Chapter = 04

Bioenergetics

The capturing and conversion of energy from one form to another and its utilization in metabolic activities is called bioenergetics.
In other words the quantitative study of energy relationships and its conversion into biological system is known as bioenergetics.

ENERGY:

- Energy is defined as the "capacity to do work."
- It exists in a number of different forms: heat, light, electrical, magnetic, chemical, atomic, mechanical and sound.

The laws which apply to energy conversion are the laws of thermodynamics

NEEDS FOR ENERGY IN LIVING ORGANISMS:

- All the living organisms perform a number of daily activities such as digestion, respiration, excretion and reproduction. For these activities energy is required.
- This energy is derived from light energy. Light energy is trapped by plants and converted into energy rich compounds.
- Most of the animals don't have ability to trapped light energy, so they obtain their energy by eating plants or other organisms that eat plants.
- All living things break down organic nutrients for energy. Half a million of species built these nutrients through photosynthesis.
- These species have the ability of carbon fixation. These half million of species support.

ROLE OF ATP AS ENERGY CURRENCY:

- Living organisms use organic food as an energy source. These organic molecules especially carbohydrates are break down to release energy, CO_2 and H_2O.
- Some of this energy is used to produce ATP. When cells require energy, they spend ATP for that and ATP break into ADP.
- ATP is also called a "high energy compound because its phosphate groups are easily removed. Under cellular condition it produces 7.3 K Cal/mole energy on conversion into ADP.
- ATP is composed of adenine, ribose sugar and 3 phosphate groups. It shows that ATP is the common energy currency of cells.
- ATP act as mediator, receiving energy from one reaction and transfer this energy to derive or perform another reaction.

For example: Oxidation of glucose provides energy which is stored in the form of ATP that is later utilized for the synthesis of cellular materials.

PHOSPHORYLATION:

"Formation ATP from ADP and inorganic phosphate is called phosphorylation or addition of inorganic phosphate into organic molecule is called phosphorylation."
There are three types of phosphorylation found in living organisms.

(i) PHOTOPHOSPHORYLATION:

"In this type of phosphorylation energy of light (photon) is utilize for the formation of ATP. It occurs in thylakoid membrane of chloroplast".

$$ADP + Pi \xleftarrow{\text{Energy Of light}} ATP$$

(ii) OXIDATIVE PHOSPHORYLATION:

"In this Type of phosphorylation energy of oxidation is utilized for the formation of ATP, produce during metabolic reactions in cell. It occurs in cristae of mitochondria".

$$ADP + Pi \xleftarrow{\text{Energy Of Oxidation}} ATP$$

(iii) SUBSTRATE LEVEL PHOSPHORYLATION:

"In this Type of phosphorylation where one substrate provides phosphate and energy to another substrate",

For ATP formation living organisms has two processes called photosynthesis and respiration.

PHOTOSYNTHESIS:

• Chemically Photosynthesis is a "redox" process in which CO_2 is reduced into glucose. Water acts as reducing agent which is oxidized into oxygen during this process.

• Bio-energetically photosynthesis is an energy conversion process in which energy poor molecules that is CO_2 and H_2O are transformed into energy rich molecule such as glucose. The extra energy is absorbed in the form of sunlight the photosynthetic pigments.

The overall reaction of photosynthesis can be summarized as follows:

Oxidation: Water is oxidized into oxygen (loss of electrons).

Reduction: CO_2 is reduced into Carbohydrates (gain of electrons).

SIGNIFICANCE OF PHOTOSYNTHESIS:

1. Photosynthetic organisms provide food for all living organisms on earth either directly or indirectly.
2. It is the only natural process that liberates oxygen in the atmosphere and balances the oxygen level.
3. Photosynthesis balances the oxygen and carbon cycle in nature.
4. Fuels such as coal, petroleum and other fossil fuels are from preserved photosynthetic plants.
5. Photosynthetic organisms are the primary producers on which all consumers depend for energy.
6. Plants provide fodder, fibre, fire wood, timber, useful medicinal products and these sources come by the act of photosynthesis.

ROLE OF LIGHT:

• The light comes in packets, called Quanta, & Proton.

• The molecules that absorb light called pigment complex, present in chloroplast.

• Chlorophyll - a (650 to 700nm), and chlorophyll b (450 to 500nm) absorb violet, blue and red light, while slighty, green light is reflected, so plants are appear in green colour.

• Each pigment has its own absorption spectrum & play important role in photosynthetic activity called action spectrum of photosynthesis.

• The energy of light photon results in the activation of electron from ground state of an excited state.

• This energy is used to start chemical reaction and all other steps of photosynthesis.

ROLE OF PHOTOSYNTHETIC PIGMENTS:
The substance in plant that absorb light are called pigments. Most important pigment required in the process are chlorophyll and carotenoid.

CHLOROPHYLE:
Chlorophyll can be distinguished into a,b,c and e. The empirical formula of chlorophyll a & b are.

Chlorophyll a ----- $C_{55} H_{72} O_5 N_4 Mg$ ---- Bluish green.

Chlorophyll b ----- $C_{55} H_{70} O_6 N_4 Mg$ ---- Yellow green

Chlorophyll is found with other pigments and form Photosystems. These photosystems have two regions.

i. ANTENNA COMPLEX:
It consist of group of few hundred molecules of Chlorophyll-a, Chlorophyll-b and Carotenoids. The antenna molecules receive photon of light.

ii. REACTION CENTRE:
When antenna complex molecules absorb light, it is transferred to reaction centre, where chemical reaction occurs and light energy is transferred into chemical energy.

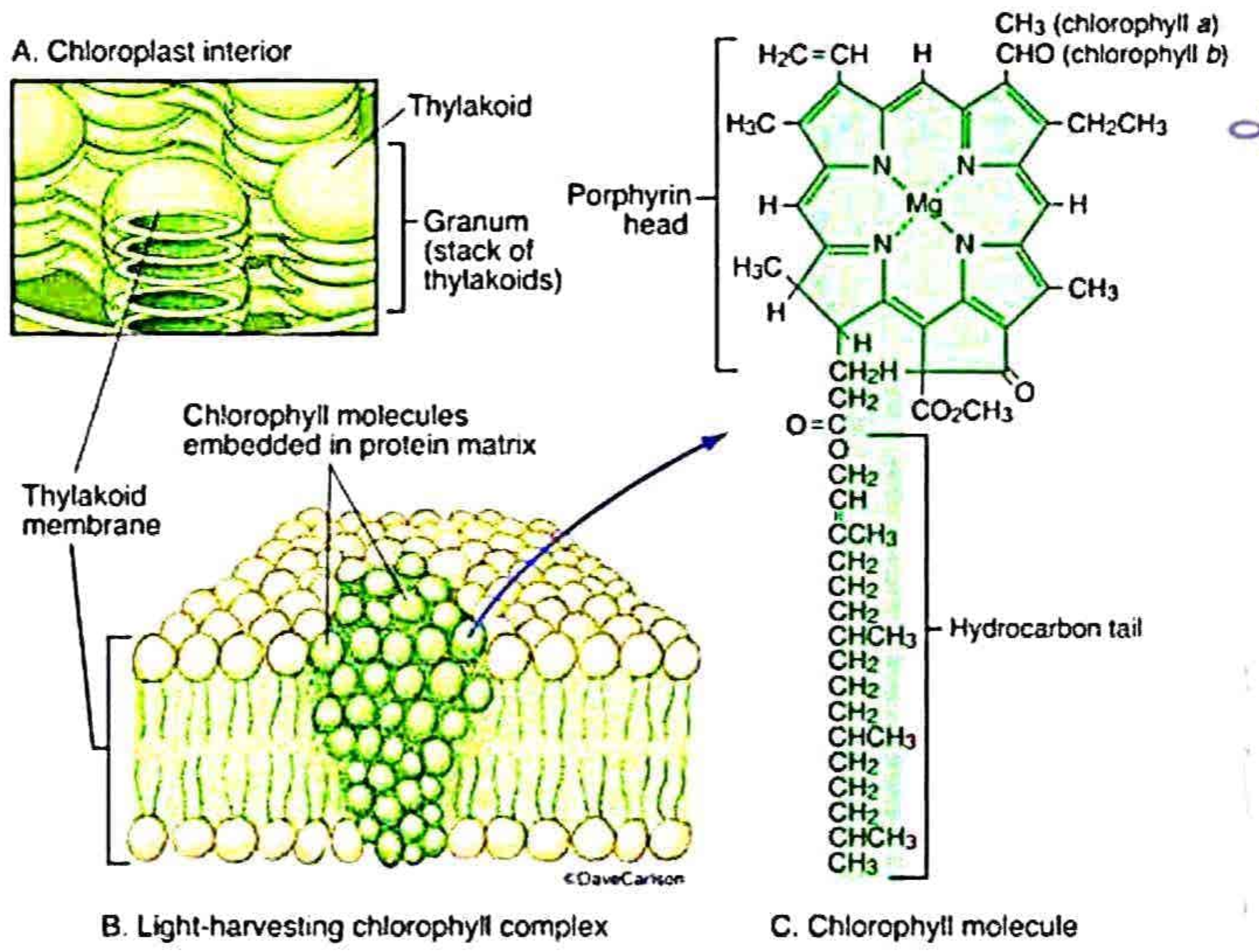
FUNCTION:
- Chlorophyll mainly absorbs violet-blue & orange-red from visible light.
- Chlorophyll- a take part in light independent reaction to convert light energy to chemical energy.
- Chlorophyll-b found with chlorophyll a & in all green plants & green algae.

