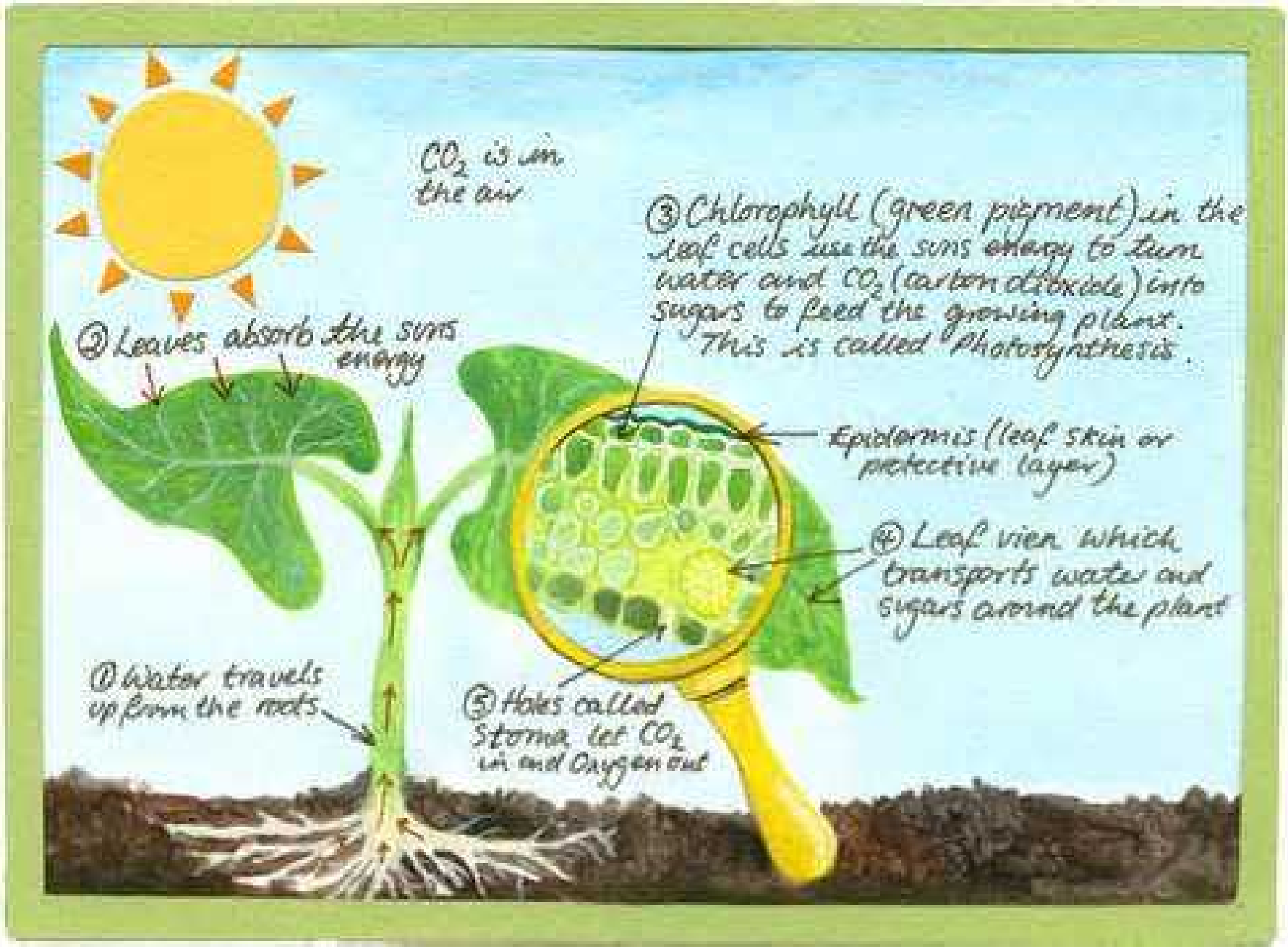

CO_2 is in the air
③ Chlorophyll (green pigment) in the leaf cells use the suns energy to turn water and CO_2 (carbon dioxide) into sugars to feed the growing plant. This is called Photosynthesis.
② Leaves absorb the suns energy
Epidermis (leaf skin or protective layer)
④ Leaf vien which transports water and sugars around the plant
① Water travels up from the roots
⑤ Holes called Stoma let CO_2 in and Oxygen out

PHOTOSYNTHESIS

Green plants capture solar energy & convert it into chemical energy – by photosynthesis.

CO_2 & H_2O ----------→ Carbohydrates & O_2

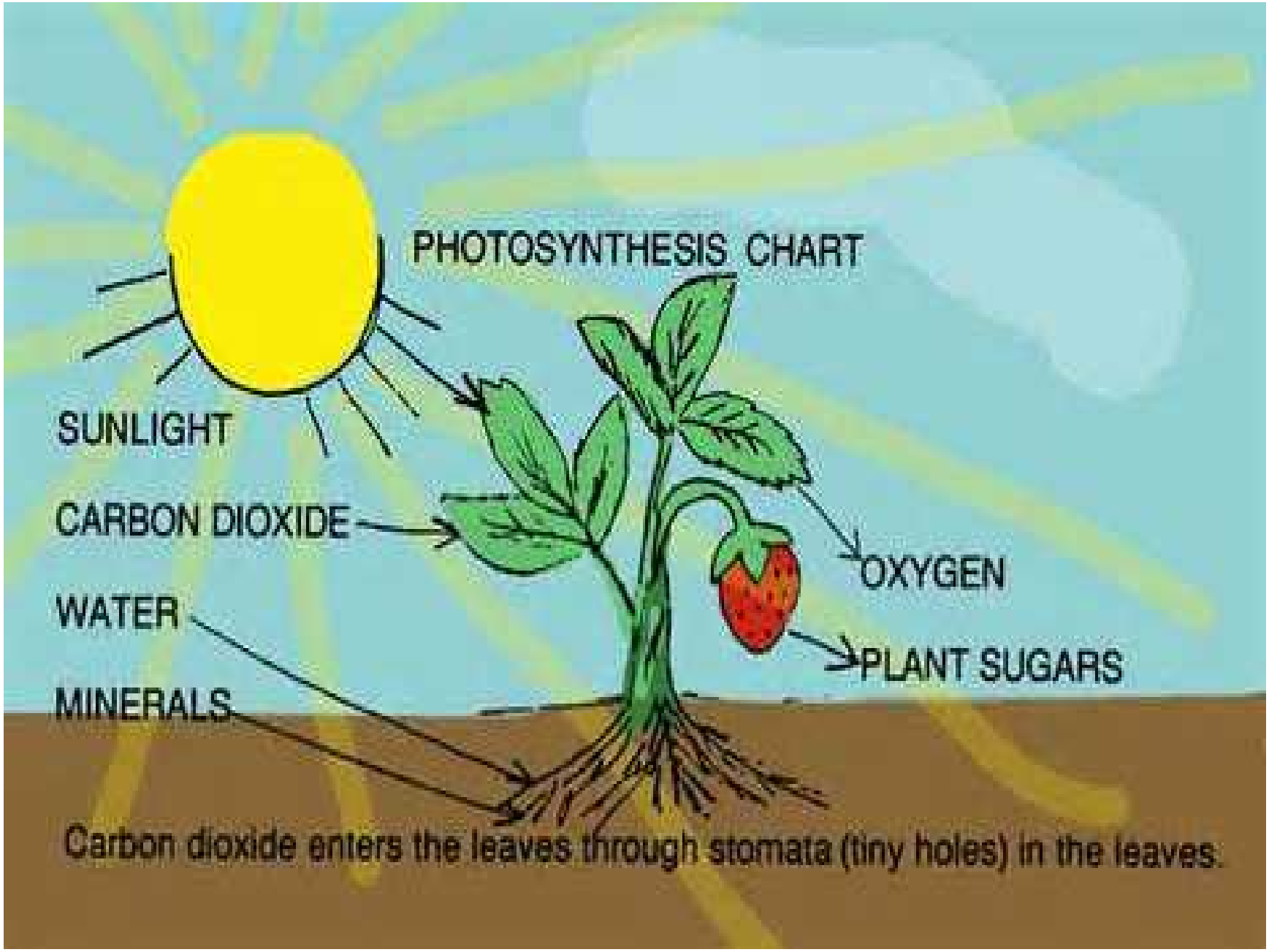
Carbohydrates ----→ lipids, nucleic acids, proteins, etc.

These organic molecules – elaborated in leaves, stem, roots, fruits, seeds & other tissues.

Plants & plant products – major source of food for all other organisms.

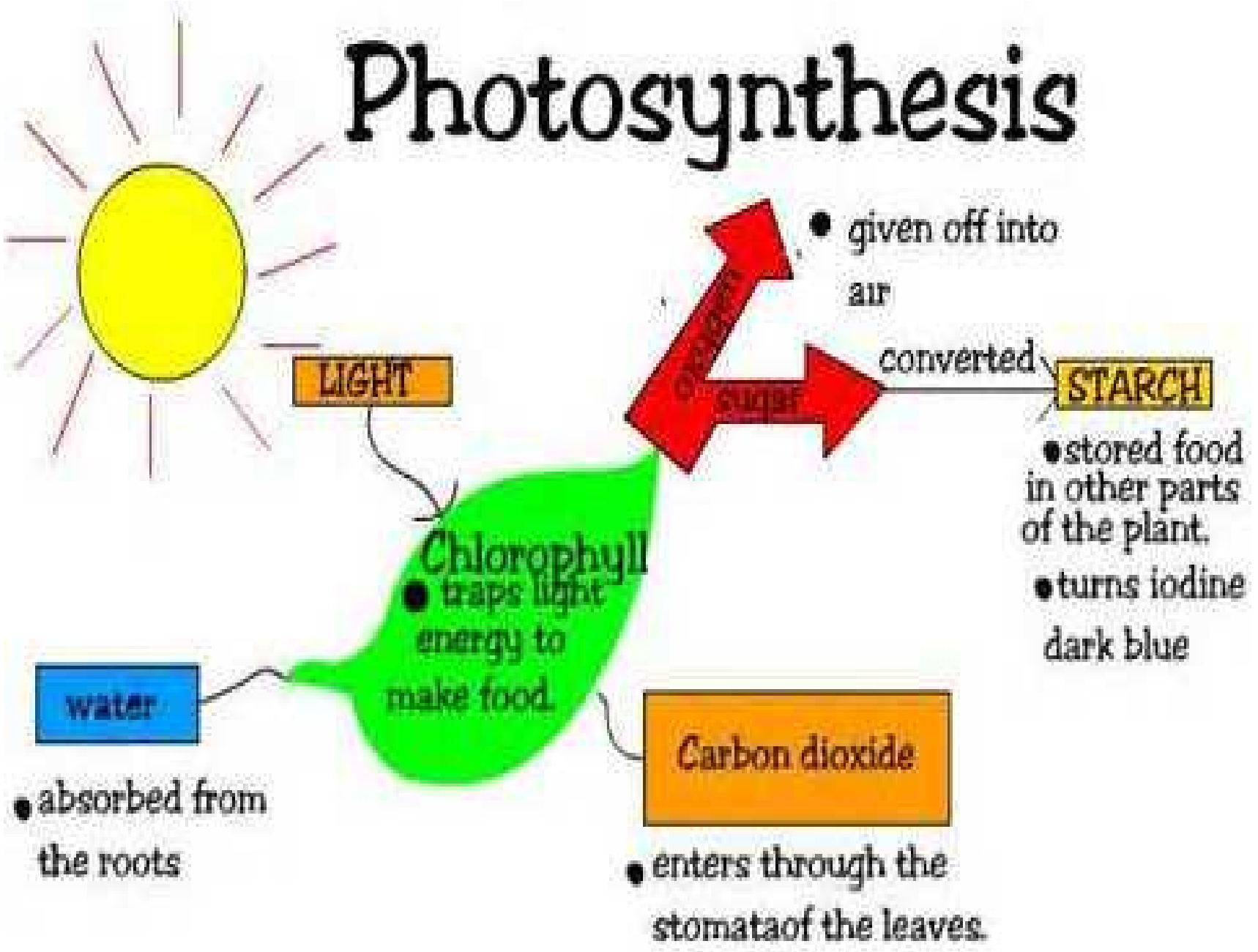
Photosynthesis – common occurrence in green plants, algae, bacteria, etc.

Nearly 0.2% light falling on earth is used for photosynthesis.


PHOTOSYNTHESIS CHART
SUNLIGHT
CARBON DIOXIDE
WATER
MINERALS
OXYGEN
PLANT SUGARS
Carbon dioxide enters the leaves through stomata (tiny holes) in the leaves.

- **70 billion tonnes of CO_2 is fixed annually.**
- **170 million tonnes of dry matter is produced on earth annually through photosynthesis.**
- **Photosynthetic organisms more abundant in oceans**
- **90% photosynthetic production is in oceans.**
- **Photosynthesis – photon = light**

  synthesis = putting together
- **It is an anabolic process - green plants synthesize carbohydrates & evolve molecular O_2.**
- **It utilizes CO_2, H_2O, light energy & chlorophyll.**


Photosynthesis
given off into air
OXYGEN
converted
SUGAR
STARCH
LIGHT
stored food in other parts of the plant.
turns iodine dark blue
Chlorophyll
traps light energy to make food.
water
absorbed from the roots
Carbon dioxide
enters through the stomataof the leaves.

- **Photosynthesis – important metabolic process – provides food to biological world.**
- **Purifies atmospheric air by removing CO2 & evolving O2.**
- **Involves transformation of photonic energy into chemical energy (carbohydrates).**

CHLOROPLAST – THE PHOTOSYNTHETIC APPARATUS

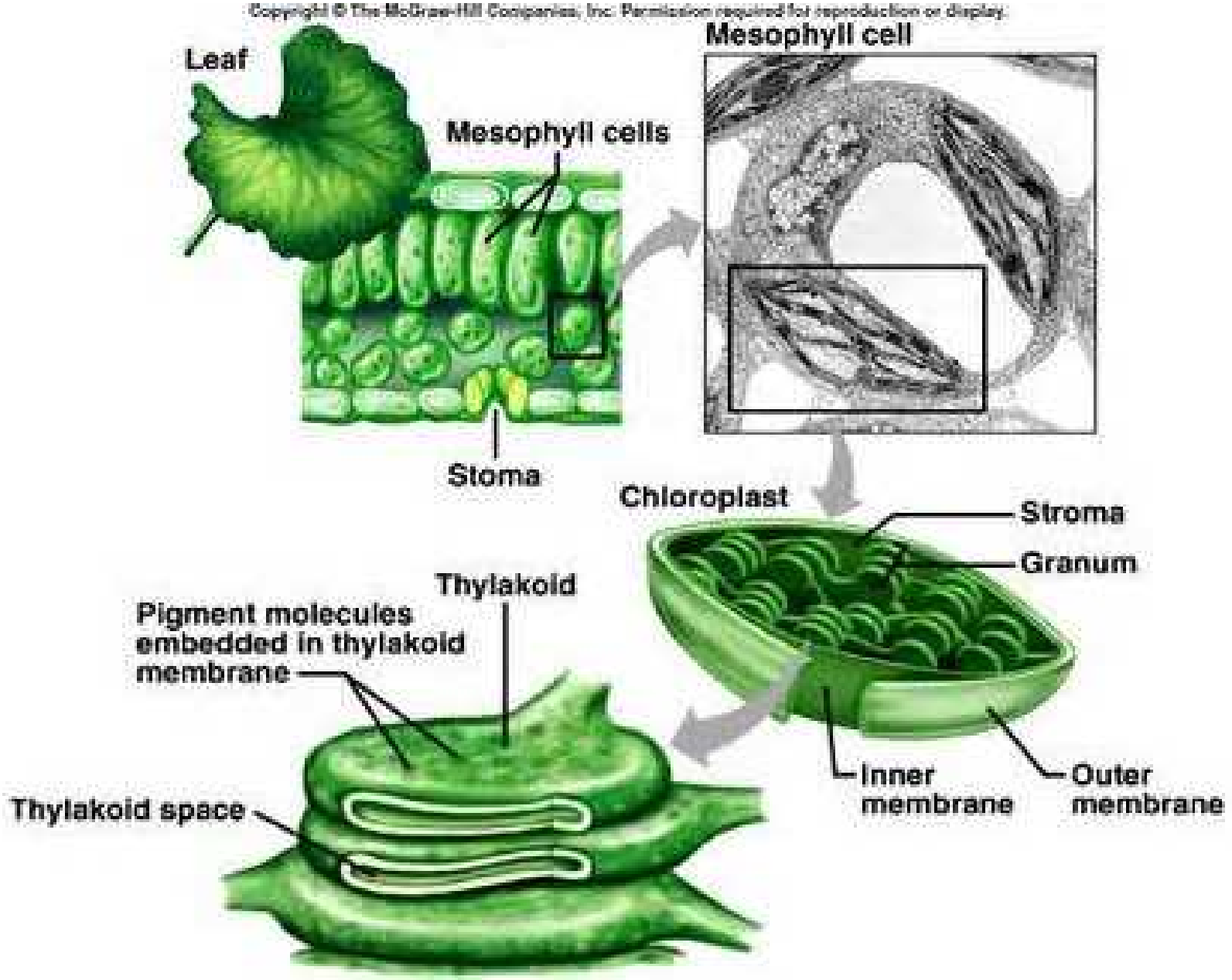
Chloroplasts – main sites of photosynthesis in green plants.

Occur in mesophyll cells of leaves.

Green, double membrane-bound organelle.

Its membranes are differentially permeable.

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- **Shape – vary with type of organism.**
- **Shape – discoid, ellipsoid, spiral, cup-shaped, reticulate, dumb-bell shaped.**

STRUCTURE OF CHLOROPLAST

Chloroplast – is a double-walled, fluid filled bag.

Has a gelatinous core –matrix or stroma – covered by 2 concentric membranes.

Outer membrane highly permeable than inner.

Intermembrane space – periplastidial space.

Membranes have lipoprotein composition, lamellar structure & fluid mosaic organization.

