YAKEEN NEET 2.0

2026

Photosynthesis in Higher Plants

BOTANY | Lecture: 01

By: Vipin Sharma Sir

PHOTOSYNTHESIS

Sunlight formation of FOOD

Sun (Ultimate source of energy on Earth)

Sunlight

Green plant parts (traps light)

Plants (Producer) → HERBIVORE (directly depends on plants) (Primary consumer) → CARNIVORE (indirectly depends on plants ∴ secondary consumer)

- Equation of photosynthesis: $6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + 6O_2$

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} \underbrace{C_6H_{12}O_6}_{\text{(FOOD)}} + 6O_2 + 6H_2O$$

O_2 is also a biproduct of photosynthesis

- Equation of PHOTOSYNTHESIS

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2\uparrow$$

- FEATURES of photosynthesis

1. Light energy gets converted into chemical energy (Law of conserv. of energy)

2. Physico-chemical process (physical + chemical reactions)

   $\Downarrow$ Light depend reactions

   Dark reaction $CO_2 \rightarrow C_6H_{12}O_6$

3. Redox reaction

   Reduction $\Downarrow$

   $CO_2 \longrightarrow C_6H_{12}O_6$

   CO_2: 1 'C', 2 'O' (CO₂ is most oxidised form of carbon)

   $C_6H_{12}O_6$: 6 'C', 6 'O', 12 'H' } 1 'C', 1 'O', 2 'H'

   - 'O' $\downarrow$ & 'H' $\uparrow$ per carbon

   $\therefore$ REDUCTION

   oxidation $\rightarrow$ $H_2O \longrightarrow O_2$

   'H' removed

   $\therefore$ oxidation

4. Products : Glucose + O_2

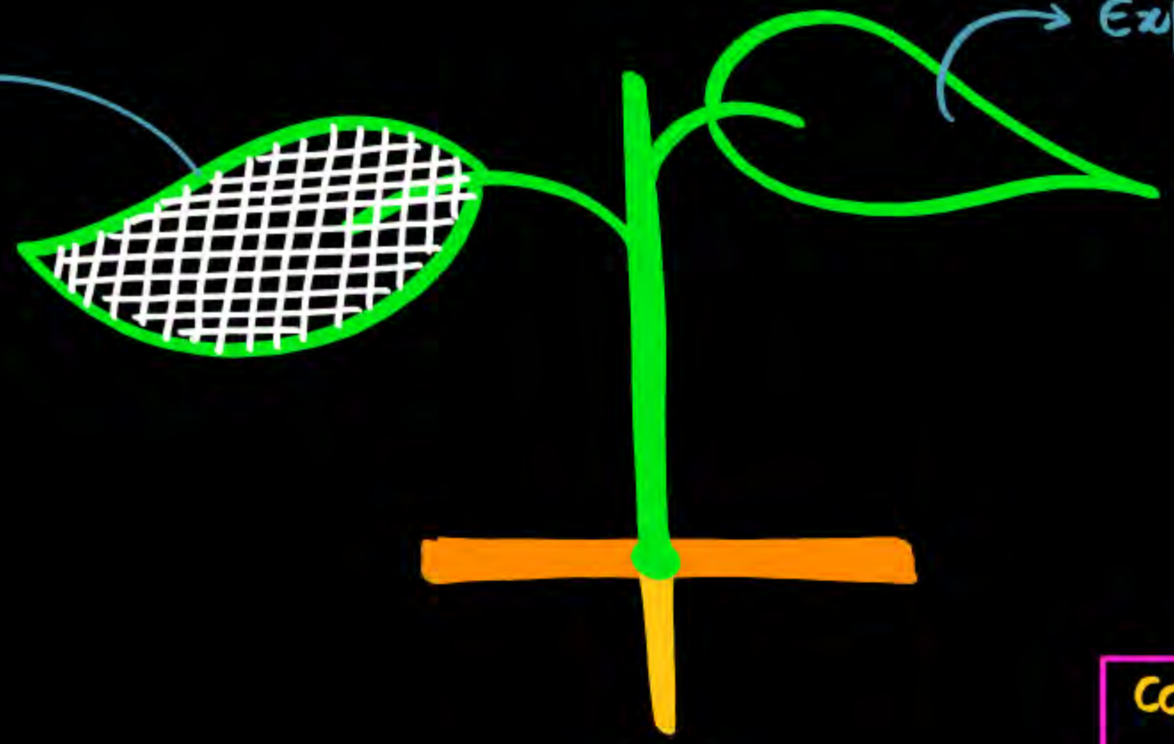
5. Anabolic process

6. Endothermic / endergonic process

7. Inorganic chemicals are converted into organic chemicals

   CO_2 $\quad$ $C_6H_{12}O_6$

Variegated Leaf Experiment



Covered LEAF

- No sunlight will fall on leaf
- No photosynthesis

∴ Glucose ✗

∴ STARCH ✗

STARCH TEST ⊖ve

Exposed leaf

∴ capture LIGHT

∴ Photosynthesis ↑

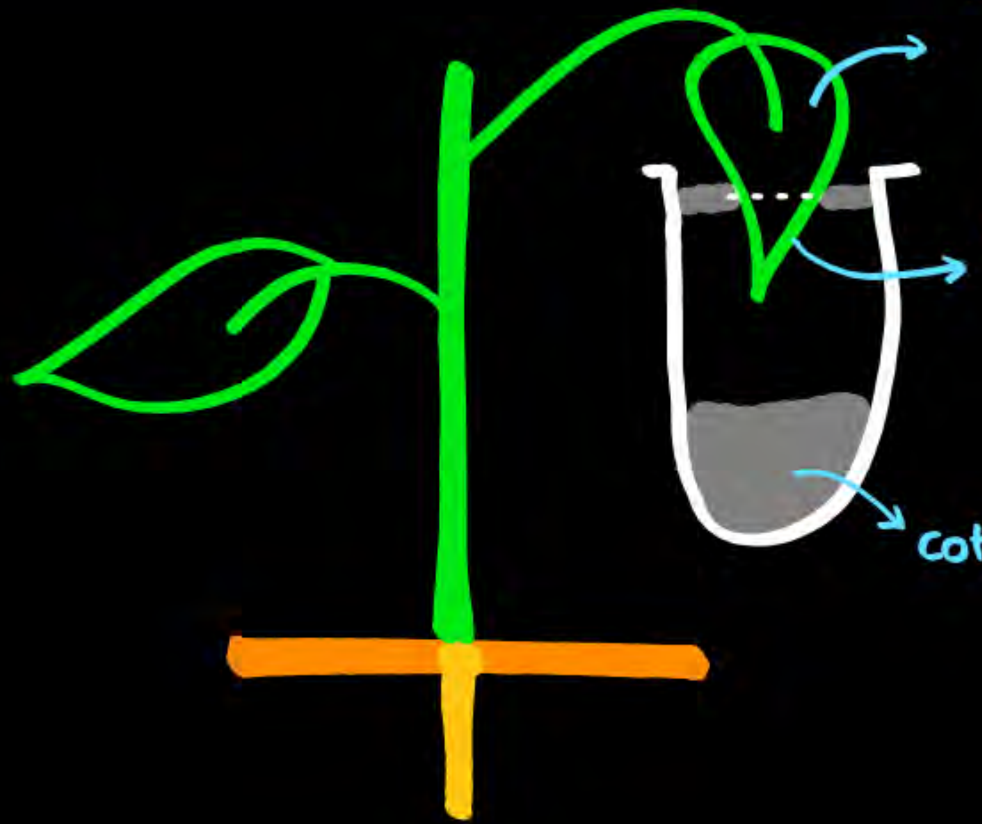
∴ Glucose ↑

∴ STARCH ↑

STARCH Test ⊕ve

CONCLUSION: LIGHT is imp. for photosynthesis

Moll's Half Leaf Experiment



CO_2 available ∴ Photosynthesis ↑
Glucose ↑ ∴ STARCH ↑ ∴ STARCH TEST ⊕ve

No CO_2 ∴ No photosynthesis
∴ No glucose ∴ No starch ∴ STARCH TEST ⊖ve

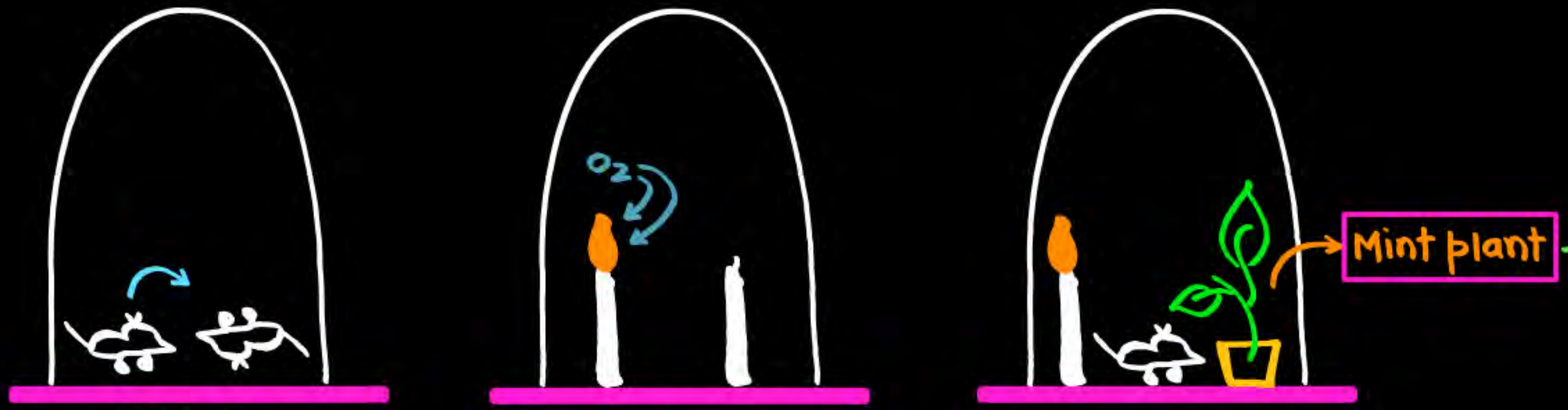
cotton soaked in 'KOH'
⇓
Absorbs CO_2
∴ no CO_2 within test-tube
∴ No photosynthesis

$\boxed{\text{CONCLUSION: } CO_2 \text{ is imp. for photosynthesis}}$

Priestley's Experiment (1733-1804)

Bell Jar experiment: 1770
Discovered O_2 in 1774

- Told us about the importance of AIR



Case-I

Mouse suffocated after sometime in BELL-JAR

- Mice depleted the air quality

Case-II

Candle was extinguished after sometime in BELL JAR

- candle depleted the air quality

Case-III

All things were in equilibrium

- candle was not extinguished
- Mice was live
- Mint plant was also live

∴ MINT Plant restored the air quality depleted by candle & mice

Julius Von Sachs (1854)

बोरा ∴ $\boxed{\text{Store}}$

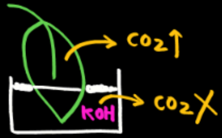
1. Glucose is stored as starch in plants
2. Chlorophyll are found in special bodies named chloroplast

* Sachs : Glucose → Starch
  Chlorophyll → Chloroplast

* $6CO_2 + 6H_2O \xrightarrow[\text{Chl.}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2 \uparrow$
  (FOOD)

* Variegated leaf exp.

* Moll's Half Leaf exp.

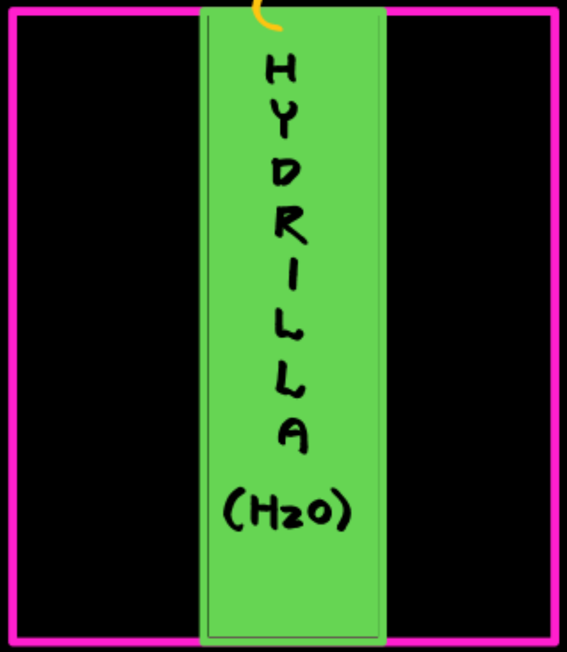


* Priestly: BellJAR exp.

Ingenhousz Experiment (1730-1799)

LIGHT

Aquatic plant



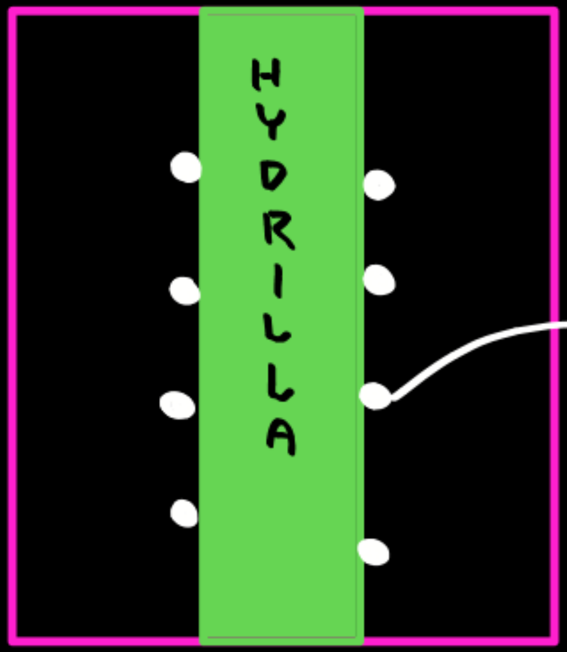
DARK CONDITION
(No sunlight)

⇓

No photosynthesis

∴ No O_2 released

∴ No BUBBLE



will only be seen in LIGHT

∴ LIGHT is imp. for photosy. & O_2 release

O_2 के bubbles

Inc. the air quality in immediate env.