CAROTENOIDS:
- Carotenoids are yellow and red to orange pigments & absorbed blue-violet light.
- It also present in human eye for protection.
- Carotenoids protect chlorophyll molecule from high intensity of light.
- Carotenoids transfer their energy to chlorophyll-b and then chlorophyll-a

Carotenoid => Chlorophyll-b => Chlorophyll – a

STRUCTURE OF CHLOROPHYLL:
- A molecule of chlorophyll consists of a head and two tails. The head is composed of a porphyrin ring with Mg in the centre. The porphyrin ring further consists of four pyrrole rings (each pyrrole ring contains four carbons and one nitrogen atom).
- The nitrogen atoms of pyrrole rings interact with central Mg atom. The pyrrole rings also contain different groups around them. The only difference between chlorophyll-a and chlorophyll-b is that chlorophyll-a has methyl group on 2 pyrrole ring whereas, chlorophyll-b has aldehyde group at this point.
- The head of chlorophyll is hydrophilic in nature. It is exposed on the surface of thylakoid membrane.
- It is light absorbing part of chlorophyll.
- The two side chains in the chlorophyll molecule are called tails. Side chains are phytol and methyl ester the chlorophyll tails are hydrophobic in nature.

• They are embedded into the thylakoid membranes and serve to anchor the chlorophyll molecule in the membrane.



ROLE OF CO_2:

CO_2 play a basic role role in dark reaction, & takes part in chemical process and involves in the formation of carbohydrates i.e. C_3 Cycle

ROLE OF WATER:

• Photosynthesis is redox process & needs. H+ and electrons, for this purpose pyrolysis of water takes place.

• Water splits into oxygen and hydrogen.

• Hydrogen ion (H_+) used in dark reaction to produce carbohydrates ($C_nH_{2n}O_n$) by the combination of CO_2.

• The oxygen is released from the plant.

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

Neil's hypothesis:

He suggested that source of oxygen released during photosynthesis is water not CO_2.

• In 1940 other scientist used radiolabelled O^{18} isotopes with H_2O & CO_2.

• Group I plants supply water with radioactive isotopes (H_2O_{18}) they produce oxygen with 0_2^{18}.

• Group II plants supply water with normal water with CO_2^{18}. They produce normal O_2 but carbohydrates with O^{18}.

• It was cleared that water is one of the raw material of photosynthesis & H produces by Splitting of water reduces NADP to $NADPH_2$.

G1 (Group 1) plants - $CO_2 + H_2O^{18}$ $\quad C_nH_{2n}O_n + O_2^{18}$

G2 (Group 2) plants – $CO_2^{18} + H_2O$ $\quad C_nH_{2n}O_n^{18} + O_2$

PROCESS OF PHOTOSYNTHESIS:

Photosynthesis is a "redox process" & consist of two parts.

i. The light dependent reaction (light reaction).

ii. The light independent reaction (Dark reaction).

LIGHT DEPENDENT REACTION (LIGHT REACTION):

This reaction takes place in the presence of sunlight and occur in the thylakoid membrane, which contain several protein complex and electrons carries Four major Group complex are present in the thylakoid membrane,

i. Photosystem I (P.SI)
ii. Photosystem II (PS. II)
iii. Cytochrome b/f (Cyt. b/f)
iv. ATP are

Some electron carries take part to transfer the electron b/w these complexes. The electron carrier are Plastoquinone (PQ), plastocyanin (PO) and Ferredoxin (Fd).

The light reaction consist of four events.

i. Photolysis of water
ii. Electron Transport chain
iii. Reduction of NADP into ($NADPH_2$)
iv. Phosphorylation.

i. PHOTOLYSIS OF WATER:

- When water react with oxidized state of chlorophyll in photosystem, it break up into $2H^+$ ion, $2e^-$ & O_2
- This breakdown occurs in the presence of sunlight therefore, it is termed as photolysis of water.

$$2H_2O \longleftarrow 2H^+ + O_2$$

The chlorophyll-b (P_{680}) get electron from water by splitting into two Hydrogen ions and an oxygen.

ii. ELECTRON TRANSPORT CHAIN:

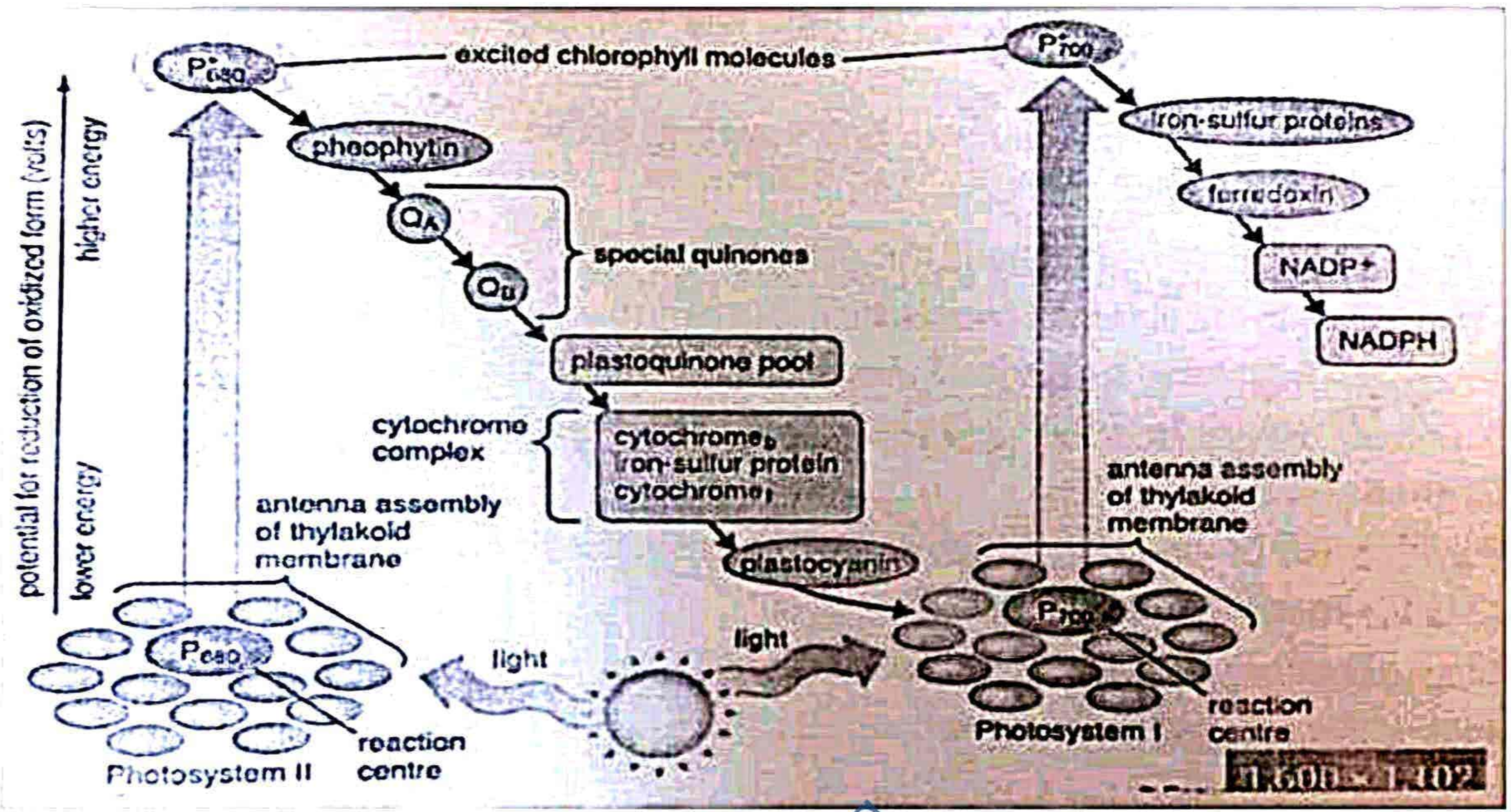
- The light reaction start from reaction centre of PS-II, It releases electron & these excited electron are transferred to different pigments of electron carries.
- The electron move from chlorophyll-b to primary acceptor Phaeophytin.
- From primary acceptor electron move to Plastoquinone (PQ).
- From Plastoquinone to Cytochrome Complex which consist of (Cyt-b6) & (Cytf). The electron flow through Cyto Chrom complex to stimulate proton (H') which moves from stroma to thylakoid inner space.
- The proton gradient activate an enzyme ATP synthase which move proton back to stroma & catalysis the reaction in which ADP and Pi combined to form ATP (Photophosphorylation).
- The whole mechanism of ATP formation in by pumping of proton from thylakoid to strome by ATPase enzyme is called chemiosmosis.

