Chapter 4

Bio - Energetics

→ Energy of sunlight is used in fixation of CO_2 to carbohydrate.

→ Reaction of photosynthesis:

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

→ Visible Light : 390nm – 760 nm

→ About 40% of total sunlight that enters our atmosphere reaches the earth.

* Chlorophyll:

→ Absorb violet-blue wavelengths (390nm – 430nm)

→ Red wave-lengths (670 – 700nm).

→ Green wavelengths are reflected

→ ~~Carbon~~ Carotenoids absorb in wavelength range : 500nm – 600nm

→ Chlorophyll and other photosynthetic pigments (carotenoids) are present within membranes of thylakoids.

* Sites of:

Light Reaction → Thylakoid Membranes

Dark Reaction → Stroma

* Chlorophyll 'a' : → most abundant and most important photosynthetic pigment
  → present in all green plants except bacteria

* chlorophyll 'b' → present in higher plants and green algae
* chlorophyll c, d, e → present in various groups of algae
* bacterio chlorophyll → present in bacteria

* Chlorophyll molecule is composed of two parts:

1. Head:
   → central magnesium atom
   → Four N-rings called Pyrrole rings attached to central atom
   → Four rings (tetra pyrrole rings) collectively called porphyrin
   → Head is hydrophilic and lies on surface of thylakoid membrane.

2. TAIL
   → Long hydrocarbon chain called phytol side chain
   → It is hydrophobic
   → lies embedded in thylakoid membrane

* Chlorophyll a and b differ by functional group bonded to porphyrin.

  Chlorophyll a → Methyl Group ($-CH_3$)
  Chlorophyll b → Carbonyl group ($-CHO$)

  Chlorophyll a → $C_{55}H_{72}O_5N_4Mg$
  Chlorophyll b → $C_{55}H_{70}O_6N_4Mg$

* Functions of carotenoids:
1. Act as accessory pigments by absorbing light and transferring it to chlorophyll a
2. protect chlorophyll from intense light and from oxidation by oxygen produced in photosynthesis

→ Absorption spectrum is the amount of light absorbed at different wavelengths from visible spectrum of light
→ Action spectrum is a measure of effectiveness of light of various wavelengths in driving photosynthesis.
→ Action spectrum of a particular pigment can be calculated by measuring the rate of photosynthesis at each type of wavelength of light.

→ Van Neil hypothesized that plants split water to release oxygen as by-product.
→ The idea of Neil was supported by Hill.
→ Neil's hypothesis was confirmed when first use of an isotopic tracer (O^{18}) in biological research was made.

Group 1:

$$CO_2^{16} + 2H_2O^{18} \longrightarrow CH_2O^{16} + H_2O + O_2^{18}$$

Group 2:

$$CO_2^{18} + 2H_2O^{16} \rightarrow CH_2O^{18} + H_2O + O_2^{16}$$

LIGHT REACTION

PSI → P700

PSII → P680

→ Each photosystem consist of several hundred pigment molecules including chlorophyll a, b, carotenoids and electron acceptors

