Extensive Questions

23. What is photosynthesis? Explain the role of light in photosynthesis.

Ans: Photosynthesis:

Chemically photosynthesis is "redox" process in which CO_2 (an oxidized form of carbon) is reduced into glucose (a reduced form of carbon). Water acts as reducing agent which is oxidized into oxygen during his process. Bio-energetically photosynthesis can be defined as an energy conversion process in which energy poor molecules i.e, CO_2 and H_2O are transformed into energy rich molecule such as glucose. The extra energy is absorbed in the form of sunlight by the photosynthetic pigments.

The overall reaction of photosynthesis can be summarized as follows:

Reduction

$$6CO_2 + 12H_2O^{18} \xrightarrow{\text{light}} C_6H_{12}O_6 + 6H_2O + 6O_2^{18}$$

Carbon dioxide | Water | Chlorophyll | Glucose | Water | Oxygen

Oxidation

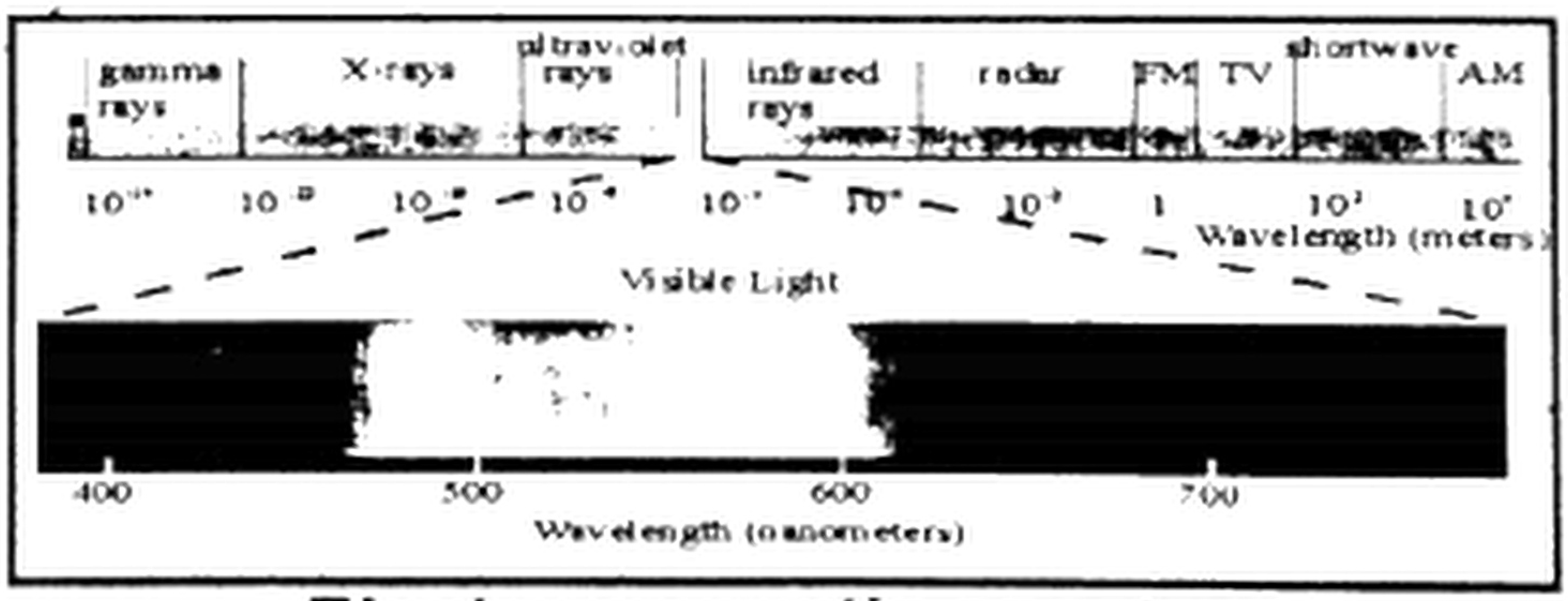
The above mentioned main concept of photosynthesis indicates that this process involves the interaction of sunlight, pigments, water and carbon dioxide.

Role of light:

Sunlight is an electromagnetic or radiant form of energy. The full range of electromagnetic radiation in the universe is called **electromagnetic spectrum**.

Visible light is only a small part of the spectrum between 380 nm to 750 nm

Which is not only seen by naked eye but is also effective for the process of photosynthesis



Electromagnetic spectrum

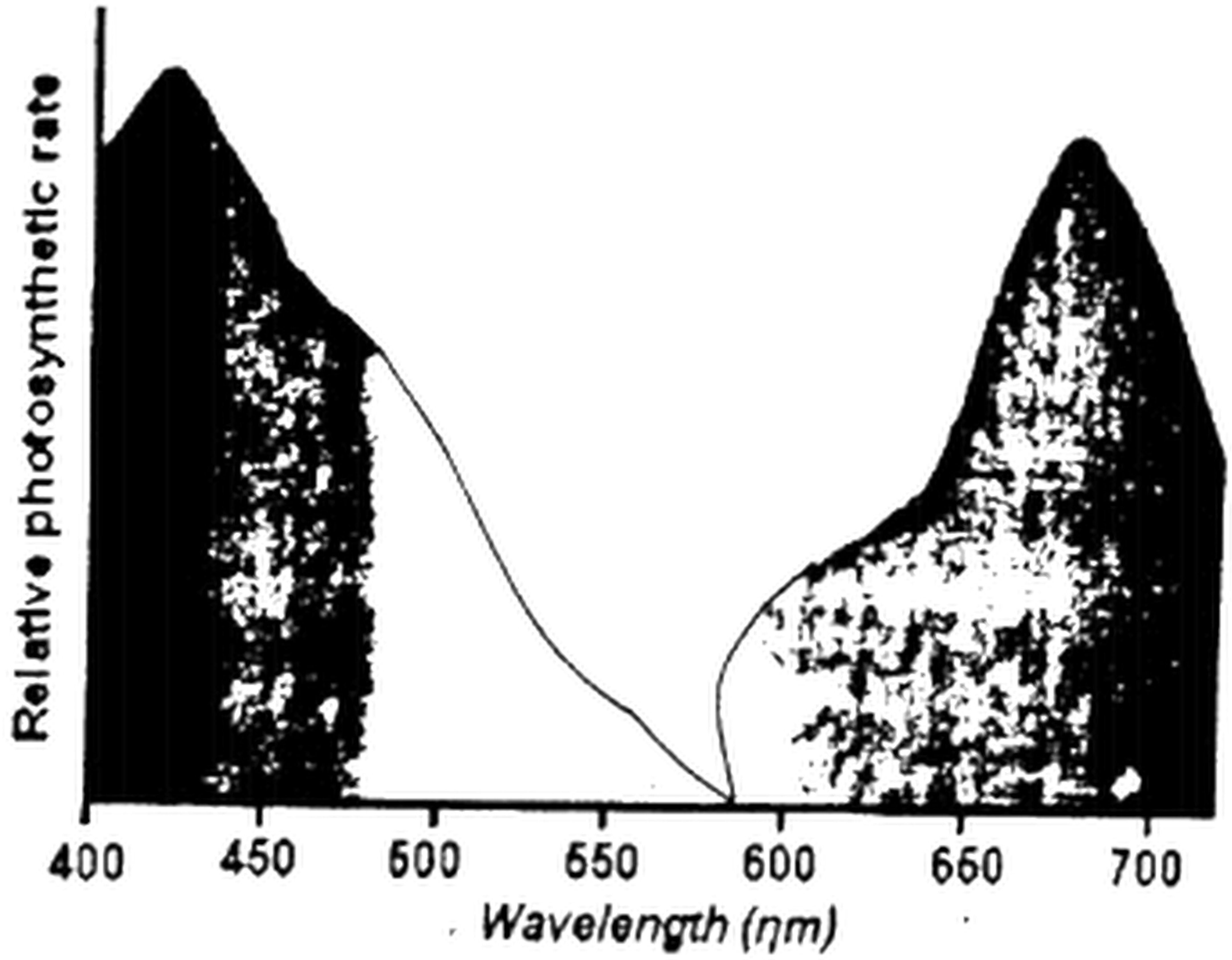
Effectiveness of wavelength of light:

The effectiveness of a particular wavelength of light for the process of photosynthesis primarily depends upon its absorption in plant body. As different wavelengths (colours) of visible light are differently absorbed by various photosynthetic pigments, therefore, each wavelength has its own effectiveness for the process of photosynthesis.

Action Spectrum:

If a plant is illuminated in different colours of light one by one, the rate of photosynthesis is measured and the data obtained in this way is plotted in a graph, you will see that the rate of photosynthesis will be variable in different colours of light. Such a graph which shows the effectiveness of different wavelength of light for the process of photosynthesis is called **action spectrum**.

Analysis of action spectrum indicates that blue (430nm) and red(670nm) wavelengths of light are the most effective for the process of photosynthesis.



Action spectrum of photosynthesis

Photosystem:

Light is absorbed in the form of photos by the **photosystem** (a cluster of photosynthetic pigments). The absorption of photons causes photoelectric effect i.e, excitation of electrons in the atoms of photosystem and ultimately these excited electrons leave the photosystem. These excited electrons after leaving the photosystem begin to flow through an electron transport chain and their energy is utilized in formation of ATP and NADPH2 by chemiosmosis mechanism.

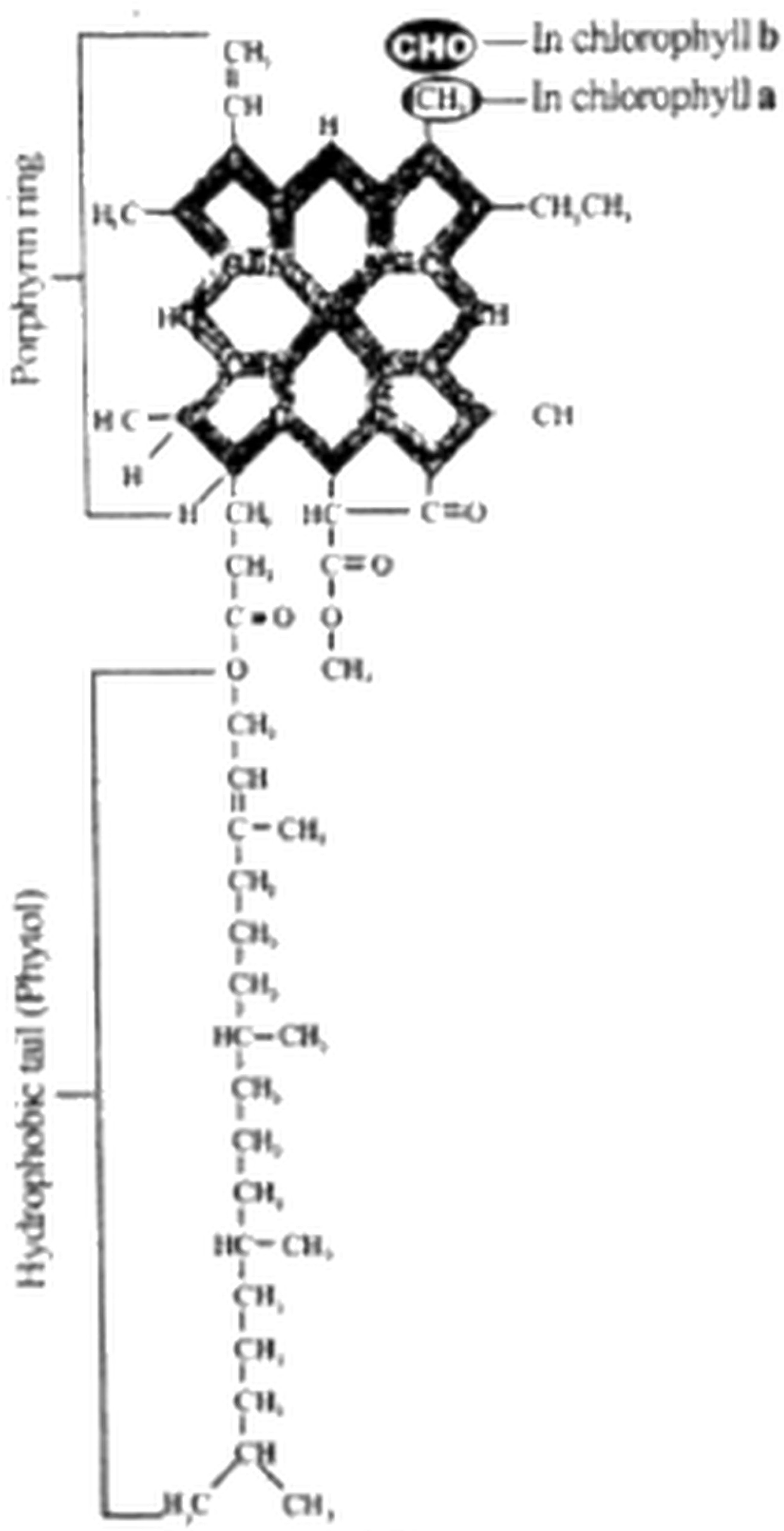
24. Describe the structure of chlorophyll.

Ans: Chlorophyll:

Chlorophyll absorb mainly violet, blue, orange, and red wavelengths. Green and yellow are least absorbed and are transmitted or reflected.

Types of Chlorophyll:

Two major types of chlorophyll are Chlorophyll-a and Chlorophyll-b.



Structure of Chlorophyll

i. **Chlorophyll-a:**
Chlorophyll-a is a bluish green pigment which is found in all photosynthetic organisms excepts photosynthetic bacteria.

ii. **Chlorophyll-b:**
Chlorophyll-b is yellowish green pigment which is also found in all photosynthetic organisms except brown, red algae and photosynthetic bacteria.

Algae also have some other form of chlorophyll i.e, Chl-c, Chl-d and Chl-e while photosynthetic bacteria have yet another type ofchlorophyll i.e, bacteriochlorophyll.

Molecular formula of chlorophyll a and b:

Chlorophyll a=C55 H72 O5 N4 Mg

Chlorophyll b=C55 H70 O6 N4 Mg

Structure of Chlorophyll:

A molecule of chlorophyll consists of a head and two tails.

Head:

The head is composed of a porphyrin ring with Mg in the centre. The porphyrin ring furthur 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 (-CH3) on 2nd pyrrole ring whereas chlorophyll-b has aldehyde group (-CHO) 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.

Tails:

The two side chains in the chlorophyll molecule are called tails. One sided chain consists of a long chain terpnoid alcohol phytol (C20 H39) esterified with propionic acid. This chain is linked with 4th pyrrole ring of the head. The other side chain consists of methyl (CH3) ester which is linked to head between 3rd and 4th pyrrole rings of porphyrin. The chlorophyll tails are hydrophobic in nature. They are embedded into the thylakoid membranes and serve to anchor the chlorophyll molecule in the membrane.

