

Photosynthesis In Higher Plants

> Green plant get their food → **Photosynthesis**
Autotrophs ←

> Other org. depend on green plant for food
Heterotrophs ←

> **Photosynthesis** (Physio - Chemical Process)
Light energy → used to derive organic compounds. Living forms on earth depends upon sunlight for energy.

Photosynthesis

Primary source
of all food

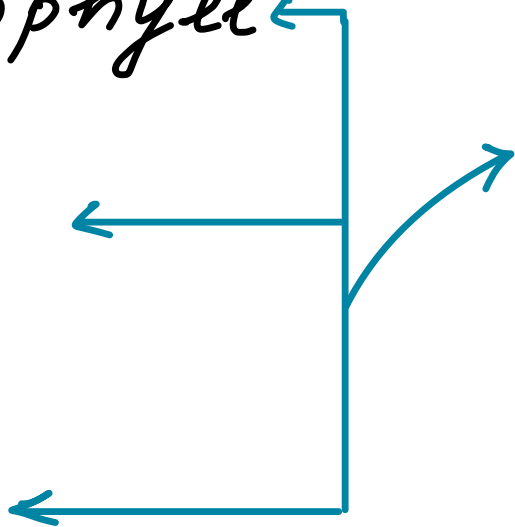
Release of O_2
into atmosphere

Chlorophyll

Light

CO_2

Required for
photosynthesis



Experiment of starch formation in two leaves

(1) A variegated leaf (i.e. partially covered with black paper)

→ exposed to sunlight → starch present
→ Photosynthesis → Only green part of leaves

(2) A part of leaf enclosed in test tube containing KOH soaked cotton (absorbs CO_2)
• other part of leaf exposed to air
• Setup placed in light → starch found on exposed parts of leaf only. → Proves CO_2 is required

early experiments:

(1) Joseph Priestley's (in 1770)

> In a closed space (a bell jar) a burning candle extinguishes and a mouse suffocates → both somehow damages air.



Mini plant placed in jar



Mouse stayed alive, Candle continues burning

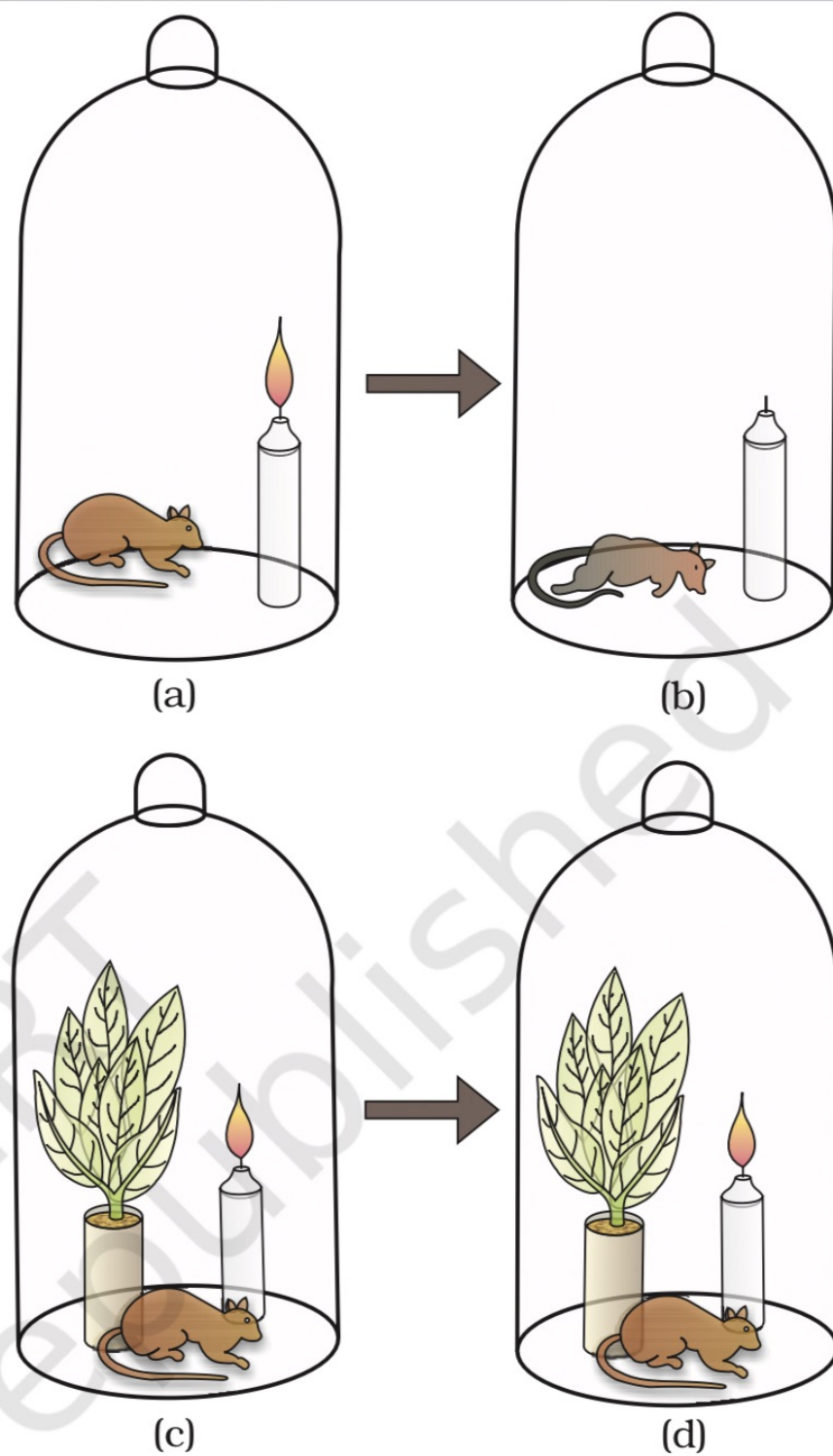


Figure 13.1 Priestley's experiment

(2) Jan Ingenhousz (1730-1799)

> Showed that sunlight is essential to plant.