REDUCTION OF NADP TO $NADH_2$:

- Chlorophyll-a (P_{700}) of PS-I receives sunlight & the electron which have been transferred from plastocyanin are excited.
- The electrons are accepted by iron containing protein ferredoxin (Fd). An enzyme called NADP reductase transfer the electrons from Fd to NADP
- NADP combined with electron and hydrogen ion to form NADPH + H^+.
- The NADPH will provide reducing power for the synthesis of sugar in the calvin cycle.

NON CYCLIC PHOSPHORYLATION:

• During the electron transport when the electron moves through the chain its energy is used by thylakoid membrane to produce ATP. The electron does not come back to its original position, & take part in reduction of NADP to $NADPH_2$, so this process is called non cyclic photo Phosphorylation.



CYCLIC PHOTOPHOSPHORYLATION:

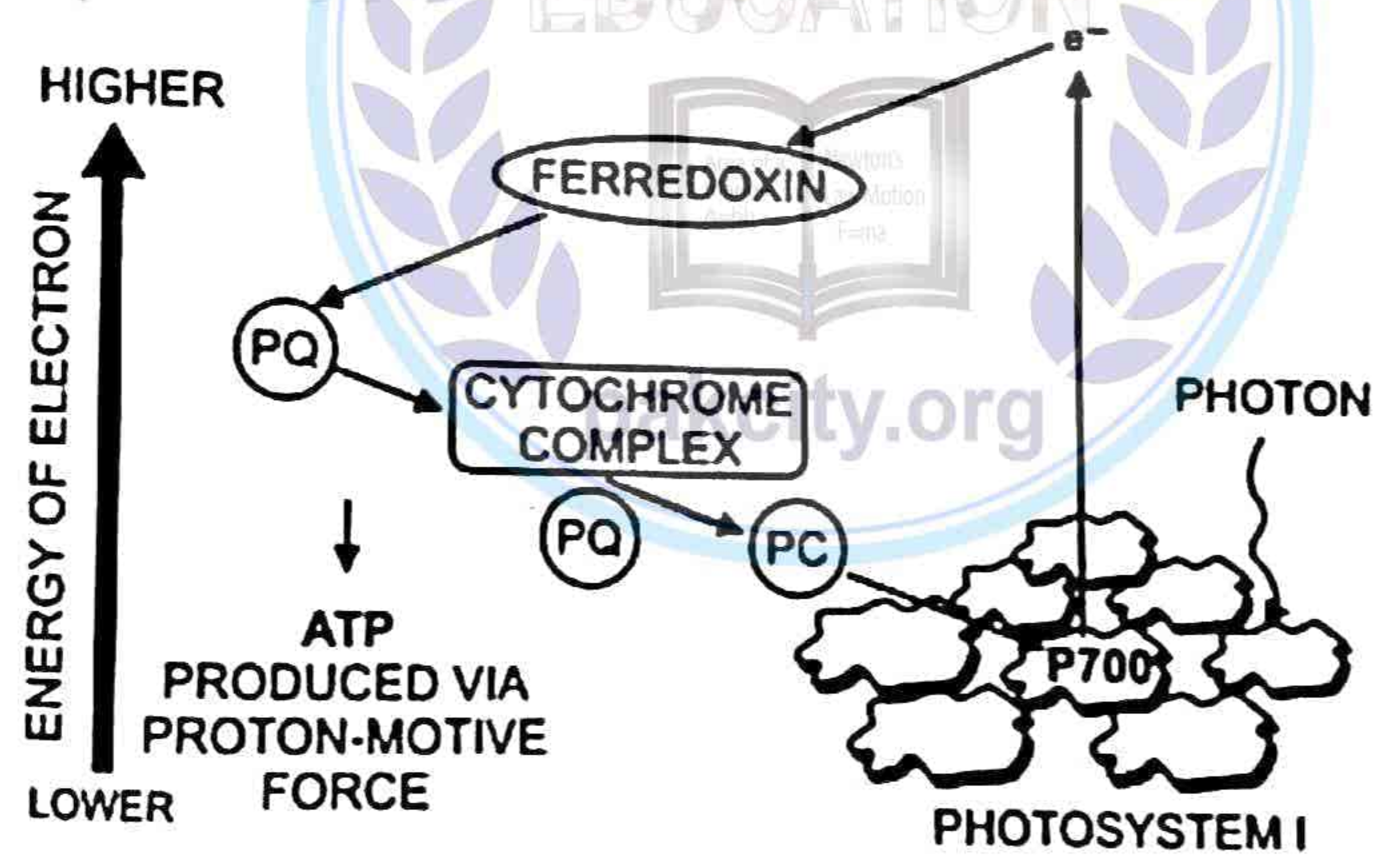
• When excited electron do not move toward NADP, they use alternative pathway i.e. cyclic electron flow.

• In this pathway they use only PS-I & the electron from primary electron acceptor to Fd and then to cytochrome complex, so it come back to (P_{700}) chlorophyll molecule.

• Now ATP is generated by adding electron by chemiosmosis.

• No further NADP is produced to $NADPH_2$, & O_2 production is also stopped.

This process of ATP formation is called Cyclic Phosphorylation.



LIGHT INDEPENDENT REACTION: (DARK REACTION)
(CALVIN BENSON CYCLE)

• The dark-reaction does not require light and may take place both in light and dark during night.

• The first product of the pathway is a 3-carbon compound (Phospho Glyceric Acid) & so it is also called as C_3 Cycle.

• It takes place in the stroma of the chloroplast.

• The calvin cycle actually consists of 13 main reactions which are catalyzed by 11 enzymes, but it can be divided into three distinct phases:

1. Carboxylation: In which CO2 combines with organic molecule, it is also called carbon fixation.
2. Reduction: In which organic moleucles are reduced and Phosphoglycer aldehyde (PGAI) compound is formed.
3. Regeneration: In which reduced carbon is used to regenerate the carbon acceptor molecules or used for metabolism.
These steps can be explained in the following way:

1. CARBOXYLATION:
It is considered that CO2 first combines with a compound, called ribulose, 1,5 biphosphate and forms a 6-Carbon compounds, called Keto acid. It is unstable compound, it breaks up into two molecules, called Glycerate 3-Phosphate (G3P). in this reaction RuBP carboxylase (Rubisco) enzyme is used.

$$3CO_2 + 3\text{ Ribulose biphosphate (RuBP)} \xleftarrow{\text{Rubisco}} 6\text{ (3-PGA)}$$

2. REDUCTION:
This reaction consists of many steps:
i. Glycerate 3-Phosphate (G3P) utilizes ATP compound from the light reaction and it is converted into Glycerate 1-3-biphosphate (G, 1-3-biphosphate)

ii. Glycerate 1-3-biphosphate combines with hydrogen from NADPH+H) and forms Glycer aldehyde 1-3 biphosphate (GA, 1-3 biP)

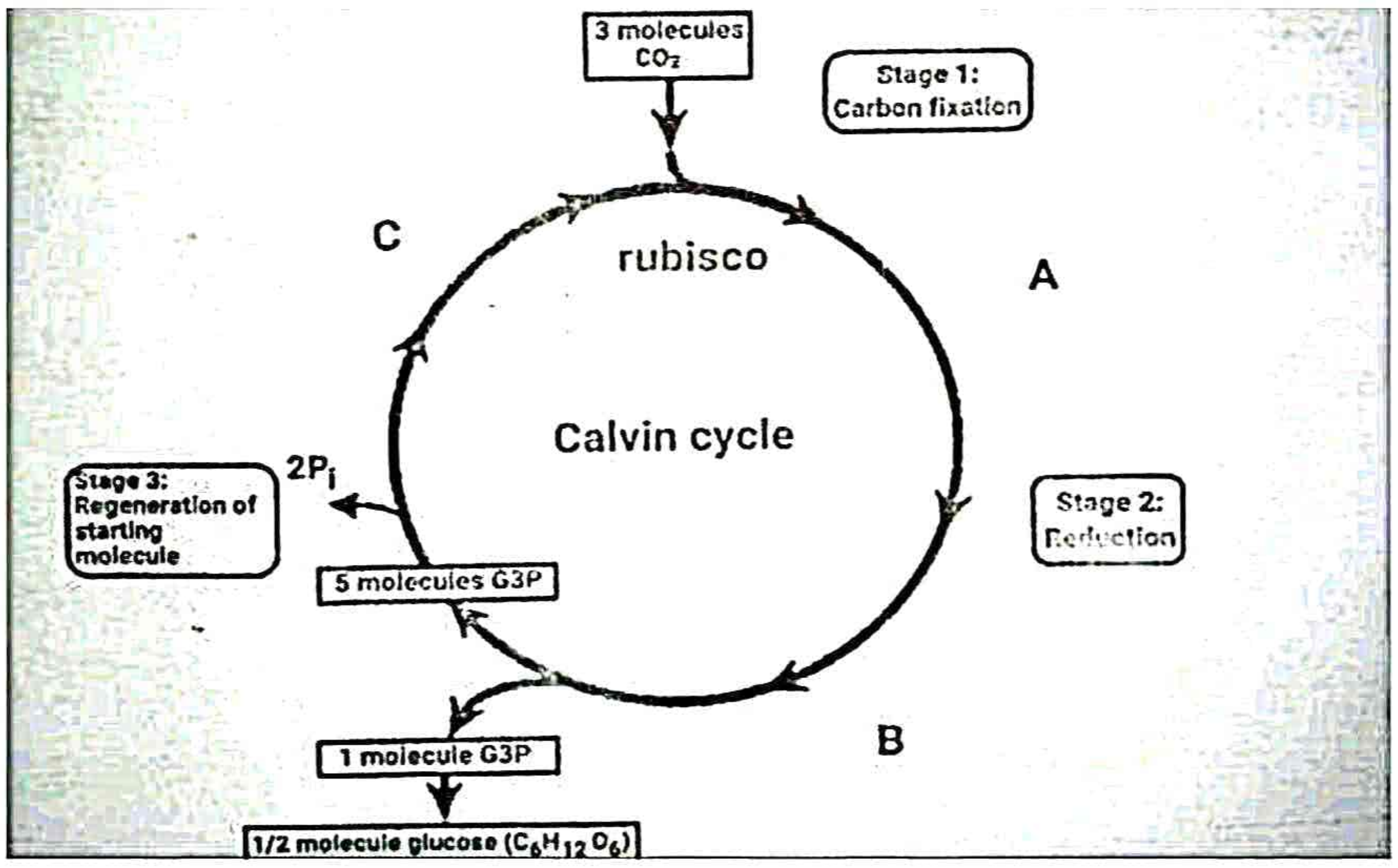
iii: 1-3-biphosphoglycer aldehyde is converted into Glycer aldehyde 3-Phosphate (GA 3P) by the release of phosphate group.