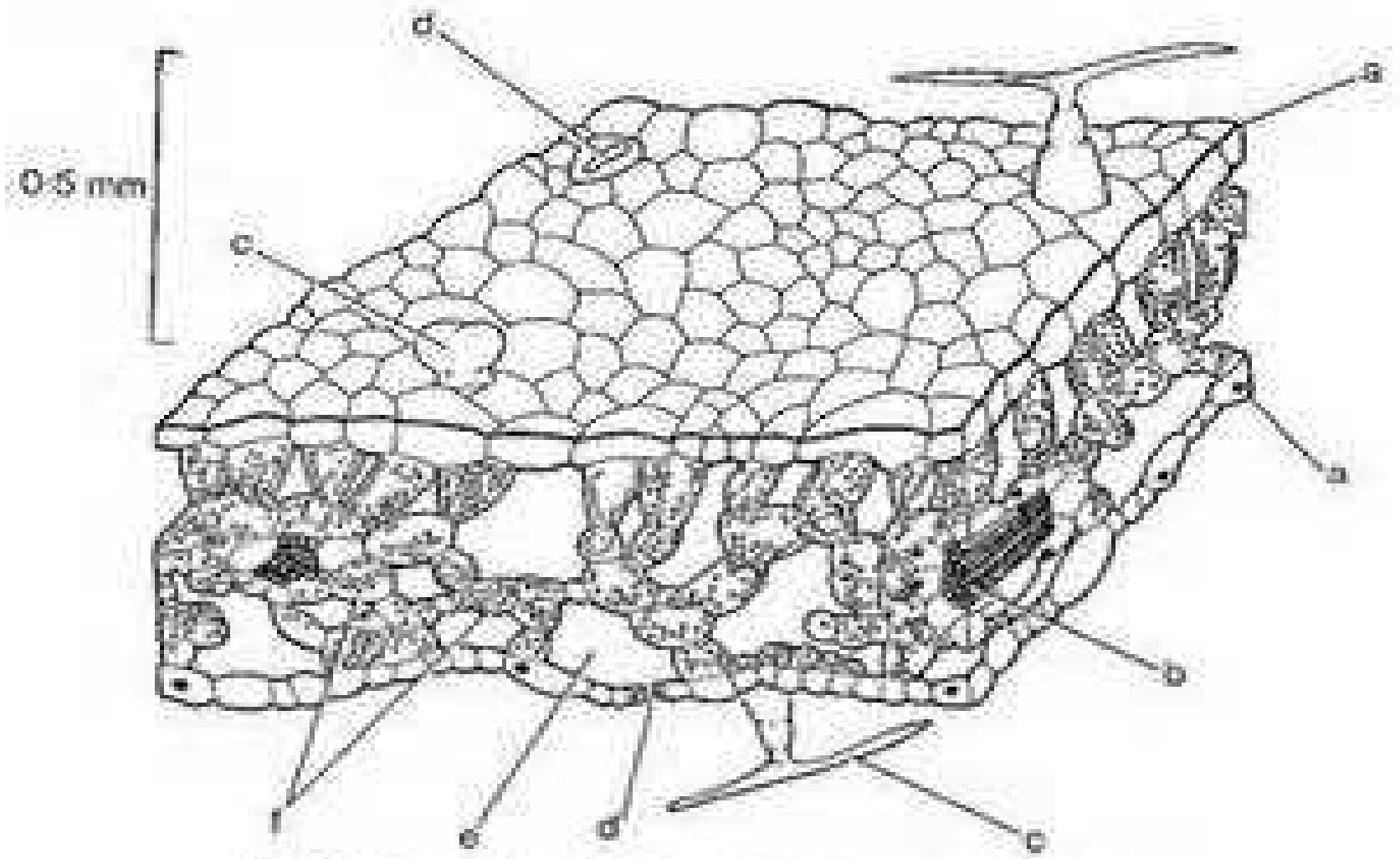
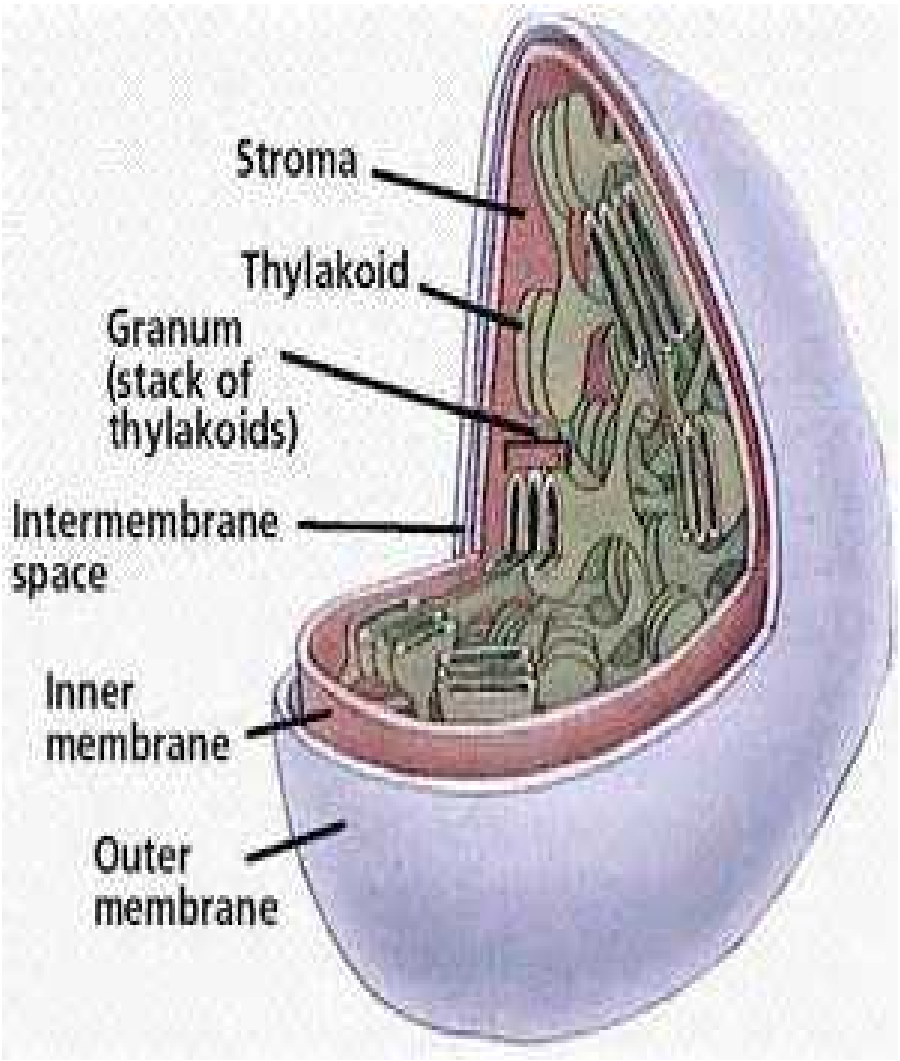
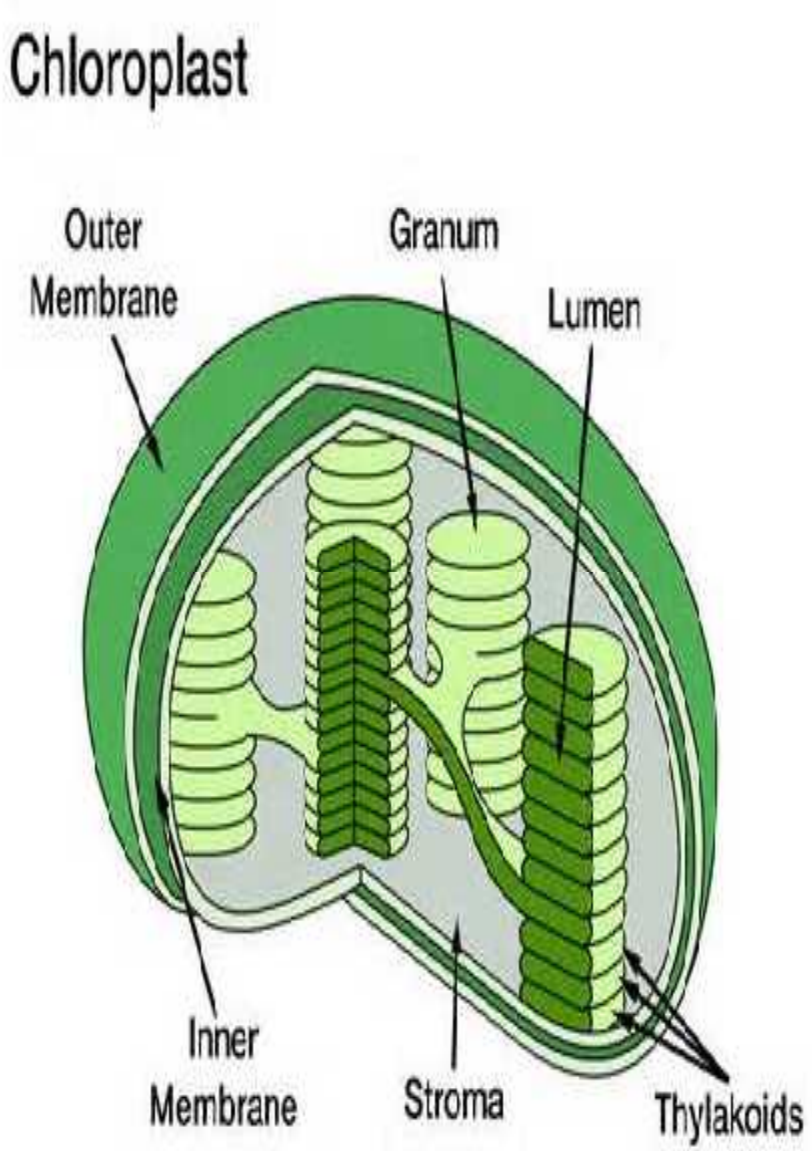


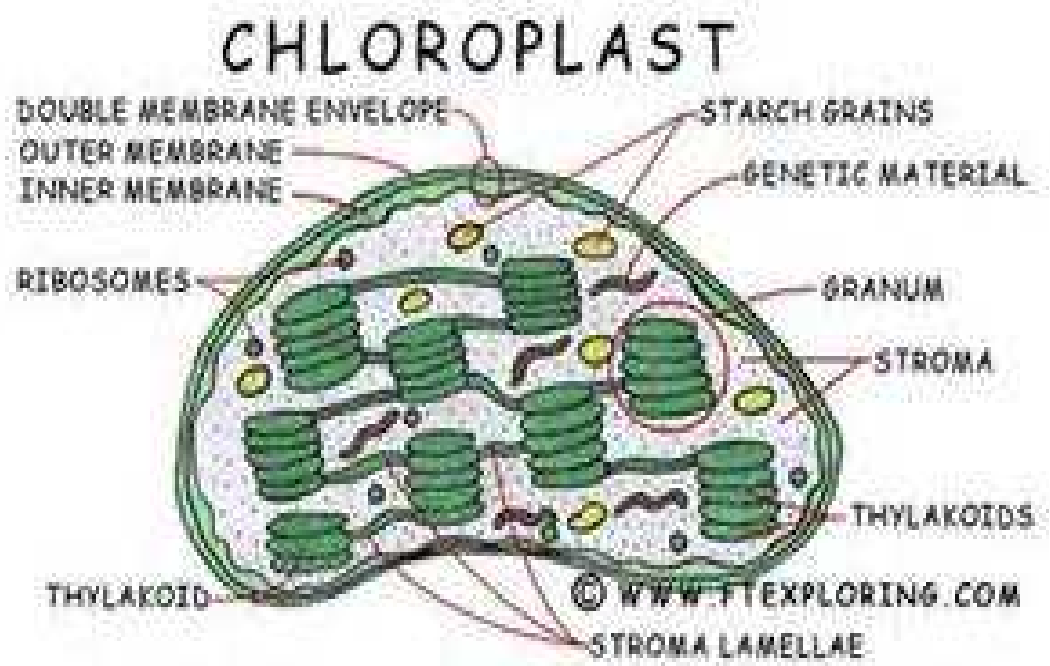
Fig. 1.4. A cross-section of a chrysanthemum leaf. a = cuticle; b = epidermis composed of transport tissue; c = surface hairs; d = stomata; e = air spaces; f = photosynthesising cells containing chloroplasts

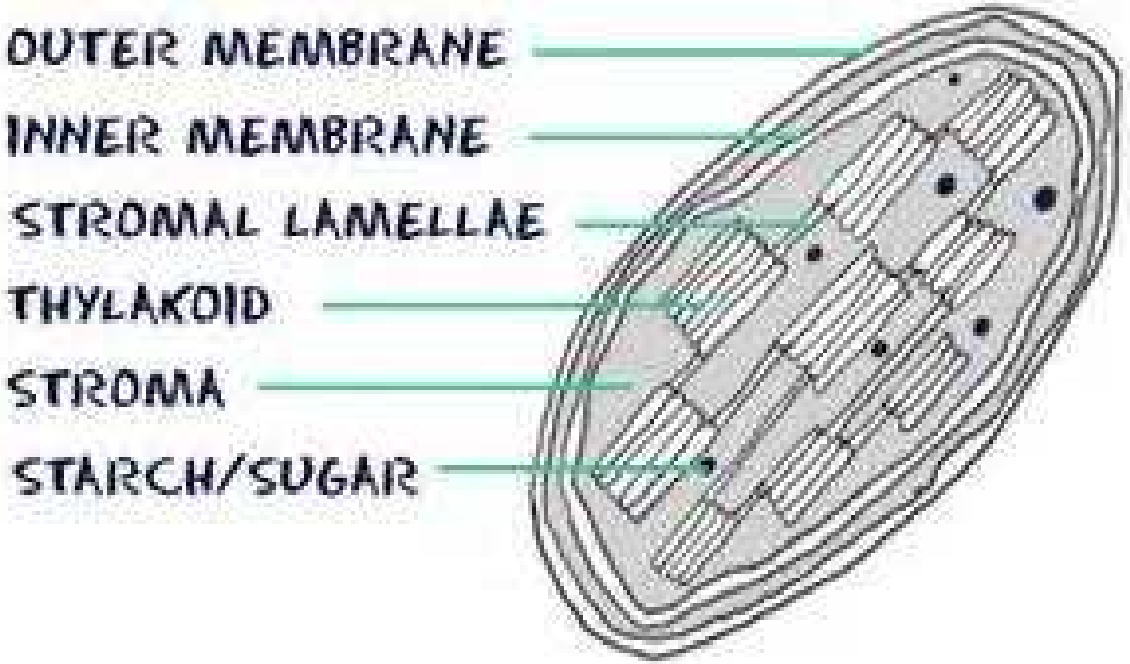
- **Stroma is the metabolic centre were CO_2 fixation & synthesis of nucleic acids, sugars, starch, fatty acids & proteins take place.**
- **Contains lamellar membrane system, ribosomes, circular DNA, mRNA, tRNA, starch grains, lipid globules, enzymes for DNA duplication, transcription, translation & dark reactions of photosynthesis.**
- **Algal chloroplasts contain pyrenoids in association with starch grains.**
- **Pyrenoids contain active enzyme – ribulose biphosphate carboxylase.**


Stroma
Thylakoid
Granum
(stack of
thylakoids)
Intermembrane
space
Inner
membrane
Outer
membrane


Chloroplast
Outer
Membrane
Granum
Lumen
Inner
Membrane
Stroma
Thylakoids

- **Extensive stromal membrane is called thylakoid system.**
- **Chlorophyll molecules & light absorbing pigments are embedded in it.**
- **It consists of several cylindrical discs – grana.**
- **Each granum – a parallel stack or pile of 5 to 50 flat, closed pigmented sacs called thylakoids.**
- **Adjacent grana connected together by tubular membranes – fret membranes.**
- **Unstacked thylakoids also present in stroma – called stromal thylakoids.**

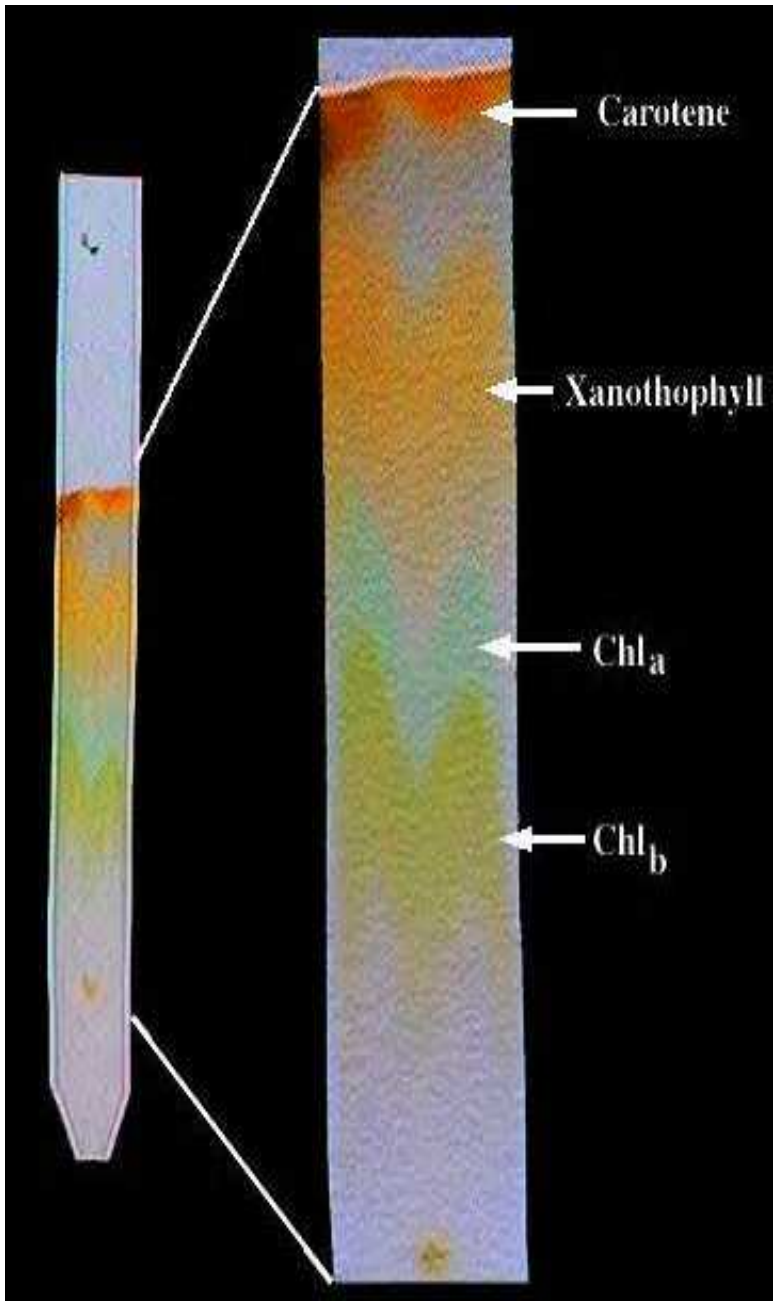

CHLOROPLAST
DOUBLE MEMBRANE ENVELOPE
OUTER MEMBRANE
INNER MEMBRANE
RIBOSOMES
THYLAKOID
STARCH GRAINS
GENETIC MATERIAL
GRANUM
STROMA
THYLAKOIDS
© WWW.FTEXPLORING.COM
STROMA LAMELLAE


OUTER MEMBRANE
INNER MEMBRANE
STROMAL LAMELLAE
THYLAKOID
STROMA
STARCH/SUGAR

- **Number of thylakoids in granum vary in different plant groups.**
- **Thylakoids have lipoprotein composition & laminar organization.**
- **They are store houses of photosynthetic pigments & enzymes of photosynthesis.**
- **Membranes contain photochemically inactive light harvesting complex proteins (LHCP).**
- **Electron carriers – cytochrome-b, cytochrome-f, plastoquinone & plastocyanin.**

PHOTOSYNTHETIC PIGMENTS

- These are light sensitive pigments located in thylakoid membranes.
- Can absorb light energy & convert it into chemical energy.
- From visible spectrum of solar radiation, each pigment absorbs light rays of specific wave length.
- Photosynthetic pigments - two major groups – principal pigments & acessory pigments.
- Principal pigments – chlorophyll-a.
- Acessory pigments –chlorophyll-b & carotenoids.


