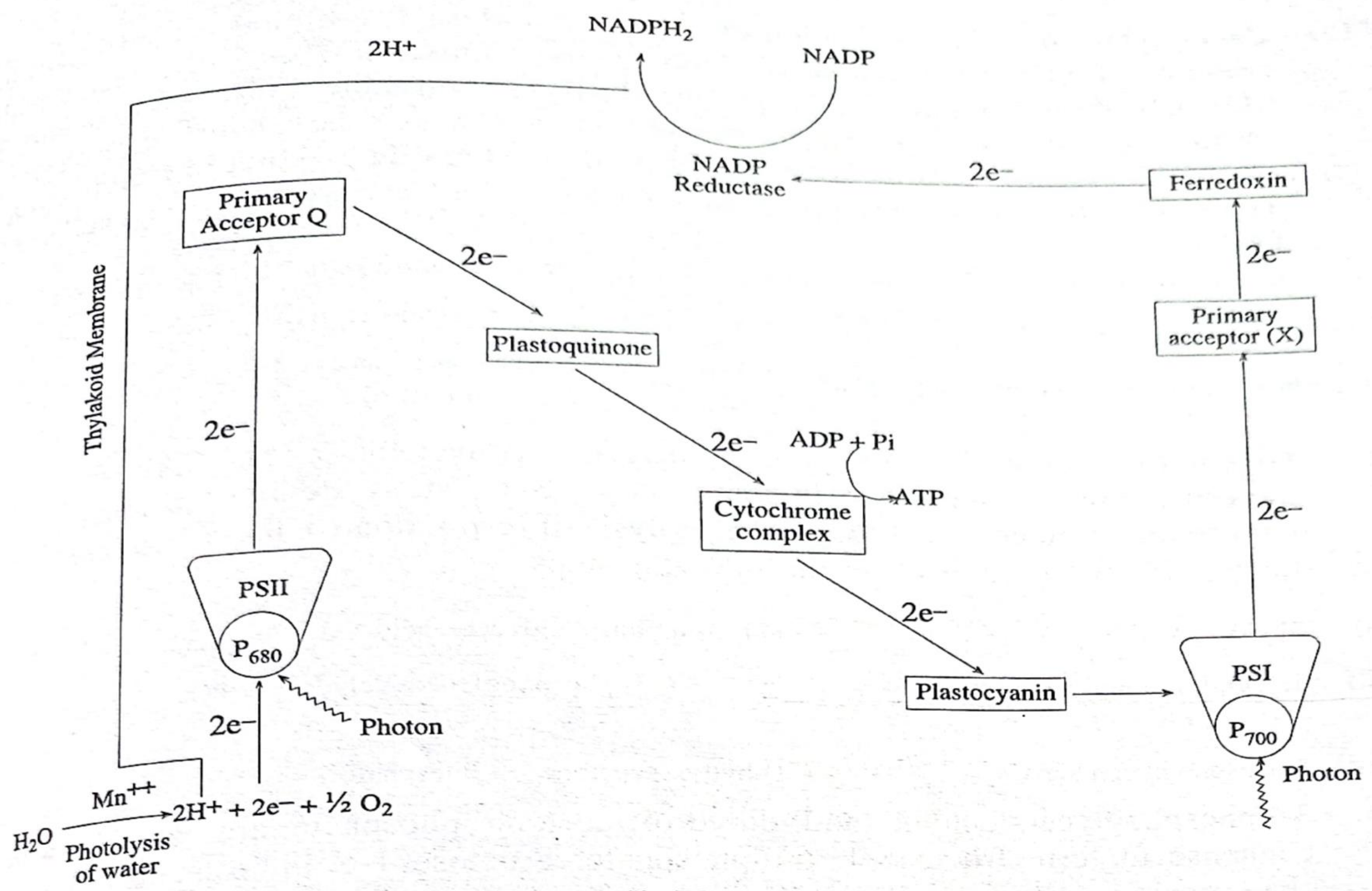


Fig 4.10: Non-cyclic Photophosphorylation

2. Cyclic Photophosphorylation

- It can be defined as the synthesis of ATP activated by PSI only. The electron gets emitted by PSI and passed through different electron acceptors and again gets back to PSI. so this is called **cyclic photophosphorylation**.

- In this cycle P_{700} of PSI absorb light energy and expels electron.
- The electrons are taken by primary acceptor. From primary acceptor e^- are transferred in the series of electron acceptor like ferrodoxin(Fd), Plastoquinone(PQ), cytochrome complex, Plastocyanin and finally back to P_{700}.
- Here energy is produced without photolysis of water and formation of $NADPH_2$.
- During the transformation of electrons from Fd to PQ and in cytochrome complex, energy is produced in the form of ATP. So the net product is 2 ATP molecules. It occurs in Bacteria.

- **Figure of cyclic photo phosphorylation from book**

HW- Difference between cyclic and noncyclic photophosphorylation

2. Dark Reaction or Blackman Reaction (light independent reaction)

- Dark reaction takes place in **stroma of chloroplast**. It was established by **Blackman**. This reaction is independent of light hence called dark reaction.

