

PHOTOSYNTHESIS

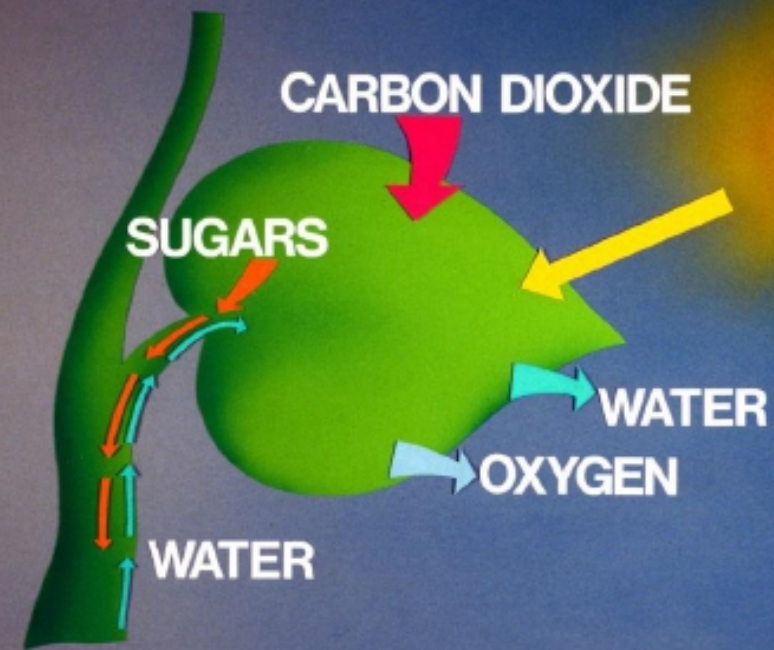


Photosynthesis, importance of photosynthesis, structure and function of chloroplast, dark and light reaction, CO_2 fixation, C_3 , C_4 and CAM, advantages of C_4 pathway, photorespiration and its implications, Factors affecting photosynthesis.

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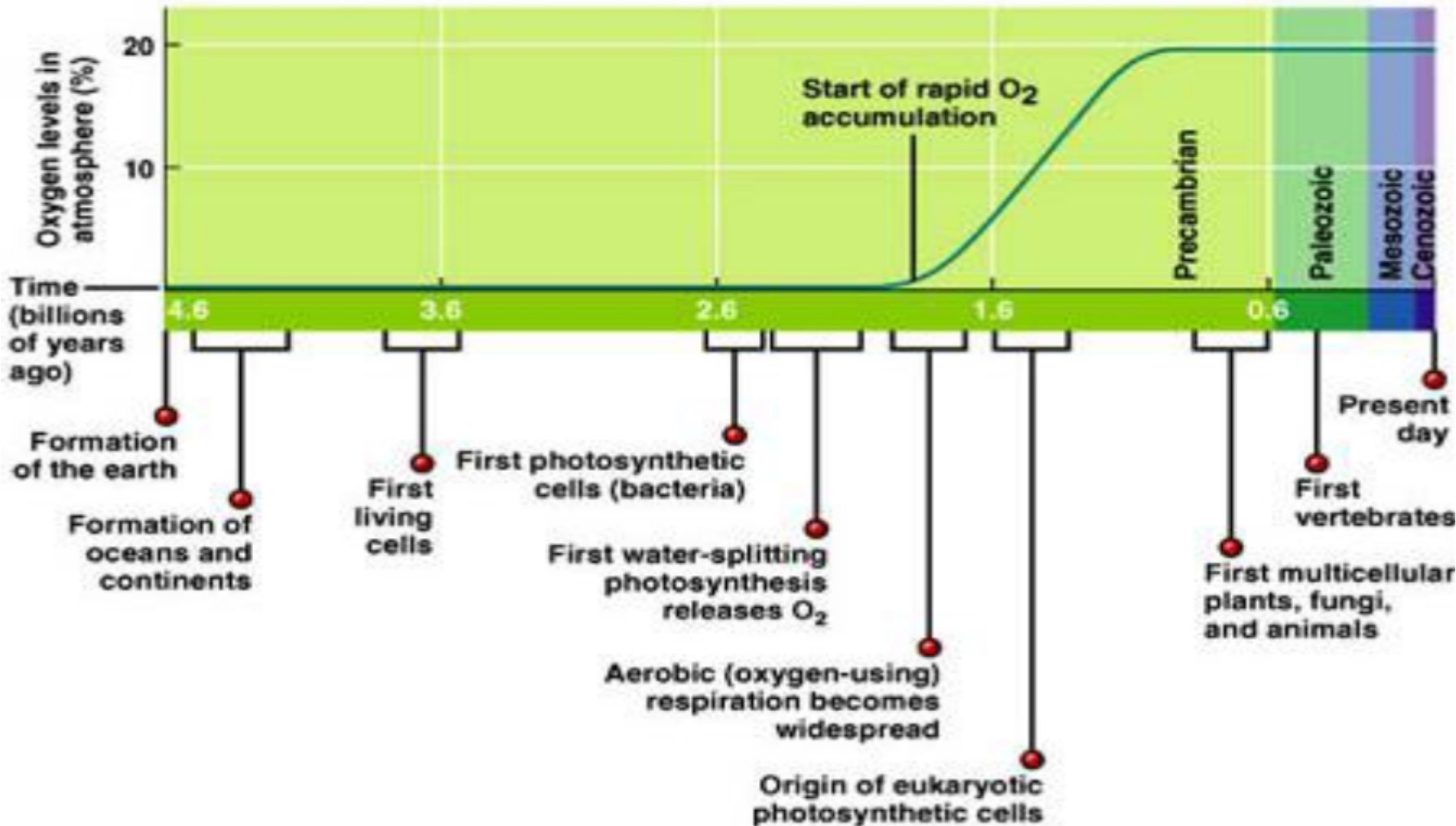
Energy can not be produce or destroyed , it can only transformed from one form to another

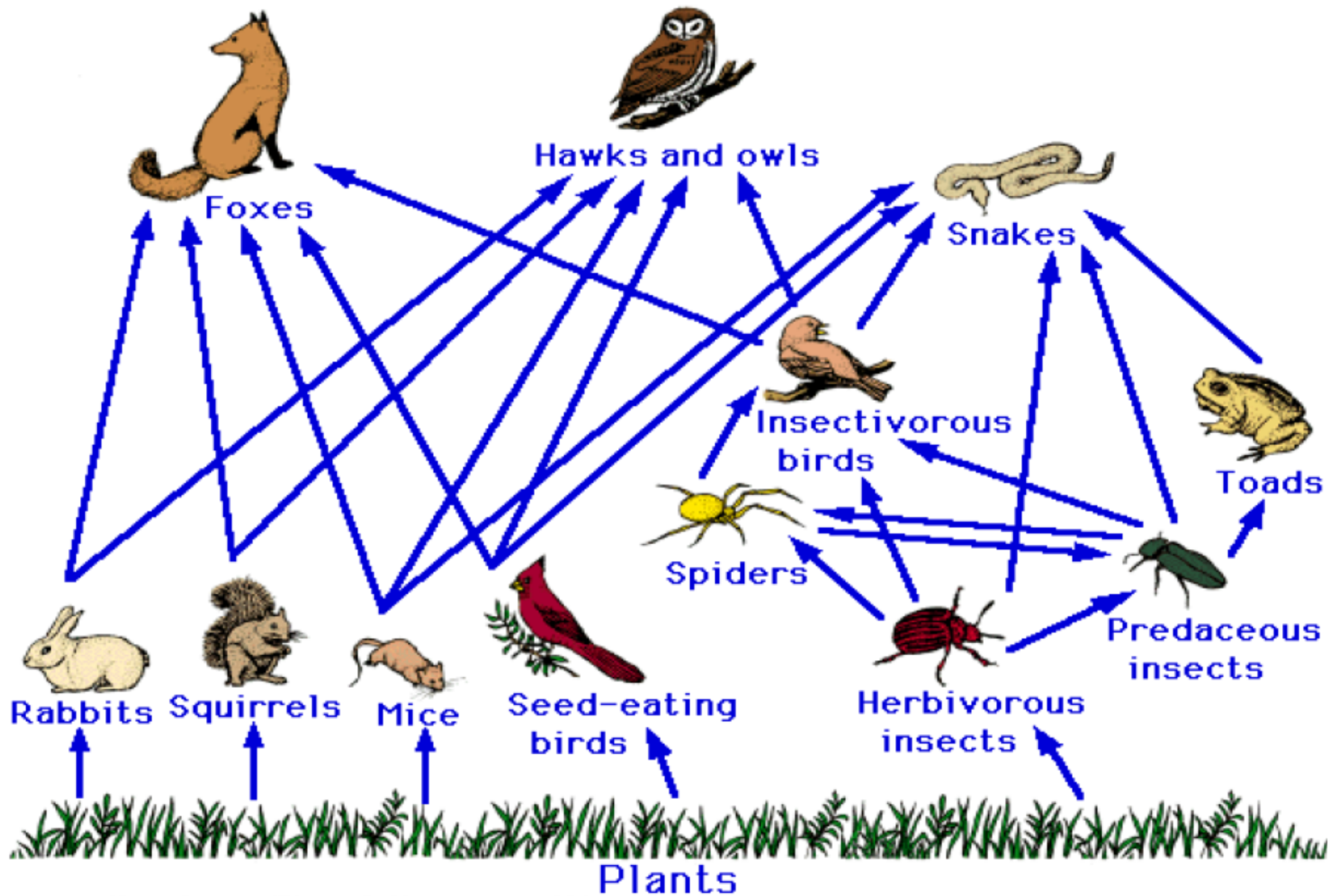
The sun: main source of energy for life on earth

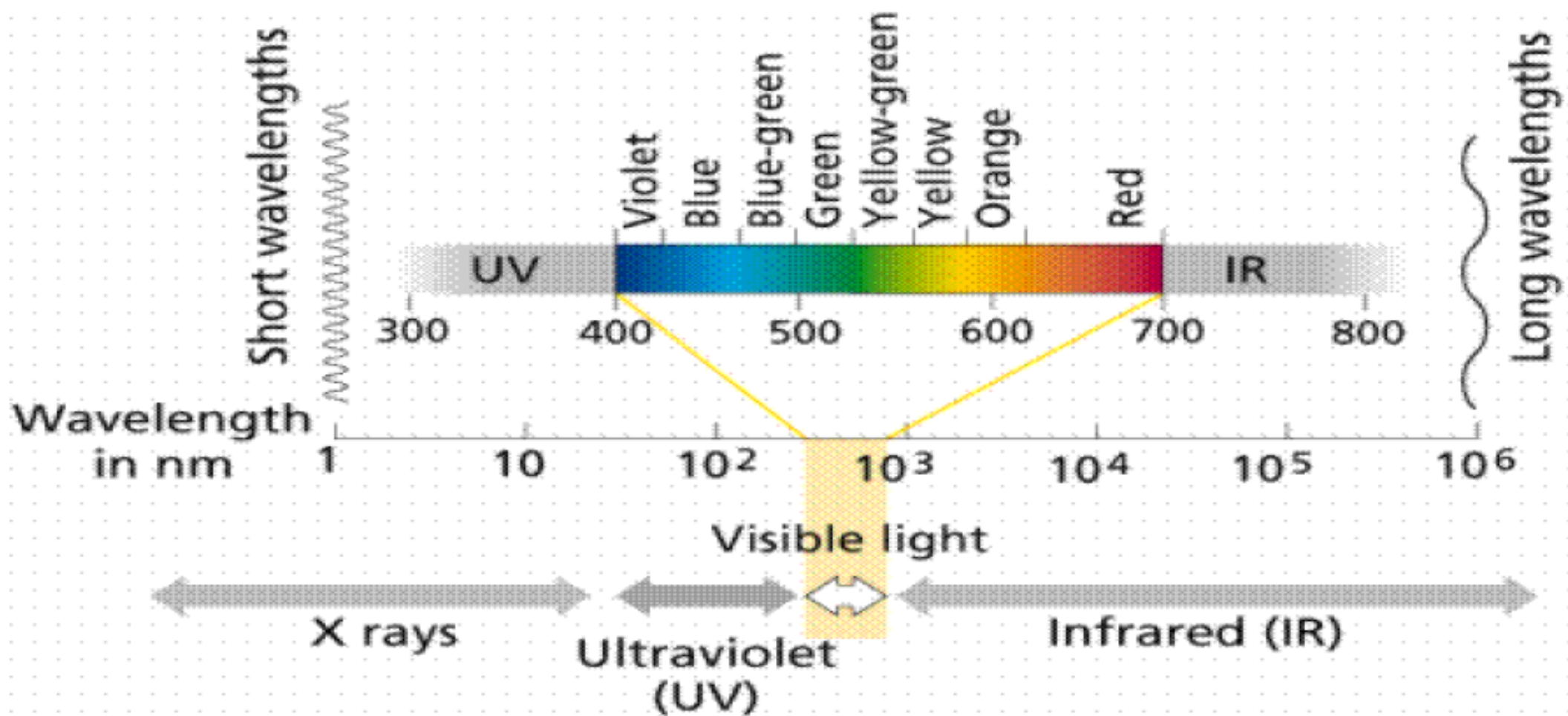


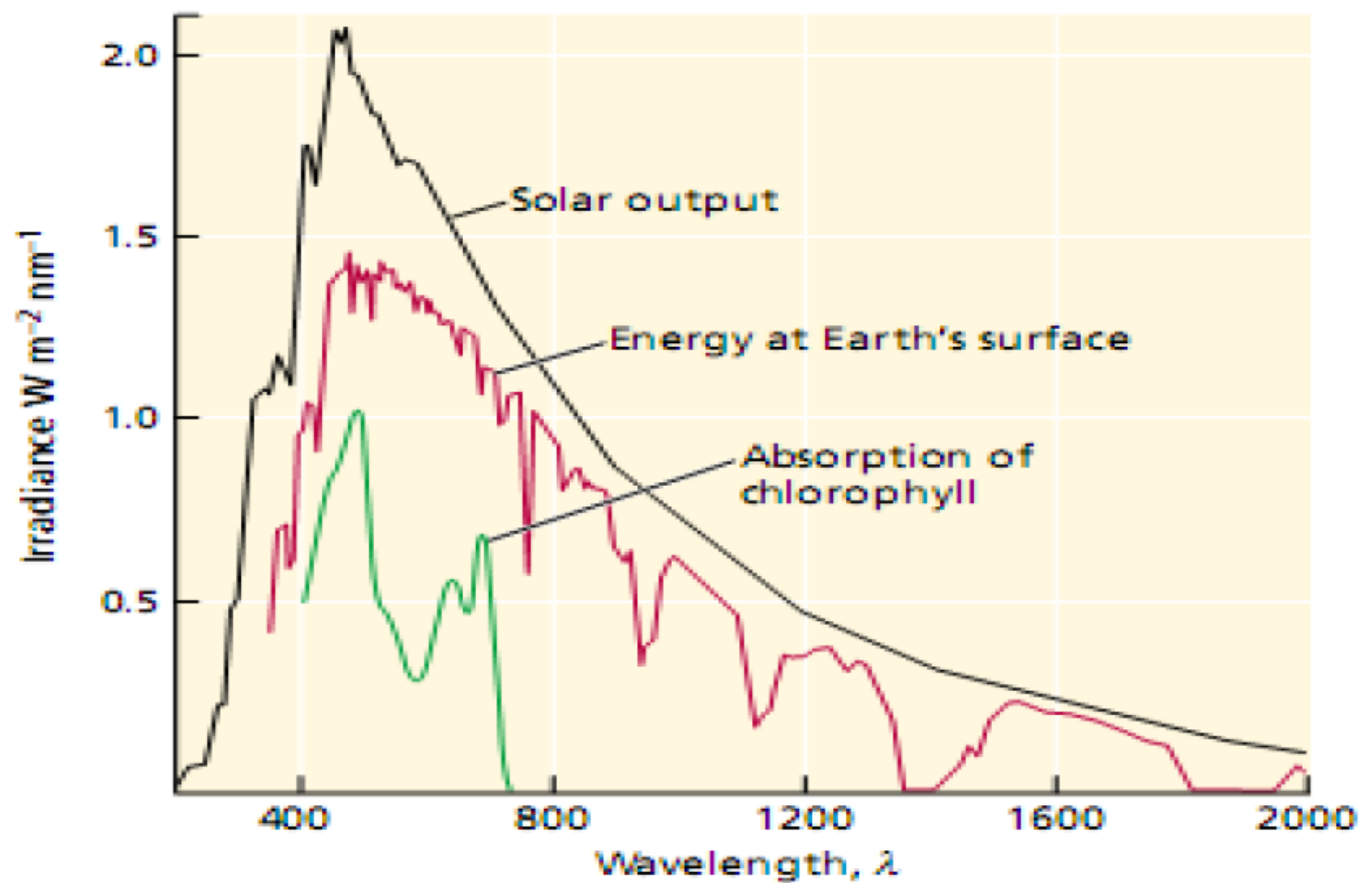
Light Energy Harvested by Plants & Other Photosynthetic Autotrophs

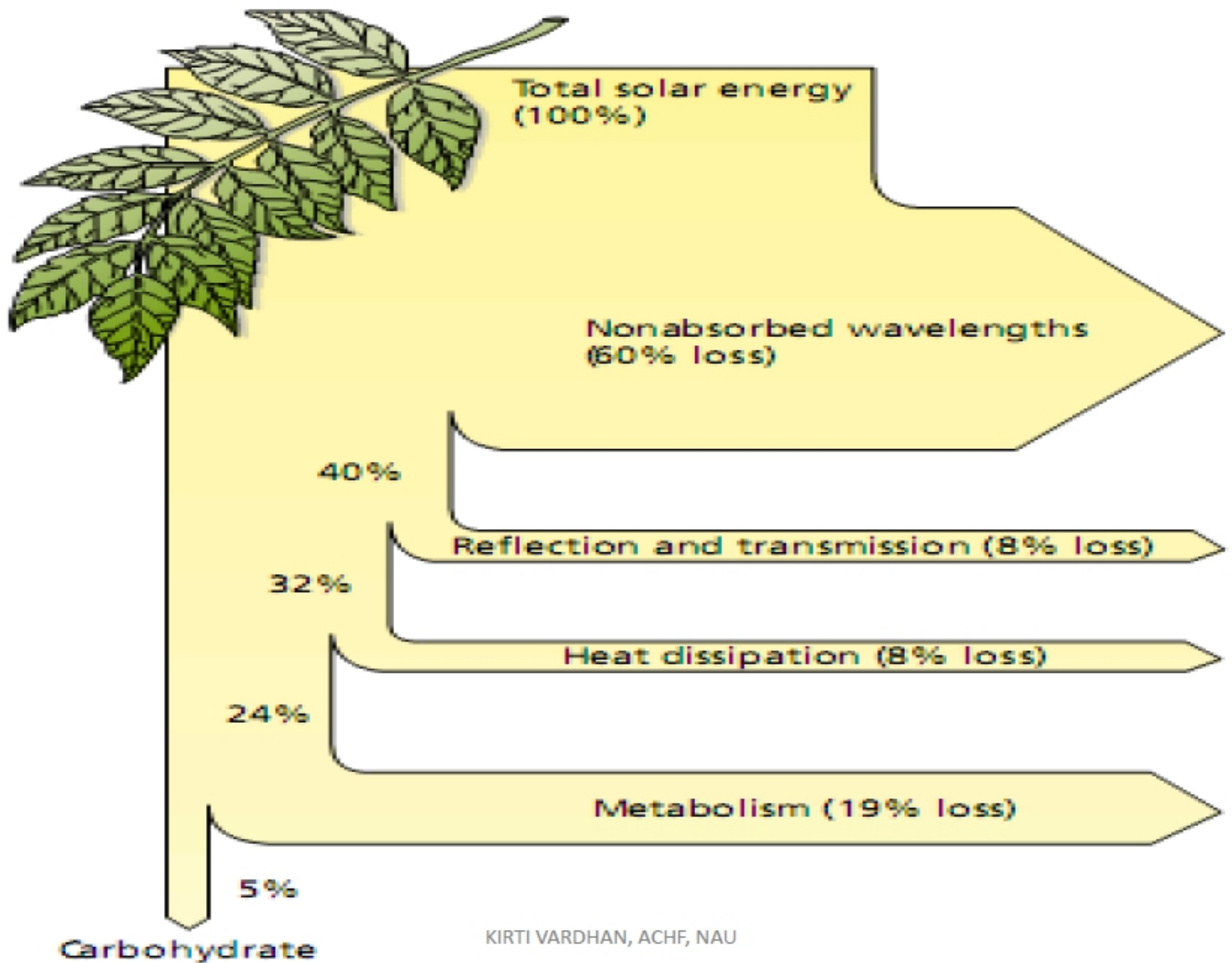
Evolution of Photosynthesis











Energy input

Sunlight
absorbed
by leaf

Heat dissipation

Long-wavelength
radiation

Conduction
and convection
to cool air
(sensible heat
loss)

Evaporative
cooling from
water loss

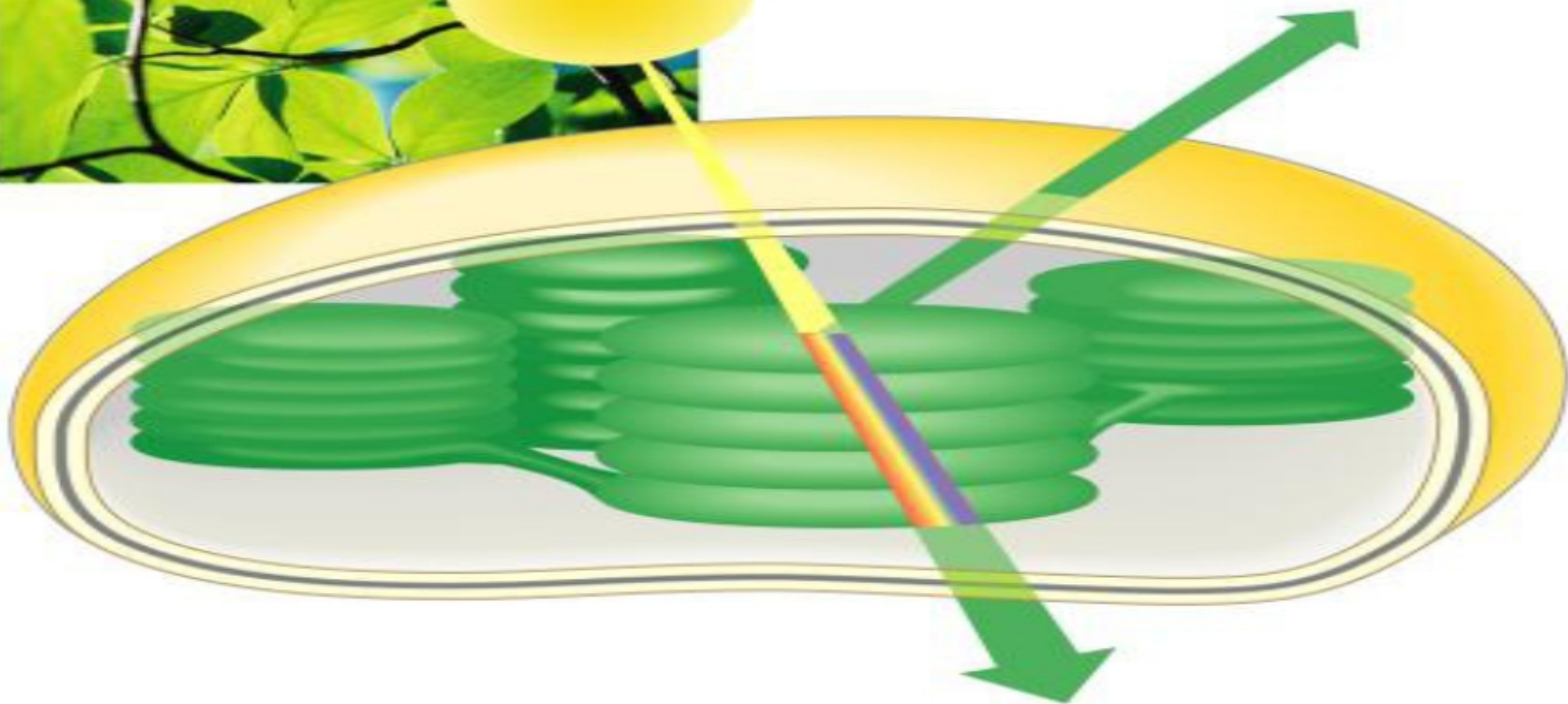




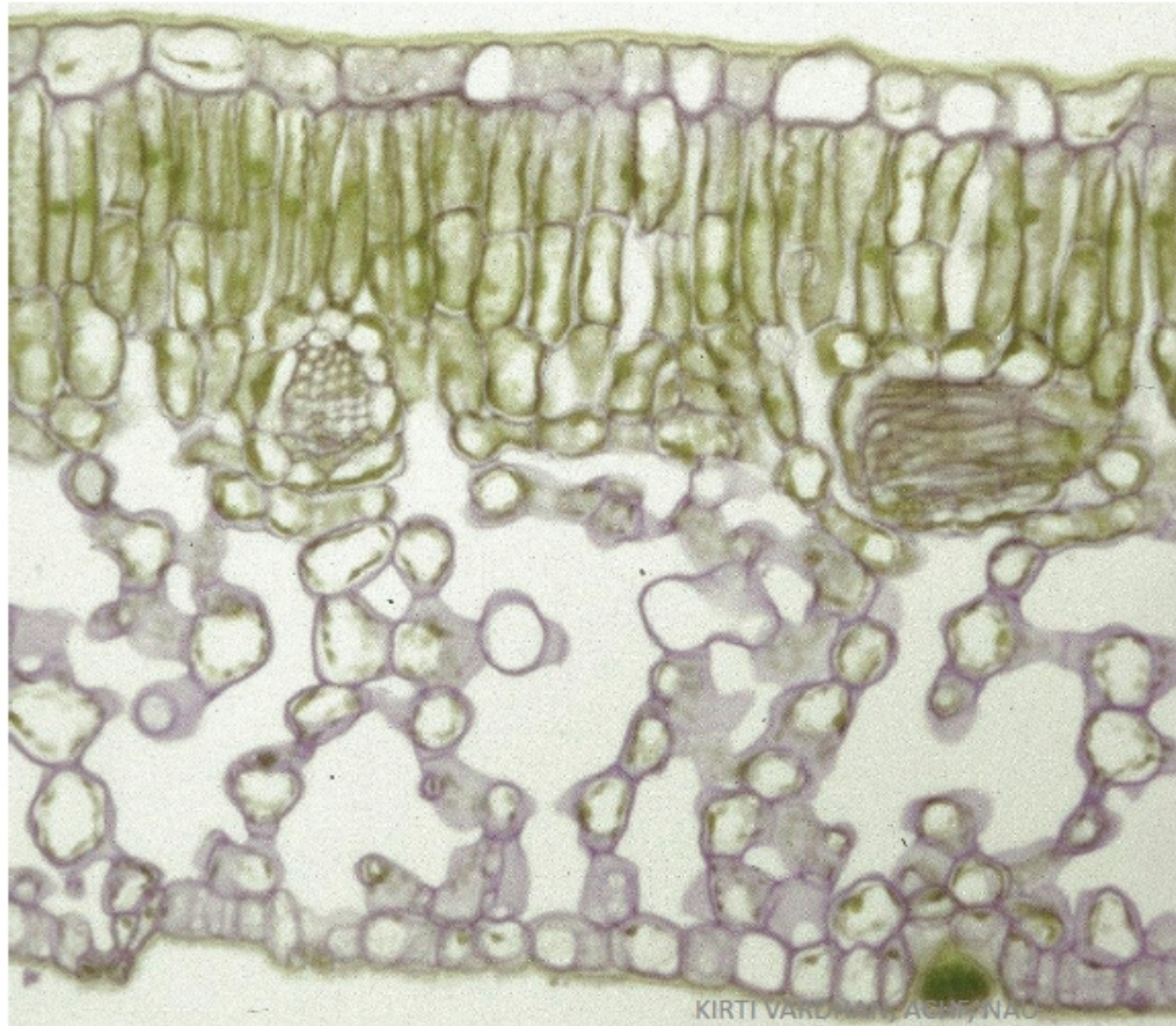
Why are plants green?