Carotene
Xanothophyll
Chl a
Chl b



CHLOROPHYLLS

Green pigments containing Magnesium.

Chief pigment required for photosynthesis.

Different kinds of chlorophyll – chl-a, chl-b, chl-c, chl-d, chl-e, bacterio chlorophyll & chlorobium chlorophyll.

Chl-a & chl-b are the most abundant types of photosynthetic pigments.

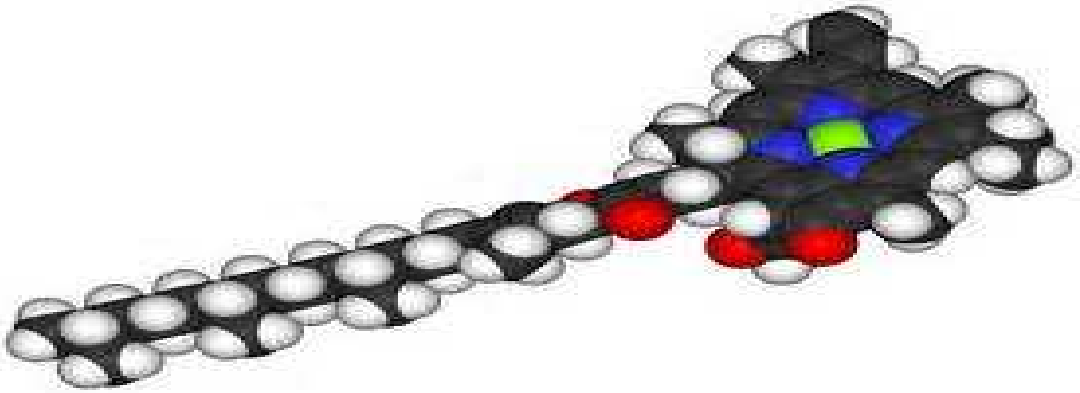
In plants photochemical reaction occurs only in chl-a.

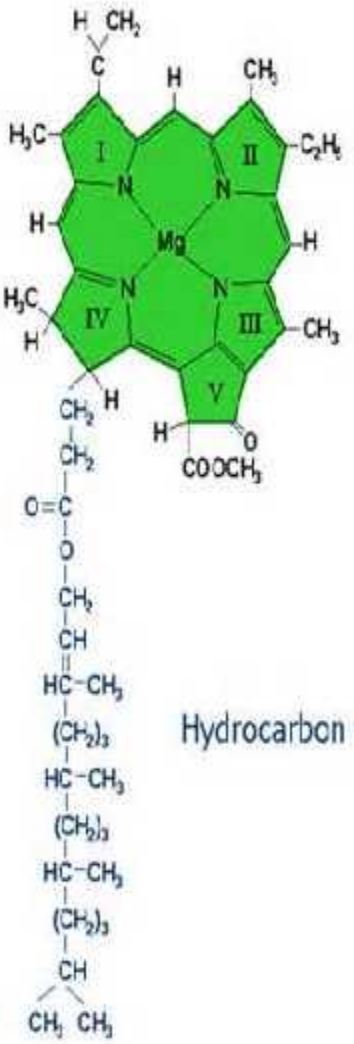
Chlorophylls can absorb blue, violet & red light & reflect green light – so they appear green.

Photosynthetic activity maximum in red light.

Chlorophylls are Magnesium-porphyrin derivatives.

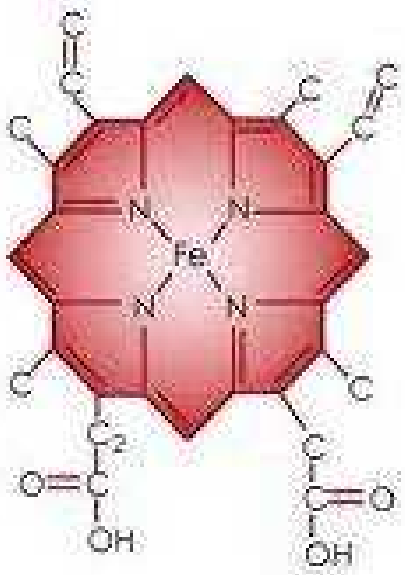
- **A chlorophyll molecule consists of a pyrole head & a phytol tail.**
- **Head is hydrophobic & tail is hydrophilic.**
- **Head is formed of four pyrole molecules- linked together by methane groups.**
- **It forms a tetrapyrole ring or porphyrin ring.**
- **Centre of the ring is the Magnesium atom.**
- **Mg - linked to pyrol ring by 2 covalent bonds & 2 co-ordinate bonds.**
- **Tail - long hydrocarbon chain.**
- **Side groups linked to ring varies in different chlorophylls.**



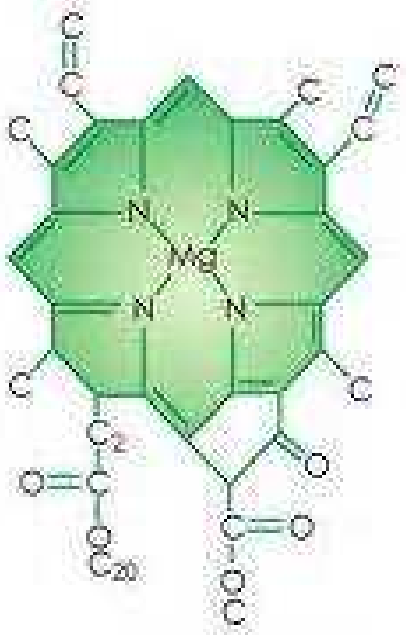


Porphyrin-like ring structure

Hydrocarbon tail



Human Blood Hemoglobin



Plant Chlorophyll

- **Nature of side groups determines properties of pigments.**
- **Side group of chlorophyll-a - methane group.**
- **Side group of chlorophyll-b - aldehyde group.**
- **Chl-a is bluish green & chl-b is olive green.**
- **Emperical formula –**

  Chl-a – $C_{55}H_{72}O_5N_4Mg$.

  Chl-b – $C_{55}H_{70}O_6N_4Mg$.
- **Varieties of Chlorophyll include –**

Chl-a 673, Chl-a 683, P680, P700, etc.

CAROTENOIDS

- Fat soluble yellow, orange, brown or red pigments present in all photosynthetic plants.
- Along with anthocyanins, carotenoids impart autumn colours to leaves.
- Found in some flowers & fruits like carrot, tomato, pumpkin, etc.
- Carotenoids are accessory photosynthetic pigments.
- Absorb blue-violet range of visible spectrum.
- Transfer light energy to chlorophyll for photosynthesis.
- Protect chl. molecules from photo oxidation.

- **Carotenoids – 2 groups - Carotenes ($C_{40}H_{56}$)**
  - Xanthophylls ($C_{40}H_{56}O_2$)
- **Carotenes – red/orange – hydrocarbons (terpenes).**
- **Xanthophylls – brown/yellow – oxygenated hydrocarbons.**
- **Commonest carotenes – carotenes, phytotene, lycopene, neurosporine, etc.**
- **Hydrolysis of beta-carotene yields vitamin-A.**
- **Xanthophylls more abundant than carotenes.**
- **Differ from carotenes in having Oxygen.**

- **Major xanthophylls – lutein, violaxanthin, zeaxanthin, neoxanthein.**
- **Diatoms & brown algae have fucoxanthin.**
- **Lutein gives yellow colour to autumn leaves.**
- **Carotenoids significant in 2 ways –**

  *** absorb solar energy & transmit to neighbouring pigment molecules.**

  *** protect chlorophyll molecules from photooxidation.**

PHYCOBILINS

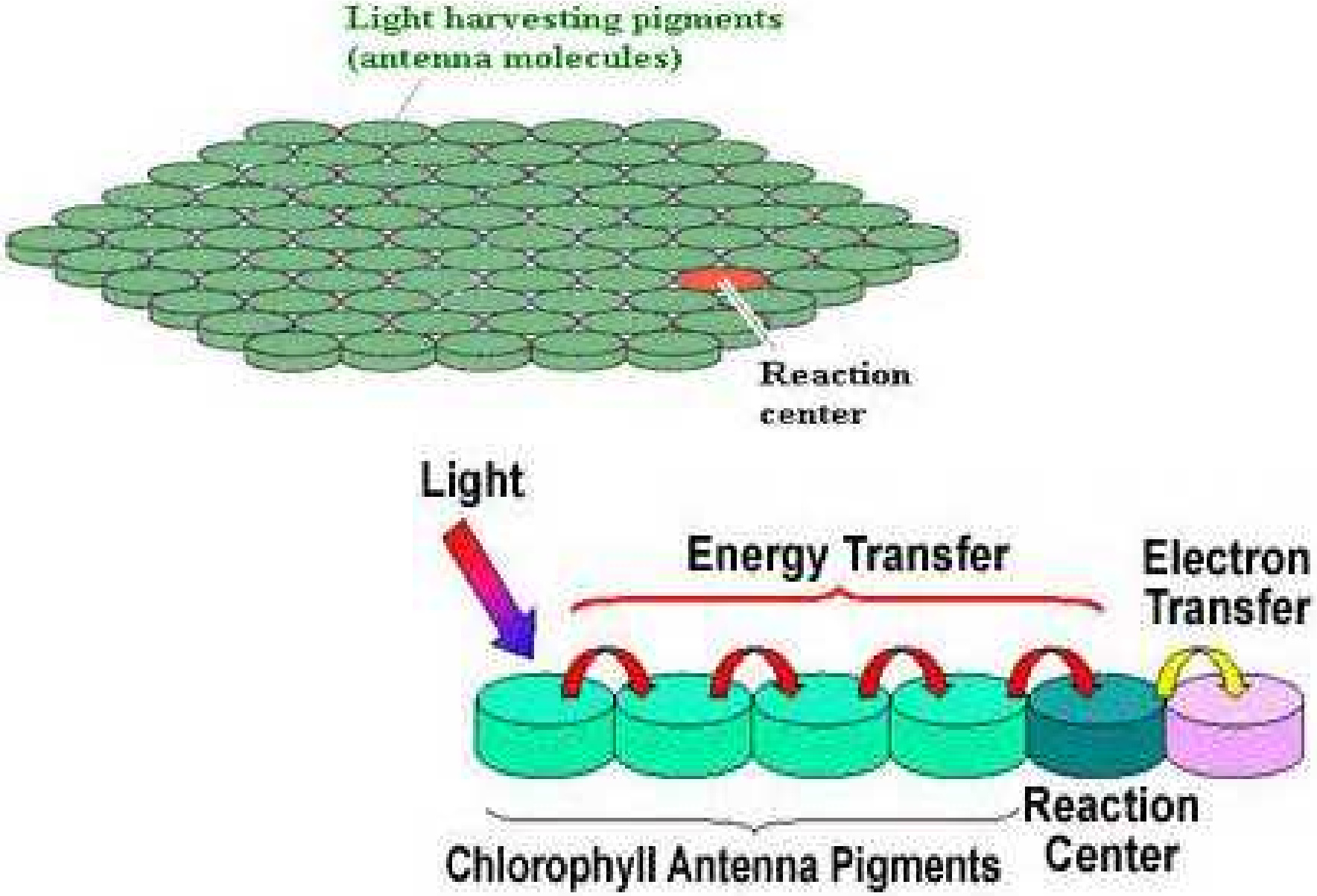
- Red or blue accessory photosynthetic pigments found in cyanobacteria & red algae.
- Differ from chlorophyll & carotenoids – in being water soluble.
- Similar to porphyrin part of chlorophylls – except that Mg is absent & tetrapyroles are linear rather than cyclic.
- Two major groups of phycobilins – phycoerythrin & phycocyanin.
- Phycoerythrin – red, absorb dim & blue green light that reach ocean depths.

- **Phycobilins enable algae to live in deep waters.**
- **Phycocyanins are blue coloured – absorb orange & red light.**

PHOTOSYSTEMS & PHOTOSYNTHETIC UNITS

TWO PIGMET SYSTEMS

- **Light absorbing photosynthetic pigments are arranged on thylakoid membranes of chloroplasts in two complex pigment systems or photosystems – photosystem I & II (PS I & PS II).**
- **Each system – thousands of photosythetic units (PSU) - quantosomes.**


Light harvesting pigments
(antenna molecules)
Reaction
center
Light
Energy Transfer
Electron
Transfer
Reaction
Center
Chlorophyll Antenna Pigments

- **Quantosomes – light-harvesting photosynthetic units – capable of carrying out photochemical reactions.**
- **Green plants – each quantosome consists of 200-400 chlorophyll molecules & many accessory pigment molecules.**
- **Pigment system can absorb all wave lengths of visible spectrum, those between 400 to 500nm & 600 to 700nm.**
- **Each functional unit has a photochemical reaction centre or photocentre – serves as energy trap for collection & conversion of light energy – so called 'trap centre'.**

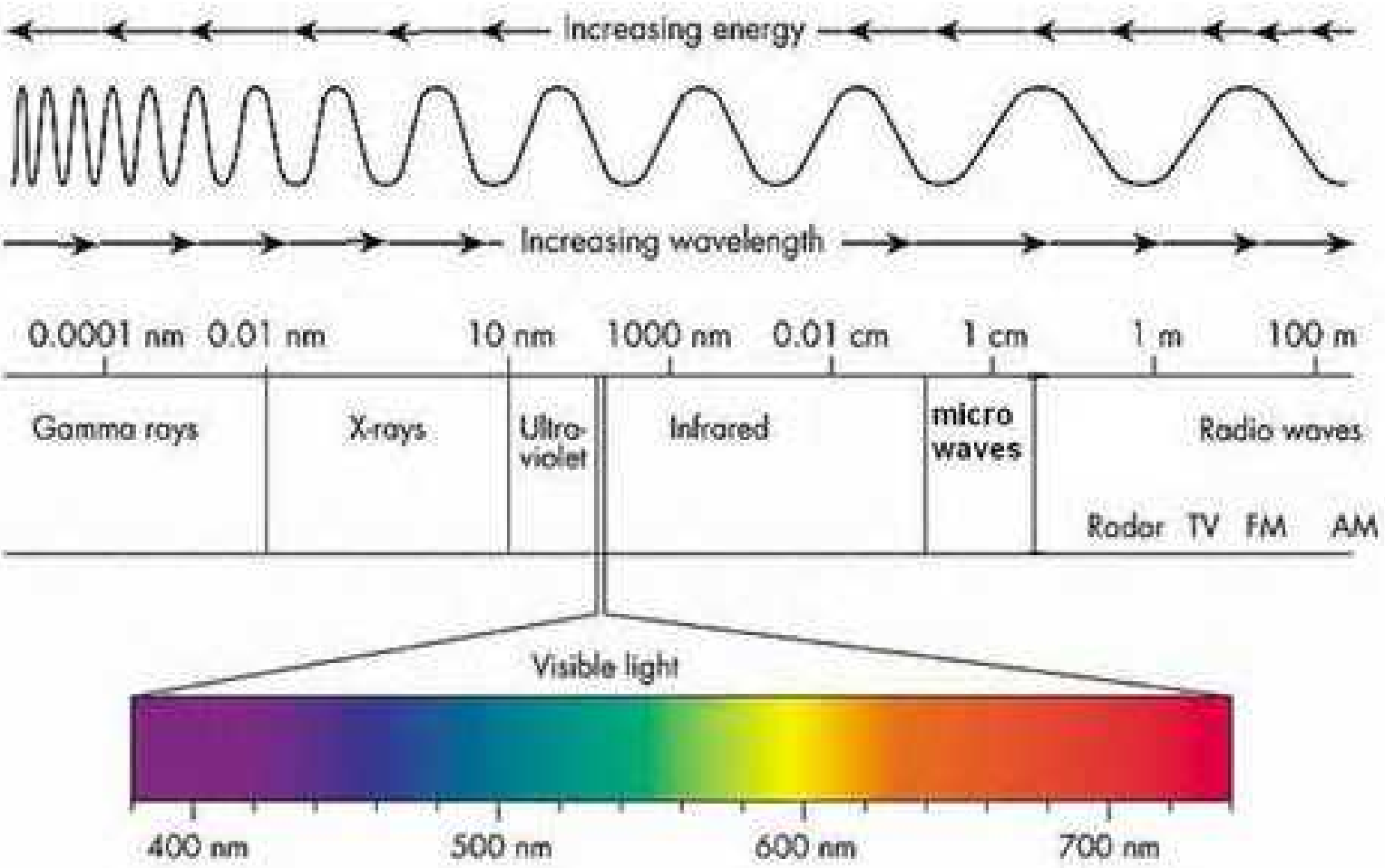
- **It is formed of special Chl-a molecule, bound to a protein complex.**
- **Reaction centre is surrounded by several hundred pigment molecules.**
- **They form a light gathering system to absorb photons.**
- **Also called light-harvesting molecules.**
- **Include chl-a, chl-b, & accessory pigments.**
- **Light harvesting pigment molecules – of two groups – core molecules & antenna molecules.**