iv. Glycer aldehyde, 3-Phosphate combines with its isomer dihydroxyacetone Phosphate (DHAP) to form carbohydrate (glucose).
It is then further changed into sucrose or starch.

3. REGENERATION:
Ribulose biphosphate (RuBP) is an important compound which acts as CO_2 acceptor in the dark reaction of photosynthesis. Many carbon rearrangements occur during the process. Three carbon compounds are arranged in different manner due to which ribulose biphosphate (RUBP) is also regenerated.

During the process 6-molecules of 3-carbon compound i.e. triose (6 x C_3) are formed. From these 6 molecules five
are used to regenerate Ribulose biphosphate (RUBP).

NET YIELD AND CONSUMPTION:
In the formation of one glycerate 3 phosphate (G3P) molecule 9 molecules of ATP and six molecules of NADPH + H^+ are used.
Glycerate 3 phosphate (G3P) compound becomes the starting point in the formation of glucose and other carbohydrates.



CELLULAR RESPIRATON:

The aerobic breakdown of glucose molecule with accompanying synthesis of ATP is called cellular respiration.

On hydrolysis of ATP, under the action of enzyme ATPase, the terminal phosphate is removed with the result that ADP and Pi are formed and certain amount of energy is released.

TYPES OF RESPIRATION:

Respiration is classified into two types as aerobic and anaerobic respiration

AEROBIC RESPIRATION:

Respiration occurring in the presence of oxygen is called aerobic respiration. During aerobic respiration, food materials like carbohydrates, fats and proteins are completely oxidized into CO_2, H_2O and energy is released. Aerobic respiration is a very complex process and is completed in three major steps:

1. Glycolysis.
2. Krebs cycle.
3. Electron Transport chain.

ANAEROBIC RESPIRATION:

The primitive type of respiration which takes place in the absence of O_2 or without O_2 is called anaerobic respiration or fermentation.

During anaerobic respiration, glucose is not broken down completely so less amount of energy.

ALCOHOLIC FERMENTATION:

The bacteria and fungi respire aerobically but when these organisms are deprived of oxygen they stop respiration aerobically and start respiring anaerobically instead, During this anaerobic respiration they produce ethyl alcohol with CO_2.

$$\text{Glucose} \longleftarrow \text{Ethanol} + CO_2 + \text{Some energy}$$

$$C_6H_{12}O_6 \longleftarrow 2C_2H_5OH + 2CO_2 + \text{Some ATP}$$

CIDIC FERMENTATION:

In animals when aerobic respiration is not enough to produced required energy they tart anaerobic respiration. During this process glucose breaks down into a substance called lactic acid

Glucose ⟵ Lactic acid + Some energy

$C_6H_{12}O_6$ ⟵ $2C_3H_6O_3$

GLYCOLYSIS OR EM-PATHWAY:

The initial stage of respiration is called glycolysis in which O2 is not used. It is common both in aerobic and anaerobic respiration. It is divided into two phases.

1. Preparatory phase or endergonic phase or hexose phase (steps 1-5).
2. Pay off phase or oxidative phase or exergonic phase or triose phase (steps 6-10).

1. PREPARATORY PHASE:

Glucose enters the glycolysis from sucrose which is the end product of photosynthesis.

i. PHOSPHORYLATION:

When glucose reacts with ATP, a phosphate group from ATP is transferred to glucose. In this way glucose is phosphorylated to glucose-6-phosphate.

ii. ISOMERIZATION:

Glucose-6-phosphate is changed to its isomer fructose-6-phosphate.

Iii. PHOSPHORYLATION:

When fructose-6-phosphate reacts with another ATP, it is phosphorylated to Fructose- 1,6-bisphosphate.

Now fructose-1, 6-bisphosphate splits up to form one molecule each of 3 carbon compounds, glyceraldehyde 3 phosphate (G3P) and dihydroxyacetone phosphate (DHAP).

iv. SPLITTING:

Now fructose-1, 6-bisphosphate splits up to form one molecule each of 3 carbon compounds, glyceraldehyde 3 phosphate (G3P) and dihydroxyacetone phosphate (DHAP).

v. ISOMERIZATION:

- The dihydroxyacetone 3-phosphate is ultimately changed into its isomer, the glyceraldehyde 3-phosphate (G3P).
- In this way preparatory phase is completed. Next phase of glycolysis is proceeded by two molecules of G3P, therefore, the remaining reactions occur twice.
- During preparatory phase two ATP molecules are consumed in step-1 and step-3.

2. PAY OFF PHASE

In this part of glycolysis ATP molecules are synthesized hence it is called energy yielding phase or pay off phase.

Vi. OXIDATION AND PHOSPHORYLATION:

- Glyceraldehyde-3-phosphate oxidized and reduced NADH. Its accepts inorganic phosphate (Pi) to form 1, 3- diphosphoglycerate.
- This is a redox reaction where Glyceraldehyde-3-phosphate (PGAL) is oxidized by removal of electrons and NAD is reduced by the addition of electrons, With the loss of two hydrogen atoms glyceraldehyde-3-phosphate or PGAL is converted into Phosphoglyceric Acid (PGA).
- Phosphoglyceric Acid (PGA) picks up phosphate group (Pi) present in cytoplasm and becomes 1-3 diphosphoglycerate (DPGA)

vii. DEPHOSPHORYLATION OR FORMATION OF ATP:

The direct synthesis of ATP from organic phosphorylated substrate is called substrate level phosphorylation. In this step a molecule of ATP is formed from 1,3- bisphosphoglycerate which is changed into 3-phosphoglycerate.

viii. ISOMERIZATION:

In this step position of phosphate group is changed from C3 to C_2

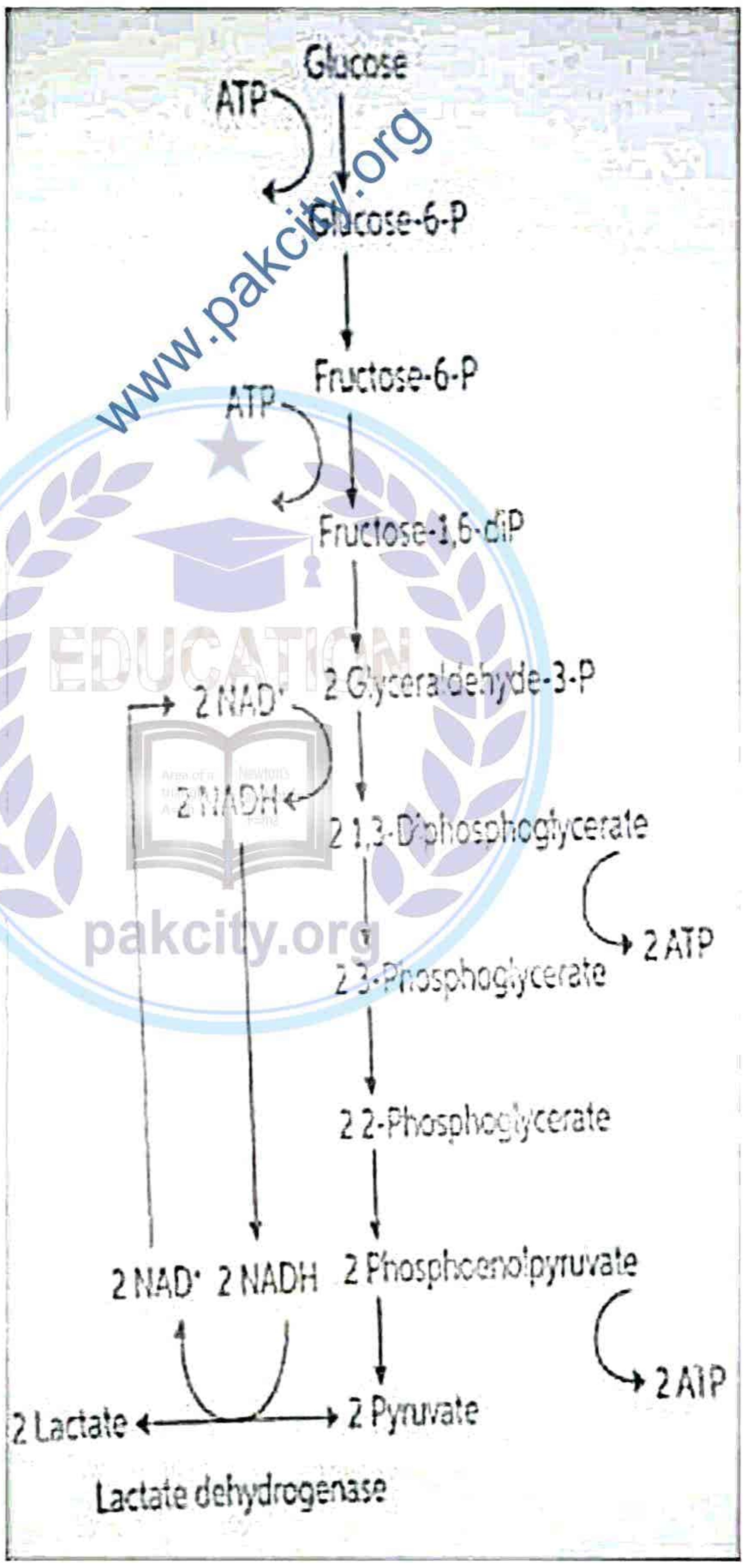
• 3-phosphoglycerate is converted into 2-phosphoglycerate.

ix. DEHYDRATION:

2-phosphoglycerate undergoes dehydration and is converted into phosphonyl pyruvate (PEP).

3.ENERGY BUDGET:

In the payoff phase totally 4ATP and 2NADH + H^+ molecules are produced. Since 2ATP molecules are already consumed in the preparatory phase, the net products in glycolysis are 2ATPs and 2NADH + H^+.



FERMENTATION:

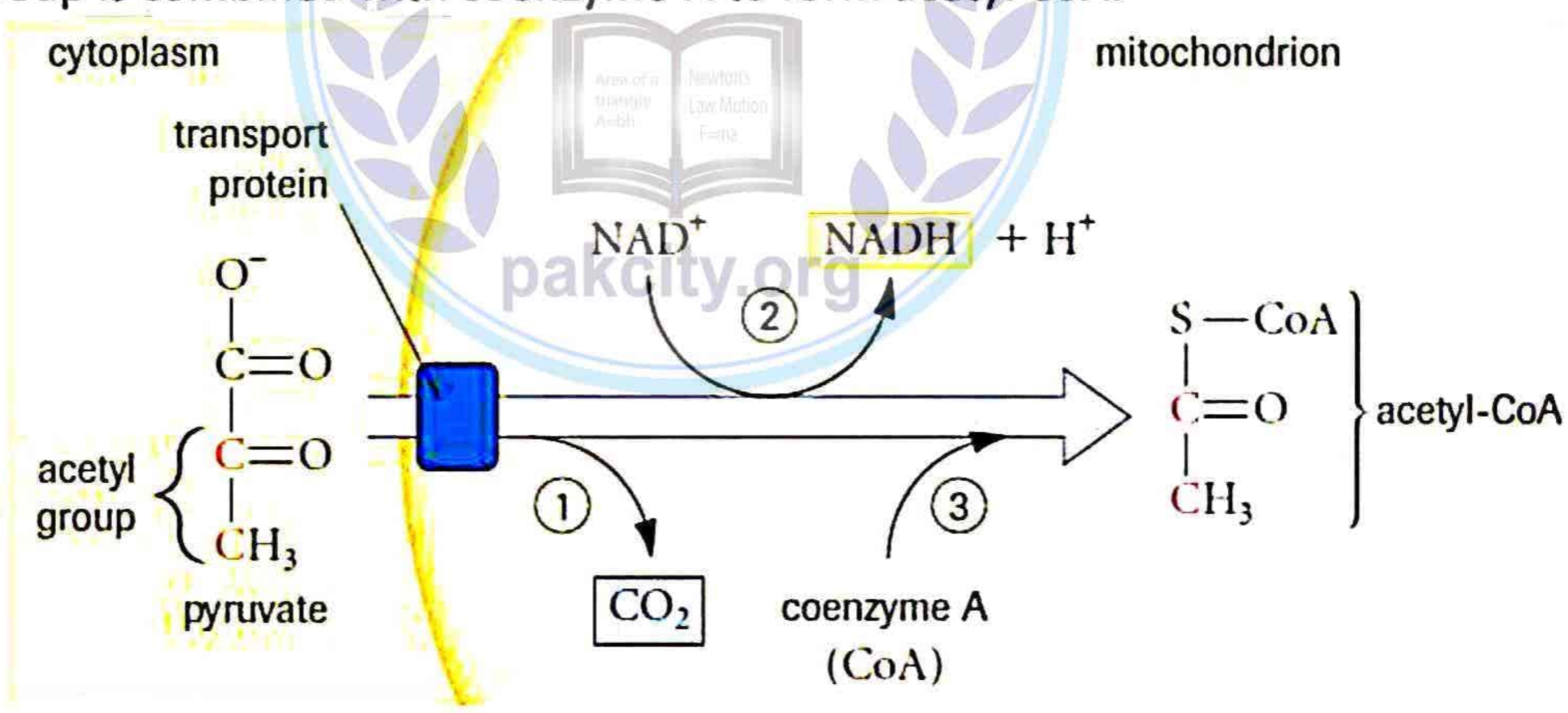
Anaerobic respiration (without O2) is also called fermentation. When ethyl alcohol is formed in this process, it is called anaerobic respiration. When lactic acid is formed in the process, it is called lactic acid fermentation.

ECONOMIC IMPORTANCE OF FERMENTATION:

- Fermentation, still an inefficient method of harvesting biological energy, is an efficient source of many valuable products such as ethyl alcohol, lactic acid, propionic acid and butanol.
- Thus, it has been of great interest to human beings.
- Brewing and dairy industries depend on fermentation .
- It is the source of ethyl alcohol in wines and beers.
- Wines are produced by fermenting fruits particularly grapes
- Beers are produced fermenting malted cereals such as barley.
- Yeast cells are used to make dough rise before it is baked to make bread.
- Cheese, yoghurt and other dairy products are produced by microbial fermentation.
- Lactic acid which is slightly sour, acid imparts flavor to yoghurt & cheese. Dairy products containing lactic acid are more resistant to spoilage. The characteristic flavor of pickles is due to lactic and acetic acid.
- Acetone and other industrially produced solvents are also by-products of fermentation.

PYRUVATE OXIDATION (LINK REACTION):

- Pyruvates do not directly participate in Krebs cycle but they undergo an intermediate phase, called oxidation of pyruvate or link reaction as it links the pathway of aerobic respiration that occurs outside the mitochondria with that occurs inside the mitochondria.
- The oxidation of pyruvate takes place in three steps.
- First, it undergoes decarboxylation in which a molecule of CO2 is removed from Pyruvate to form acetaldehyde.
- In second step NAD removes hydrogen from acetaldehyde. As a result of this oxidation/ dehydrogenation a 2Cfragment acetyl and NADH are produced.
- Finally, acetyl group is combined with coenzyme-A to form acetyl CoA.