25. Write a note on the photosynthetic pigment carotene.

Ans: Role of photosynthetic pigments:

Pigment is any substance that absorbs light energy. All the wavelengths which are absorbed by a pigment are disappeared. Aparticular pigment shows only those wavelengths which are reflected back. All the pigments that take part in photosynthesis are embedded in thynakoid membranes (grana lamella) within chloroplasts. Higher plants have two major group of pigments i.e, chlorophyll and carotenoids.

Carotenoids:

Carotenoids are terpenoid lipids, which are yellow, orange, red or brown pigments.

Spectrum of Carotenoids:

They absorb light strongly in the blue-violet range. They are seen in leaves before leaf fall, present in some flowers and fruits.

Role of Carotenoids:

The carotenoids act as accessary pigment along with chlorophyll-b as, they absorb light energy and then tranfer it to the chlorophyll-a. Therefore, they protect the chlorophyll-'a' from excess of light. They also attract insects, birds and other animals for pollination and disperal.

Types of Carotenoids:

There are two types of caroteniods, carotenes and xanthophylls.

i. **Carotenes:**
The carotenes are orange red pigments, composed of isoprenoid units and are found in all photosynthetic eukaryotes. The most widespread and important carotene is ß (beta) carotene.

ii. **Xanthophylls:**
Xanthophylls are yellow in colour and are also composed of isoprenoid units Lutein is widely distributed xanthophylls which is responsible for yellow colour of foliage in autumn.

26. Explain the arrangement of photosystems.

Ans: Arrangements pf pigments (Photosystems):

For efficient absorption and utilization of light energy, the photosynthetic pigments are arranged in the form of clusters in thylakoid membranes. These clusters are called **photosystems.**

Structure of Photosystem:

The pherioheral part of photosystem is called **antenna complex** which consists of neceesary pigments such as chlorophyll-b and carotenoids. The central part of photosystem is called **reaction centre** which contains only chlorophyll-a and associated proteins. Since chlorophyll-a generally has an optimal absorption wavelength of 660nm.

Types of Photosystem:

It associates with different proteins in each type of photosystem to slightly shift its optimal wavelength, producing two distinct photosystem types i.e, photosystem-I (PS-I) and photosystem-II (PS-II).

Photosystem-I (PS-I):

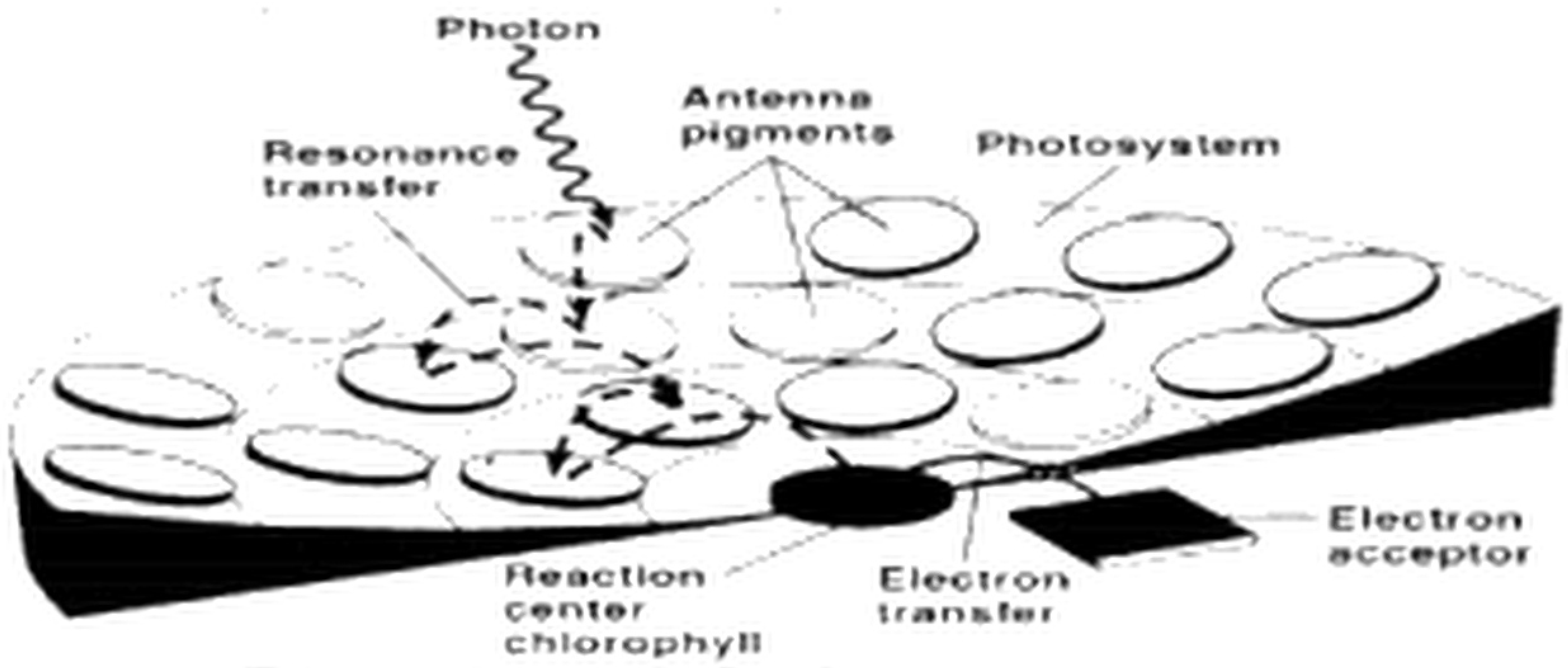
The chlorophyll-a in the reaction centre of PS-I can absorb maximum 700nm wavelength of light, hence called P700.

Photosystem-II (PS-II):

Similarly, the chlorophyll-a in the reaction centre of PS-II can absorb maximum 680nm wavelength of light, hence called P680. The photosystems are named for the order in which they were discovered and not for the order in which they occur in the thylakoid membrane.

Electron Transport:

As chlorophyll-a can only absorb light of a narrow wavelength, it works with the pigments of antenna complex to gain energy from a larger part of spectrum. The pigments absorb light of various wavelengths and pass along their gained energy to chlorophyll-a of the reaction centre. When the energy reaches the chlorophyll-a its electrons become so excited that they escape and move to a nearby electron transport chain. In this way chlorophyll molecule becomes oxidized.



Structure of photosystem

Chlorophyll	$\xrightarrow{\text{light energy}}$	Chlorophyll	+	e-
(reduced form)		(Oxidized form)		Electron

The elecron transport system plays an important role in generation of ATP by the conversio of light energy into chemical energy.

27. Describe the role of water in photosynthesis.

Ans: Role of Water in phorosynthesis:

Water is one of the raw materials for photosynthesis. Water acts as hydrogen and electron donor in photosynthesis. It replaces the electron lost by the P680 during photosynthesis. Actually, during the light reaction, chlorophyll-a (P680) in the reaction centre of photosystem-II loses electrons due to the absorption of light energy. This event makes the chlorophyll in this state the water molecule is broken down into 2H+ ions, 2e and ½ O2.

Photolysis of Water:

This splitting of water in the presence of sunlight is called **photolysis of water.** The electrons released from water are used to reduce the oxidized chlorophyll-a so that it can absorb light energy again, whereas, 2H+ ions are taken up the NADP+ to form NADPH. On the other hand, the oxygen which is produced by photolysis of water isreleased in atmosphere.

Hypothesis of Van Niel:

This role of water in photosynthesis was first reported by **Van Niel** in 1930. He hypothesized that plants spli water as a sourse of hydrogen, releasing oxygen as a byproduct. This observation was based on investigations of photosynthesis in bacteria that make carbohydrates, from carbon dioxide, but do not release oxygen.

Niel's hypothesis was confirmed in 1940, when for the first time ^{18}O in biological research was used. In the first experiment water was made of ^{18}O . The water tagged ^{18}O was added to an alga suspension. The oxygen evolved during photosynthesis, was found to be radioactive. It was separated and identified. In another experiment carbon dioxide with tagged ^{18}O was added. The oxygen evolved contained none of the isotopes.

Thus the source of evolved oxygen was proved to be water.

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O^{18}} \xrightarrow[\text{Chlorophyll}]{\text{light}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Water}}{6H_2O} + \underset{\text{Oxygen}}{6O_2^{18}}$$

$$\underset{\text{Carbon dioxide}}{6CO_2^{18}} + \underset{\text{Water}}{12H_2O^{18}} \xrightarrow[\text{Chlorophyll}]{\text{light}} \underset{\text{Glucose}}{C_6H_{12}O_6^{18}} + \underset{\text{Water}}{6H_2O} + \underset{\text{Oxygen}}{6O_2}$$

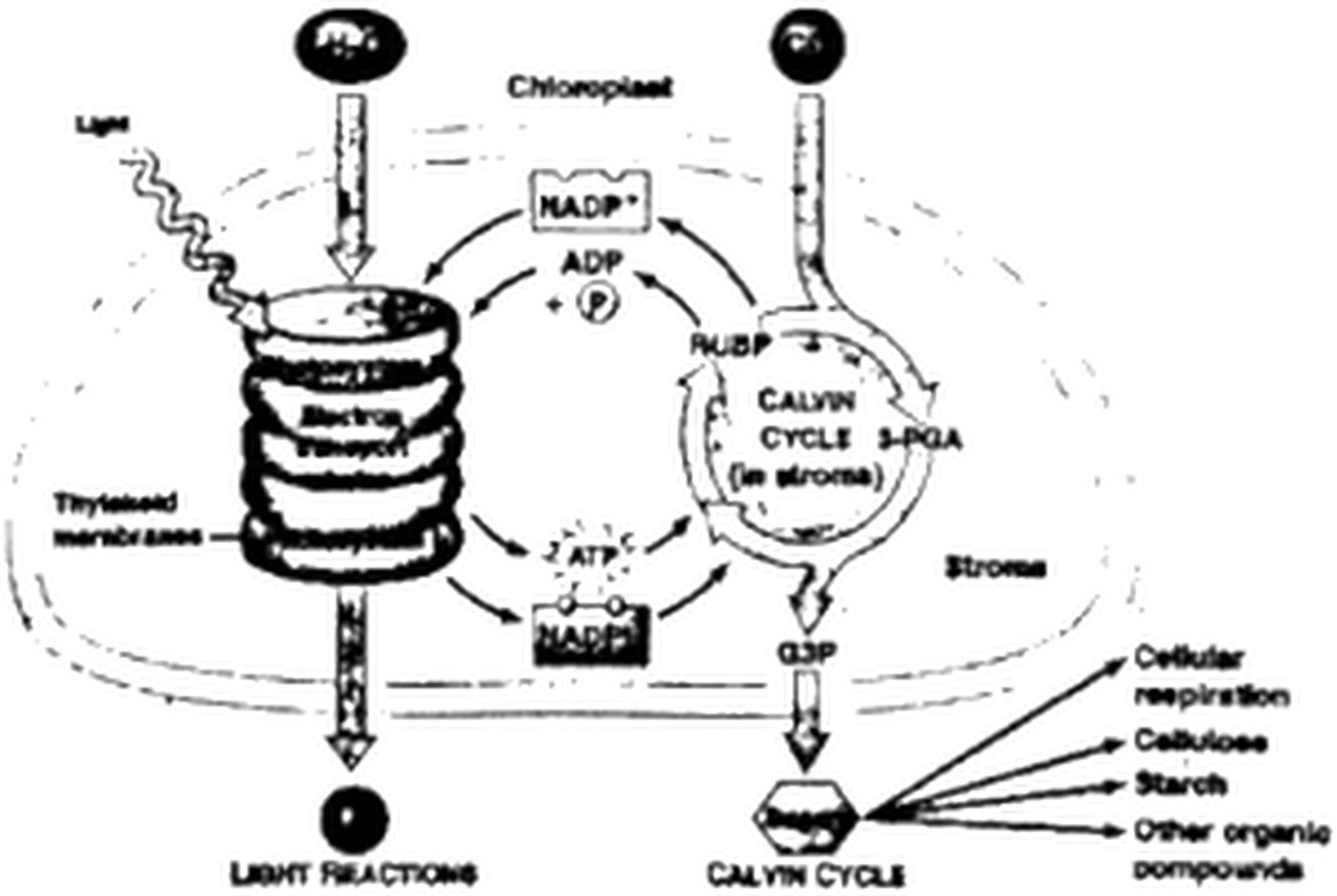
28. Describe the mechanism of photosynthesis.

Ans: Mechanism of photosynthesis:

The process of photosynthesis has been divided into two phases

Light Dependent Phase (light reaction):

The first phase is called light dependent phase (light reaction) bbecause it can take place only in the presence of light. The light-dependent phase occurs in the thylakoid membranes. In this phase light energy is used to make ATP (assimilating power) and NADPH (reducing power), whereas , water and oxygen are supposed to be input and output respectively.



An overview of photosynthesis

Light Independent Phase (dark reaction):

The second phase of photosynthesis is called the light independent phase (dark reaction) because it can take place whether light is present or not. This phase actually requires the products of light reaction i.e, ATP and NADPH. Since these products are available in day therefore, dark reaction also occurs in day time. In this phase CO2 acts as input which is converted ino glyceraldehyde-3-phosphate (G3P), the output of this phase. The ATP is hydrolyzed to ADP and Pi (H3PO4) and its energy is incorporated in this phase, whereas, NADPH provides energized electron and hydrogen for the formation of G3P, which is an eenergy rich molecule.

29. Explain in detail the light dependent phase of photosynthesis?

Ans: Light Dependent Phase (Light Reaction):

Light dependent phase of photosynthesis involves the absorption of light by the photosystems, excitation and flow of electrons through an electron transport chain, chemiosmotic synthesis of ATP and reduction of NADP+ to NADPH.

The flow of excited electrons through an electron transport chain during light reaction is of two different types i.e, non-cyclic and cyclic.

$$ADP + Pi \longrightarrow ATP$$

In non-cyclic electron flow, the excited electrons after leaving a particular photossystem do not comeback, these electrons after losing their energy are incorporated into another molecule. On the other hand, in cyclic electron flow, the excited electrons after leaving a particular photosystem finally comeback to their photosystem again. The most important event in light reaction is the production of ATP. This production of ATP during light reaction is called **photophosphorylation** and the mechanism involved in this photophosphorylation is called **chemiosmosis**.

The process of photophosphorylation during non-cyclic electron flow is called noncyclic photophosphorylation and during cyclic electron flow is called cyclic photophosphorylation.

(a) Non-cyclic photophosphorylation:

It is predominant pathway of light reaction in higher plants that occurs in routine in this process both photosystems i.e, PS-I and PS-II are utilized and two electron transport chains are involved. When PS-II absorbs light, its excited electrons after flowing through an electron transferred to PS-I. similarly, the excited electrons which are liberated from PS-I are finally accepted by NADP+. Therefore it is called non-cyclic electron flow. The events of non-cyclic photophosphorylation are continuous but here they are discussed in steps for convenience.