Small bubbles around green parts

release oxygen

(3) Julius Von Sachs (1854)

> Glucose made in green parts (chloroplast)
• Stored as starch

[4) T.W. Engelmann (1843-1909)

Using prism → Split light into spectral components

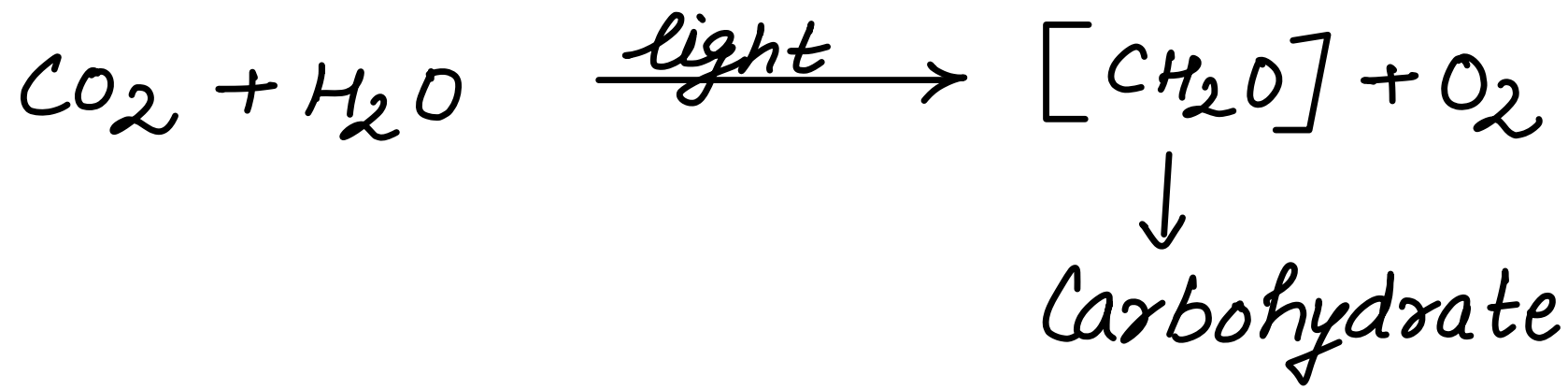


Illuminated green algae
(Cladophora)

in suspension of aerobic bacteria



mainly accumulated in blue &
red light

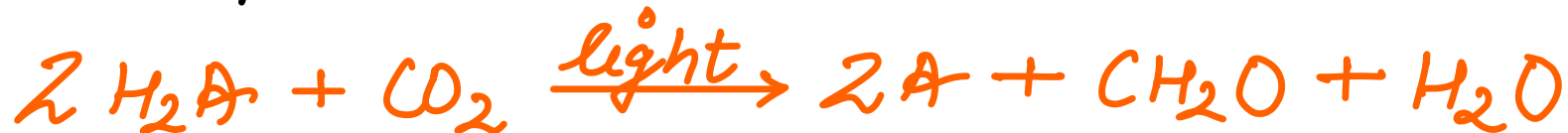


(5) Cornelius Von Niel (1897 - 1985)

> Studies on purple & green bacteria

↓
Photosynthesis, light dependent process

↓
Hydrogen forms a suitable oxidisable compound → reduces CO_2 to carbohydrate



- Green plant : H_2O is the H-donor & oxidised to O_2

Some organism (purple & green sulfur bacteria)

> Sulphur is the oxidation product

Therefore, O_2 comes from H_2O not CO_2



Proved by radio-isotope techniques

Where does photosynthesis take place?

→ Mesophyll cells in chloroplast

Align themselves along the walls of
mesophyll cell

↓
To get optimum quantity of incident
light

Chloroplast → Membranous system
consisting of grana + Stroma lamellae
+ Matrix stroma

Membrane system $\rightarrow$ trap light



Synthesis of ATP + NADPH

$\rightarrow$ light reaction (Photochemical Rxns)

Stroma $\rightarrow$ Enzymatic reactions synthesize
sugars



Forms starch

$\rightarrow$ Dark reaction (carbon reactions)

Dark reaction $\rightarrow$ Not directly light driven
 $\downarrow$
dependent on products of light reaction
(ATP + NADPH)