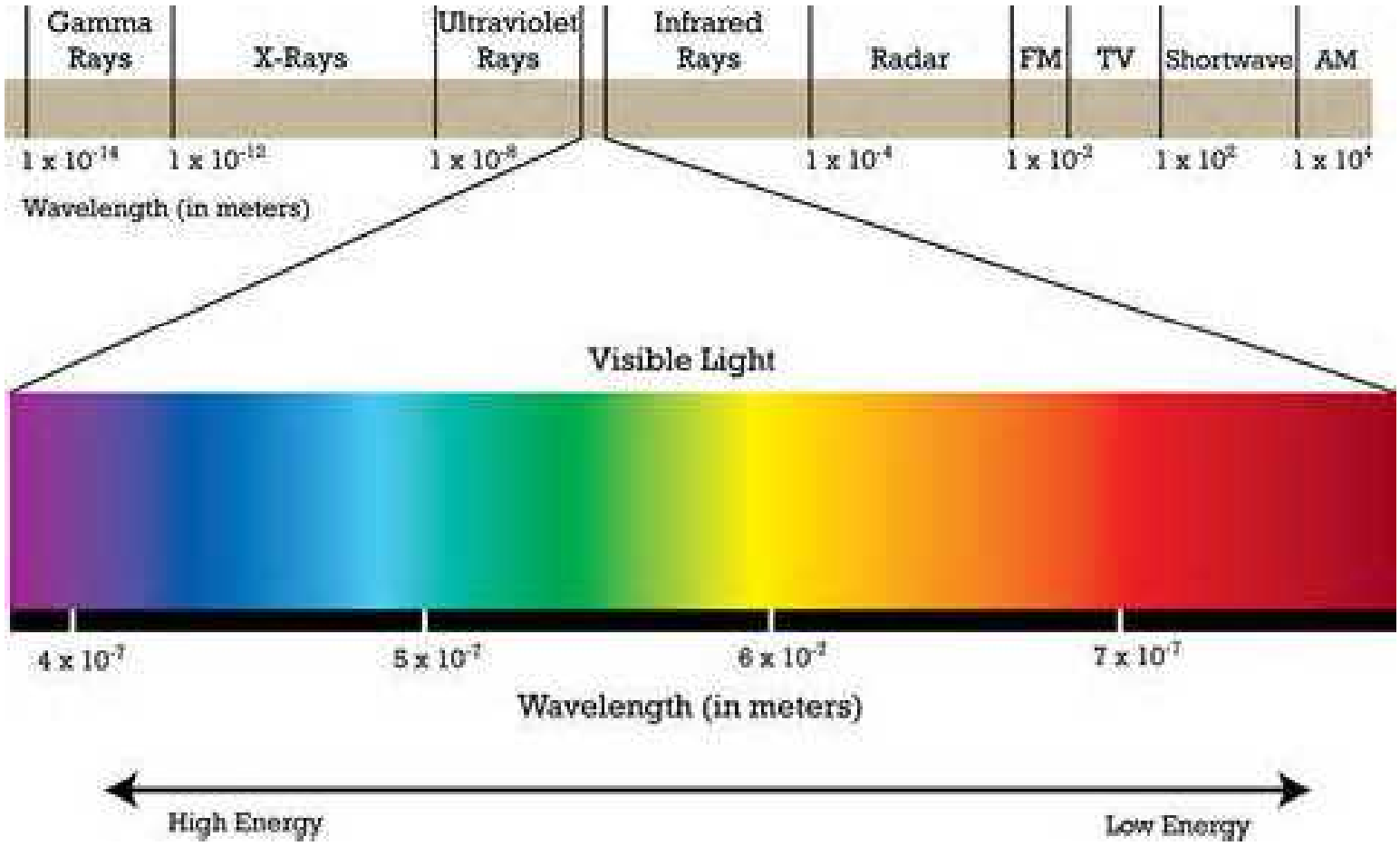
- **Core molecules are located immediately around the reaction centre.**
- **Antenna molecules – lie around core molecules.**
- **Core molecules – consists of 20-30 chlorophyll molecules.**
- **Antenna molecules – 200-300 chlorophyll molecules & varying number of carotenoid molecules.**
- **Antenna molecules of each photosystem absorb light energy – get excited – transfer excitation energy – to reaction centre – by resonance transfer.**

- **Efficiency of resonance transfer – depends on distance between the pigment molecules & their orientation to each other.**
- **More close the orientation - the more efficient will be the power of energy transfer.**
- **In the photosystems – pigment molecules are closely & orderly arranged.**
- **Enables each molecule to absorb photon energy & then pass on to next molecule & finally to reaction centre – in a chain transfer mechanism.**

SOLAR SPECTRUM – ELECTROMAGNETIC RADIATION – RADIENT ENERGY

- **Photosynthesis – possible only with help of light – chief source of light – sun.**
- **Solar radiations are electromagnetic in character – electromagnetic radiations**
- **Different radiations emitted from sun – form a spectrum – emission spectrum – solar spectrum – electromagnetic spectrum.**
- **A part of it consists of visible light – visible spectrum.**


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
micro waves
Radio waves
Radar TV FM AM
Visible light
400 nm
500 nm
600 nm
700 nm


Gamma Rays
X-Rays
Ultraviolet Rays
Infrared Rays
Radar
FM
TV
Shortwave
AM
1 x 10^-14
1 x 10^-12
1 x 10^-8
1 x 10^-4
1 x 10^-2
1 x 10^2
1 x 10^4
Wavelength (in meters)
Visible Light
4 x 10^-7
5 x 10^-7
6 x 10^-7
7 x 10^-7
Wavelength (in meters)
High Energy
Low Energy

- **Other parts include – Xrays, gamma rays, cosmic rays, UV rays, IR rays & radio waves – in the order of increasing wave length.**
- **Visible spectrum – located between UV & IR radiations.**
- **Visible region – wave length ranges between 390 & 760 nm.**
- **It is a combination of seven different radiations – VIBGYOR.**
- **They exist in the order of increasing wave length.**
- **Violet has shortest & red has longest wave length.**

- **Portion of spectrum between 400nm & 700nm – very important in photosynthesis - referred to as photosynthetically active radiation.**
- **Wave lengths which reach earth's surface from sun ranges from 300nm in the UV to 2600 nm in the IR zone.**
- **Half of solar energy reaching earth surface is in visible IR region.**
- **Visible spectrum – source of energy for photosynthesis.**
- **Hence plants not able to carry out photosynthesis in dark.**

- **Light – travels as waves of tiny particles or energy packets called photons.**
- **Speed of light rays – 3lakh km per second.**
- **Energy contained in a photon is called – quantum.**
- **Quantum is inversely proportional to wave length.**
- **Photons/ quanta required for photosynthetic production of one molecule O2 – quantum requirement.**

- **No. of chlorophyll molecules – involved in absorption of one quantum of light energy – constitute a photosynthetic unit – quantosome - 200 to 400 molecules in green plants.**
- **Each pigment absorbs only specific wave lengths of light & reflects others.**
- **Beam of light falling on a green leaf excites chlorophyll – photoexcitation or photochemical excitation.**
- **Very quick & takes only 10 to 15 secs.**
- **Excited state is very short – lasting for 10-8 secs.**
- **This short duration enough to chemically trap light energy.**

- **Normal unexcited state of chlorophyll molecule is called ground state.**
- **Gets excited hen photon collides – activated state – excited state.**
- **Outer valence electron of chlorophyll molecule – gets pushed to higher energy state – by absorbing energy.**
- **Excited state is unstable & short living.**
- **Excited molecule returns to its ground state.**
- **Return causes release of extra energy – in the form of radiation – flurescence.**

SIGNIFICANCE OF PHOTOSYNTHESIS

- **Photosynthesis is an extremely significant biological phenomenon.**
- **Transformed the anaerobic reducing atmosphere to the present day aerobic oxidising one.**
- **Only biological process that releases molecular O2 for all aerobic organisms.**
- **This O2 caused evolution of aerobic respiration & emergence of aerobic heterotrophs.**
- **Serves as a source of energy & carbon for all organisms.**

- **Plays a significant role in the purification of atmospheric air by removing CO2.**
- **Brings about energy fixation & initiates dynamics of ecosystems.**
- **Builds up O2 in the atmosphere for aerobic organisms.**
- **Provides O2 for the formation & maintenance of stratospheric ozone layer.**
- **Ozone layer protects biosphere from incoming harmful solar & cosmic radiations.**
- **Maintains constant level of O2 & CO2.**

- **Serves as link between plants & animals – supplies O2 for animals – in return gets CO2.**
- **Fossil fuels – coal, petroleum & natural gas are photosynthetic products.**

MECHANISM OF PHOTOSYNTHESIS

- **Most fundamental process in nature.**
- **All life on earth depends on this process directly or indirectly.**
- **Light energy is converted into chemical energy.**
- **Water & CO2 incorporated into organic compounds - CO2 assimilation.**

- **During photosynthesis – green plants synthesize carbohydrates using CO_2 and water in the presence of sunlight & releases O_2.**
- **Overall process represented as –**

$$6CO_2 + 12\,H_2O \xrightarrow[Chl]{LE} C_6H_{12}O_6 + 6H_2o + 6O_2.$$

- **Complex redox reaction – H_2O gets oxidised & CO_2 gets reduced – producing sugar & releasing O_2.**
- **Consists of two sets of reactions – light & dark.**

- **Light reaction – light dependant - photochemical reaction.**
- **Dark reaction – light independant - thermochemical reaction.**
- **Light reaction – light energy is trapped – used for synthesis of ATP & NADPH.**
- **Dark reaction – products of light reaction used for fixation of CO_2.**
- **In dark reaction CO_2 is reduced to sugar – using reducing power of NADPH & ATP.**

LIGHT REACTION

- Photochemical reaction – photophase reaction – Hill reaction (Robert Hill, 1937).
- Light dependant first phase of photosynthesis.
- Occurs in the thyllakoid membranes of chloroplast.
- Photosynthetic pigment absorbs light energy for
  - photolysis of water
  - phosphorylation of ADP
  - reduction of NADP
- Photolysis of water releases O2, electrons & protons.

- **Phosphorylation of ADP produces ATP**
- **Reduction of NADP produces NADPH.**
- **ATP & NADPH serve as substrates of dark reaction for synthesizing sugar.**
- **Light reaction involves four major events –**
  - **photochemical excitation of chlorophyll.**
  - **photophosphorylation of ADP to form ATP.**
  - **photolysis/photooxidation of water.**
    (oxidative splitting of water).
  - **photoreduction of NADP to NADPH + H+.**

PHOTOEXCITATION OF CHLOROPHYLL

- Light reaction begins with excitation of photosynthetic pigments.
- First step – absorption of light (photons) – by antenna molecules of photosystems.
- Each molecule gets excited / transformed to a high energy state.
- Excitation unstable & extremely short living.
- Soon pigment molecules return to ground state.
- Leads to transfer of excitation energy to next molecule.

- **E energy reaches chlorophyll-a molecules of photocentre through a chain transfer process.**
- **Energy of excitation is transferred from one pigment molecule to another by resonance transfer.**
- **Resonance transfer of energy – sensitised fluorescence.**
- **Becomes efficient when pigment molecules of photosystems are very close to each other.**
- **Chl-a molecule of photocentre gets excited.**
- **An electron of one of its atoms takes up the extra energy & transforms to high energy state.**

- **Pigment molecule returns to low energy state by emitting the high energy electron from it.**
- **Chl-a molecule gets oxidised by losing electron.**

  Chl-a (reduced) .....> Chl-a (oxidised) + e- (energised electron).
- **High energy electron emitted from the reaction centre – accepted by a primary electron acceptor.**
- **Reduction of primary electron acceptor brings about conversion of light energy to chemical energy.**

- **Primary electron acceptor of Pigment system I is Phaeophytin - a colourless Mg – lacking Chl-a.**
- **From reduced primary acceptor electron travels 'down hill' from one acceptor to another.**
- **Results in a series of oxidation-reduction reactions.**
- **These redox reactions are linked to phosphorylation reactions to synthesize ATP.**

ELECTRON TRANSPORT & OXIDATIVE PHOTOPHOSPHORYLATION

- Pigment systems PS-I & PS-II differ from each other with regard to electron affinity.
- PS-I has lesser affinity for electrons than PS –II.
- When PSs are excited simultaneously with photons, ejection of electron occurs first from PS-I.
- Ejected high energy moves down the electron transport chain.
- During this oxidative photophosphorylation production of ATP & reduction of NADP occurs.

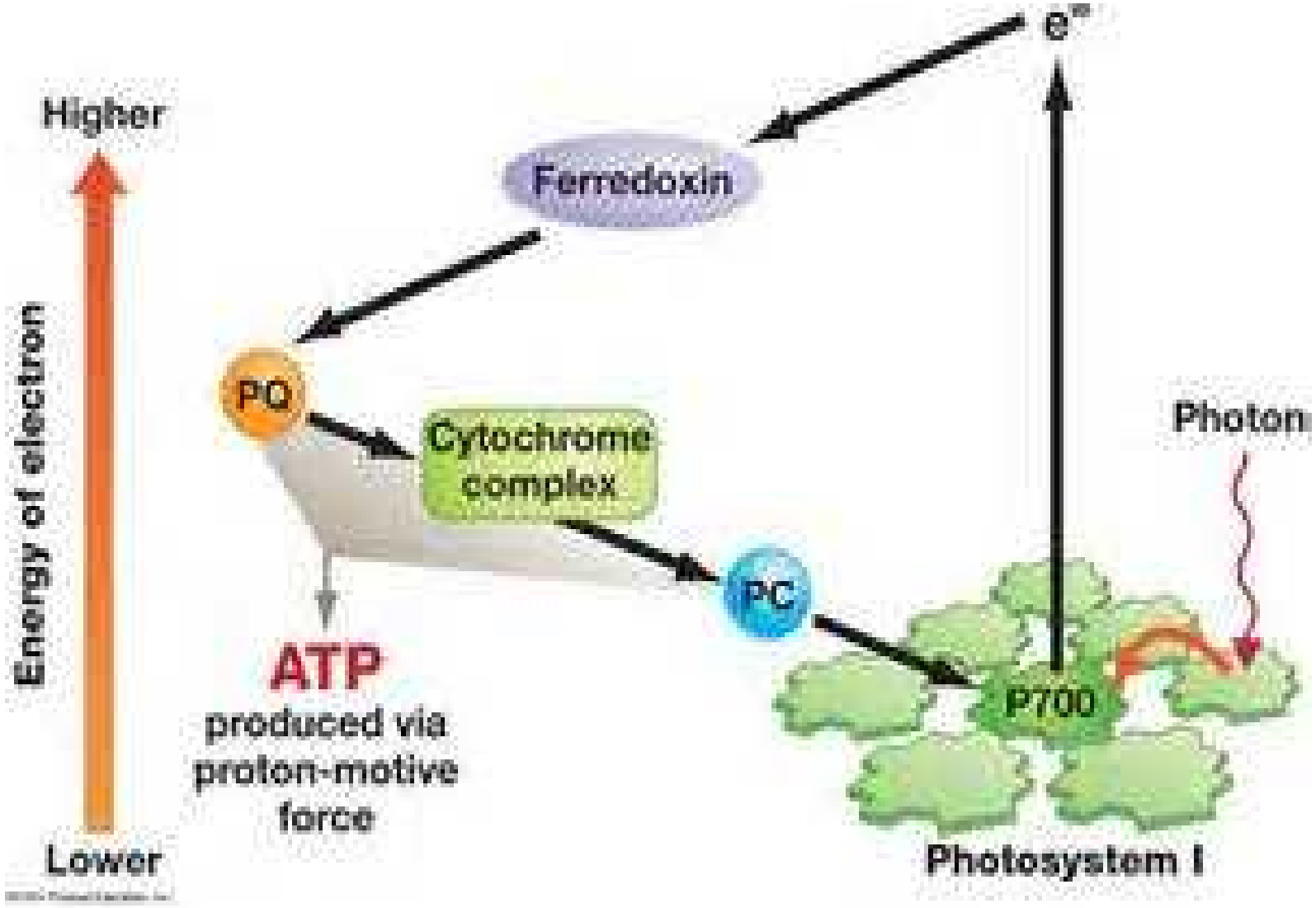
PHOSPHORYLATION OF ADP

- It is the photosynthetic production of ATP from ADP & Pi (inorganic phosphate) using light energy.
- It is completed in two stages – cyclic photophosphorylation & non cyclic photophosphorylation.
- Both these involve transfer of electrons through an electron transport chain (ETC/ETS).
- ETS consists of a series of electron acceptors.
- In cyclic process there is a cyclic flow of electrons

- **In non-cyclic process – no cyclic flow.**
- **Cyclic process involves the functioning of PS I.**
- **Non-cyclic involves both PS I & PS II.**
- **Non-cyclic – water undergoes photolysis & acts as electron donor.**
- **Products of non-cyclic photophosphorylation include ATP,NADPH & O2.**
- **Product of cyclic phosphorylation is only ATP.**

CYCLIC PHOTOPHOSPHORYLATION

- High energy electrons released from P700 of PS I – flow down in a cyclic pathway – a series of redox reactions.
- Electrons move to a primary acceptor (X) & then to ferredoxin (Fd) – an iron containing protein.
- From ferredoxin electrons cycle back to P700 in a step by step manner – through a chain of electron carriers.
- This is called cyclic electron transfer or cyclic electron flow.