Absorption of light by PS-II and excitatio of its electrons:

When just two stirke the antenna complex of PS-II, the two electrons become excited and begi to move along the atoms of different pigments within photosystem. Ultimately, the absorbed energy reaches the reaction centre of PS-II (P680) and causes its two electrons to be excited. These excuted electros are captured by the **primary electron acceptor** of PS-II and leave two "electron holes" (electron defficency) in the photosystem behind.

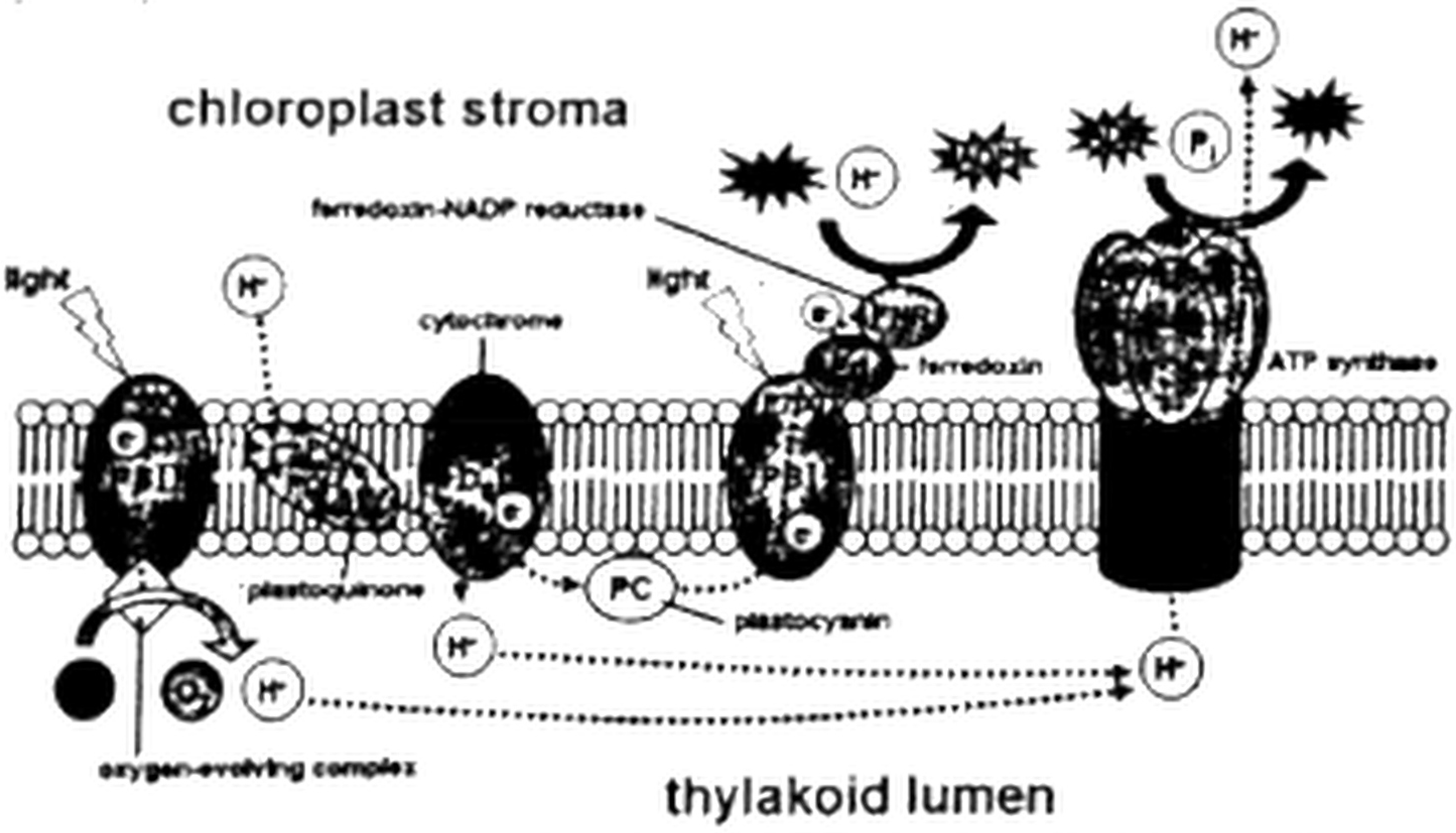
Photolysis of water:

The electron holes of photosystem must be filled so that in the presence of water splitting ezyme reaction can proceed. When water acts with oxidized state of chlorophyll in photosystem, it breaks uo into 2H+ IONS 2e- and ½ O2. Since this breakdown occurs in the presence of sunlight therefore, it is termed as photolysis of water. The electrons released from water are used to fill the "electron holes" of PS-II.

$$H_2O \xrightarrow{\text{photolysis of water}} 2H^+ + 2e^- + 1/2O_2$$

Electron flow from PS-II to PS-I:

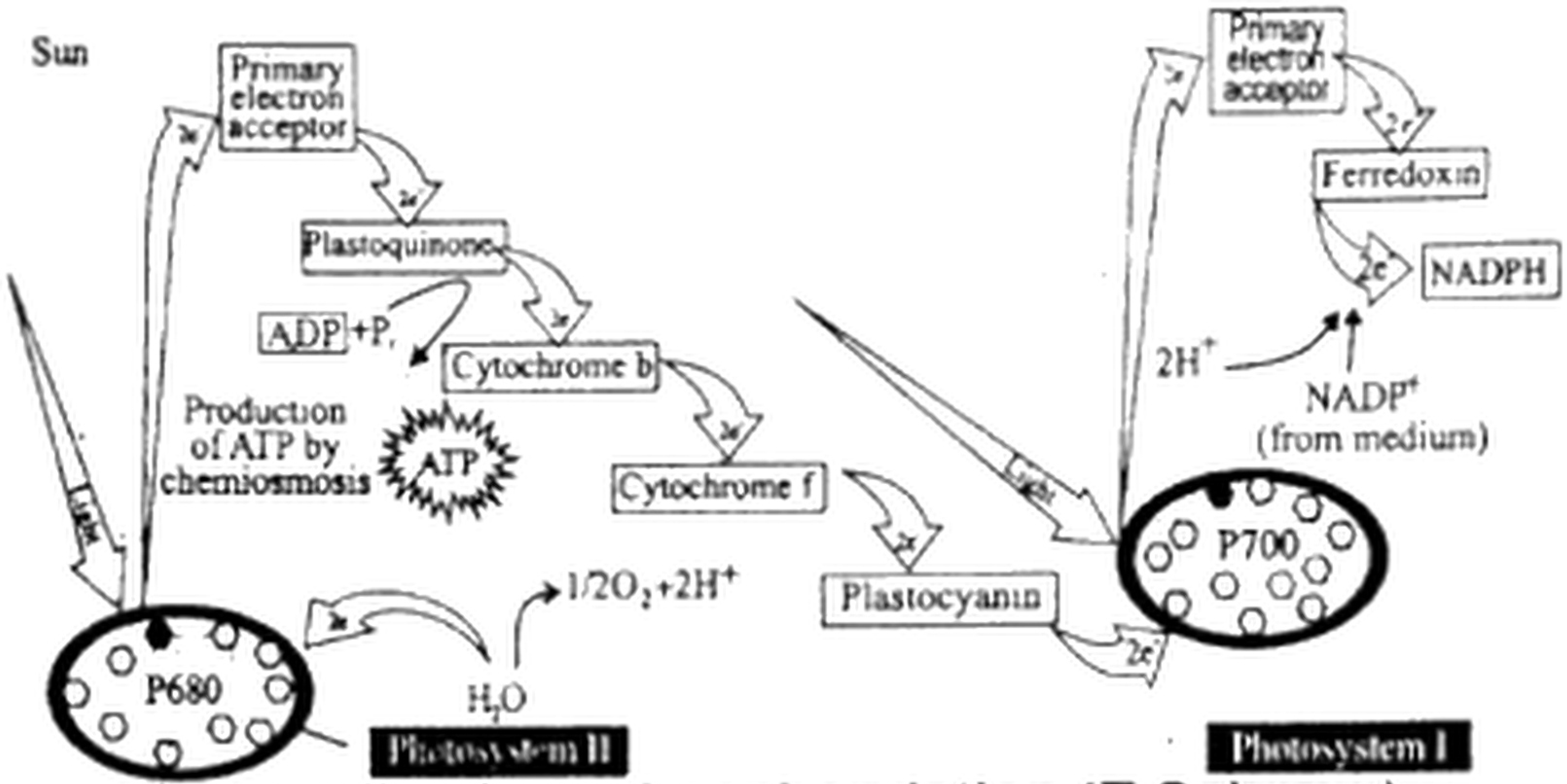
The excited/energized electrons which have been released from PS-II captured by primary electron acceptor now begin to flow to PS-I through an electron transport chain. The primary electron acceptor is an iron containing protein, the **plastoquinone (PQ).** From PQ the elctrons flow through a cluster/complex of another iron containing proteins, the **cytochromes (Cyt)** which consist of **Cyt-bs** and **Cyt-f.** the cytochrome complex is not only an electron carrier but it also works as proton pump. The electrons flow throught the cytochrome complex stimulates it to pump the protons from stroma to the thylakoid inner space. In this way the energy of flowing electrons is transformed into a gradient of protons in the thylakoid inner space. The proton gradient activated an enzyme in thylakoid membrane called **ATP synthesis** which not only moves the prootns back into stroma but also catalyzes a reaction in which ADP and Pi are combined to form ATP (photophosphorylation). This whole mechanism which involves flow of electron, pumping of protons and generation of ATP by thylakoid membranes is called **chemiosmosis**. This ATP, generated by light of ATP generated by light reactions will provide chemical energy for the synthesis of sugar during Calvin cycle. The energuzed electrons after losing their energy, move from cyctochrome complex to a copper containing protein, the **plastocyanin (PC)** and finally incorporated into the PS-I.



Chemiosmotic synthesis of ATP during light reaction

Absorption of light by PS-I and excitation of its electron:

On the other hand, when P700 in the reaction centre of PS-I molecule absorbs two photon of light, electrons are boosted to a higher level. P700 molecule passes these excited electrons to a primary electron acceptor pf PS-I, creating "electron holes". The electron holes of P700 are filled by the pair of electrons received from P680 (photosystem II) via electron transport chain.



Non-cyclic photophosphorylation (Z Scheme)

Electron flow from PS-I to NADP+:

The primary electron acceptor of phorosystem I passes the photoecited electrons to a second transport chain. The electrons are accepted by **ferredoxin (Fd).** It is an iron containing protein. An enzyme called **NADP reductase** (flavoprotein enzyme) transfers the elctrons from Fd to NADP+ NADP+ combines with electrons and hydrogen ions to form NADPH (reduced). The NADPH will provide reducing power for the synthesis of sugar in the Calvin cycle.

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

The path of electron transport through the two photosystems during non-cyclic photophosphorylation is known as **Z-Scheme** due to its conceptual zigzag shape.

30. Explain in detail the light independent phase of photosynthesis?

Ans: Light Independent Phase (Dark Reaction):

The light independent phase (dark reaction) takes its name from the fact that light is not directly required for these reactions occur.

This phase requires the availability of NADPH. ATP (the products of light reaction) and CO2. However, this phase can occur at night but generally it takes place in day time because the products of light reaction are available in day time.

In this phase of photosynthesis, NADPH is used to reduce carbon dioxide while ATP is used to incorporate energy. Finally , CO2 is converted into a phosphorylated triose carbohydrate i.e, glyceraldehyde-3-phosphate (G3P) also called **phosphoglyceraldehyde** (PGAL) which are later on used to make glucose.

Dark reaction generally involves a complicated metabolic pathway, the Calvin Cycle of C3 pathway.

However, in some plants in addition to Calvin cycle another metabolic pathway is also involved, called **Hatch-Slack cycle** or **C4 pathway**. The plants in which only Calvin cycle occurs during dark reaction are called **C3 plants.** Whereas, the plants in which both Calvin cycle and Hatch-Slack cycle occur are called C4 plants.

31. Describe cyclic photophosphorylation.

Ans: Cyclic photophosphorylation:

the rise in NADPH and deficit of ATP may stimulates a temporary shift from a non-cyclic to cyclic electron flow until ATP supply catches uo the demand. It is also a predominant pathway of light reaction during bacterial (except cyanobacteria) photosynthesis.

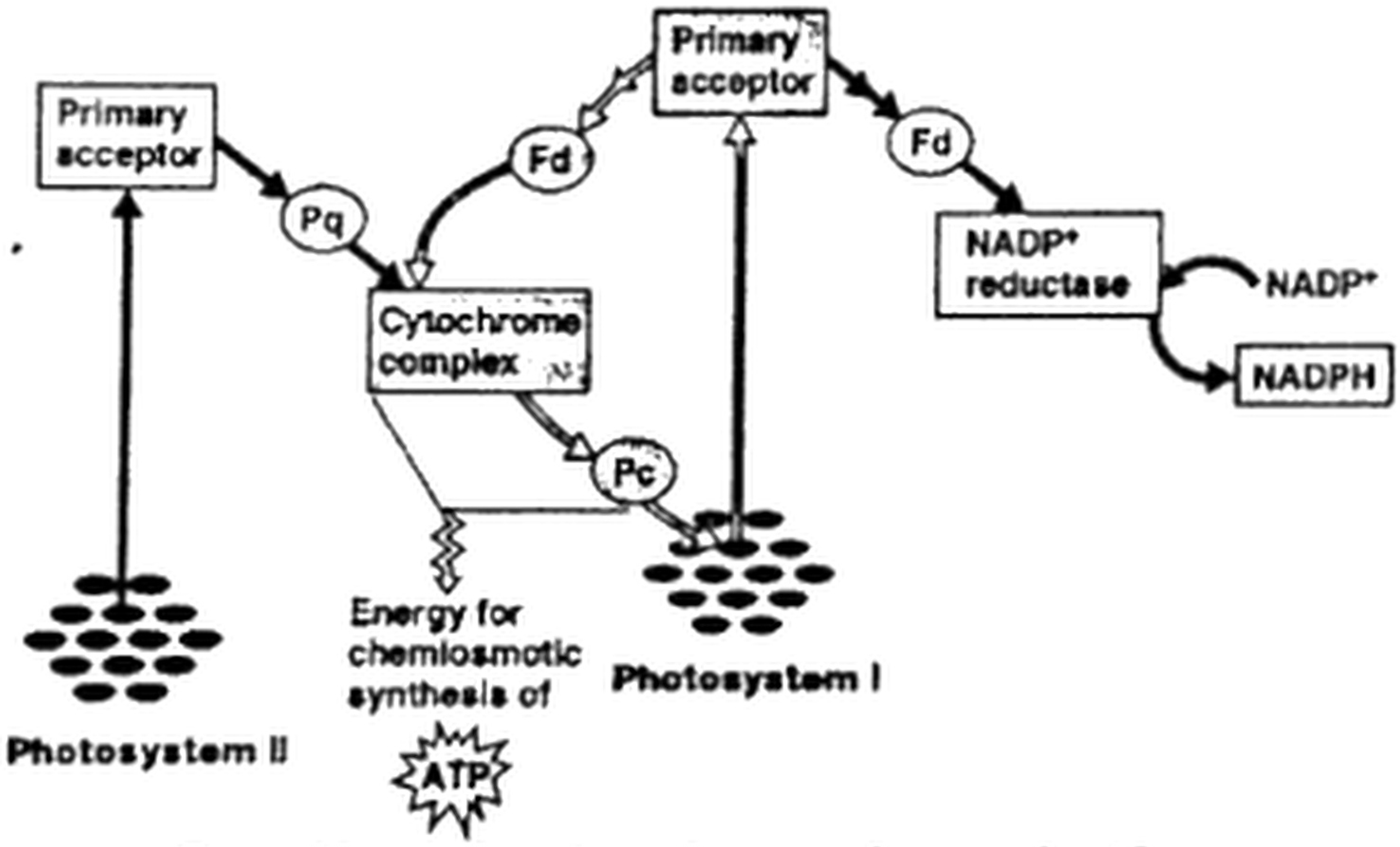
i. In this mechanism only PS-I is utilized. It absorbs energy in the form of photons.
ii. When energy reaches the reaction centre of PS-I the electrons are boosted upto the higher energy level. Such excited electrons are first

captured primary electron acceptor of PS-I, then they move through an electron transport chain containing ferridoxin, cytichrome D6-f complex and plastocyanin.

iii. When electrons are passed from cutochrome b6-f complex an ATP is generated by chemiosmosis.

iv. Finally. The electrons after losing the energy return back to P700 chlorophyll in PS-I reaction centre.

v. There is no production of NADPH, no occurrence of photolysis of water therefore, no release of oxygen.