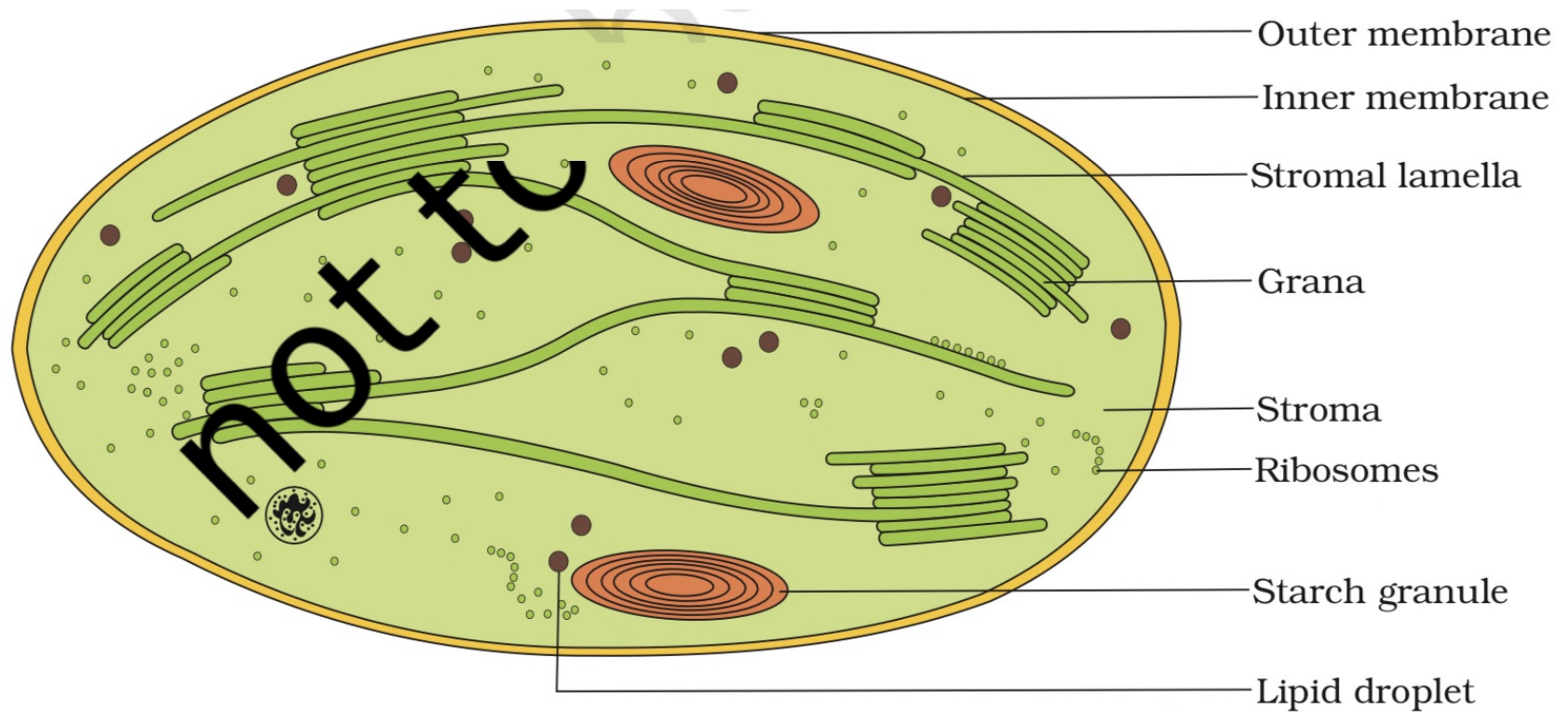


Figure 13.2 Diagrammatic representation of an electron micrograph of a section of chloroplast

How many types of pigments are involved in Photosynthesis?

> Chlorophyll a (bright or blue green)

Chlorophyll b (yellow green)

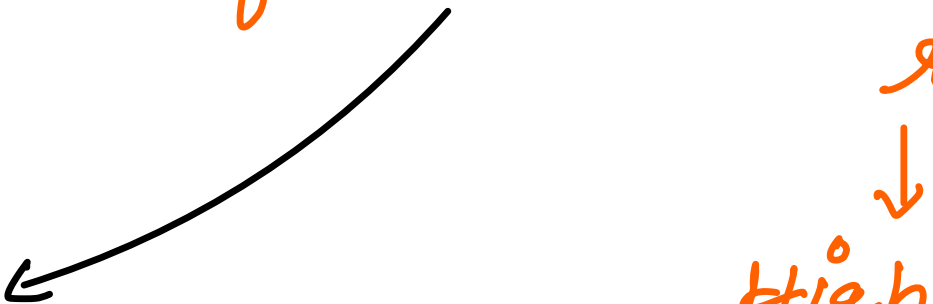
Xanthophylls (yellow)

Carotenoids (yellow to yellow orange)

→ Accessory pigment → not only enable wide range of wavelength of incoming light to be utilised for photosynthesis. But also protect Ch. A from photo-oxidation.

Max. absorption of chl A → Blue/Red
region
↓
Higher rate
of photo-
synthesis

Chief
Pigment



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graph TD; A[Max. absorption of chl A] --> B[Blue/Red region]; B --> C[Higher rate of photo-synthesis]; D[Chief Pigment] --> A;
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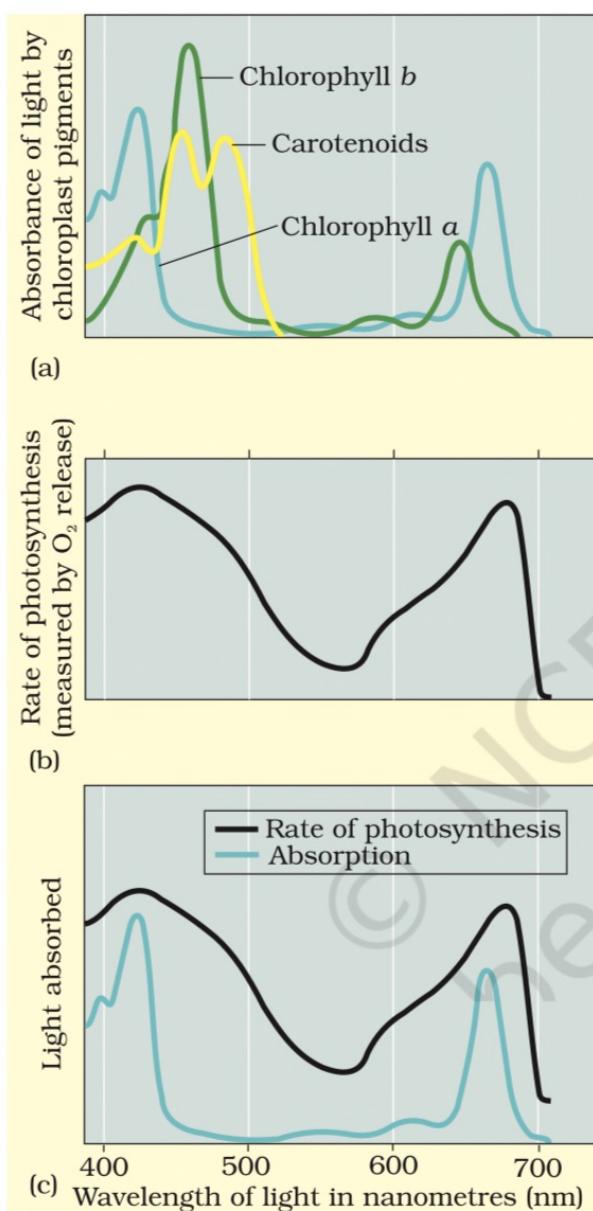


Figure 13.3a Graph showing the absorption spectrum of chlorophyll *a*, *b* and the carotenoids