Reflected light

Transmitted light



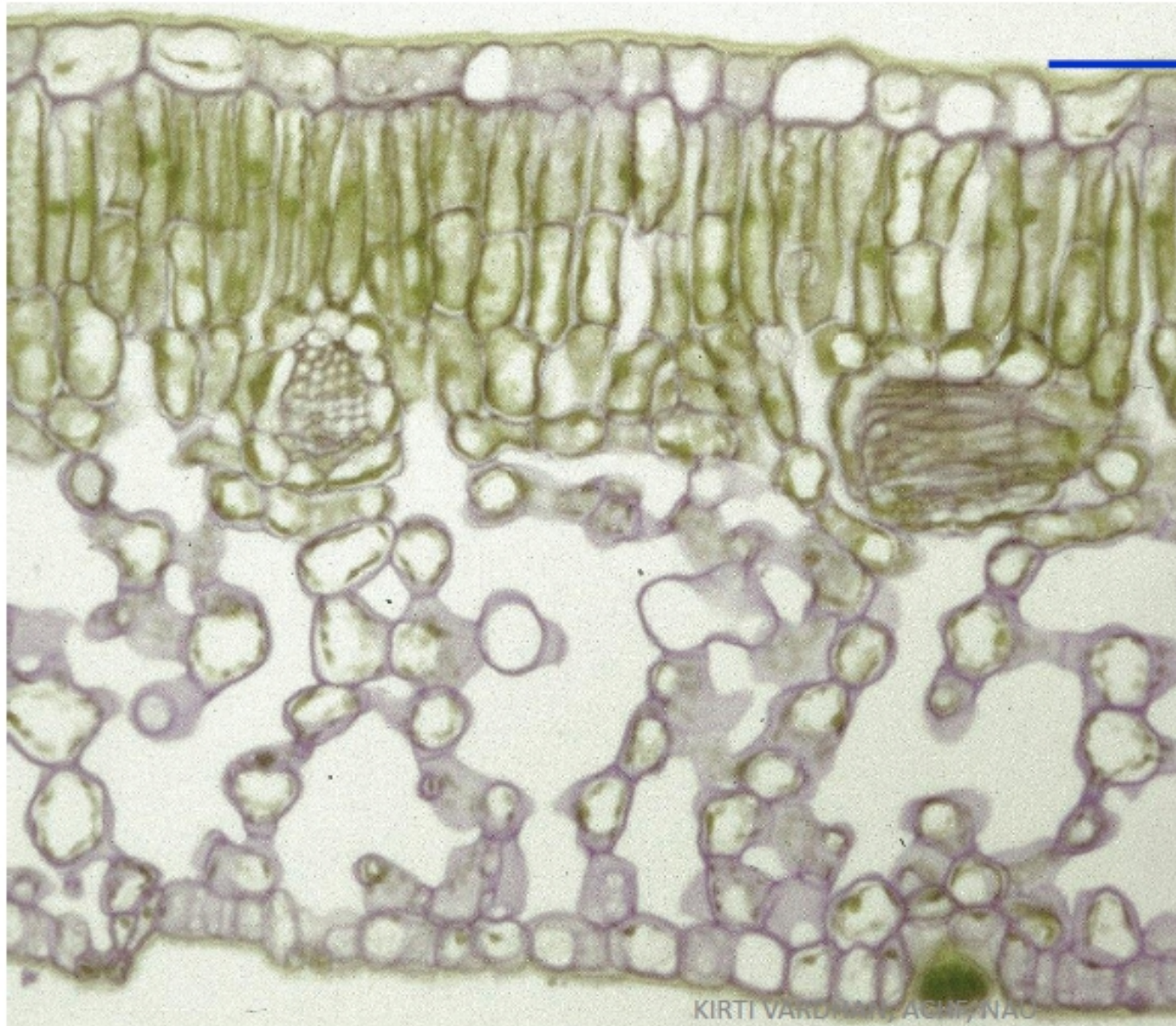
Structure of Leaf



**upper
epidermis**

protect internal
tissues from
mechanical
damage and
bacterial and
fungal invasion

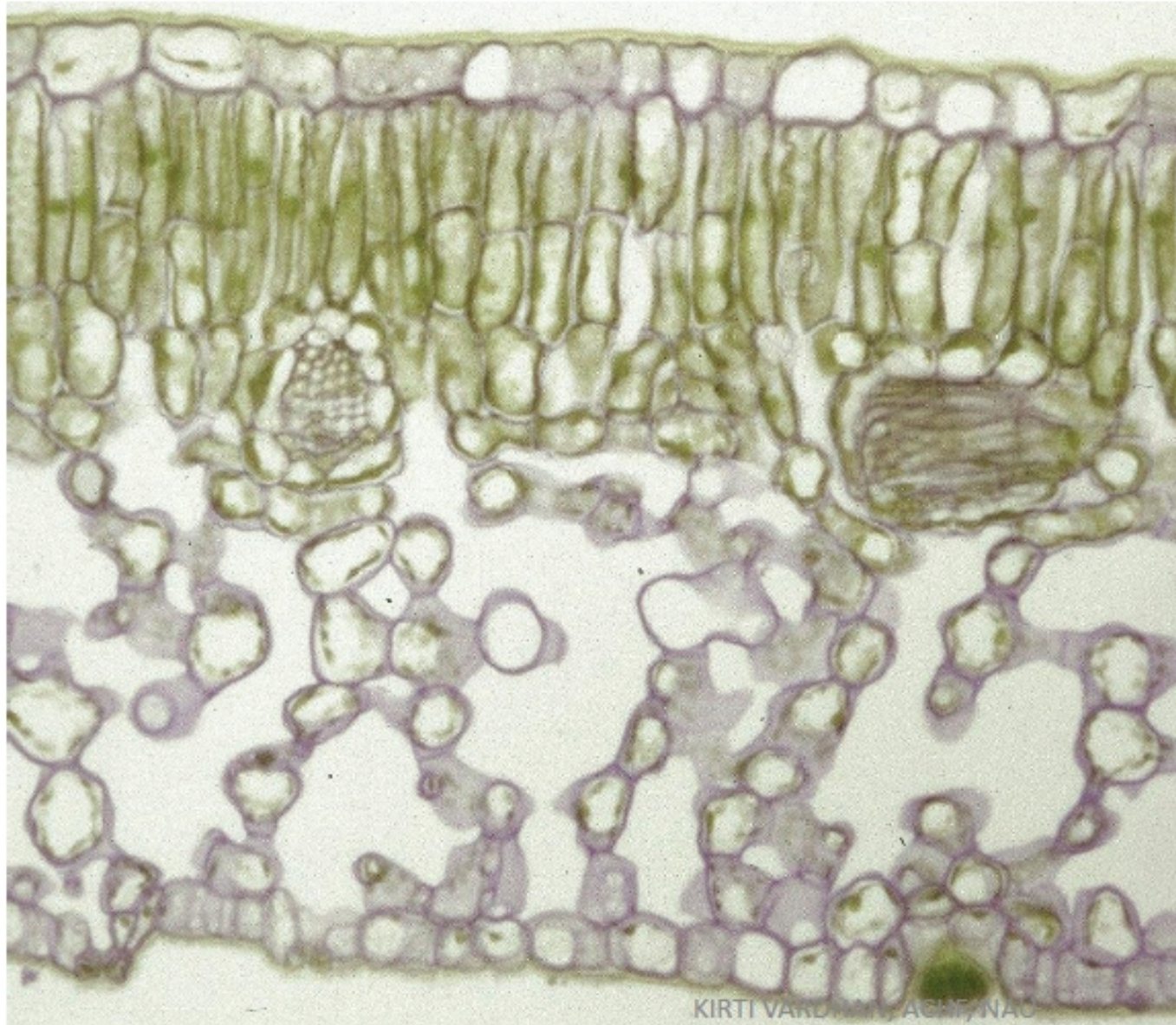
Structure of Leaf



Cuticle

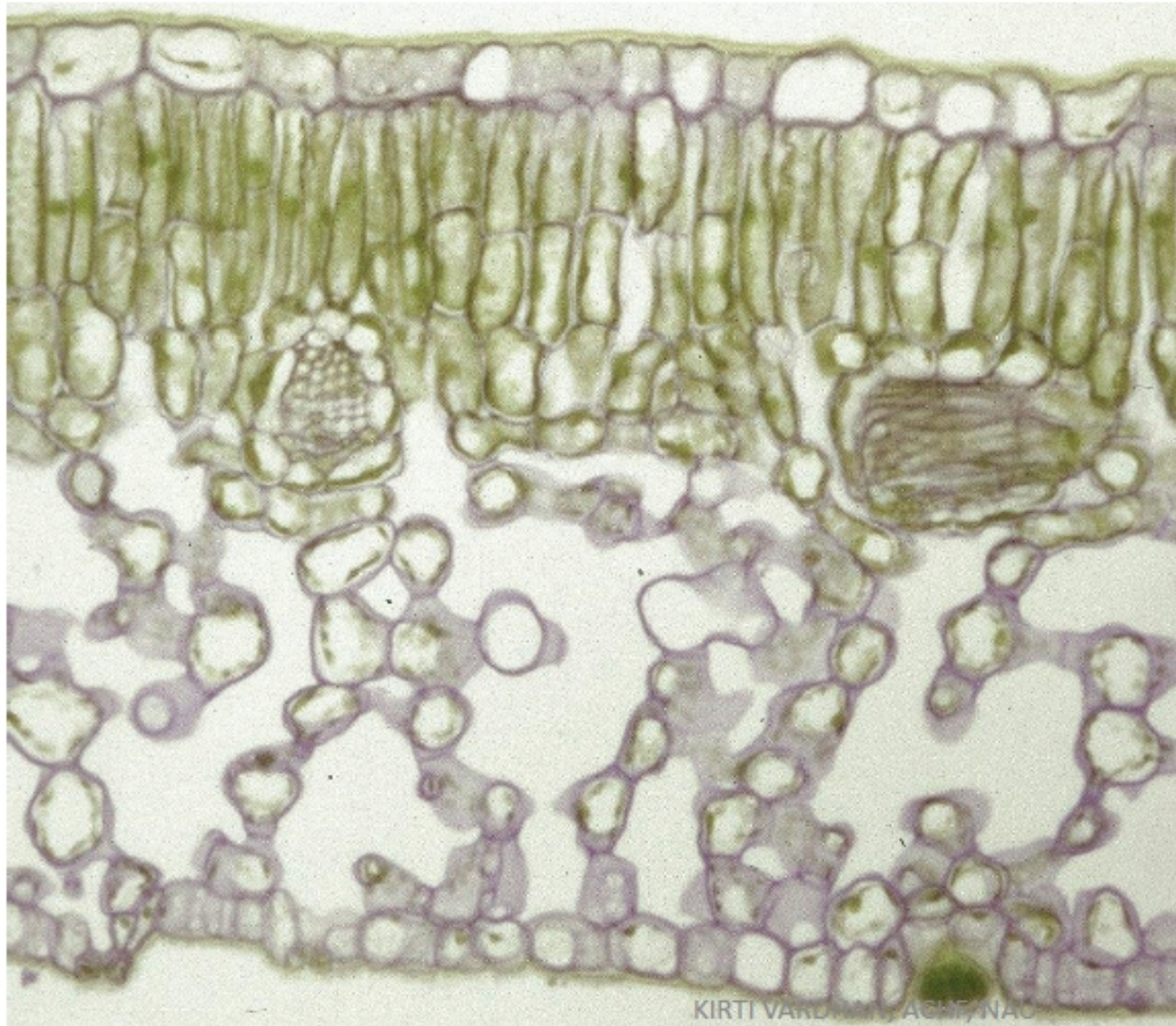
- a waxy layer
- prevent water loss from the leaf surface

Structure of Leaf



mesophyll

Structure of Leaf

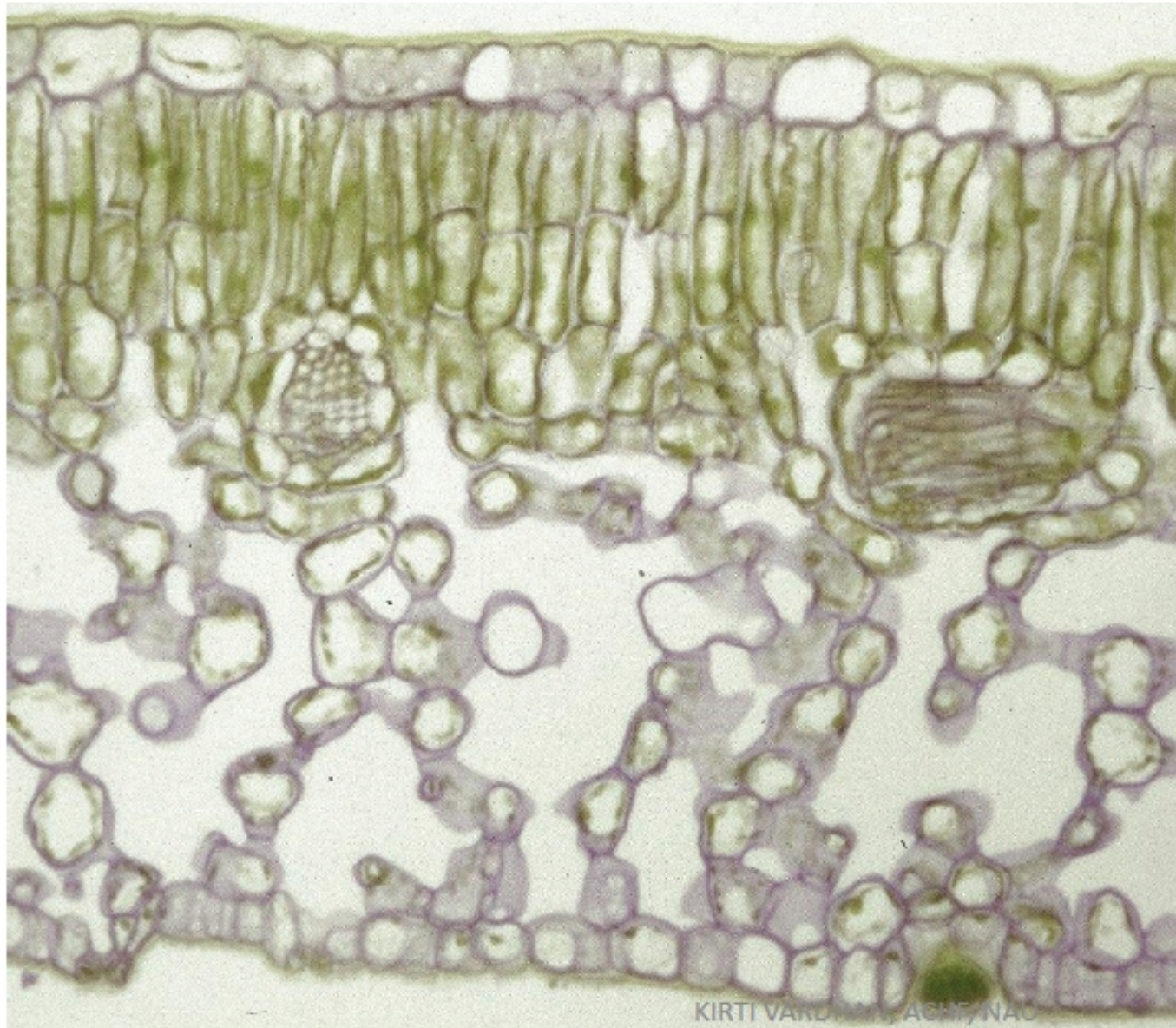


**palisade
mesophyll**

contains many
chloroplasts
closely packed
together

∴ absorb light more
efficiently

Structure of Leaf

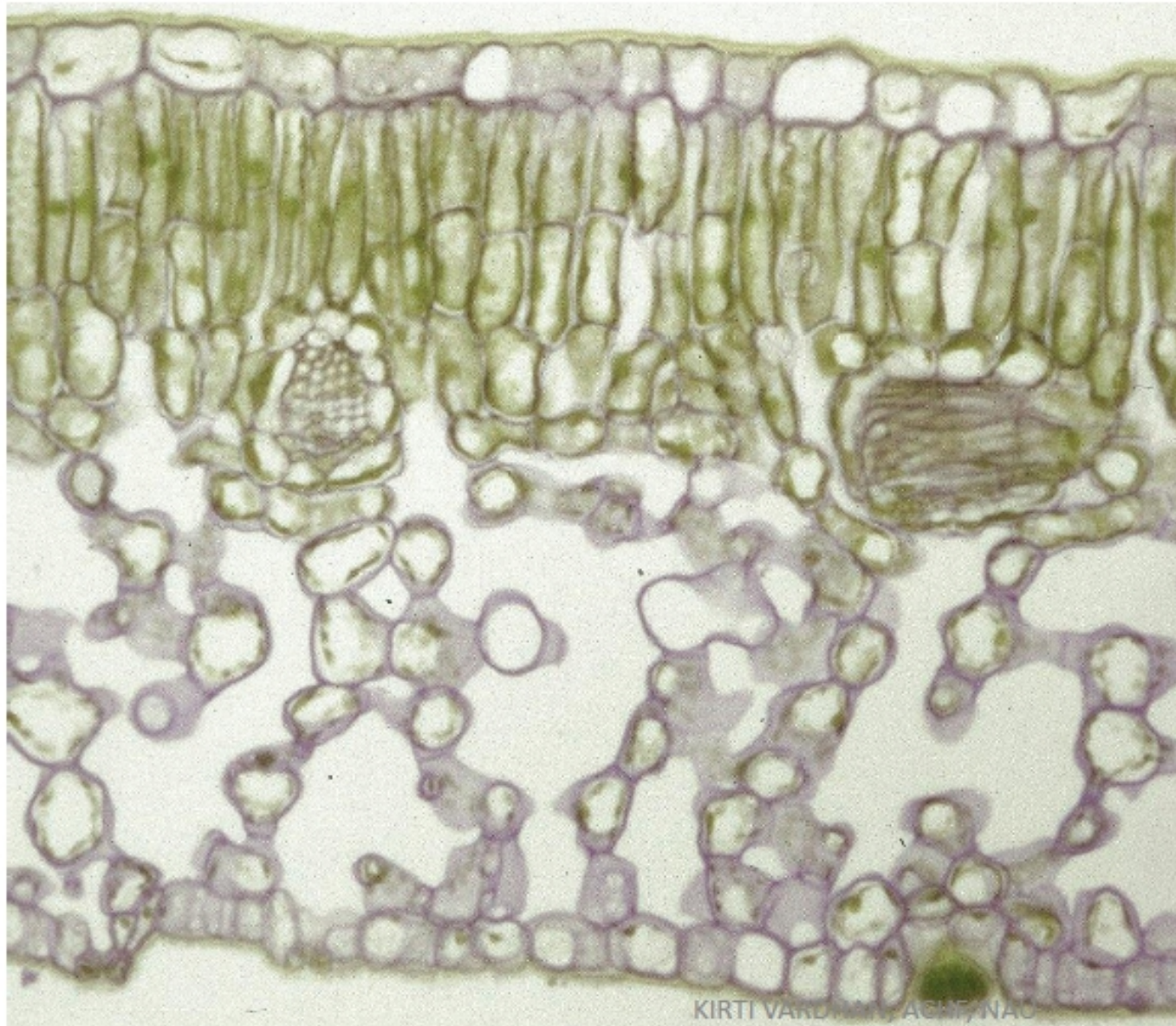


irregular cells loosely
packed together to
leave numerous large
air spaces

→ allow rapid diffusion
of gases throughout
the leaf for
photosynthesis

**spongy
mesophyll**

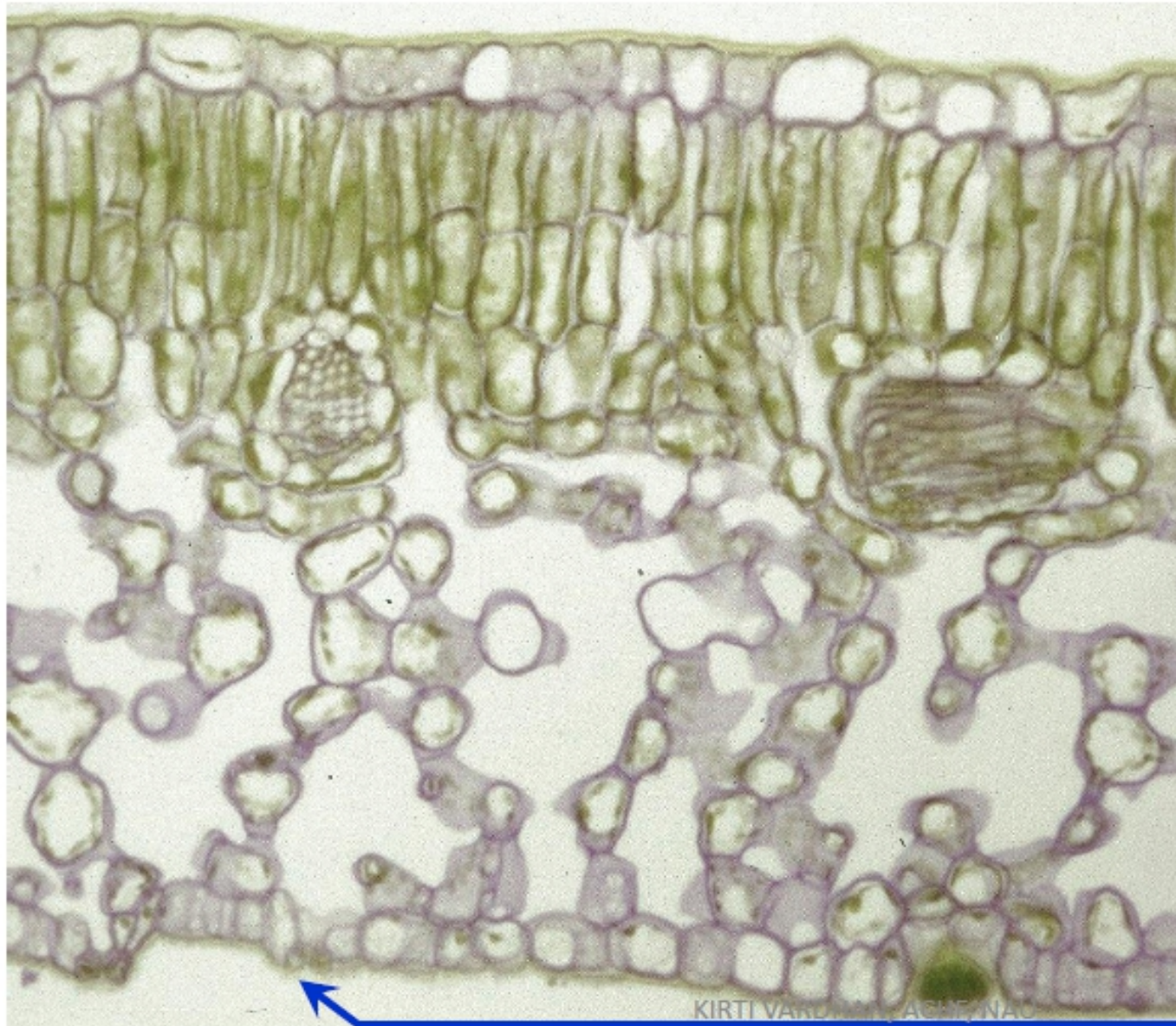
Structure of Leaf



same as upper
epidermis except
the cuticle is
thinner

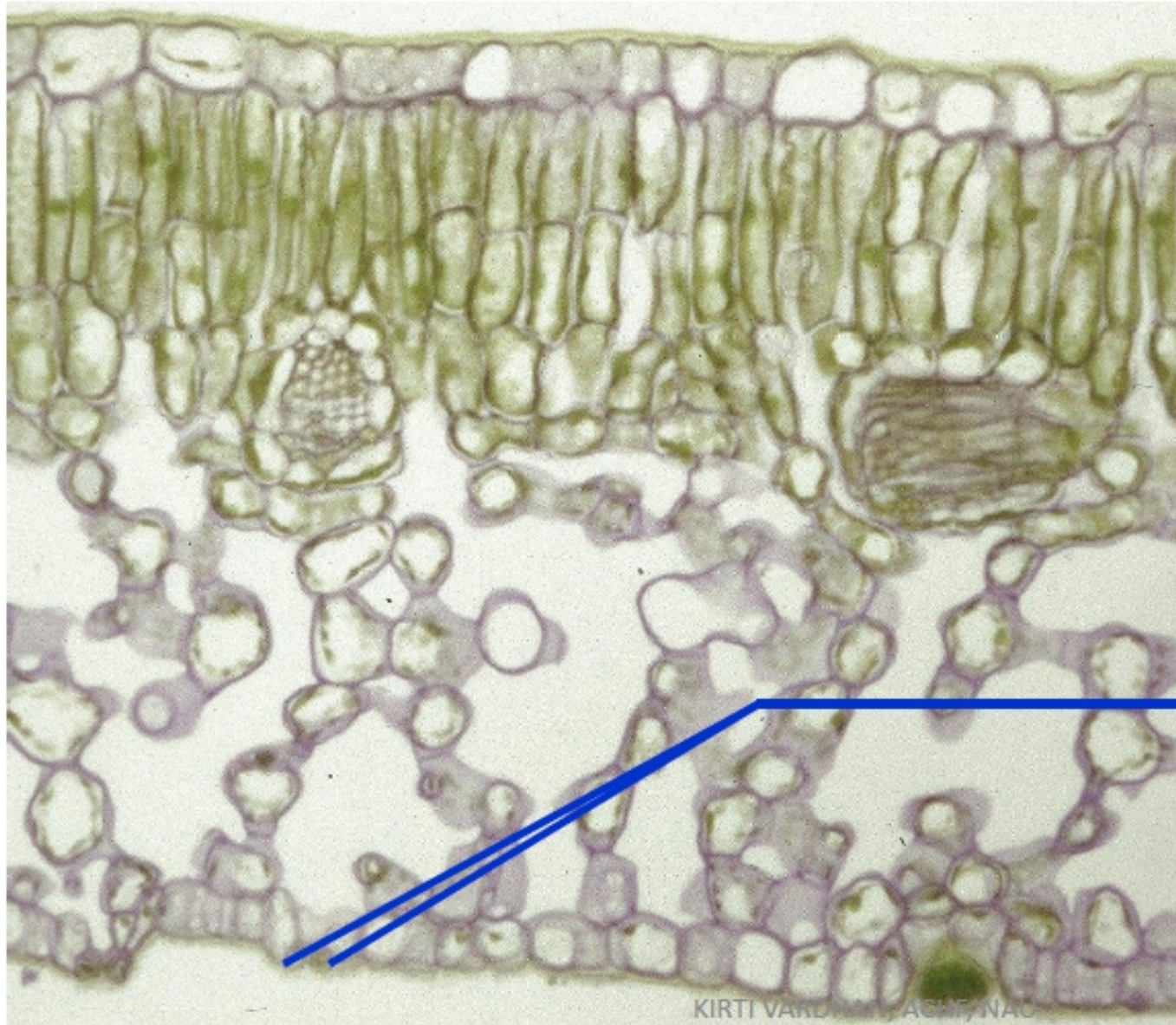
lower
epidermis

Structure of Leaf



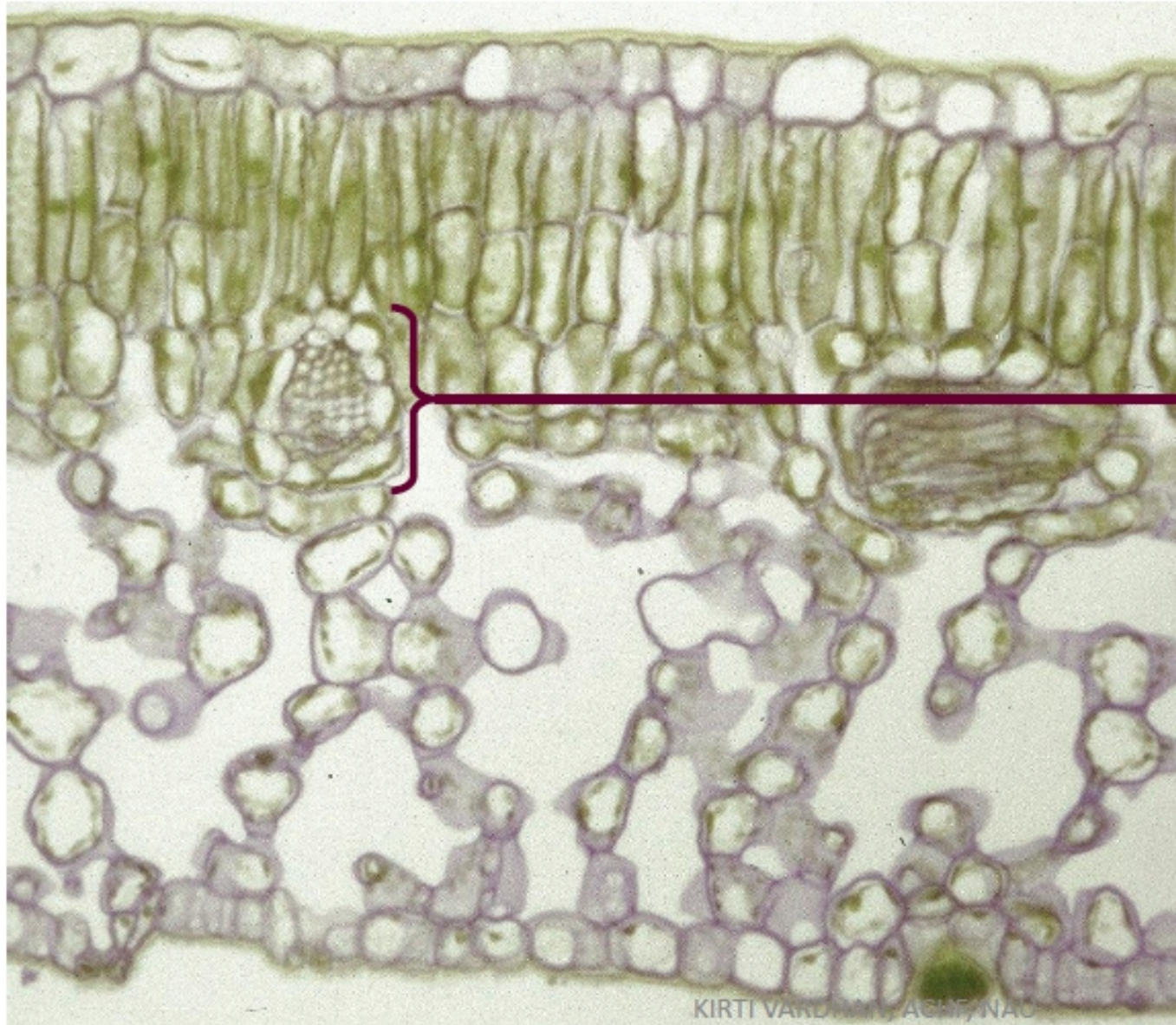
stoma
opening which
allows gases to pass
through it to go into
or out of the leaf

Structure of Leaf



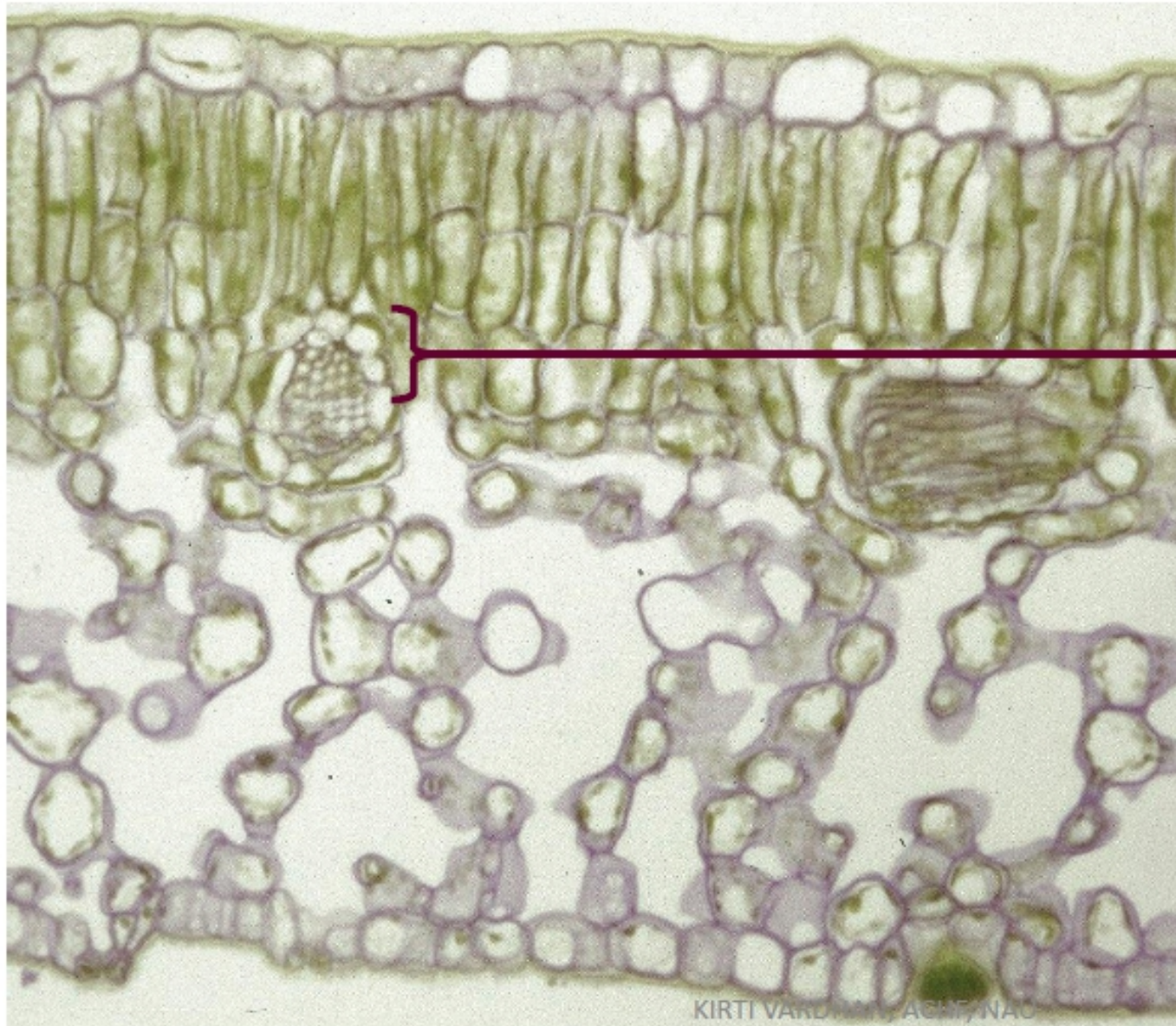
guard cells
control the size of
stoma

Structure of Leaf



vascular
bundle
(vein)