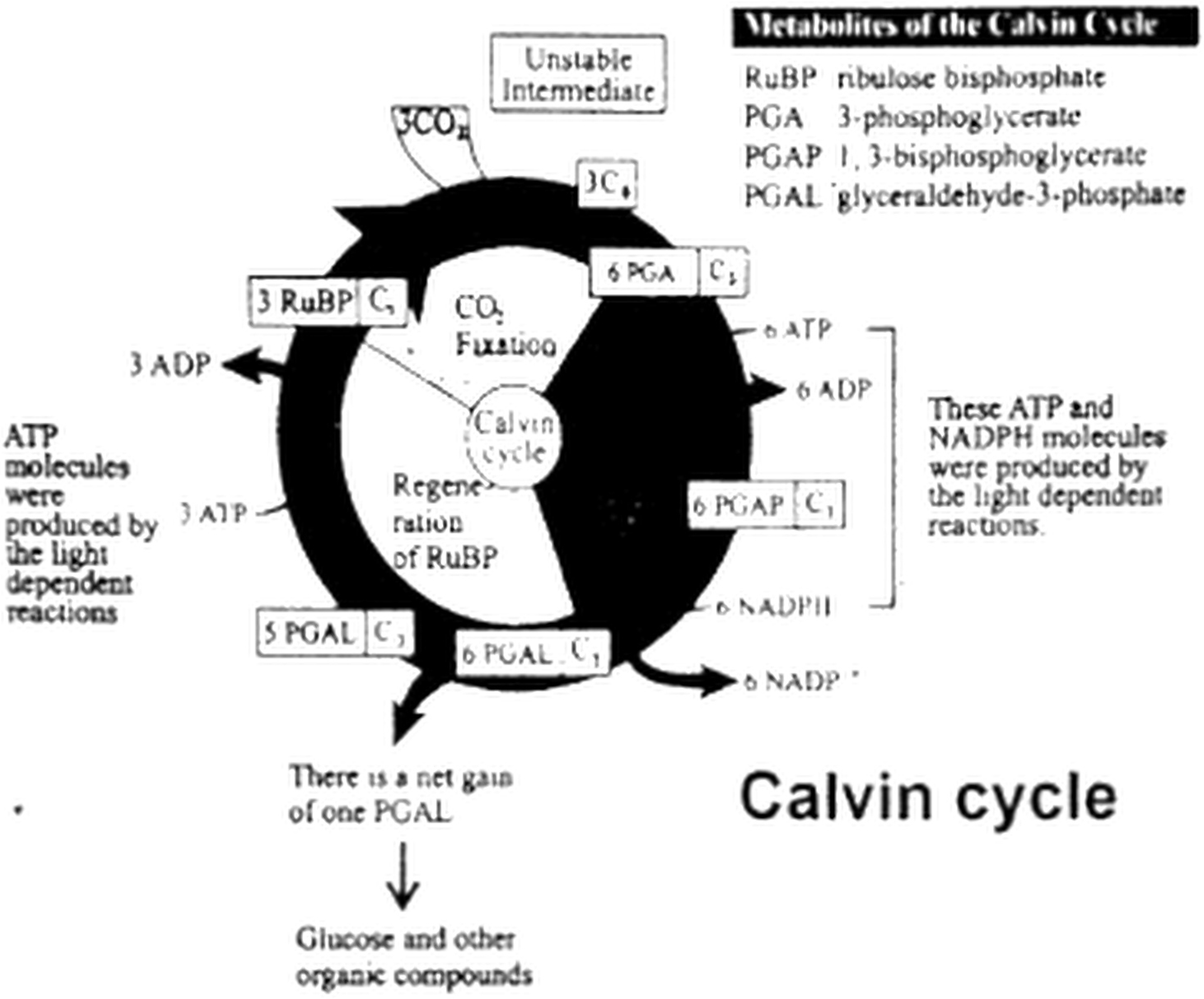


Cyclic photophosphorylation

32. Describe Calvin cycle.

Ans : Calvin cycle:

Calvin cycle term is applied to the series of metablic reactions in which CO2 is reduced to produce G3P. These reactions have been explored by **Melvin Calvin** and coworkers at the University of California. Melvin Calvin won the Nobel Prize in 1961 for this work. The Calvin cycle can be divided into three phases, carbon fixation, reduction and regeneration of carbon dioxide acceptor i.e, RuBP.



Calvin cycle

Carbon fixation:

Ribulose Biphosphate (RuBP):

One of the key substance in this process is a five carbon phophorylation sugar called **ribulose biphosphate (PuBP).** It is generally referred as **CO2 acceptor** because it is capable of combining with carbon dioxide with the help of Ribulose biphosphate (RuBP) carboxylase/oxygenase also known as **RuBisCO.**

Carbon fixation:

Three intermediate molecules of six carbons are formed during this reaction. These molecules are unstable and exist for such a short time that, they cannot be isolated. Each six carbon breaks down to form two molecules of 3-phosphoglycerate)3-phosphoglyceric acid or 3-PGA), a phosphorous containing compound with three carbon atoms. Since, the carbon of inorganic compound (CO_2) becomes the part of organic compound (RuBP) during this phase, hence, it is called **carbon fixation**

C3 Pathway:

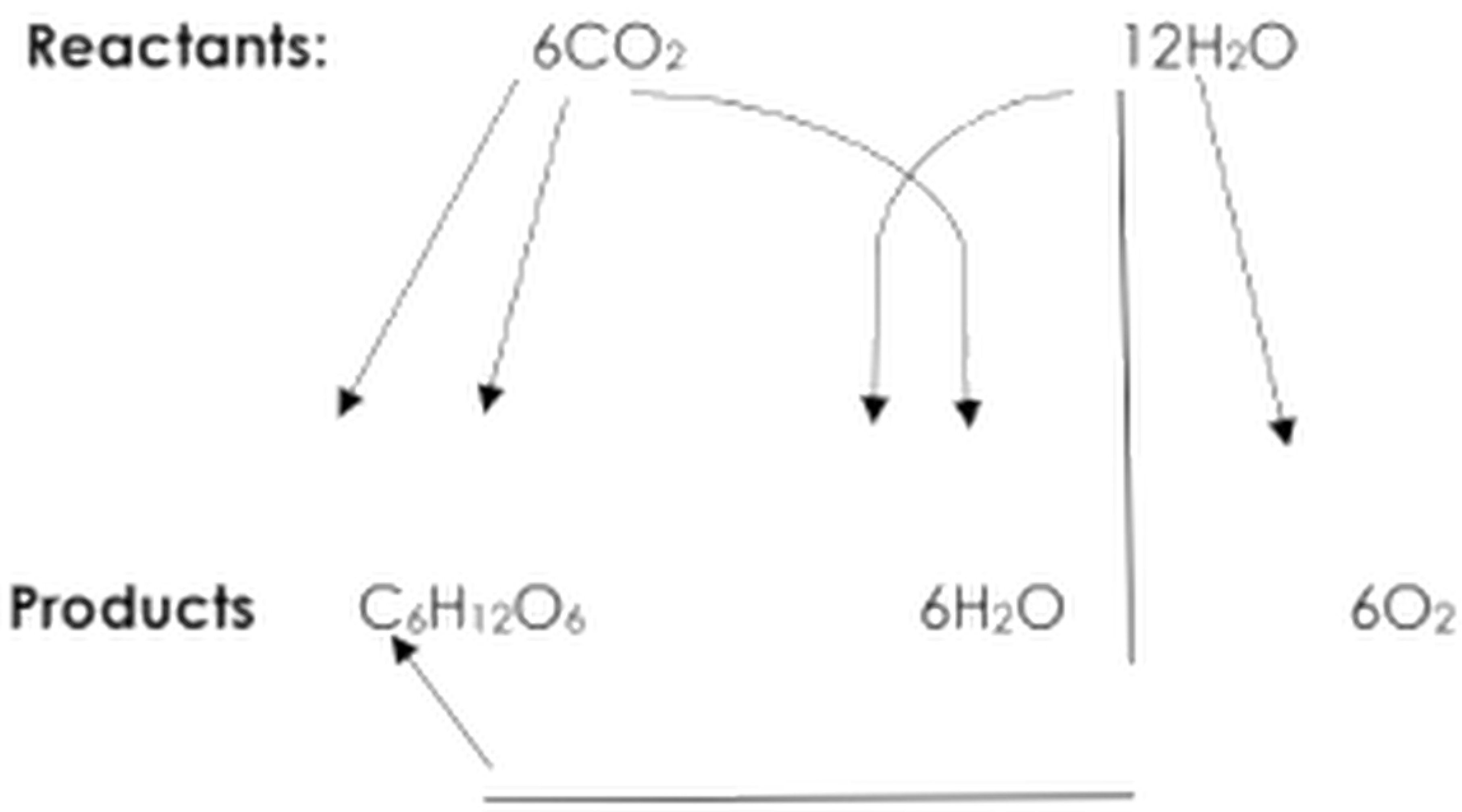
As thw first stable compound in the Calvin cycle is a three carbon compound (3-PGA) that is why Calvin cycle is also known as **C3 pathway.**

Reduction:

In this phase six molecules of 3-phosphoglycerate (3-PGA) react with six ATP molecules , a phosphate from each ATP is transferred to each 3-PGA. In this way, 3-PGA molecules are changed into 1,3-Biphosphoglycerate (1,3-BisPGA pr PGAP).

These molecules are then reduced by the hydrogen of NADPH and finally glyceraldehyde 3 phosphate (G3P or PGAL) molecules are produced.

During this reduction process a phosphate group from each 1,3-BisPGA molecule is also given off. These are total six molecules of G3P or PGAL are produced in this phase but only one molecule is released from the cycle while rest of the five molecules are used to regenerate the CO_2 acceptor molecules in the next phase.



Regeneration of CO2 acceptor:

Fives molecules of G3P or PGAL from the previous phase are used to regenerate the RuBP (CO_2 acceptor) in this phase. These five molecules each containing three carbon atoms undergo a series of reactions (not given in the diagram) in which three molecules of ribulose phosphate (RuBP) each containing five carbon atoms are produced. When three molecules of RuP react with three molecules of ATP, a phosphate group from each ATP is transferred to each RuP. Ultimately RuP are cinverted into RuBP (CO_2 acceptor) which again participate in the next cycle.

The whole process of Calvin cycle indicates that there are three molecules of CO_2, six molecules of NADPH (reducing power) and nine molecules of ATP (assimilating power) are used to release just one molecule of G3P or PGAL form the cycle. However , in order to produce a glucose molecule , two molecules of G3P or PGAL are required. The overall process if Calvin cycle can be represented as:

$$3CO_2 + 6NADPH + 9ATP \longrightarrow G3P + 3H_2O + 9ADP + 9Pi$$

33. Describe the kinds of cellular respiration.

Ans: Cellular Respiration:

In biological systems oxidation-reduction is a chemical reaction usually involves the removal of hydrogen atom from one molecule and the gain of hydrogen atom by another molecule. Cellular respiration is a series of complex oxidation-reduction reactions by which living cells obtain energy through the breakdown of organic matter.

Kinds of Cellular Respiration:

There are two kinds of respirations:

i. **Aerobic Respiration** ii. **Anaerobic Respiration**

i. **Aerobic Respiration:**

Aerobic respiration takes place in the presence of abundant atmospheric oxygen.

Mechanism of Aerobic Respiration:

Aerobic respiration is a catabolic process which involves complete oxidative breakdown of organic food (especially glucose) into carbon dioxide and water with release of great deal of energy in the form of ATPs. It is predominant respiratory pathway in most of the organisms. Aerobic respiration is completeld in four phases: glycolysis, oxidation of pyruvates, krebs cycle and respiratory electron transport chain.

ii. **Anaerobic Respiration:**

Anarobic respiration occurs in the absence of oxygen.