Figure 13.3b Graph showing action spectrum of photosynthesis

Figure 13.3c Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyll *a*

Light Reaction

> light absorption $\rightarrow$ H_2O splitting



O_2 release



ATP + NADPH

LHC (light harvesting complex) $\begin{matrix} \nearrow \text{PSI} \\ \searrow \text{PSII} \end{matrix}$

made up of 100s
of pigment molecule
bound to protein

Named in sequence
of their discovery

> Each PS → All pigments except 1
molecule of chl a

↓

Forming antennae

Chl a → forms reaction centre

PS I → absorption peak at 700nm
↓
P700

PS II → Absorption peak at 680nm
↓
P680

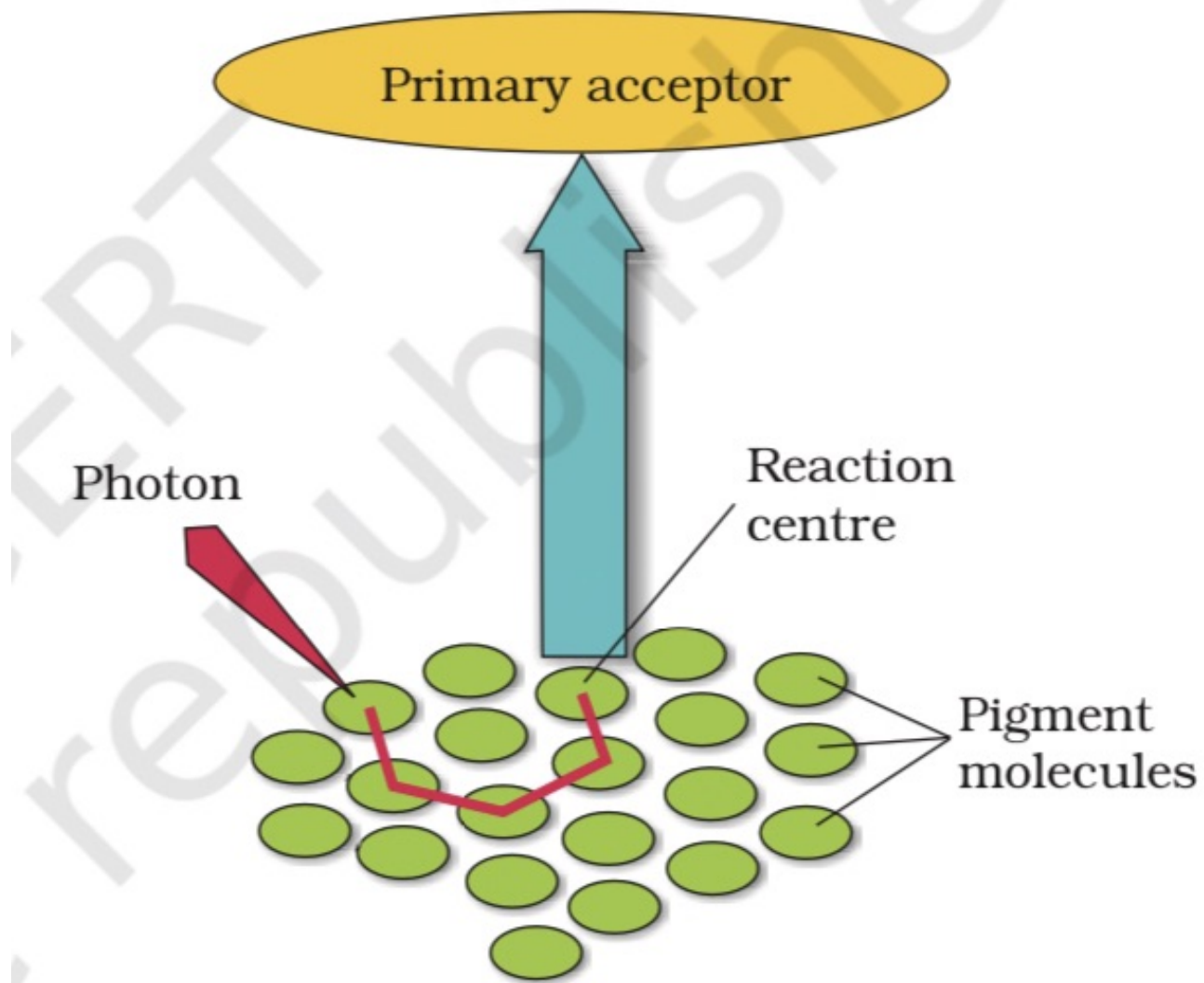


Figure 13.4 The light harvesting complex

The Electron Transport

> In PSII, chl a absorbs 680 nm wavelength of red light

↓
e⁻ excited & jump into an orbit farther from atomic molecule

↓
e⁻ picked up by e⁻ acceptor

↓
e⁻ passes to ETS consisting of cytochrome (downhill)