(Now placed in sunlight)

⇓

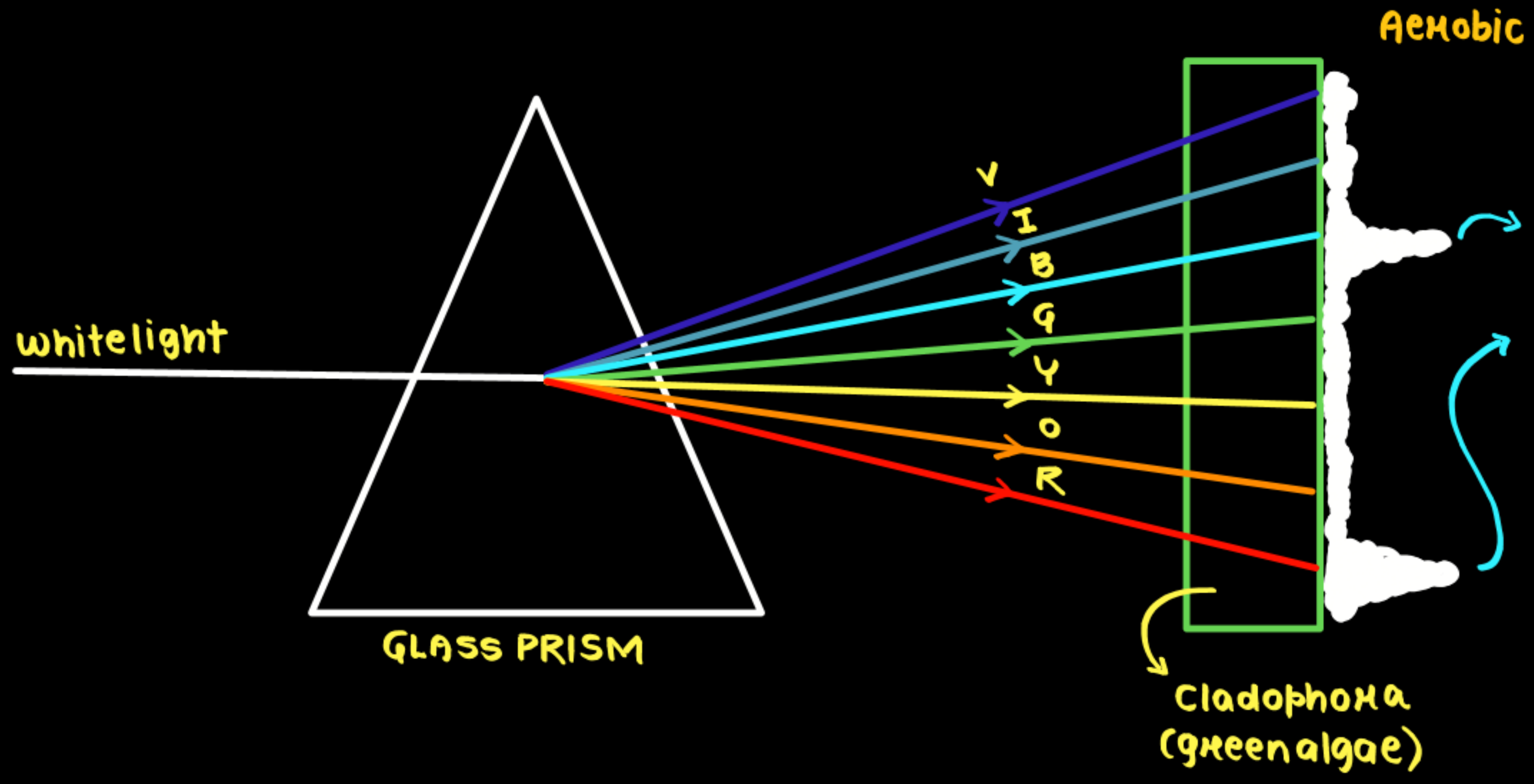
Photosynthesis will occur

∴ O_2 gas will be evolved

↓

BUBBLES will be seen

Engelmann's Experiment (1843-1909)



Aerobic bacteria accumulated

∵ O_2↑ is released by plant here

∵ Photosynth.↑ is performed

⇓

Photosynthesis is done best by Blue & Red light of visible region

(NOTE : Red > Blue)

⇓

- Engelmann gave us first action spectra of photosynthesis
- Action spectra resembles with absorp. spectra of chl-a & chl-b

Van Neil (1897-1985)

- Van Neil was a MICRO-BIOLOGIST
  Purple-sulphur bacteria

- In photosynthesis 'CO_2' is reduced to '$C_6H_{12}O_6$'
  To reduce 'CO_2', hydrogens from a suitable oxidisable compound are added to CO_2

e.g., In green plants: $CO_2 + H_2O \xrightarrow[\text{sunlight}]{\text{chlorop.}} CH_2O + O_2$ released from H_2O & not from CO_2

e.g., Green & purple 'Sulphur' bacteria: $CO_2 + H_2S \xrightarrow[\text{chlorop.}]{\text{sunlight}} CH_2O +$ Sulphur / Sulphate

These bacteria shows Anoxygenic photosynthesis
Ant

- General equation of photosynthesis : $6CO_2 + 6H_2O \xrightarrow[\text{Chlorophy.}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$

- Emperical equation : $CO_2 + H_2O \xrightarrow[\text{Chlorophy.}]{\text{sunlight}} CH_2O + O_2$

- Van Neil : $CO_2 + H_2\text{'A'} \xrightarrow[\text{Chlorophy.}]{\text{sunlight}} CH_2O + 2\text{'A'}$

$CO_2 + H_2\text{'O'} \xrightarrow[\text{Chlorophy.}]{\text{sunlight}} CH_2O + 2\text{'O'}$ → O_2

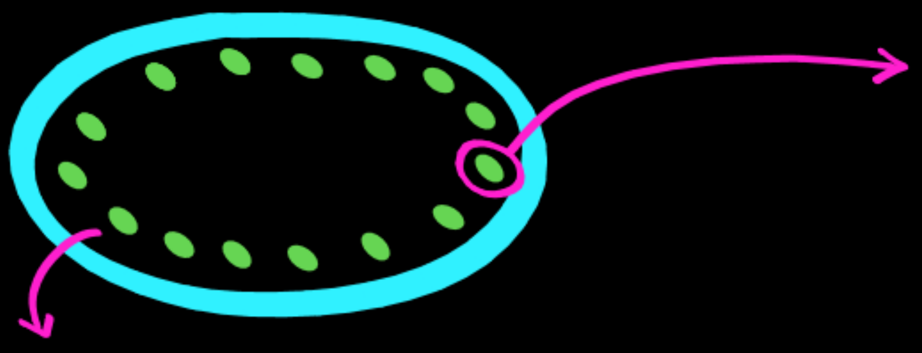
$CO_2 + H_2\text{'S'} \xrightarrow[\text{Chlorophy.}]{\text{sunlight}} CH_2O + 2\text{'S'}$ → S_2

- 'O_2' in photosynthesis comes from 'H_2O' NOT 'CO_2'
- To prove this, we used radioisotope O^{18}

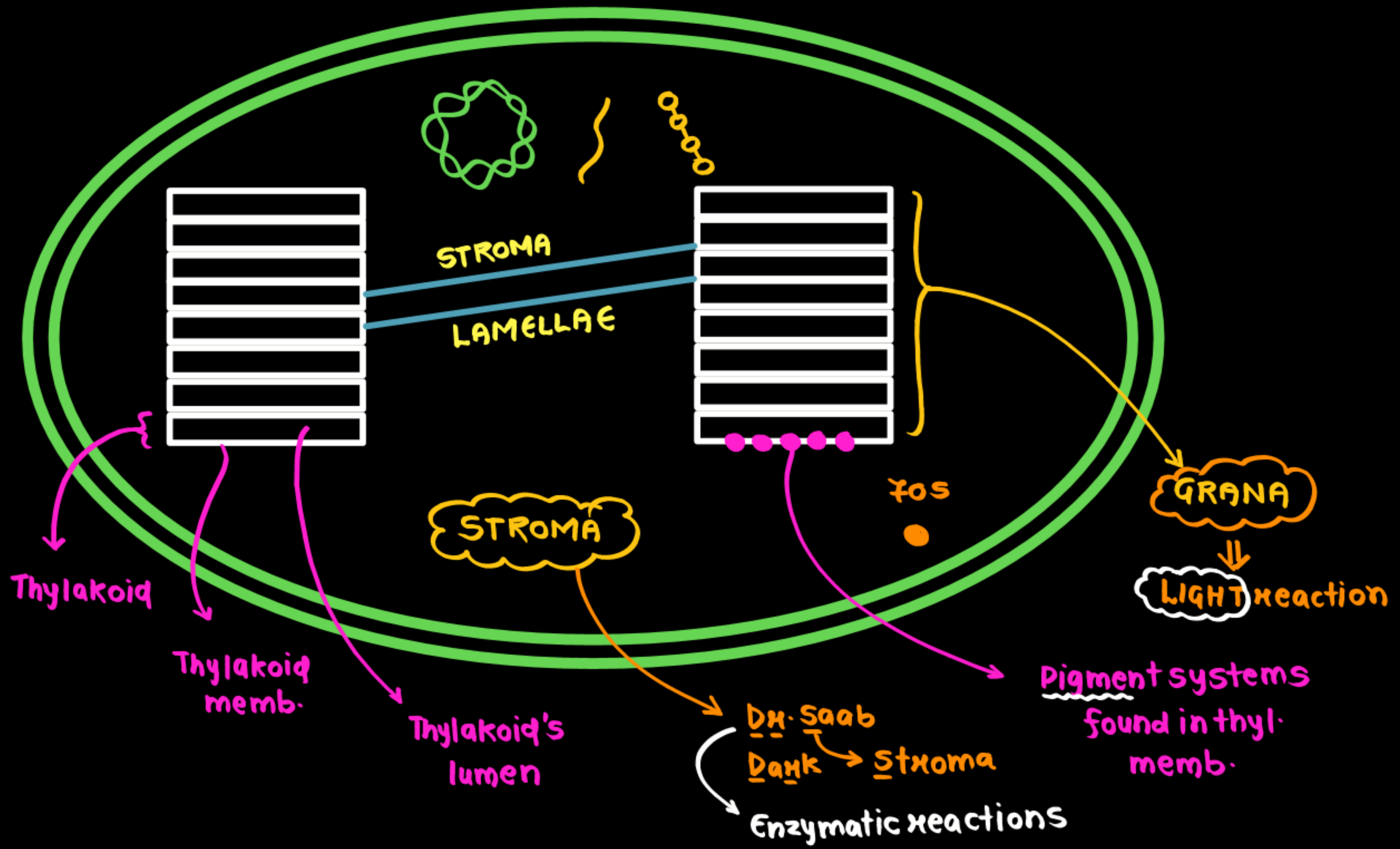
$CO_2 + H_2O \longrightarrow C_6H_{12}O_6 + O_2$

SITE OF PHOTOSYNTHESIS

- Green parts of plant performs photosynthesis as they have many mesophyll cells



Chloroplasts align themselves on boundary of mesophyll cells to capture optimum sunlight



Light and Dark Reaction

LIGHT REACTION

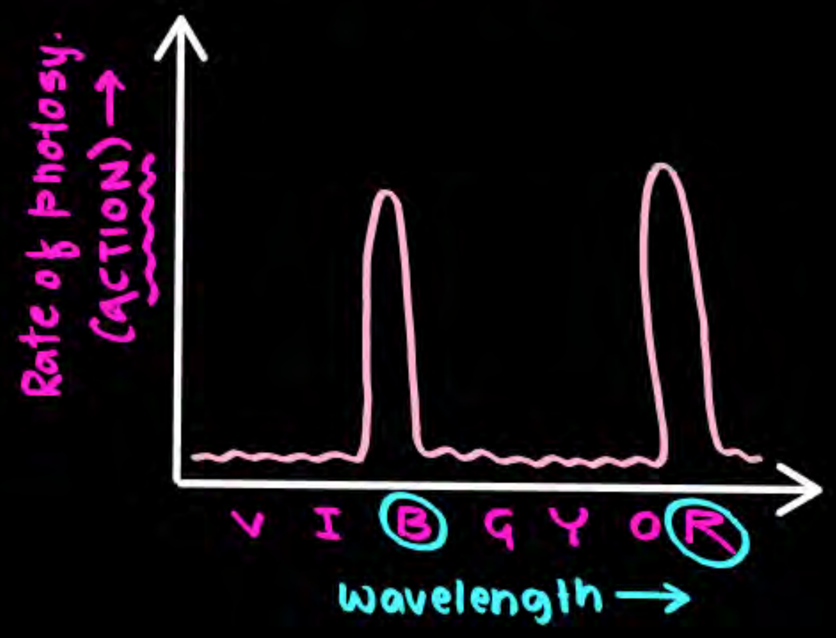
- Location: Grana
  ∵ pigment system to trap light is ⊕nt on thylakoid membrane
- Directly depends on LIGHT
- Product: ATP, NADPH
  O_2 will be released

DARK REACTION

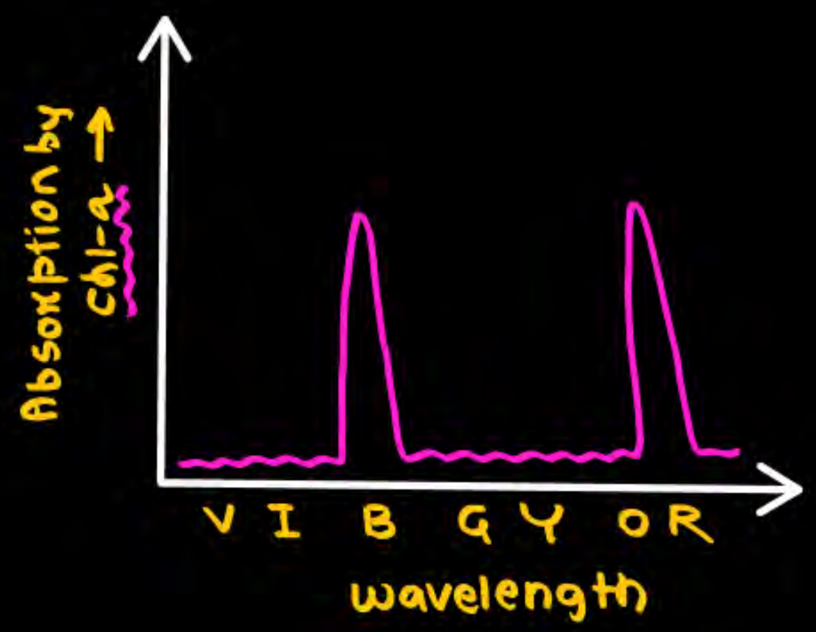
- Location: stroma
- Product: $CO_2 \longrightarrow C_6H_{12}O_6$ *
  (reduction of CO_2 takes place here)
- Name: it is a misnomer (misleading)
  ⇓
  It has nothing to do with DARK BUT these reactions depends on the products of LIGHT reaction
  ↓
  $\boxed{\text{ATP, NADPH}}$