Structure of Leaf



xylem

- to transport water and mineral salts towards the leaf

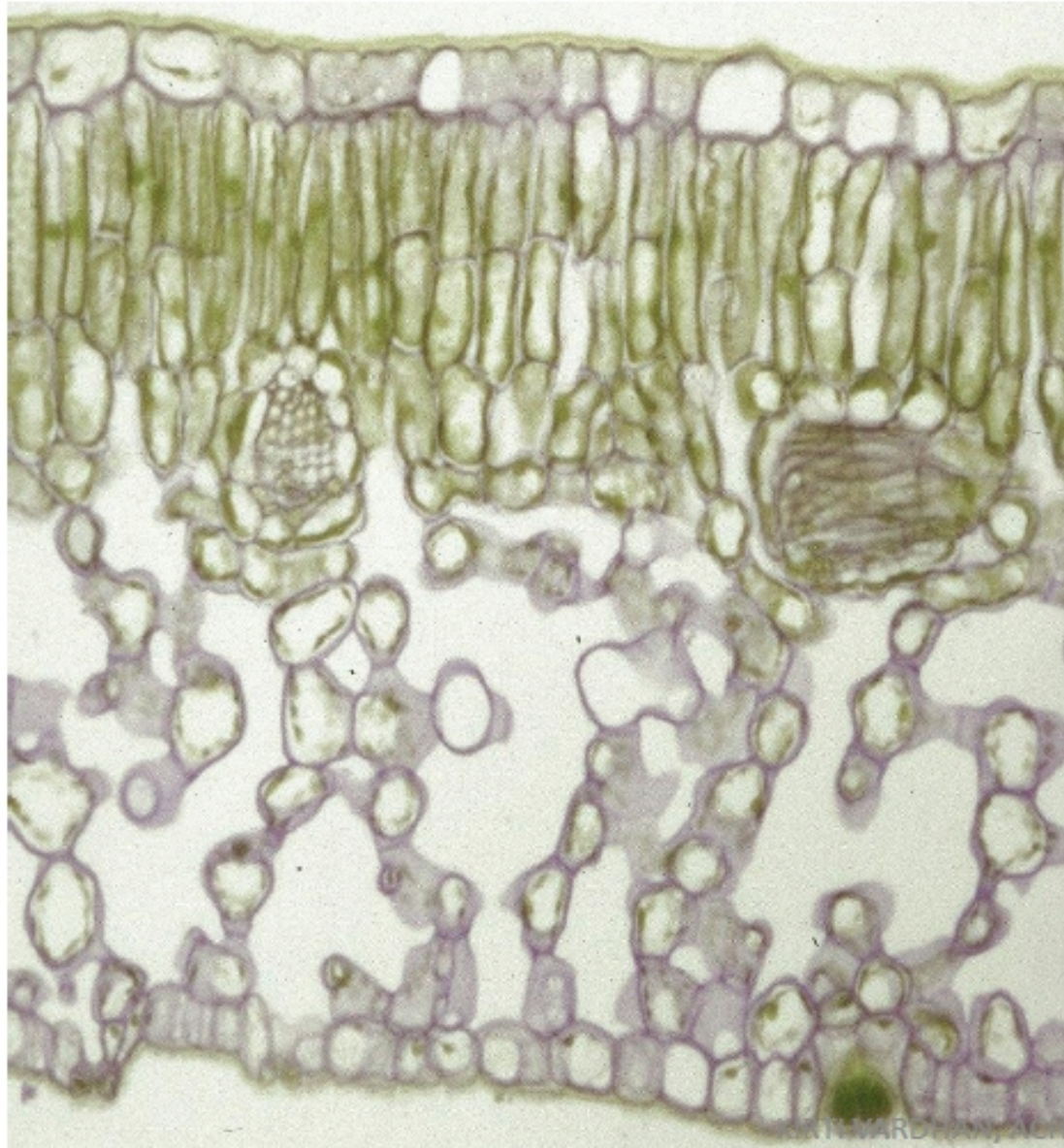
Structure of Leaf



phloem

- to transport organic substances away from the leaf

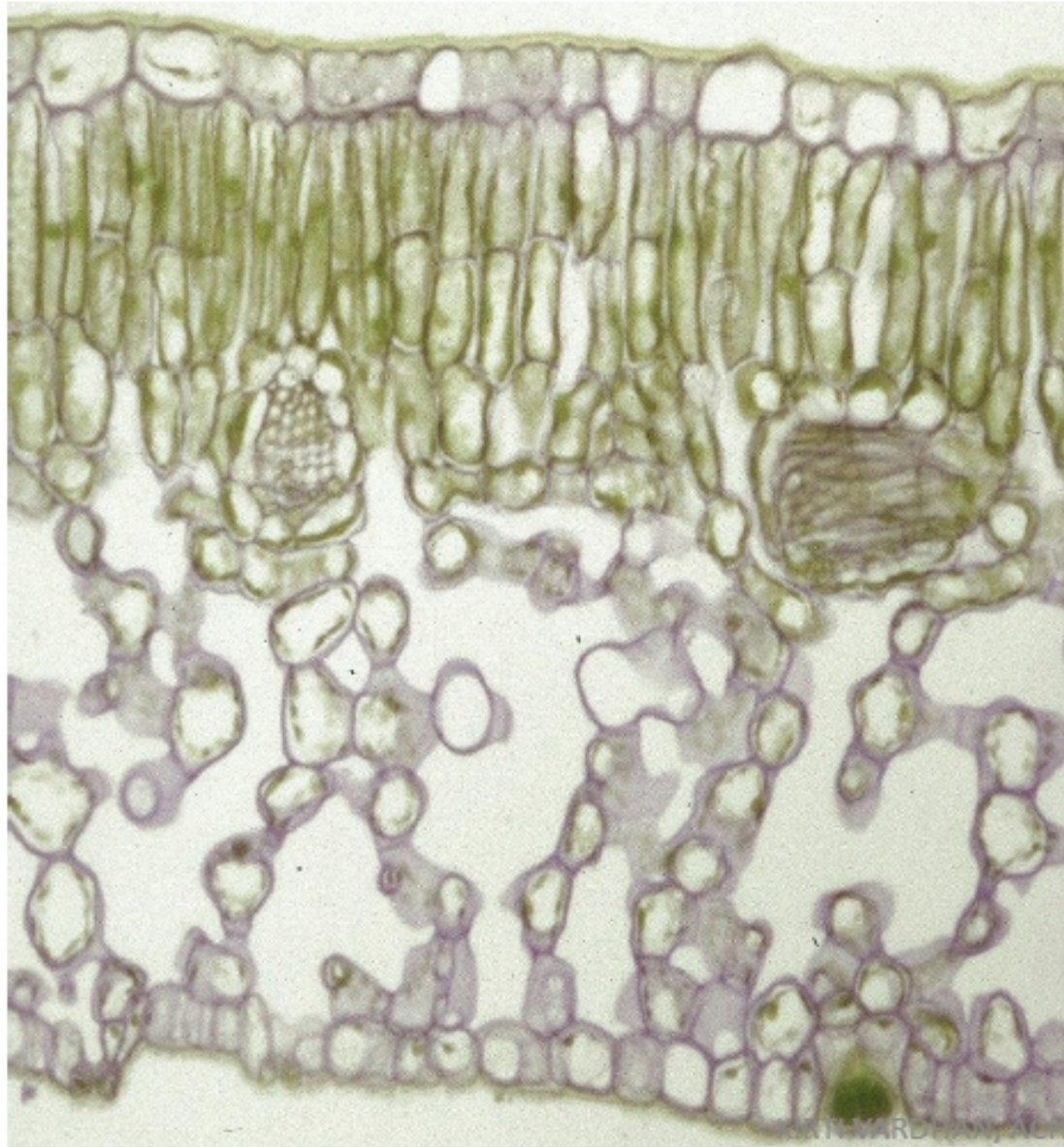
Adaptation of leaf to photosynthesis



Upper epidermis
and cuticle is
transparent

Allows most light to
pass to
photosynthetic
mesophyll tissues

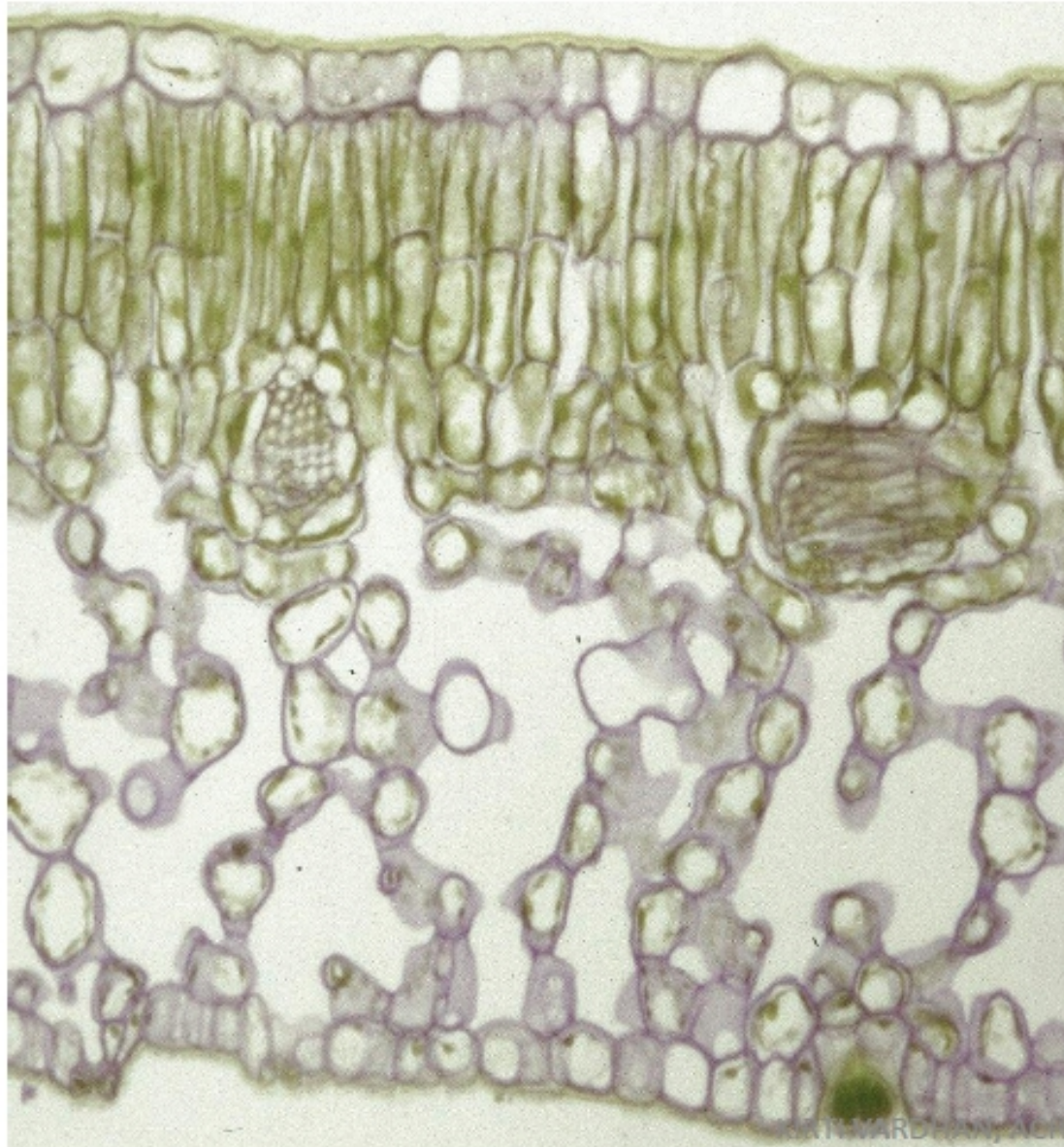
Adaptation of leaf to photosynthesis



Palisade mesophyll cells are closely packed and contain many chloroplasts

To carry out photosynthesis more efficiently

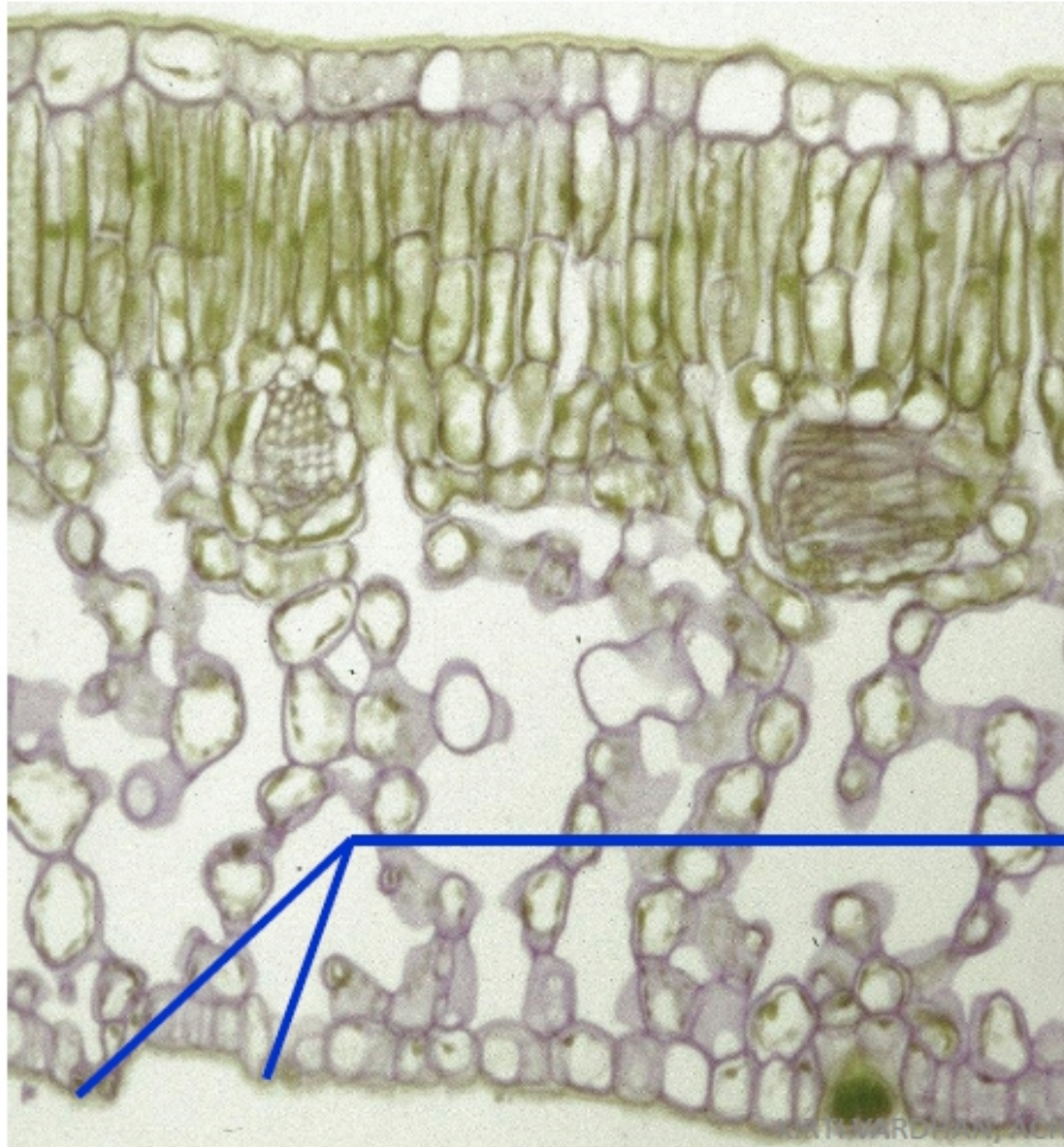
Adaptation of leaf to photosynthesis



Spongy mesophyll cells are loosely packed with numerous large air spaces

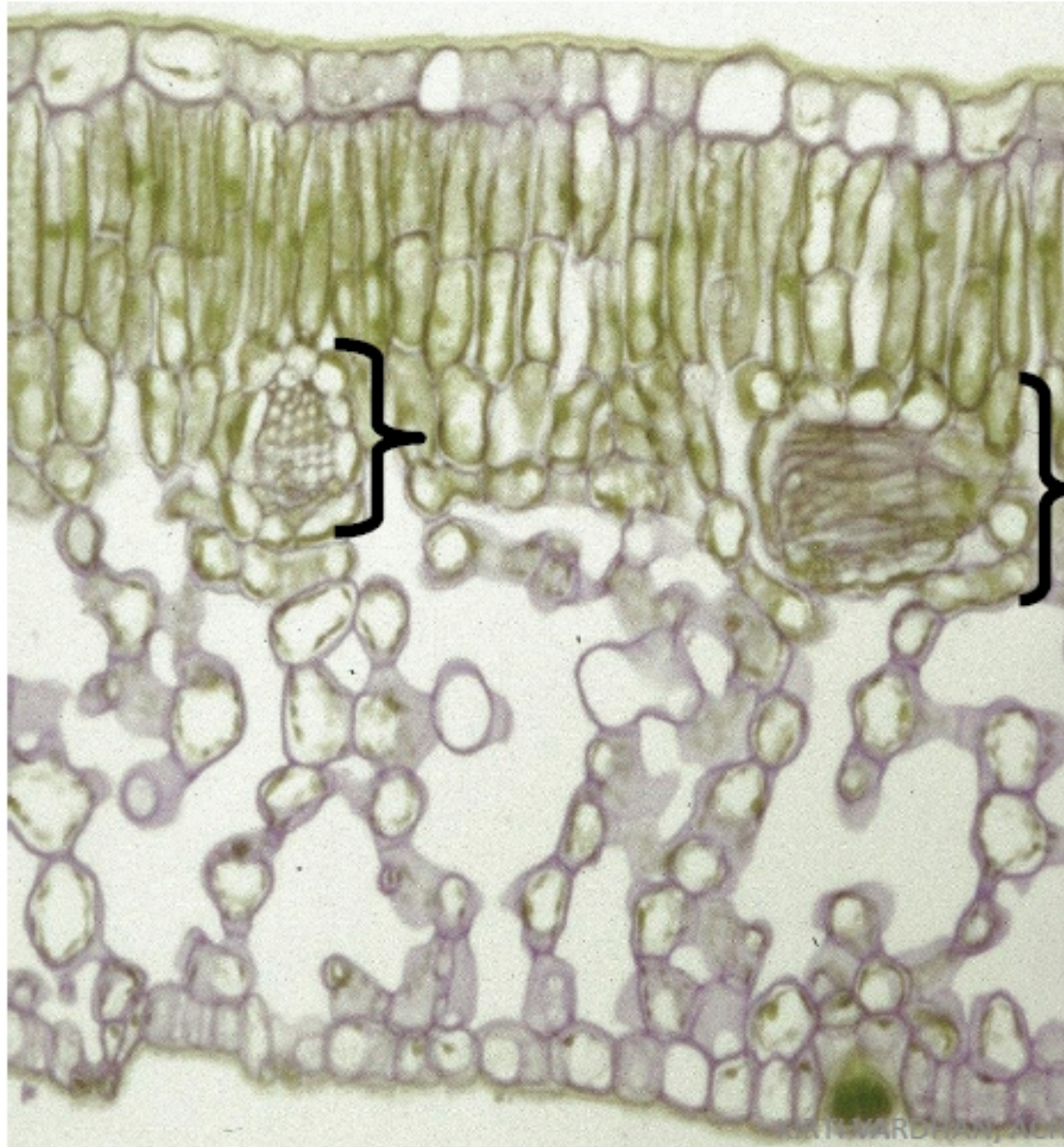
To allow rapid diffusion of gases throughout the leaf

Adaptation of leaf to photosynthesis



Numerous stomata
on lower epidermis
To allow rapid
gaseous exchange
with the
atmosphere

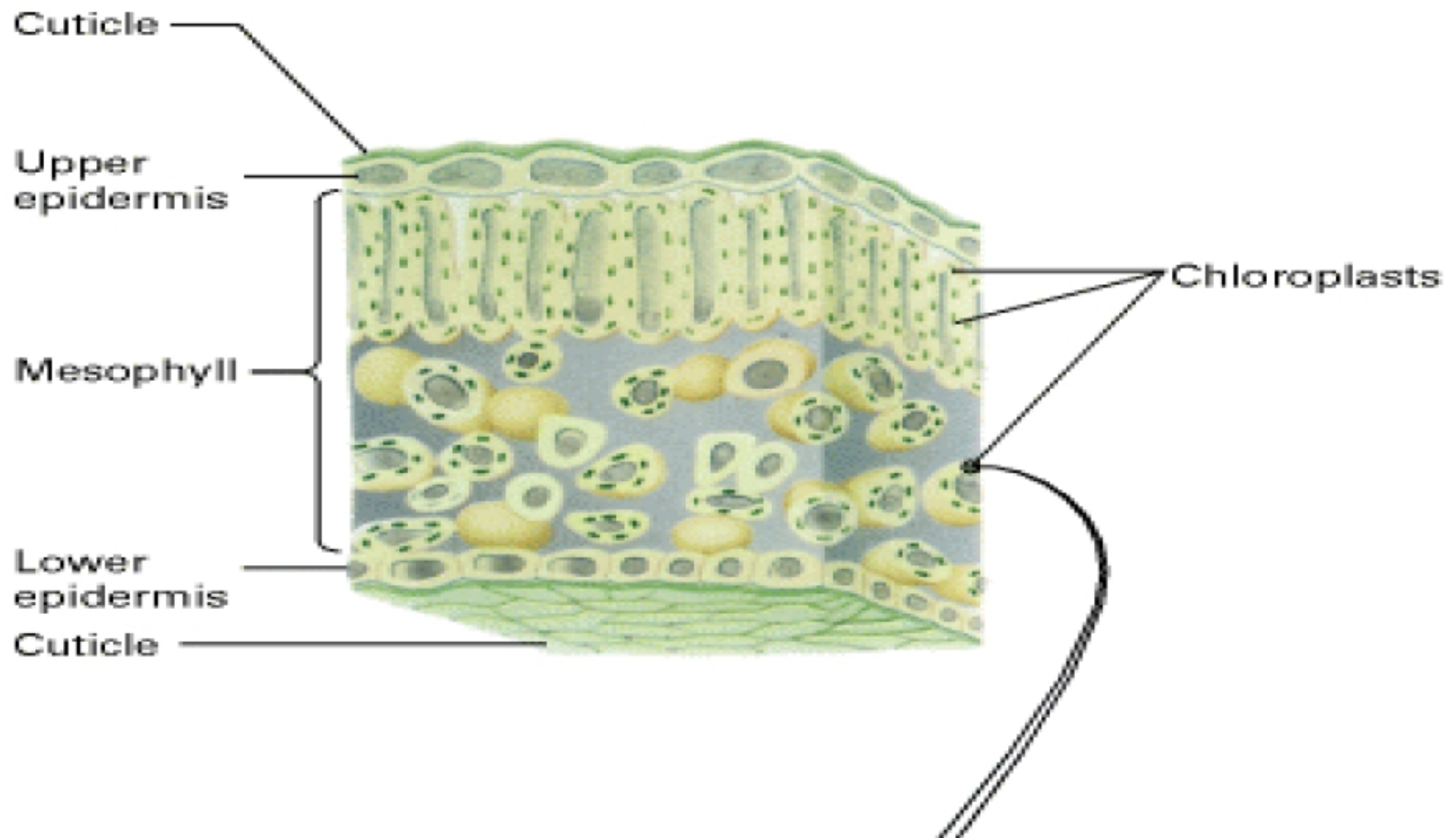
Adaptation of leaf to photosynthesis

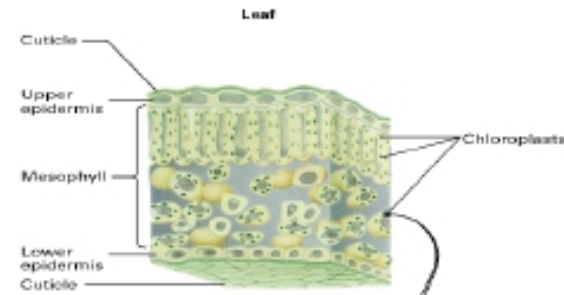


Extensive vein system

- Allow sufficient water to reach the cells in the leaf
- To carry food away from them to other parts of the plant

Leaf



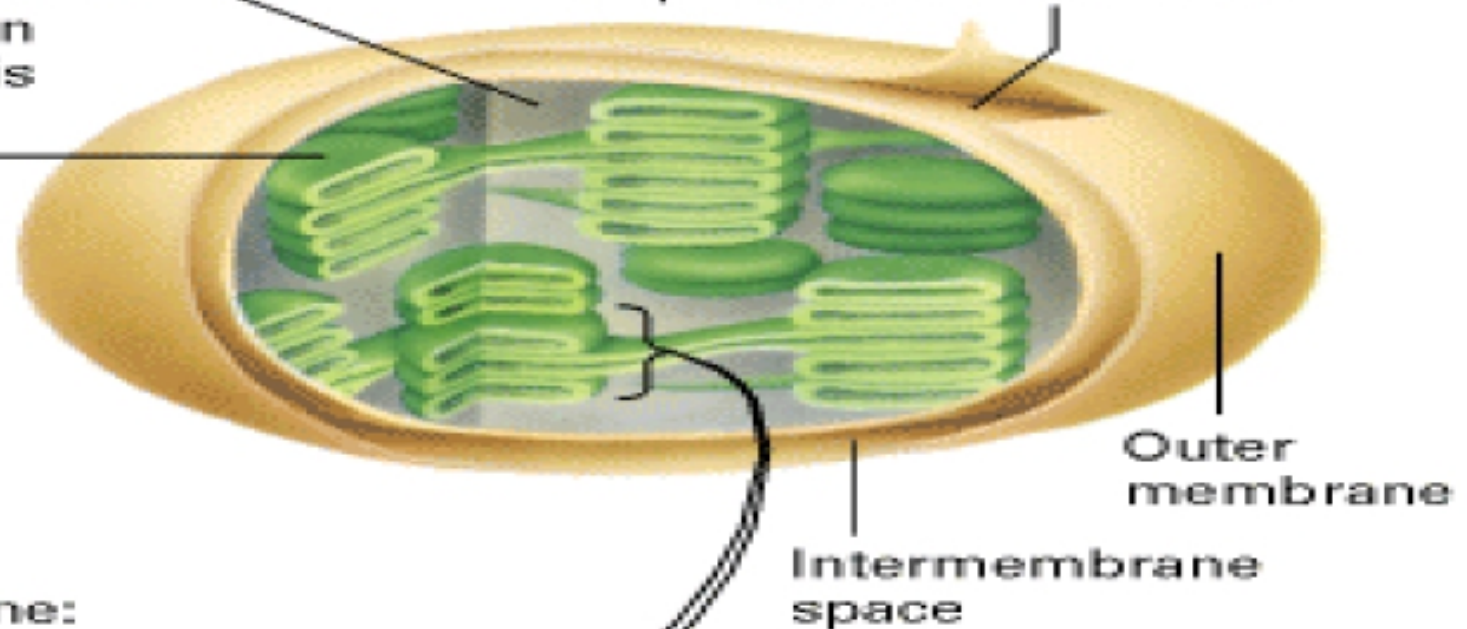


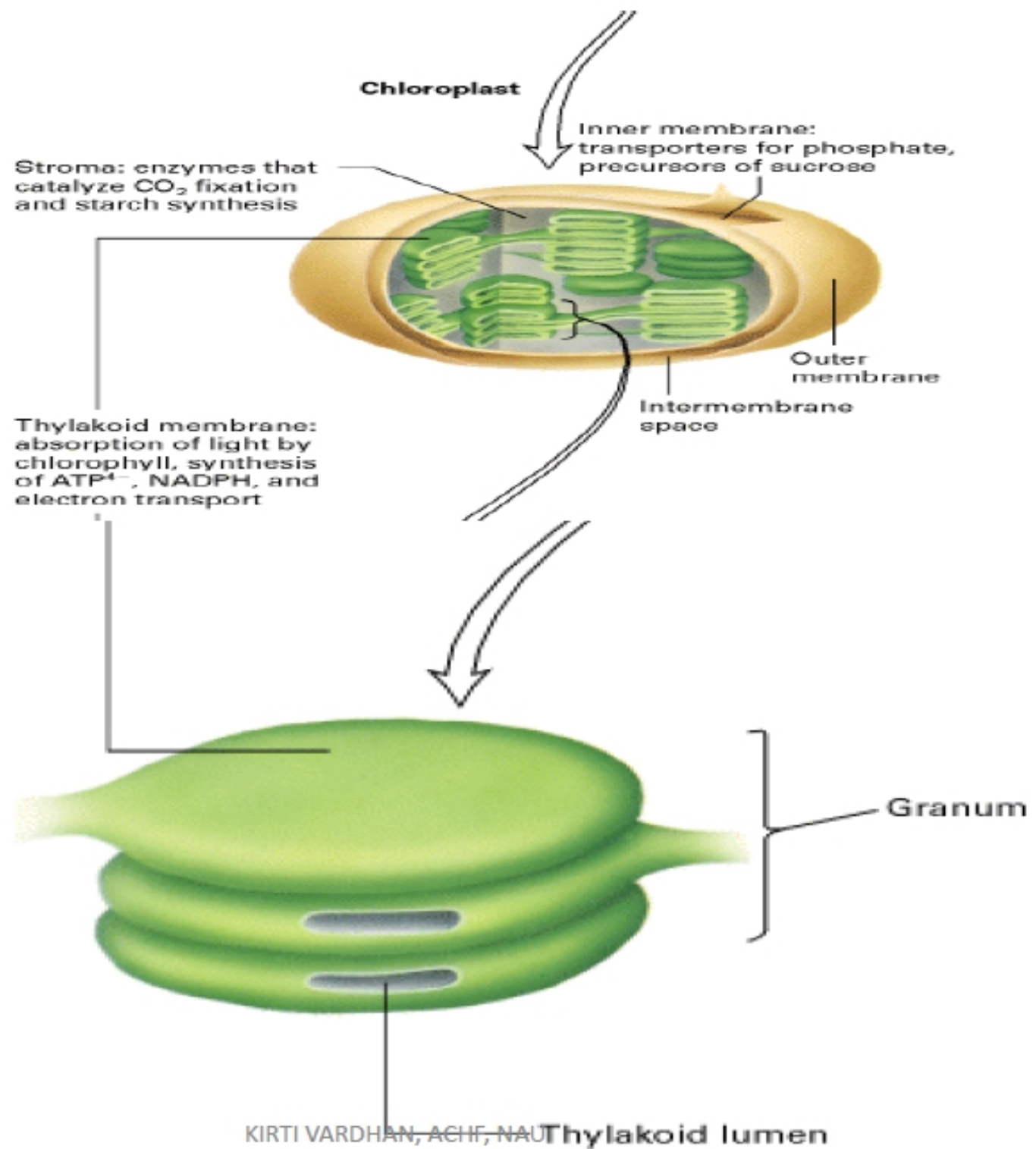
Chloroplast

Stroma: enzymes that catalyze CO_2 fixation and starch synthesis

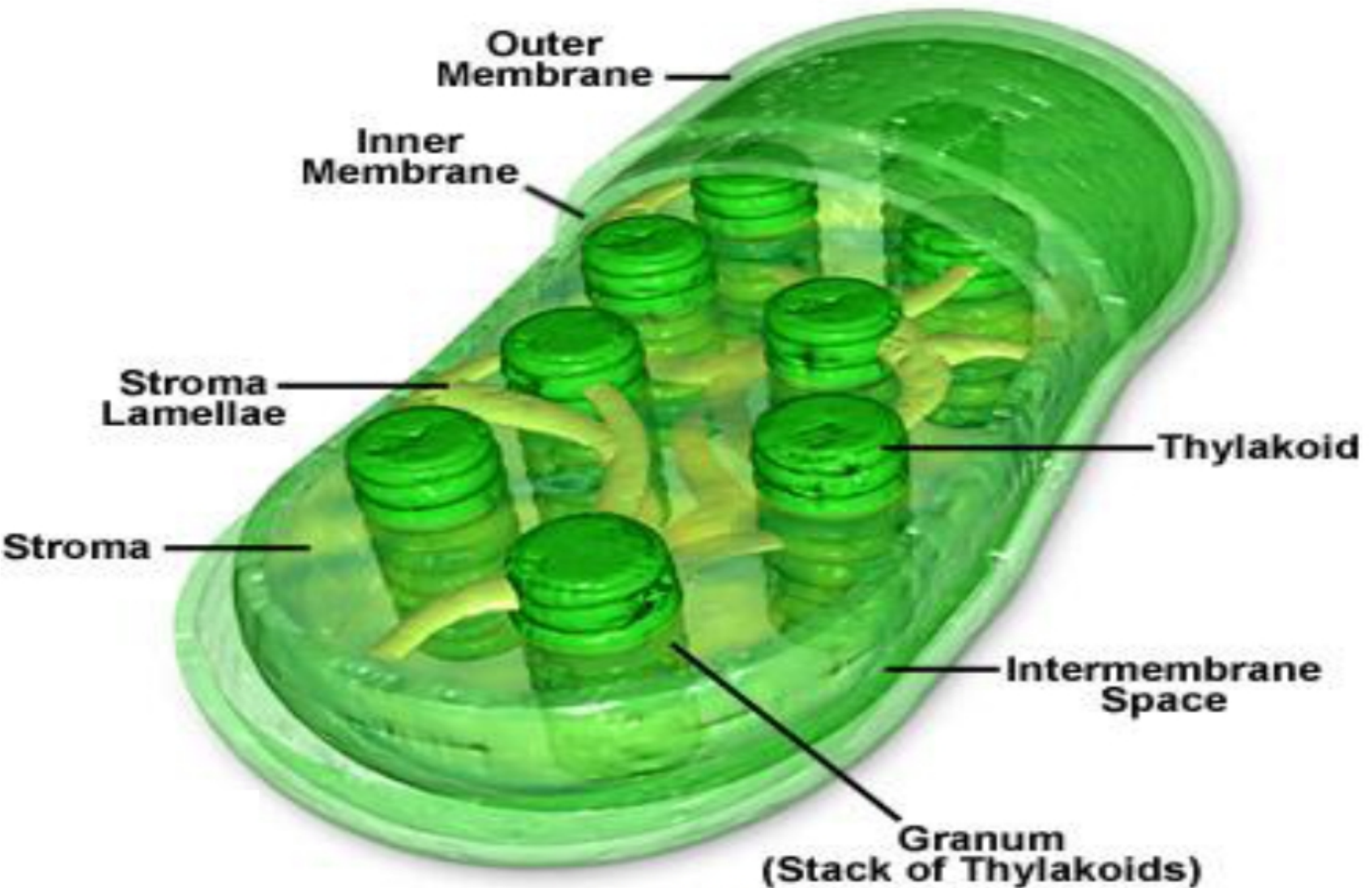
Inner membrane: transporters for phosphate, precursors of sucrose

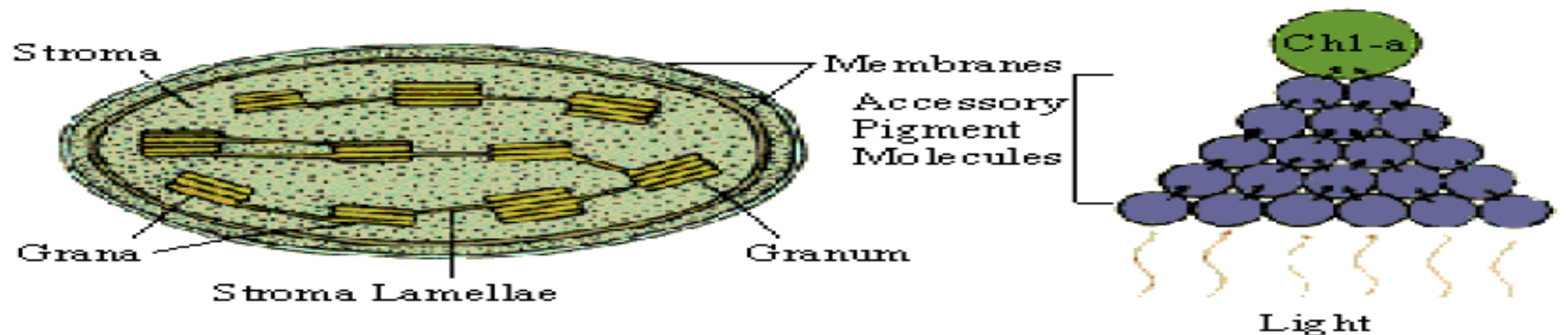
Thylakoid membrane: absorption of light by chlorophyll, synthesis of ATP^{4-} , NADPH, and electron transport





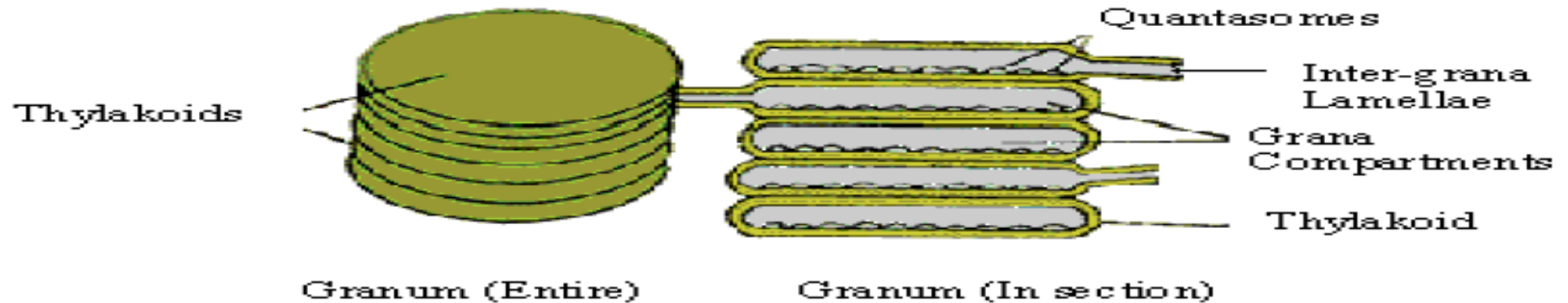
Plant Cell Chloroplast Structure





(A) Section of chloroplast showing internal structure

(D) Transfer of light energy by accessory pigment molecules to chl-a



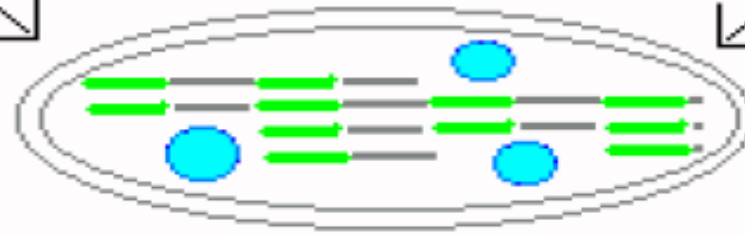
(B) Structure of Granum



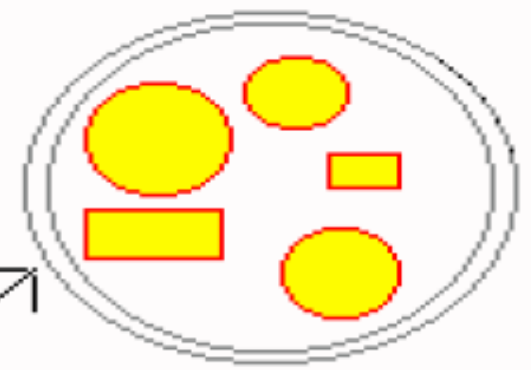
(C) Structure of a thylakoid lamella



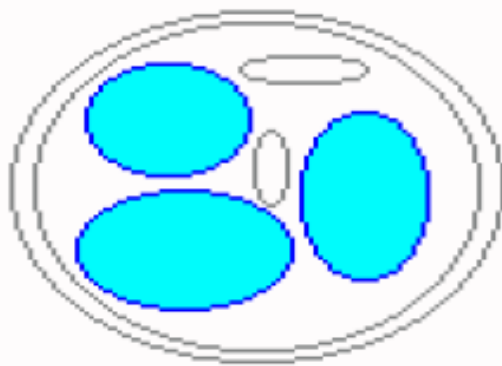
leucoplast



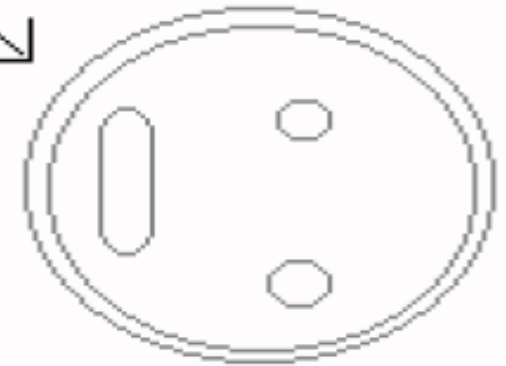
chloroplast



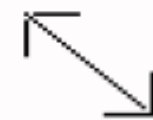
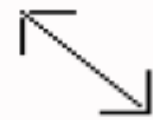
chromoplast



amyloplast



proplastid



Function of chloroplast:

Photosynthesis

The chlorophyll molecules in the chloroplasts are essential in the process of photosynthesis.