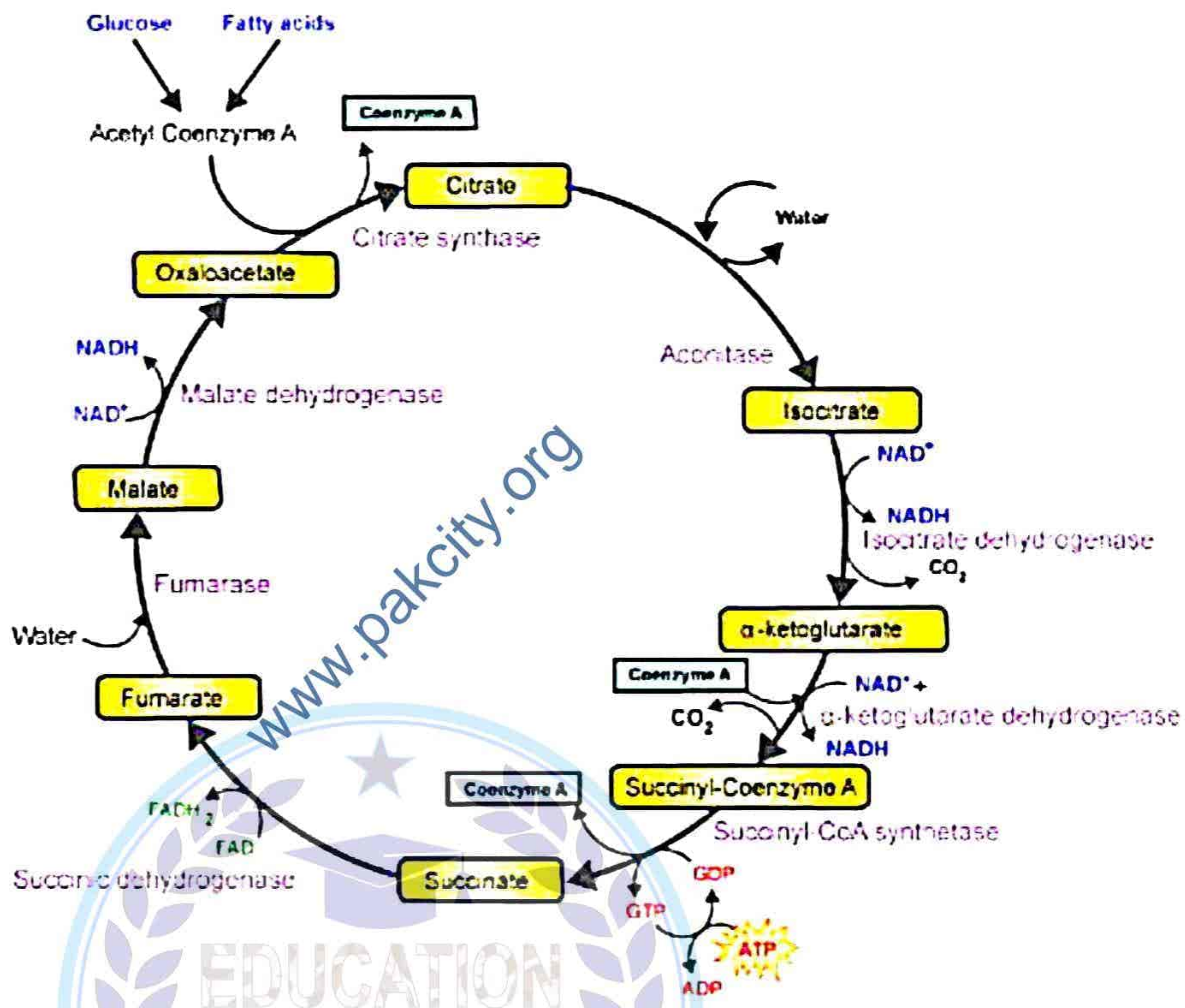
Krebs's Cycle (Citric Acid Cycle):

In the presence of sufficient amount of oxygen the pyruvic acid is oxidized. In the presence of co-enzyme A, it release CO_2 and changes into acetyl co-enzyme A. the acetyl co-enzyme A enters the Krebs's cycle. The details of Krebs's cycle is as follows:

- The acetyl CoA combines with oxalic acetic acid and changes into citric acid. A is released and one molecule is used.

- Citric acid is converted into cis-aconitic acid in the presence of enzyme in which an H_20 molecule is released.
- From succinyl CoA, compound CoA is released and converted into succinic acid. Succinic acid is converted into fumaric acid. In this process FAD receive two hydrogen atoms from succinic acid.
- Cis-aconitic acid is converted into Isocitric acid. Water molecule is used.
- Isocitric produces oxalo-succinic acid produces CO_2 and changes into a-Keto-gluteric acid. The a-Keto-gluteric acid further releases CO2 in the presence of CoA forming succinyl CoA. Hydrogen releases and combines with NAD to form NADH2.
- Fumaric acid is changed into Maleic acid by the release of H20.
- In citric acid cycle, Maelic acid changed into oxalo-acetic acid.

The oxalo acetic-acid again picks up another acetyl CoA and Krebs's Cycle starts once again.



ELECTRON TRANSPORT CHAIN (ETC) (RESPIRATORY CHAIN) (TERMINAL OXIDATION):

Electron transport chain is the last stage of aerobic respiration. This process takes place in mitochondria. These steps are as follows:

- Hydrogen atom releases in the process of glycolysis and Krebs's cycle. Its electron is accepted by NAD and converted into $NADH_2$.
- From $NADH_2$, a pair of electron is transferred to FAD. In this step ATP is formed.
- From FAD, electrons area transferred into cytochrome (cyt. b).
- From cyt. b, electrons are transferred into cytochrome c.
- From cyt. c, electrons are transferred into cytochrome a.
- From cyt. a, electrons are transferred into cytochrome a3. In this step, ATP molecule is produced.
- In addition, the energy is liberated which is also react with ATPase to synthesize third and final ATP molecule from one molecule of $NADH_2$.
- The synthesis of ATP during electron transport chain in the presence of oxygen is called oxidative phosphorylation.
- After the completion of process, hydrogen combines with O_2 to form H_2O. Complete oxidation of glucose molecule results in a net gain of 36 ATP molecules which are released in cytoplasm available for different metabolic reactions.

CELLULAR RESPIRATION OF FATS AND PROTEINS.

a) Fats

• When a fat is used as an energy source, it breaks down to glycerol and three fatty acids. In which glycerol is converted to G3P, a metabolite in glycolysis.

• The fatty acids are converted to acetyl-CoA, which enters the Krebs cycle.

• An 18-carbon fatty acid results in nine acetyl-coA molecules.

b) Protein:

• The protein hydrolyzed into amino acids whose R-group size determines whether the carbon chain is oxidized in glycolysis or the Krebs cycle.

• The carbon chain is produced in the liver when an amino acid undergoes deamination, the removal of the amino group. The amino group becomes ammonia (NH,), which enters the urea cycle and becomes part of urea.

PHOTORESPIRATION:

• The photorespiration occurs in green cells in the presence of light and release of carbon dioxide. It needs oxygen and produce CO2 and H2O like aerobic respiration.

• However ATP is not produced during photorespiration and it's known as waste full process.

MECHANISM OF PHOTORESPIRATION:

• When the CO_2 levels inside the leaf drop than Ribulose bisphosphate. carboxylase/oxygenase (RuBisCO) starts to combine O_2 with RuBP instead of CO_2 and producing two molecules phosphoglycerate (PGA), phosphoglycolate.

• The Phosphoglycolate breaks into three steps and to release carbon dioxide.

• First it immediately removes of the phosphate group, converting the molecule to glycolate.

RuBP+O2 ← Phosphoglycolate + Phosphoglycerate ← Glycolate

Glycolate ← Glycine

Glycine ← Serine+CO_2

• The Glycolate is then transported to the peroxisome and converted to glycine.

• The glycine is then transported into the mitochondria where it is converted into serine and release CO_2.

• The serine is then used to make other organic molecules.

ALTERNATIVE MECHANISMS OF CARBON FIXATION IN HOT, ARID CLIMATE:

To avoid photorespiration some plants adapt themselves by developing following alternative mode of carbon dioxide fixation.

i. C4 Cycle

ii. Crassulacean acid metabolism (CAM)

C4 CYCLE OR DICARBOXYLIC ACID OR HATCH & SLACK:

This alternative mechanism of CO2 fixation found in several tropical and sub-tropical plants,