Higher
Energy of electron
Lower
e⁻
Ferredoxin
PQ
Cytochrome complex
PC
Photon
P700
ATP
produced via proton-motive force
Photosystem I

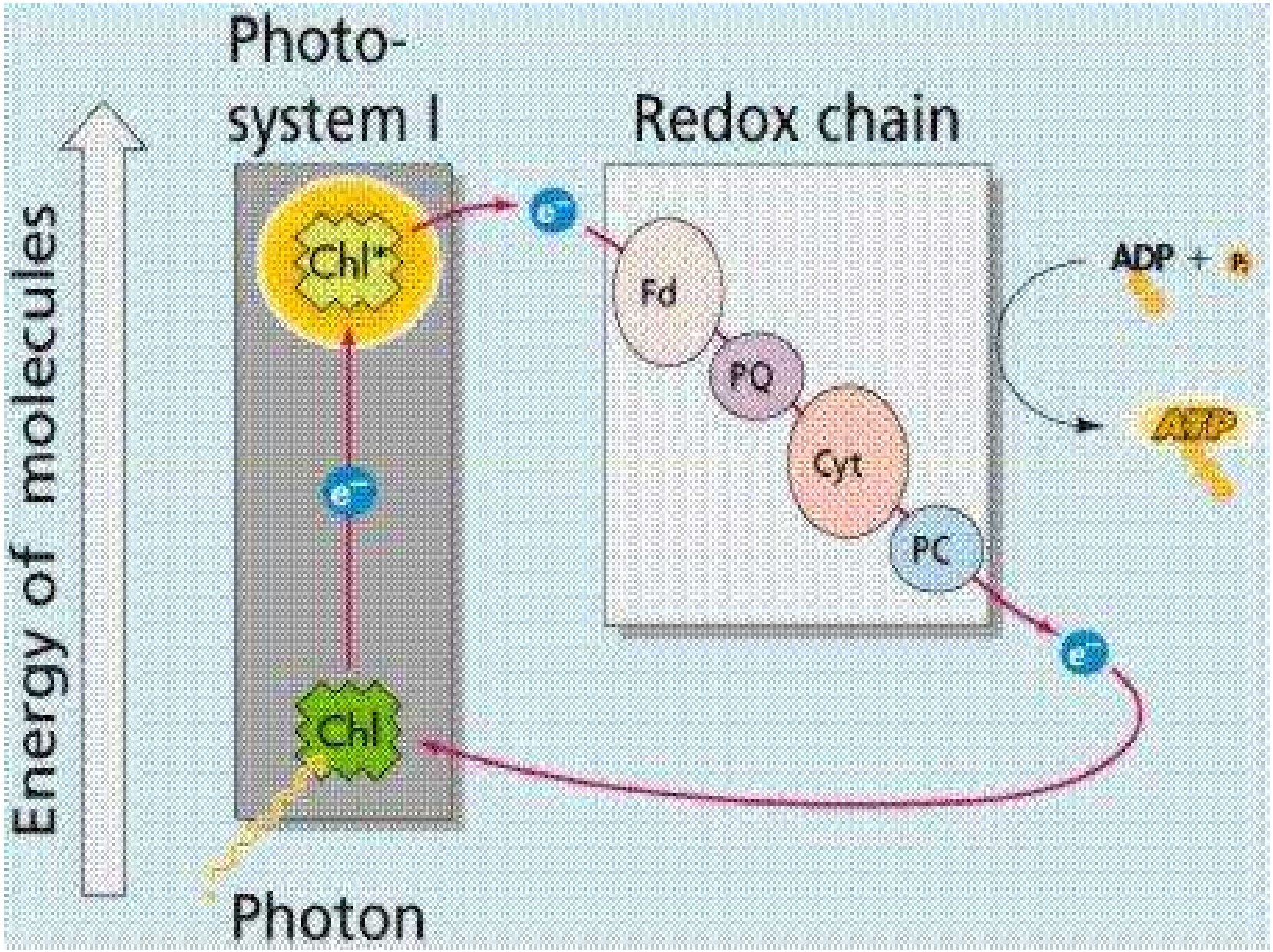
- **Major electron carriers include – cytochrome-b6, plastoquinone, cytochrome-f & plastocyanin.**

  Cytochrome-b6 ---- Cyt-b6

  Plastoquinone ----- PQ (a terpenoid)

  Cytochrome-f -----Cyt-f

  Plastocyanin---PC (a copper containing protein)
- **During this cyclic flow, electrons release energy twice.**
- **ADP molecules capture this energy & undergo phosphorylation – resulting in formation of ATP.**

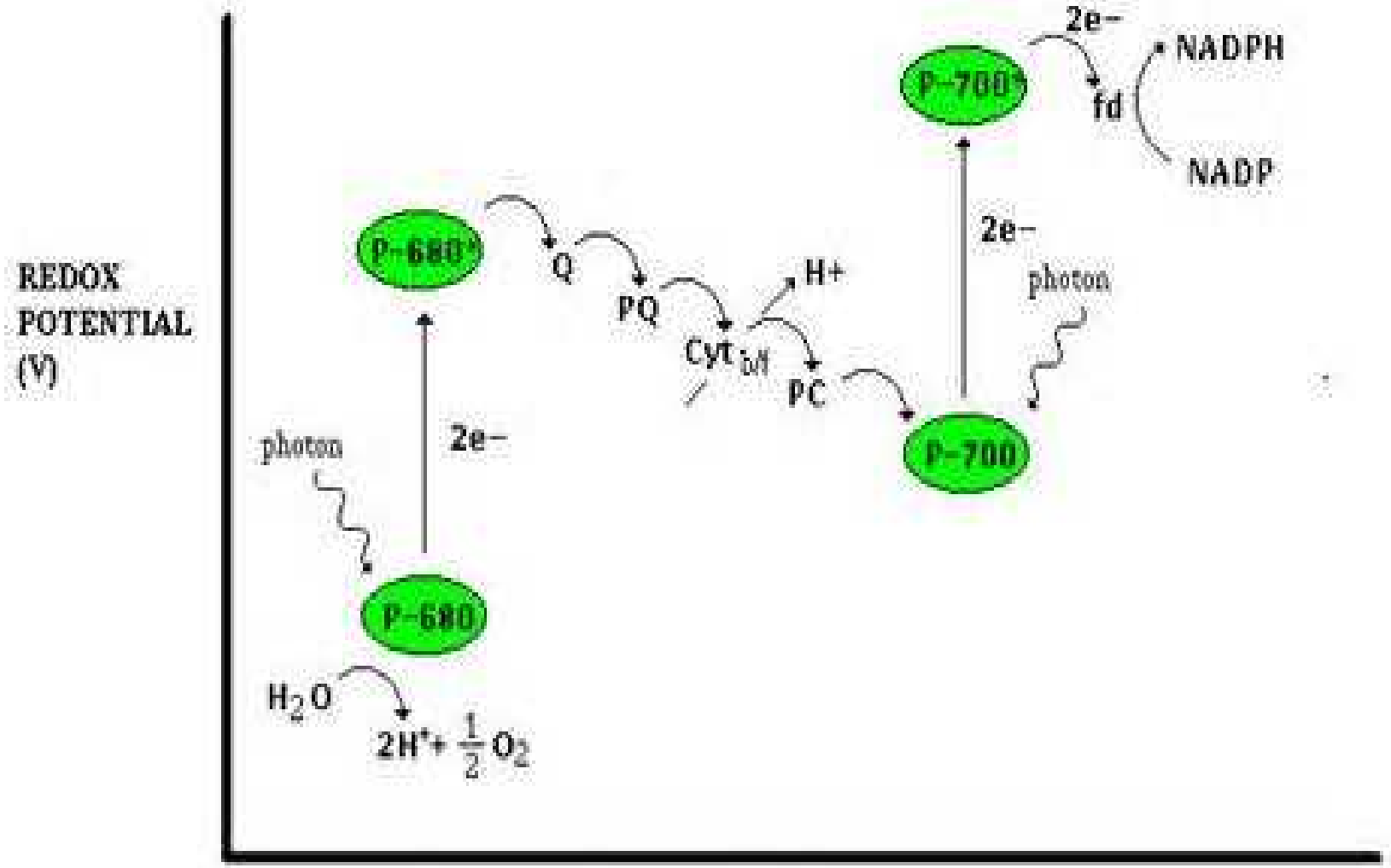

Photo-
system I
Redox chain
Energy of molecules
Chl*
e⁻
Fd
PQ
Cyt
PC
ADP + Pi
ATP
e⁻
Chl
Photon

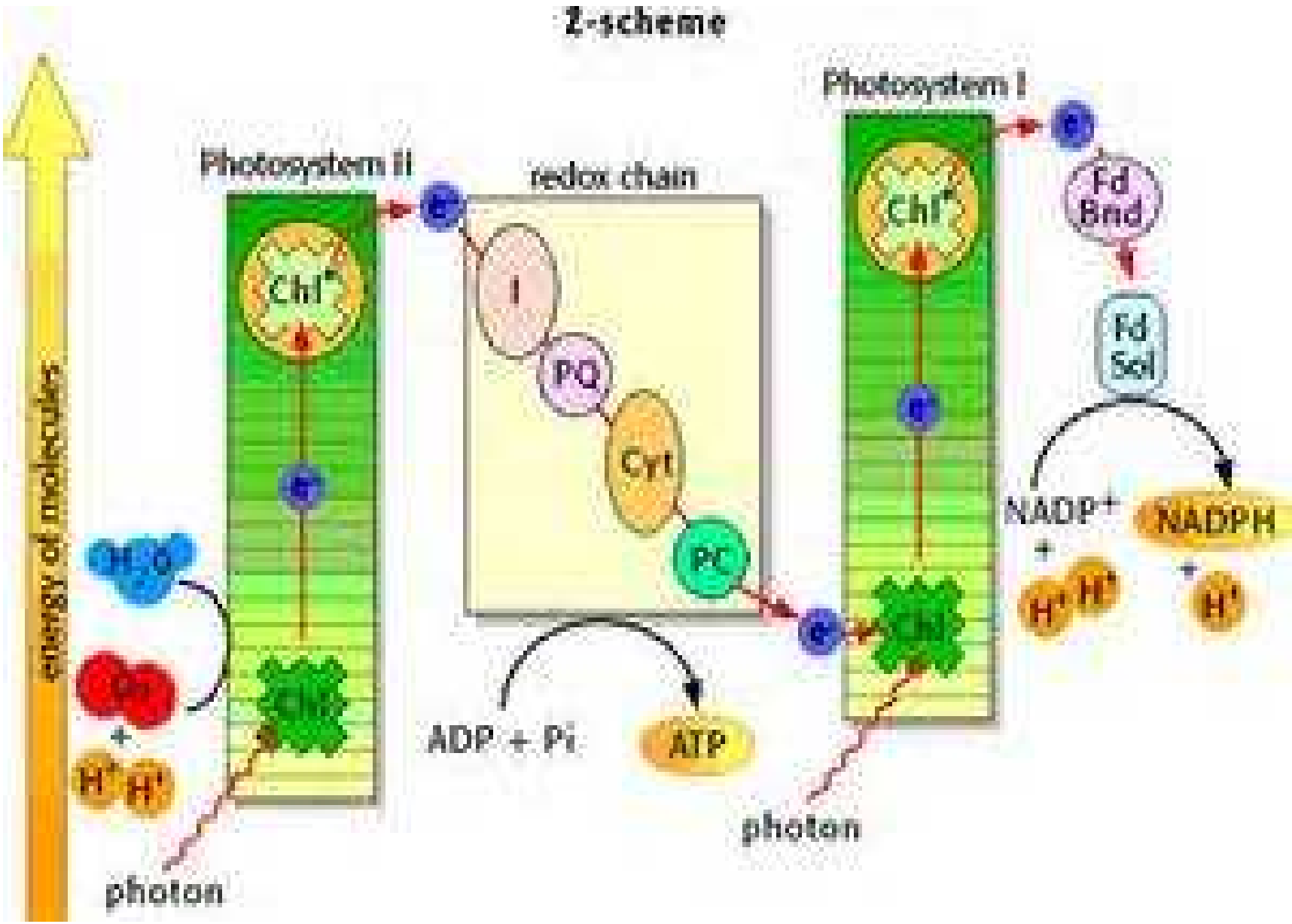
- **This phosphorylation is always coupled with cyclic flow of electrons – cyclic redox reactions – and so called cyclic oxidative photophosphorylation.**
- **After phosphorylation – de-energised electrons return to reaction centre of PS-I to re-energise.**
- **During this the lost electrons are replaced.**

NON-CYCLIC PHOTOPHOSPHORYLATION

- **Initiated by light falling on PS-II or P-680.**
- **High energy electrons flow down non-cyclically from PS-II to PS-I.**
- **Results in a series of redox reactions & subsequent production of ATP.**
- **Pathway also called Z-pathway – due to its shape.**
- **Energised electrons from P-680 of PS-II accepted by primary electron acceptor P.**

NONCYCLIC PHOTOPHOSPHORYLATION




Z-scheme
Photosystem II
redox chain
Photosystem I
energy of molecules
Chl*
e⁻
I
PQ
Cyt
PC
Fd
Bnd
Fd
Sol
NADP+
+
NADPH
+
H+ H+
H+
H2O
+
H+ H+
ADP + Pi
ATP
photon
photon

- **From this reduced acceptor, electrons are shuttled to P-700 of PS-I through a chain of electron carriers.**
- **This is called non-cyclic electron transfer or non-cyclic electron flow.**
- **Major electron carriers between PS-II & PS-I include Plastoquinone(PQ), Cytochrome-b6, Cytochrome-f & Plastocyanin (PC).**
- **During non-cyclic flow, electrons release energy only once & this energy is trapped by ADP for production of ATP (phosphorylation).**

- **Since phosphorylation occurs during a non-cyclic electron flow, it is called non-cyclic photophosphorylation.**
- **De-energised electrons - transferred to P-700.**
- **From P-700, electrons move in pairs non-cyclically to NADP through a primary acceptor X & ferridoxin.**
- **Each NADP molecule accepts a pair of electrons.**
- **Two protons also enter it that reduces NADP to NADPH +H – balancing negativity of electrons.**

- **Reduction of NADP to NADPH using photon energy is called photoreduction of NADP.**
- **NADPH would be used in the dark reaction for fixation of CO2.**

$$NADP^+ + 2e^- + 2H^+ \longrightarrow NADPH + H^+$$

- **Electrons & protons required for photo-reduction of NADP are obtained by photolysis of water.**
- **Electrons are supplied through PS-II & protons are available directly.**
- **Non-cyclic electron transport supplies assimilatory power in the form of NADPH in addition of ATP for CO2 assimilation.**

PHOTOLYSIS OF WATER

- **Photolysis or photo-oxidation of water & the evolution of O2 – are associated with non-cyclic electron transport.**
- **Flow of electrons from PS-II causes electron deficiency in P680 – electron gap / electron hole.**
- **Deficiency is soon made up by electrons released by photolysis of water.**
- **Photolysis is the light dependant oxidation – photo-oxidation of water.**
- **It releases electrons, protons & molecular O2.**

$H_2O \rightarrow H^+ + OH^-$

$OH^- \rightarrow 1/2O_2 + H^+ + 2e^-$

$H_2O \rightarrow 2H^+ + 2e^- + 1/2O_2$

- Electrons released by photolysis of water are first carried to P680 by a carrier system – Mn protein system.
- From P680 to P700 through electron transporting chain.
- In P700 they get boosted to high-energy level by illumination.
- From there they move to NADP through a second electron transport chain.

DARK REACTION

BLACKMAN REACTION

- First explained by Blackmann in 1905.
- Synthesis of carbohydrates – a light insensitive phase called dark reaction.
- Carbon reduction cycle – reduction of CO2 using reducing power (NADPH) occurs.
- CO2 is reduced to hexose sugar using ATP & NADPH produced in the light reaction.
- ATP – used as source of energy.
- NADPH – used as source of electrons.

- **If plant has previous exposure to light, dark reaction can occur in complete dark at a fast rate.**
- **In eukaryotes it occurs in chloroplast stroma.**
- **Results in the synthesis of carbohydrate from CO_2 – carbon fixation/carbon assimilation.**
- **Six CO_2 molecules are converted to a hexose sugar molecule ($C_6H_{12}O_6$) – mostly glucose & sometimes fructose .**
- **Utilizes 12 ATP molecules & 12 pairs of electrons from 12 NADPH molecules.**

- **Key step in this process is covalent bonding of CO2 with a 5-carbon (pentose) molecule – ribulose-1,5-biphosphate (RuBP).**
- **RuBP is a 6-carbon unstable intermediate – gets hydrolysed to two 3-carbon molecules (triose).**
- **Two possible cyclic pathways of dark reaction –**

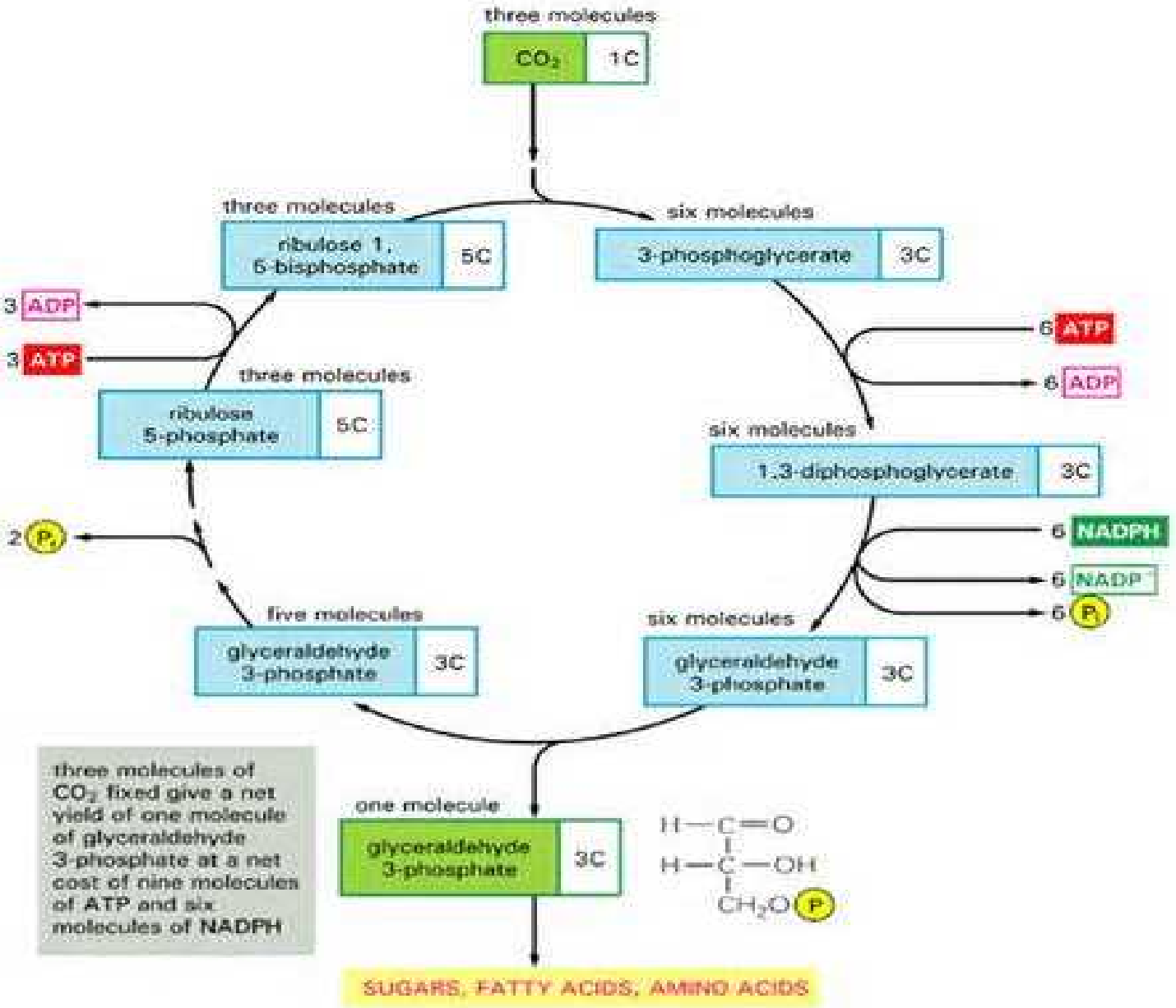
  C3 pathway or C3 cycle – C3 plants.