Action and Absorption Spectrum

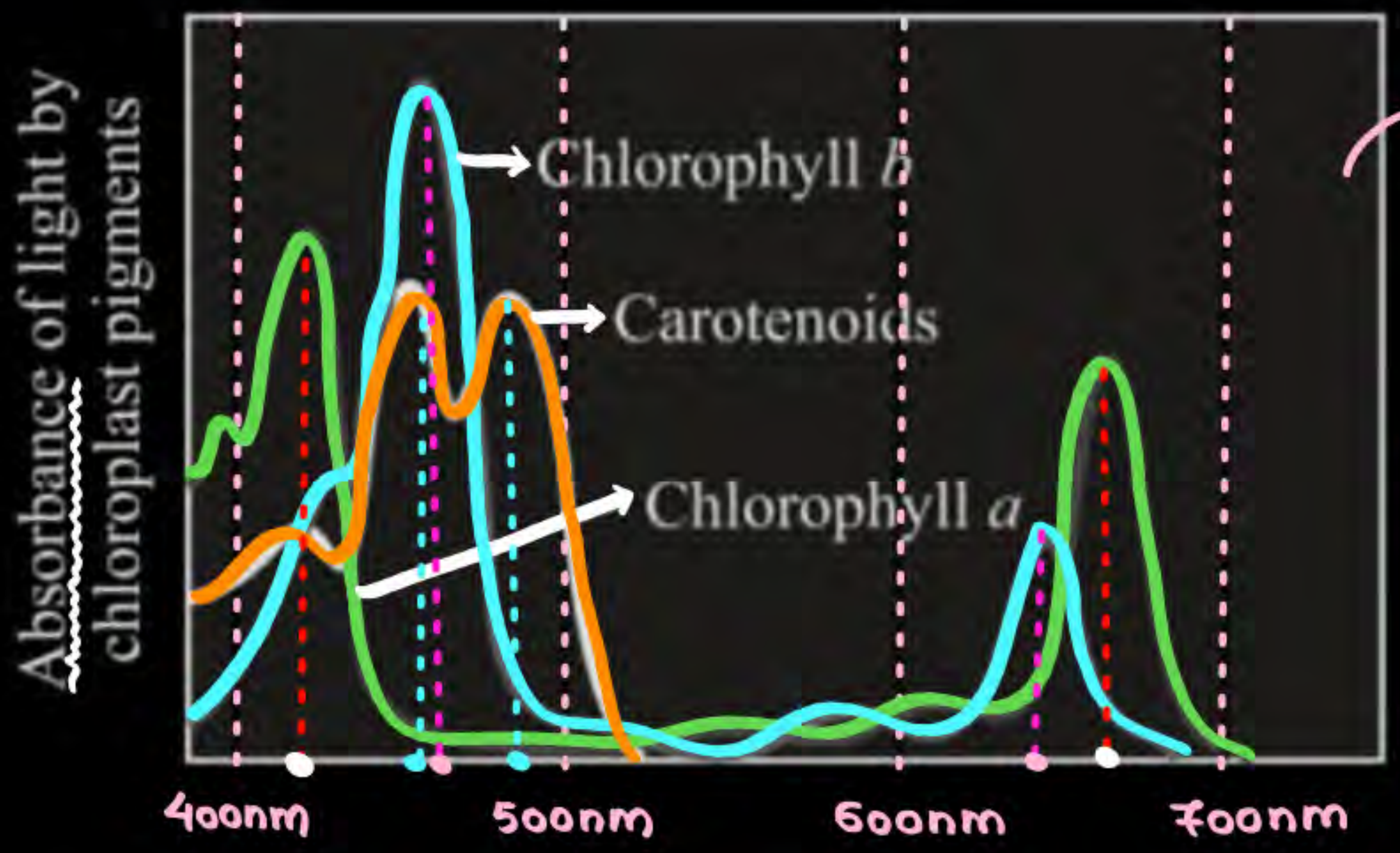
- Graph which represents the regions in which maximum photosynthesis takes place (Action)



- It is a graph which represents that which pigment absorbs which particular wavelength of LIGHT



Action and Absorption Spectrum



Rough IDEA :

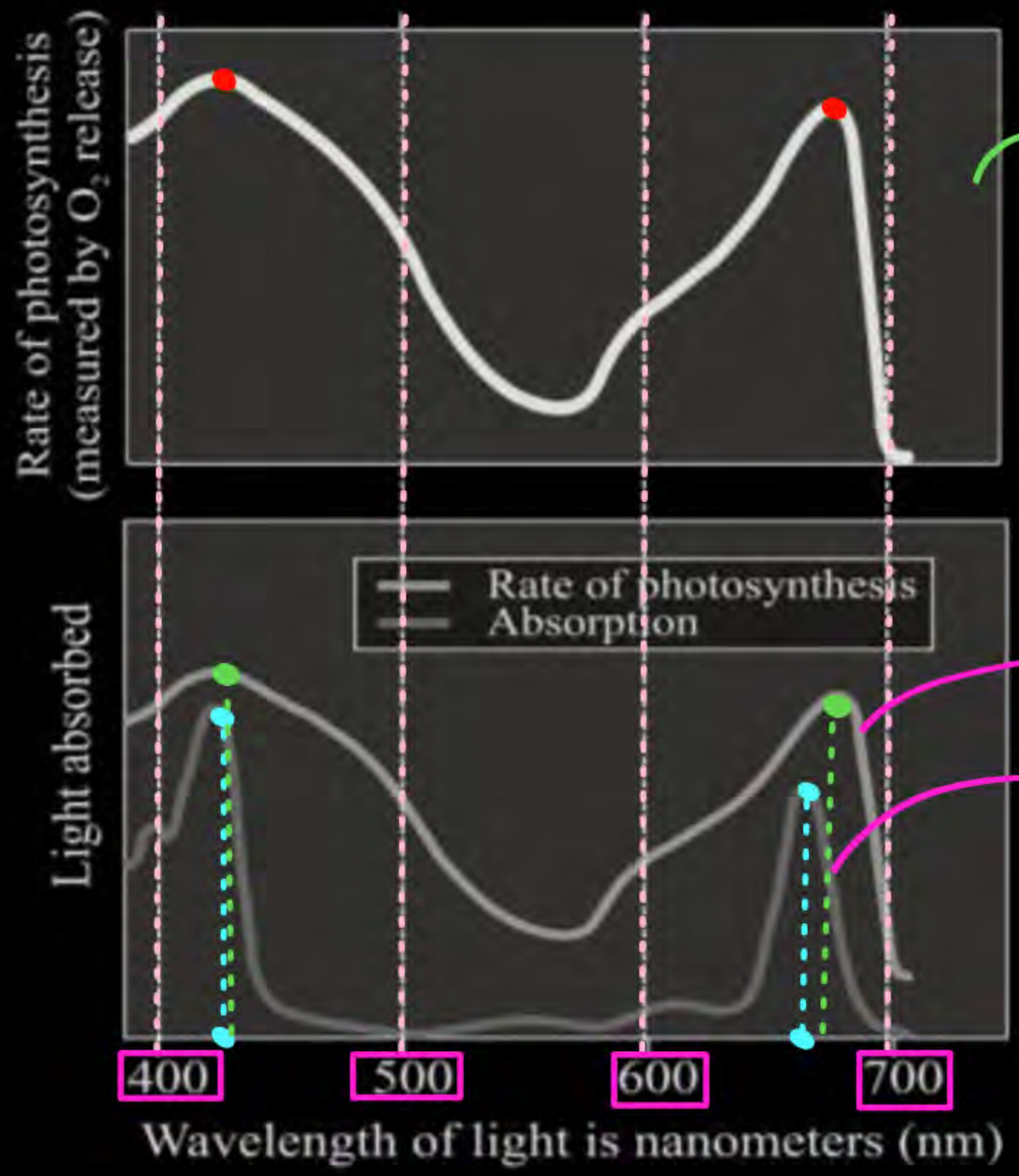
1. Peak absorption by Chl-a : 420nm , 680nm
2. Peak absorption by chl-b : 470nm , 640nm
3. Peak absorption by carotenoid : 490nm

Conclusion: Plants have diff. types of PIGMENTS to absorb complete visible range spectra efficiently

↓

400-700nm

Action and Absorption Spectrum



Absorption spectra of 'Chl-a' is similar to 'Action spectra' of photosynthesis

∴ Chl-a is the Chief pigment / Boss Pigment

- All rest pigments like Chl-b, xanthophyll, carotenoids are accessory pigments

Action spectra of photosynthesis

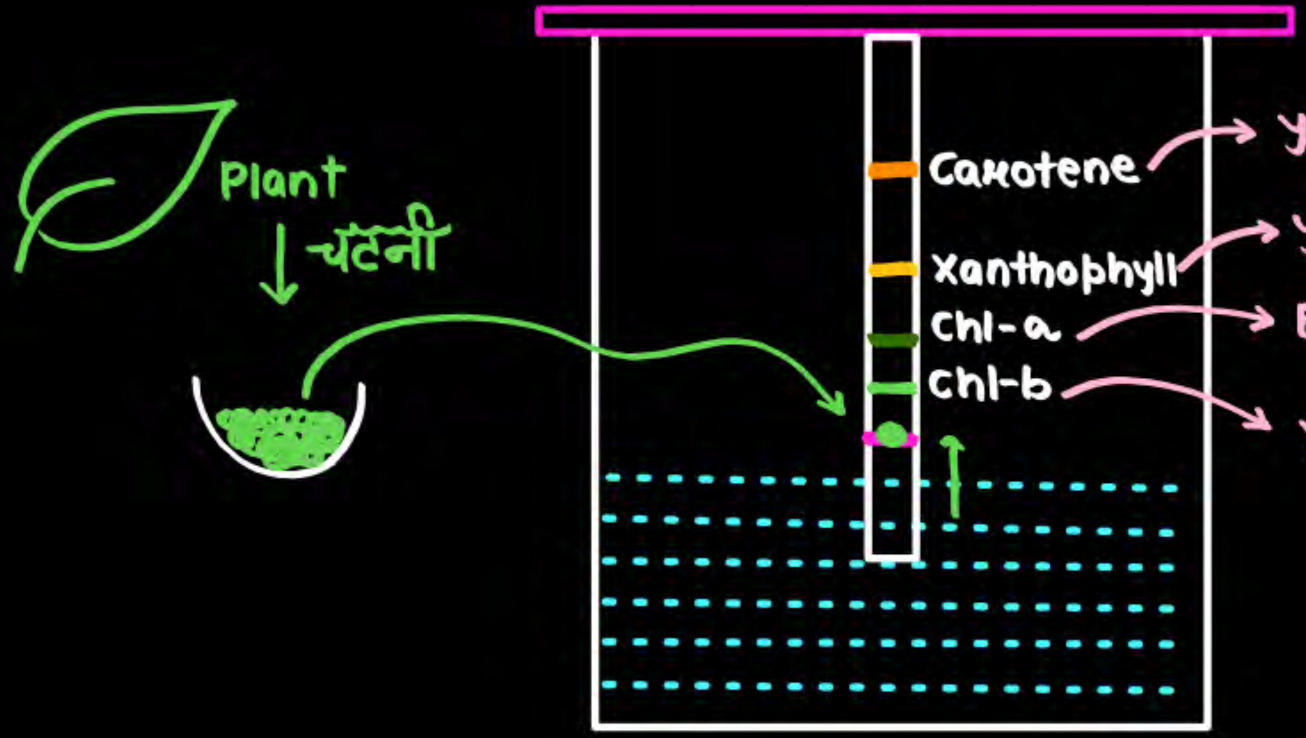
Absorption graph of Chl-a

Pigments in Leaf

- we can separate all diff. pigments of leaf via paper chromatography technique

  chromatography → colour/pigment

  paper ↳ porous (capillary action ↑)