Protein Synthesis

Chloroplasts are capable of doing Protein Synthesis.

Carriers of Heredity Characters

Chloroplasts have a limited role in cytoplasmic inheritance since these contain traces of DNA.

Chlorophyll

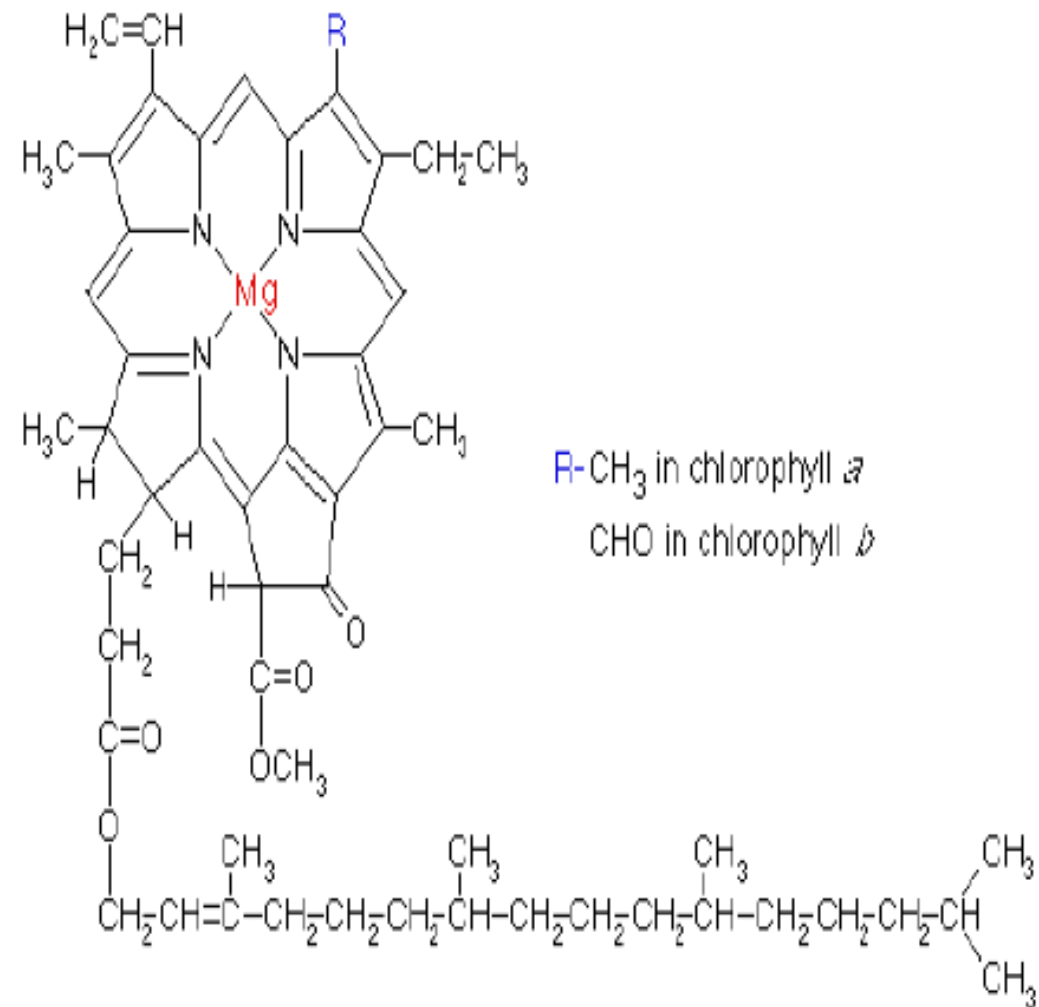
Chlorophyll is the molecule that traps this 'most elusive of all powers' - photoreceptor.

It is found in the chloroplasts of green plants,

The basic structure of a chlorophyll molecule is a porphyrin ring, co-ordinated to a central atom.

This is very similar in structure to the heme group found in hemoglobin,

except that in heme the central atom is iron, whereas in chlorophyll it is magnesium.



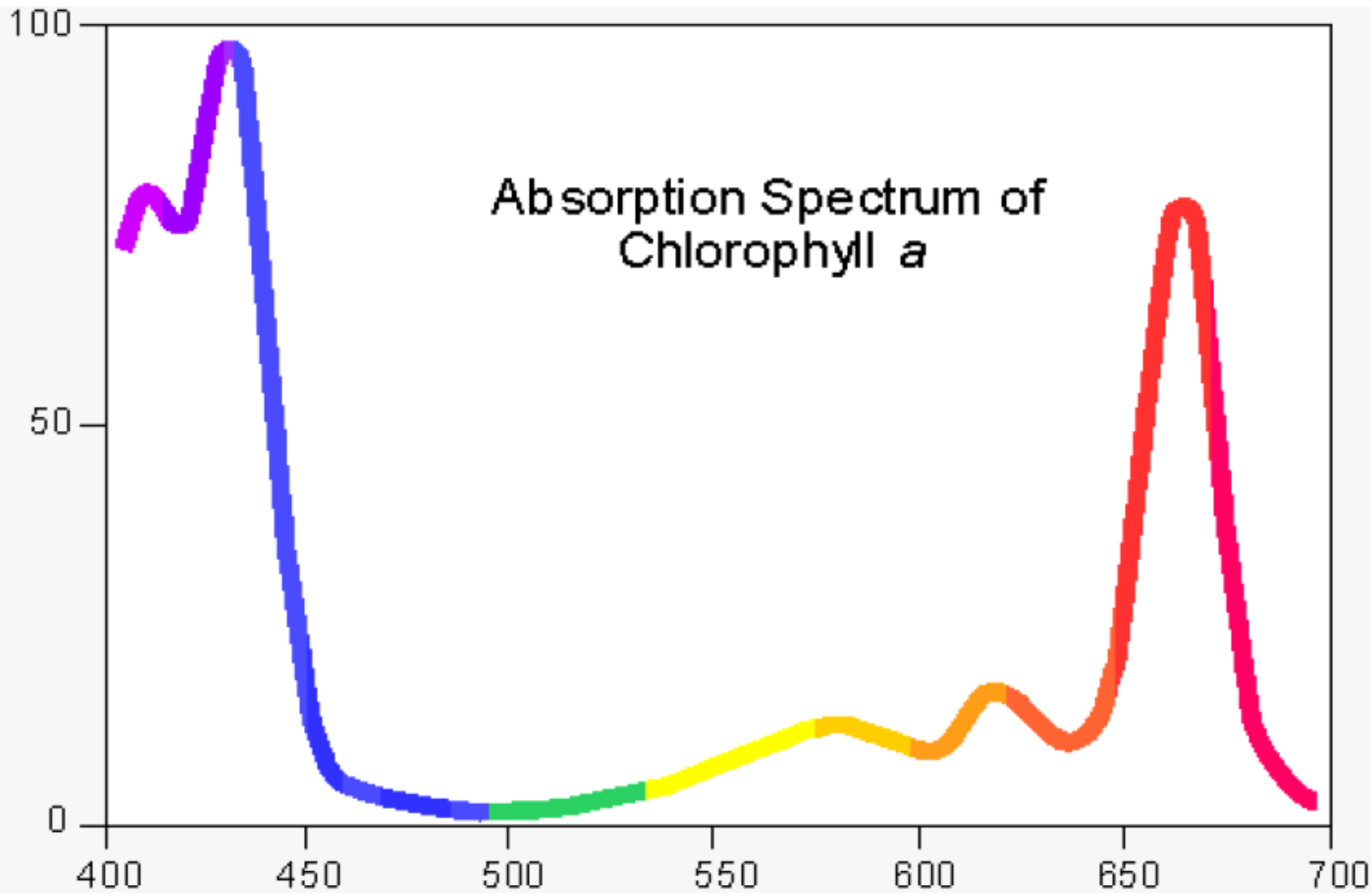
The structure of chlorophyll

Percent Absorption

Absorption Spectrum of Chlorophyll *a*

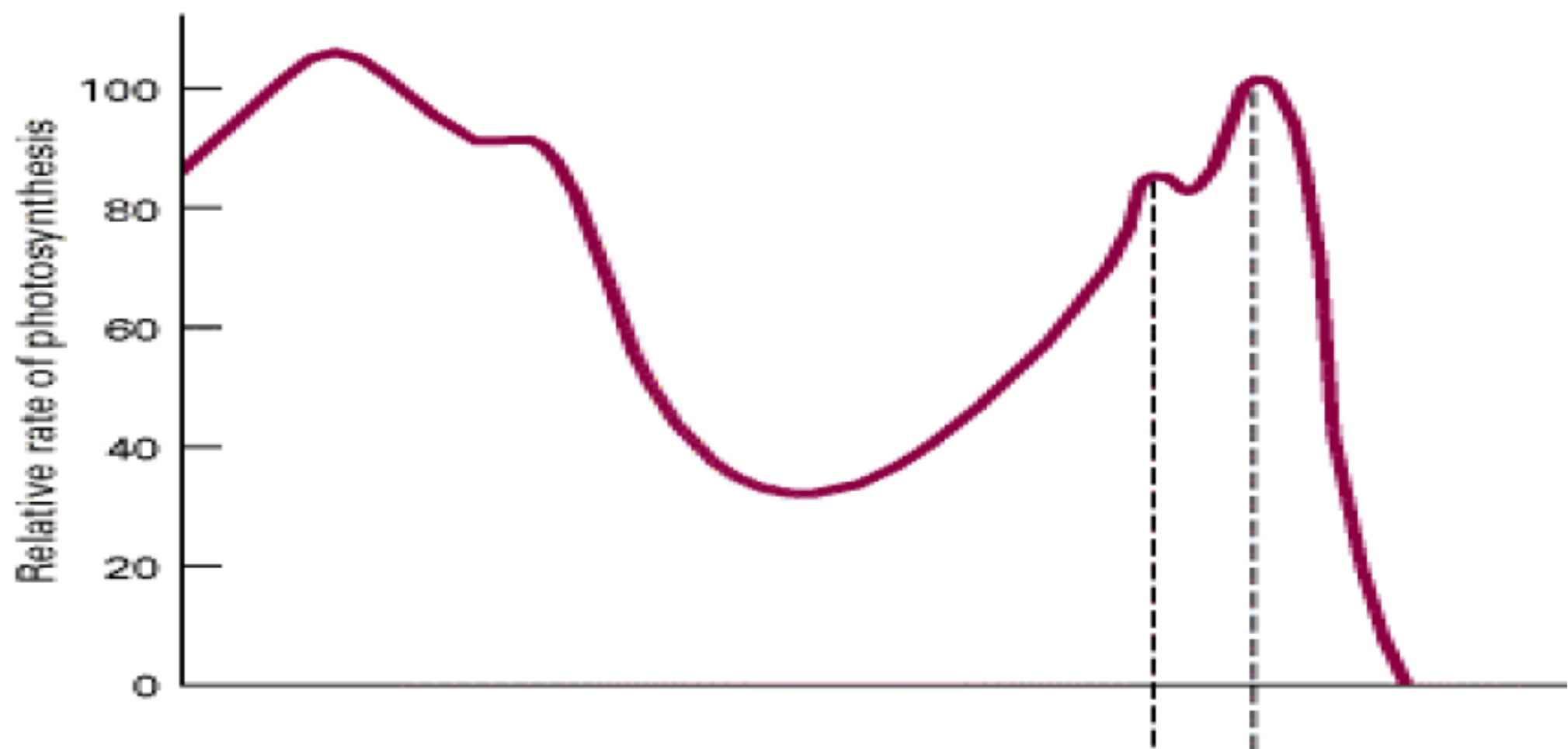
Wavelength (nm)

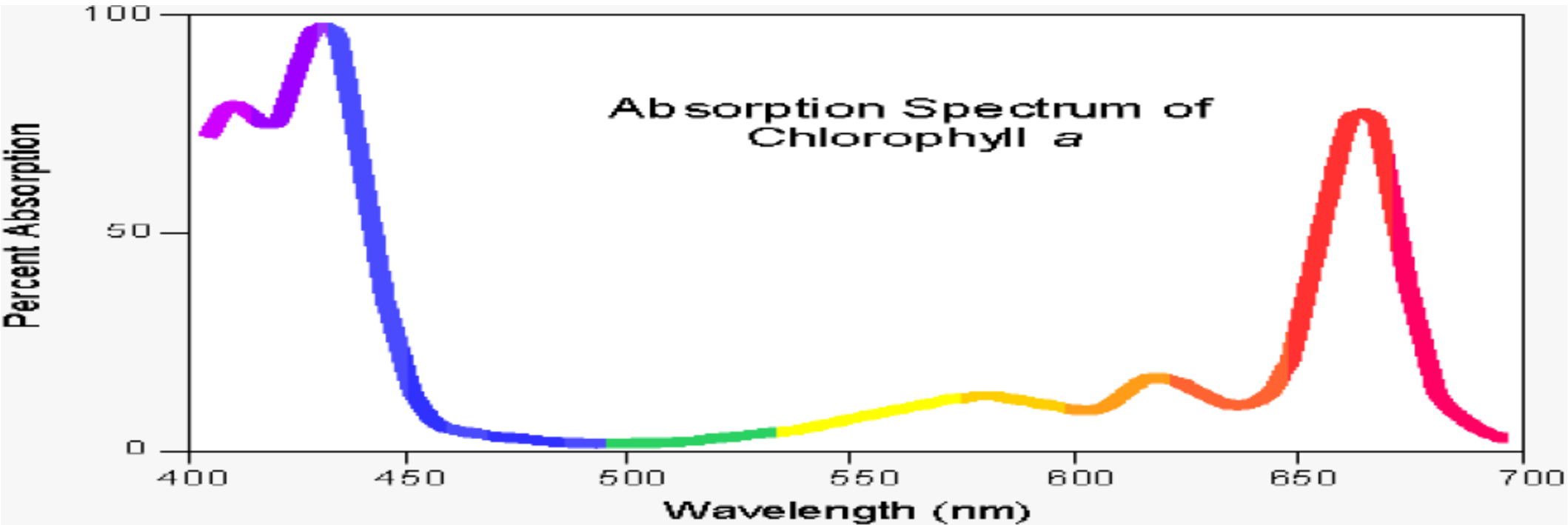
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(a)

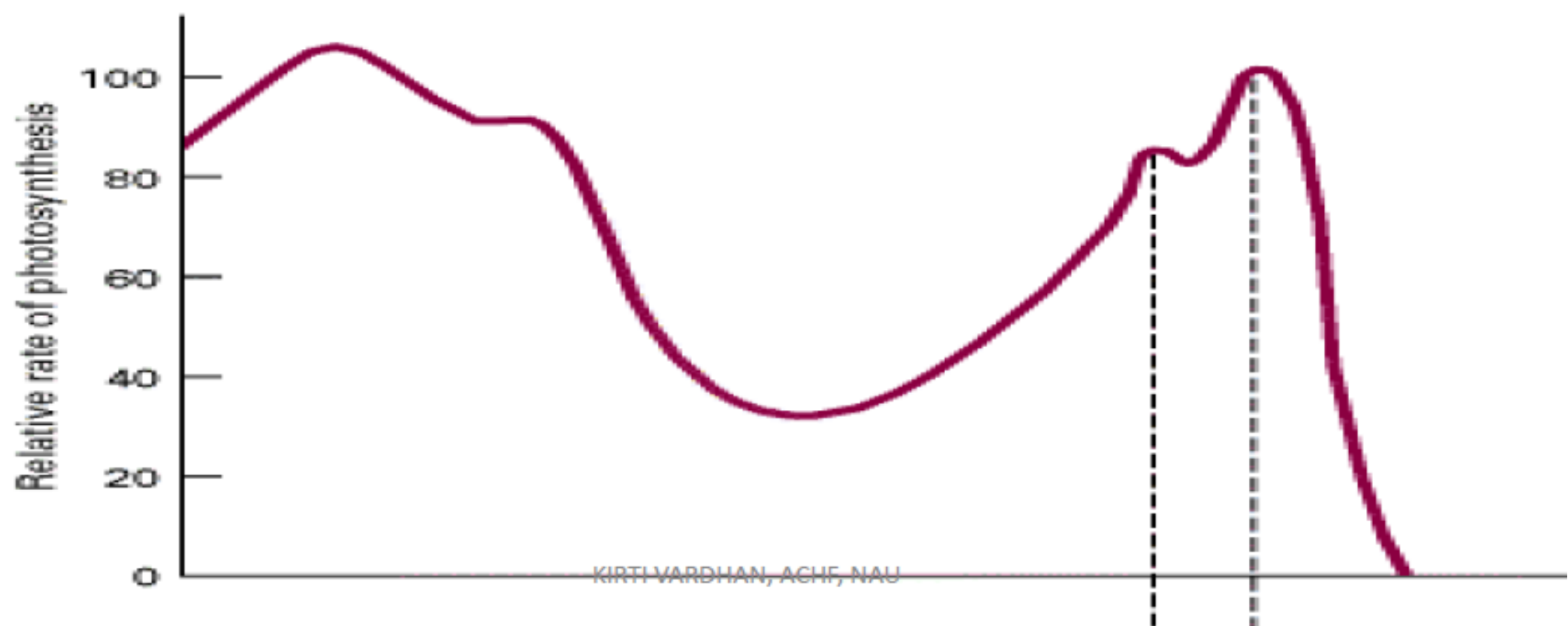
Action spectrum of photosynthesis





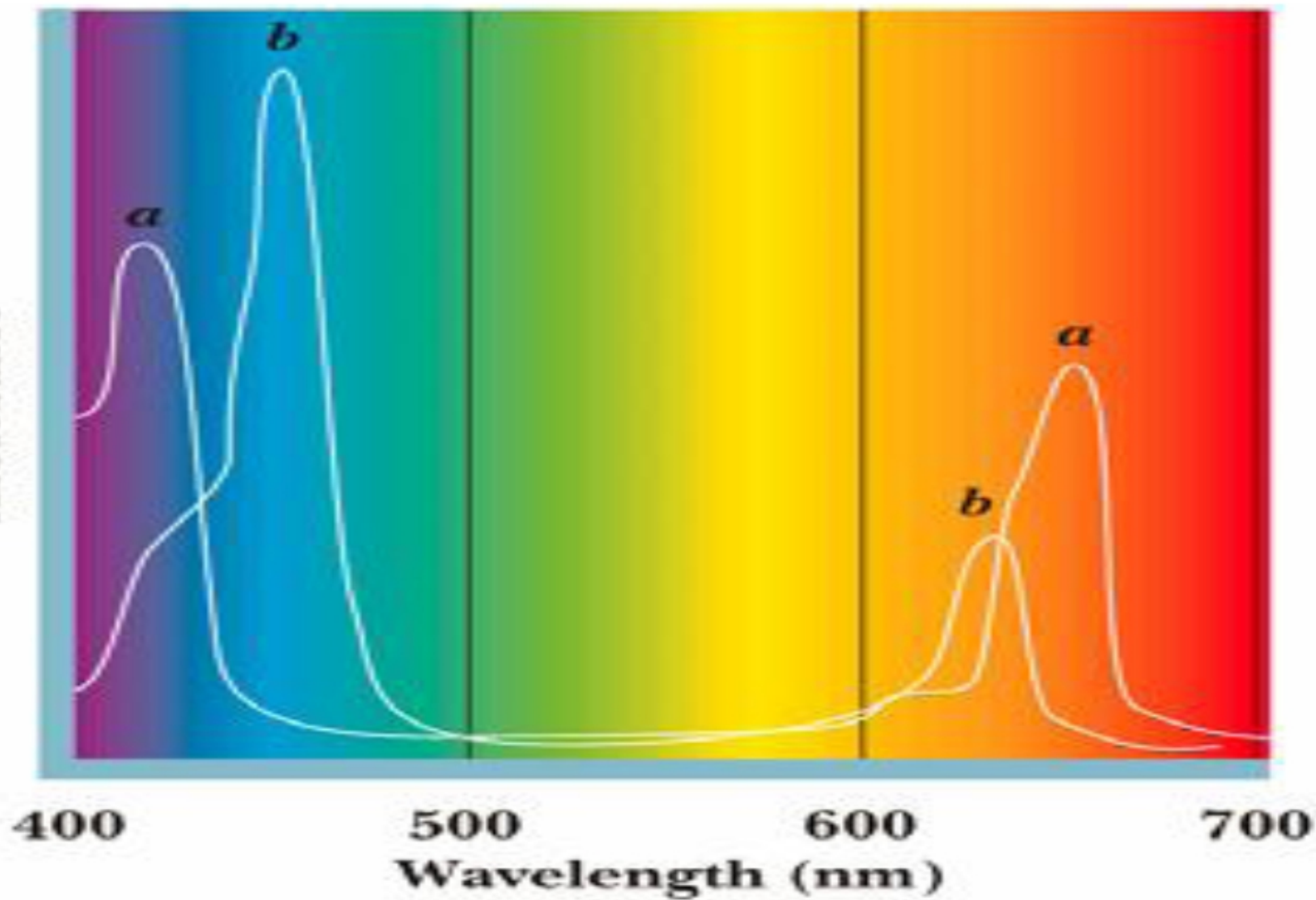
(a)

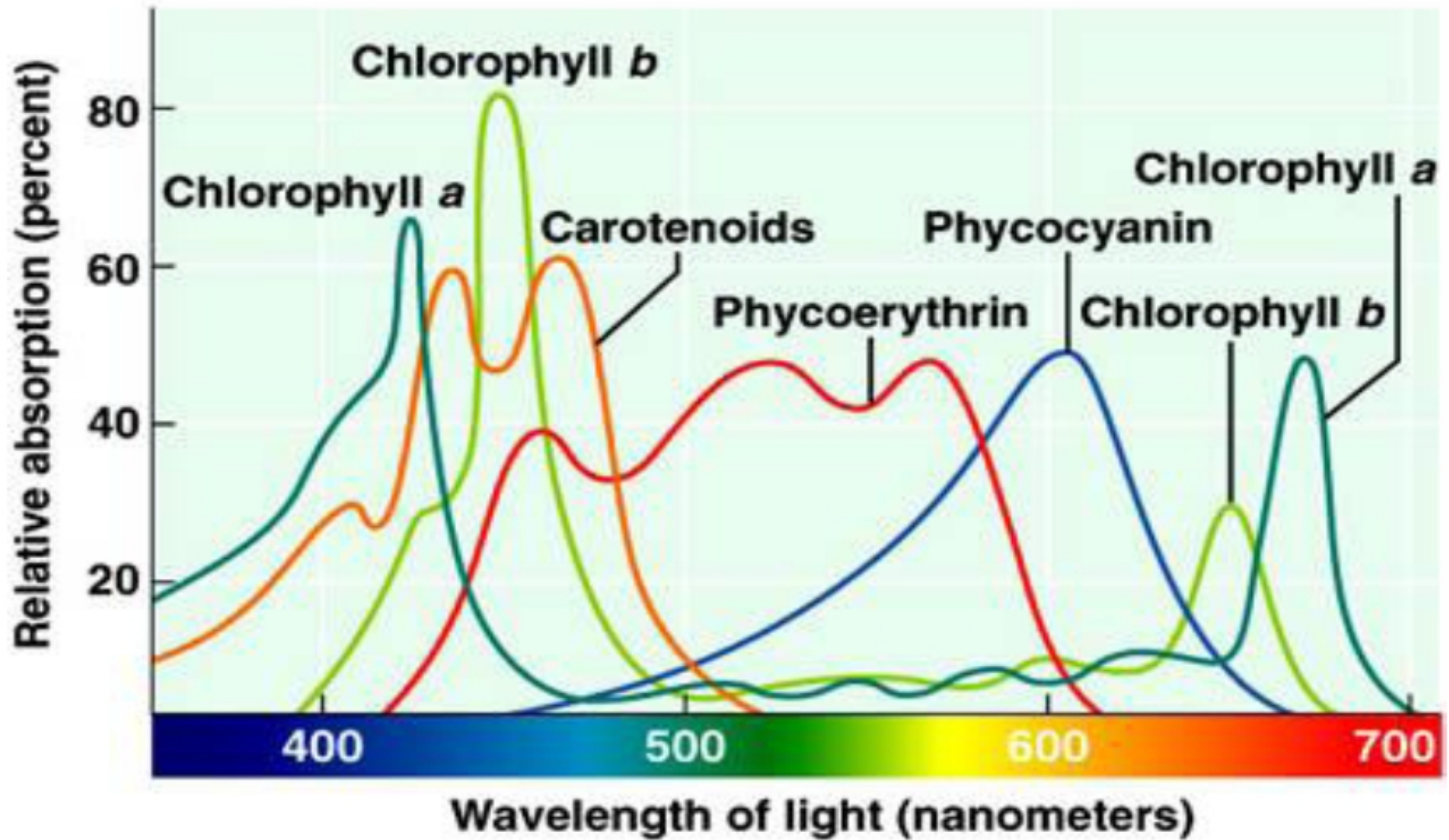
Action spectrum of photosynthesis



Organism	Chlorophylls				Bacteriochlorophylls						Carotenoids	Phycobiliproteins	
	a	b	c	d	a	b	c	d	e	g			
Eukaryotes													
Mosses, ferns, seed plants	+	+	-	-								+	-
Green algae	+	+	-	-								+	-
Euglenoids	+	+	-	-								+	-
Diatoms	+	-	+	-								+	-
Dinoflagellates	+	-	+	-								+	-
Brown algae	+	-	+	-								+	-
Red algae	+	-	-	+								+	+
Prokaryotes													
Cyanobacteria	+	-	-	+								+	+
Prochlorophytes	+	+	-	-								+	-
Sulfur purple bacteria					+	or	+	-	-	-	-	+	-
Nonsulfur purple bacteria					+	or	+	-	-	-	-	+	-
Green bacteria					+	-	+	or	+	or	+	+	-
Heliobacteria					-	-	-	-	-	-	+	+	-