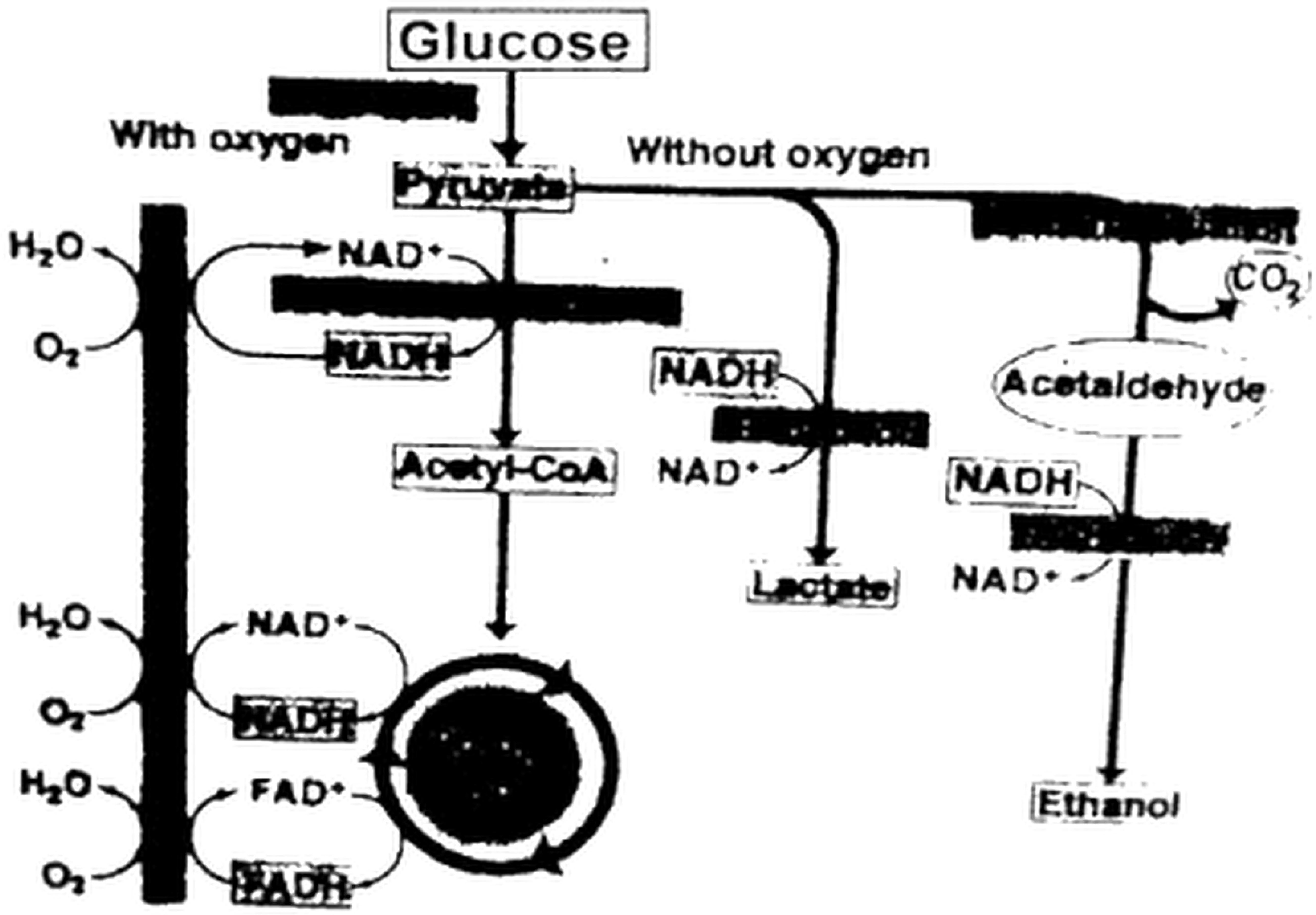
Mechanism of Anaerobic Respiration:

Anarobic respiration takes place in many microorganisms (bacteria, yeast), muscle cells of vertebrates and in the cells of hight plants Anarobic respiration is incomplete breakdown of glucose in the absence of oxygen. It is also known as **fermantation.** There are two pathways of anaerobic respiration depending upon the nature of final products i.e. lactic fermentation and alcoholic fermentation.

Common Steps of Anarobic Respiration and Anaerobic Respiration:

The organic molecule that generally udergoes breakdown in cellular respiration in order to release energy is glucose, therefore is supposed to be **respiratory fuel**. The initial breakdown of glucose in both aerobic and anaerobic respirants is quite same, in which it is broken down into aerobic respirations is called **glycolysis.**

The pyruvates undergo in different respiratory pathways depending upon the availability of oxygen and the kind of organism. If oxygen is available, the further breakdown of pyruvates takes place aerobilcally and the final products are carbon dioxide and water with the release of large amount of energy i.e, 36 ATPs (in deukaryotes) or 38 ATPs (in prokaryotes). If oxygen is absent , then the pyruvates are broken down anaerobically and the final products are either lactic acid or ethanol and carbon dioxide with release of very small amount of energy i.e, just 2ATPs.



An overview of respiratory pathways

34. Give account of 'Glycolysis'.

Ans : Glycolysis:

EMP pathway:

It is also called **EMP pathway** because it was discovered by three German scientists **Embden, Meyerhof** and **Parnas.** Glycolysis is the process of breakdown of glucose or similar hexose sugar into two molecules of pyruvates through a series of enzymatic reactions releasing some energy (as ATP) and reduced coenzymes (as NADH). It occurs in the cytoplasm.

Phases of Glycolysis:

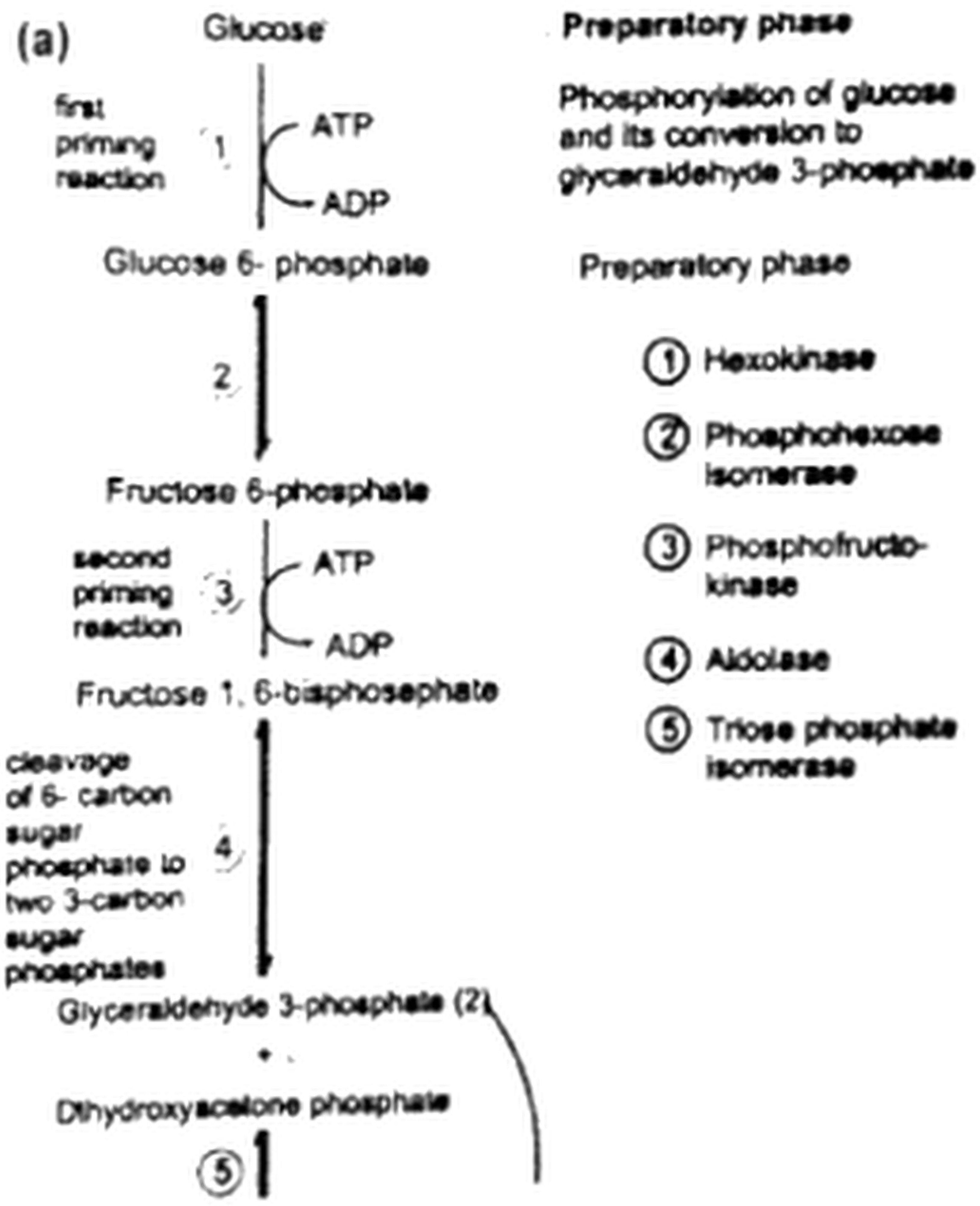
It is completed in two phases i.e. preparatory phase and oxidative phase.

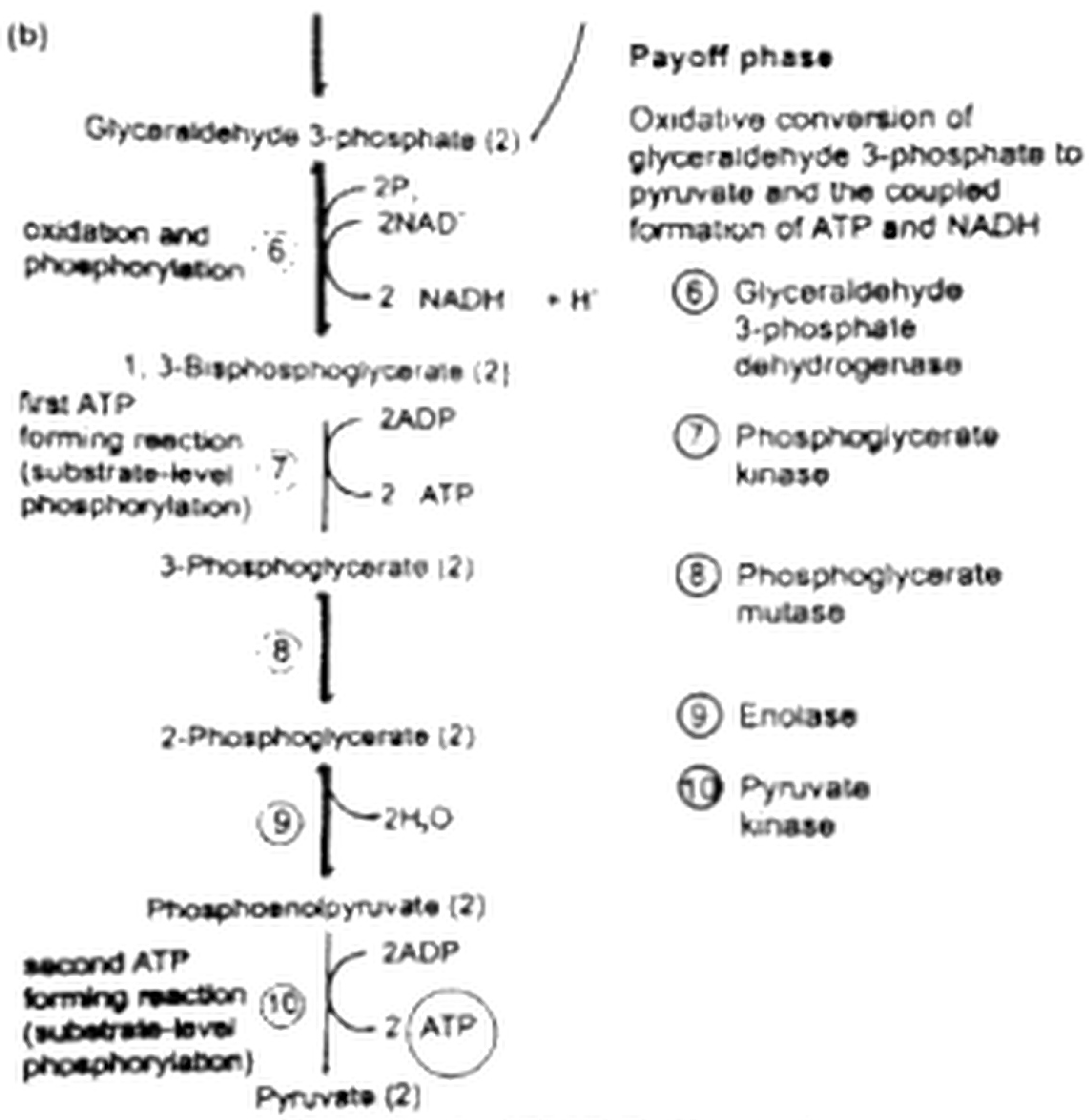
a. **Preparatory Phase:**
   Preparatory phase is an investment phase in which two ATPs are comsumed. Its end products are two molecules of G3P or PGAL.
b. **Oxidative Phase:**
   On the other hand oxidative phase is oay off phase in which mot only ATPs are produced through substrate level phosphorylation but it also produces NADH which upon further oxidation in respiratory electron transport chain yields more ATPs.

Sub steps of Glycolysis Pathway:

The whole glycolysis pathway takes place in the following sub steps.

1. When glucose reacts with ATP in the presence of enzyme hexokinase or glucokinase, a phosphate group from ATP is transferred to glucose. In this way glucose is phosphorylated to glucose-6-phosphate and ATP is changed into ADP.


(a)
Glucose
first priming reaction
1
ATP
ADP
Glucose 6- phosphate
2
Fructose 6-phosphate
second priming reaction
3
ATP
ADP
Fructose 1, 6-bisphosephate
cleavage of 6- carbon sugar phosphate to two 3-carbon sugar phosphates
4
Glyceraldehyde 3-phosphate (2)
+
Dihydroxyacetone phosphate
5
Preparatory phase
Phosphorylation of glucose and its conversion to glyceraldehyde 3-phosphate
Preparatory phase
1 Hexokinase
2 Phosphohexose isomerase
3 Phosphofructo-kinase
4 Aldolase
5 Triose phosphate isomerase



Glycolysis (EMP Pathway)

2. **Isomerization:**

   Glucoses-phosphate is changed to its isomer fructose-6-phosphate with thw help of enzyme phosphohexose isomerase. Fructose-6-phosphate can also be produced directly by phosphorylation of fructose with the help of enzyme fructokinase.

3. **Phophorylation:**

   When fructose-6-phosphate reacts with ATP in the presence of enzyme phosphogructo –kinase, a phosphate group from ATP is again transferred to fructose-6-phosphate. In this way fructose-6-phosphate is phophorylated to Fructose-1,6 bisphosphate and ATP is changed into ADP.

4. **Splitting:**

Now fructose 1,6-bisphosphate splits up by an enzyme aldolase to form one molecule each of 3-carbon compounds, glyceraldehyde 3-phosphate (G3P) also known as 3-phosphoglyceraldehyde (PGAL) and dihydroxyacetone 3-phosphate (DHAP).

5. **Isomerization:**

   The dihydroxyacetone 3-phosphate (DHAP) is ultimately changed into its isomer,

   The glyceraldehyde 3-phosphate (Q3P) by enzyme triose phosphate isomerase (phosphotriose isomerase). In this way preparatory phase is completed. Next phase of glycolysis is proceeded by two molecules of G3P or PGAL, therefore the remaining reactions occur twice.

6. **Dehydrogenation and phosphorylation (Oxidative phosphorylation):**

   In the presence of enzyme glyceraldehyde 3-phosphate dehydrogenase, G3P donates hydrogen to NAD to form NADH and accepts inorganic phosphate (Pi)

   To form 1,3-bisphophoglycerate.

7. **Formation of ATP:**

   The direct synthesis of ATP from organic phosphorylated substrate is called sybstrate level phosphorylation. In this step a molecule of ATP is formed by substrate level phosphorylation when an enzyme, phodphohlycerate kinase removes a phosphate group from 1,3-bisphosphoglycerate which is taken up by the ADP to form ATP. In this way, 1,3-bisphosphoglycerate is changed into 3-phosphoglycerate after dephosphorylation.