- In dark reaction fixation and reduction of carbon- dioxide into carbohydrate takes place by utilizing **ATP and NADPH$_2$** molecules formed during light reaction. Similarly carbon dioxide and ribulose are needed. Carbon dioxide (co2) comes from atmosphere and ribulose molecule is already present in the stroma. Dark reaction is completed in two phases.

1. **Calvin cycle or C_3 cycle**

2. Hatch and Slack pathway or C_4 cycle

1. Calvin Cycle (C3 cycle)

Draw the cycle from book

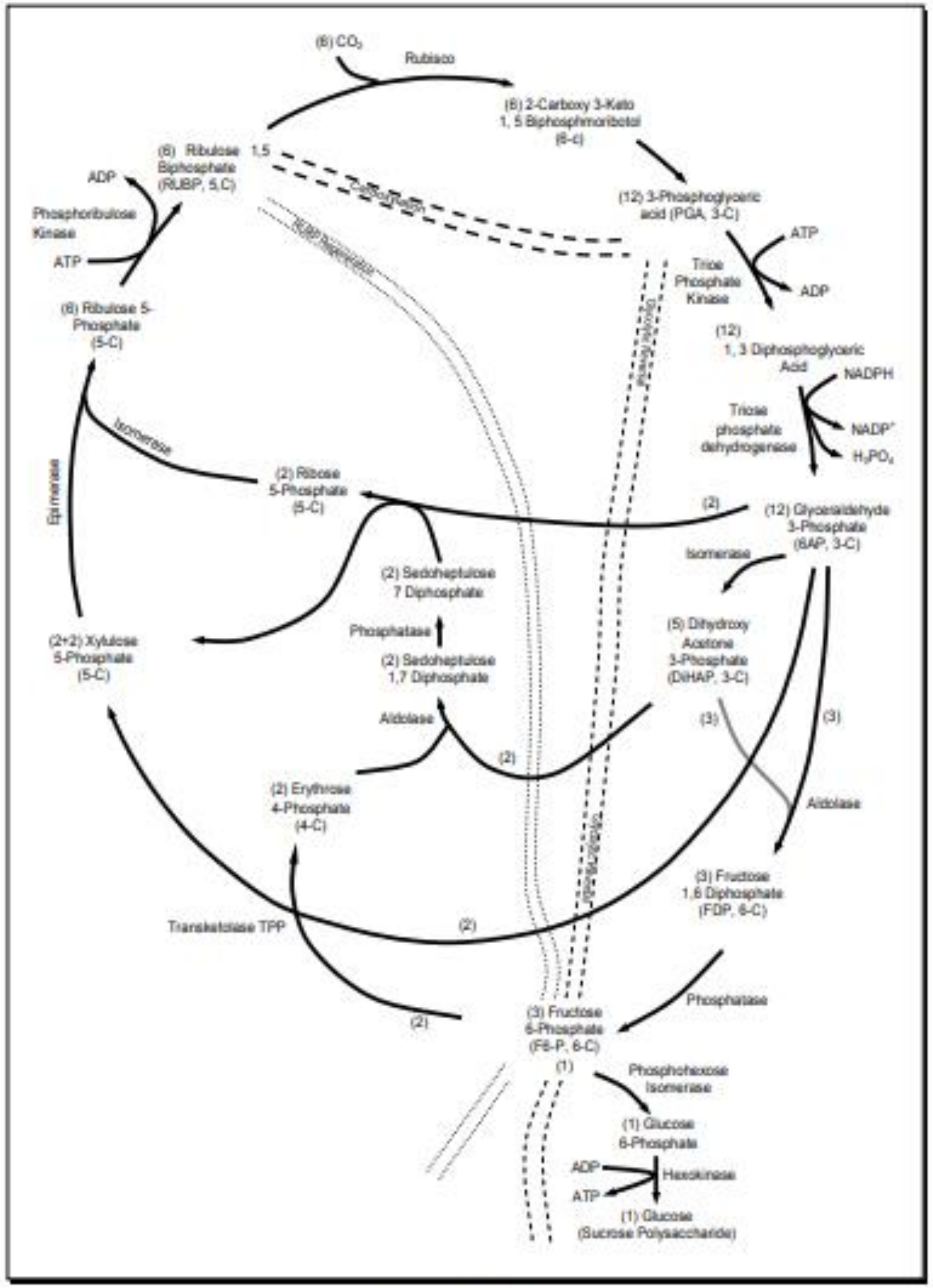


Fig 3.4: Calvin Cycle.