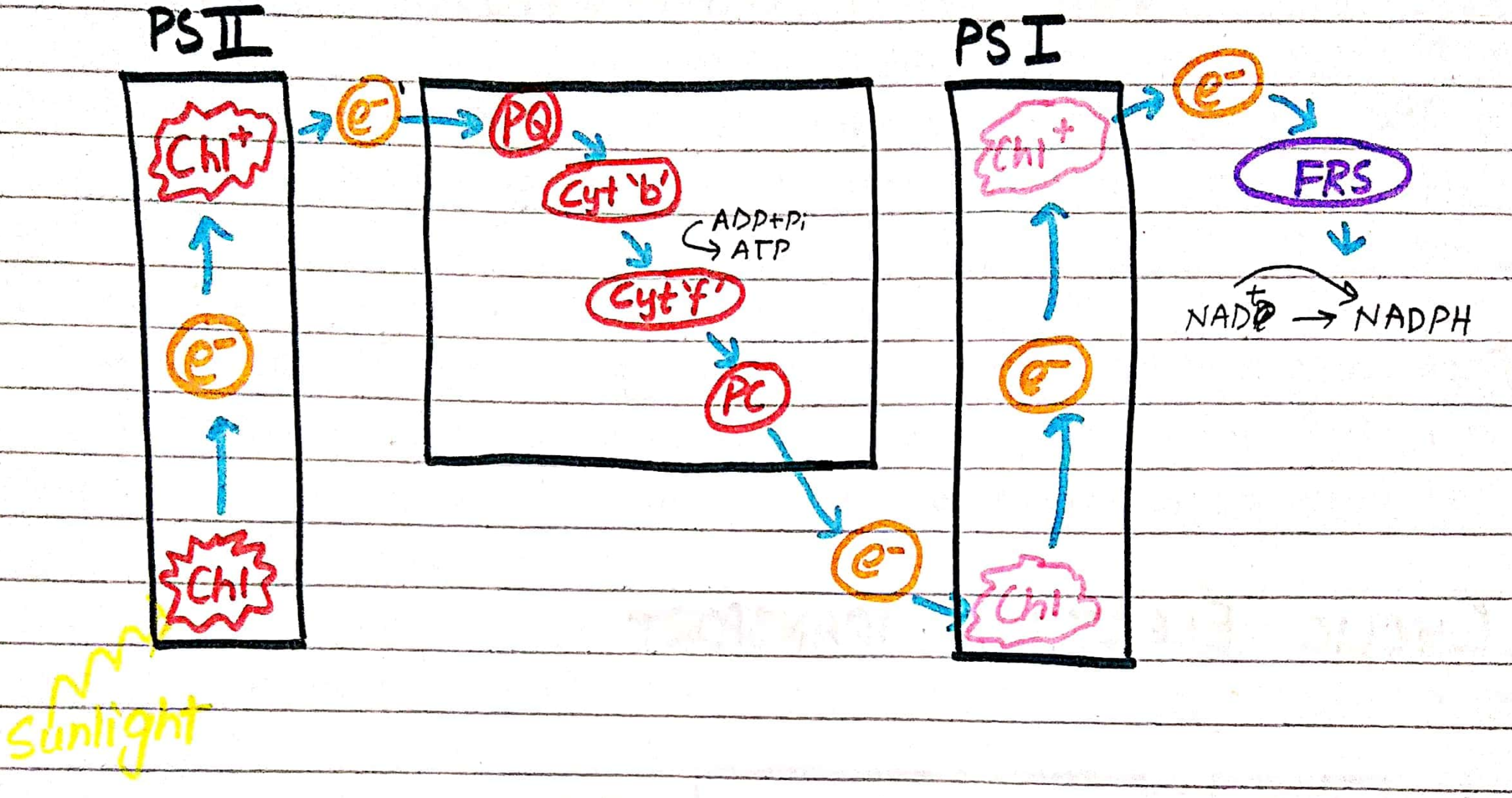
→ Two parts of photosystems:

1. Antenna Complex: has many molecules of chlorophyll b and carotenoids, all absorb energy and transfer it to reaction center.
2. Reaction center: has one or more molecules of chlorophyll a molecules along with primary electron acceptor and electron carriers.

→ Two possible pathways of electrons in light reaction is:

1. Non- Cyclic Electron Transport
2. Cyclic Electron Transport

NON- CYCLIC ELECTRON TRANSPORT



* Primary Electron Acceptor of PS II → Plastoquinone (PQ)
* Primary Electron Acceptor of PS I → Ferrodixn Reducing Substance (FRS)

Cyt 'b' → Cytochrome b

PC → Plastocyanin

→ When PS II absorbs light, water molecules splits int OH^- and H^+. The OH^- ions react to form some water again and release oxygen and electrons.

$$4\,H_2O \rightarrow 4H^+ + 4\,(OH^-) + 2e^-$$

$$4\,(OH^-) \rightarrow 2H_2O + O_2$$

→ Electrons from water molecules are accepted by positively charged chlorophyll molecule of PS II, filling the gap produced by two energized electrons.

→ The electron deficiency of PSI has been filled by electrons coming from PSII.