↓
ATP forms from ADP + iP



e^- passed to PS-I

e^- excited when red light (700nm) received

e^- picked up by e^- acceptor that has a greater redox potential

e^- moved downhill + formation of NADPH_2

> Z-scheme → due to its characteristic shape

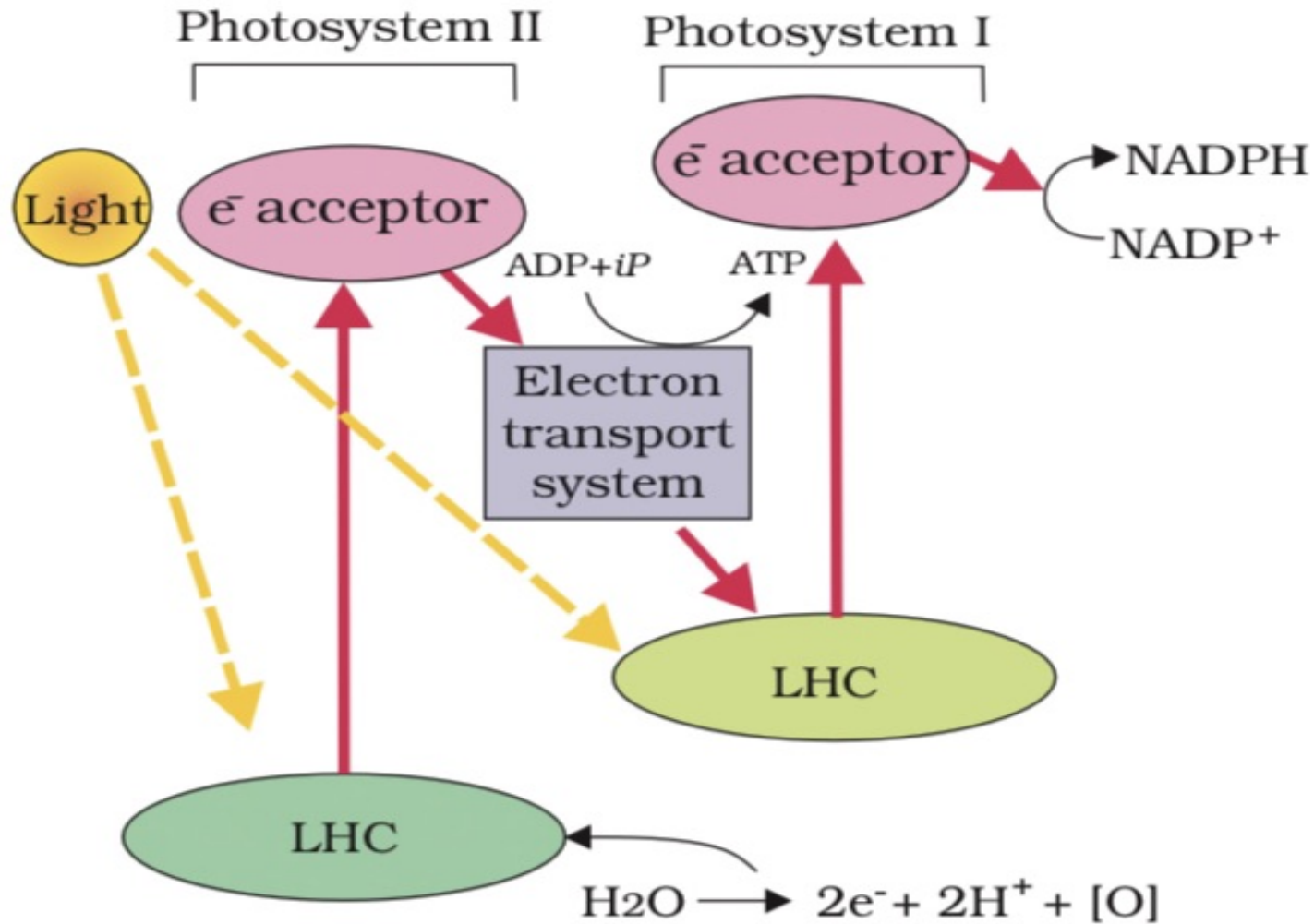


Figure 13.5 Z scheme of light reaction

splitting of H_2O : associated with $PSII$



located on inner side

$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$ of membrane of
thylakoid.

Cyclic and Non-Cyclic Photophosphorylation

Synthesis of ATP (mitochondria

+
Chloroplast)
= Phosphorylation

↓ In Presence of
light

Photophosphorylation

- Non cyclic $\rightarrow$ Z-scheme $\rightarrow$ Both
PSI & PSII functional
 $\downarrow$
Both ATP & NADPH₂ forms
 $\downarrow$
Membrane or lamellae of grana
- Cyclic $\rightarrow$ Only PSI functional
 $\downarrow$
stroma lamellae membrane
 $\downarrow$
Only ATP forms
 $\downarrow$
Locks NADP reductase enzyme