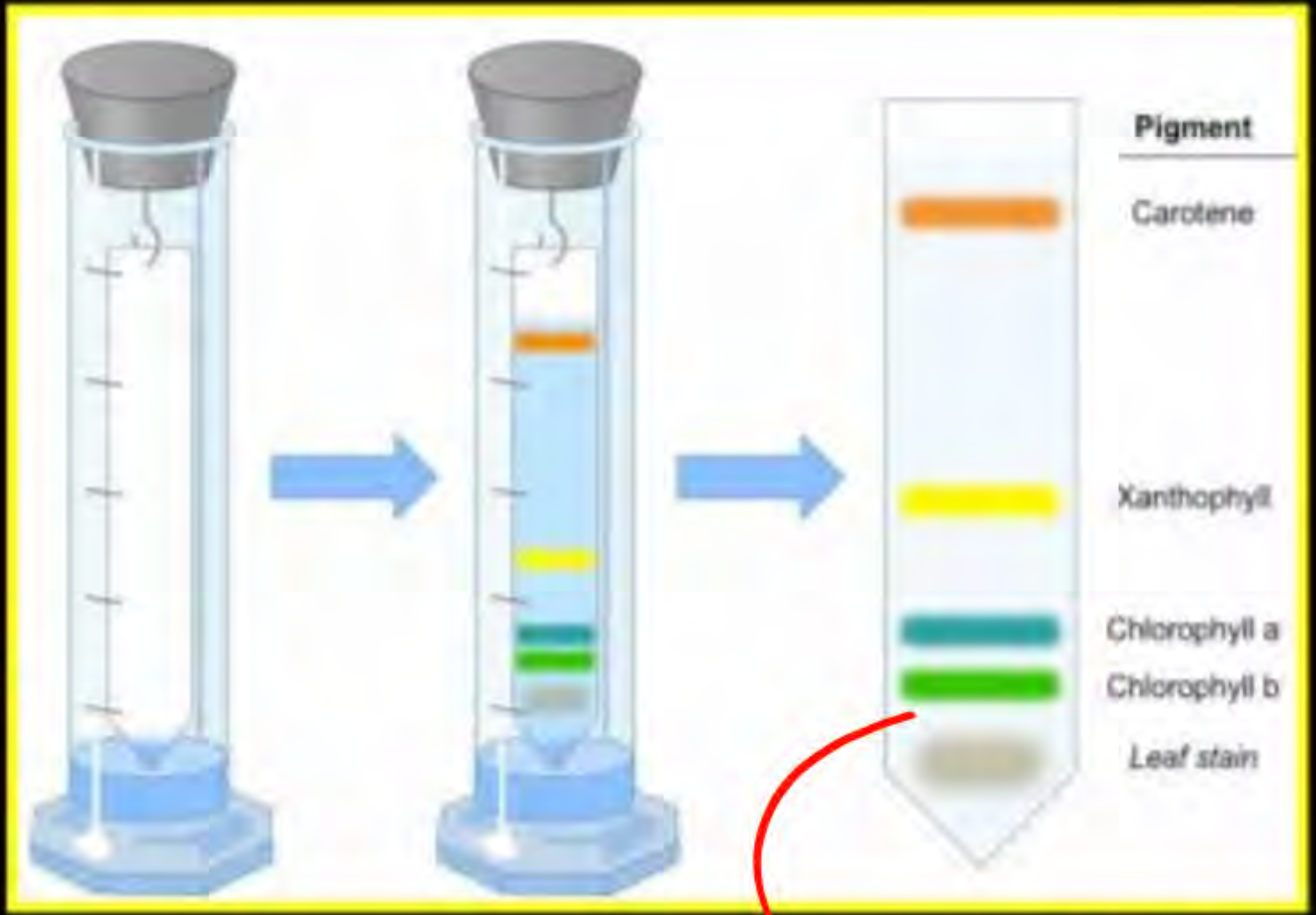


Carotene → yellow-orange (accessory)

Xanthophyll → yellow (accessory)

Chl-a → Bright/blue-green (chief)

Chl-b → yellow-green (accessory)



BAX-C → carotene

↓ Chl-b, Chl-a, xanth.

Chl-b → closest to the dot/H_2O (heaviest)

- There are 2 photosystems (PS) in plants namely PS-I and PS-II
- They are named on the basis of their sequence of discovery ∴ PS-I was discovered before PS-II
- PS-II participates before PS-I in Non-cyclic photophosphorylation

Photosystems

- **PS-I**
  - Reaction center (BOSS PIGMENT)
    ⇓
    Chl-a
    (P700)
    ⇓
    absorption maximum at 700nm
  - Light Harvesting complex / LHC / Antenna molecules
    ⇓
    100s of proteins & accessory pigments
- **PS-II**
  - Reaction center (BOSS PIGMENT)
    ⇓
    Chl-a
    ⇓
    P680
    ⇓
    absorption maximum at 680nm
  - Light Harvesting complex / LHC / Antenna molecules
    ⇓
    100s of proteins & access pigments

• Why accessary pigments are needed ?

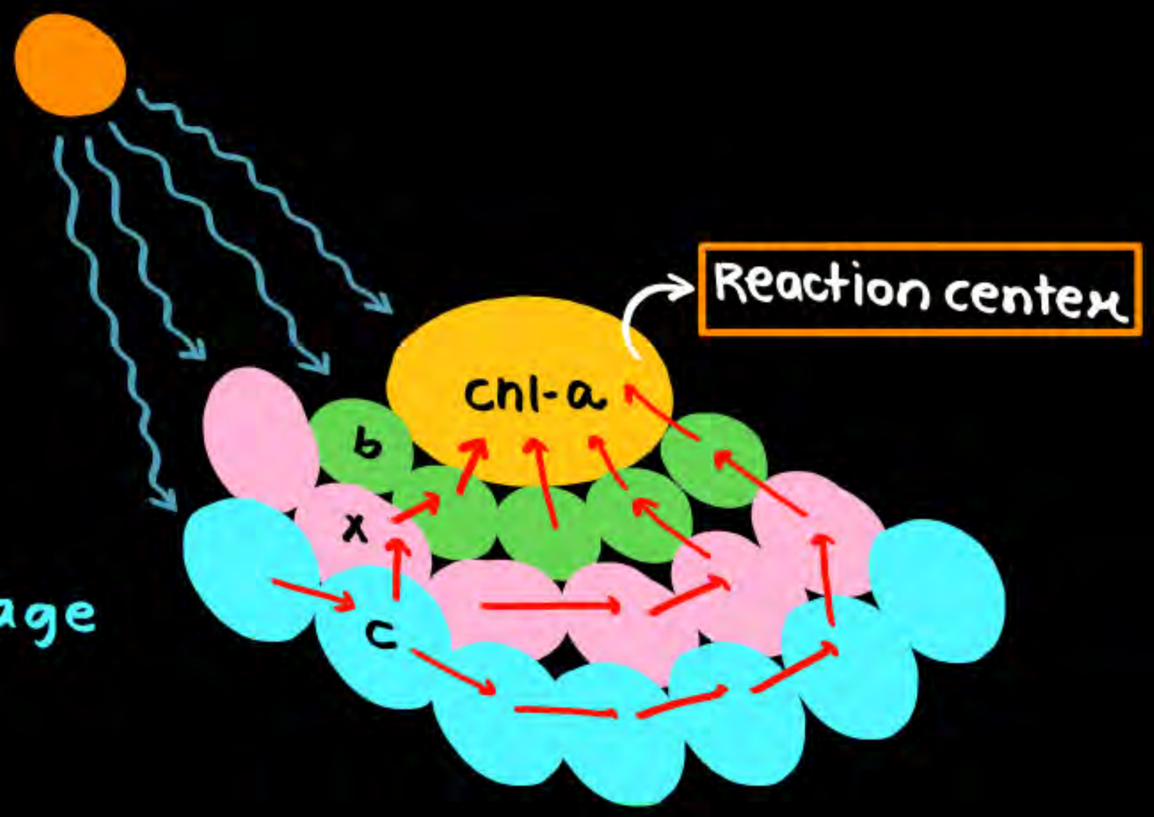
1. A solo pigment can't absorb the light of whole visible Spectra

∴ To trap various light wavelengths we need diff. pigments

2. Accessary pigments protects 'Chl-a' from photo-oxidative damage

⇓

scorching/
↑intensity



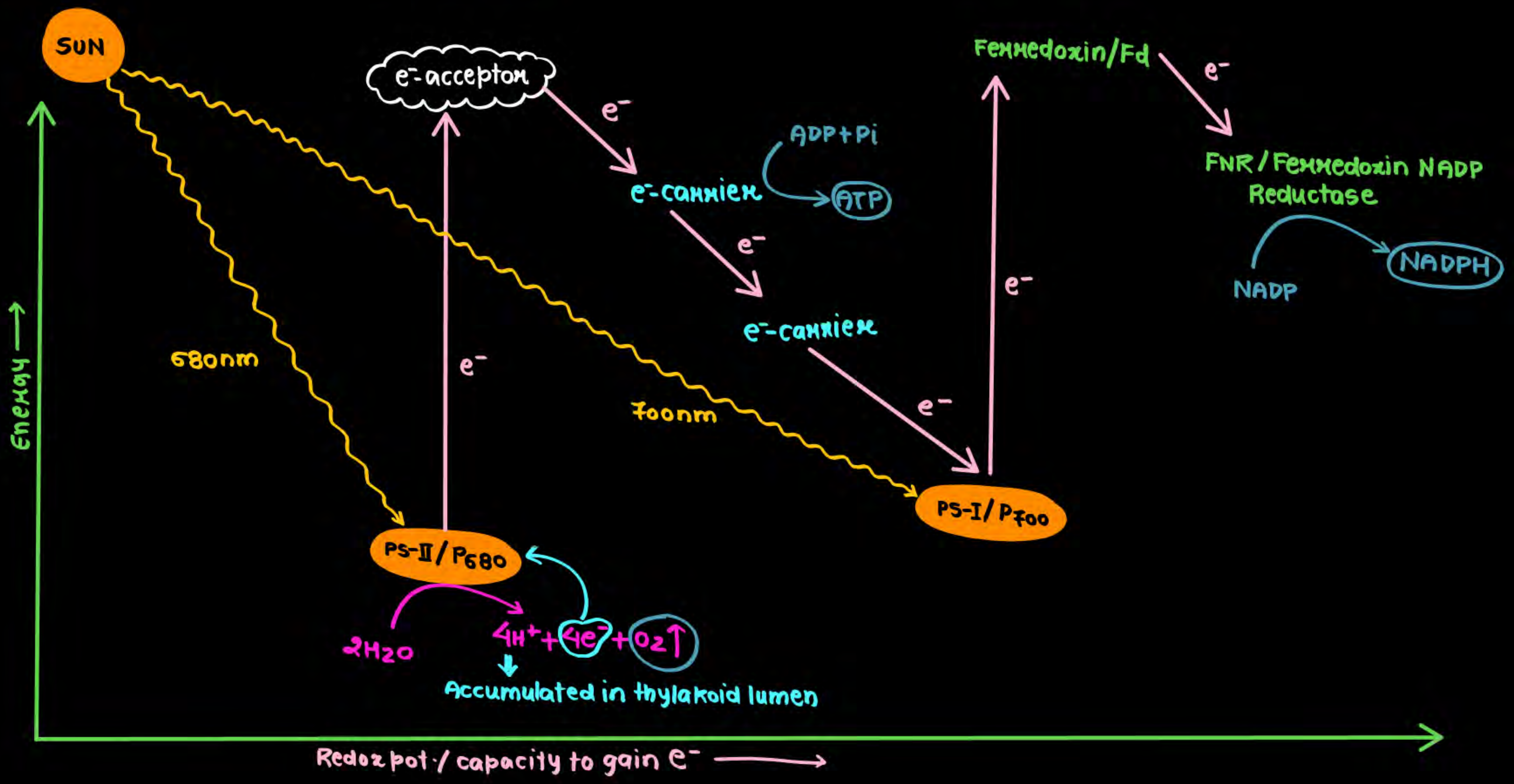
Steps in Light Reaction

1. Absorption of LIGHT
2. Splitting of H_2O or PHOTO-LYSIS of H_2O

$$2H_2O \xrightarrow{Mn, Cl} 4H^+ + 4e^- + O_2\uparrow$$

3. Release of O_2
4. Formation of ATP & NADPH

NON-CYCLIC PHOTOPHOSPHORYLATION



NON-CYCLIC PHOTOPHOSPHORYLATION

e^- from PS-II, donot Come back & is used to make NADPH

Photo: light energy

Phosphorylation: $ADP + Pi \rightarrow ATP$

- H_2O is splitted at PS-II ∵ PS-II was facing continuous loss of e^- → O_2 also released at PS-II
- H_2O is NOT splitted at PS-I
- when e^- move b/w PS-II & PS-I, ATP is synthesised
- NADPH is formed at the end
- 

up → down → up → down

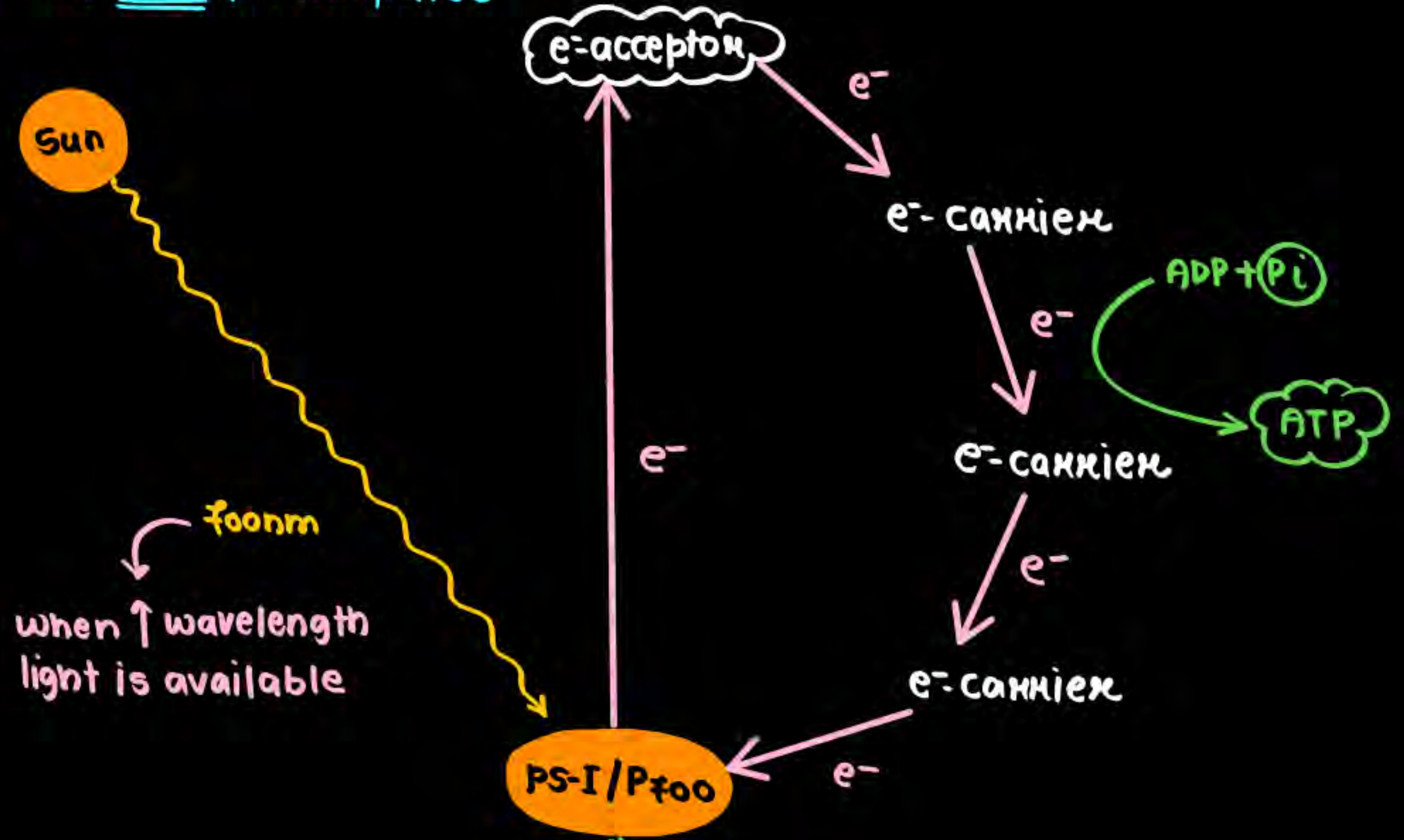
'z' scheme if we see from axis of redox potential