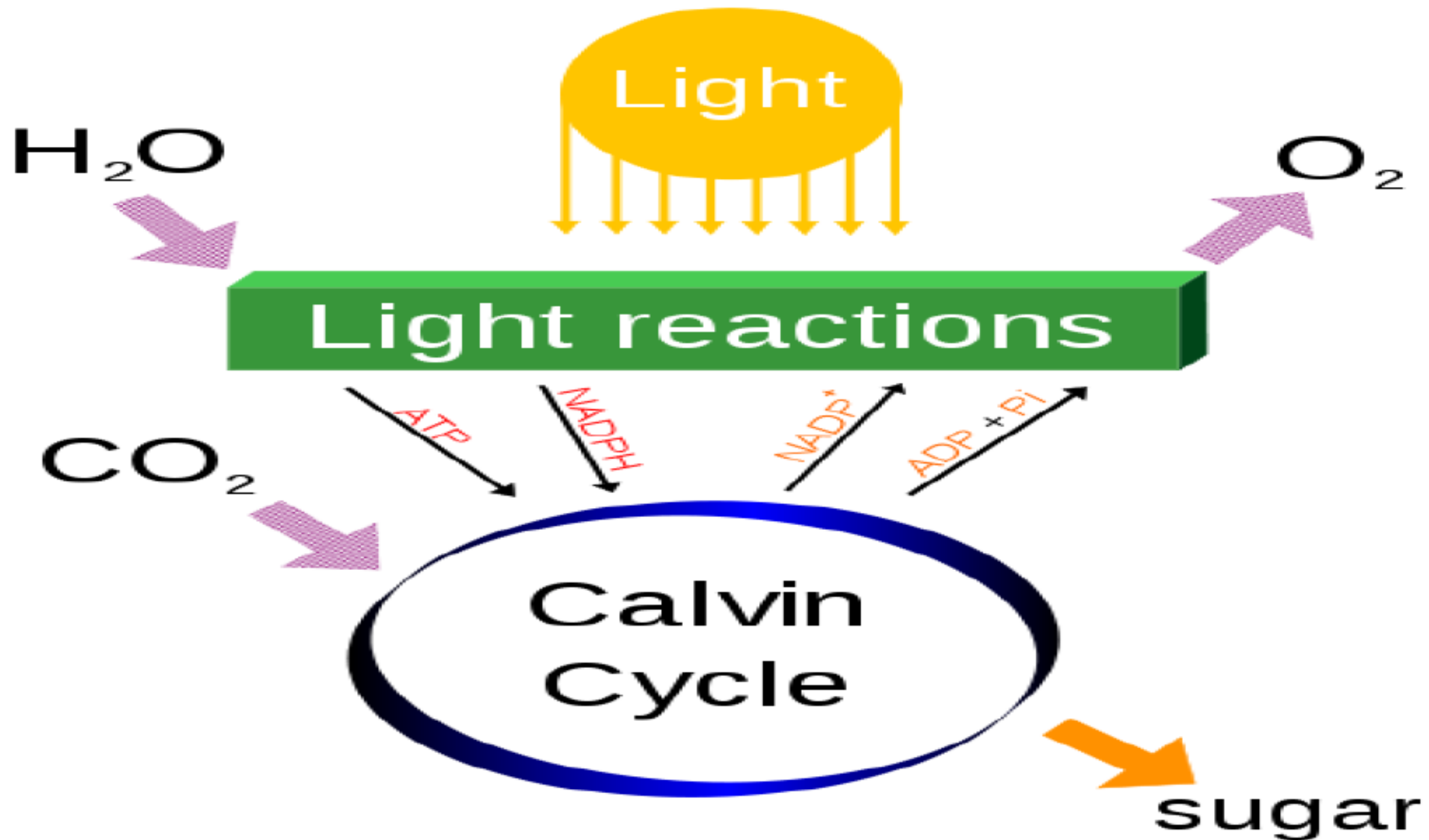
Absorbance







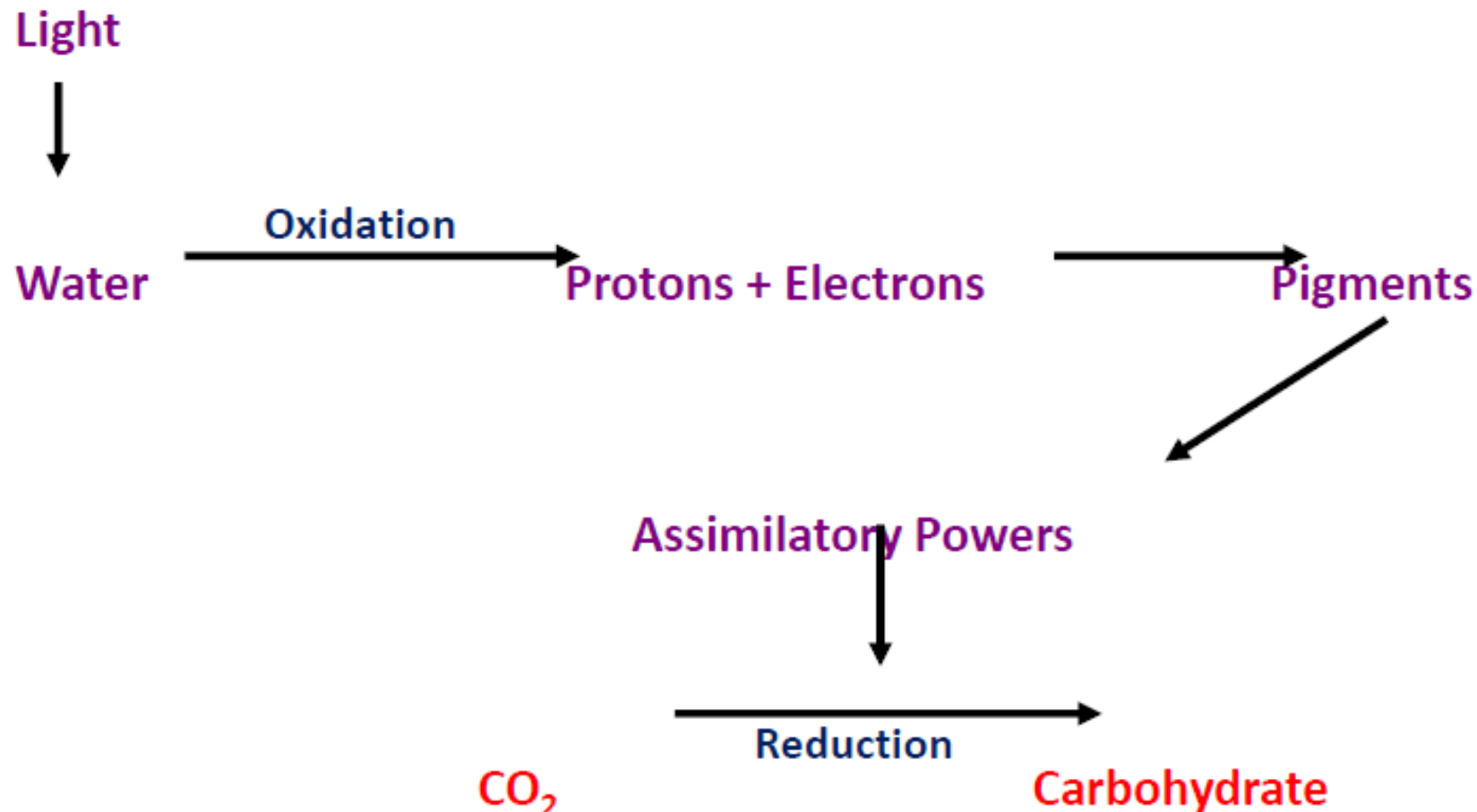
Photosynthesis Mechanism:



PHOTOSYNTHESIS

Solar energy to Chemical energy

Oxidation – Reduction process



Evidence of Light and Dark reaction:

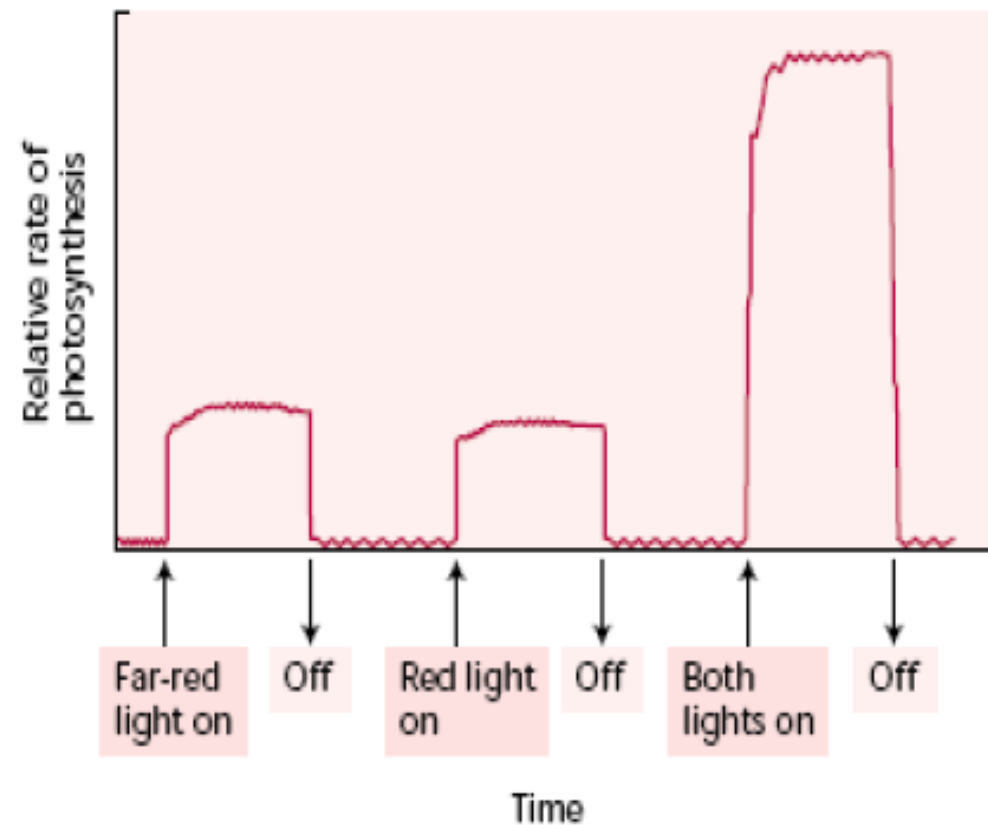
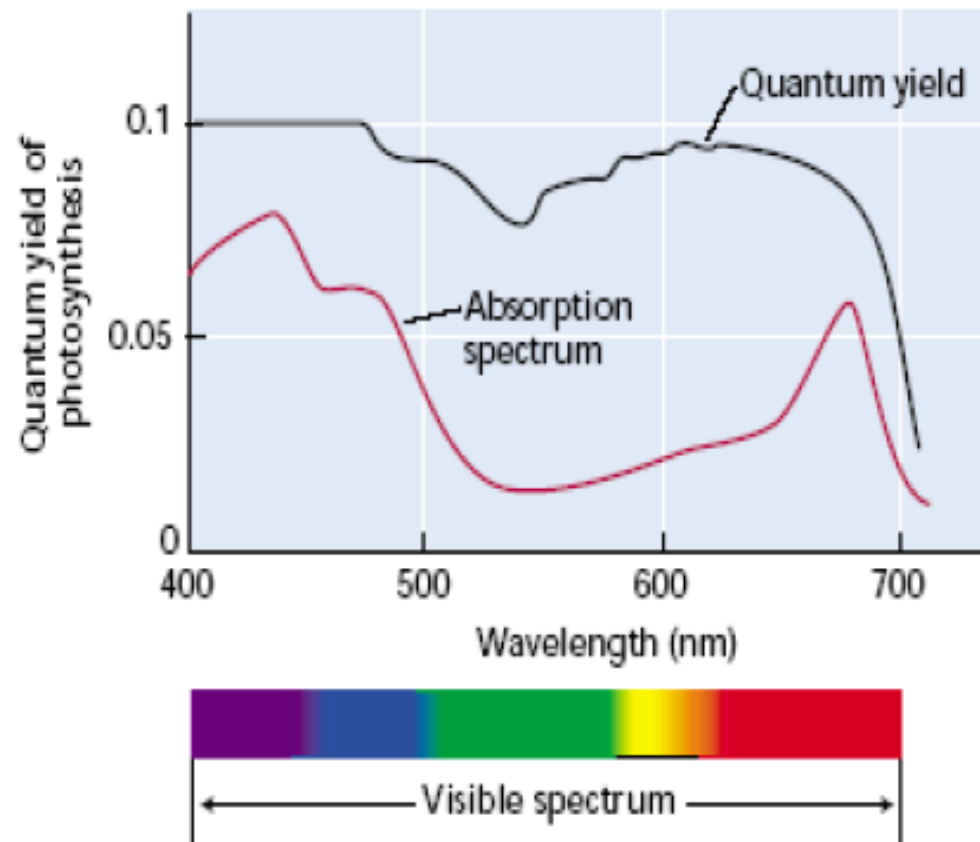
Temperature coefficient

Intermittent light

Tracer technique

Red drop

sharp decrease in quantum yield at wavelength greater than 680 nm, in the red part of the spectrum, the phenomenon was called as *red drop*



Emerson enhancement effect

inefficient far-red light beyond 680 nm could be made fully efficient if supplemented with RED light

LIGHT REACTION

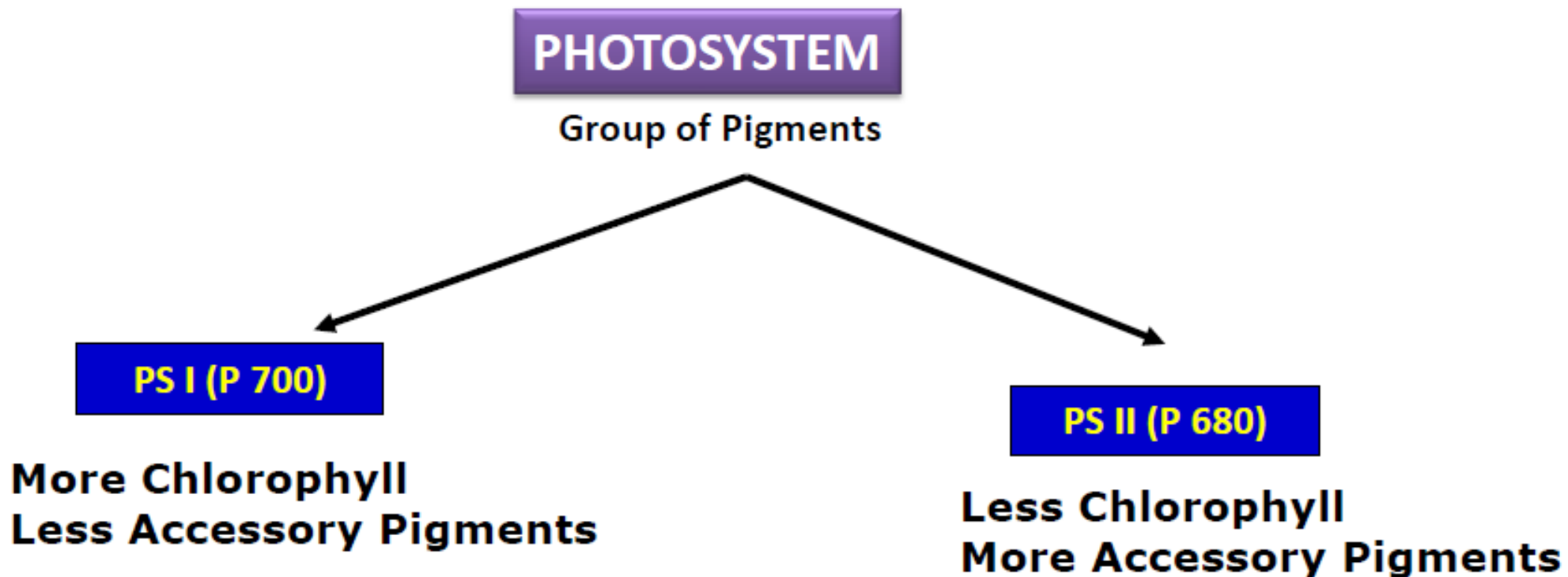
**Production of Assimilatory Powers (ATP and NADPH)
by light, water and pigments**

- 1. Absorption of light energy by the pigments**
- 2. Activation of Chlorophyll molecule**
- 3. Photolysis of water**
- 4. Electron Transport Chain**
- 5. Synthesis of Assimilatory Powers**

Absorption of Light Energy

All pigments – Absorb – Light Energy – Transfer to – **Chlorophyll a**

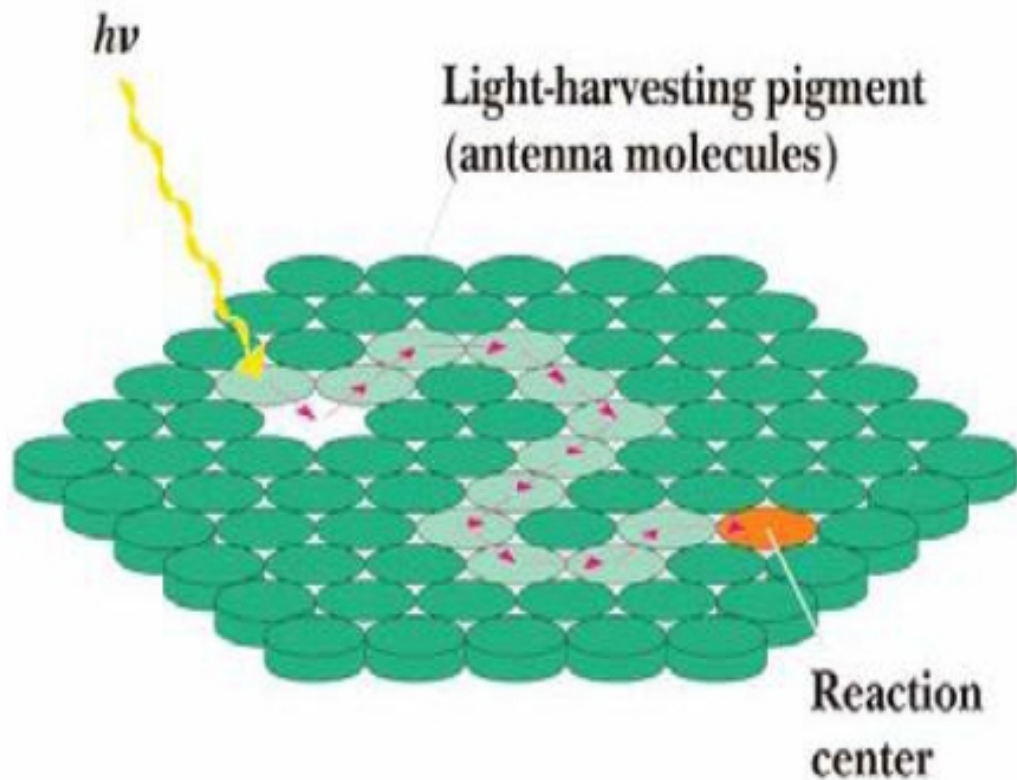
Chlorophyll a – Absorb and Conversion – To Chemical Energy



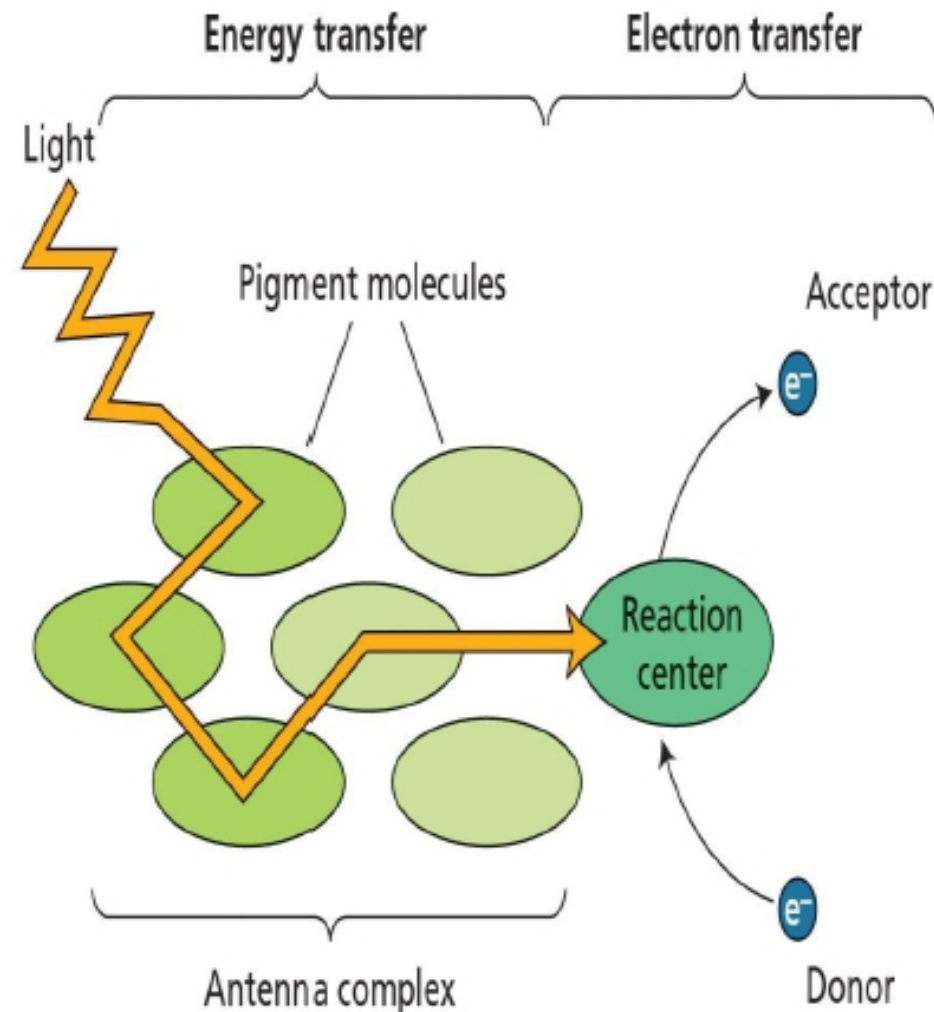
Absorption of light energy by chloroplast pigments

Different chloroplast pigments absorb light in different regions of the visible part of the spectrum

Garrett & Grisham: Biochemistry, 2/e
Figure 22.9



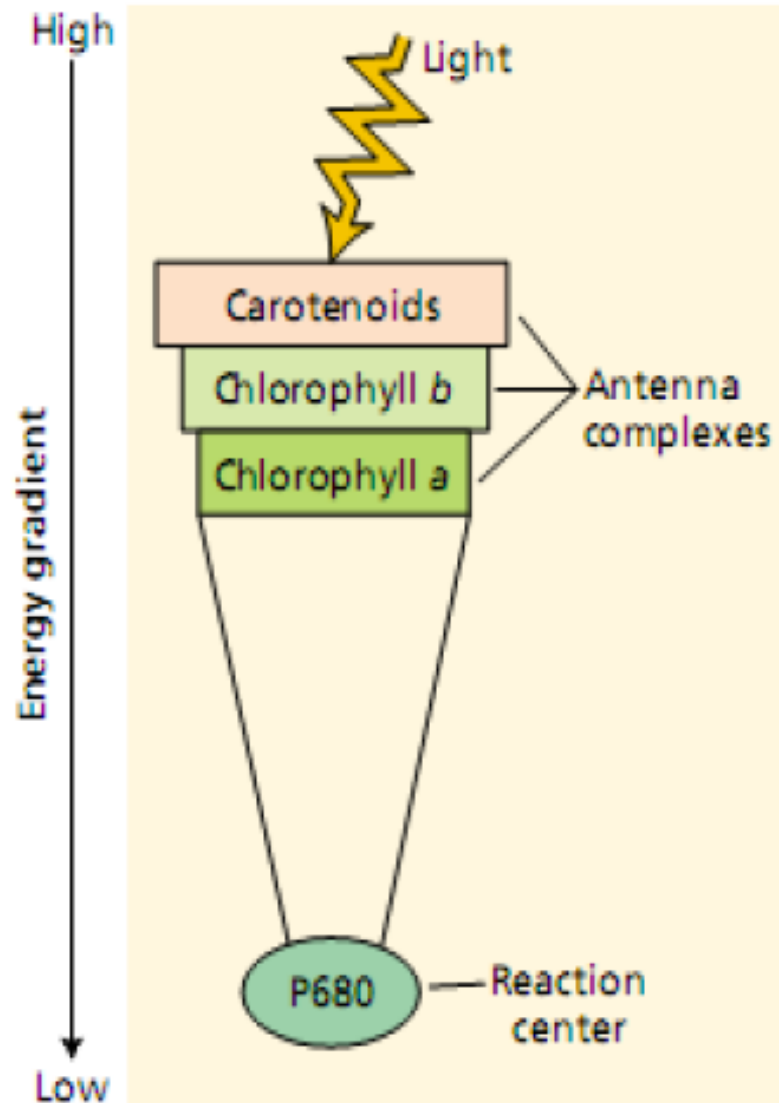
Saunders College Publishing



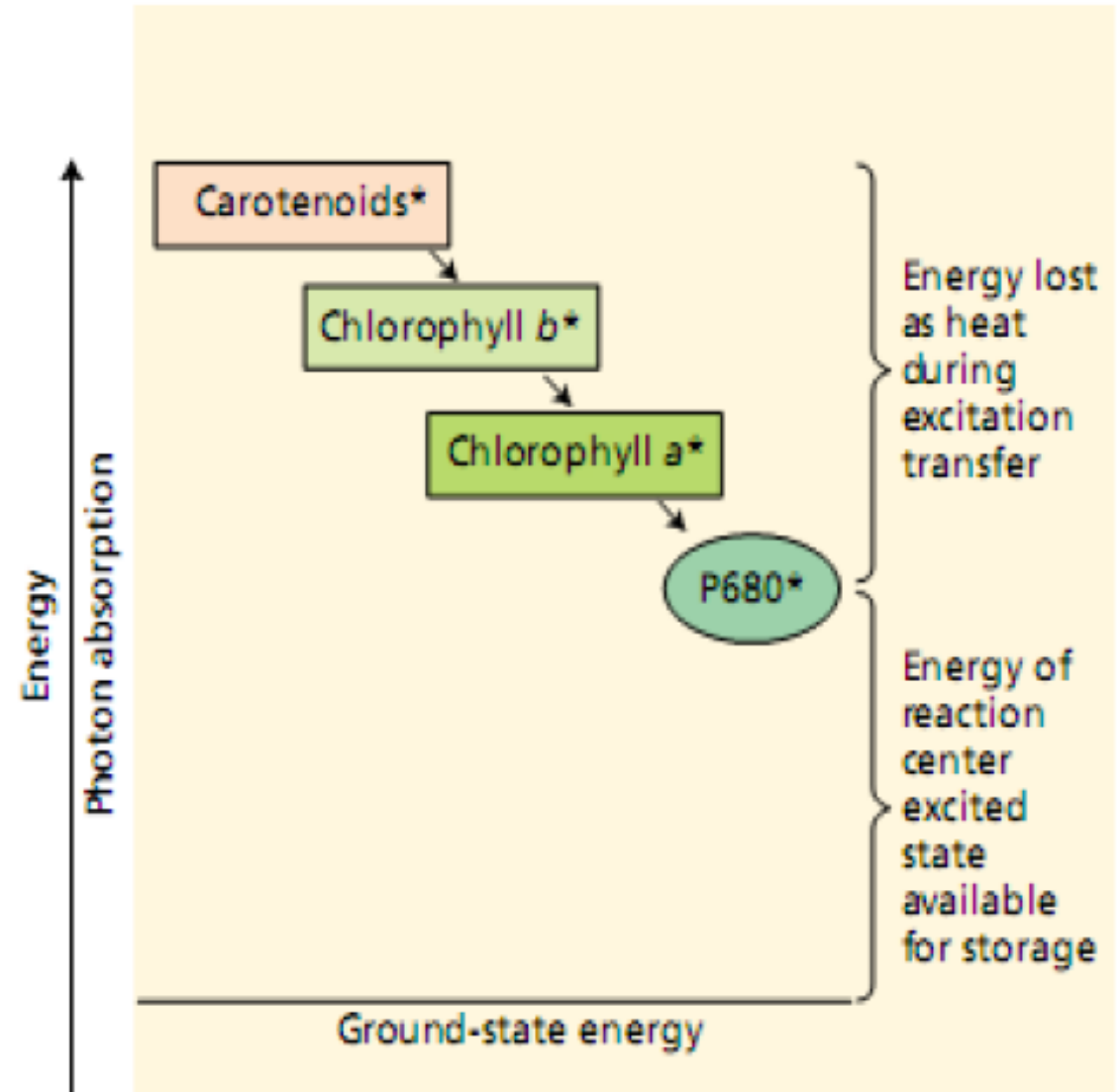
PLANT PHYSIOLOGY, Third Edition, Figure 7.11 © 2002 Sinauer Associates, Inc.

Transfer of light energy from accessory pigments to chlorophyll *a*

(A)

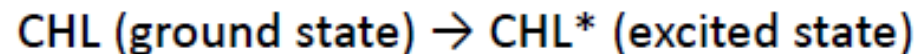


(B)



What happens when chlorophyll absorbs light?

The chlorophyll molecule becomes excited (this takes only 10^{-15} sec = fempto sec) and an electron moves to an outer energy level.

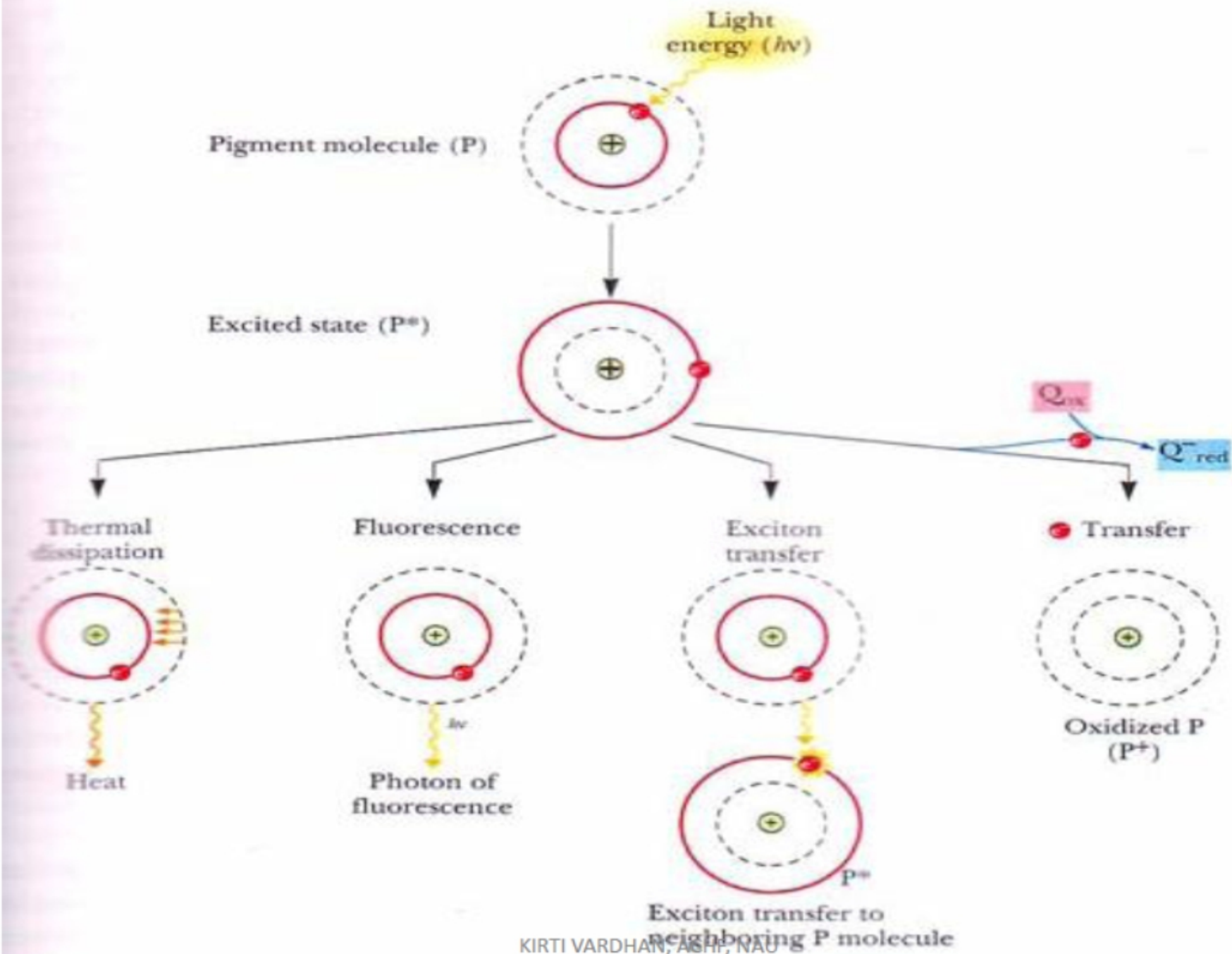


Electrons don't stay excited long (10^{-9} sec), because they either:

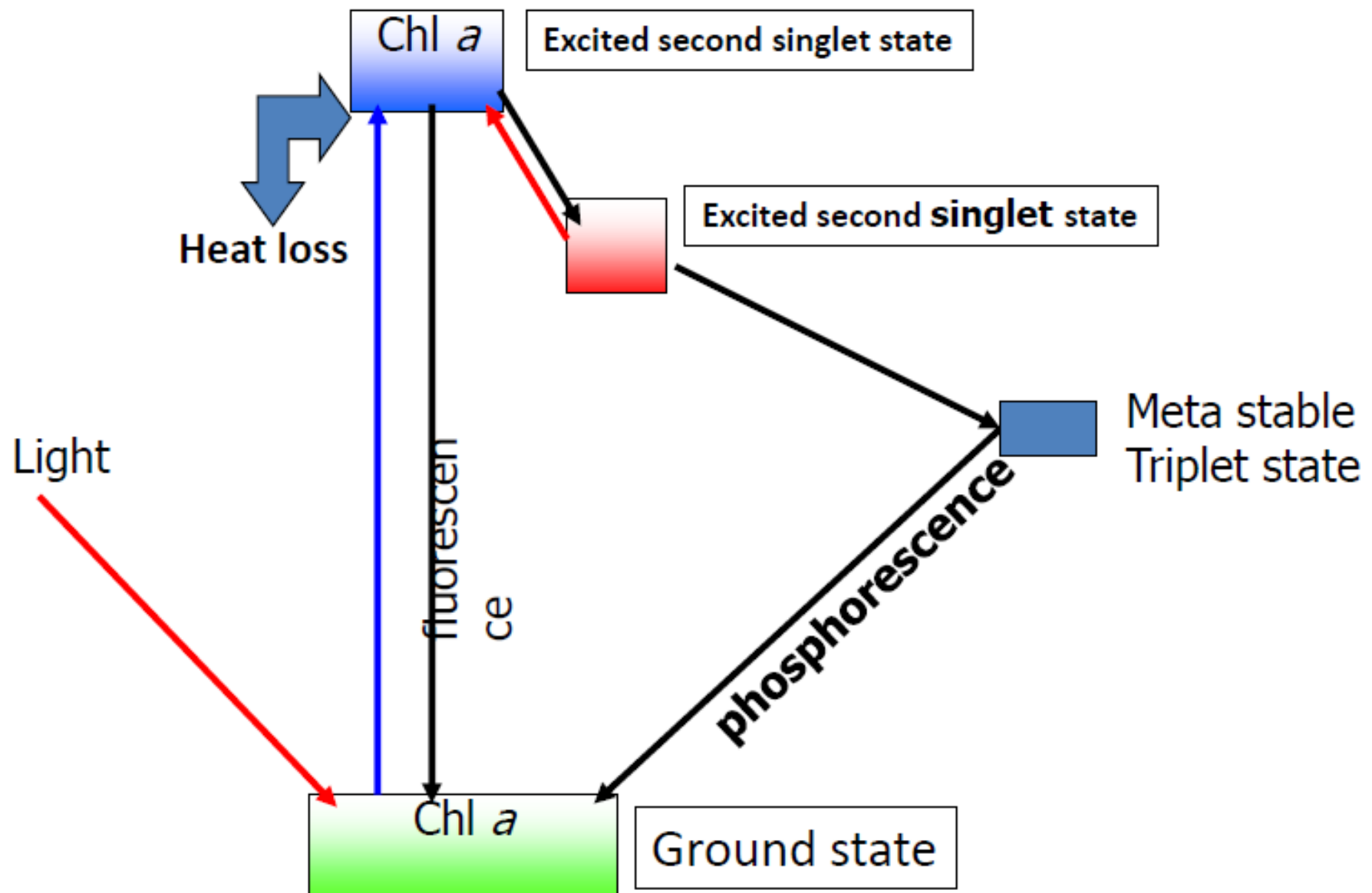
return to the ground state and release their absorbed energy as heat
(*thermal deactivation*);