1. CALVIN CYCLE OR C_3 CYCLE

- **Calvin, Benson, Bentham** discover common pathway of dark reaction in unicellular green algae chlorella, which is also called as C_3 $_{\text{cycle.}}$ In C_3 cycle 3-phosphoglyceric acid is first stable product which contain 3 carbon.
- Through this cycle hexose sugar (glucose) is made from Co_2 and a 5-carbon compound ribulose-bi-phosphate (RuBP) . The overall reaction of dark reaction is:

$$6H_2O + 6\ Co_2 + 12NADPH + 12H^+ + 18ATP \longrightarrow \mathbf{C_6H_{12}0_6} + 12NADP + 18\ ADP + 18Pi + 12\ H_2O$$

Calvin cycle has following 3 steps:

a. Carboxylation

b. Glycolytic reversal

c. Regeneration of RUBP

1. Carboxylation

- 6 –molecule of **carbon-dioxide** is first accepted by 6 molecules of 5-carbon Ribulose 1,5-bisphosphate (RUBP) in presence of enzyme Ribulose biphosphate carboxylase (Rubisco) to form 6 molecules of 6 carbon unstable intermediate compound (Carboxy-3-keto 1,5 Biphosphomoribotol) which breaks into 12 molecules of 3- carbon compound called 3-**phosphoglyceric acid (3-PGA**) which is first stable compounds of Calvin cycle

$$6CO_2 + 6RUBP \xrightarrow{\text{Rubisco}} 3PGA$$

.

2. Glycolytic reversal:

It is the process of conversion of PGA into glucose molecule. It involves following steps

i. Now 12 molecules of PGA are phosphorylated by 12 molecules of ATP with the help of enzyme Triose Phosphate kinase to form 12 molecules of 1,3- diphosphoglyceric acid.

$$12PGA + 12ATP \xrightarrow{\text{Triose Phosphate kinase}} 12(\text{1,3-diphophoglyceric acid}) + 12\ ADP$$

ii. Then 12 molecules of 1,3- diphosphoglyceric acid is reduced by 12 molecules of NADPH through an enzyme Triose Phosphate dehydrogenase to form 12 molecules of 3- phosphogylceraldehyde or glyceraldehyde-3-phosphate.

$$12\ (\text{1,3- diphosphoglyceric acid}) + 12NADPH \xrightarrow{\text{Triose Phosphate dehydrogenase}} 12(\text{3- phosphogylceraldehyde}) + 12\ NADP^{+} + 12H_3PO_4$$

iii. 5 molecules of 3- phosphogylceraldehyde are converted into 5 molecules of Dihydroxyacetone-3-phosphate in presence of enzyme phospho-triose isomerase.

$$5(\text{3- phosphogylceraldehyde}) \xrightarrow{\text{Phospho-triose isomerase}} 5(\text{Dihydroxyacetone-3-phosphate})$$

iv. 3 molecules of 3- phosphogylceraldehyde and Dihydroxyacetone-3-phosphate condense to form 3 molecules of Fructose 1,6-diphosphate in presence of enzyme aldolase.

$$(\text{3- phosphogylceraldehyde}) + 3\ (\text{Dihydroxyacetone-3-phosphate}) \xrightarrow{\text{Aldolase}} 3\ (\text{Fructose 1,6-diphosphate})$$

v. 3 molecules of fructose 1,6-diphosphate loose 1 phosphate group to form 3 molecules of fructose-6-phosphate in presence of enzyme phosphatase

3(fructose 1,6-diphosphate) + $3H_2O \xrightarrow{\text{Phosphatase}}$ Fructose-6-phosphate + $3H_3PO_4$

vi. One molecule of Fructose-6-phosphate is converted into one molecule of Glucose-6-phosphate in presence of enzyme Phospho-hexose isomerase.

Fructose-6-phosphate $\xrightarrow{\text{Phospho-hexose isomerase.}}$ Glucose-6-phosphate

vii. One molecule of Glucose-6-phosphate is converted into one molecule of glucose in presence of enzyme hexokinase.

Glucose-6-phosphate + $H_2O \xrightarrow{\text{Hexokinase}}$ Glucose + H_3PO_4

3. Regeneration of RUBP

In this step RUBP is regenerated back so that it is available once again in the carboxylation process.

i. 2 molecules of Fructose-6- phosphate and 2 molecules of 3-phosphoglyceraldehyde react in presence of enzyme transketolase to form 2 molecules of erythrose-4-phosphate and 2 molecules of xylulose-5 –phosphate.

2 (Fructose-6- phosphate) + 2 (3-phosphoglyceraldehyde) $\xrightarrow{\text{Transketolase.}}$ 2 (Erythrose-4-phosphate)+ 2 (xylulose-5 –phosphate)

ii. Now 2 molecules of erythrose- 4-phosphate combine with 2 molecules of Dihydroxyacetone-3-phosphate in presence of enzyme aldolase to form 2 molecules of sedoheptulose 1,7-diphosphate.

2 (erythrose- 4-phosphate) + 2 (Dihydroxyacetone-3-phosphate) $\xrightarrow{\text{Aldolase.}}$ 2 (sedoheptulose 1,7-diphosphate)

iii. 2 molecules of sedoheptulose 1,7-diphosphate. Loses one phosphate in presence of enzyme phosphatase to form 2 molecules of sedopheptulose-7-phosphate.