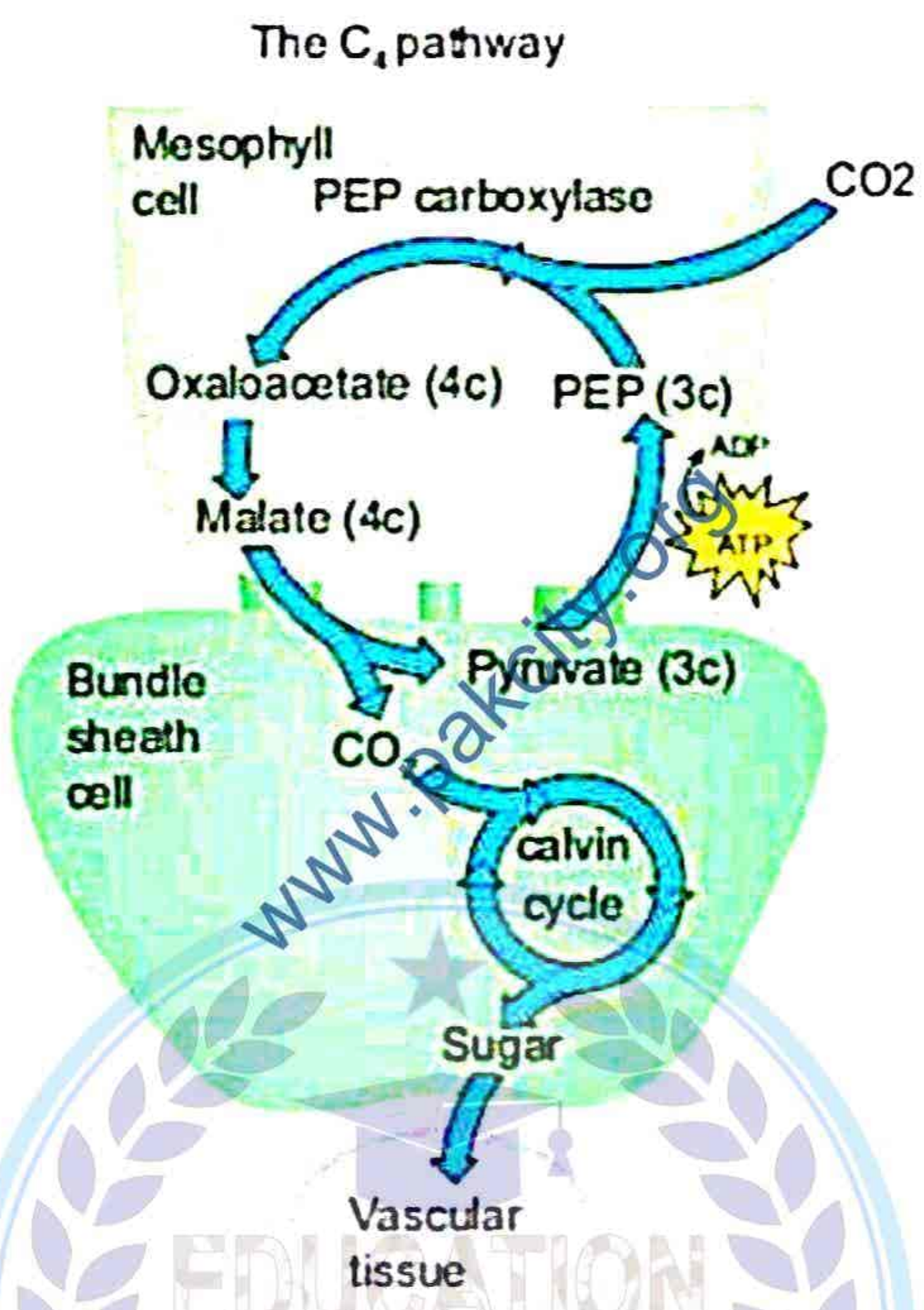
Mechanism Of C4 Cycle:

First CO_2 is fixed with phosphor enol pyruvate form 4-Carbon oxaloacetate by the help of enzyme called PEP carboxylase in the mesophyll cells than Oxaloacetate convert into malate and its transfer from mesophyll cell to bundle sheet cell. Inside the bundle sheath, malate breaks down, releasing a molecule of CO_2

How They Minimizes Photorespiration:
However, because the mesophyll cells constantly pump CO_2 into neighbouring bundle- sheath cells in the form of malate, there's always a high concentration of CO_2 relative to O_2 right around Rubisco. This strategy minimizes photorespiration.

SIGNIFICANCE OF C4 CYCLE:

- Plants having C_4 cycle are mainly of tropical and sub-tropical regions and are able to survive in environment with low CO_2 concentration.
- C_4 plants are partially adapted to drought conditions.
- Oxygen has no inhibitory effect on C_4 cycle since PEP carboxylase is insensitive to O_2 Due to absence of photorespiration, CO_2 Compensation Point for C_3, is lower than that of C3 plants.



CRSSULACEAN ACID METABOLISM:

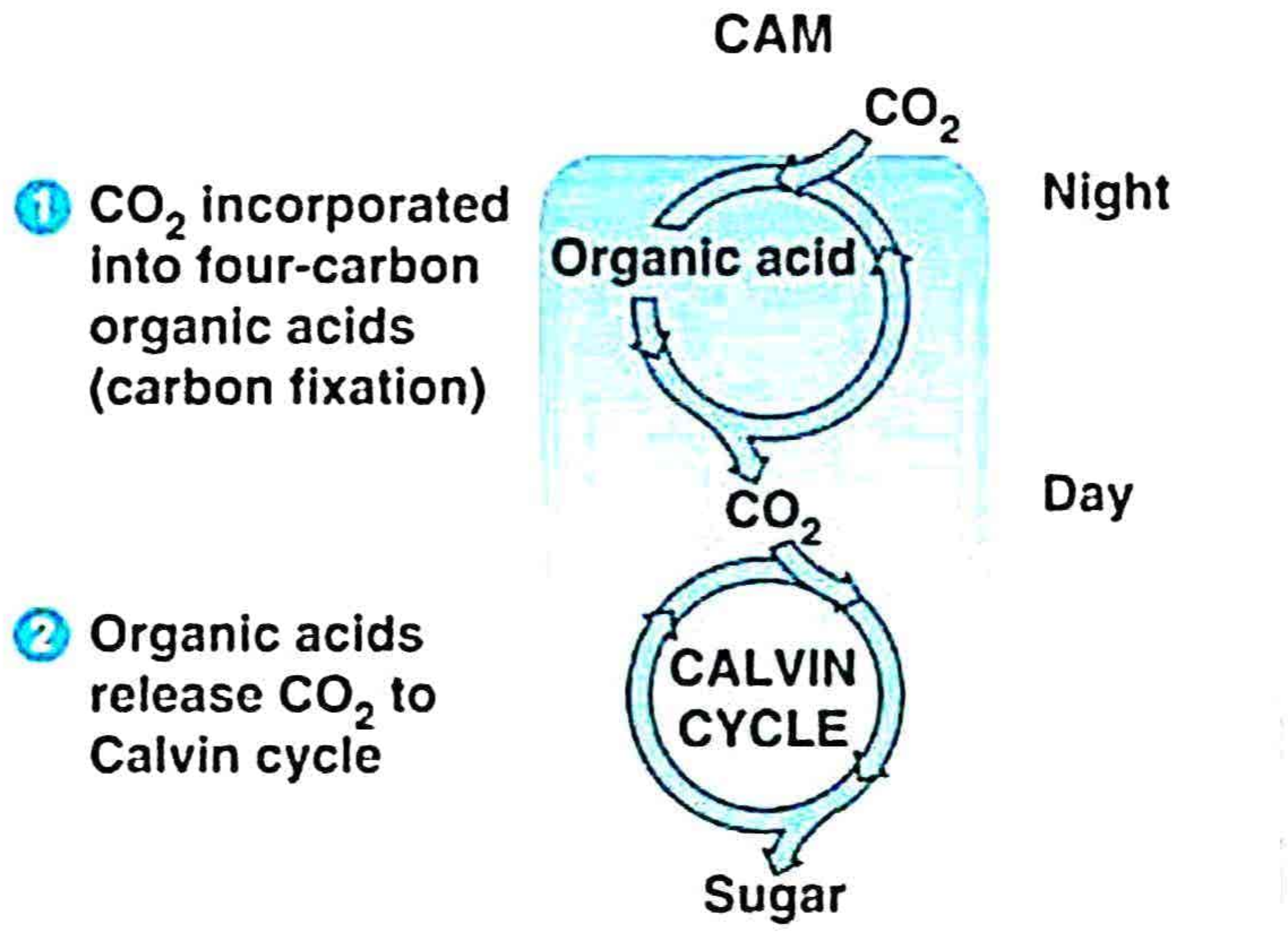
- It is one of the carbon pathways identified in succulent plants growing in semi-arid or xerophytic condition.
- The stomata are closed during day and are open during night.
- This reverse stomatal rhythm helps to conserve water loss through transpiration and will stop the fixation of CO_2 during the day time.
- At night time CAM plants fix CO_2 with the help of Phospho Enol Pyruvic acid (PEP) and produce oxalo acetic acid (OAA). Subsequently OAA is converted into malic acid like C_4 cycle and gets accumulated in vacuole increasing the acidity.

- During the day time stomata are closed and malic acid is decarboxylated into pyruvic acid resulting in the decrease of acidity.
- Thus CO2 formed and enters into Calvin Cycle and produces carbohydrates.

SIGNIFICANCE OF CAM CYCLE:

1. It is advantageous for succulent plants to obtain CO2 from malic acid when stomata are closed.
2. During day time stomata are closed and CO2 is not taken but continue their photosy

3. Stomata are closed during the day time and help the plants to avoid transpiration and water loss.



DIFFERENCE BETWEEN CHLOROPHYLL (a) AND CHLOROPHYLL (b)

CHLOROPHYLL (a)	CHLOROPHYLL (b)
Chlorophyll (a) is the primary photosynthetic pigment.	Chlorophyll (b) is the accessory pigment that collects energy and passes it on to chlorophyll (a).
Chlorophyll (a) absorbs energy from wavelengths of blue violet and orange red light.	Chlorophyll (b) absorbs energy from wavelengths of green light.
Chlorophyll (a) absorbs energy at 675nm	Chlorophyll (b) absorbs energy at 640 nm.
Chlorophyll (a) is less absorbent	Chlorophyll (b) is more absorbent
Chlorophyll (a) has methyl ($-CH_3$) as a functional group.	Chlorophyll (b) has carbonyl (-CHO) as a functional group.