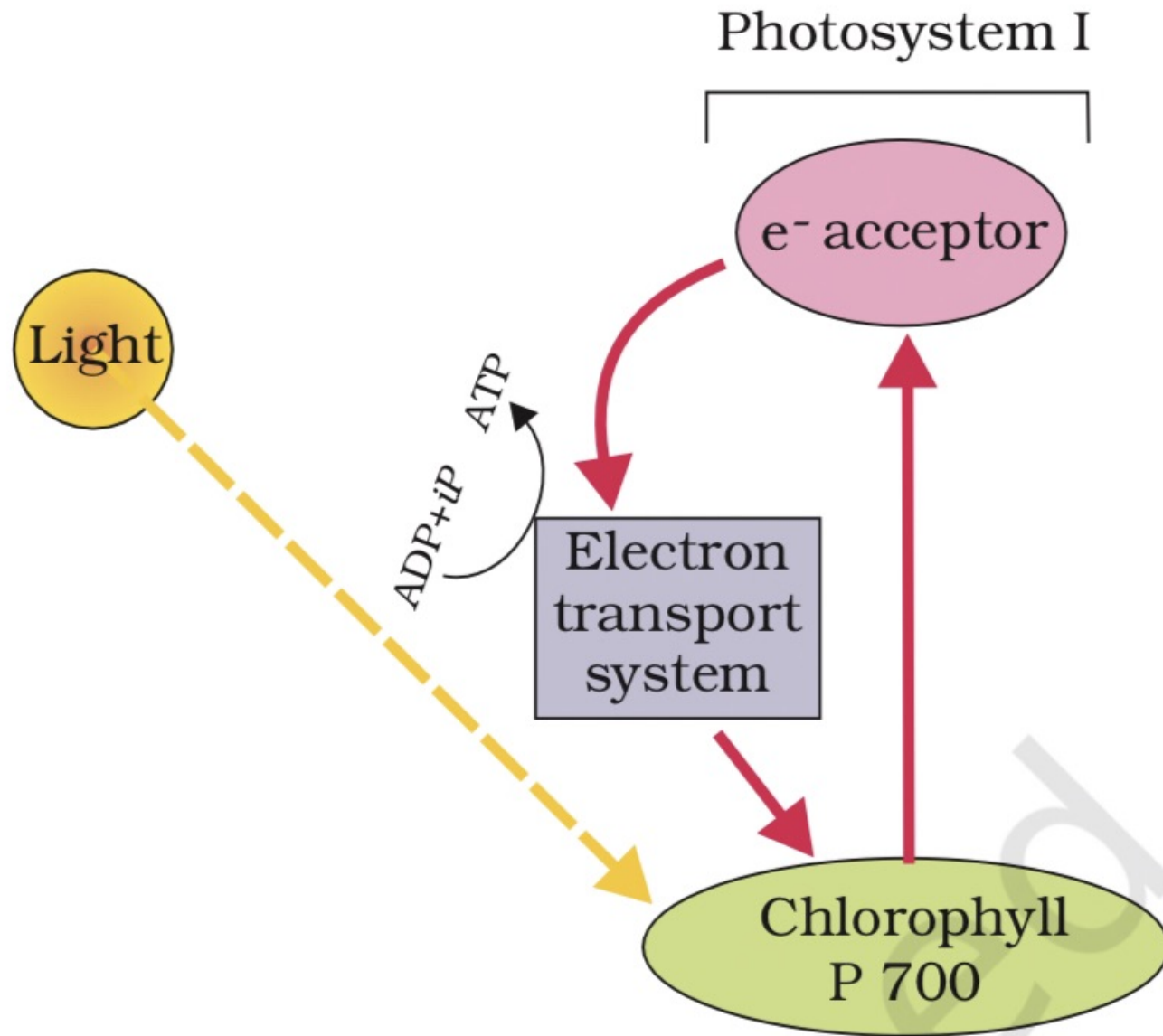


Figure 13.6 Cyclic photophosphorylation

Chemiosmotic Hypothesis

Like in respiration, photosynthesis too, ATP synthesis is linked to development of proton gradient across membrane

- > In photosynthesis → Proton accumulates in lumen (inside the membrane)
- > In Respiration → Proton accumulates in the intermembrane space of mitochondria.

- (a) Since splitting of the water molecule takes place on the inner side of the membrane, the protons or hydrogen ions that are produced by the splitting of water accumulate within the lumen of the thylakoids.
- (b) As electrons move through the photosystems, protons are transported across the membrane. This happens because the primary acceptor of electron which is located towards the outer side of the membrane transfers its electron not to an electron carrier but to an H carrier. Hence, this molecule removes a proton from the stroma while transporting an electron. When this molecule passes on its electron to the electron carrier on the inner side of the membrane, the proton is released into the inner side or the lumen side of the membrane.
- (c) The NADP reductase enzyme is located on the stroma side of the membrane. Along with electrons that come from the acceptor of electrons of PS I, protons are necessary for the reduction of NADP^+ to $\text{NADPH} + \text{H}^+$. These protons are also removed from the stroma.

Within chloroplast, proton in stroma ↓
in number, while in lumen proton ↑



Creates proton gradient as well as ↓ in pH



Broken down due to movement of proton
across stroma membrane through
transmembrane channel of C_F_0 of
ATP synthase.

ATP synthase

$CF_0 \rightarrow$ embedded in thylakoid membrane

$CF_1 \rightarrow$ Protudes on outer surface of thylakoid membrane

> Chemiosmosis requires a membrane, a proton pump, a proton gradient,

ATP synthase

> ATP synthase $\rightarrow$ has a channel
 $\downarrow$
allows diffusion of proton.

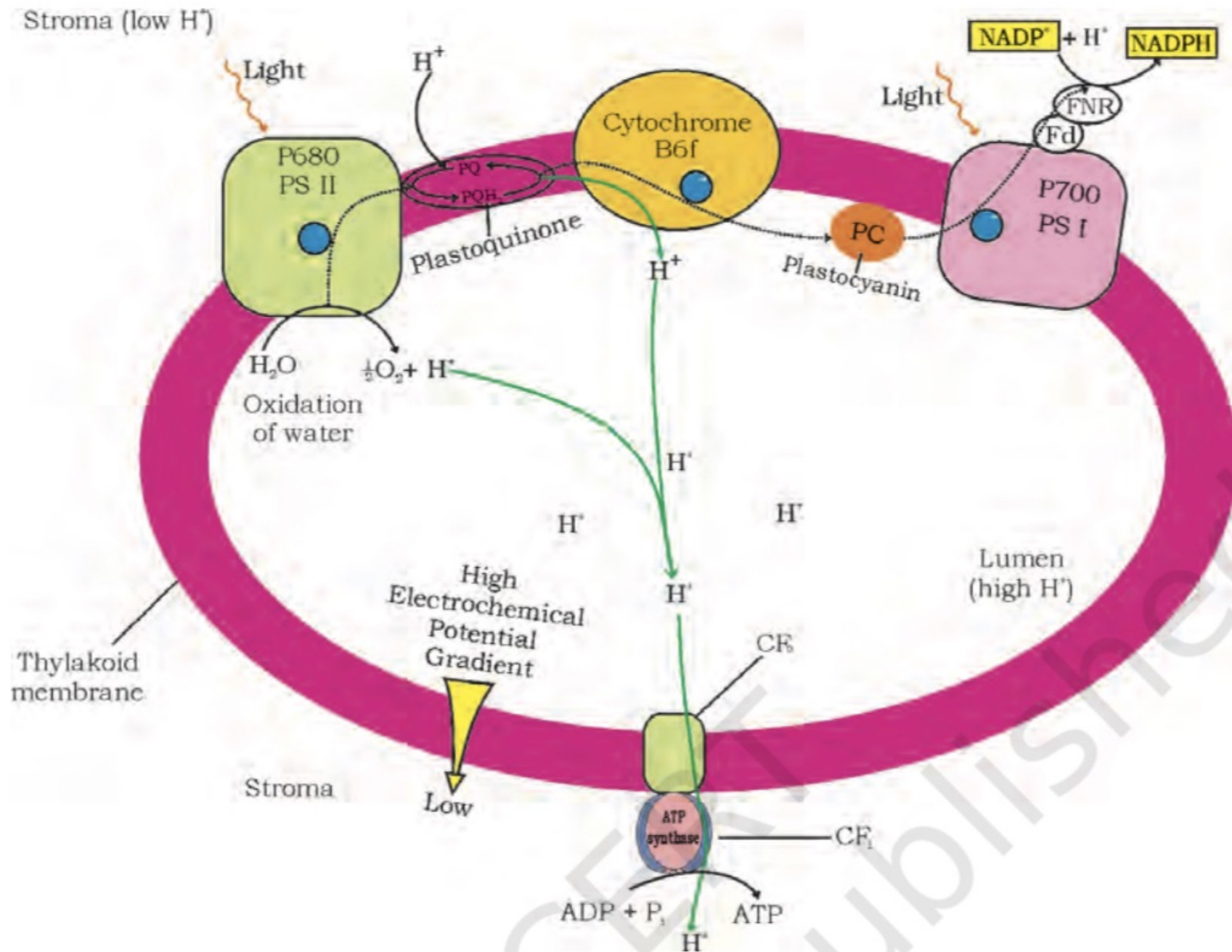


Figure 13.7 ATP synthesis through chemiosmosis

Where are the ATP and NADPH used?