2 (sedoheptulose 1,7-diphosphate) + 2 H_2O $\xrightarrow{\text{Phosphatase}}$ 2(Sedoheptulose 7- phosphate) + 2 H_3PO_4

iv. 2 molecules of Sedoheptulose 7- phosphate react with 2 molecules of 3-phosphoglyceraldehyde in presence of enzyme transketolase to form 2 molecules of Ribose-5-phosphate and 2 molecules of xylulose-5-phosphate.

2 (Sedoheptulose 7- phosphate) + 2 (3-phosphoglyceraldehyde) $\xrightarrow{\text{Transketolase}}$ 2 (Ribose-5-phosphate) + 2 (xylulose-5-phosphate)

v. 2 molecules of Ribose-5-phosphate are converted into 2 molecules of Ribulose-5-phosphate in presence of enzyme isomerase.

2 (Ribose-5-phosphate) $\xrightarrow{\text{Isomerase}}$ 2 (Ribulose-5-phosphate)

vi. Altogether 4 molecules of xylulose-5-phosphate are converted into 4 molecules of Ribulose-5-phosphate in presence of enzyme epimerase.

4 (xylulose-5-phosphate) $\xrightarrow{\text{Epimerase}}$ 4 (Ribulose-5-phosphate)

vii. 6 molecules of Ribulose-5-phosphate combines with ATP to form 6 molecules of Ribulose 1,5-biphosphate in presence of enzyme phosphoribulose kinase.

$$6\,(\text{Ribulose-5-phosphate}) + 6\,ATP \xrightarrow{\text{Phosphoribulose kinase}} 6(\text{Ribulose 1,5-biphosphate}) + 6\,ADP$$

2. HATCH AND SLACK PATHWAY (C_4 cycle)

- Hatch and Slack discovered another alternative pathway of dark reaction in tropical plants like Maize, Sugarcane, *Amaranthus*, etc.
- In C_4 cycle 1st stable product is 4-carbon compound i.e. oxaloacetic acid. Therefore the plants are called C_4 plants
- The anatomy of leaf of C_4 plants is called Kranz anatomy.
- Kranz anatomy means vascular bundles are surrounded by bundle sheath of large sized chlorenchymatic cells arranged like a ring.
- The chloroplast of inner ring or bundle sheath lack grana but the outer ring of bundle sheath or mesophyll cell contain smaller chloroplast with grana.
- So light reaction and fixation of carbon dioxide occurs in mesophyll cell whereas as reduction and re-fixation occur in bundle sheath.