CYCLIC PHOTOPHOSPHORYLATION

↓

e^- will return BACK

- Only <u>PS-I</u> participates



⇓

- No water splitting
- No O_2 released
- No NADPH formed

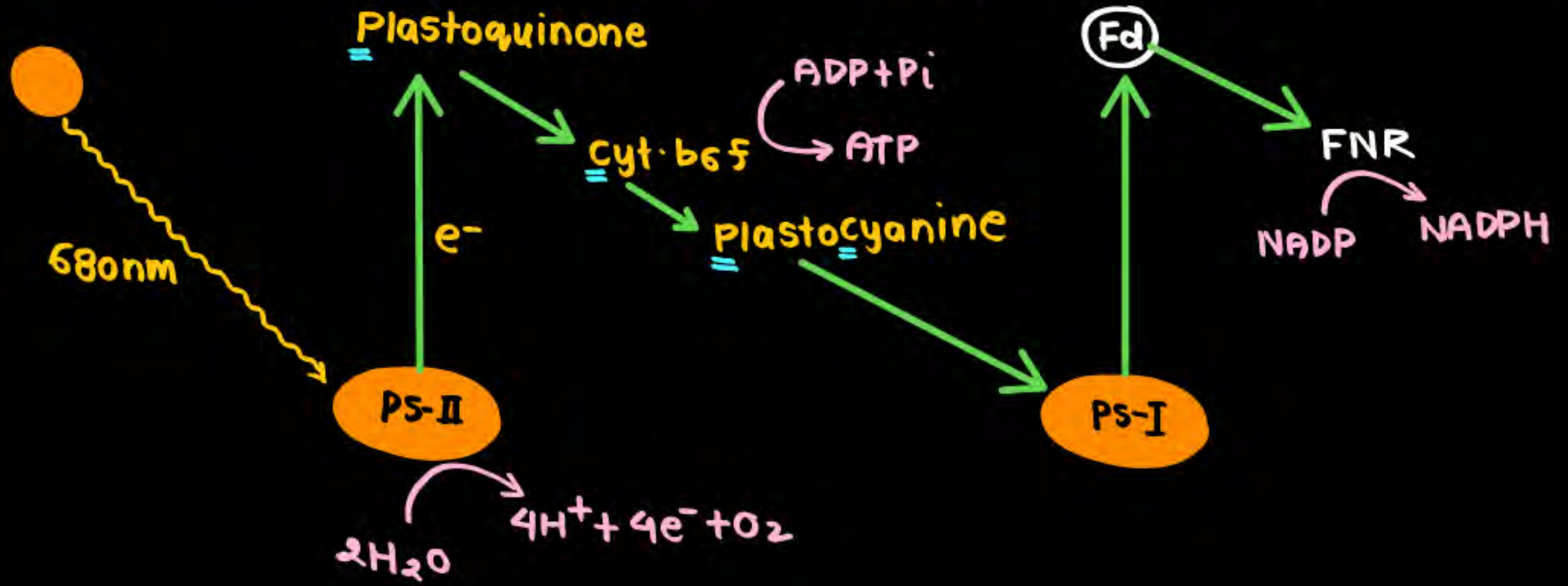
Pointers:

- This process occur in STROMA LAMELLAE where only PS-I is found
- No water splitting complex ⊕nt
- No NADP-reductase (FNR) enzyme is found

Non-Cyclic vs Cyclic Photophosphorylation

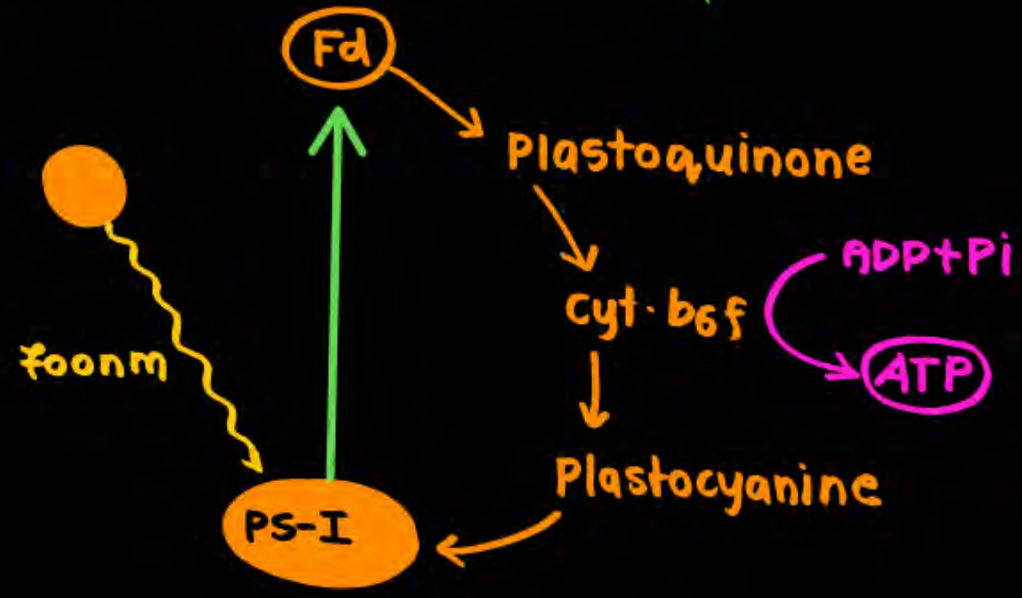
Non-Cyclic

- PS-II & PS-I, both participates
- H_2O splitting at PS-II
  $2H_2O \rightarrow 4H^+ + 4e^- + O_2\uparrow$ evolve
- ATP & NADPH, both are formed

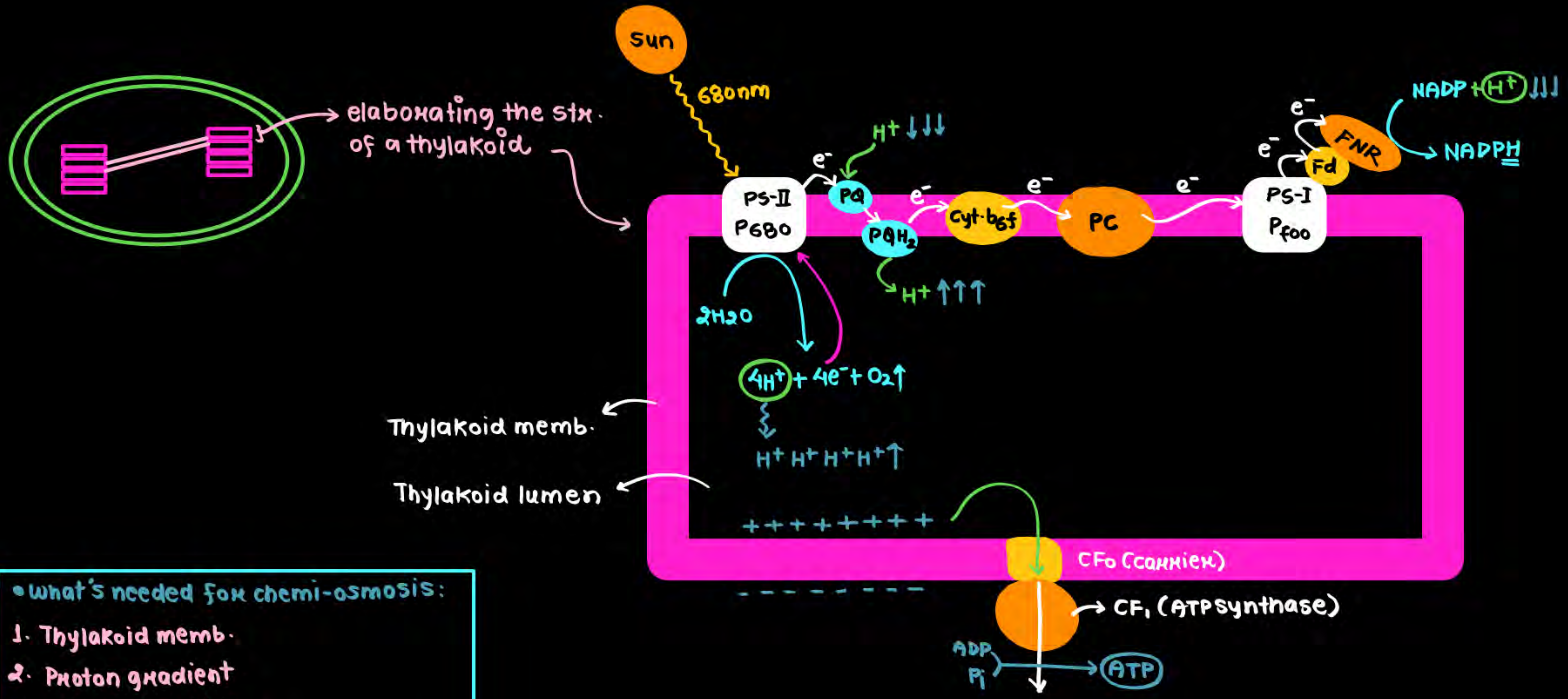


Cyclic

- Only PS-I will participate
- No water splitted
- No O_2 released
- ∵ No FNR is present ∴ No NADPH is formed
- ATP is formed



* ATP is formed in both phosphorylations
∴ ATP formed > NADPH formed
∴ ATP to be used in dark reaction is also more



- what's needed for chemi-osmosis:

1. Thylakoid memb.
2. Proton gradient
3. CF_0 - CF_1 particle
4. e^--carriers

• 3 main reasons for the dev. of proton gradient

1. H_2O splitting associated with PS-II, takes place on inner side of thylakoid memb. i.e., towards lumen

$$2H_2O \xrightarrow{Mn/Cl} 4H^+ + 4e^- + O_2\uparrow$$

$4H^+$ → Lumen↑

$4e^-$ → given to PS-II

O_2 → can go out from stomata

2. NADPH is formed on STROMAL SIDE

NADP + H ⟶ NADPH

H → H^+ from stroma ∴ H^+↓ in stroma

H → e^- → from ETS

3. 'PQ' is a 'H' carrier

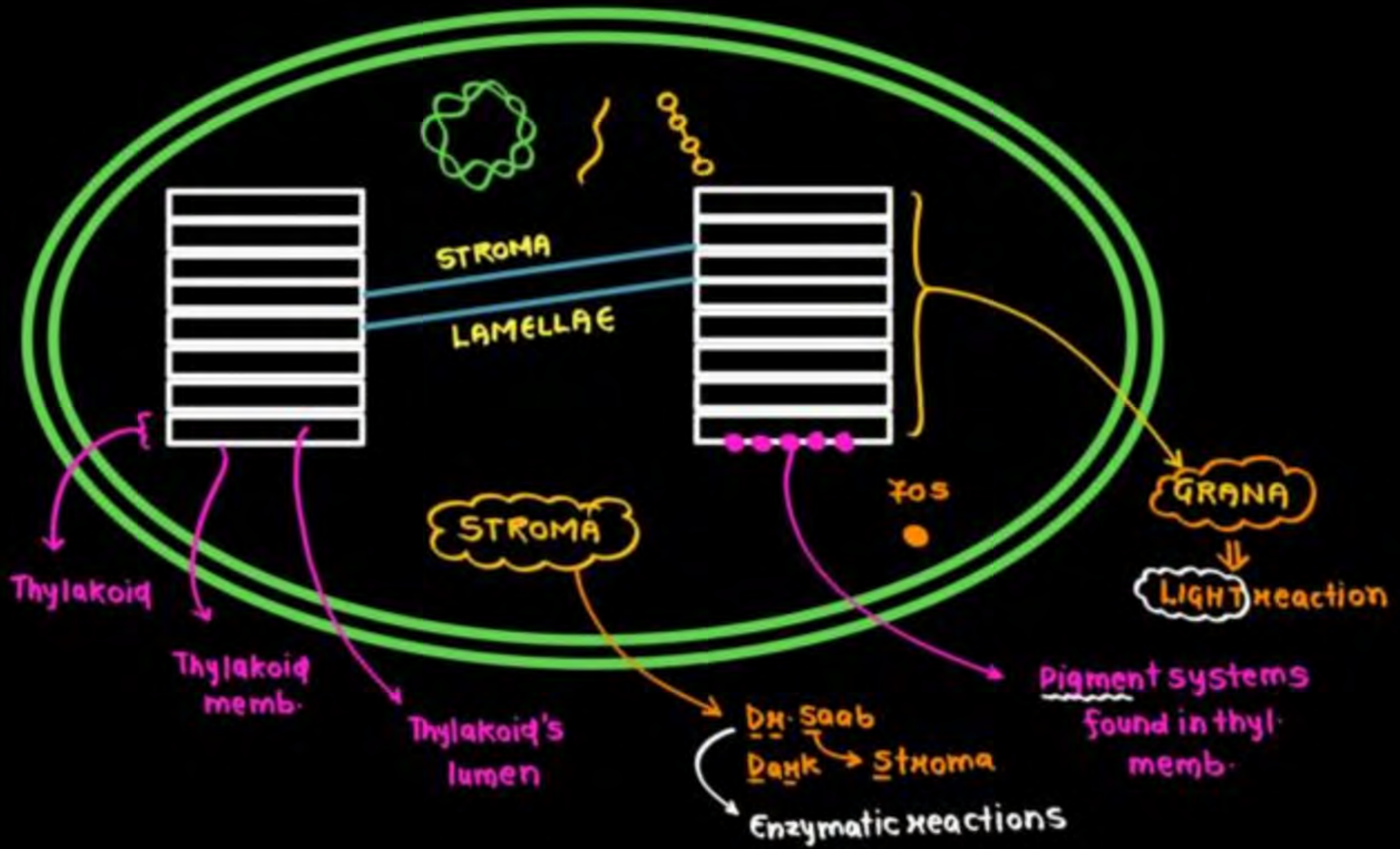
→ takes H^+ from stroma ∴ H^+ in stroma ↓↓

→ dumps H^+ in lumen ∴ H^+ in lumen ↑

SITE OF PHOTOSYNTHESIS

- Green parts of plant performs photosynthesis as they have many mesophyll cells

Chloroplasts align themselves on boundary of mesophyll cells to capture optimum sunlight



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  $\boxed{\text{ATP, NADPH}}$

C3 Cycle

- It is a universal cycle i.e., it occur in all green plants.