8. **Isomerization:**

   In this step position of phosphate group is changed from C3 to C2 phosphoglycerate. In this way, 3-phosphoglycerate is changed into its isomer, the 2-phosphoglycerate by an enzyme, the phosphoglycerate mutase (also known as phosphoglyceromutase).

9. **Dehydration:**

In this step, 2-phosphoglycerate undergoes dehydration (rmoval of water molecule) in the presence of an enzyme enolase. In this way 2-phosphoglycerate is converted into phosphoenol pyruvate (PEP).

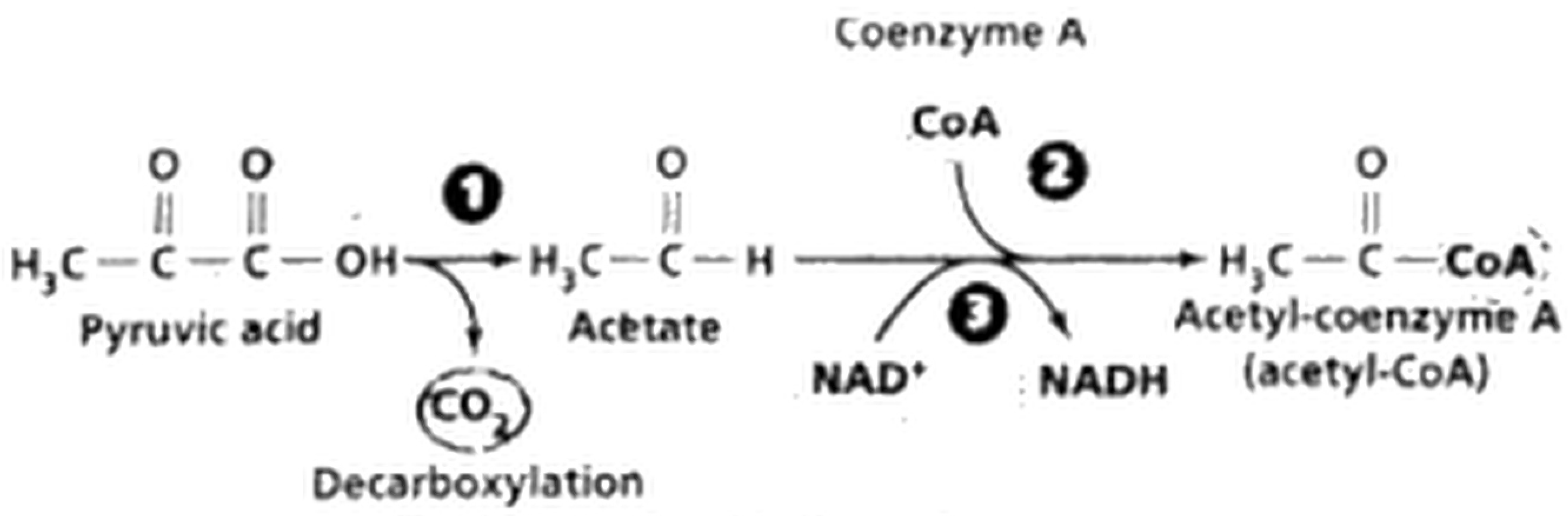
10. Formation of ATP:

Again a molecule of ATP is produced by substrate level phosphorylation when phosphoenol pyruvate loses phosphate group which is taken up by the ADP to form ATP in the presence of an enzyme pyruvate kinase. The phosphoenol pyruvate after dephosphorylation is finally converted into pyruvate.

35. Explain oxidation of pyruvates.

Ans: Oxidation of pyruvate:

Pyruvate are produced in cytosol. Beacause pyruvate is a charged molecule, it must enter the mitochondrion via active transport with the help of the transport protein **pyruvate translocase.** On enetering the mitochondria, pyruvates do not directly participate in Krebs cycle but they undergo an intermediate phase, called **oxudatio of pyruvate** or **link reaction** as it links the pathway of aerobic respiration that occurs outside the mitochondria with that occurs inside the mitochondria.



Pathway of oxidation of pyruvate

Steps in Oxidation of Pyruvate:

The oxidation of pyruvate takes place in these three steps:

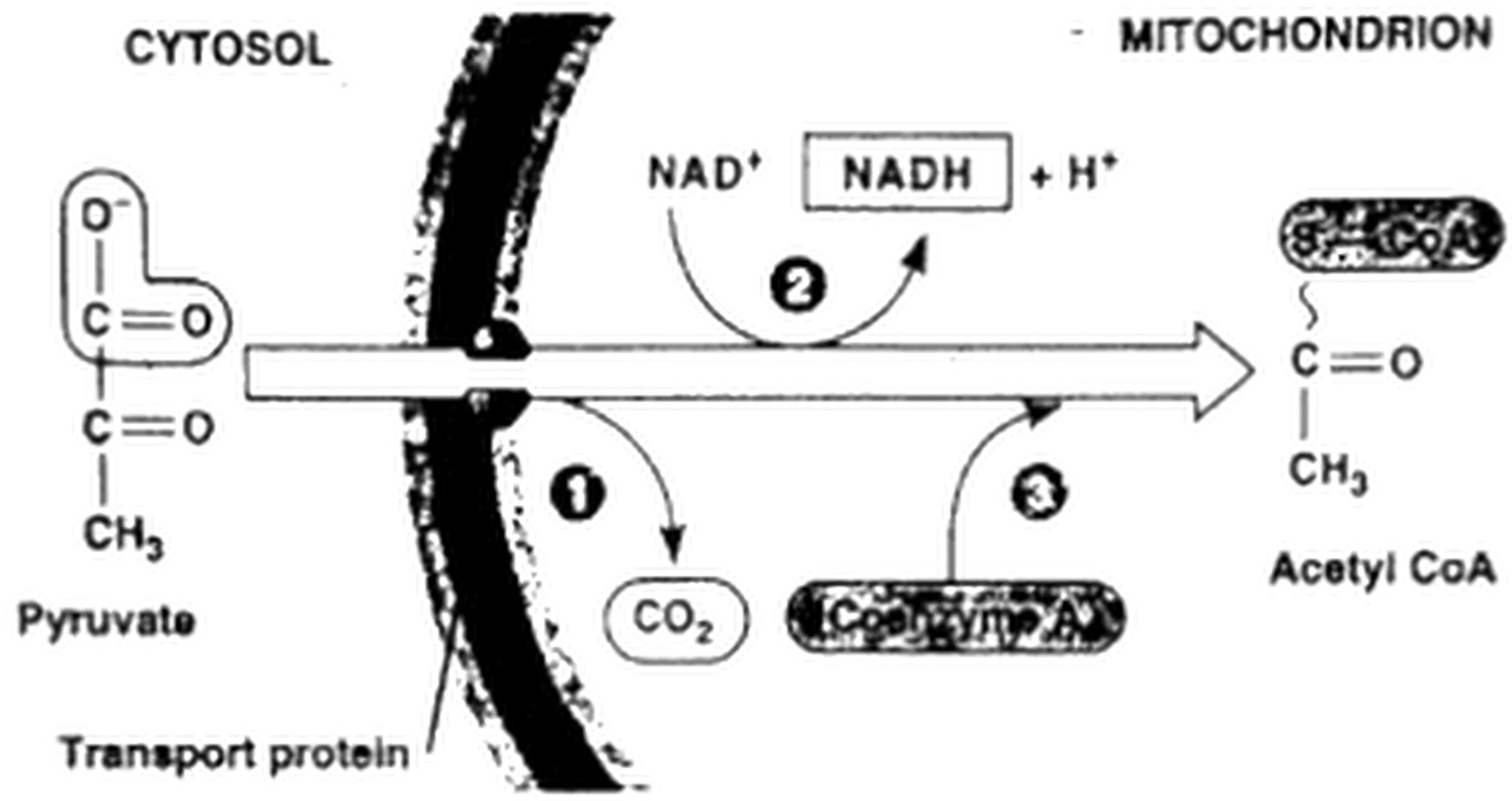
i. First, it undergoes decarboxylation in which a molecule of CO2 is removed from pyruvate to form acetate.

ii. Then NAD+ removes hydrogen from acetate. As s results of this oxidation/dehydrogenation a 2C fragment acetyl and NADH are produced.

iii. Finally , acetyl group is combined with coenzyme-Atoform acetyl CoA. The whole oxidative decarboxylation and addition of coenzyme Ais catalyzed by a cluster of three enzymes and five factores called pyruvate dehydrogenase complex.

Site of oxidation of pyruvate:

Conversation of pyruvate to acetyl CoA, the junction between glycolysis and the citric acid cycle.



36. Explain Krebs cycle.

Ans: Krebs cycle:

Complete oxidation of acetyl coenzyme A into CO2 and H2O takes place in Krebs cycle. It begins with the binding of Acetyl CoA to 4C compund, the **oxaloacetate.** The resulting 6C compound is called **citrate** which passes through a series of electron yielding oxidation, reactions in which NADH and FADH2 are produced that releases ATP upon further oxidation in respiratory chain. In addition, ATP is also produced directly by substrate level phosphorylation. Two CO2 molecules are split off regenerating the 4C compund, the oxaloacetate which is free to bind another acetyl group. In this way the process become cyclic. In each turn of the cycle a new acetyl group comes into, to replace the two CO2 molecules that are lost and more electrons are extracted.

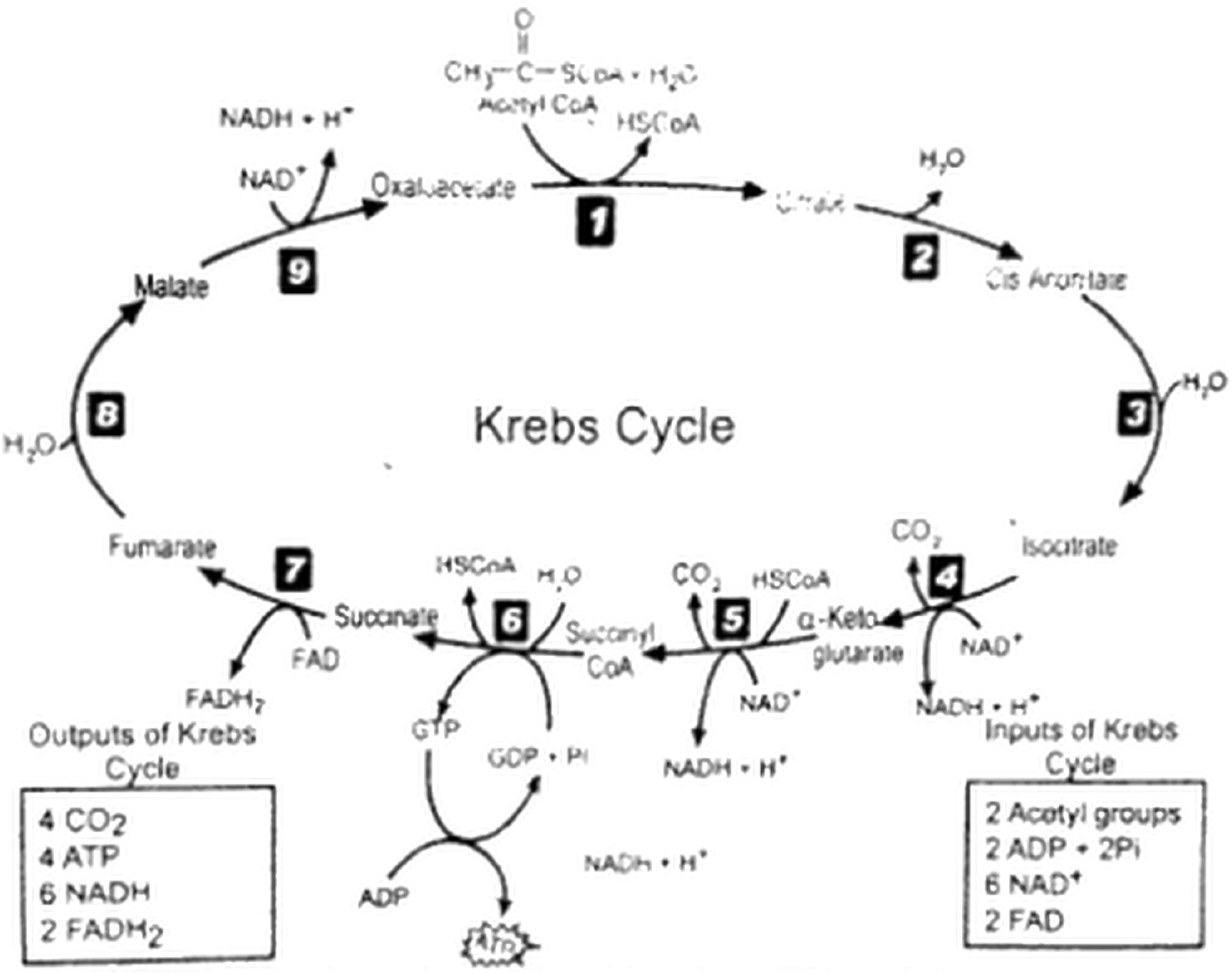
Discovery of Krebs Cycle:

This cycle was discovered by British scientist **Sir Hans Kreb,** therefore called **Krebs cycle.** It is also called **Citric acid cycle** or **Tri carboxylic acid** (TCA) cycle because the first compound which is formed in the cycle is **citrate** (citric acid) that contains three carboxylic acid groups.

Steps pf Krebs Cycle:

The Krebs cycle comprises following nine steps.

1. **Synthesis:**
   Acetyl CoA (2-carbon compound) and a water molecule combine with oxaloacetate (4-carbon compound) in the presence of citrate synthetase enzyme to form a tricarboxylic 6-carbon compound called citrate (citric acid). It is the first products of Krebs cycle. CoA is liberated.
2. **Dehydration:**
   Itrate undergoes reorganization by the removal of a water molecule (dehydration) in the presence of an enzyme aconitase. The resulting compound is cis-aconitate.



Krebs cycle (Citric acid cycle or TCA cycle)

3. **Hydration:**

   Cis-aconite is converted into isocitrate with the addition of water (hydration) in the presence of same enzyme aconitase. Actually, citrate and isocitrate are isomers of each other.

4. **Oxidative decarboxylation:**

   This is two-step process which involves oxidation/dehydrogenation of isocitrate to oxalosuccinate, followed by the decarboxylation of oxalosuccinate to alpha-ketoglutarate. Both these steps are catalyzed by enzyme complex isocitrate dehydrogenases. The hydrogen and electrons which are released from isocitrate are taken up by NAD+ to form NADH while the carboxyl group is released in the form of CO2.

5. **Oxidative decarboxylation and addition of CoA:**

   a-Ketoglutarate again undergoes oxidative decarboxylaion to form succinate in the presence of an enzyme complex a-Ketoglutarate dehydrogenase. He hydrogen and electrons which are released from a-Ketoglutarate are taken up by NAD+ to form while carboxyl group is released in the form of CO2. Then, succinate combines with coenzyme A to form succinyl CoA in the presence of same enzyme.