> In biosynthetic phase

Work of Melvin Calvin



Use of radioactive ^{14}C by him in
algal photosynthesis



Discovery of 1st CO_2 fixation product



3-C organic acid [3-PGA]

C₃ pathway → 1st CO₂ fixation product
is 3C (PGA) → Primary
acceptor 5-C (RuBP)

C₄ pathway → 1st CO₂ fixation product
is 4C (OAA) → Primary
acceptor 3C (PEP)

The Calvin Cycle

> Common in C_3 & C_4 plants

(1) Carboxylation (a) Most crucial step

(b) Fixation of CO_2 into stable organic intermediate

(c) Catalysed by RuBisCo

(2) Reduction Involve 2 molecules of ATP and 2 molecules of NADPH

For, 1 mol. of glucose, 6 turns of cycle required.

3) Regeneration Requires one ATP for phosphorylation to form RuBP

For every CO_2 molecule, 3 molecules of ATP & 2 molecules of NADPH

In	Out
6 CO_2	1 glucose
18 ATP	18 ADP
12 NADPH	12 NADP

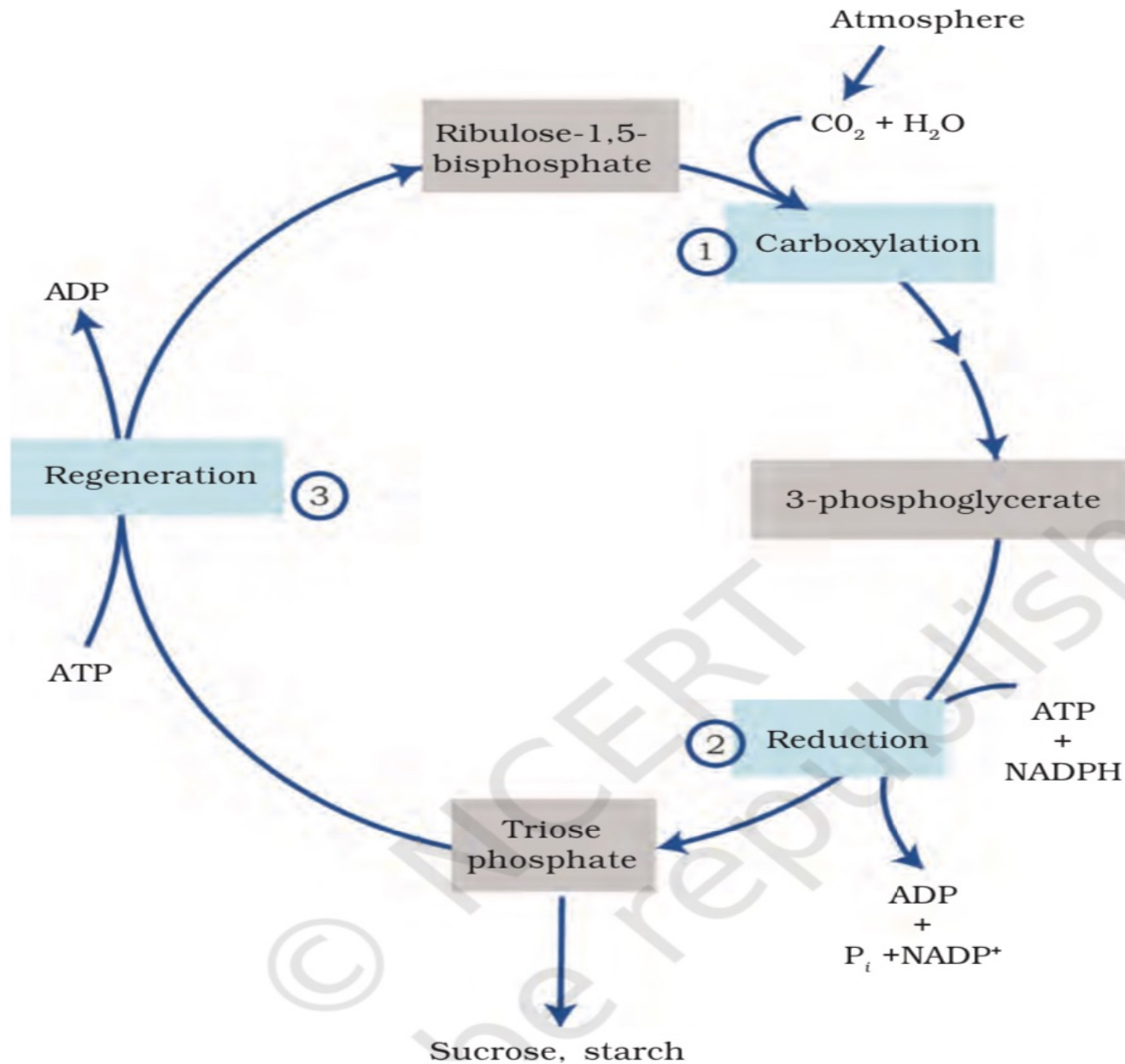


Figure 13.8 The Calvin cycle proceeds in three stages : (1) carboxylation, during which CO_2 combines with ribulose-1,5-bisphosphate; (2) reduction, during which carbohydrate is formed at the expense of the photochemically made ATP and NADPH; and (3) regeneration during which the CO_2 acceptor ribulose-1,5-bisphosphate is formed again so that the cycle continues

C₄ - Pathway

> Plants adapted to dry tropical regions
↳ C₄

> Special leaf anatomy → Kranz anatomy
(Wreath)



several layer around vascular bundles

+

large no. of chloroplast

+

Thick wall impervious to gas exchange

+

No intercellular spaces

→ Maize or Sorghum

- # Tolerate higher temp.
- # Response to high light intensity
- # Lack photorespiration
- # greater productivity of biomass
- # Presence of Bundle Sheath
↓
C₄ plants

Hatch and Slack Pathway

> Primary CO_2 acceptor $\rightarrow$ PEP (present in mesophyll)

enzyme responsible for fixation
 PEPCASE

> Mesophyll lack RuBisCO

> C_4 -acid OAA formed in mesophyll cell


Then forms C_4 compounds like malic acid or aspartic acid in mesophyll itself.