- 3-Steps: 1. Carboxylation - most crucial step: RuBP + CO_2 via RuBisco enzyme

2. Reduction: CO_2 is reduced to carbohydrate

3. Regeneration of RuBP

- One carbon is fixed per Calvin cycle ∴ to make a glucose molecule of 6-carbons, 6 rounds of Calvin cycle need to be performed.

- Per CO_2 fixation: 3 ATP and 2 NADPH are needed

∴ For making one glucose molecule (6C): 18 ATP and 12 NADPH are needed

In	Out
Six CO_2	One glucose
18 ATP	18 ADP
12 NADPH	12 NADP

C-acceptors → C_3 → "STABLE" 3C → CO_2 + 2 carbon → 3C

1, 2

CO_2 + 5C → 6C → 3C, 3C

1, RuBP, Rib. bis phosp. (accep.)

C^{14}

UNSTABLE

STABLE

⇓

PGA

C_3

C-acceptors → C_4 → STABLE C_4

↓

CO_2 + ? → 4C

1, 3, 4

PEP, (OAA)

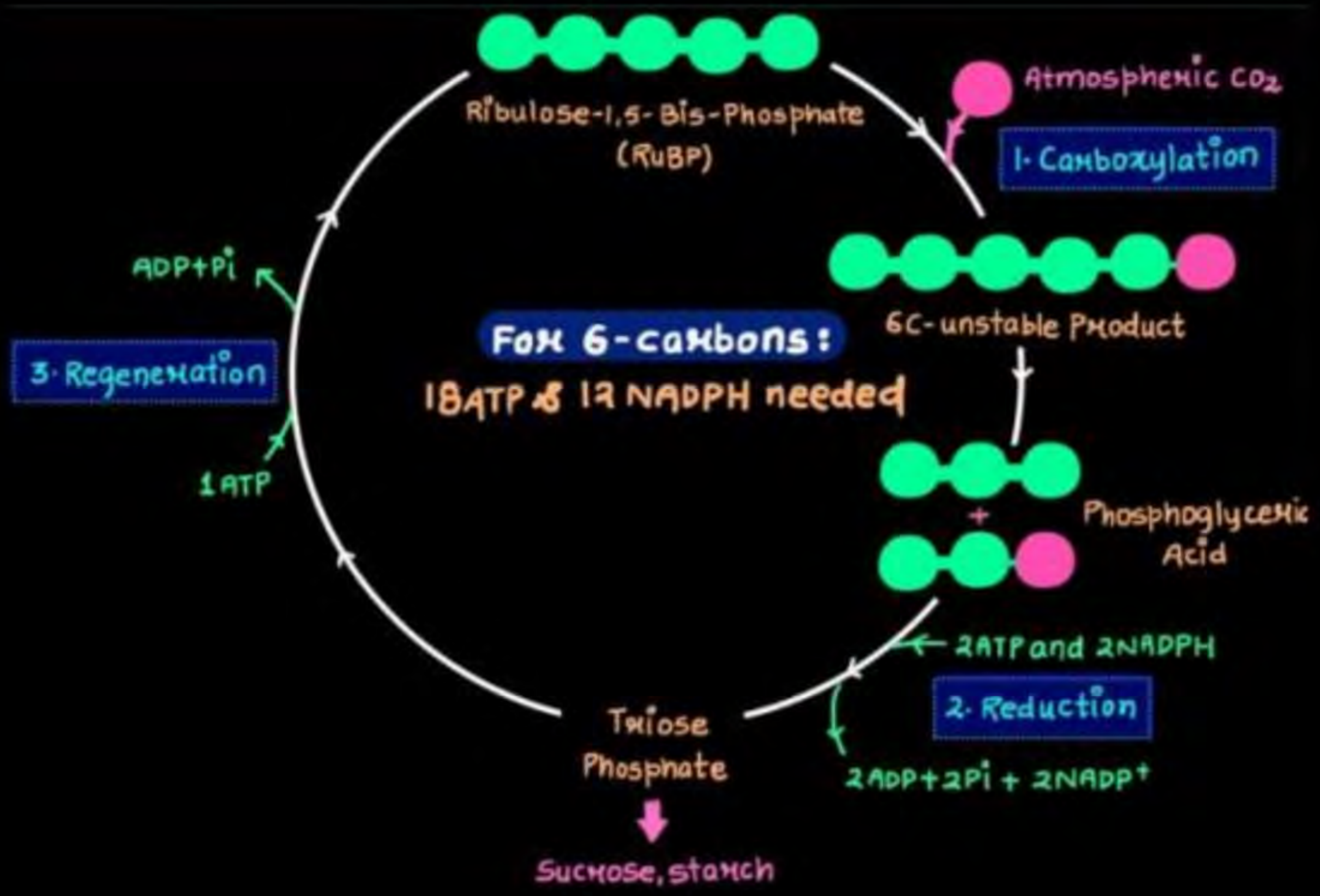
	C_3	C_4
Acc.	RuBP	PEP
Prodn	PGA	OAA

1 1 1 1 1 1

6

12+2 = 14

C3 Cycle



Ribulose-1,5-Bis-Phosphate
(RuBP)
Atmospheric CO_2
1. Carboxylation
6C-unstable Product
Phosphoglyceric
Acid
2ATP and 2NADPH
2. Reduction
2ADP+2Pi + 2NADP+
Triose
Phosphate
Sucrose, starch
1ATP
3. Regeneration
ADP+Pi
For 6-carbons:
18ATP & 12 NADPH needed

RuBisCO

- Ru → Ribulose
- Bis → bis-phosphate
- C → Carboxylase
- O → Oxygenase

• RuBisco is the most abundant enzyme in biosphere as it can work with both CO_2 and oxygen.

■ When CO_2 and O_2 concentration is similar; RuBisco will bind with CO_2 due to higher affinity ∴ Carboxylation will occur

■ Binding at RuBisco is competitive ∴ when $O_2 \gg CO_2$: oxygenation will occur.

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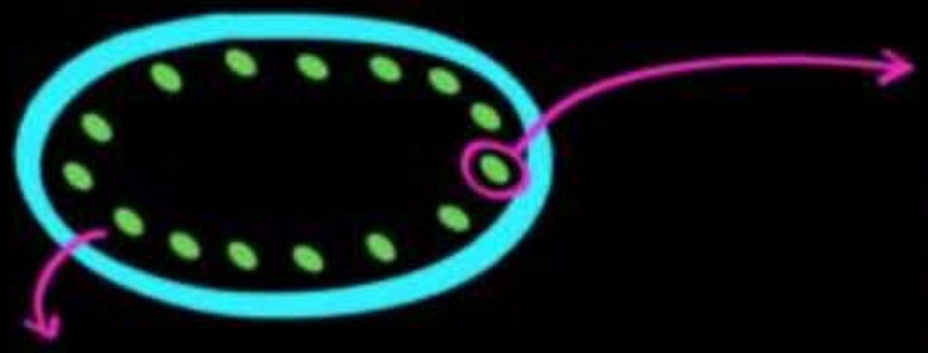

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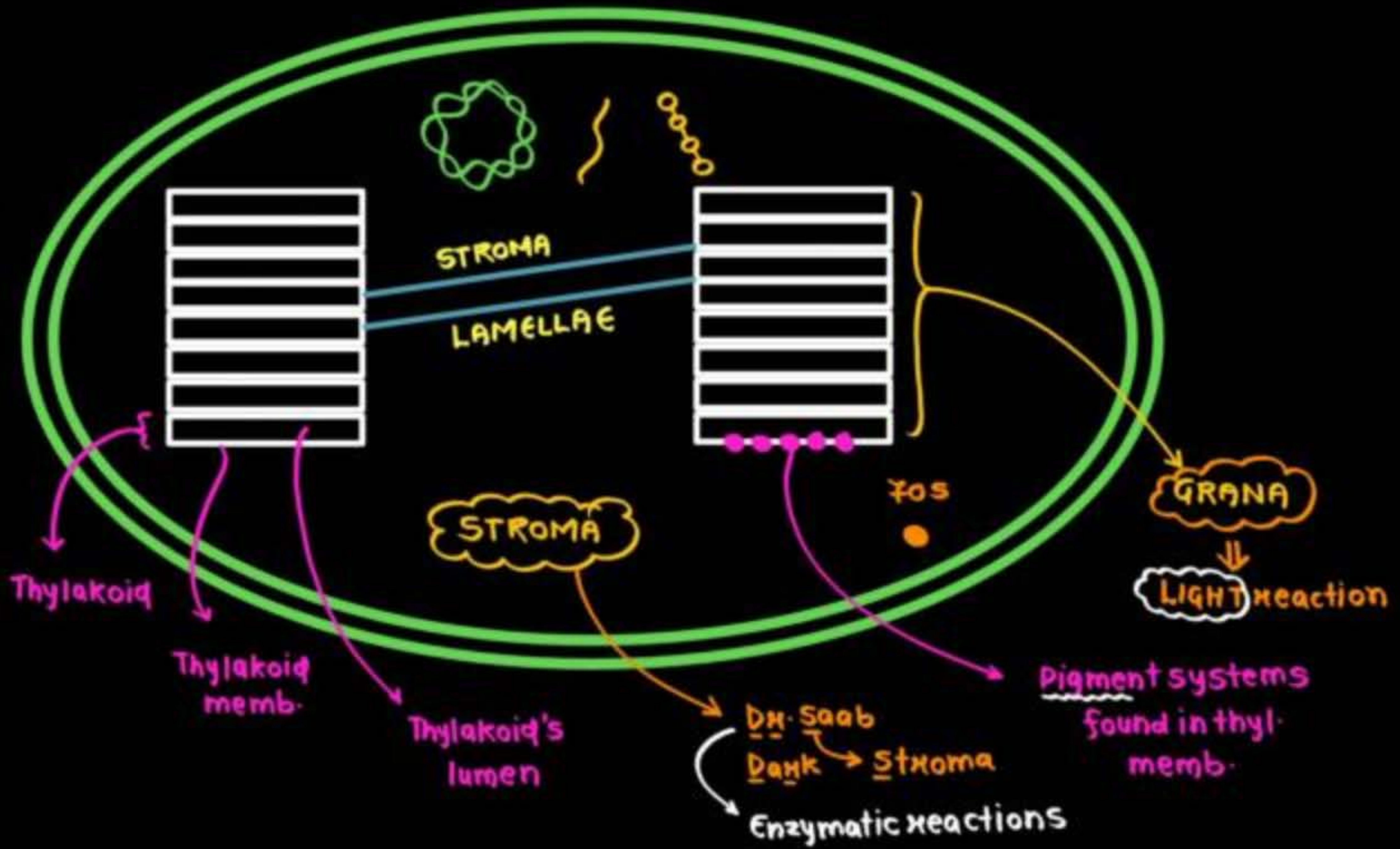

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  $\boxed{\text{ATP, NADPH}}$

Carbon Acceptors in C3 and C4 Cycle

C_3 / Calvin cycle
given by Melvin Calvin
First stable product is of 3-carbons (Phosphoglyceric acid / PGA)

* NOTE: C_3 cycle is a UNIVERSAL CYCLE

- Calvin analysed Algal photosynthesis by using C^{14} radioisotope
  Radioisotopy became common after World War-II

- RuBP (Ribulose-bis-phosphate) (5C) + CO_2 (1C) $\longrightarrow$ 6C $\boxed{\text{(unstable)}}$ $\longrightarrow$ 3C + 3C (PGA) $\Downarrow$ 1st stable product

  RuBP (5C): Carbon acceptor

Carbon Acceptors in C3 and C4 Cycle

C_4 pathway / Hatch & Slack pathway

1st stable product is of 4-carbons

Scientists who elucidated/explained C_4 pathway

- Phospho-enol-pyruvate (PEP) (3C) + CO_2 $\longrightarrow$ Oxaloacetic acid (4C)