DIFFERENCE BETWEEN LIGHT REACTION AND DARK REACTION:

LIGHT REACTION	DARK REACTION
1. This phase requires light.	This phase does not require light.
2. In this process CO_2 does not play any role.	In this phase CO_2 enters the process and helps in the formation of glucose.
3. Glucose is not produced in this phase.	Glucose is produce in this face.
4. In this system light is used in the photolysis of water.	In this system there is no photolysis of water.
5. In this process chlorophyll absorbs sunlight.	In this phase there is no role of chlorophyll.
6. In this phase pigment Sys I (P.S.I) and pigment system II (P.S.II) are involved.	P.S.I and P.S.II are not involved in this phase.

DIFFERENCES BETWEEN CYCLIC PHOTOPHOSPHORYLATION AND NON-CYCLIC PHOTOPHOSPHORYLATION:

CYCLIC PHOTOPHOSPHORYLATION	NON-CYCLIC PHOTOPHOSPHORYLATION
1. PS I only involved.	1. PS I and PS II involved.
2. Reaction centre is P700.	2. Reaction centre is P680.
3. Electrons released are cycled back.	3. Electron released are not cycled back.

4. Photolysis of water does not take place.	4. Photolysis of water takes place.
5. Only ATP synthesized.	5. ATP and NADPH 1 H1 are synthesized.
6. Phosphorylation takes place at two places.	6. Phosphorylation takes place at only one place.
7. It does not require an external electron donor.	7. Requires external electron donor like H_2O or H_2S.

DIFFERENCES BETWEEN AEROBIC AND ANAEROBIC RESPIRATION

AEROBIC RESPIRATION	ANAEROBIC RESPIRATION
1. It occurs in all living cells of higher organisms.	It occurs in yeast and some bacteria.
2. It requires oxygen for breaking the respiratory substrate.	Oxygen is not required for breaking the respiratory substrate.
3. The end products are CO_2 and H_2O.	The end products are alcohol, and CO_2 (or) lactic acid.
4. Oxidation of one molecule of glucose produces 36 ATP molecules.	Only 2 ATP molecules are produced.
5. It consists of four stages- glycolysis, link reaction, TCA cycle and electron transport chain.	It consists of two stages- A glycolysis and fermentation.
6. It occurs in cytoplasm and mitochondria.	It occurs only in cytoplasm.

DIFFERENCES BETWEEN ALCOHOLIC FERMENTATION AND LACTIC ACID FERMENTATION:

ALCOHOLIC FERMENTATION	LACTIC ACID FERMENTATION
1. It produces alcohol and releases CO_2 from pyruvic acid.	It produces lactic acid and does not release CO_2 from pyruvic acid.
2. It takes place in two steps.	It takes place in single step.
3. It involves two enzymes, pyruvate decarboxylase with Mg++ and alcohol dehydrogenase.	It uses one enzyme, lactate dehydrogenase with Zn^{++}.
4. It forms acetaldehyde as intermediate compound.	Does not form any intermediate compound.
5. It commonly occurs in yeast.	Occurs in bacteria, some fungi and vertebrate muscles.

DIFFERENCES BETWEEN C3 AND C4 PLANTS:

C3 PLANTS	C4 PLANTS
1. CO_2 fixation takes place in mesophyll cells only.	1. CO_2 fixation takes place mesophyll and bundle sheath.
2. CO_2 acceptor is RUBP only.	2. PEP in mesophyll and RUBP in bundle sheath cells.
3. First product is 3C- PGA.	3. First product is 4C- OAA.
4. Granum is present in mesophyll cells.	4. Granum present in mesophyll cells and absent in bundle sheath.
5. Optimum temperature 20_0 to 25_0C.	5. Optimum temperature 30_0 to 45_0C.
6. Fixation of CO_2 at 50 ppm.	6. Fixation of CO_2 even less than 10 ppm.
7. Less efficient due to higher photorespiration.	7. More efficient due to less photorespiration.
8 RUBP carboxylase enzyme used for fixation.	8. PEP carboxylase and RUBP carboxylase used.
9.18 ATPs used to synthesize one glucose.	9. Consumes 30 ATPs to produce on

10. Example: Paddy, Wheat, Potato and so on.	10. Example: Sugar cane, Maize, Sorghum, Amaranthus.

REASONS:

Q#1: Where energy is stored?

COMPLEX COMPOUNDS:

The energy is used as fuel for life, the energy is derived from light energy which is trapped by plant and converted into energy rich compounds like ATP, $NADPH_2$ and $FADH_2$ which is then stored in molecules like carbohydrates,
Lipids etc.

Q#2: Why energy is required?

METABOLISM:

All the living organisms perform a number of daily activities such as digestion, respiration, excretion and reproduction for these activities energy is required.

Q#3: How ATP act as energy currency?

COMPLEX ENERGY COMPOUNDS:

ATP act as mediator, receiving energy from one reaction and transfer This energy to another compound. In ATP molecules, there is a strong bond between ADP and Pi molecule. This bond breakage provides a bulk of energy.i.e. 7.3 K cal/mole.

Q#4: Why antenna complex contain other pigments with chlorophyll?

INITIATERS:

In photosystem, antenna complex contains different colour pigments such as: carotenoids having different spectrums and wavelengths. These clusters of pigments gathers energy and initiates electron transport chain, which leads to first light dependent reaction.

Q#5: Why photosynthesis called redox-Reaction?

REDOX-REACTION:

Photosynthesis is called Redox-Reaction, because in photosynthesis both oxidation & reduction occurs such as reduction of NADP. To $NADPH_2$ reduction of carbon and oxidation of water etc.

Q#6: How cyclic photo-phosphorylation is helpful?

REDUCTION OF STEPS:

Sometimes during photo-phosphorylation, excited electrons do not move towards NADP, they take an alternative pathway, i.e. cyclic flow of electrons. It is helpful in such a way that there is production of ATP, ATP as an individual fulfil energy requirements for further steps of photosynthesis, within only one photosynthesis (i.e. photosystem I) and one redox reaction chain.

Q#7: Why calvin cycle is also called C_3-Cylce?

C_3-CYCLE:

Calvin Cycle is also called C_3-Cylce, because during the cycle, CO_2 is reduced to two molecule of three carbon compound i.e. 3PGA, that's why, cycle is also called as C_3-Cylce.

Q#8: Why oxidation of pyruvate required more energy than Lactic Acid fermentation?

REQUIRMENTS:

Oxidation of pyruvate requires more energy than Lactic Acid fermentation, because oxidation of pyruvate occurs in the presence of oxygen and involves number of processes. While, Lactic Acid fermentation is a part of an aerobic respiration, which occurs quickly at the time of need and provides few amount of energy.

Q#9: Why G_3P is an important molecule?

IMPORTANCE OF G_3P:

G_3P plays an intermediate role in respiration and photo-synthesis. It appears during glycolysis which leads to the formation of pyruvate. On the other hand G_3P is the initial source of carbohydrates like sucrose, Glucose etc.

Q#10: How photo-respiration is considered as dis-advantageous process?

CONSUMPTION OF 02:

During day-time plant oxidizes pentose sugar, For this plant uses own manufactured, and by-product releases carbon-dioxide, without production of ATP and $NADPH_2$, that's why Photo-respiration is considered as disadvantageous process.

Q11: Why red & blue part of spectrum are more efficient?

ABSORPTION SPECTRUM:

Peaks of action and absorption spectrum of chlorophyll and other pigments is different the difference occurs due to the accessory pigments in the carotenoids. The absorption spectrum of blue & red is 430nm-670nm respectively, Which helps them to work efficiently.

Q#12: Why ATP formation during photosynthesis is called non-cyclic photophosphorylation?

ATP FORMATION AS NON-CYLIC PHOTOPHOSPHORYLATION:

During photosynthesis formation of ATP is non-cyclic because of linear flow of electron from water to NADPH electron never back to its initial state and coupled of ATP are synthesized.

Q#13: Why ATP formation during glycolysis is called substrate level phosphorylation?

ATP AS SUBSTRATE LEVEL:

During glycolysis ADP directly phosphorylated by the help of enzyme with the removal of high energy phosphate from 1,3 diphosphoglycerate and phosphor enol pyruvate.

Q#14: Why photo respiration is called waste full process?

PHOTORESPIRATION AS WASTE FULL PROCESS:

When supply of CO_2 inside the leaf is low than most of Rubisco combine with O_2 giving one molecule of phosphoglycerate and one molecule of phosphoglycerate. Where phosphoglycerate breaks and release CO_2 by the utilization of ATP and NADH and no one ATP and NADH are formed that's why it's known as waste full process.

Q#15: How plants adopt themselves to avoid from photo respiration?

PREVENTATION FROM PHOTO RESPIRATION:

Plant adopt alternative mechanism of carbon di oxide fixation that minimize photorespiration even in hot and arid environment these mechanism are C_4 and CAM.