  C4 pathway or C4 cycle - C4 plants.

CALVIN CYCLE – C3 PATHWAY

- Cyclic pathway by which CO_2 is fixed as hexose sugar.
- Carbon dioxide fixation cycle or photosynthetic carbon reduction (PCR cycle).
- Calvin-Benson-Bassham (1954) cycle / Calvin cycle.
- First stable compound/product – a 3-carbon compound – C3 cycle.
- Plants – C3 plants – most crop plants.
- Calvin experimented with Chlorella.

- **Radioactive isotope of carbon – C14 was used to trace path of carbon.**
- **Illuminated suspension of cells were allowed to photosynthesize in an atmosphere of CO_2.**
- **Algal cells were killed at different intervals of time using boiling methanol – arresting life activities.**
- **Compound formed at different intervals of time – analysed - Chromatography & Autoradiography.**
- **Results compiled – Calvin formulated Pathway of Carbon - Calvin cycle.**

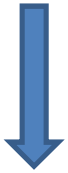

three molecules
CO_2
1C
three molecules
ribulose 1,
6-bisphosphate
5C
six molecules
3-phosphoglycerate
3C
3 ADP
3 ATP
6 ATP
6 ADP
three molecules
ribulose
5-phosphate
5C
six molecules
1,3-diphosphoglycerate
3C
2 P_i
6 NADPH
6 $NADP^+$
6 P_i
five molecules
glyceraldehyde
3-phosphate
3C
six molecules
glyceraldehyde
3-phosphate
3C
three molecules of CO_2 fixed give a net yield of one molecule of glyceraldehyde 3-phosphate at a net cost of nine molecules of ATP and six molecules of NADPH
one molecule
glyceraldehyde
3-phosphate
3C
H—C=O
H—C—OH
CH_2O P
SUGARS, FATTY ACIDS, AMINO ACIDS

- **Calvin cycle – three major phases –**
  - **carboxylation of RuBP.**
  - **reversal of glycolysis.**
  - **regeneration of RuBP.**

<u>Carboxylation of RuBP</u>

- **First step – fixation of atmosperic CO2 by carboxylation reaction.**
- **6 molecules of CO2 combine with 6 molecules of RuBP – formation of 6 molecules of unstable hexose compound.**
- **Reaction catalysed by *ribulose bisphosphate carboxylase – oxygenase* (Rubisco) enzyme.**

Ribulose 1,5-biphosphate

CO_2 +H_2O  **Rubisco**

6 Carbon compound

RuBP is the phosphorylated form of the pentose sugar – ribose – with two attached phosphate groups.

Rubisco is the most abundant enzyme (protein) of the living world. Widely distributed in all green plants, green algae & green bacteria.

- **Rubisco brings about fixation of CO_2 in photosynthesis & acts as oxygenase in CO_2 fixation in photorespiration.**

<u>Reversal of Glycolysis</u>

- **Conversion of unstable hexose compound to glucose.**
- **It is completed in a reaction chain – utilizing the ATP & NADPH produced in light reaction.**
- **Reaction chain represents a reversal of glycolysis.**
- **Involves 7 major steps.**

- **<u>Symmetrical splitting of hexose</u>**

  Each 6-carbon intermediate molecule undergoes symmetrical cleavage - produces two stable triose – 3 carbon molecules – 3-phosphoglyceric acid (3-PGA). Altogether 12 PGA molecules are formed. PGA is the first stable compound produced in photosynthesis. Since it is the first stable compound that undergoes cyclic changes in dark reaction – the cycle is called C3 cycle or C3 pathway.

6mols of 6C compound ---→ 12mols (6X2) of 3-phosphoglyceric acid (PGA).

- **Phosphorylation of PGA**

12 molecules of 3-phosphoglyceric acid are phosphorylated by 12 molecules of ATP to form 12 molecules of 1,3-biphosphoglyceric acid (1,3BPGA) in the presence of phosphoglycero kinase.

12 3-PGA +ATP ----------12 1,3-BPGA + 12 ADP

PG kinase

- **Reduction of BPGA**

12 mols of 1,3-BPGA are then reduced to 12 mols of 3-phosphoglyceraldehyde (3-PGAL) using 12 NADPH in the presence of triosphosphate dehydrogenase.

12 -1,3-BPGA ---------12-3-PGAL+12NADPH +12iP

triosephosphatedehydrogenase

- **<u>Isomerisation of PGAL</u>**

Of the 12 mol. of 3-PGA, two get isomerised to form dihydroxyacetone phosphate (DHAP) in the presence of triosephosphate isomerase.

Both the isomers exist in equilibrium.

3-PGAL ----------DHAP

triosephosphate isomerase

- **Formation of Fructose -1,6-biphosphate**

3 molecules of 3-phosphoglyceraldehyde & 3 molecules of dihydroxyacetone phosphate combine to form 2 molecules of fructose 1,6-biphosphate in the presence of *aldolase.*

3-PGAL+DHAP----------Fructose 1,6-biphsphate

aldolase

- **Dephosphoryation of Fructose1,6-biphosphate**

F 1,6-biphosphate loses one phosphate in the presence of *phosphatase* to form fructose-6-phosphate.

F 1,6-biphosphate----------F 6-phosphate + iP

phosphatase

- **Isomerization of Fructose 6-phosphate**

Fructose 6-phosphate undergoes isomerization & transforms to Glucose 6-phosphate, in the presence of isomerase – the end product of Photosynthesis.

Fructose 6-phosphate ----Glucose 6-phosphate

isomerase

Entire C3 pathway or Calvin cycle requires 6CO2, 6RuBP,12NADPH & 18 ATP for the synthesis of one molecule of hexose sugar & the regeneration of 6 RuBP molecules.

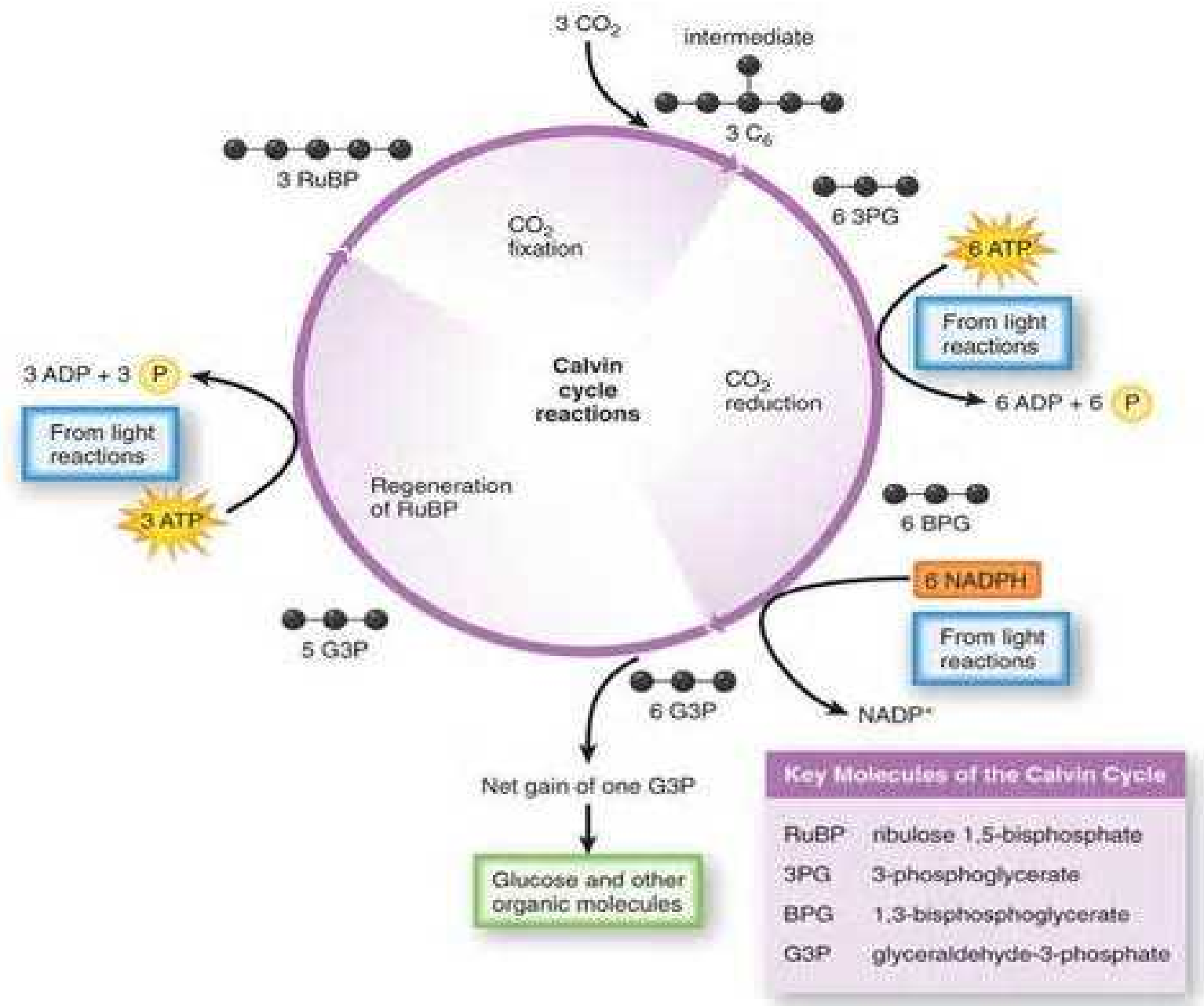
Overall Calvin cycle can be represented as -

$6CO_2$ + 6RuBP + 12NADPH + 18 ATP ---------
$C_6H_{12}O_6$ + 6RuBP + 12NADP + 18 ADP + 18iP

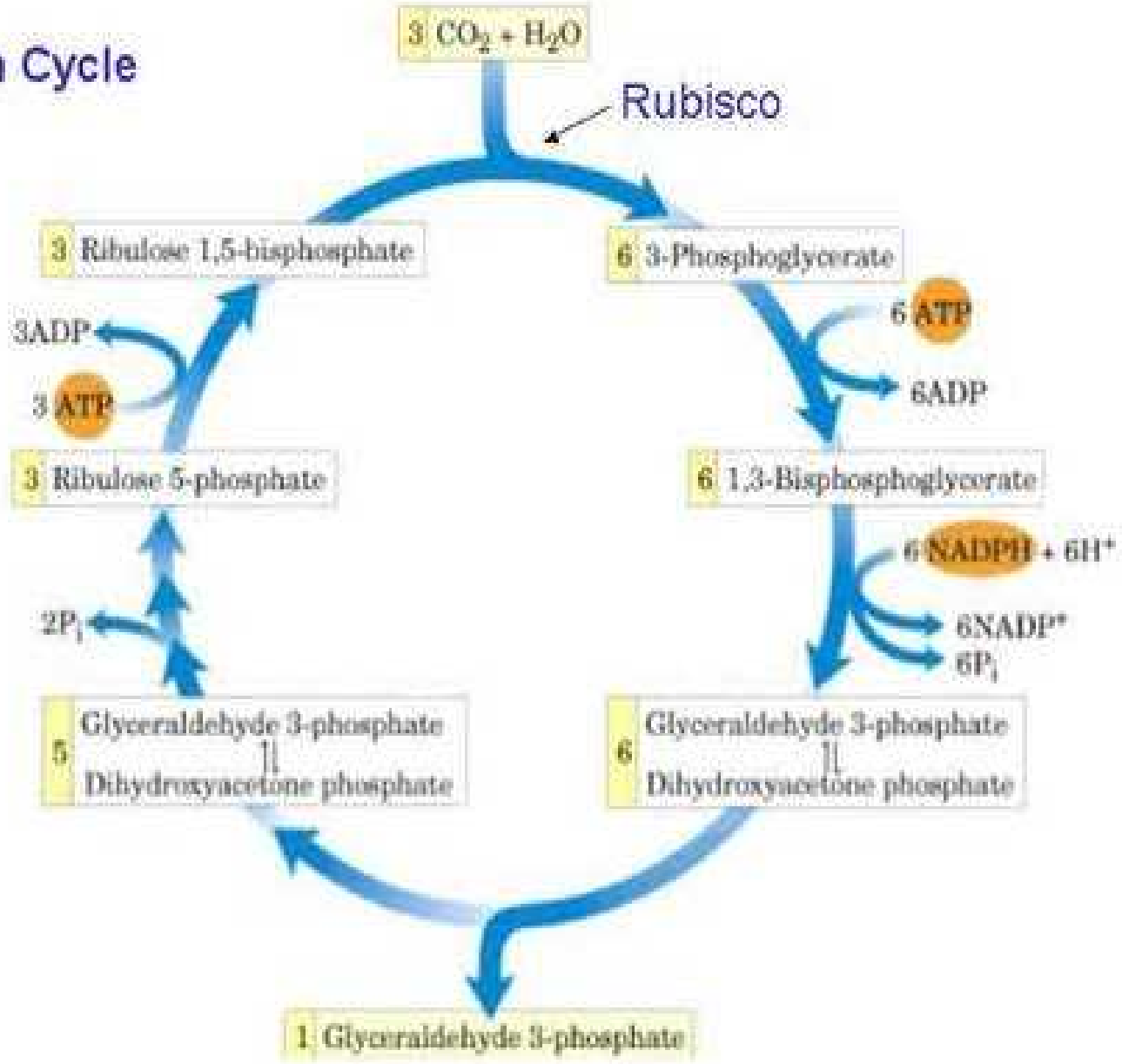
Out of 18 ATP, 12 are utilized to convert 12 molecules of 3-PGA to 12 molecules of 1,3-biphosphoglyceric acid.

Remaining 6 ATP utilized for regeneration of RuBP.

ADP & NADP are utilized for light reaction.


3 CO_2
intermediate
3 C_6
3 RuBP
6 3PG
CO_2 fixation
6 ATP
From light reactions
6 ADP + 6 P
Calvin cycle reactions
CO_2 reduction
3 ADP + 3 P
From light reactions
3 ATP
Regeneration of RuBP
6 BPG
6 NADPH
From light reactions
$NADP^+$
5 G3P
6 G3P
Net gain of one G3P
Glucose and other organic molecules
Key Molecules of the Calvin Cycle
RuBP ribulose 1,5-bisphosphate
3PG 3-phosphoglycerate
BPG 1,3-bisphosphoglycerate
G3P glyceraldehyde-3-phosphate

Calvin Cycle



HATCH AND SLACK PATHWAY (C4 PATHWAY)

- **Carbon pathway of dark reaction – first metabolic product is – a four carbon dicarboxylic acid – oxaloacetic acid (OAA).**
- **Exhibited by some members of Poaceae, Amaranthaceae & Euphorbiaceae.**
- **Mesophyll cells of these plants have normal granal chloroplasts while bundle sheath cells have agranal chloroplasts.**
- **Mesophyll cells contain the primary carboxylating enzyme – *phosphoenol pyruvate carboxylase* (PEP carboxylase) & bundle sheath cells contain *Rubisco*.**

- **In mesophyll cells CO2 first combines with PEP carboxlase – produces a stable 4-carbon compound – oxalo acetic acid (OAA) – the cycle so called C4 cycle.**
- **First investigated by Hatch & Slack – so called Hatch & Slack pathway.**
- **Plants which exhibit this – C4 plants.**
- **C4 pathway is an adaptation to overcome losses of photorespiration.**
- **C4 plants are found in tropical & sub tropical regions.**

- **Reported in more than 1000 species – among them 300 are dicots & the rest monocots.**

  Eg. Sugarcane, Sorghum, Maize, Cyperus, Amaranthus, Euphorbia, etc.
- **Plants have very special type of leaf anatomy – 'Kranz anatomy'.**
- **Vascular elements in C4 plants - surrounded by a layer of bundle sheath cells which in turn are surrounded by mesophyll cells that fill the leaf.**
- **Intercellular spaces between mesophyll cells are smaller.**
- **Chloroplasts in C4 leaves are dimorphic.**

- **Choloroplasts of bundle sheath cells are large, agranal & centripetally arranged.**
- **Chloroplasts of mesophyll cells - small & granal.**
- **Mesophyll cells of C4 plants are centres of C4 cycle & bundle sheath cells are centres of C3 cycle.**
- **C4 plants do not carry out photorespiration.**
- **C4 plants posses chloroplasts in mesophyll cells as well as in bundle sheath cells.**
- **CO2 fixation is carried out by both kinds of cells.**
- **Steps involved are as follows.**

- **Atmospheric CO_2 first comes in contact with mesophyll cells.**
- **Primary acceptor of CO_2 in C4 cycle is 3-carbon compound – phosphoenolpyruvic acid (PEP).**
- **Initial reaction occurs in cytoplasm of mesophyll cells.**
- **PEP combines with CO_2 & forms 4-carbon oxalo acetic acid (OAA) – the first stable compound.**
- **Reaction is catalysed by *PEP carboxlase*.**

Phosphoenol pyruvic acid + CO_2 + H_2O ----------

---------- Oxalo Acetic acid + H_3PO_4.