Phospho-enol-pyruvate (PEP) (3C) → 1st carbon acceptor

Oxaloacetic acid (4C) → 1st stable product

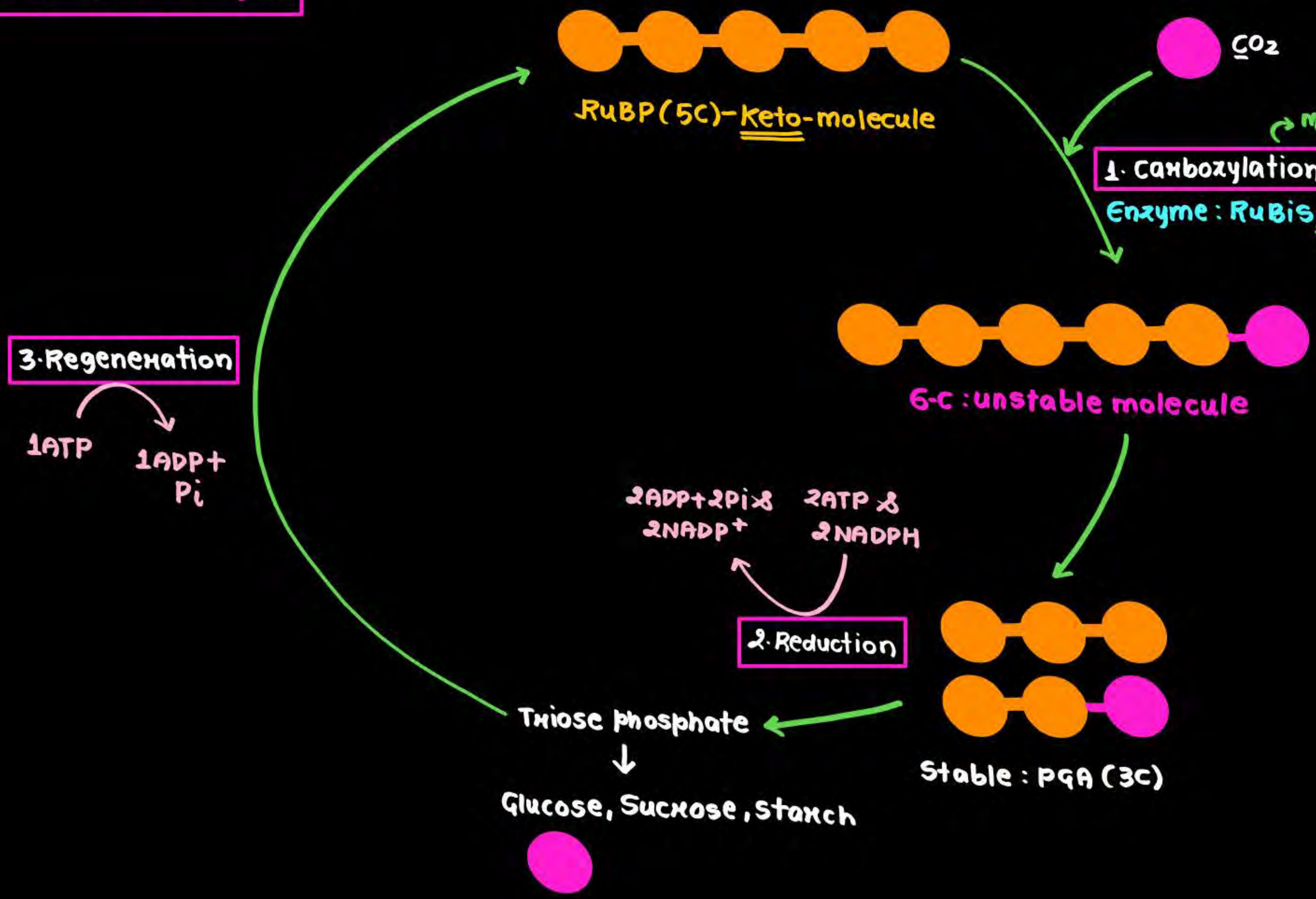
Note:

C_3 plant : C_3 cycle

C_4 plant : C_3 + C_4 cycle

e.g., Maize, Sorghum, Sugarcane

C3 Cycle / Calvin Cycle



For 1-carbon / 1 cycle
3ATP + 2NADPH

e.g., For 1 glucose
18 ATP + 12 NADPH

e.g., For starch of 200C
600 ATP + 400 NADPH

RuBisCo
- Ru Bis → RuBP (Ribulose-bis-phosphate)
- C → Carboxylase
- O → oxygenase

- It is the most abundant enzyme on BIOSPHERE
  - Biomass of plants is high ↑
  - It has association with CO_2 & O_2

NOTE: Binding of CO_2 & O_2 with RuBisCo is competitive

RuBisCO

$O_2 \uparrow\uparrow > CO_2 \downarrow\downarrow$
∵ O_2 conc. is more
RuBisco will do
oxygenation

$CO_2 \uparrow\uparrow > O_2 \downarrow\downarrow$
∵ CO_2 conc. is more
∴ RuBisco will show
carboxylation

$\boxed{CO_2 = O_2}$
Carboxylation will be done
∵ RuBisco have more affinity
for CO_2

related to light

$\boxed{C_2\text{-pathway / photorespiration}}$ → LOSS PROCESS : ATP ✗

NADPH ✗

Glucose/Carbohydrate ✗

Energy waste ↑

CO_2 released ↑

CO_2 released

Initial product will be of 2-carbons

⇓

PHOSPHOGLYCOLATE

- It occur in C_3 plants & not in C_4 plants

  C_3: Loss ↑, productivity ↓

  C_4: Loss ↓, productivity ↑

- when O_2 ↑↑ > CO_2

$$\underset{(5C)}{RuBP} + \underset{\text{(zero Carbon)}}{O_2} \xrightarrow{\text{RuBisCO}} \underset{(3C)}{PGA} + \underset{(2C)}{\text{Phosphoglycolate}}$$

Photorespiration occur in 3-organelles : PCM

1. Chloroplast
2. Peroxisome
3. Mitochondria

C_4 pathway

1st carbon acceptor : Phospho-enol-pyruvate : PEP (3c)

- 1st stable product : oxaloacetic acid (OAA) : 4c
- Hatch & Slack pathway
- C_3 plant or C_4 plant

C_3 plant → C_3 cycle

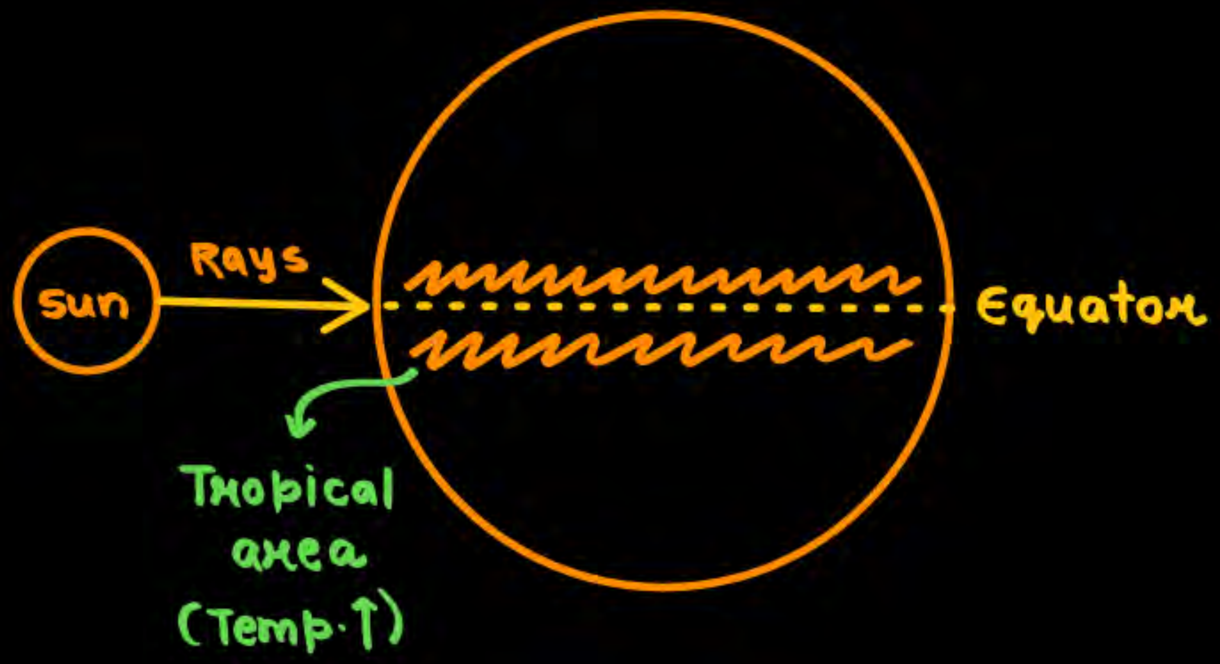
C_4 plant → C_3 cycle → universal; C_4 cycle

- e.g. of C_4 plants : Maize, sorghum, Sugarcane
- C_4 plants : usually found in dry - tropical areas

C_4 plants → Strategies to conserve H_2O or to reduce water loss

dry → $H_2O\downarrow$

tropical → Temp.↑



- Photorespiration was NOT SEEN

∴ Loss↓ ; productivity↑ ; BIOMASS↑

Why C_4 plants are special?

- C_3 plants open up their stomata whenever they need CO_2

  BUT due to this, H_2O also exits the plant

  ∴ water loss↑

  ∴ C_3 plants can't occur at arena's where H_2O↓ or Temp.↑ is seen

  ∴ C_3 plants can't store CO_2 inside

  There will be some instances where O_2↑ in cells ∴ photorespiration can occur

- C_4 plants can open their stomata & can take very high amount of CO_2 in its cells & can even store it

  ∵ Stomata is not opened frequently

  ∴ H_2O loss is less

  ∴ C_4 plants can survive in dry regions

  In cells: CO_2↑
  O_2↓

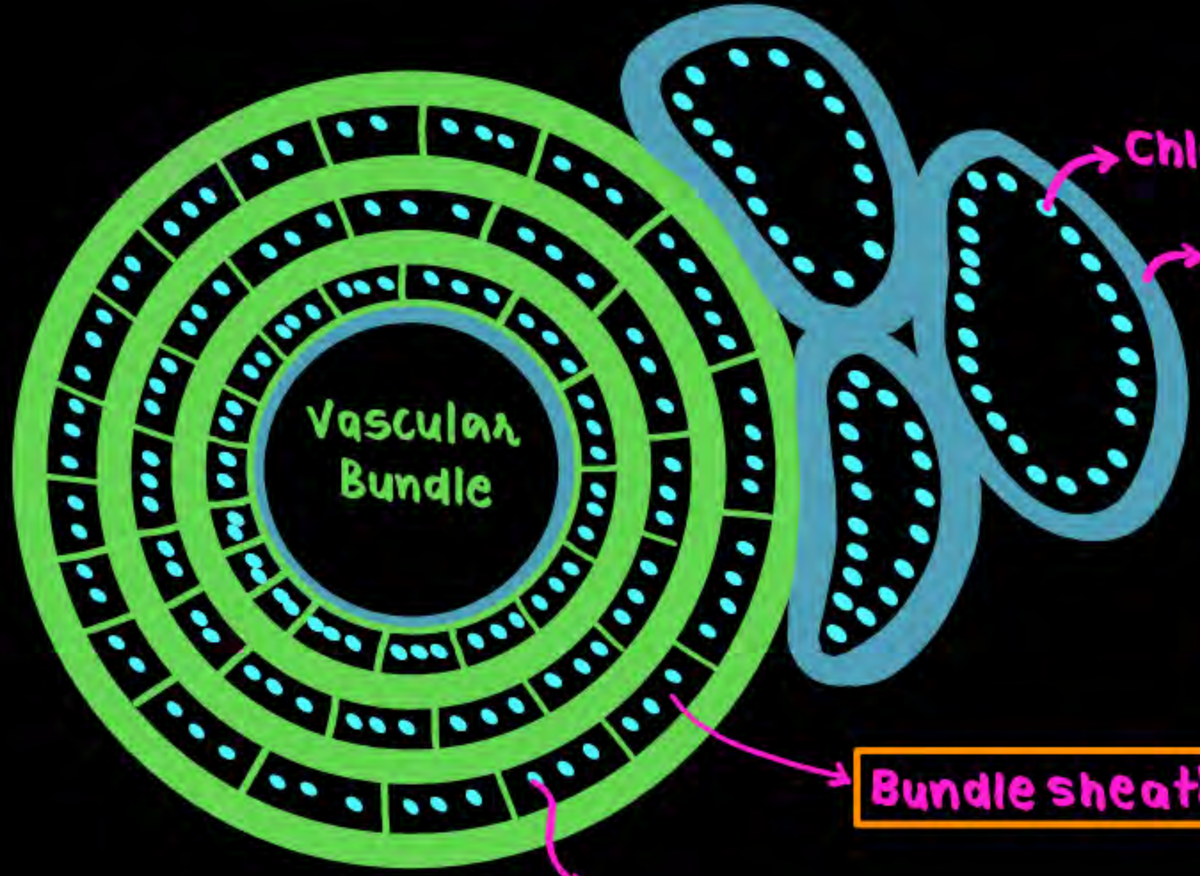
  ∴ No photoresp.

  ∴ No loss

Kranz Anatomy

- speciality of C_4 plants
- kranz means 'wreath' → Arrangement of diff. cells
  - Mesophyll cells
  - Bundle sheath cells (BS cells)

NOTE: In C_3 plants, only mesophyll cells participates in Carbon fixation



- Multilayered
- Chloroplast are abundant
- Cells are TIGHTLY PACKED ∴ intercell. space ⊖nt
- Impervious to gaseous exchange (∴ no entry or exit of gases)