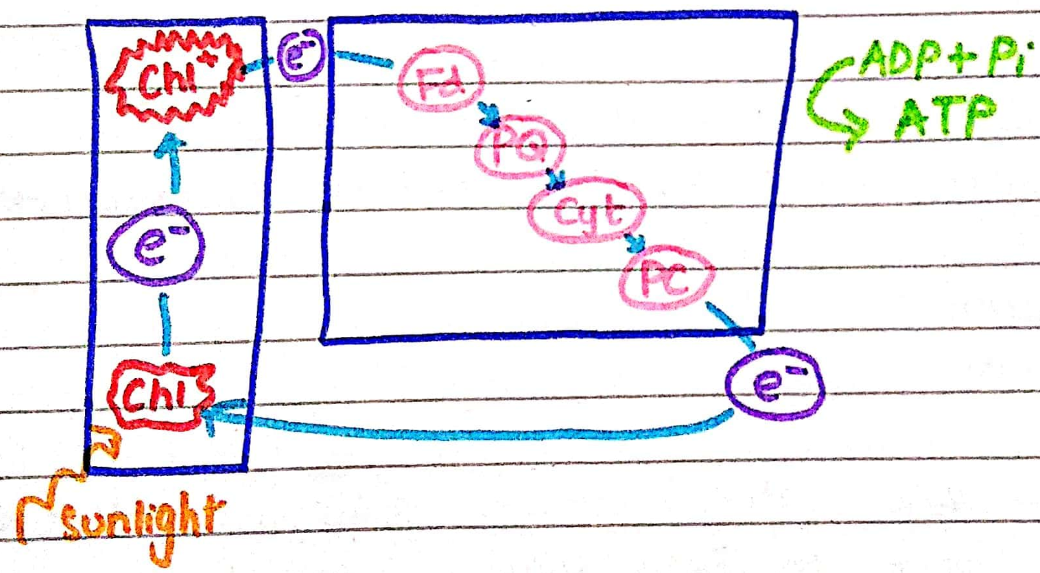
→ Non-cyclic path also called zig zag path.

→ The energy from sunlight is converted into small amount of ATP and NADPH ; both of which are used in dark reactions.

Photophosphorylation: The process of formation of ATP from ADP and inorganic phosphate using energy from sunlight is called photophosphorylation.

CYCLIC ELECTRON TRANSPORT

→ occur in rare condition i.e when PSII is blocked



DARK REACTIONS OR CALVIN CYCLE OR LIGHT INDEPENDANT REACTIONS

RuBP (5-C sugar) + CO_2 $\xrightarrow{\text{RuBisCo}}$ 6-C compound → 2 PGA (3-C)

2 PGA + 2ATP + 2NADPH $\xrightarrow{2H_2O}$ 2PGAL (3-C) + 2ADP + 2P + 2NADP

Out of every 6 molecules of PGAL formed, only one molecule leaves the cycle to be used by the plant for making glucose and other organic compounds. The other 5 PGAL molecules are recycled to regenerate 3 molecules of RuBP

5 PGAL (3-C) → 3 RuBP (5-C)

→ A sugar molecule is formed from 6 successive calvin cycles.

- →2 PGAL formed per cycle
- →6 PGAL formed in 3 cycles
- → 6 PGAL ⇒ 5 PGAL → Regeneration of RuBP (3 molecules)
  1 PGAL → For Glucose Synthesis

AEROBIC RESPIRATION

Reaction :

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 36\,ATP$$

1. GLYCOLYSIS

Glycolysis is the breakdown of glucose, a 6-C molecule, in two molecules of pyruvate (3-C) and a net gain of two ATP molecules.