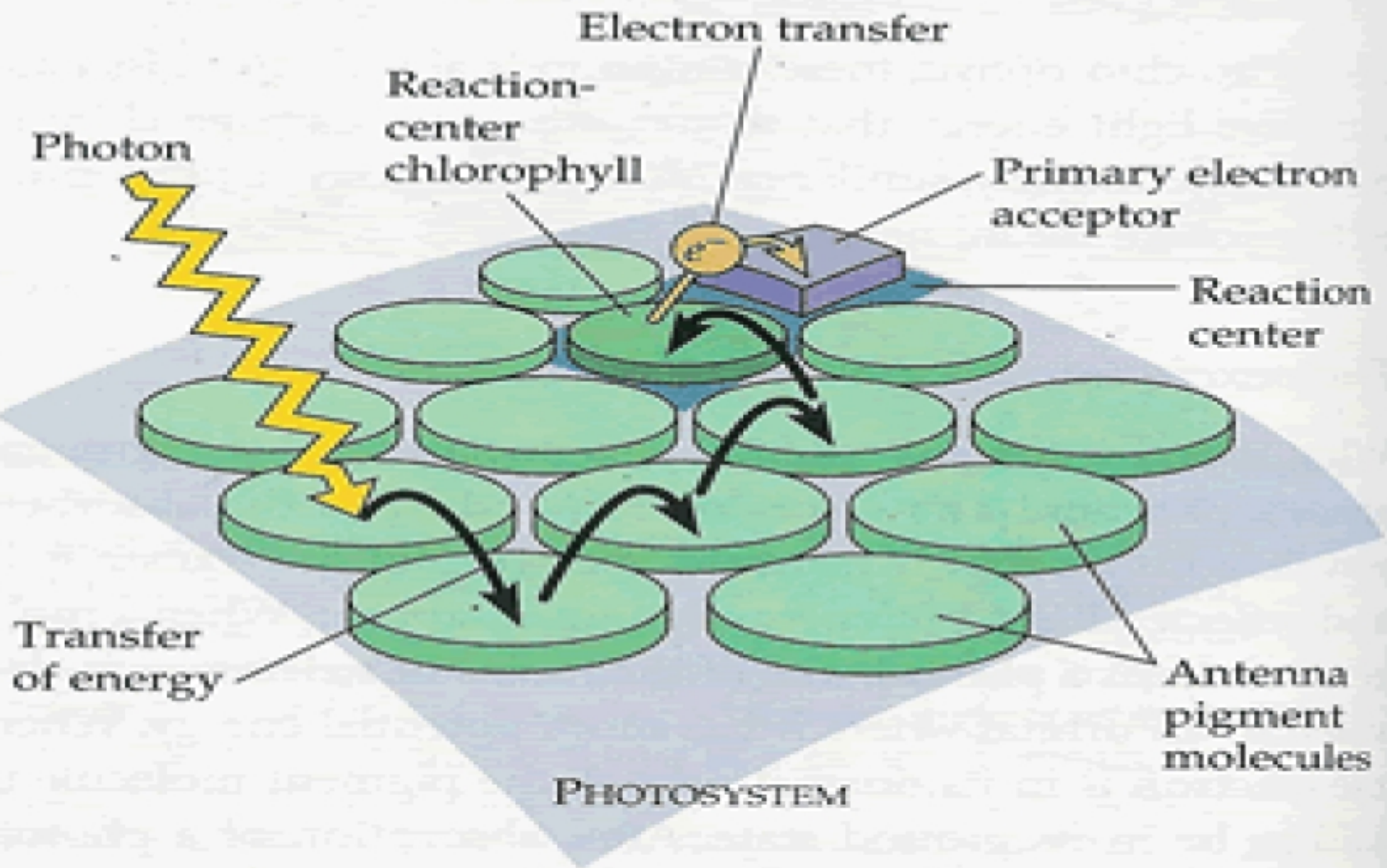
return to ground state and release their extra energy as light (*fluorescence*);

transfer their energy to another molecule; kind of like hitting pool balls (*resonance transfer*); or be used in a photochemical reaction (*photochemistry*).



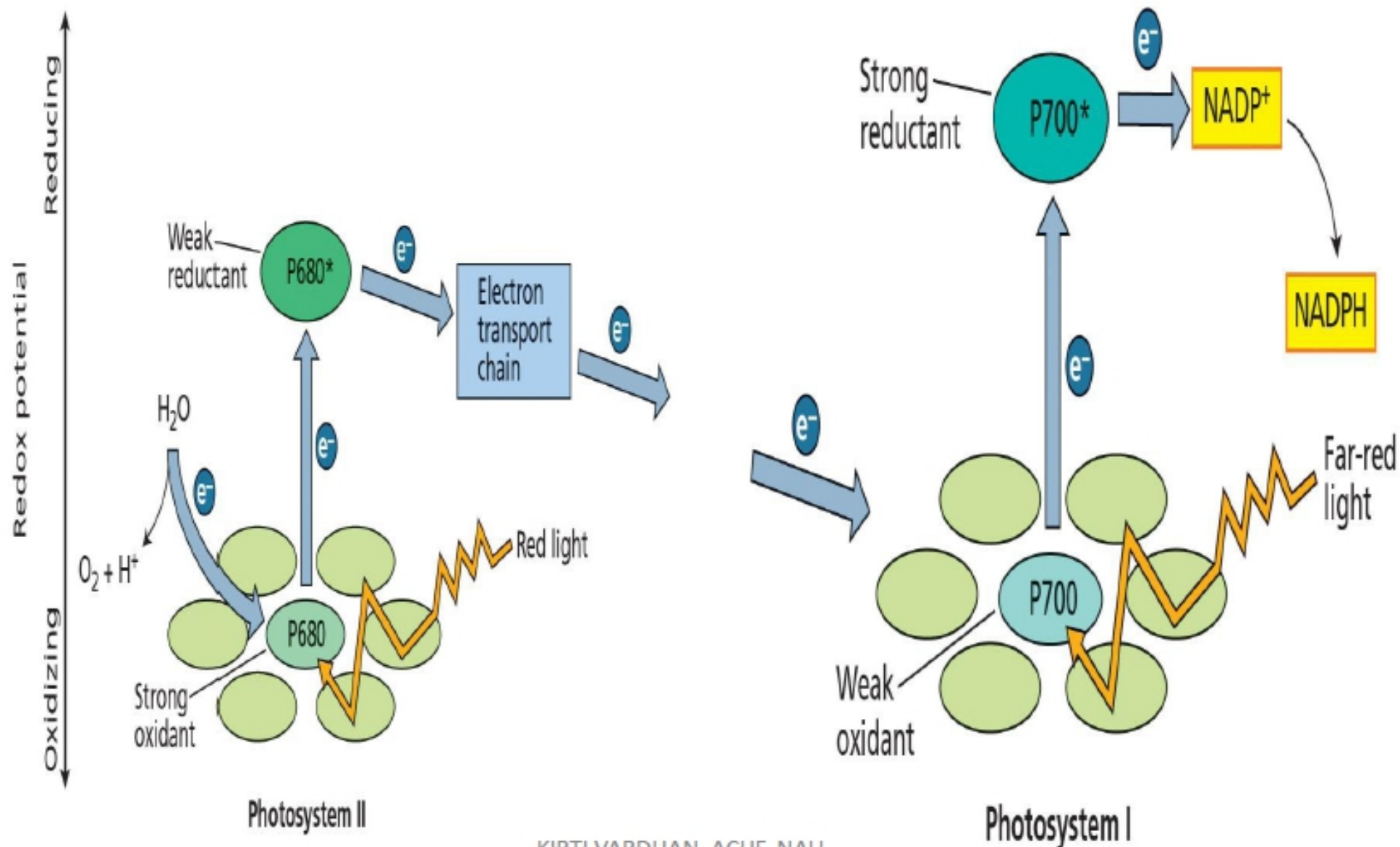
Activation of chlorophyll molecule by photon of light





Photosystem :

Two physically and chemically distinct photosystems (I and II), each with its own antenna pigments and photochemical reaction center. The two photosystems are linked by an electron transport chain



PSI

Is located on the outer surface of non appressed parts of grana thylakoids.

Comprises of about 200 - 400 chlorophylls, 50 carotenoids, one molecules of P_{700}

Is light green in colour

Is not directly involved with photooxidation of H_2O and evolution of molecules of O_2

PSII

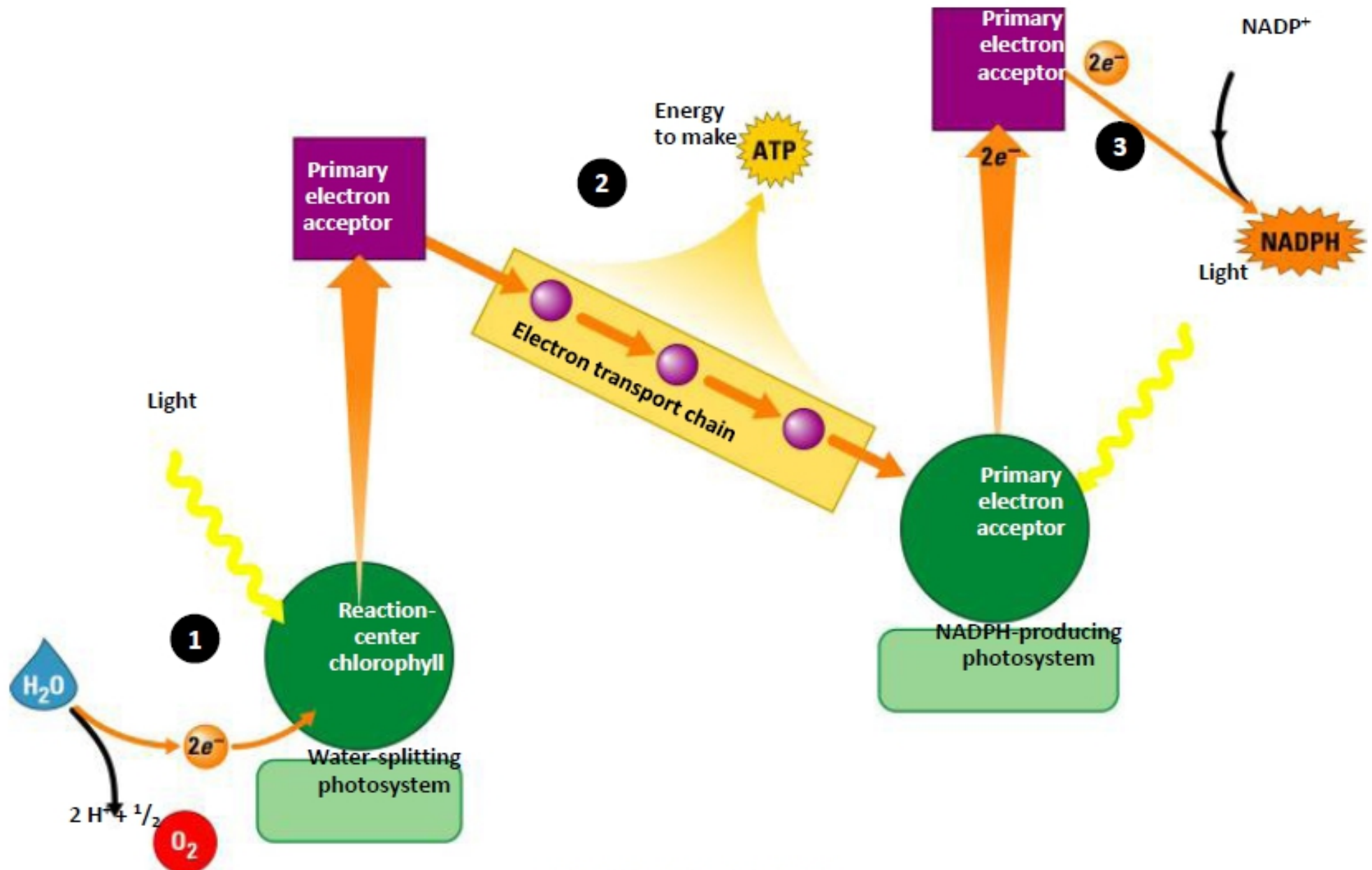
Is located on the inner surface of appressed parts of grana thylakoids.

Comprises of about 200 chlorophylls, 50 carotenoids, one molecules of P_{680}

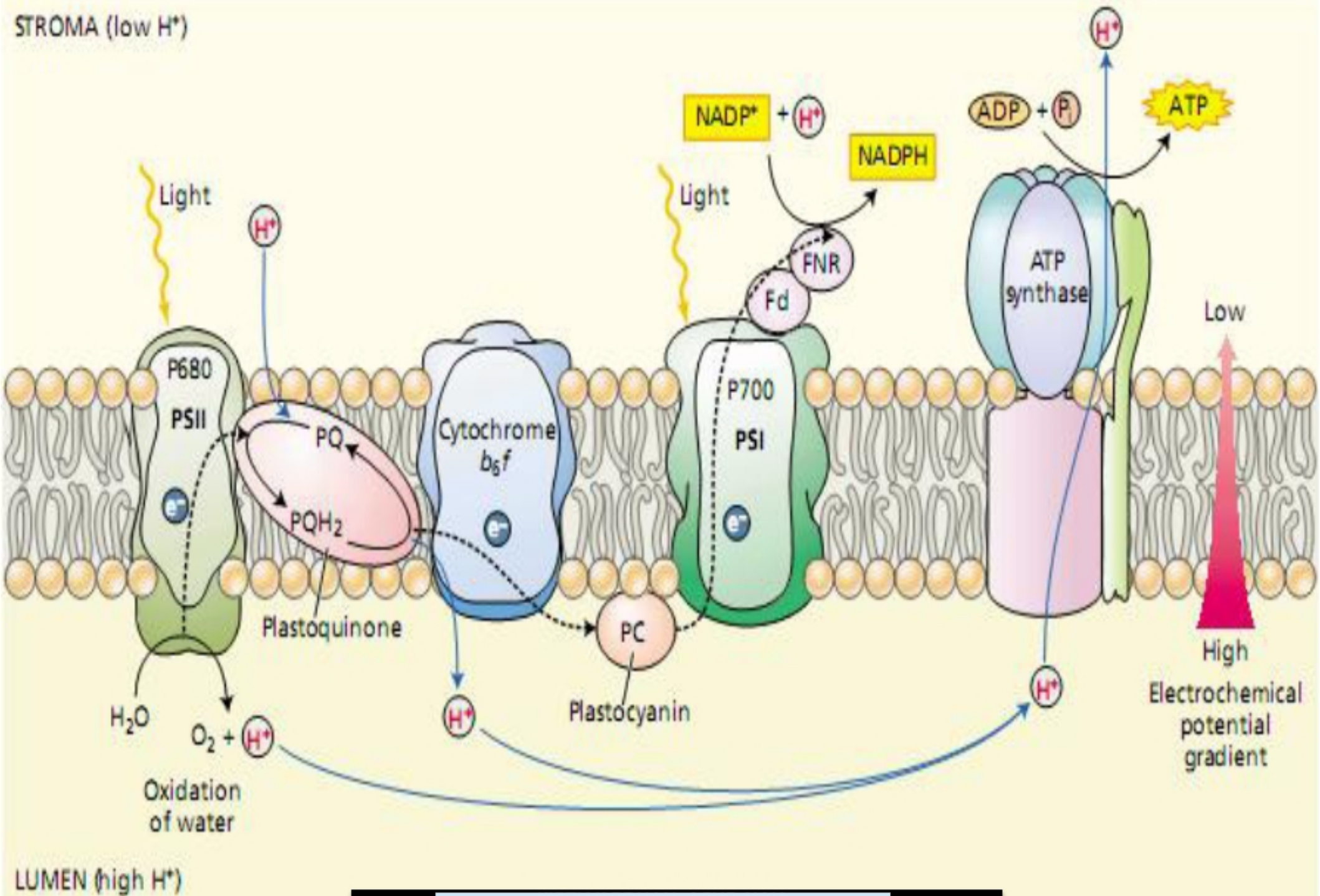
Is dark green in colour

Is directly involved with photooxidation of H_2O and evolution of molecules of O_2

How the Light Reactions Generate ATP and NADPH



STROMA (low H^+)

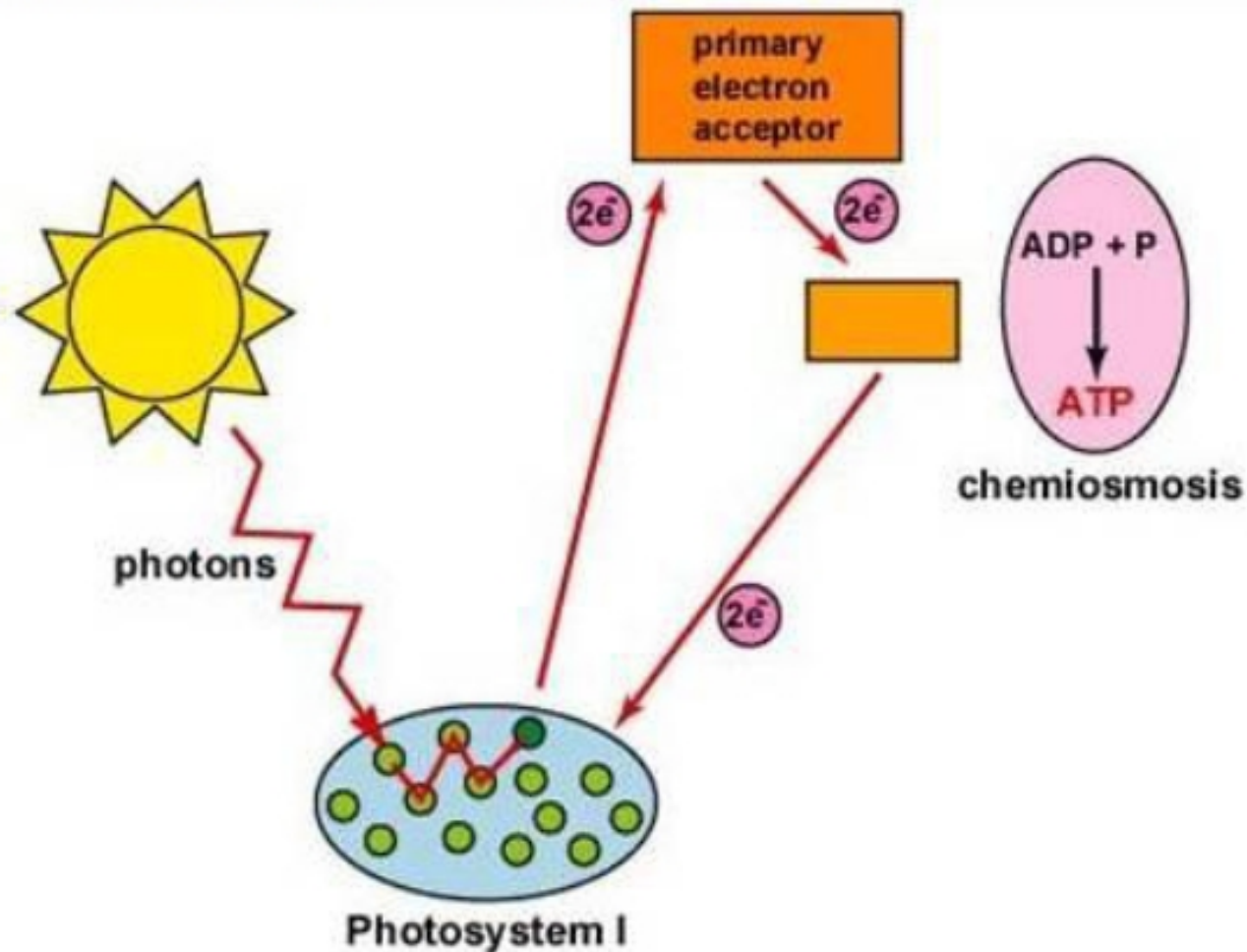


LUMEN (high H^+)

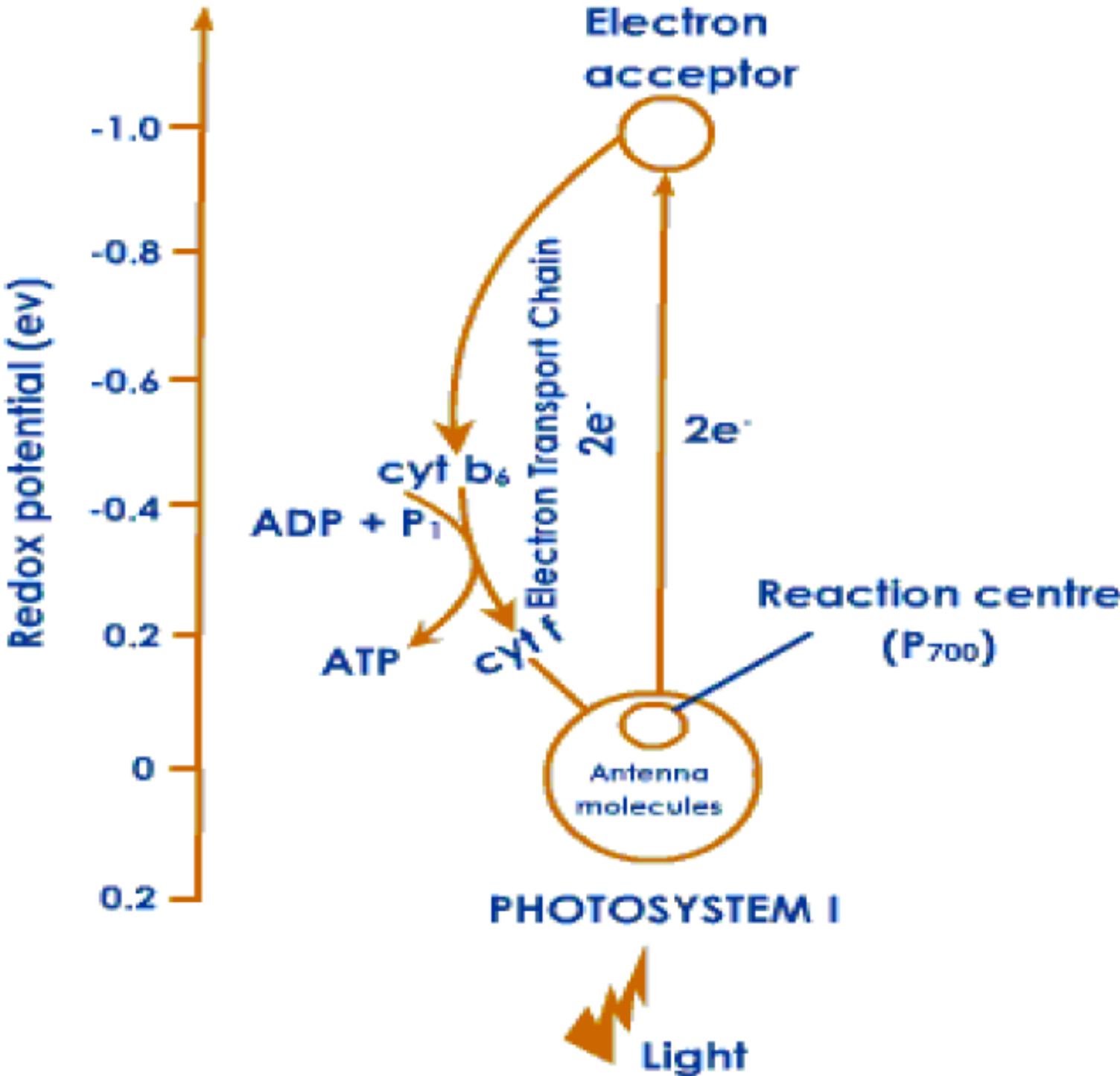
See related animation

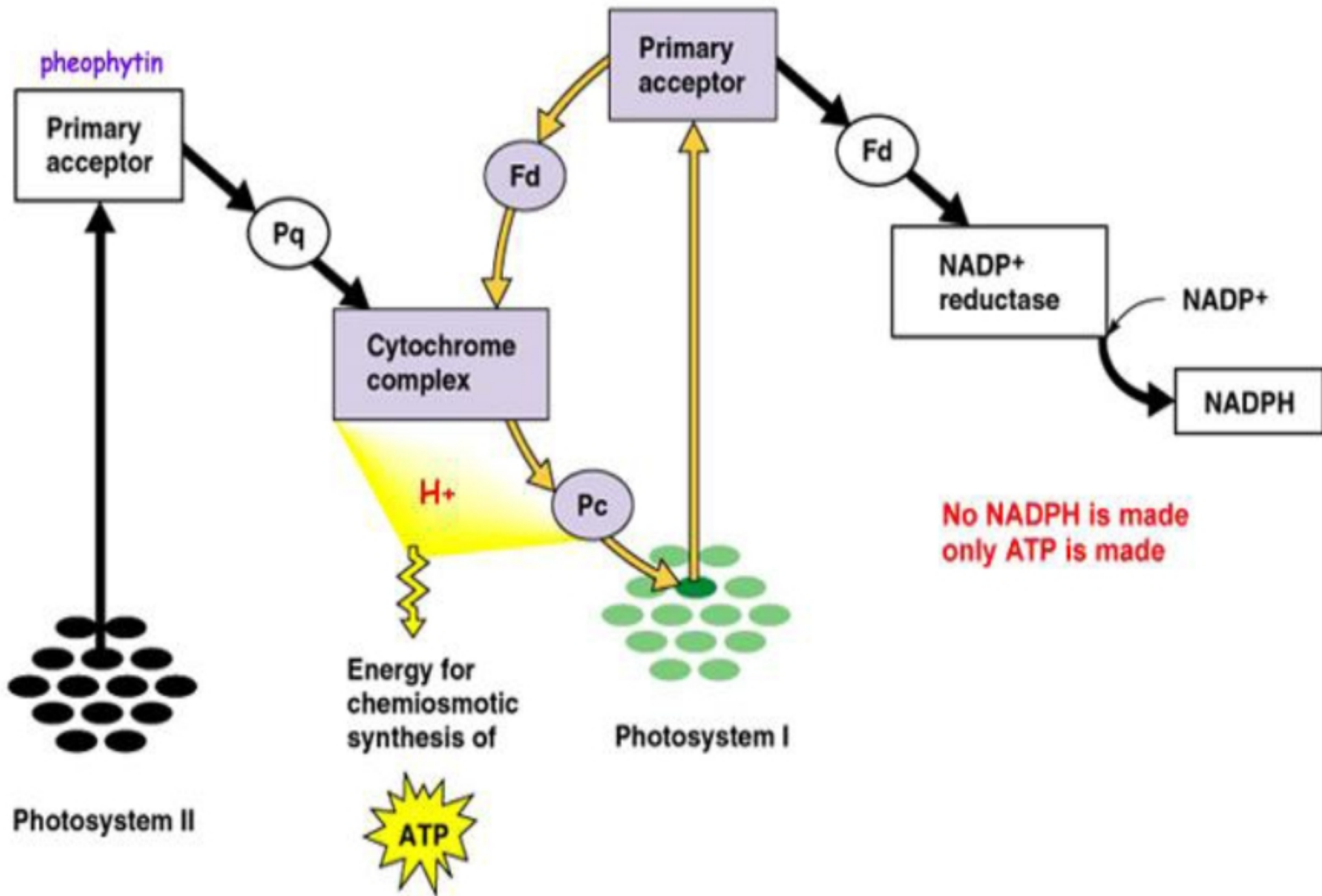
Cyclic Photophosphorylation

- Process for ATP generation associated with some Photosynthetic Bacteria
- Reaction Center => 700 nm



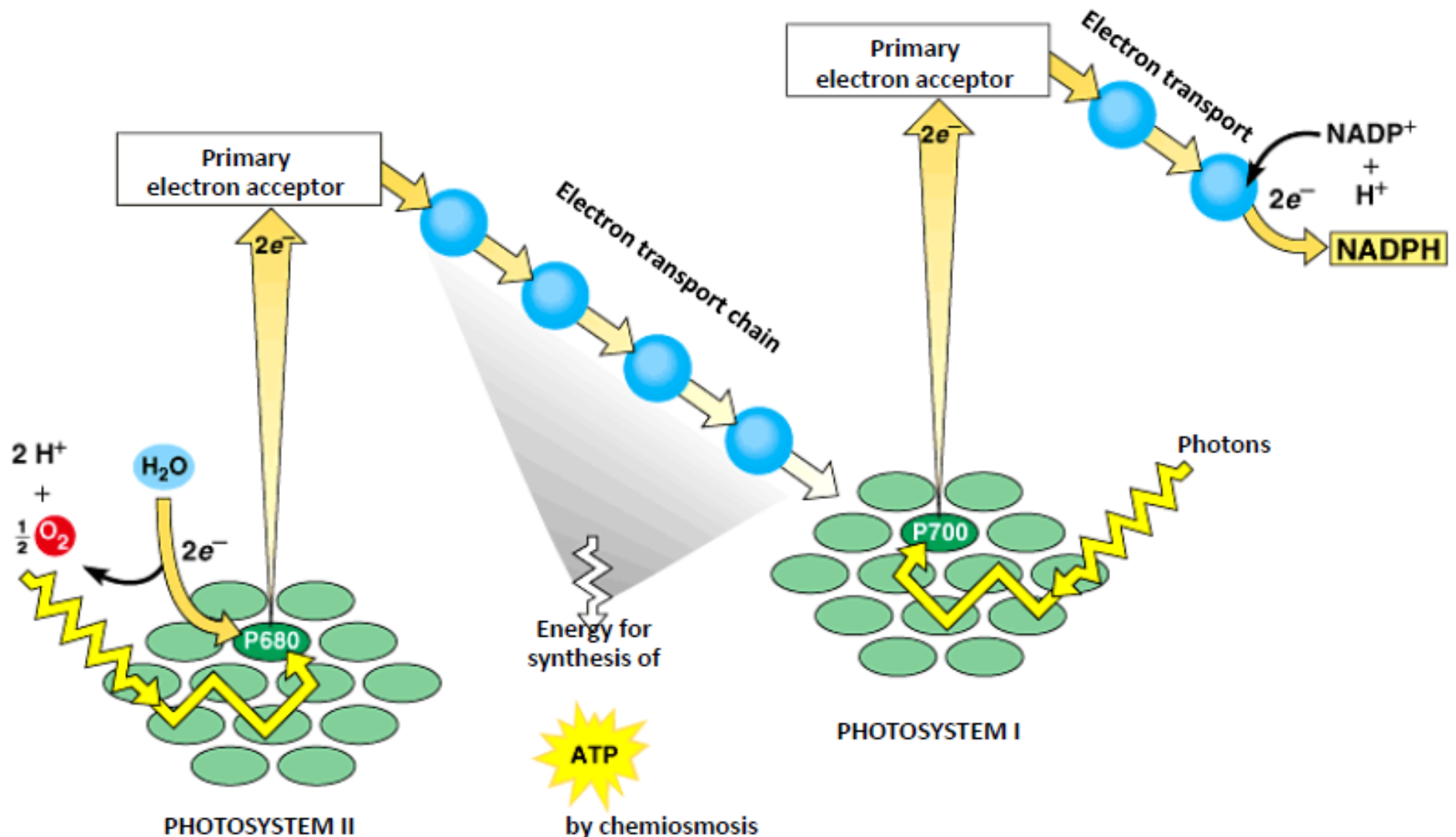
Cyclic photophosphorylation



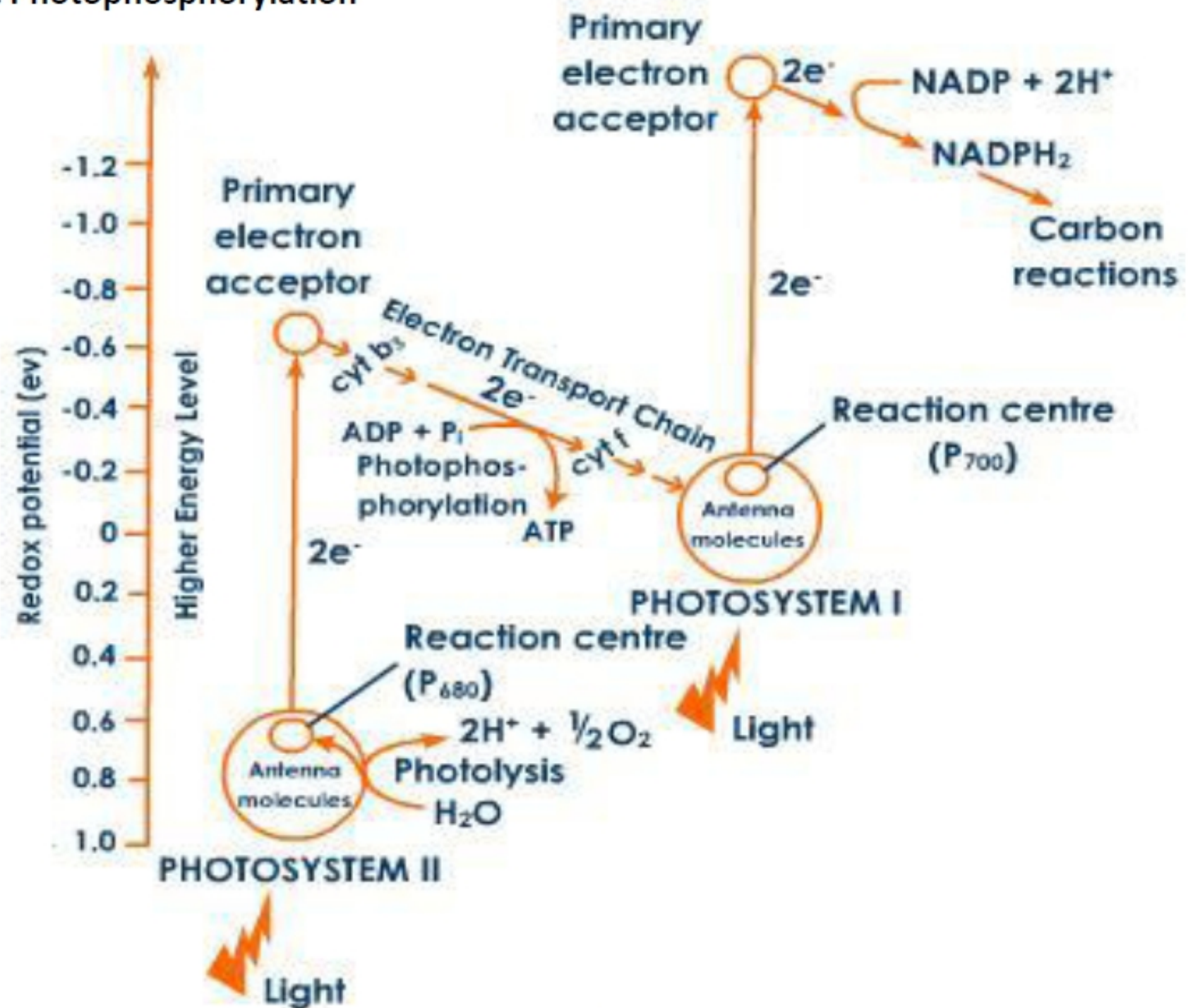


Noncyclic Photophosphorylation

- Photosystem II regains electrons by splitting water, leaving O_2 gas as a by-product