6. **Formation of ATP by substarte level phosphorylation:**
   Succinyl CoA is acted upon by enzyme succinyl thiokinase to remove coenzyme A, hence succinate is formed. The reaction releases sufficient energy which is used to combine GDP and Pi forming GTP. GTP reacts with ADP to form ATP while GTP is again converted into GDP. In this way a molecule of ATP is generated in this reaction.
7. **Dehydrogenation/oxidation:**
   Succinate undergoes dehydrogenation/oxidation to form fumerate with the help of succinate dehydrogenase enzyme which uses FAD as oxidizing agent. The hydrogen and electrons whixh are released from succinate are taken up by FAD to form FADH2.
8. **Hydration:**
   A molecule of water gets added (hydration) to fumerate to form malate in the presence of an enzyme fumarase.
9. **Dehydrogenation/oxidation:**
   Malate undergoes dehydrogenation or oxidation in the presence of an enzyme malate dehydrogenase to produce oxaloacetate. The hydrogen and electrons which are released from malate are taken up by NAD+ to form NADH.
   Oxaloacetate picks up another molecule of acetyl CoA (activated acetate) to repeat the cycle.

37. Explain electron transport chain.

Ans: Electron Transport Chain:

Inner mitochondrial membrane contains groups of electron and proton transporting enzymes. In each group the enzymes are arranged in a specific series called electron transport chain (ETC). an electron transport chain or system is a series of electron carriers and some of them also work as proton pumps. They take part in the passage of electrons from NADH or FADH2 to its ultimate acceptor i.e , molecular oxygen.

Components of electron transport chain:

The components of electron transport chain.

(1) NADH-Q reduces or NADH-dehydrogenase complex (flavin mononucleotide i.e , FMN and iron sulohur (Fe-S) complex).

(2) FADH-dehydrogenase or coenzyme Q or Ubiquinone (UQ).

(3) Cytochrome (Cyt) reductase complex (Cytb and Cyt-C1).

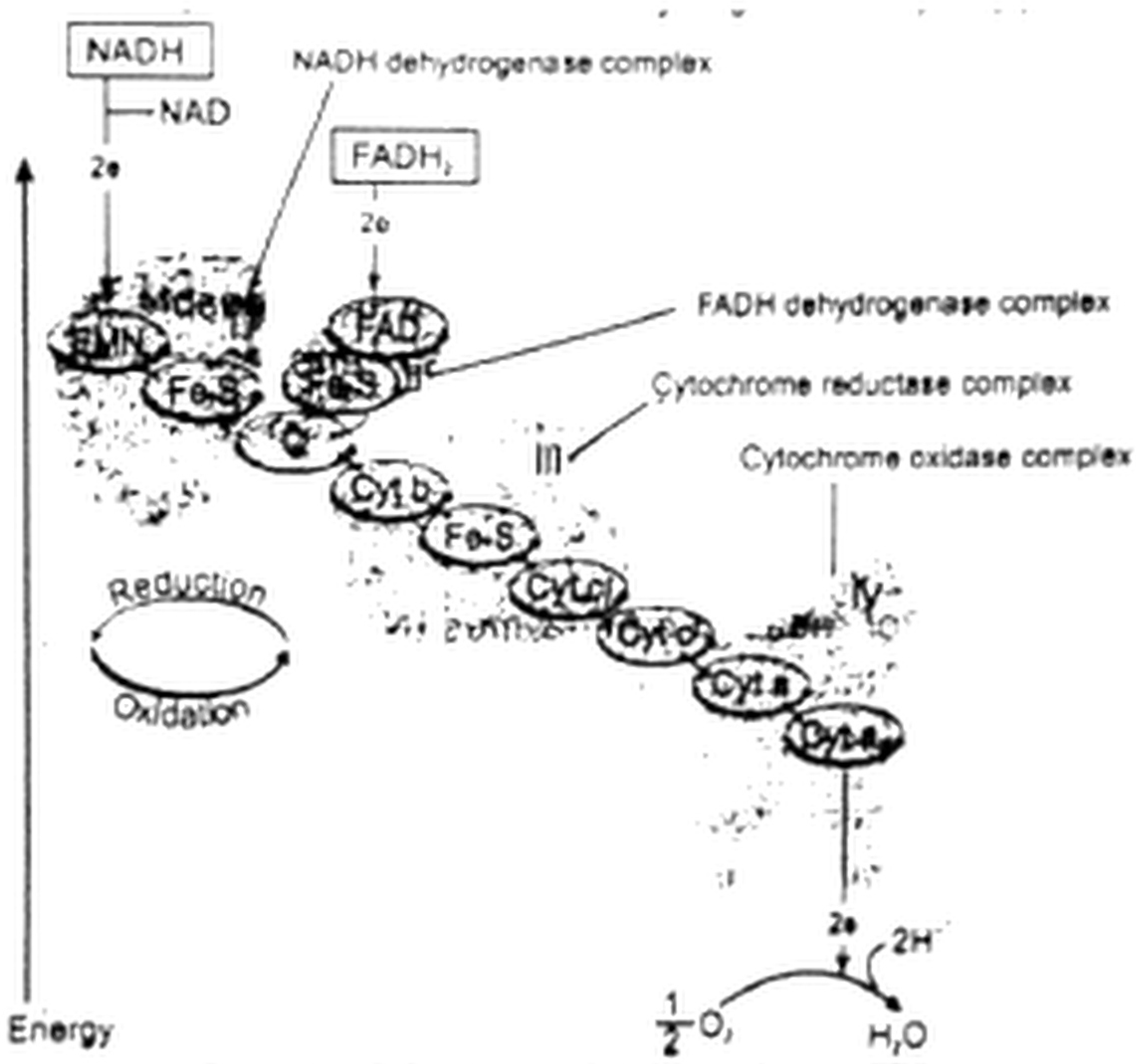
(4) Cytochrome-c, (5) Cytochrome oxidase complex (Cyt-a and Cyt-a3).

The passage of electrons from one carrier to the next is a downhill journey with a loss of energy at each step because the energy of flowing electrons is ultilized by some carriers to pump protons (H+) from matrix (inner chamber) to intermembrane space is termed as proton gradient which activates the ATP synthetase to catalyze oxidative phosphorylation (synthesis of ATP in the presence of oxygen).

Passage of electron flow:

i. Electrons removed from NAD+ during glycolysis and Krebs cycle form NADH. NADH is oxidized when it reacts with NADH-dehydrogenase complex (I). it has two prosthetic groups, flavin mononucleotide (FMN) and iron sulphur (Fe-S) compex. Both electrons and protons pass from NADH to FMN. The 3FMN now moves the electron to the Fe-S complex and pumps the protons to inter-membrane space.

ii. Electron now moves from Fe-S complex to a mobile electron carrier, to the coenzyme Q, also called ubiquinone (UQ). If FADH2 is to be oxidized through ETC, it also hands its electrons and protons to coenzyme Q, therefore this enzyme is also known as FADH dehydrogenase complex (II).



Sequence of electron carriers in respiratory ETC

iii. The flowing electrons from coenzyme Q are now transferred to cytochrome reductase complex (III) which has three components i.e , cytrochromem b,Fe-S complex and cytochrome C1. This enzyme complex not only forwards the electrons to the next electron carrier but it also pumps protons into the intermembrane space.

iv. Cytochrome c1 hands over its electron to cytochrome c. Like co-enzyme Q, cytochrome c is alos mobile carrier of electrons.

v. Cytochrome c delivers the elctrons to cytochrome oxidase complex (IV) which comprises cytochrome-a and cytochrome-a3. Cytochrome-a3 also possesses copper. This enzyme complex also works as an electron carrier as well as proton pump.

vi. Finally, the electrons from Cyt-a3 are transferred to oxygen. The oxygen is the ultimate acceptor of electrons. It becoes reactive. Each oxygen atom also picks up pair of hydrogen ions from the aqueous solution forming water.

vii. Energy released during passage of electrons from one carrier to the next is made available to specific transmembrane complexes, which pimp protons
(H+) from the matrix side of the inner mitochondrial membrane to the outer chamber. There are three such sites, corresponding to three enzymes present in the electron transport chain (NADH-dehydrogenase complex cytochrome reductase and cytochrome oxidase (see figure)). It the energy were released in one step, most of it would be lost as non-useable heat.

FMN—— CoQ,Cyt b—— Cyt c1,Cyt a—— Cyt a3

viii. The electron transport chain makes no ATP directly. Its function is to ease the fall of electrons from food to oxygen releasing energy in manageable amounts. How does the mitochondrion couple this electron transport chain and energy to ATP synthesis?
The answer is a mechanism called chemiosmosis.

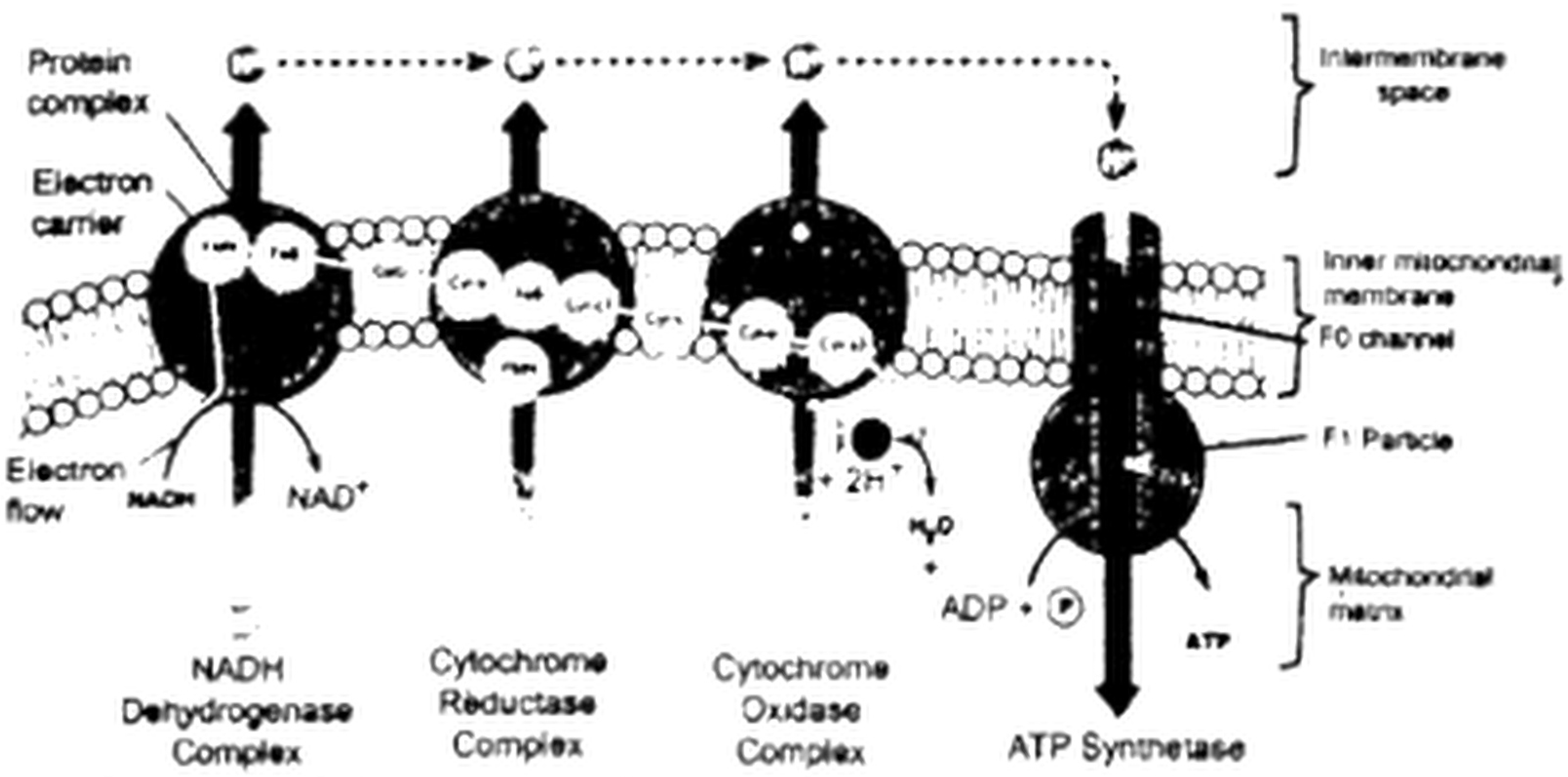
38. Explain chemiosmosis and oxidative phosphorylation.

Ans : Chemiosmosis and Oxidative Phosphorylation:

Oxidative phosphorylation is the synthesis of ATP molecules with the help of energy liberated during oxidation of reduced co-enzyme (NADH, FADH2) produced in respiration. The enzyme required for this synthesis is called ATP synthetase which is also called **oxysome** or **stalked particles.**

it is located in the inner mitochondrial membrane. It consists of two parts i.e , F0 and F1. F0 is embedded in the membrane and involves in the movement of protons from inter-membrane space to mitochondrial matrix F1 or elementary particle is a head like part which is projected from the surface of membrane towards matrix. It catalyzes ATP synthesis by the combination of ADP and Pi. ATP synthetase becomes active in ATP formation only when a proton gradient having higher concentration of H+ or protons on the F0 side as compared to F1 side is established. The flow of protons through the F0 channel induces F1 particles to function as ATP-synthesis i.e , the energy of the proton gradient is used in attaching a phosphate radicle to ADP by higher energy bond. This produces ATP. Oxidation of one molecule of NADH2 produces 3 ATP molecules while a similar oxidation of FADH2 forms 2 **ATP** molecules.

The theory of ATP production by this mechanism is called chemiosmosis because this mechanism specifically involves the diffusion of protons (H+) across the membranes as osmosis involves similar diffusion of water molecules only.



Mechanism of chemiosmosis in respiratory electron transport chain

Peter Mitchell, received a Nobel prize in 1978 for his chemiosmosis theory of ATP production in mitochondria and chloroplast.

39. Describe substrate level phosphorylation.

Ans: Substrate Level phosphorylation:

The prime objective of cellular respiration is to generate the ATPs. There are two ways to do this during aerobic respiration chemiosmosis and substrate level phosphorylation, the former we have already discussed.