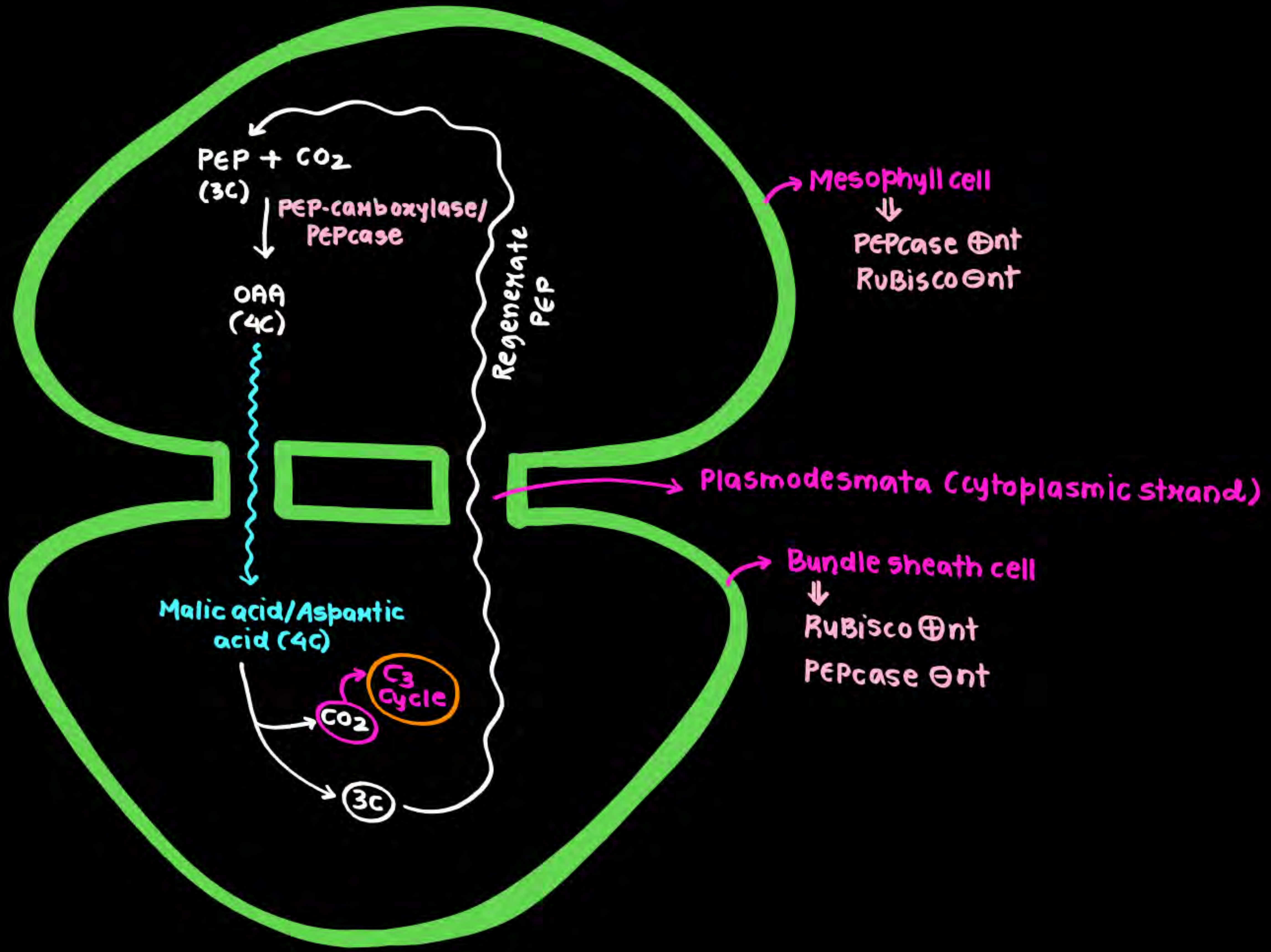
C_4 cycle

Calculation for '1' CO_2

C_3 : 3ATP
2NADPH

C_4 : PEP regeneration*
2ATP*

5ATP
2 NADPH



CAM Pathway

Crassulacean Acid Metabolism

Normal plant

⇓

open stomata at DAY

- Temp.↑
  Transpiration↑
  H_2O loss↑

CAM-plants

⇓

CO_2 enter

open stomata at NIGHT

⇓

Temp.↓
Transpiration↓
H_2O loss↓
H_2O conservation↑

e.g., Euphorbia

Factors $\boxed{\text{Affecting}}$ Photosynthesis

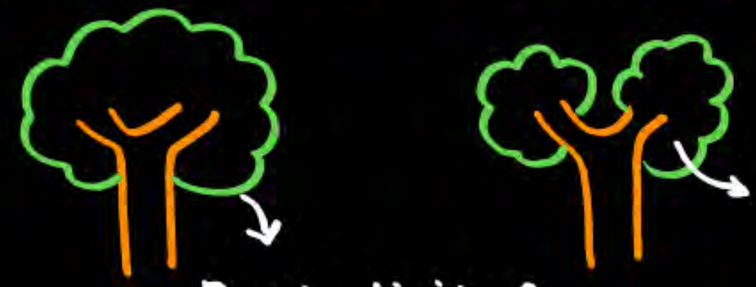
Rate ↑
Rate ↓

If we understand, what factors can affect the rate of photosynthesis in a plants, then we can alter the quantity of some factors to make plant more productive ↑

Factors Affecting Photosynthesis

Internal Factors

- Depends on Genetic predisposition & Growth of plant



Productivity ↑ ; Productivity ↓

- Number, size, age & orientation of leaves, mesophyll cells, chloroplasts, chlorophyll

age → young ↓ (leaf ↓) ; adult ↑ ; old ↓

leaves ↓ no. ↑ ; size ↑ ; photosynthesis ↑

mesophyll cells ↓ no. ↑ ; size ↑ ; photosyn. ↑

chlorophyll ↓ Amount ↑ ; photosynth. ↑

- Internal CO_2 conc : ↓ in C_3 plants
  ↑ in C_4 plants ∴ ↑ productive

External factors

1. Light
2. Temperature
3. CO_2 concentration (external)
4. H_2O

$$2H_2O \xrightarrow[Mn,\,Cl]{\text{Splitting}} 4H^+ + 4e^- + O_2\uparrow$$

Participates as a reactant but it does not affect the photosynth. directly

- H_2O↓ Leaves will curl ; Surface area ↓ Light ↓ ; photosynth. ↓
- H_2O↓ ; Stomata close ; CO_2↓ ; photosynthesis ↓

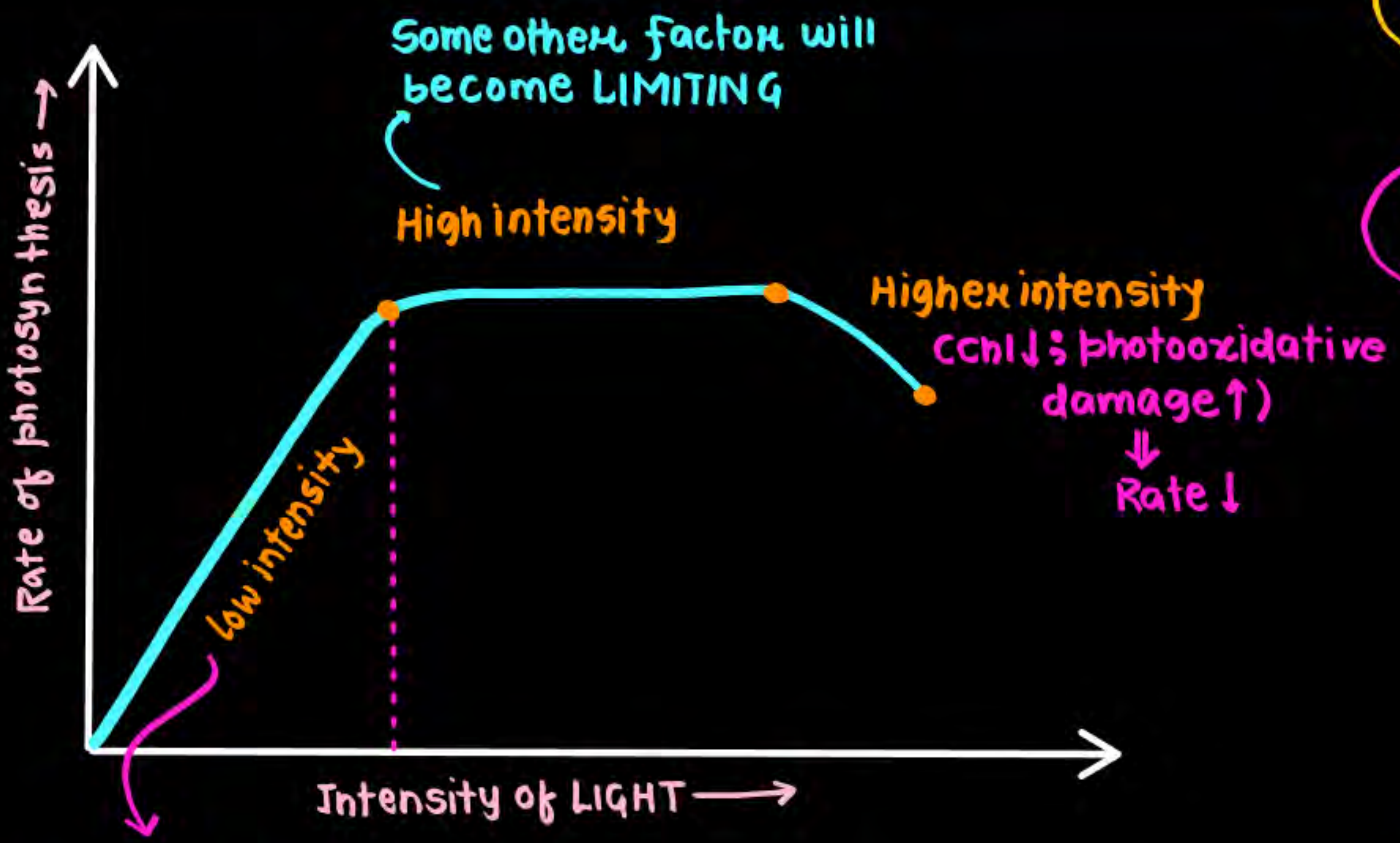
Blackman's Law of Limiting Factors (1905)

	Refill	Body	Cap	Total PEN
Case-1	50	40	30	30
Case-2	50	40	39	39
Case-3	50	45	46	45
Case-4	60	60	59	59
Case-5	75	73	79	73
Case-6	100	105	103	100

According to this rule: if a process depends upon many factors, then the rate of the process mainly depends on the factor which is limiting/ Sub-optimal.

e.g., If a plant was given: Light↑; CO_2↑; H_2O↑
Temp↓ → Rate determining

Light



∵ intensity is low
∴ intensity act as a LIMITING FACTOR

$\boxed{\therefore \text{RATE} \propto \text{INTENSITY (LOW)}}$

1. Intensity of LIGHT
2. Quality of LIGHT (wavelength)
3. Duration of LIGHT

400-700nm visible light is needed for photosynthesis
⇓
Blue & Red region lights are BEST

- 400-700nm region called 'PAR': Photosynthetically active radiation

3. Duration of sunlight:

4hr : 4kg biomass
8hr : 8kg biomass
} Rate is same : 1kg/hr

∴ Light duration have no impact on rate of photosynth.

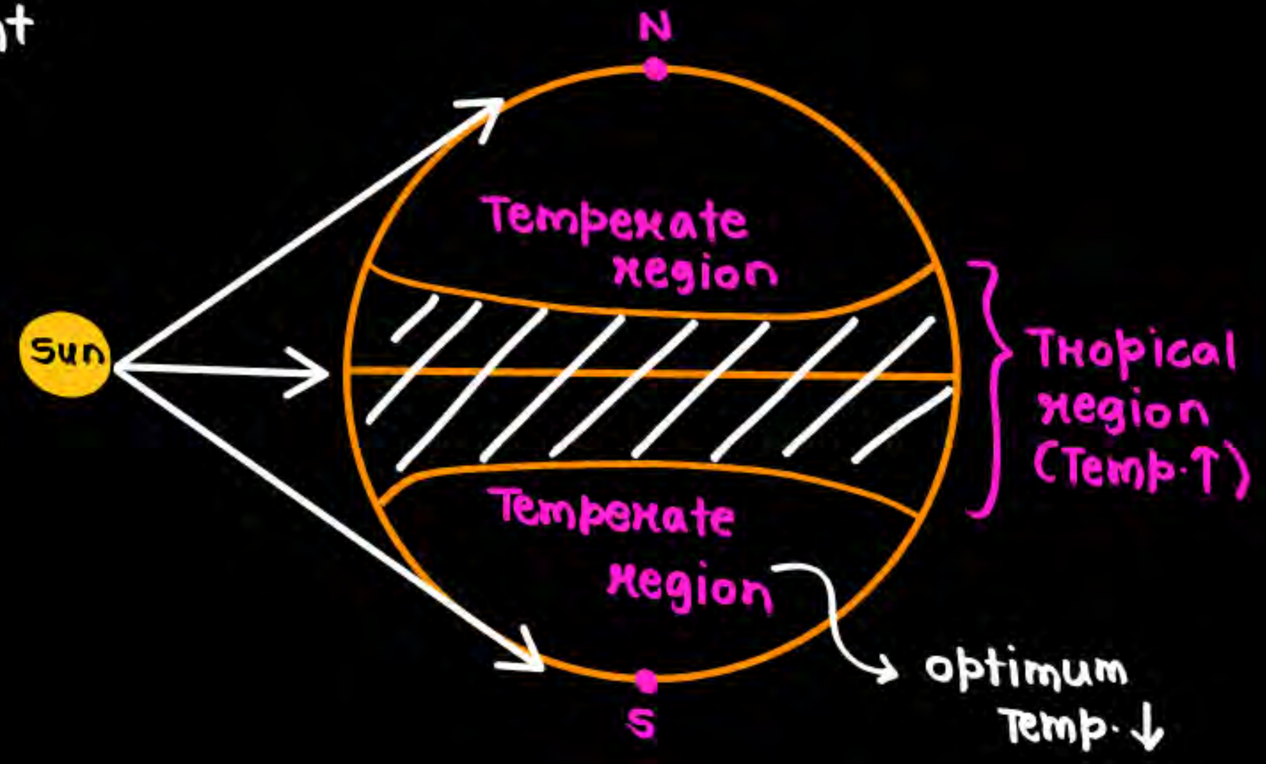
Temperature

- NOTE : LIGHT is usually NOT A LIMITING FACTOR ∵ plants need only 10% of PAR for performing photosynthesis
- Plants growing in shade, near caves or deep in ocean may feel scarecity of LIGHT

Temperature

∵ Dark reactions are enzymatic ∴ they are controlled by Temp.
LIGHT reaction are controlled by temp. upto less extent

C_3 plants का optimum Temp: 20-25°C
C_4 plants का optimum Temp: 30-40°C
Prevent the loss of H_2O



CO_2 Concentration

- CO_2 is a major LIMITING FACTOR in photosynthesis
  ∵ Its quantity in atmosphere is very less i.e., 0.03-0.04%

  ↓

  If we inc. this upto 0.05% ; Rate of photosynth. ↑
  BUT beyond this, it becomes TOXIC

- At low light intesity (limiting) ; if we ↑ CO_2 conc. then both C_3 & C_4 plants won't respond
  But at higher light intensity ; if we ↑ CO_2 conc. the BOTH C_3 & C_4 plants will show higher rate of photosyn.

  C_3 → saturates at 450 µlL⁻¹ / 450 PPM

  C_4 → saturates at 360 µlL⁻¹/PPM

- Some C_3 plants like Tomato & Bell pepper are grown in green houses with ↑ Temp. & ↑ CO_2 for higher yield