- > In bundle sheath cell, C_4 acid broken into CO_2 & 3-C molecule.
- > This 3-C molecule transported back to mesophyll cell and converted to PEP again.
- > CO_2 released in bundle sheath cell enters C_3 or calvin pathway.

Vascular bundle rich in RuBisCO
but lack PEPcase

C₃ → Calvin cycle in mesophyll cell.

C₄ → Calvin cycle in bundle sheath cell.

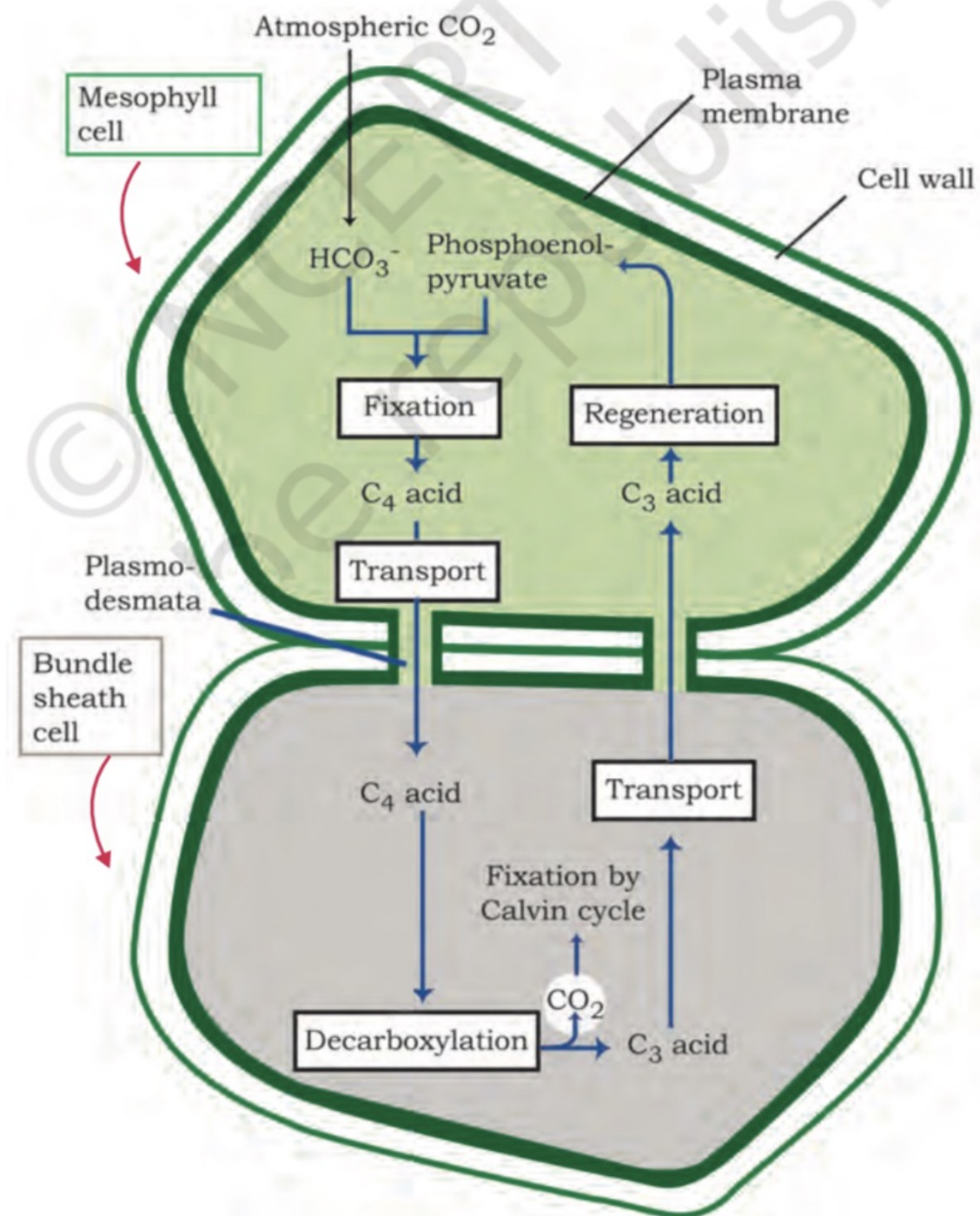


Figure 13.9 Diagrammatic representation of the Hatch and Slack Pathway

Photorespiration

Most abundant in world



has much greater affinity for CO_2 when CO_2 and O_2 is nearly equal.

In C_3 plants, O_2 binds to RuBisCO



forming 1 molecule of phosphoglycolate (3C)

→ Results in release of CO_2 with ATP

utilization

NO sugar, NO ATP, NO NADPH

C₄ → No photorespiration because they have mechanism to ↑ CO₂ conc. at enzyme site.

Factor Affecting Photosynthesis:

Blackman's law of limiting factor (1905):-

- > If a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value: it is the factor which directly affects the process if its quantity is changed.

> Light : There is linear relationship
blw incident light and

CO₂ fixation rate at low light intensity

• Light saturation occurs at 10% of
the full sunlight.

> CO₂ conc. : Major limiting factor

↑ in conc. upto 0.05% cause
↓

↑ in CO₂ fixation

Further ↑ → becomes damaging

C₄ → show saturation at 360 μL^{-1}

C₃ → show saturation beyond
450 μL^{-1}

> Temperature : C₄ respond to higher temp. and show $\uparrow$ rate of photosyn.

C₃ → much lower temp. optimum

Water :