Noncyclic Photophosphorylation



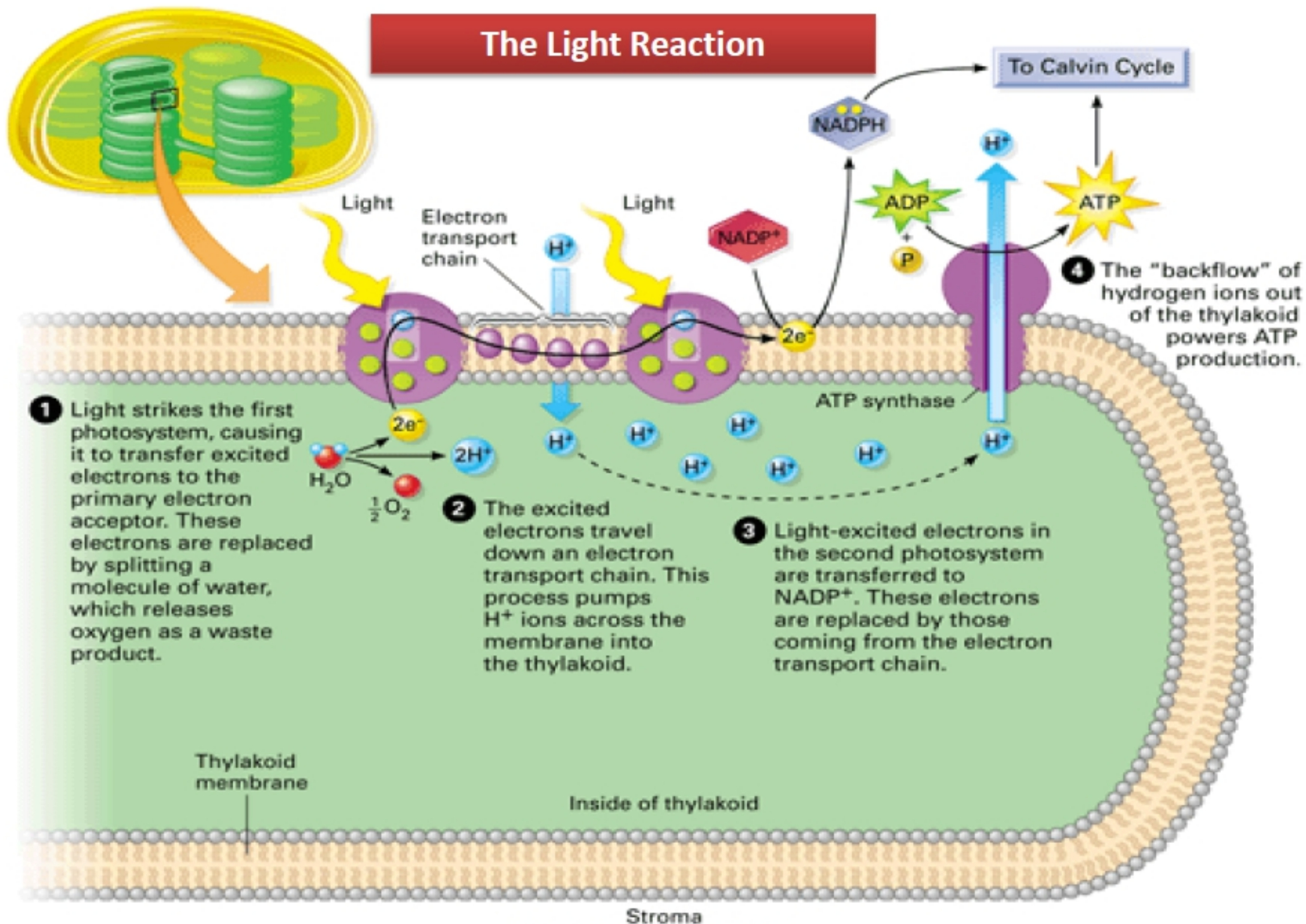
In the light reactions, electron transport chains generate ATP, NADPH, & O₂

- Two connected photosystems collect photons of light and transfer the energy to chlorophyll electrons
- The excited electrons are passed from the primary electron acceptor to electron transport chains
 - Their energy ends up in ATP and NADPH

Chemiosmosis powers ATP synthesis in the light reactions

- The electron transport chains are arranged with the photosystems in the thylakoid membranes and pump H^+ through that membrane
 - The flow of H^+ back through the membrane is harnessed by ATP synthase to make ATP
 - In the stroma, the H^+ ions combine with $NADP^+$ to form NADPH

The Light Reaction



PHOTOSYNTHESIS

```
graph TD; A[PHOTOSYNTHESIS] --> B[LIGHT REACTION]; A --> C[DARK REACTION]; B --> D[OR]; D --> E[PRIMARY PHOTOCHEMICAL REACTION]; E --> F[OR]; F --> G[HILL'S REACTION]; C --> H[OR]; H --> I[PATH OF CARBON IN PS]; I --> J[OR]; J --> K[BLACK MAN'S REACTION];
```

LIGHT REACTION

OR

PRIMARY PHOTOCHEMICAL REACTION

OR

HILL'S REACTION

DARK REACTION

OR

PATH OF CARBON IN PS

OR

BLACK MAN'S REACTION

DARK REACTION

**Reduction of CO_2 to Carbohydrate by utilizing
Assimilatory Powers (ATP and NADPH_2)
Produced by Light Reaction**

DARK REACTION

```
graph TD; A[DARK REACTION] --> B["C3 PATHWAY  
CALVIN CYCLE  
REDUCTIVE PENTOSE  
PHOSPHATE [RPP] CYCLE"]; A --> C["C4 Pathway  
Hatch and Slack  
Cycle"]; A --> D["CAM  
Pathway"];
```

**C₃ PATHWAY
CALVIN CYCLE
REDUCTIVE PENTOSE
PHOSPHATE [RPP] CYCLE**

**C₄ Pathway
Hatch and Slack
Cycle**

**CAM
Pathway**

Calvin cycle or C3 cycle

Calvin cycle was first observed by Melvin Calvin in chlorella

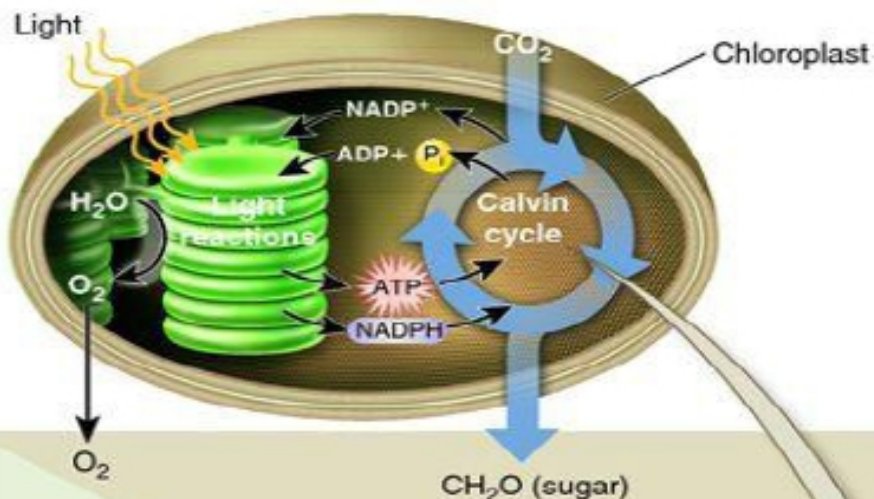
Calvin was awarded Nobel Prize for this work in 1961

It is a cyclic reaction occurring in the dark phase of photosynthesis

CO₂ is converted into sugars and it is a process of carbon fixation

**First stable compound in Calvin cycle is a 3 carbon compound
(3 phosphoglyceric acid)**

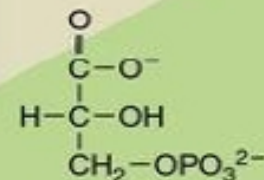
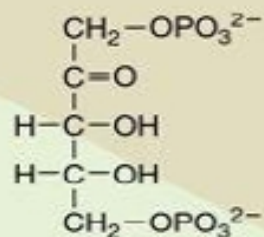
cycle is also called as C3 cycle



Input
6 × CO_2

1

Phase 1: Carbon fixation.
 CO_2 is incorporated into an organic molecule via rubisco.



Rubisco 12 × 3-phosphoglycerate (3PG)



12 ATP
12 ADP

6 × Ribulose biphosphate (RuBP)



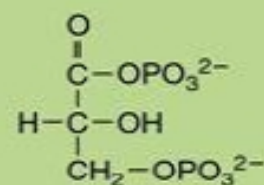
12 × 1,3-bisphosphoglycerate (1,3-BPG)



12 NADPH

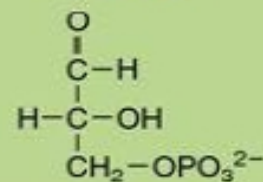
12 NADP⁺

12 P_i



Calvin cycle

12 × Glyceraldehyde-3-phosphate (G3P)



10 × G3P



2 × G3P



Glucose and other sugars

3

Phase 3: Regeneration of RuBP.
Two G3P are used to make glucose and other sugars; the remaining 10 G3P are needed to regenerate RuBP via several enzymes. ATP is required for RuBP regeneration.

6 ADP
6 ATP

2

Phase 2: Reduction and carbohydrate production.
ATP is used as a source of energy, and NADPH donates high-energy electrons.

Synthesis of carbohydrate

Ribulose 1,5 diphosphate + CO₂+H₂O → 3 Phosphoglyceric acid (2 molecule)
Rubisco

3 PGA + NADPH + H → 3 Phosphoglyceral aldehyde
ATP + Triose phosphate dehydrogenase

3 Phosphoglyceral aldehyde ↔ Dihydroxy acetone phosphate
Triose phosphate isomerase

3 Phosphoglyceral aldehyde → Fructose 1,6 diphosphate
+ Dihydroxy acetone phosphate
Aldolase

Regeneration of Ribulose diphosphate

Fructose 6 phosphate + 3 Phosphoglyceraldehyde → Erythrose 4 phosphate +
Xylose-5- phosphate

Transketolase

Erythrose 4 phosphate + Dihydroxy acetone phosphate



Aldolase

Sedoheptulose 1, 7 diphosphate

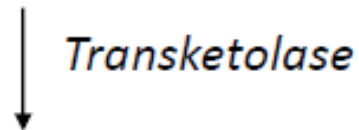


Phosphatase

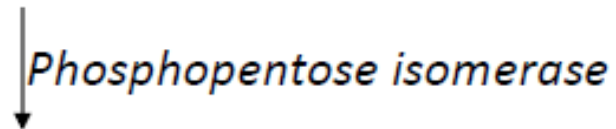
Sedoheptulose 7 diphosphate

Sedoheptulose- 7- phosphate

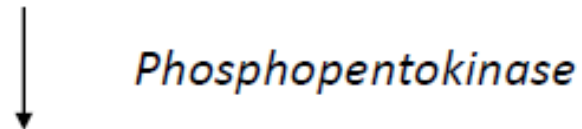
3 Phosphoglyceraldehyde



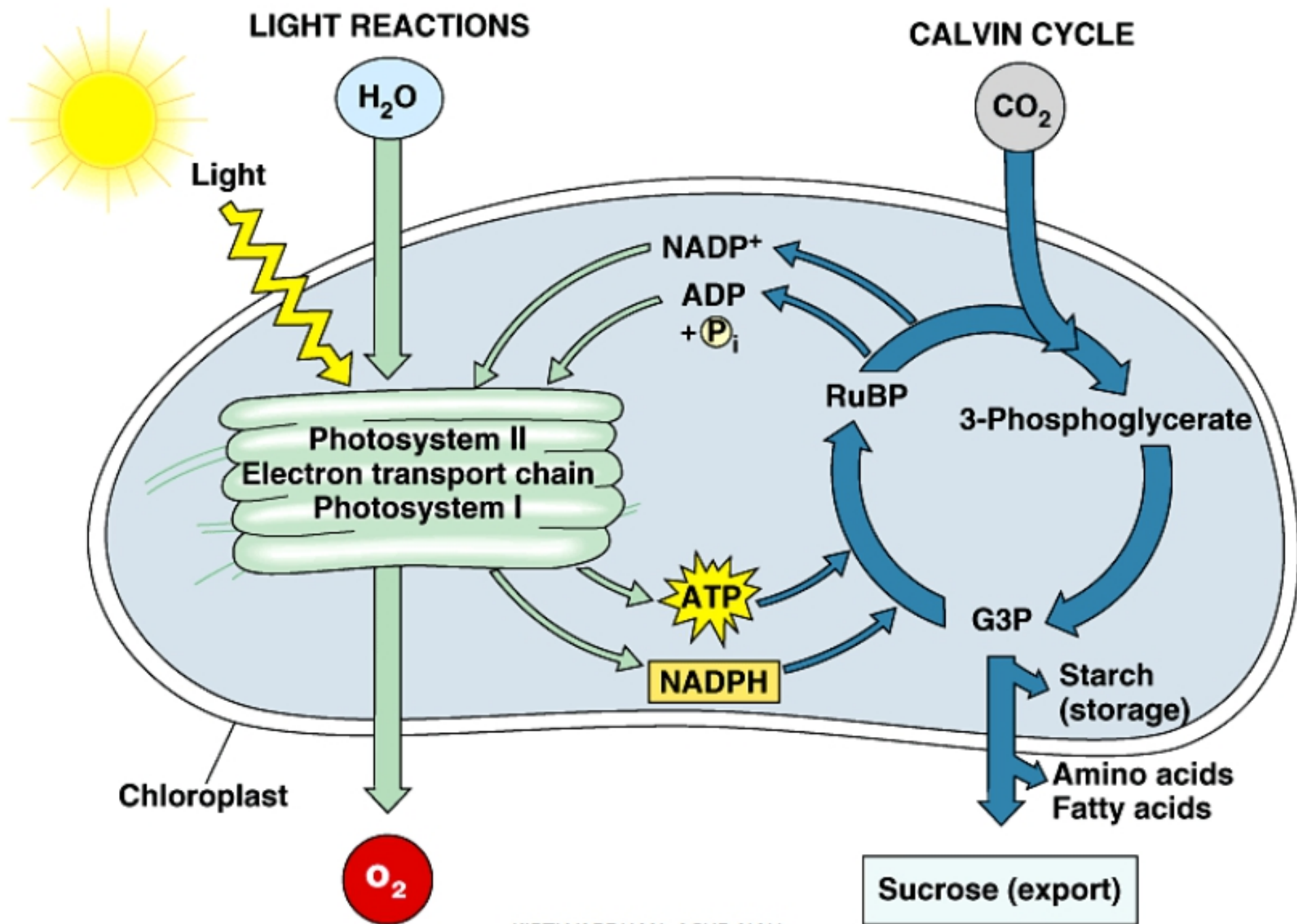
Xylose 5 phosphate + Ribose 5 Phosphate



Ribulose 5 phosphate + ATP



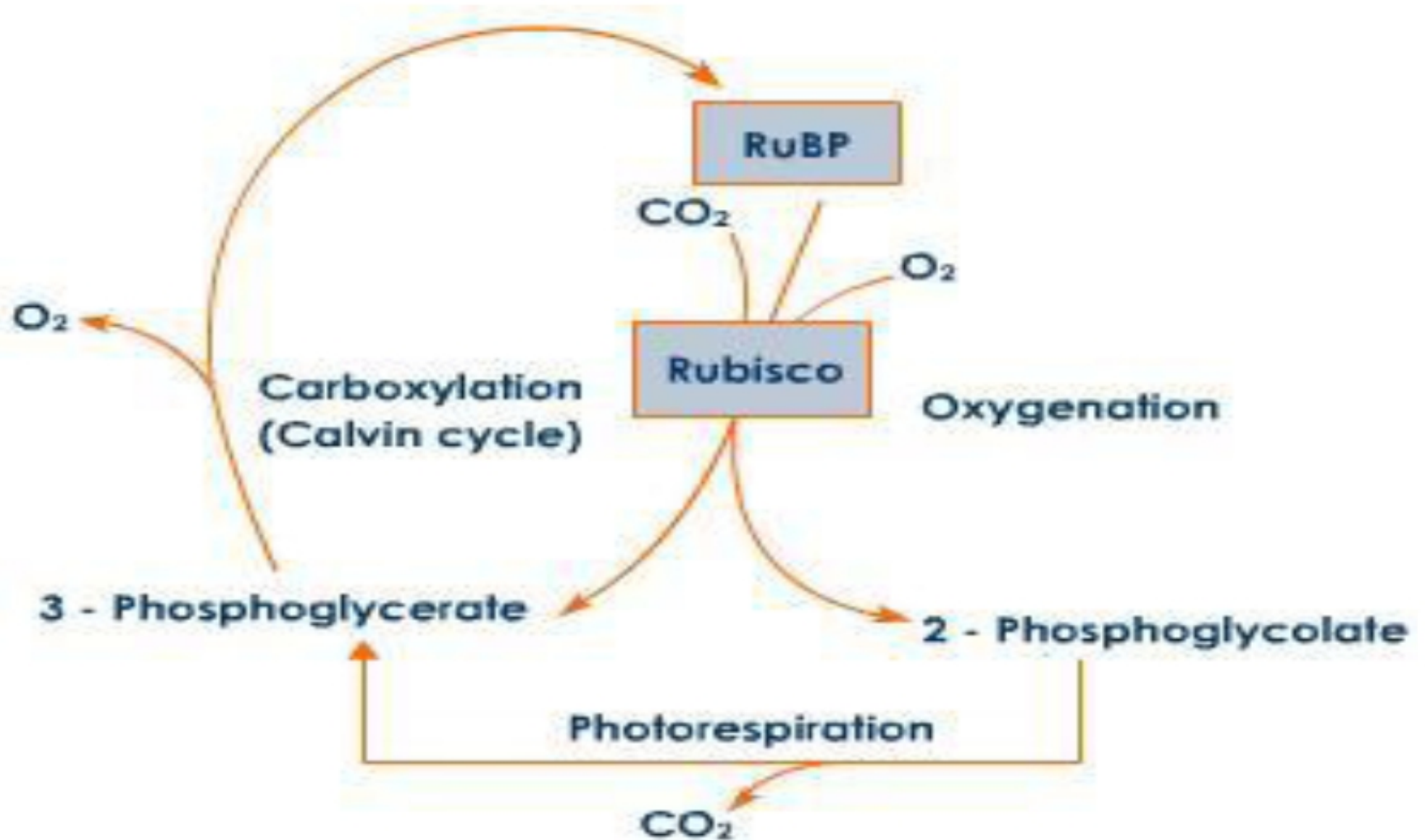
Ribulose, 1, 5 diphosphate



Photorespiration

High light intensity

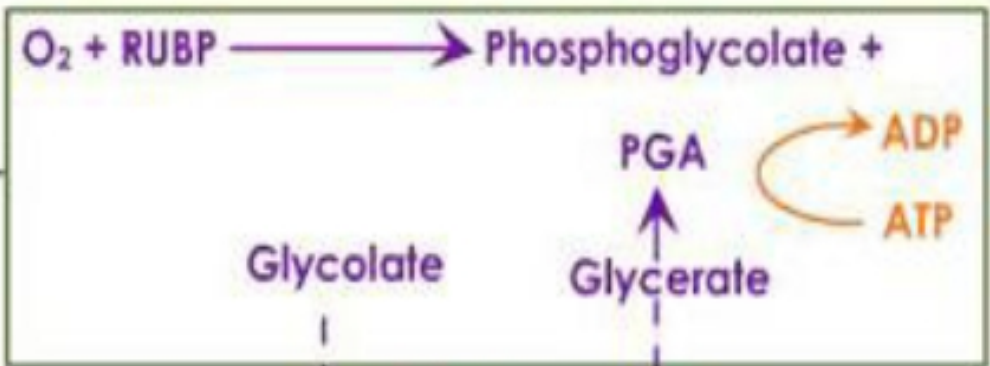
Low CO₂, High O₂



Chloroplast

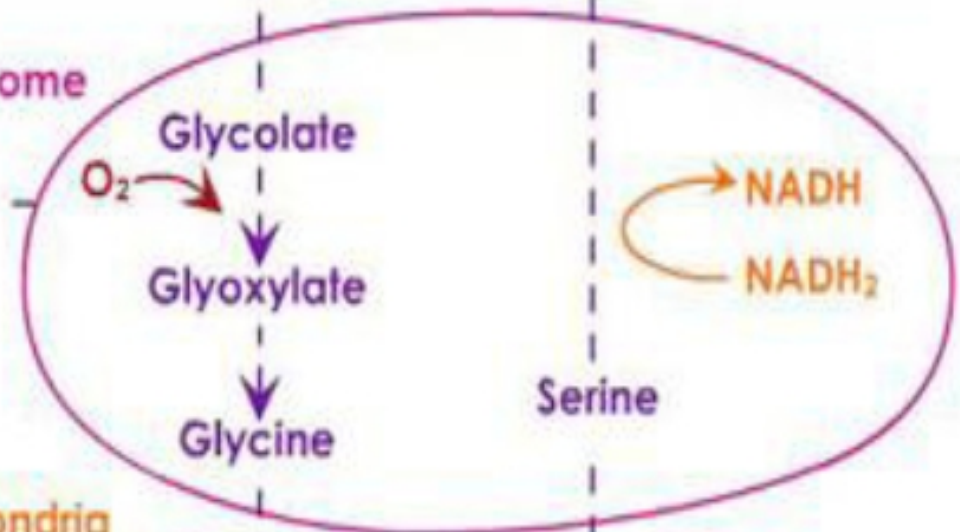
Utilisation of oxygen and RUBP

RUBP used can be formed by
photosynthesis only



Peroxisome

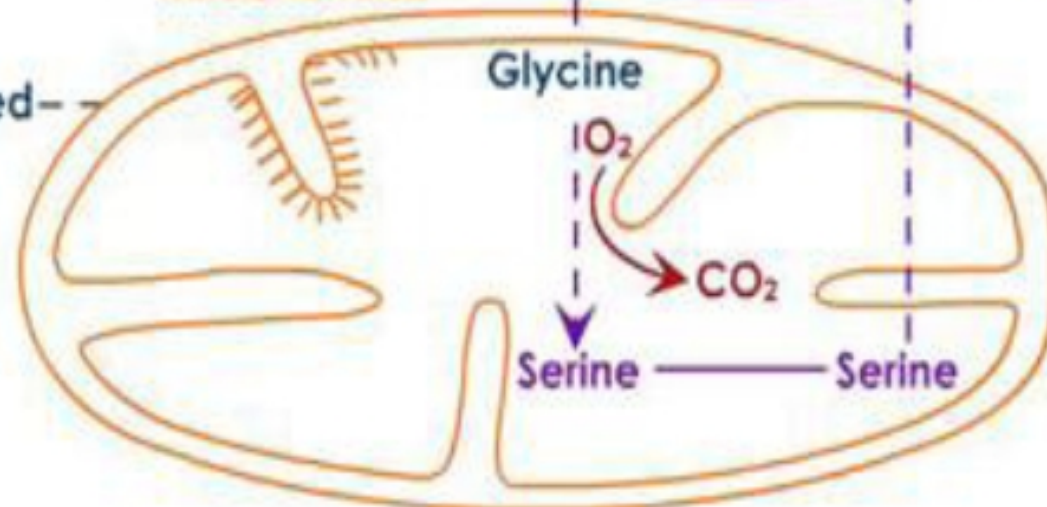
Function of photorespiration is to
recover some of the carbon
from the excess glycolate



Mitochondria

O_2 used and CO_2 is produced

Pathway of
Photorespiration



C4 cycle/ Hatch and Slack / C4 dicarboxylic acid pathway

It is the alternate pathway of C3 cycle to fix CO₂

first formed stable compound 4 carbon oxaloacetic acid

Enzyme - PEP carboxylase

different type of leaf anatomy- chloroplasts are dimorphic in nature

vascular bundles are surrounded by bundle sheath of larger parenchymatous cells have chloroplasts

chloroplasts of bundle sheath are larger, lack grana

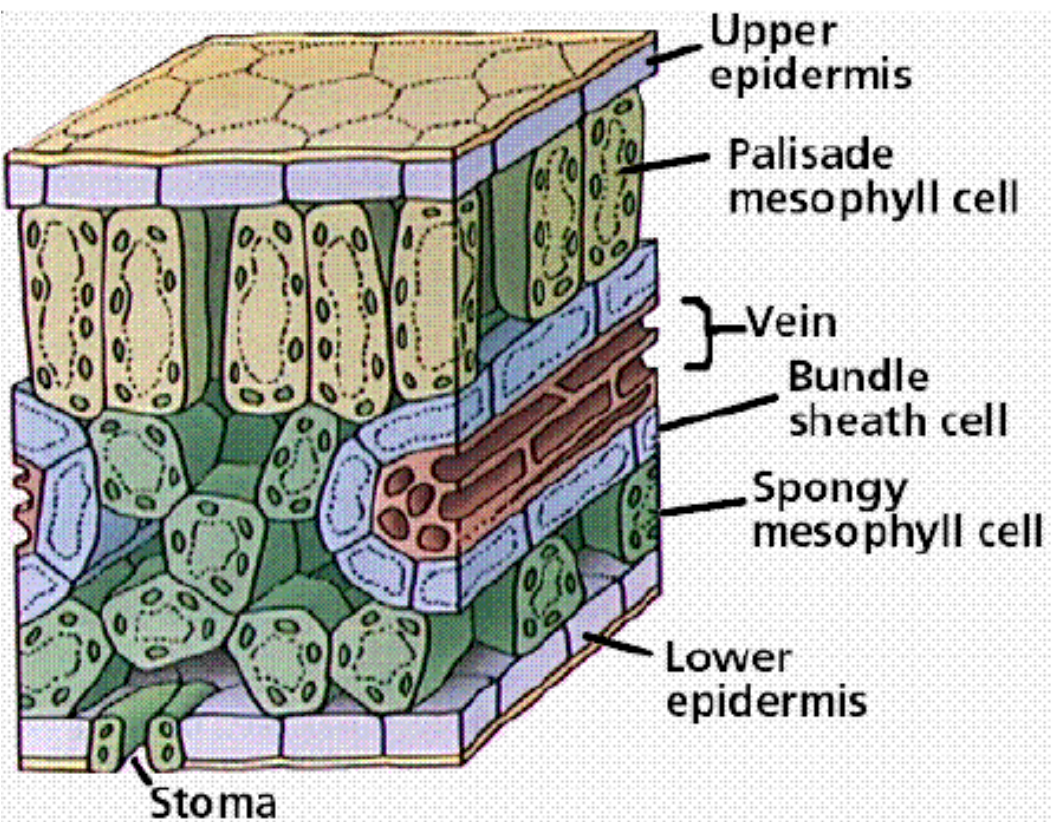
peculiar anatomy of leaves of C4 plants is called Kranz anatomy

Eg : sugar cane, maize, sorghum and amaranthus

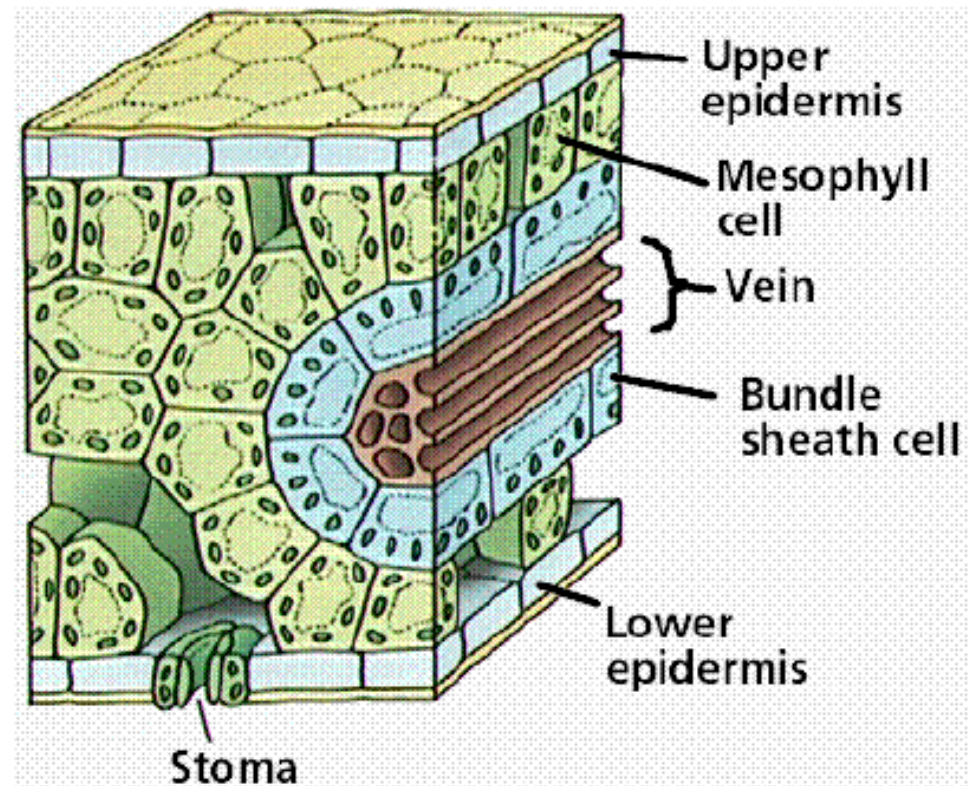
C₄ cycle consists of four stages

1. Fixation of CO₂ by the **carboxylation** of phosphoenolpyruvate in the mesophyll cells to form a C₄ acid (malate and/or aspartate)
2. **Transportation** of the C₄ acids to the bundle sheath cells
3. **Decarboxylation** of the C₄ acids within the bundle sheath cells and generation of CO₂, which is then reduced to carbohydrate via Calvin cycle
4. Transport of the C₃ acid (pyruvate or alanine) that is formed by the decarboxylation step back to the mesophyll cell and **regeneration** of the CO₂ acceptor phosphoenolpyruvate

C₃ leaf

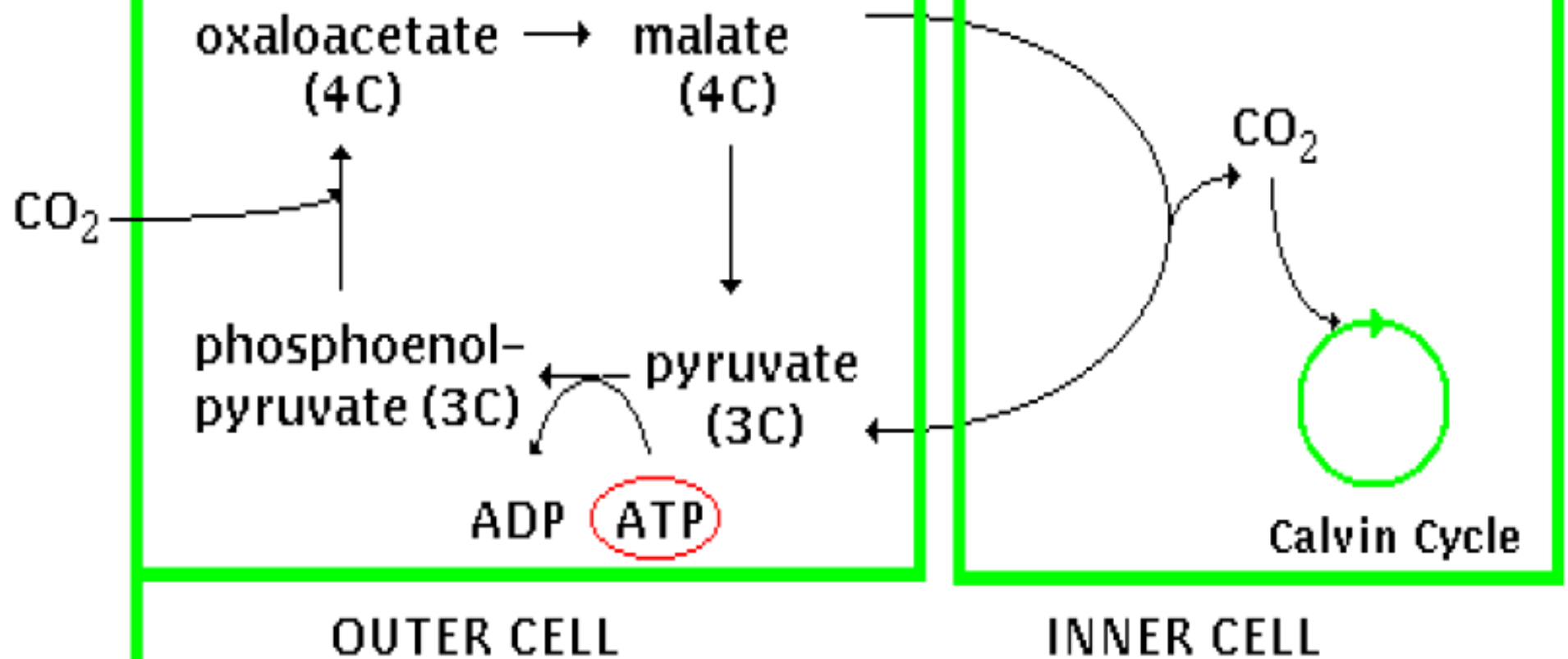


C₄ leaf



THE C4 PATHWAY

AIR



Structural specification of C4 plants:

Dimorphism of chloroplast

Kranz anatomy

Differences b/w C3 and C4 Plants

CO₂ acceptor and stable product

Efficiency of CO₂ absorption (CO₂ compensation point)

Type of chloroplast

Calvin cycle enzymes

Light saturation point

Photorespiration

Optimum temp.