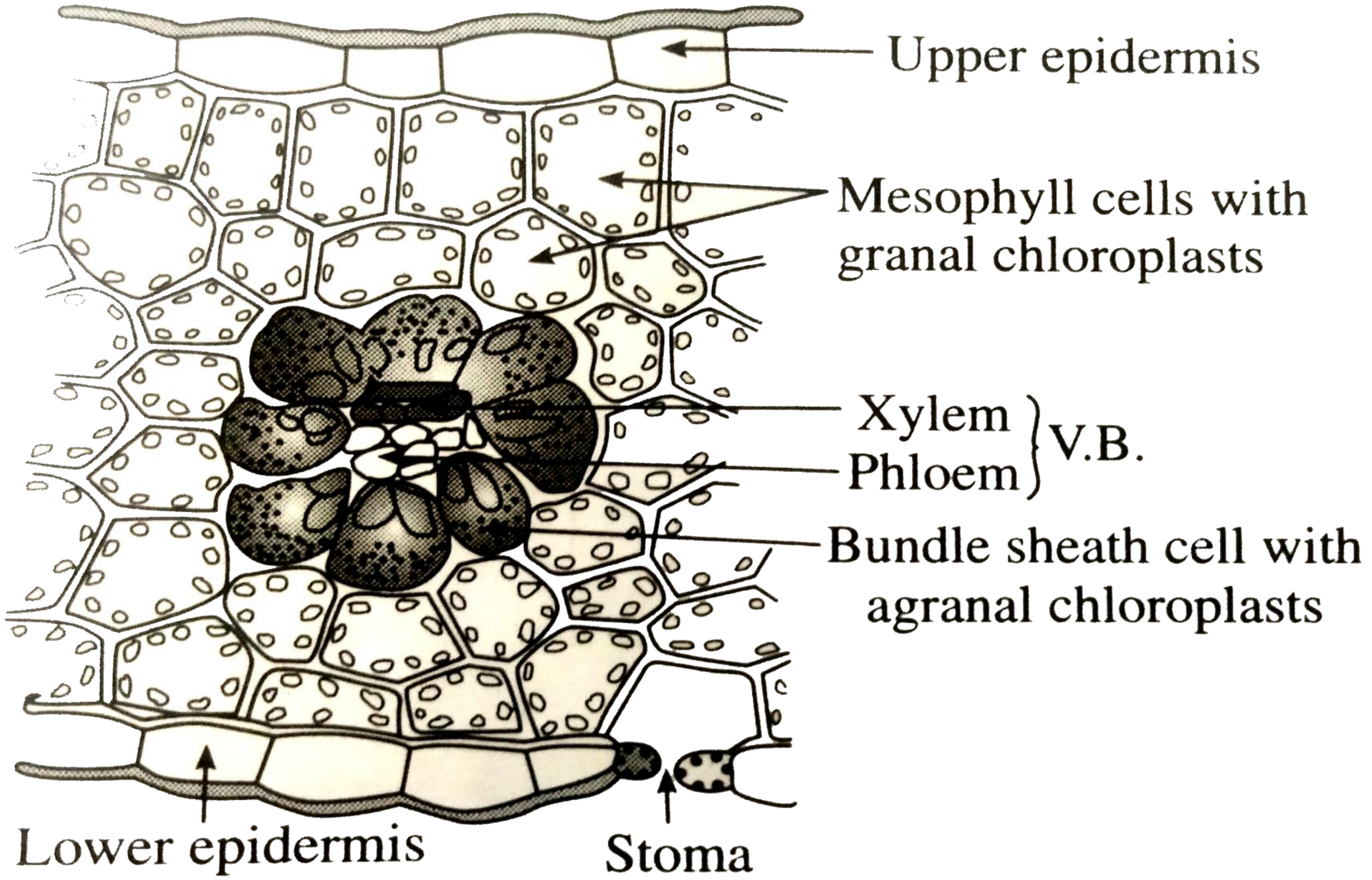


Fig: Anatomy of leaf of C_4 plants showimg Kranz anatomy

2.HATCH AND SLACK PATHWAY……

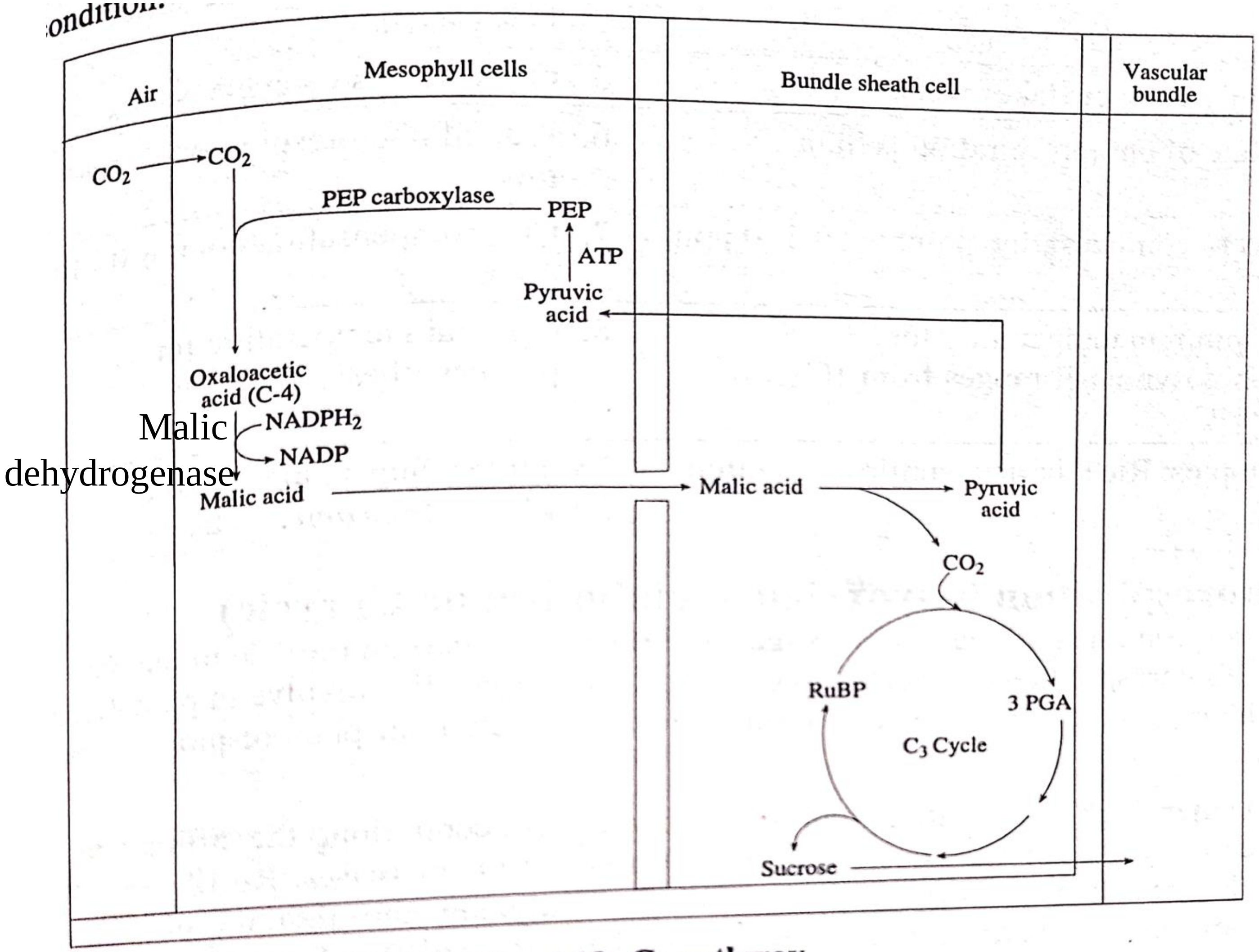


Fig. 4.13: C_4 pathway

P_i=inorganic phosphate

2.HATCH AND SLACK (C_4) PATHWAY……

- The C_4 cycle involves the following steps

i. **Reaction in mesophyll cells**

ii. Reaction in bundle sheath cells

i. **Reaction in mesophyll cells**

- The atmospheric CO_2 is taken by Phosphoenol pyruvate in presence of PEP Carboxylase.
- The PEP combines with CO_2 and form first product oxaloacetic acid (OAA) which is made up of four carbons thus, named as C_4 cycle.