PEP carboxylase

- **OAA is then transported to mesophyll chloroplasts.**
- **It is then reduced to malic acid by enzyme *malic acid dehydrogenase* – using NADPH as reducing agent.**
- **OAA can also get converted to aspartic acid.**

OAA +NADPH----------Malic acid

Malic dehydrogenase

- **Malic acid is soon transported mesophylls to bundle sheath chloroplasts – “malic acid shunt”.**

- **Malic acid undergoes oxidative decarboxlation to yield pyruvic acid & CO2 – catalysed by the enzyme *malic dehydrogenase* – using NADP as oxidising agent.**

Malic dehydrogenase

Malic acid----------Pyruvic acid + NADPH + CO2.

- **CO2 produced by decarboxylation of malic acid enters Calvin cycle.**
- **It combines with RuBP to form phosphoglyceric acid molecules.**
- **Pyruvic acid formed by decarboxylation of malic acid returns to mesophyll cells.**

- **It undergoes phosphorylation using ATP & regenerates phosphoenol pyruvic acid catalysed by *pyruvate phosphate dikinase*.**

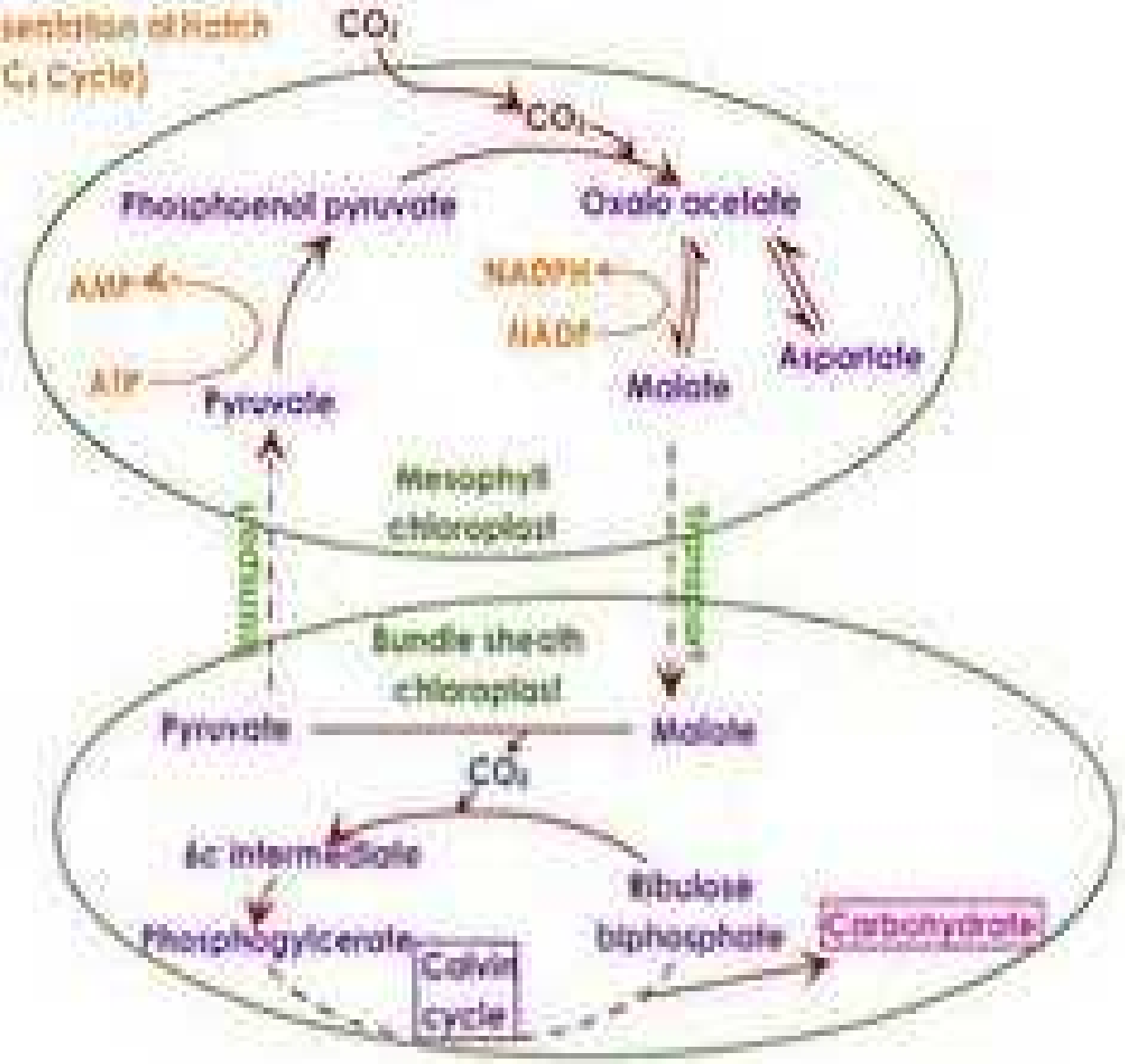
Pyruvate phosphate dikinase

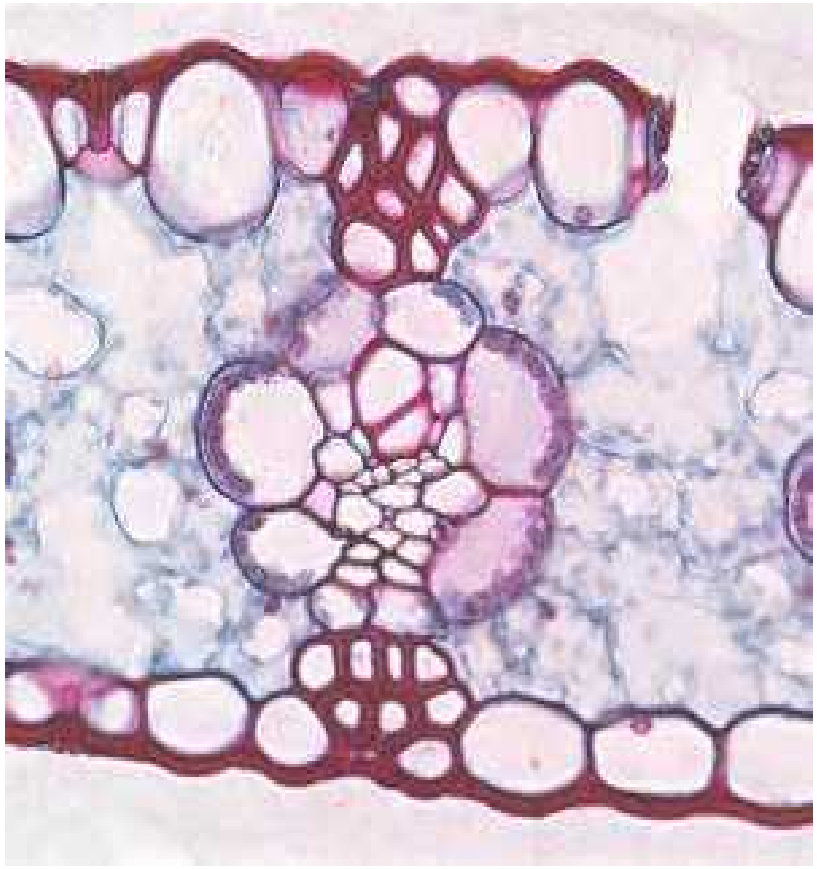
Pyruvic acid + ATP----------Phosphoenol pyruvic acid + ADP.

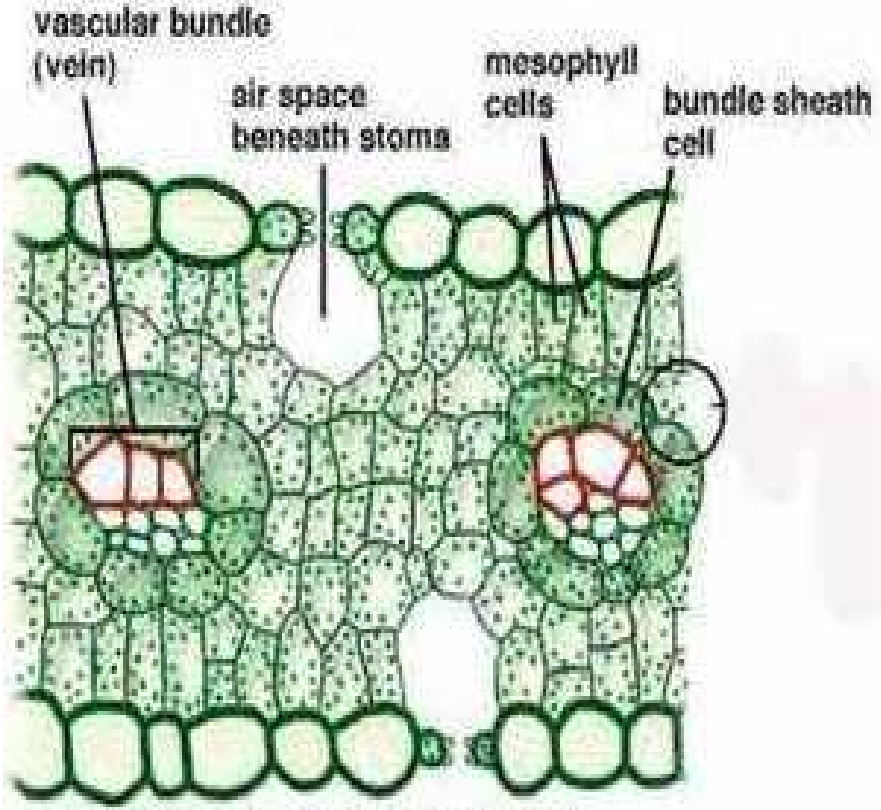
- **C4 pathway is energetically more expensive than C3 cycle.**
- **Requires 30 ATP molecules for the synthesis of one molecule of glucose.**
- **Vital adaptation to prevent loss of Carbon through photorespiration.**

- **Feeds Calvin cycle with CO_2 – increases rate of photosynthesis.**
- **5 ATP & 2 NADPH required to fix one molecule of CO_2.**
- **C4 plants have high rate of CO_2 fixation & low rate of photorespiration.**
- **Plants have 2 to 3 times more yield than C3 plants.**
- **Plants can perform high rate of photosynthesis.**
- **Plants require more light energy.**
- **Plants better adapted to tropical conditions.**

The schematic representation of Hatch and Slack pathway (C_4 Cycle)







PORTION OF A CROSS SECTION
OF A LEAF WITH C_4 PHOTOSYNTHESIS

CRASULACEAN ACID METABOLISM

- **Succulent plants of semi arid regions fix atmospheric CO2 in darkness.**
- **They display diurnal pattern of organic acid formation.**
- **Organic acids accumulate in leaves at night & during day time acid level falls low.**
- **Process was first observed in plants belonging to Crassulaceae – *Bryophyllum, Kalanchoe*, *Sedum, Opuntia, Crassula*, etc. – so termed as Crassulacean Acid Metabolism (CAM).**

- **This is a special type of photosynthetic pathway – reported from 23 families of flowering plants.**
- **Eg. Crassulaceae, Cactaceae, Euphorbiaceae, Polypodiaceae (Ferns), & Welwitschia.**
- **Unique feature of CAM plants – remarkable ability for water conservation.**
- **Plants adapted to survive in extremely dry habitats.**
- **Plants are succulent with xerophytic adaptations – thick fleshy leaves, thick cuticle, sunken stomata, etc.**

- **Stomata of these plants remain closed during day time & open during night (scotoactive).**
- **Helps CAM plants to conserve water.**
- **In CAM plants there is a special type of carbon route – 'Crassulacean Acid Metabolic Pathway'.**
- **CO_2 is fixed into organic acids during night time.**
- **During day these acids undergo decarboxylation, releasing CO_2 within the leaf.**
- **This CO_2 is taken up by chloroplasts to synthesise sugars through C3 pathway.**

- **Organic acid metabolism in CAM plants is significant in two respects –**

  - it builds internal store of CO_2 for feeding the C3 pathway

  - internal store of CO_2 causes stomata to open only for less time in the light & this reduces transpiration & water loss.

- **CAM pathway – consists of two major phases – acidification phase (operates at night) & deacidification phase (operates at day).**

Acidification Phase

- **At night stomata remain open – permitting entry of CO2 into the leaf & escape of water from leaf to outside.**
- **Carbohydrate synthesised during day enters glycolytic pathway – gets converted to PEP.**
- **PEP undergoes carboxylation – combines with CO2 – forms OAA – catalysed by *PEP carboxylase.***
- **OAA undergoes NAD-dependant dehydrogenation – to form malic acid.**
- **Reducing agent is NADH.**
- **Malic acid accumulates & increases acidity – Acidification Phase.**

- **This occurs in three major steps**
- **CO_2 enters leaf through stomata**
- **Carbohydrate ----------PEP**

Glycolysis

- **PEP +CO_2 + H_2O ----------OAA + Pi**

PEPcase

Dehydogenase

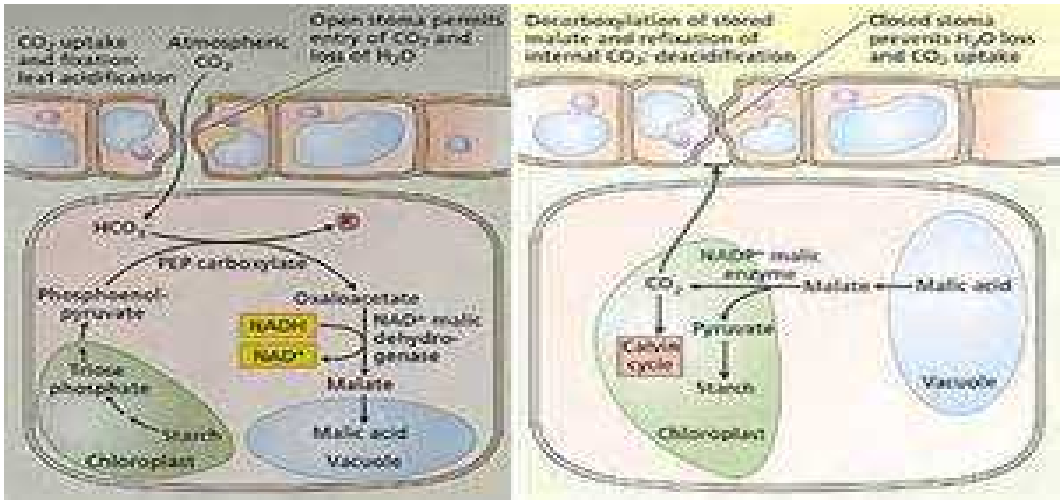
- **OAA ----------Malic acid**

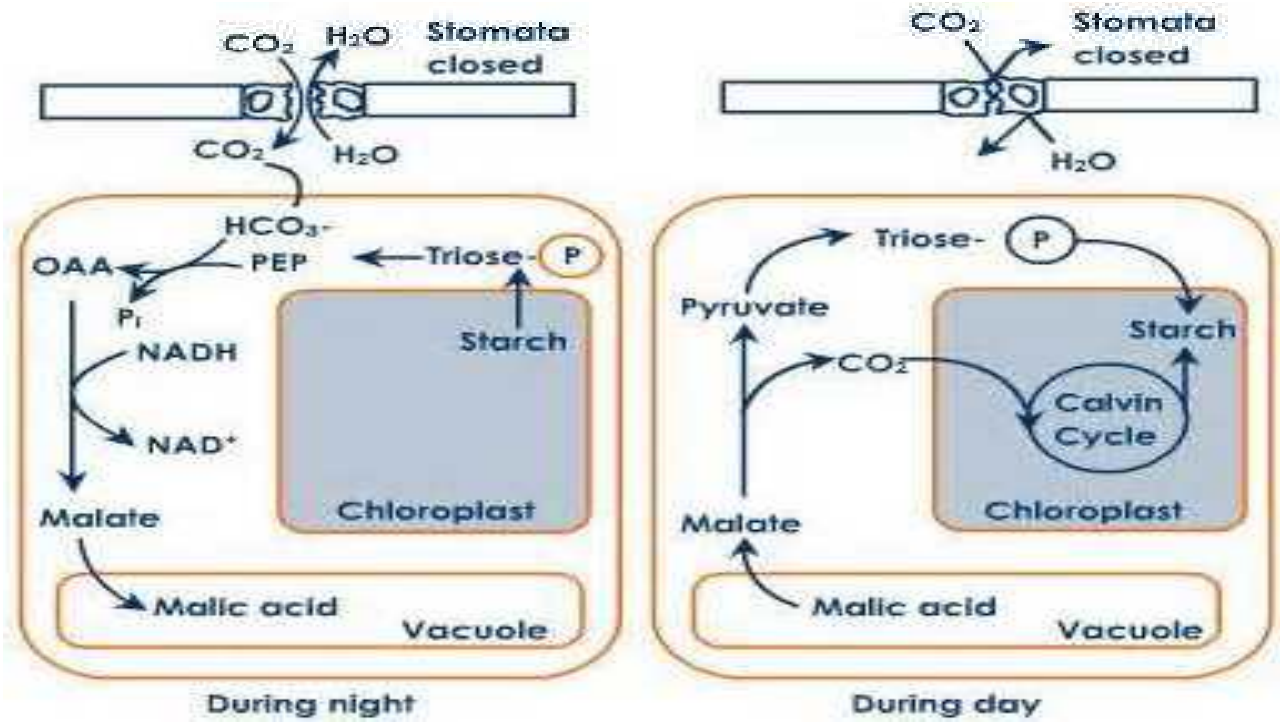
NADH----------NAD+

Deacidification Phase

- **Malic acid produced at night forms source of CO_2 for diurnal photosynthesis.**
- **During day – stomata remain closed – preventing entry of CO_2 & escape of H_2O from leaf.**
- **Malic acid – undergoes decarboxylation – forming pyruvic acid & CO_2 catalysed by *Malic acid dehydrogenase.***
- **Pyruvic acid may enter TCA cycle or converted to sugar.**

- **With this acid level is lowered – removing intracellular acidity – so called deacidification phase.**
- **CO2 produced during this phase is used for photosynthesis.**
- **It diffuses into chloroplast – enters C3 pathway – contribute to the synthesis of Sugar.**
- **CAM pathway is an adaptation for xerophytic mode of life.**
- **Vital when availabilty of water is very low.**
- **Plants carry out photosynthesis without much loss of water.**


Open stoma permits entry of CO_2 and loss of H_2O
CO_2 uptake and fixation; leaf acidification
Atmospheric CO_2
HCO_3^-
PEP carboxylase
Phosphoenol-pyruvate
Oxaloacetate
NADH
NAD^+
NAD^+ malic dehydro-genase
Malate
Triose phosphate
Starch
Chloroplast
Malic acid
Vacuole
Decarboxylation of stored malate and refixation of internal CO_2; deacidification
Closed stoma prevents H_2O loss and CO_2 uptake
$NADP^+$ malic enzyme
CO_2
Malate
Malic acid
Pyruvate
Calvin cycle
Starch
Chloroplast
Vacuole


CO_2
H_2O
Stomata closed
CO_2
H_2O
HCO_3^-
PEP
OAA
Triose-P
P_i
NADH
NAD^+
Starch
Malate
Chloroplast
Malic acid
Vacuole
During night
CO_2
Stomata closed
H_2O
Triose-P
Pyruvate
Starch
CO_2
Calvin Cycle
Malate
Chloroplast
Malic acid
Vacuole
During day

FACTORS INFLUENCING PHOTOSYNTHESIS

EXTERNAL FACTORS

Intensity, Quality & Duration of Light

- Directly proportional to light intensity.
- Directly proportional to quality or wave length of light – highest in red light & lowest in green light.
- Greater in intermittent or flash illumination than in continuous illumination.