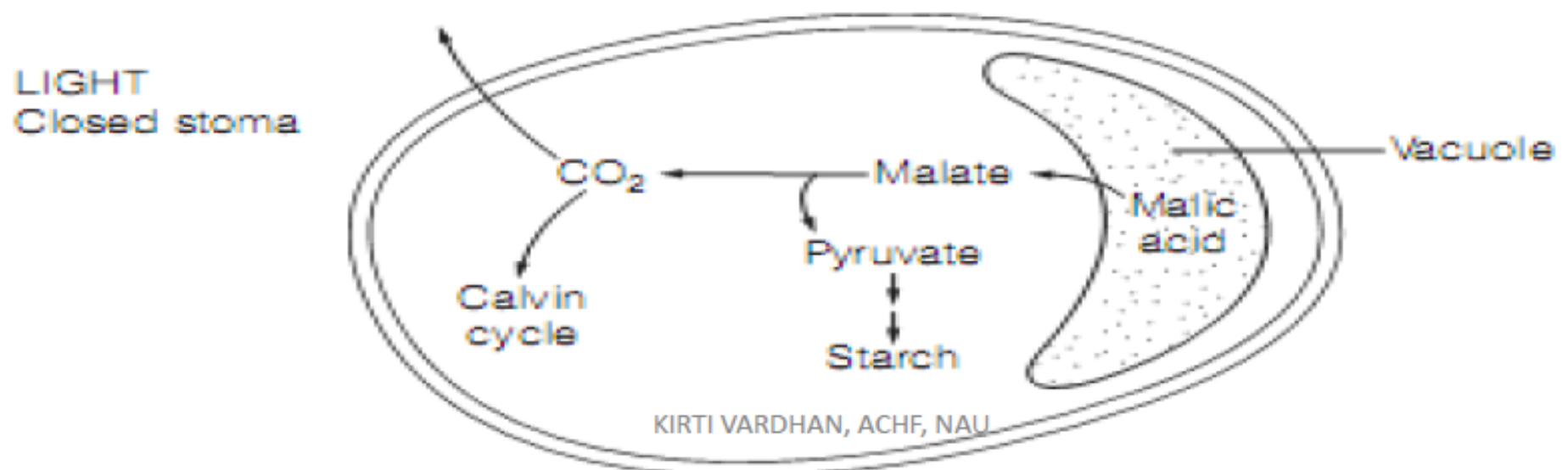
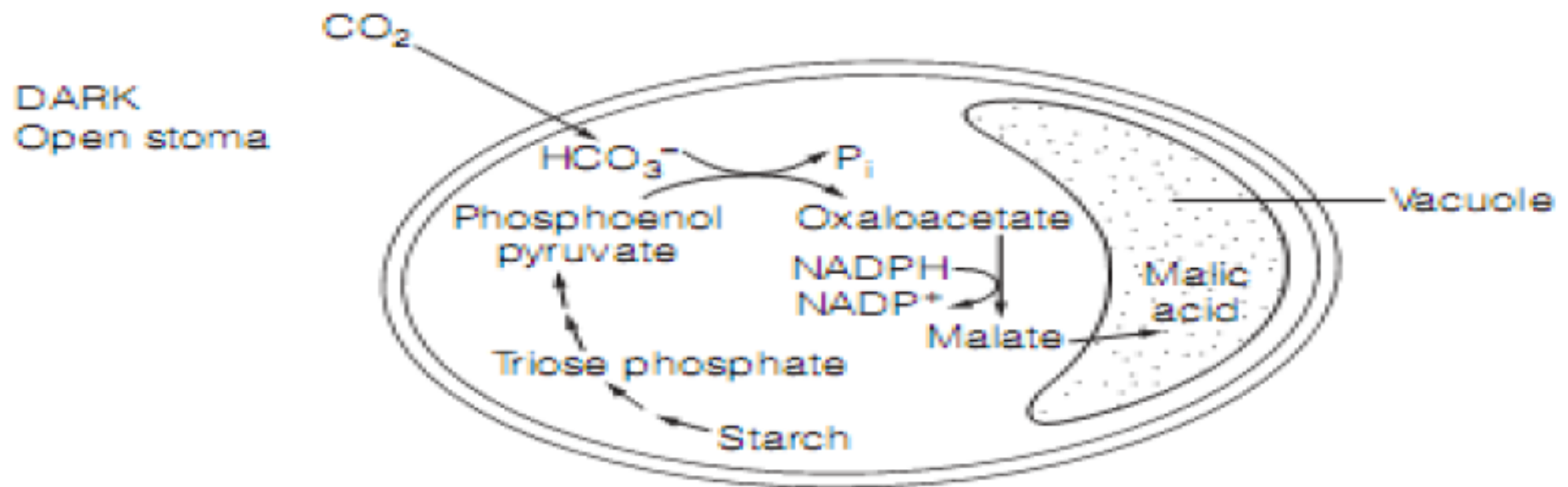
Biological Significance of C4 plants

Photosynthesis in low CO₂

Xeric condition – partial stomatal closure

Absence of photorespiration, higher fixation

CAM(Crassulacean acid metabolism) Fixation

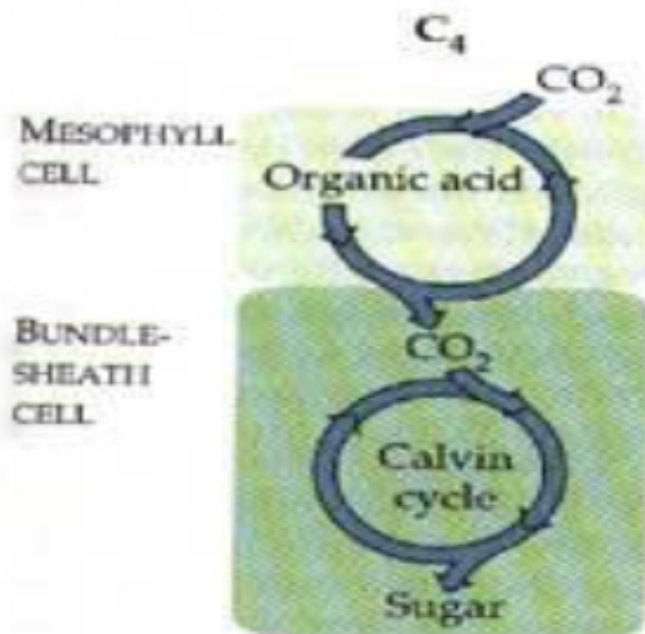




SUGARCANE

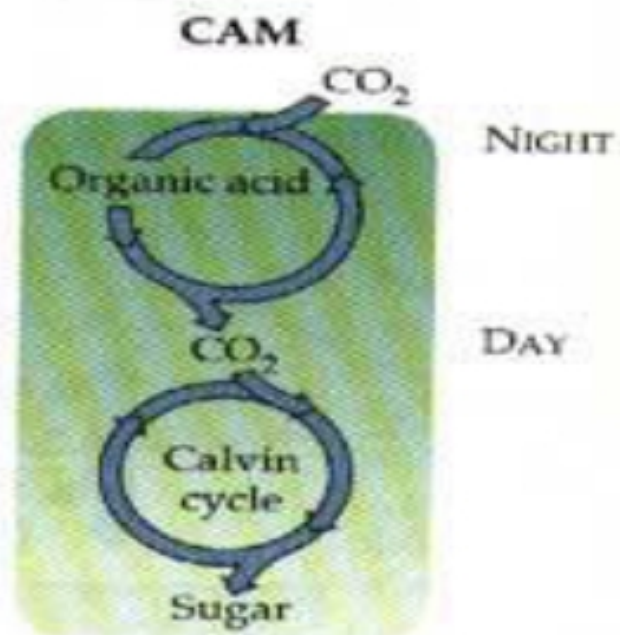


PINEAPPLE



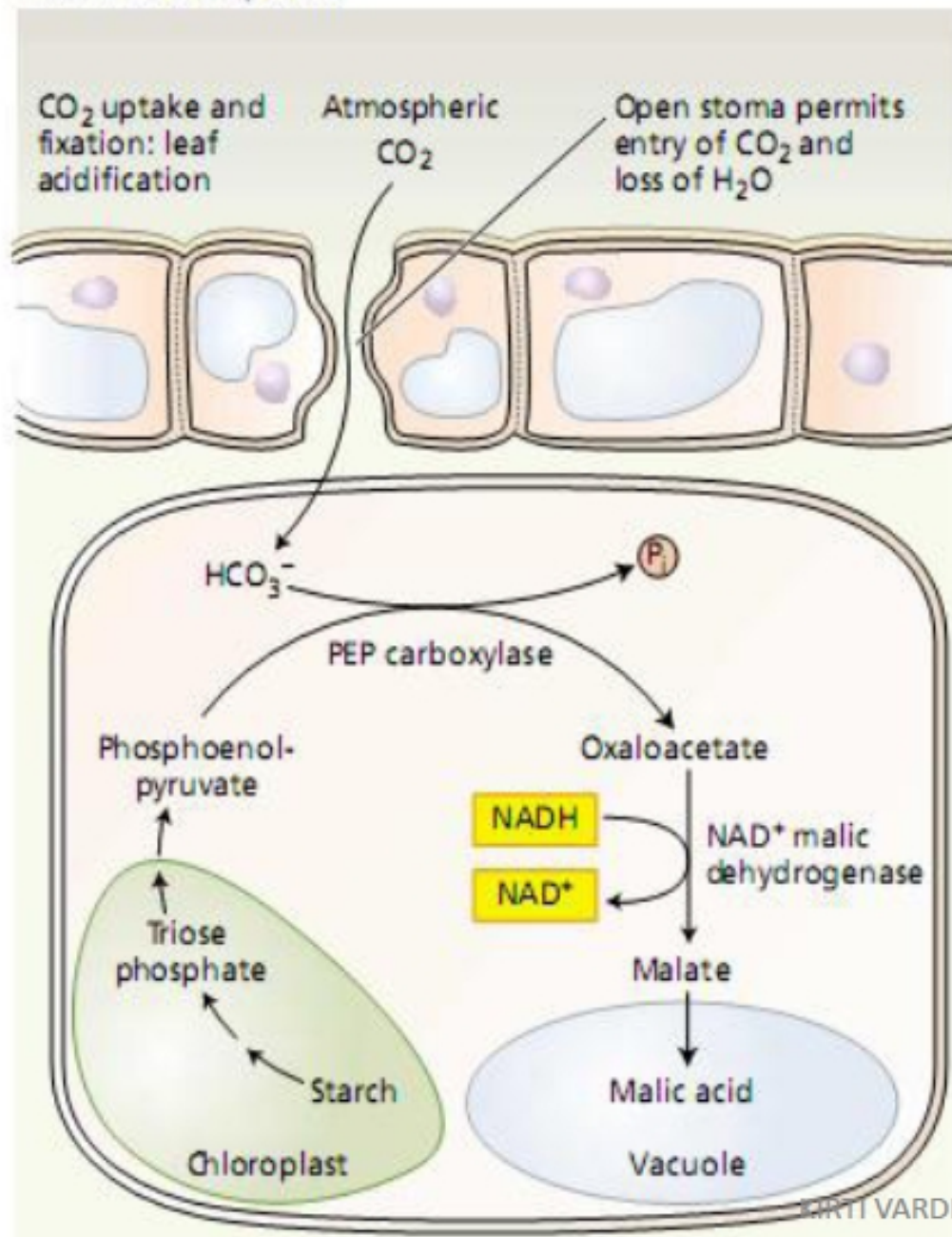
Step 1: CO₂ incorporated into four-carbon organic acids

Step 2: Organic acids release CO₂ to Calvin cycle

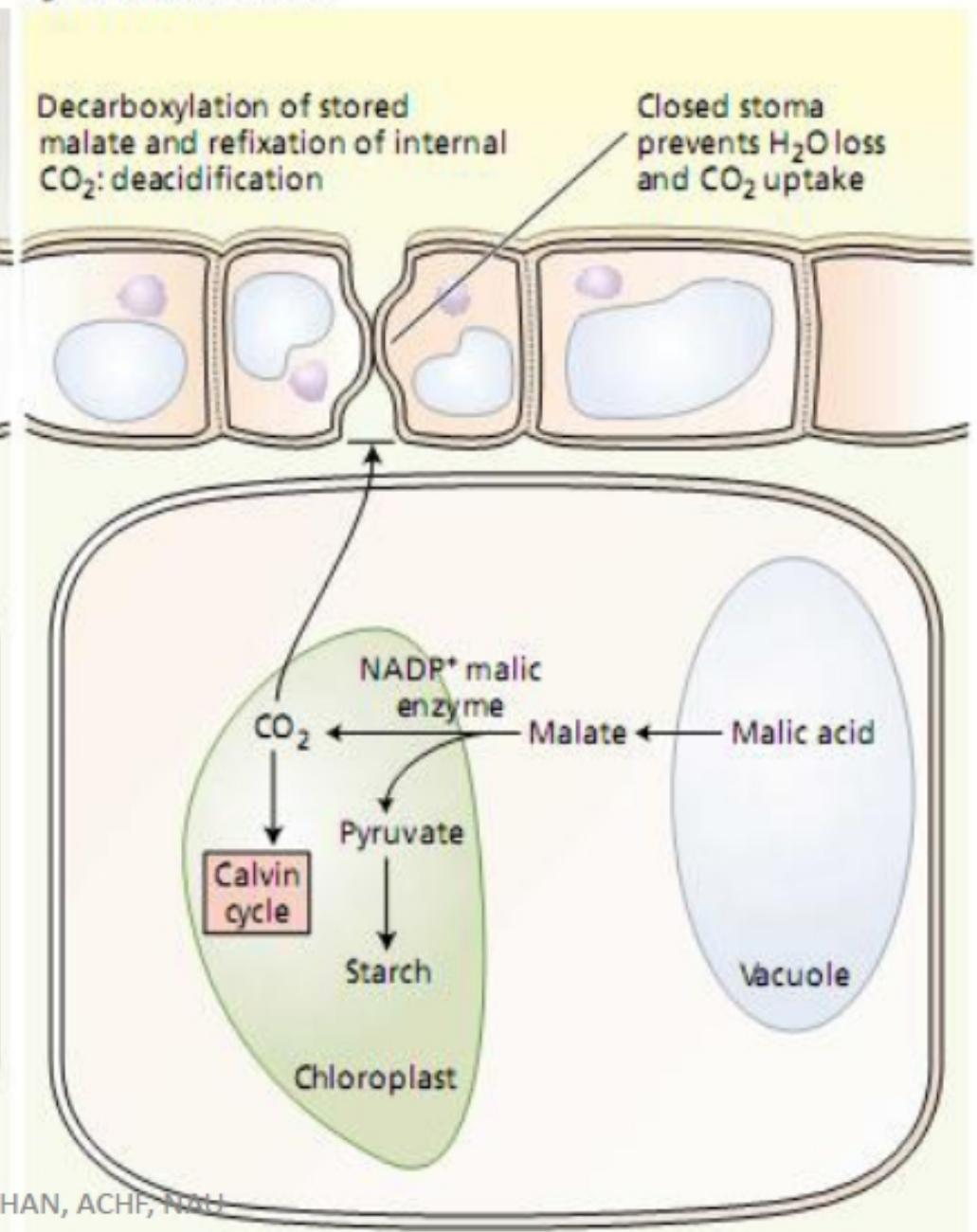


CAM Photosynthesis

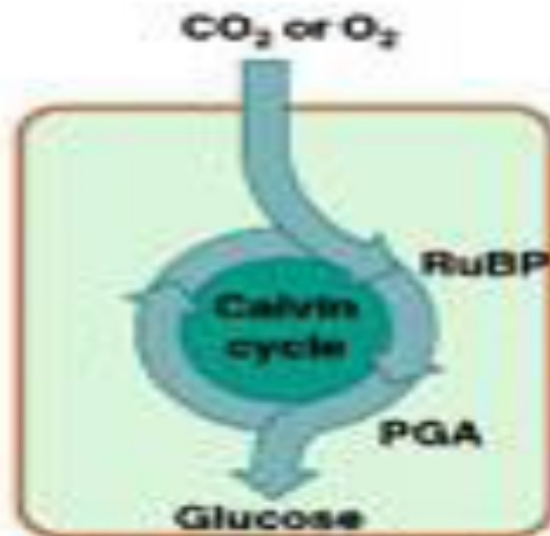
Dark: Stomata opened



Light: Stomata closed



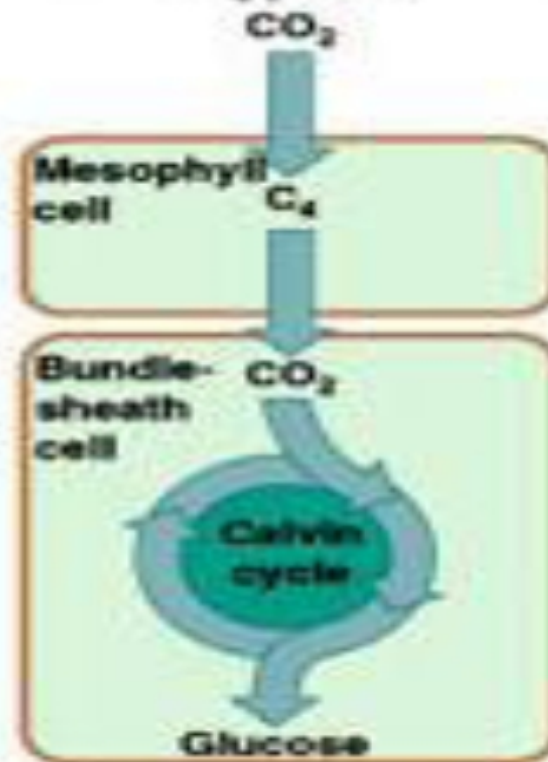
C₃ plant



With high temperatures photorespiration predominates in C₃ plants.

A

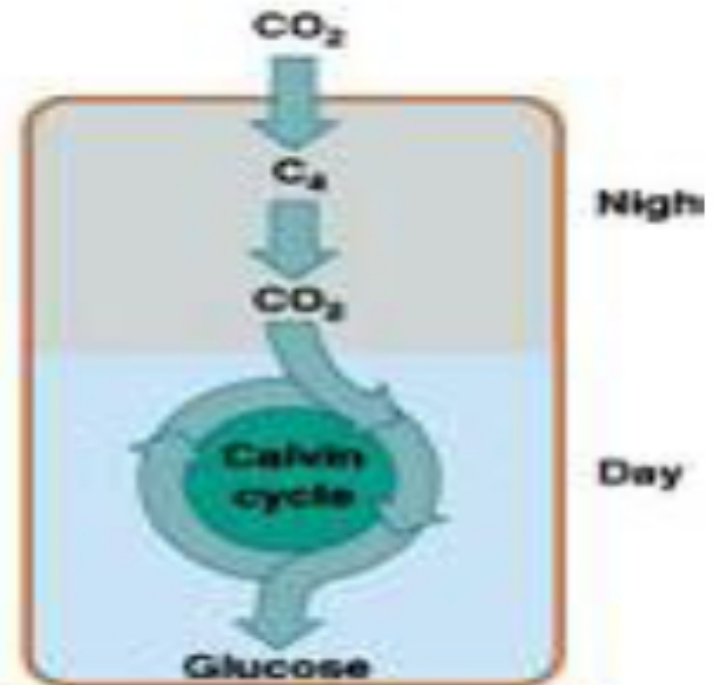
C₄ plant



With high temperatures Calvin cycle predominates in C₄ plants.

B

CAM plant



With high temperatures Calvin cycle predominates in CAM plants.

C

	C3	C4	CAM
Leaf anatomy	no distinct bundle sheath	Kranz anatomy	Usually no palisade cells, large vacuoles
Initial carboxylating enzyme	rubisco	PEPcase	PEPcase
Product of CO ₂ fixation	PGA (C3)	OAA (C4)	OAA (C4)
Chloroplasts	one type	dimorphic	one type
Theoretical energy requirements (CO ₂ : ATP: NADPH)	1: 3: 2	1: 5 : 2	1: 6.5: 2
Transpiration ratio (g H ₂ O/g dry wt)	450-950	250-350	18-125
Photosynthesis rate (mg CO ₂ fixed dm ⁻² h ⁻¹)	15 - 30	40 - 80	(low)
Carbon dioxide compensation point (ppm)	50 - 150 (Hi)	0-10 (low)	0-5 (in dark)
Response to light	Light saturation easily achieved	No light saturation	-
Photosynthesis inhibited by oxygen?	Yes	No	Yes
Temperature optimum for photosynthesis	15-25	30-47	35

Factor affecting photosynthesis:

Internal factor: Chlorophyll

Leaf resistance

Demand for photosynthates

Genotype

Fate of carbohydrate products in the plant

carbon dioxide and water

photosynthesis

carbohydrates (e.g. glucose)

mineral salts
(e.g. NO_3^- , SO_4^{2-})

fatty acids

glycerol

amino acids

water

Fate of carbohydrate products in the plant

carbon dioxide and water

photosynthesis

carbohydrates (e.g. glucose)

mineral salts
(e.g. NO_3^- , SO_4^{2-})

fatty acids

glycerol

amino acids

water

release energy by respiration

Fate of carbohydrate products in the plant

carbon dioxide and water

photosynthesis

carbohydrates (e.g. glucose)

mineral salts
(e.g. NO_3^- , SO_4^{2-})

fatty acids

glycerol

amino acids

water

convert into starch for storage

Fate of carbohydrate products in the plant

carbon dioxide and water

photosynthesis

carbohydrates (e.g. glucose)

mineral salts
(e.g. NO_3^- , SO_4^{2-})

fatty acids

glycerol

amino acids

water

change into sucrose and is transported to other parts through phloem

Fate of carbohydrate products in the plant

carbon dioxide and water

photosynthesis

carbohydrates (e.g. glucose)

mineral salts
(e.g. NO_3^- , SO_4^{2-})

fatty acids

glycerol

amino acids

water

combine to form fats and oils to form
cell membranes and as a food store

Fate of carbohydrate products in the plant

carbon dioxide and water

photosynthesis

carbohydrates (e.g. glucose)

mineral salts
(e.g. NO_3^- , SO_4^{2-})

fatty acids

glycerol

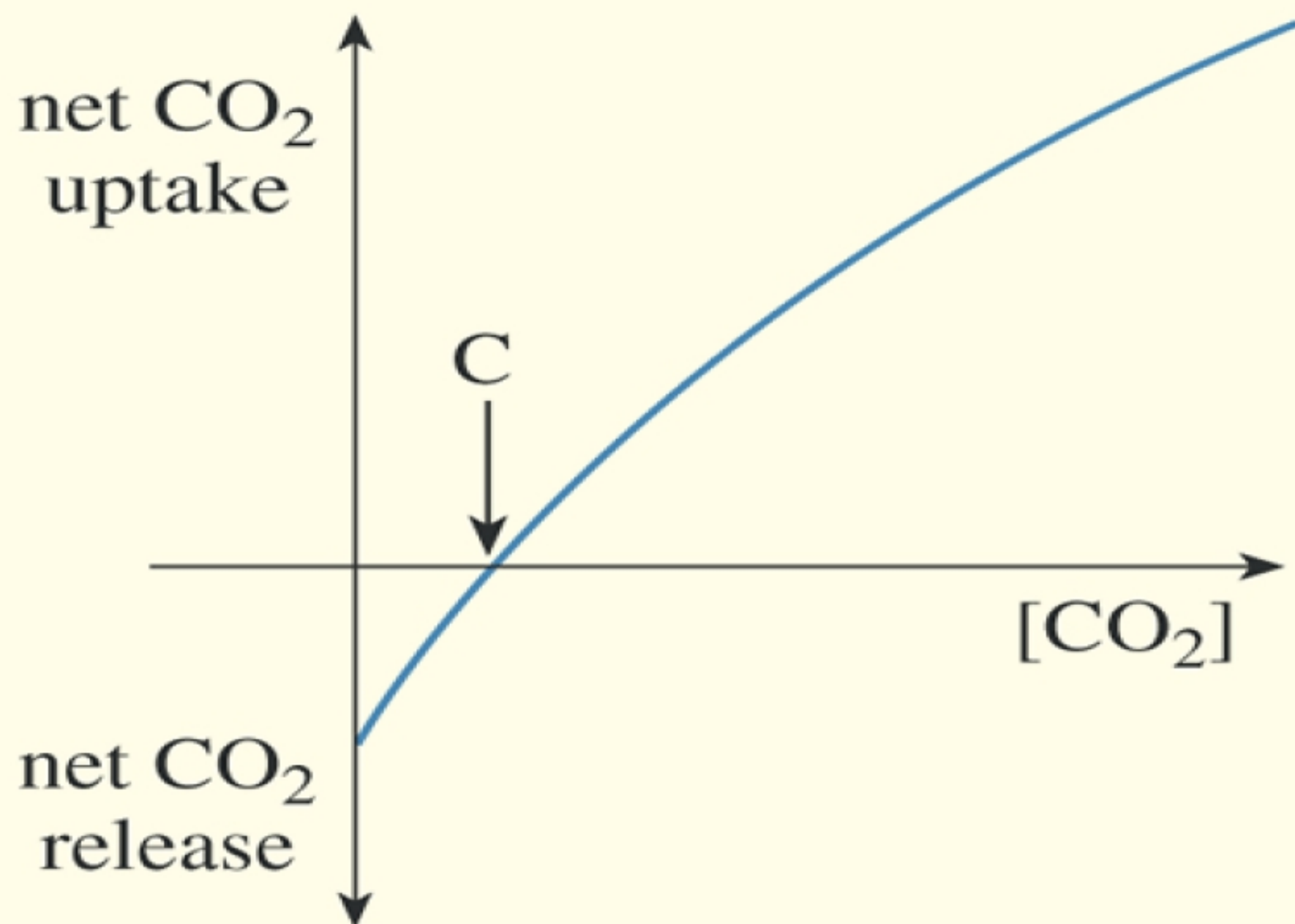
amino acids

water

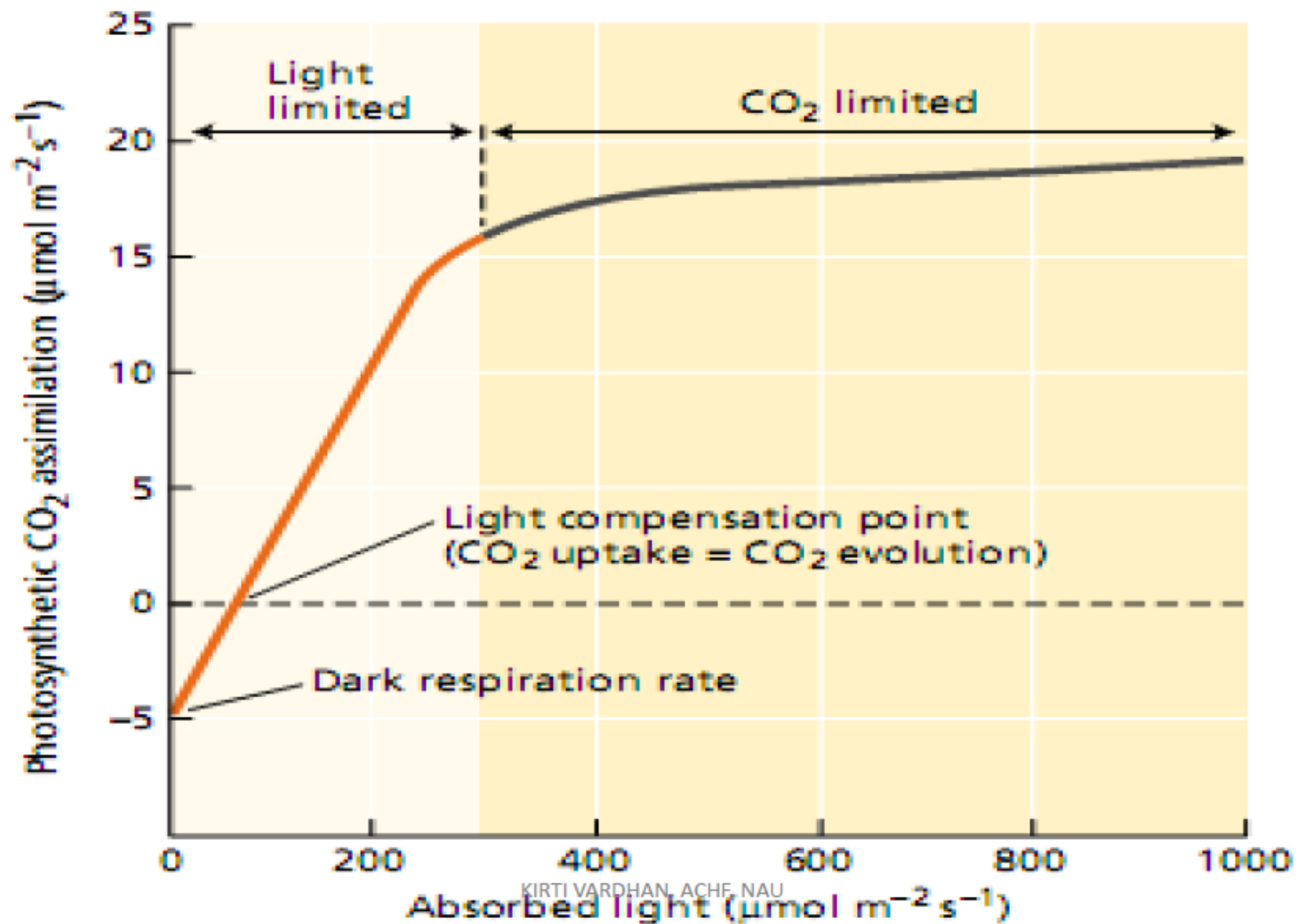
join together to become
protein molecules

KIRTI VARDHAN, ACHF, NAU

External Factor : CO_2



External Factor : Light



External Factor:

Temperature

Water

Nutrient



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Thank You