$$\textbf{PEP (3c)+ } CO_2 + H_2O \xrightarrow{\text{PEP Carboxylase}} \textbf{Oxaloacetic acid (4c) + } H_3PO_4$$

2.HATCH AND SLACK PATHWAY……

- The OAA is reduced to malic acid in presence of enzyme malate dehydrogenase

$$OAA + NADPH_2 \xrightarrow{\text{Malate dehydrogenase}} \text{Malic acid} + NADP^+$$

2. Reaction in bundle Sheath Cells

- Now the malic acid enter to bundle sheath cell through plasmodesmata where decarboxylation takes place.
- Malic acid + $NADP^+ \longrightarrow$ Pyruvic acid + CO_2 + NADPH + H^+
- Thus, formed pyruvic acid is transported into mesophyll cell where it is changed into PEP (Phosphoenol pyruvic acid) in presence of enzyme phosphopyruvate dikinase.
- Pyruvic Acid + ATP+ $H_3PO_4 \xrightarrow{\text{Phosphopyruvate dikinase}}$ PEP + AMP + Pyrophosphate

2.HATCH AND SLACK PATHWAY……

- Cells of bundle sheath contain RuBP Carboxylase so CO_2 is again fixed inside the bundle sheath cells through Calvin cycle.
- Carbohydrates (Sugar) are synthesized in C_3 cycle
- In C_4 cycle , ATP molecules are utilized. The overall reaction is given below

$$6PEP + 6\ RuBP + 6\ CO_2 + 30\ ATP + 12\ NADPH_2 \longrightarrow 6\ PEP + 6\ RUBP + C_6H_{12}O_6 + 30\ ADP + 30\ H_3PO_4 + 12\ NADP^+$$

C_3 Plants

- The plants showing C_3 pathway are called as C_3 plants.
- They are called C_3 because first stable compound is 3-carbon phosphoglyceric acid (PGA).
- These plants use calvin cycle in the dark reaction of photosynthesis
- Leaves donot show Kranz anatomy.
- About 95% of shrubs, trees and small plants are C_3 plants.
- e.g. cereals like Oats, rice, wheat, eucalyptus, sunflower, soybeans, sugar beets, potatoes, tobacco etc.

C_4 plants

- The plants showing C_4 or Hatch-slack pathway during the dark reaction of photosynthesis are called as C_4 plants.
- They are called C_4 because first stable compound is 4-carbon Oxaloacetic acid (OAA).
- Leaves show Kranz anatomy.
- About only 5% of shrubs, trees and small plants are C_3 plants.
- e.g. sugarcane, maize, sorghum, amaranthus, pineapple etc.

SIGNIFICANCE OF C_4 PLANTS/C_4 CYCLE

Although it consumes more energy, it has following significance

- C_4 plants have very low photorespiration
- C_4 plants are more efficient in fixation of CO_2 in low concentration of CO_2 , because of high affinity of PEP.
- They are adapted to high temperature (30-45^{oC}), intense radiation and saline condition

Difference between C3 and C4 plants (Note from Book)

Table No.4.3: Differences between C_3 and C_4 Cycle

C_3 cycle (C_3 plant)	C_4 Cycle (C_4 plant)
1. The CO_2 acceptor molecule is Ribulose biphosphate.	1. The CO_2 acceptor molecule is phosphoenol pyruvic acid.
2. The first stable product is 3-phosphoglyceric acid (3 carbon compound).	2. The first stable product is oxaloacetic acid (four carbon compound).
3. C_3 plants have not Krantz anatomy.	3. C_4 plants have Krantz anatomy.
4. Only one type of chloroplast is found.	4. Two types of chloroplast are found. In mesophyll cell, chloroplast bears grana where as bundle sheath cells lack grana.
5. Only C_3 cycle takes place.	5. C_3 as well as C_4 cycle occurs.
6. Rate of photorespiration is high	6. Rate of photorespiration is very low.
7. CO_2 compensation point is 50-100 ppm	7. CO_2 compensation point is 0 - 10 ppm.
8. Optimum temperature for photosynthesis ranges from 10°C to 25°C	8. Optimum temperature for photosynthesis 30°C – 45°C
Examples: Rice, barley, sunflower, cotton etc.	Examples: Sugarcane, maize, *Sorghum*, *Amaranthus* etc.