(i) PREPARATORY PHASE

Glucose

↓ (ATP → ADP)

Glucose-6 Phosphate

↓

Fructose-6 Phosphate

↓ (ATP → ADP)

Fructose 1,6-bisphosphate

↙ ↘

PGAL (3-C) | DAP (3-C)

↓ | ↓

PGAL | PGAL

(ii) OXIDATIVE PHASE

PGAL

↓ (Ⓟ →) (NAD^+ → NADH)

1,3 bisphosphoglycerate

↓ (ADP → ATP)

PGA (3-phosphoglycerate)

↓ (→ H_2O)

Phosphoenol pyruvate (PEP)

↓ (ADP → ATP)

Pyruvate

All these are produced as double bcz 2 PGAL are produced at the end of preparatory phase

- → Altogether two NADH are produced in oxidative phase
- → Two molecules of pyruvate are the end products of glycolysis.
- → Two molecules of ATP are utilized to start the process of glycolysis and 4 molecules of ATP are produced in metabolic pathway, therefore there is net gain of two molecules of ATP.
- → In aerobic respiration, oxygen is the final electron acceptor and water is formed.

SITES OF:

* Glycolysis → Cytoplasm
* Linked Reaction → Mitochondria
* Krebs Cyclic / Citric Acid Cycle → Mitochondrial matrix
* Respiratory Electron Transport chain → Mitochondrial membraner (cristae)

LINKED REACTION

→ conversion of pyruvate to Acetyl-CoA

→ Coenzyme A consist of nucleotide and a portion of one of B vitamins

Reactions:

Pyruvic Acid → Acetyl Group (2-C) + CO_2 + 2H

Acetyl Group + CoA → Acetyl Co-A

NAD + 2H → $NADH_2$

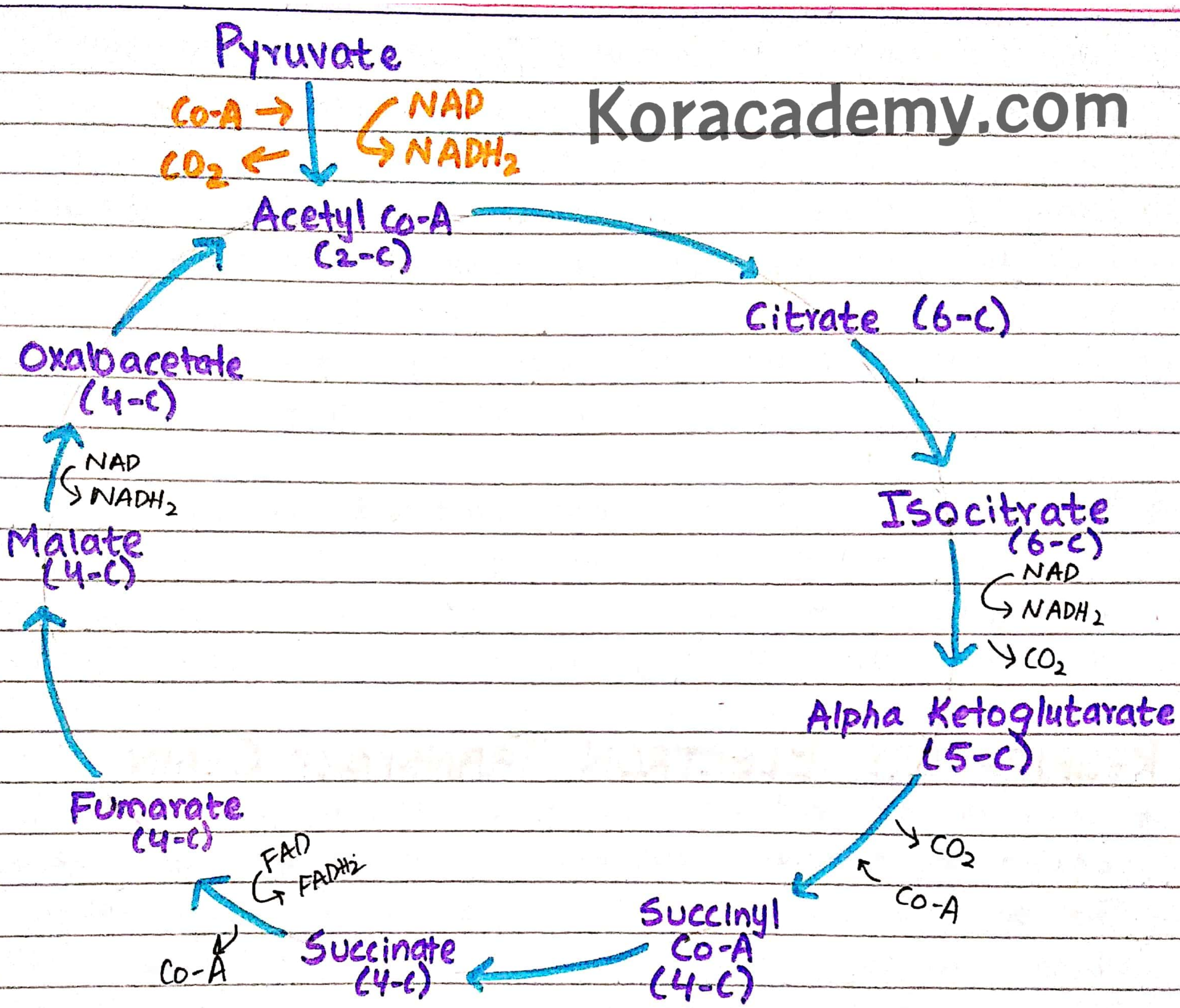
KREB'S CYCLE / CITRIC ACID CYCLE / TRICARBOXYLIC ACID CYCLE

→ Acetyl Co-A (2-C) is completely oxidized into two molecules of CO_2 and hydrogen atoms are removed which reduces NAD and FAD to $NADH_2$ and $FADH_2$.

→ Oxalo acetic acid (4-C) is already present in mitochondrial matrix

→ Citric Acid (6-C)

→ Ketoglutarate (5-C)


Pyruvate
Co-A
CO2
NAD
NADH2
Acetyl Co-A
(2-C)
Citrate (6-C)
Isocitrate
(6-C)
NAD
NADH2
CO2
Alpha Ketoglutarate
(5-C)
CO2
CO-A
Succinyl
Co-A
(4-C)
Succinate
(4-C)
Co-A
FAD
FADH2
Fumarate
(4-C)
Malate
(4-C)
NAD
NADH2
Oxaloacetate
(4-C)

→ The two carbons of acetyl group which entered into the Krebs cycle are oxidized into two molecules of CO_2.

→ Overall 8 molecules of $NADH_2$, two molecules of $FADH_2$, and two molecules of ATP are formed from one glucose molecule in mitochondrial matrix.

→ There are two turns of Krebs cycle for one glucose molecule as two pyruvate are formed in glycolysis.

→ Two molecules of CO_2 are produced in one Krebs cycle so total 4 molecules of CO_2 are produced from one glucose molecule.

→ Two molecules of CO_2 are released in Linked Reactions.

RESPIRATORY ELECTRON TRANSPORT CHAIN

→ oxidation of reduced coenzymes $NADH_2$ and $FADH_2$ produced in glycolysis and Kreb's cycle by molecular oxygen.

→ The pairs of hydrogen atoms pass along a series of electron carriers called coenzymes and cytochromes.

→ The final electron acceptor at the end of electron transport chain is oxygen forming water.

→ Various Molecules involved in ETC are:
$NADH_2$, $FADH_2$, coenzyme Q, cytochrome b, cyt.c, cyt.a, cyt.a_3.

→ The carriers of ETC are present on cristae

→ In ETC, the proton gradient develop across the intermembrane space.

SYNTHESIS OF ATP

1. Light Reactions → Photophosphorylation
2. Glycolysis → Substrate Level Phosphorylation
3. Kreb's Cycle → Substrate Level Phosphorylation
4. Electron Transport Chain → Oxidative Phosphorylation

PRODUCTS OF :

1. Light Reaction → ATP + NADPH
2. Dark Reaction / Calvin Cycle → Sugar
3. Glycolysis → 2 Pyruvic Acid + 2ATP + 2 $NADH_2$
4. Linked Reaction → 2 Acetyl Co-A + 2 CO_2↑
5. Kreb's Cycle → 4 CO_2 + 8 $NADH_2$ + 2 $FADH_2$ + 2ATP
6. Electron Transport chain → 34 ATP + H_2O

TOTAL ATP

Glycolysis → 2

Kreb's Cycle → 2

Electron Transport Chain → 34

Total → 38

CELLULAR RESPIRATION OF:

1. PROTEINS

→ Proteins broken into amino acids
→ Amino group removed from amino acids forming ammonia
→ Remaining molecule enters the Kreb's cycle according to no. of carbon atoms

2. LIPIDS (FATS)

→ hydrolyzed into glycerol and 3 fatty acids.
→ Glycerol (3-C) converted into PGAL and enters glycolytic pathway.
→ Each fatty acid degraded into 2-C fragments acetyl groups which enters into Kreb's cycle.
→ e.g oleic acid is a fatty acid with 18 carbon atoms and breaks down into 9 acetyl groups.
→ These nine acetyl groups would generate 108 ATP molecules.

ANAEROBIC RESPIRATION (FERMENTATION)

→ incomplete breakdown of glucose without the utilization of oxygen.

→ Fermentation consist of two steps

1. Glycolysis
2. Reduction of pyruvate into alcohol or lactate

1. LACTIC ACID FERMENTATION

→ occurs in muscles cells of human and in many microorganism.

→ First step : Glycolysis

→ Second step : Reduction of pyruvic acid (3-C) by $NADH_2$ into lactic acid (3-C).

→ Yields only 2 ATP molecules.

2. ALCOHOLIC FERMENTATION

→ brought about by microorganisms

→ First step : Glycolysis

→ Second step : Pyruvic Acid is converted into ethyl alcohol (2-C) and CO_2

$$\text{Pyruvic Acid} \xrightarrow{\nearrow CO_2} \text{Acetaldehyde} \xrightarrow{NADH \to NAD} C_2H_5OH + ATP$$

→ 2 ATP molecules are produced

PHOTO RESPIRATION

→ The process in which oxygen combines with RuBP in the presence of sunlight and CO_2 is produced.

→ RuBisCo can act both as carboxylase and oxygenase. The reaction depends on concentration of CO_2 and O_2.

→ occurs in dry and hot weather when stomata are closed and CO_2 concentration ~~increase~~ decrease in leaf.

STEPS

→ In stroma:

RuBP + O_2 ⟶ Glycolate

→ In Peroxisome:

Glycolate ⟶ Glycine (simplest amino acid)

→ In mitochondria:

Glysine ⟶ Serine + CO_2

C4 PHOTOSYNTHESIS

C3 PLANTS

→ 3-C compound, PGA formed as first detected product.

→ RuBisCo is used to react CO_2 with RuBP

→ Chloroplasts present only in mesophyll cells of leaf

→ All mesophyl cells carry out Calvin cycle by fixing CO_2 and producing glucose.

C4 PLANTS

→ plants growing in dry and hot conditions
→ 4-C compound called oxaloacetate is the first product of CO_2 fixation in dark reactions
→ use pepco (phosphoenol pyruvate carboxylase) instead of RuBisCo to fix CO_2 to a compound called phosphoenol pyruvate (PEP)
→ PEP is reduced to malate
→ Malate carries CO_2 to special type of cells called bundle sheath cells where Calvin cycle proceeds
→ Chloroplasts are present both in mesophyll cells and in bundle sheath cells.
→ Mesophyll cells only fix CO_2 by using pepco while bundle sheath cells carry out Calvin cycle ~~using~~ producing glucose.
→ e.g sugar cane, maize etc

→ Final electron acceptor of non-cyclic light reaction is NADP.

→ Final electron acceptor of cyclic light reaction is PSI.

→ Final electron acceptor of E.T.C is oxygen

→ End product of E.T.C is water

→ Chloroplast, peroxisome and mitochondria is involved in photo-respiration.

→ 1 Acetyl Group produce 12 ATP

→ A compound having 16-C yield 96 ATP

→ In head region of chlorophyll functional group is attached to 2nd carbon of pyrrole ring

→ No. of ATP produced from one $NADH_2$ of link reaction during ETC is 3

→ Spongy mesophyll cells and palisade mesophyll cells is the characteristic anatomy of only C3 plants

→ No. of $NADH_2$ produced in linked reaction is 2

→ Total ATP produced in link reaction is zero

→ No. of ATP produced during oxidation of one molecule of one $FADH_2$ in ETC is 2