Availability of CO2

- CO2 – important raw material.

- **Increase in CO_2 increases photosynthesis.**
- **Very high concentration of CO_2 toxic to plants – inhibits photosynthesis.**

<u>Concentration of Oxygen</u>

- **Inversely proportional to rate of photosynthesis.**
- **High conc. of O_2 increases respiration & decreases photosynthesis.**
- **Inhibition of photosynthesis by high O_2 conc. Is called 'Warburg effect'.**
- **O_2 competes with CO_2 for RuBP – lowers rate of CO_2 fixation.**

Temperature

- Varies from plant to plant.
- Some bacteria & BGA carry out photosynthesis at high temp. – 70 C.
- In conifers – it occurs at -6C.
- Optimum temp. is between 20 & 30 C.
- Temp. has impact on enzyme controlled reactions.

Availability of Water

- Decrease in water content reduces photosynthesis.
- Dehydration affects enzyme action.

INTERNAL FACTORS

Age of Leaf

- As leaves mature – photosynthesis increases gradually & reaches maximum around maturity.

Anatomy of Leaf

- Number, structure & distribution of stomata, size & distribution of intercellular spaces, proportion & distribution of palisade & spongy, thickness of cuticular layer & size & distribution of vascular tissues.

Chlorophyll content

- **Most essential for photosynthesis.**
- **Increases with increase in chlorophyll content.**
- **Quantity of CO_2 fixed by one gram of chlorophyll in a unit time of one hour is called photosynthetic number or assimilation number.**

Enzyme action

- **Directly related to rate of enzyme action.**
- **When enzymes most active – photosynthesis will be high.**
- **Enzyme activity depends on temperature, water content, pH, etc.**

Phytohormones

- Gibberllins & cytokinins stimulate photosynthesis.

Chemicals

- Enzyme inactivators inhibit photosynthesis.
- Cyanides, H2S, hydroxylamines, CO, chloroform, herbicides, etc. act as inhibitors.

Product accumulation

- Excessive accumulation of products inhibit photosynthesis.
- Occurs due to slow translocation or utilization.

BACTERIAL PHOTOSYNTHESIS

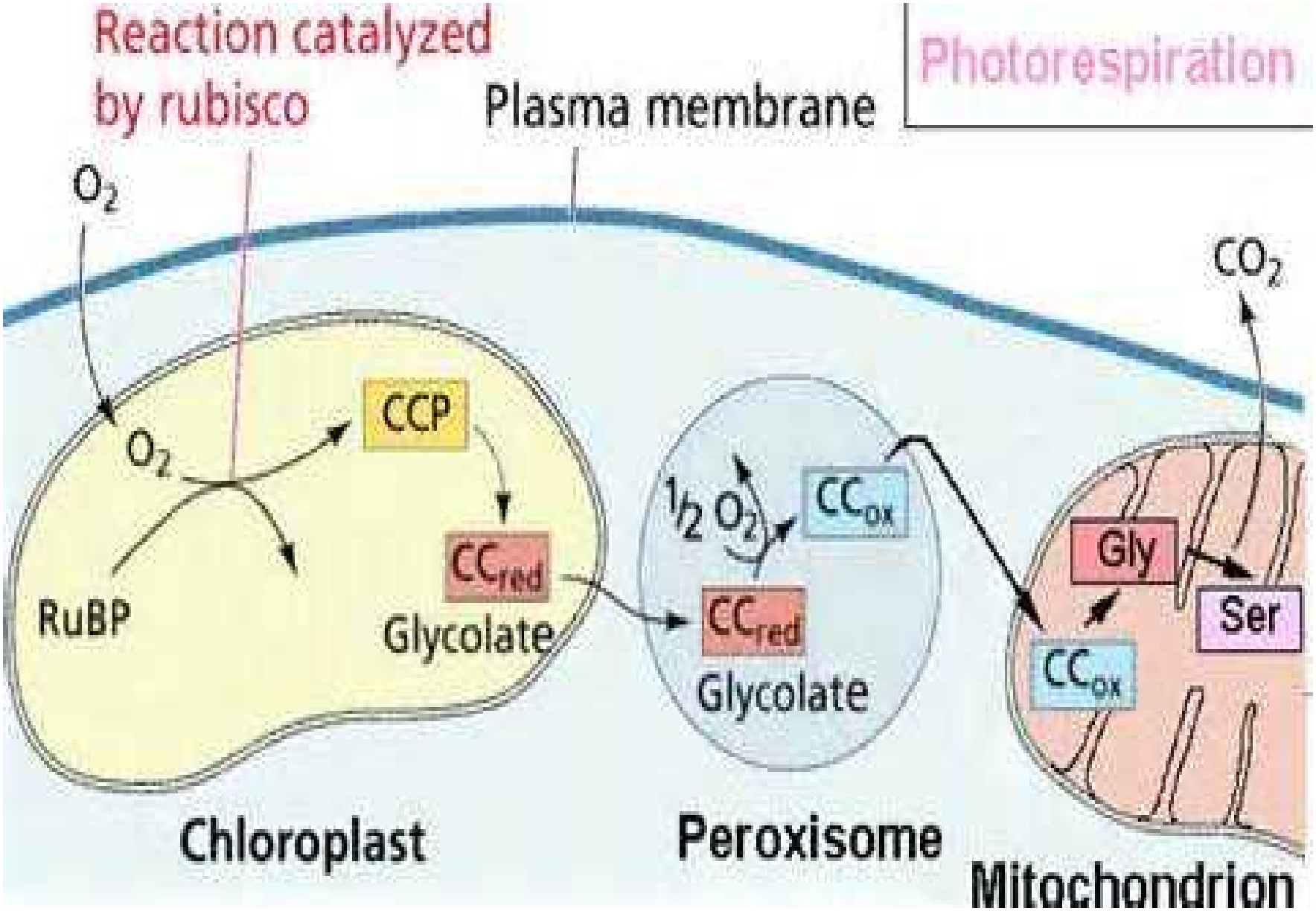
- Some bacteria are photosynthetic.
- Similar to photosynthesis of green plants.
- Photosynthetic bacteria belong to three groups
  - green sulphur bacteria (Chlorobium)
  - purple sulphur bacteria (Chromatium)
  - non-sulphur bacteria (Rhodospirillum)
- Hydrogen donor – H_2S ----GSB
  Thiosulphate ----PSB
  Malate/Alcohol ----NSB

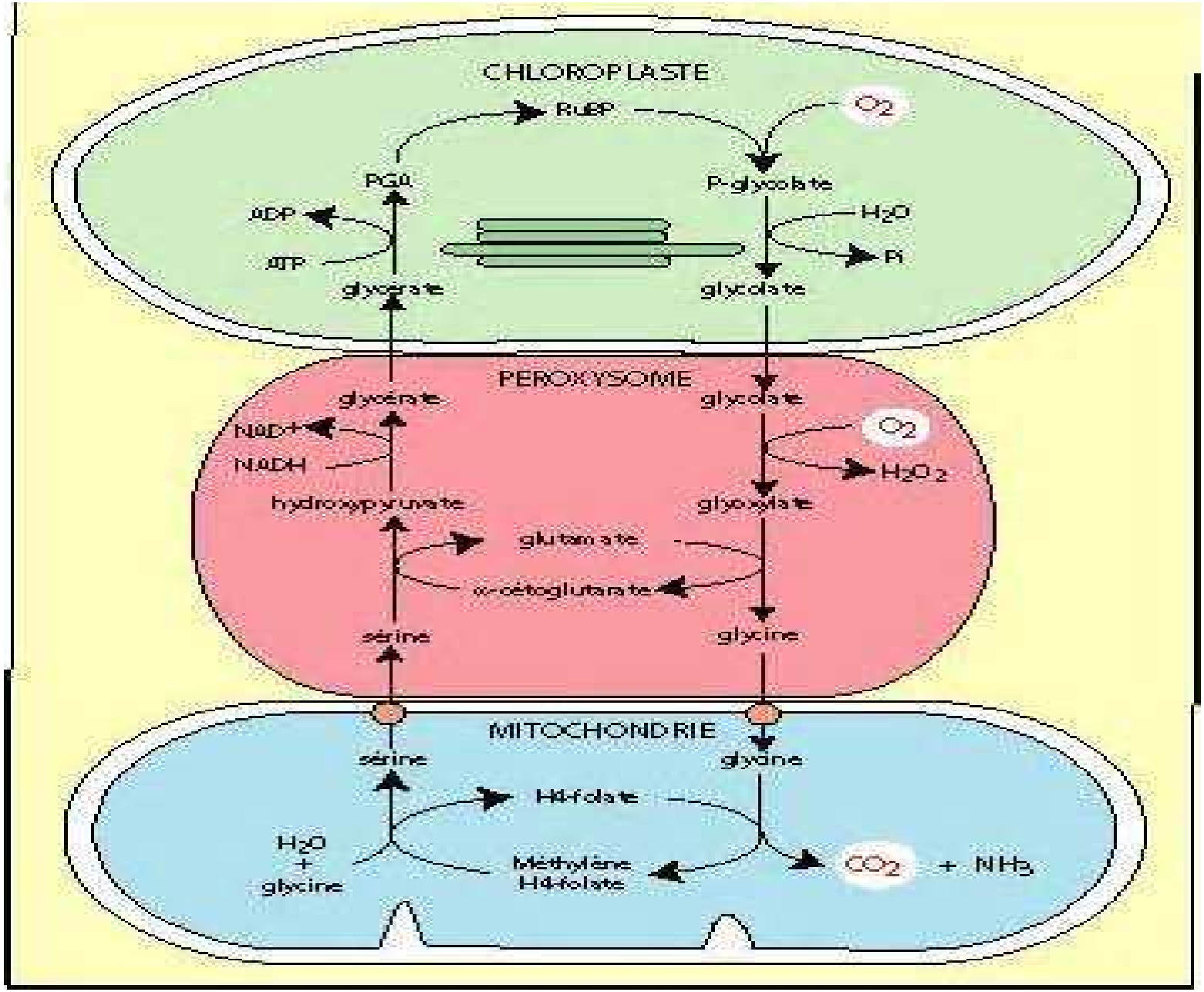
- **Since H donor is not water, bacterial photosynthesis is never oxygenic – O producing.**
- **Pigment system includes – Bacterioviridin (green pigment) & Bacterial chlorophyll (red purple pigment).**
- **These pigments are Mg- containing & similar to chlorophylls of green plants.**
- **Bacterial photosynthesis involves only one pigment system, one photosystem, one reaction centre, two light-harvesting complexes & one photochemical reaction.**
- **Reaction centre is P840 0r P870.**

- **Photosynthetic apparatus is located in the plasma membrane since chloroplasts are absent.**
- **Reducing agent is NAD+**
- **Utilizes radiant energy of the infra-red region of the solar spectrum (870-1020nm).**
- **Hydrogen donor is never water.**
- **Photosynthesis is not oxygenic, since H_2O is not the hydrogen donor.**
- **Both cyclic & non-cyclic photophosphorylation occur.**

PHOTORESPIRATION

- Glycolate pathway or C2 cycle.
- Light dependant respiration – occur in most photosynthetic plants.
- Light & O2 dependant CO2 evolution.
- Production of CO2 in light by photosynthetic tissues.
- Releases large amount of CO2.
- Rate of photorespiration is 3 – 5 times faster than in C3 plants than in C4 plants.
- Resembles true respiration – both involve O2 intake & CO2 release.
- Does not yield energy.


Reaction catalyzed by rubisco
Plasma membrane
Photorespiration
O_2
O_2
CCP
RuBP
CC_{red}
Glycolate
Chloroplast
$\frac{1}{2}$ O_2
CC_{ox}
CC_{red}
Glycolate
Peroxisome
CO_2
Gly
Ser
CC_{ox}
Mitochondrion


CHLOROPLASTE
RuBP
O_2
PGA
P-glycolate
ADP
ATP
H_2O
Pi
glycérate
glycolate
PEROXYSOME
glycérate
glycolate
NAD+
NADH
O_2
H_2O_2
hydroxypyruvate
glyoxylate
glutamate
α-cétoglutarate
sérine
glycine
MITOCHONDRIE
sérine
glycine
H4-folate
H_2O
+
glycine
Méthylène
H4-folate
CO_2
+ NH_3

- **Photorespiration is a light dependent metabolism of glycolic acid – a two carbon organic acid.**
- **Pathway also called ‘glycolate pathway’ or C2 cycle.**
- **Common in most C3 plants under conditions of high intensity light, high temperature & high cellular concentration of O2.**
- **Adversely affects Calvin cycle & lowers photosynthetic efficiency of plants.**
- **Involves photosynthesis, photorespiration & N metabolism.**

- **Major sites – chloroplasts, peroxisomes & mitochondria.**
- **Initial substrate is the two Carbon glycolate.**
- **Glycolate is produced in chloroplasts, when cellular concentration of O2 is much higher than that of CO2.**
- **First phase of photorespiration occurs in chloroplasts.**
- **First step – oxidation of RuBP – catalyzed by RuBP carboxylase-oxygenase (RUBISCO).**
- **Products – 3-phosphoglyceric acid & 2-phosphoglycolate.**

- **Rubisco has dual existence –**

High CO_2 level – it behaves as carboxylase – catalyse carboxylation of RuBP in Calvin cycle.

High O_2 level - it behaves as oxygenase – catalyse oxidation of RuPB in Photorespiration.

- **RuBP +CO_2----------3PGA**

  (RuBP carboxylase – Calvin cycle)

  RuBP + O_2 ----------3PGA + 2-phosphoglycolate

  (RuBP oxygenase – Photorespiration)

- **Phosphoglycolate soon converted to glycolate by dephosphorylation (removal of phosphate)**

- **Glycolate – primary substrate of photorespiration**
- **It moves from chloroplast to peroxisome.**
- **In peroxisome - oxidised to glyoxylate & H_2O_2.**
- **H_2O_2 – broken down by enzyme *catalase.***
- **Glyoxylate – transamination reaction – gets aminated – yielding aminoacid glycine.**
- **Glycine moves to mitochondria.**
- **Two molecules of glycine get converted to serine (3C) & CO_2 – by oxidation.**
- **This is the actual process of photorespiration.**

- **Glycine – immediate source of photorespired CO_2.**
- **Serine returns to peroxisome – gives up amino group – in a transamination reaction – transforms to hydropyruvic acid – undergoes hydrogenation – gets reduced to glyceric acid.**
- **Glyceric acid moves to chloroplast – undergoes phosphorylation – forms 3-PGA – returns to C3 cycle – forms glucose-6-phosphate.**
- **Release of CO_2 during conversion of glycine to serine - accompanied by release of N as ammonia – re-assilmilated in the chloroplast.**

FEATURES OF PHOTORESPIRATION

- **Photorespiration – light dependent uptake & utilization of O_2 & output of CO_2.**
- **O_2 used when glycolate is oxidised to glyoxylate in peroxisome & when glycine is oxidised to serine in mitochondria.**
- **CO_2 is released when glycine is oxidised to serine.**
- **Rate of photorespiration depends on levels of O_2& CO_2 – these compete for same active site – Rubisco.**
- **Increased level of O_2 increases photorespiration.**

- **Increased level of CO_2 decreases photorespiration & increases photosynthesis.**
- **Rate of photorespiration increases with increase in O_2 level, temperature, light intensity & age of leaf.**
- **Has no relation to normal respiration & yields no energy.**
- **Involves co-ordination between chloroplasts, peroxisomes & mitochondria.**
- **Occurs when Rubisco acts as oxygenase.**
- **Reduces photosynthetic efficiency of C3 plants.**

Advantages of Photorespiration

- **Brings about production of amino acids – glycine & serine.**
- **Recovers carbon from excess glycolate produced in glycolate pathway of C3 plants.**

Disadvantages of Photorespiration

- **Interferes with C3 pathway & adversely affects photosynthesis.**
- **Causes wastage of energy & carbon without yielding energy.**