PHOTORESPIRATION

PHOTORESPIRATION

- The process of utilizing oxygen and releasing carbon-dioxide in the presence of light is called photorespiration.
- It is detected in c_3 plants.
- Photorespiration requires three organelles i.e. chloroplast, peroxisomes and mitochondria.
- Steps of photorespiration are given below

1. Under high temperature ,high concentration of oxygen and low concentration of CO_2

Rubisco helps to accept O_2 instead of CO_2, resulting in the formation of two carbon compound Phosphoglycolate and 3-phosphoglyceric acid.

$$RuBP+O_2 \xrightarrow{\text{RuBP oxygenase}} PGA+ \text{Phosphoglycolate}$$

2. Phosphoglycolate loses phosphate group to form glycolate

Phosphoglycolate+ H_2O $\xrightarrow{\text{Phosphatase}}$ **Glycolate+H_3PO_4**

3. Glycolate is passed into peroxisomes of mesophyll and oxidized into glyoxylate and glyoxylate is converted into Glycine.

Glycolate+O_2 $\longrightarrow$ Glyoxylate + H_2O_2

Glyoxylate $\xrightarrow{\text{Transaminase}}$ Glycine

4. Two molecules of glycine then interact to form serine. This reaction takes place in mitochondria. Serine passes out of mitochondria and converted into 3 phosphoglyceric acid which is transported to chloroplast for the synthesis of RuBP. Thus the cycle repeats again.

Photorespiration involves the synthesis of two carbon compound(serine, Glyoxylate), so it is called C_2 cycle.

2 Glycine $\longrightarrow$ Serine + CO_2

Serine + ATP $\longrightarrow$ PGA + NH_3 + ADP

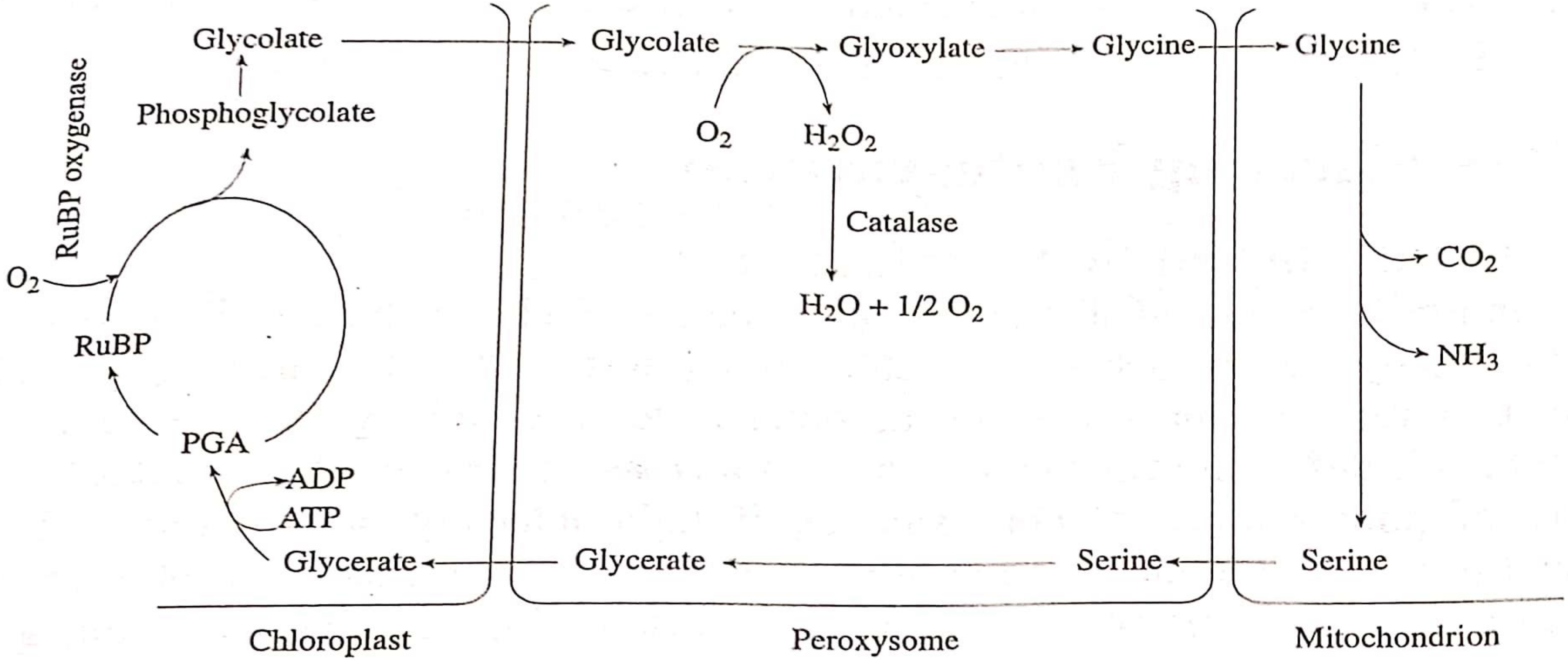


Fig. 4.14: Photorespiration (C_2 cycle)

SIGNIFICANCE OF PHOTORESPIRATION

- It reduces the carbon in the form of CO_2.
- It does not produce ATP and reducing power($NADPH_2$) but it consume energy.
- It reduces the rate of photosynthesis, it is a wasteful process.
- It protect the plant form photo-oxidative damage .

Factor affecting the rate of photosynthesis

The process of photosynthesis is influenced by following factors:

1. External Factor
2. Internal Factor

1. EXTERNAL FACTORS

a. Light

- Light intensity, light quality and duration affect the rate of photosynthesis

i. **Light intensity:** With the increase in light intensity the rate of photosynthesis increases. At low or diffused light intensity, the rate of photosynthesis is reduced. But extreme intense light may affect plants negatively by solarization.

ii. Light quality: In blue and red light of spectrum the most of the absorption is carried out by chlorophylls. In this region rate of photosynthesis is higher. Green light is reflected by chlorophyll so photosynthesis is lower in green light.

iii. Light duration: The rate of photosynthesis is high in intermittent light than in continuous light because in continuous light energy is not consumed in dark reaction at the same rate at which it is produced in light reaction.

b. Temperature

- The rate of photosynthesis increased with increase in temperature at the range from 10^0C to 35^0C.
- Temperature below 10^0C and above 35^0C show adverse effect on the rate of photosynthesis.

c. Water

- Plant uses less than 1% of absorbed water in photosynthesis
- Water deficiency causes closing of stomata (as it maintains turgidity of guard cells) and wilting leading to decrease in photosynthesis

d. Oxygen

- Increase in oxygen concentration in many plants (C_3) plants results in decrease in the rate of photosynthesis. This effect is called **Warburg's effect.** It is not shown by c_4 plants.

e. CO_2

- An increase in CO_2 concentration about 1% increases the rate of photosynthesis. But very high concentration of CO_2 may reduce photosynthesis.

2. INTERNAL FACTORS

a. Chlorophyll Content

- Photosynthesis cannot occur in the absence of chlorophyll.
- Photosynthesis is directly related with the amount of chlorophyll because it is the main pigment to absorb light energy
- But yellowing of leaf due to chlorosis reduces the rate of photosynthesis

b. Age of Leaf

- Rate of photosynthesis increases as the leaf matures but it decreases in aging leaf

c. Leaf Anatomy

- The rate of photosynthesis is also influenced by leaf anatomy.
- The thickness of cuticle and epidermis, structure and distribution of stomata, distribution and relative proportion of chlorophyllous and non-chlorophyllous mesophyll tissue all influence the rate of photosynthesis

d. **Accumulation of end products of photosynthesis**: The accumulation of carbohydrates in photosynthesizing cells retards the rate of photosynthesis. The quick translocation of end products or carbohydrates will have favourable effect on photosynthesis.

Differences between photorespiration and respiration

Differentiate between Photorespiration and Respiration	
Photorespiration	**Respiration**
1. It occurs only in the presence of light	1. It occurs in all times i.e. day and night
2. It occurs in chloroplasts, peroxisomes and mitochondria	2. It occurs in mitochondria of the cell
3. There is a wasteful loss of ATP and $NADPH_2$.	3. There is release of energy in the form of ATP and $NADPH_2$.
4. It is not an essential process for cells.	4. It is essential process for all the cells.
5. It reduces the yield of C_3 plants growing in tropics.	5. It does not reduce the yield of crops.
6. It is pronounced in C_3 plants and negligible in C_4 plants.	6. It is pronounced in all organisms.
7. In photorespiration uptake of oxygen and evolution of carbon dioxide are light dependent.	7. Exchange of gases is independent of light.
8. Photorespiration increases with the availability of oxygen.	8. It is not influenced by change in oxygen concentration between 10-25%. Beyond it there is a decline in the rate of respiration.
9. The substrate for photorespiration is RuBP and its breakdown product called glycolate.	9. The substrate is commonly glucose though other food materials (fat, protein, organic acids) can also be used.
10. Toxic H_2O_2 may be formed during oxidation of the substrate.	10. Hydrogen peroxide is not produced.
11. End products are CO_2 and PGA.	11. End products are CO_2 and water.
12. It rises rapidly with the rise in temperature.	12. It rises normally with rise in temperature for other biochemical reactions.

Significances of Photosynthesis

1. Photosynthesis is only process by which organic compound can be prepared from the inorganic raw materials. Thus food for all living organism is prepared by green plants by this process.
2. Chlorophylls can change radiant energy into chemical energy during photosynthesis. This energy can be used by all the living beings to perform their life activities.
3. There is utilization of CO_2 in photosynthesis and evolution of O_2 after photosynthesis. So photosynthesis helps in balance of atmospheric gasses.
4. It reduces CO_2 concentration in atmosphere. Higher concentration of CO_2 may be harmful to living beings.
5. All the useful plant products such as resin, oil, fibres, drugs, rubber, timber, etc. are derived by the process of photosynthesis
6. The fossil fuels like coal, petroleum, gases, etc. are photosynthetic products.