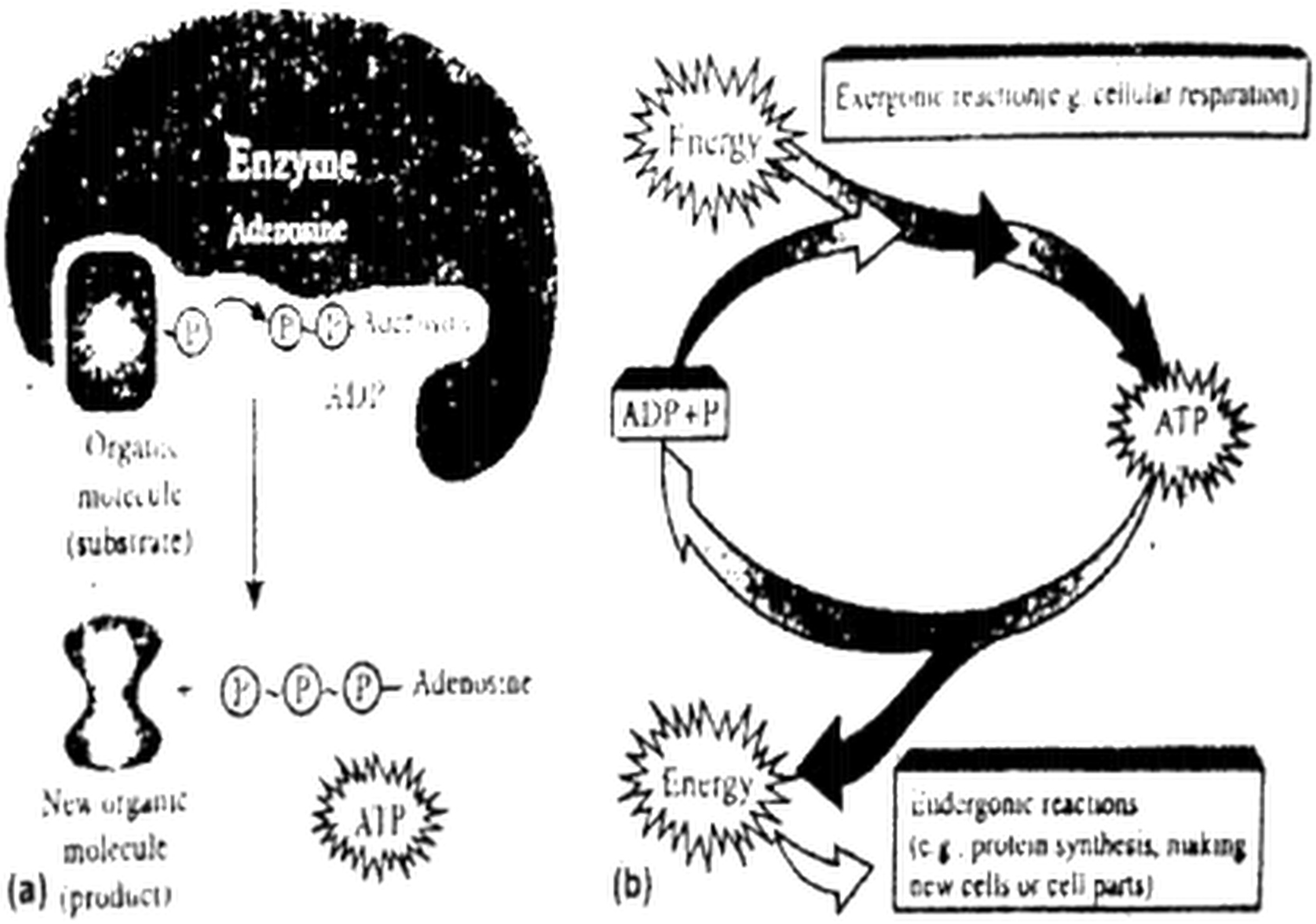
As far as substrate level phosphorylation is concerned, you are already familiar that the addition of inorganic phosphate to any organic molecule is called phosphorylation but when phosphate is enzymatically transferred fron an organic substrates molecule it is called **substrate level phosphorylation.** Howeve, it accounts for only a small percentage of the ATP that a cell generates.

It occurs at three occasions during aerobic respiration.

i. In glycolysis, substrate level phosphorylation occurs when 1,3-bisphosphoglycerate is converted into 3-phosphoglycerate (7th reaction) and when phosphoenol pyruvate is converted into pyruvate (10th reaction). There are four ATPs are produced by this mechanism during glycolysis but two of them are supposed to be consumed in preparatory phase so net product by substrate level phosphorylation is 2 ATP.

ii. In Krebs cycle, substrate level phosphorylation occurs when succinyl CoA is converted into succinate. There are two molecules of ATP are produced at this occasion. Since, ATP can be synthesized directly from the organic substrates of exergonic reactions (energy releasing reactions e.g cellular respiration), therefore, it is said that substrate level phosphorylation couples the exergonic reactions with the synthesis of ATP.

iii. These ATP are then used to drive endergonic reactions (energy storing reaction e.g , protein synthesis). In this way , out of total 36 ATP which are produced during aerobic respiration in most of human cells , 4 ATP are the result of substrate level phosphorylation and remaining 32 ATP are produced by chemiosmosis through electron transport chain.


Enzyme
Adenosine
ADP
Organic molecule (substrate)
P~P~P— Adenosine
ATP
New organic molecule (product)
(a)
Exergonic reaction(e.g. cellular respiration)
Energy
ADP+P
ATP
Energy
Endergonic reactions (e.g. protein synthesis, making new cells or cell parts)
(b)

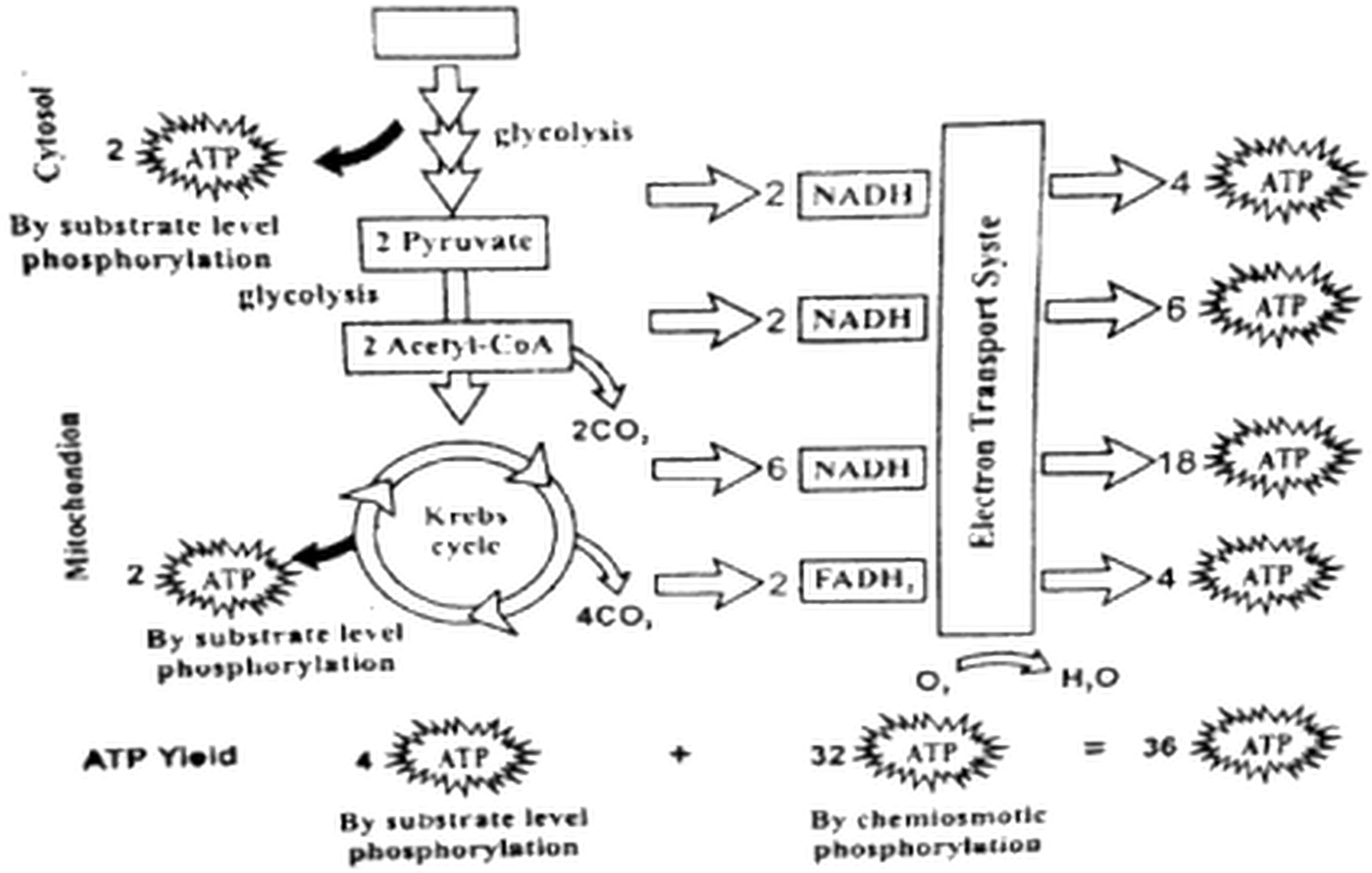


Fig: (a) Substrate level phosphorylation , **(b)** Because ATP is responsible for coupling many exergonic and exergonic reactions it is an important link between anbolism and catabolism in living cells, **(c)** ATP Budget in aerobic respirations.

Note: Actually, the two molecule of the NADH of glycolysis are produced in cytoplasm.

These cannot be taken up by mitochondria because the mitochondrial membrane is impermeable for NADH. Therefore, at the time of their uptake only the energized electrons of NADH are transferred inside the mitochondrion by a complex mechanism . These electrons are received by two molecules of FAD+ in the mitochondrial matrix to produce two molecule of FADH2. Hence , four ATP molecules are produced instead of six. So, eukaryotes yield two less number of ATP that prokaryotes.

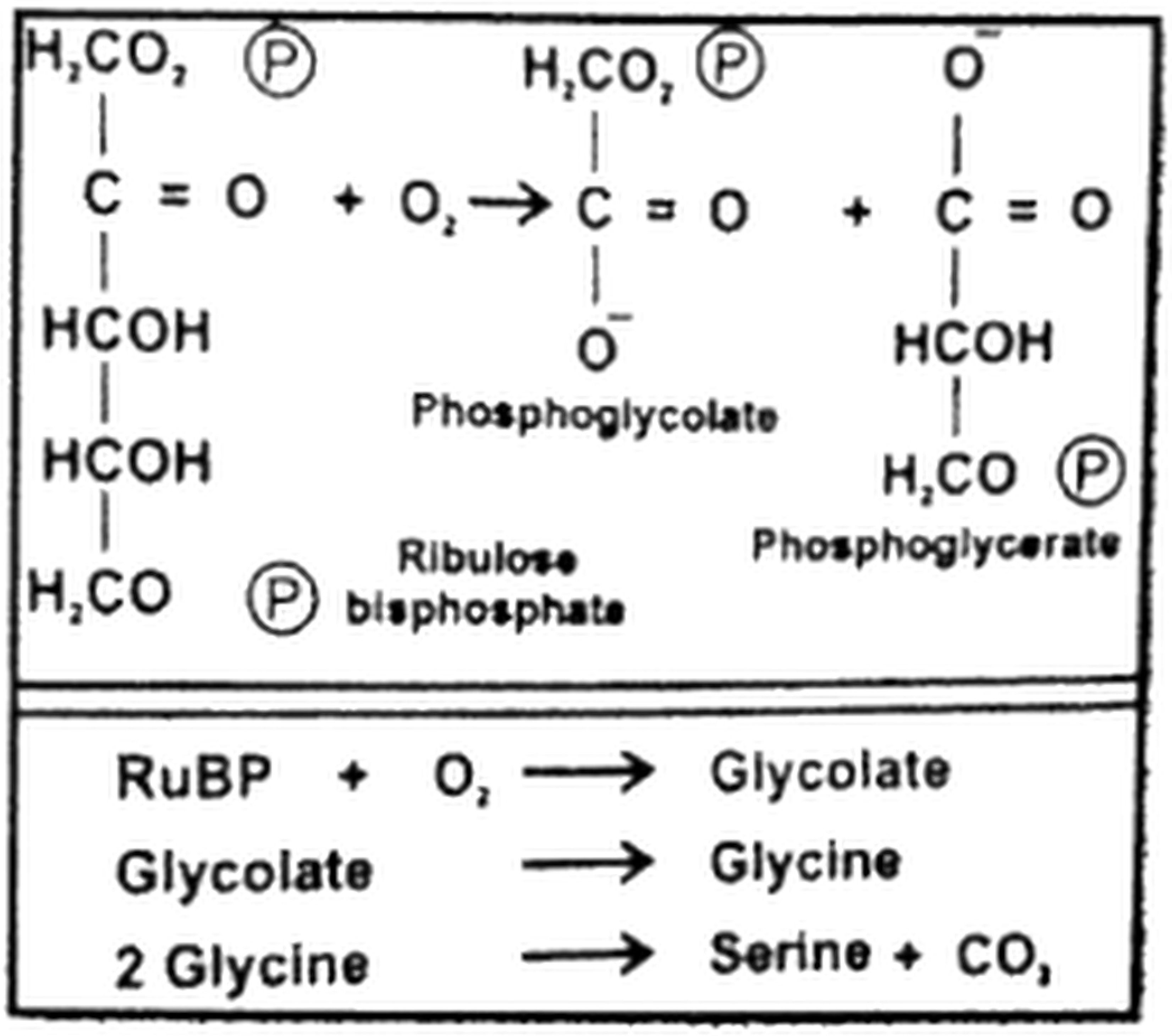
40. Give an account of photorespiration in plants.

Ans: Photorespiration:

The respiratory activity that occurs in green cells in the presence of light resulting in release of carbon dioxide is termed as **photorespiration.** It needs oxygen and produce CO2 and H2O like aerobic respiration. However ATP is not produced during photorespiration.

Mechanism of Photorespiration:

i. When the CO2 levels inside the leaf drop to around 50 ppm (part per million) ribulose bisphosphate carboxylase/oxygenase (RuBisCO) starts to combine O2 with RuBP instead of CO2.



ii. The net result of this is that instead of producing two 3C molecules of phosphoglcerate (PGA), only one molecule of PGA is produced and a toxic 2C molecule called phosphoglycolate is produced.

iii. The plant must get rid of the phosphoglycolate. First it is immediately gets rid of the phosphate group, converting the molecule to glycolic acid (glycolate).

iv. The glycolic acid is then transported to the peroxisome and there converted to glycine. The glycine is then transported into the mitochondria where it is converted into serine. The serine is then used to make other organic molecules.

Effect of temperature on the activities of RuBisCO:

Phosphorespiration is related to the functioning of the enzyme ribulose bisphosphate (RuBP) **carboxylase/oxygenase**. It is often called **RuBisCO** becuause it can have an oxygenase activity in addition to carboxylase activity. Its activity depends upon the relative concentration of O2 and CO2 in leaves. Phosphorespiration starts when the CO2 levels inside a leaf become low. This happens on hot dry days when plants begins to secrete abscistic acid which causes closing of stomata to prevent excess water loss. If the plant continues CO2 fixation in photosynthesis when its stomata are closed , the CO2 will be used up and the O2 released from photosynthesis will be prevented to release out of plant body. In this way, ratio of O2 in the leaf will increase relative to CO2 concentrations.

Disadvantages and Evolution of Photorespiration:

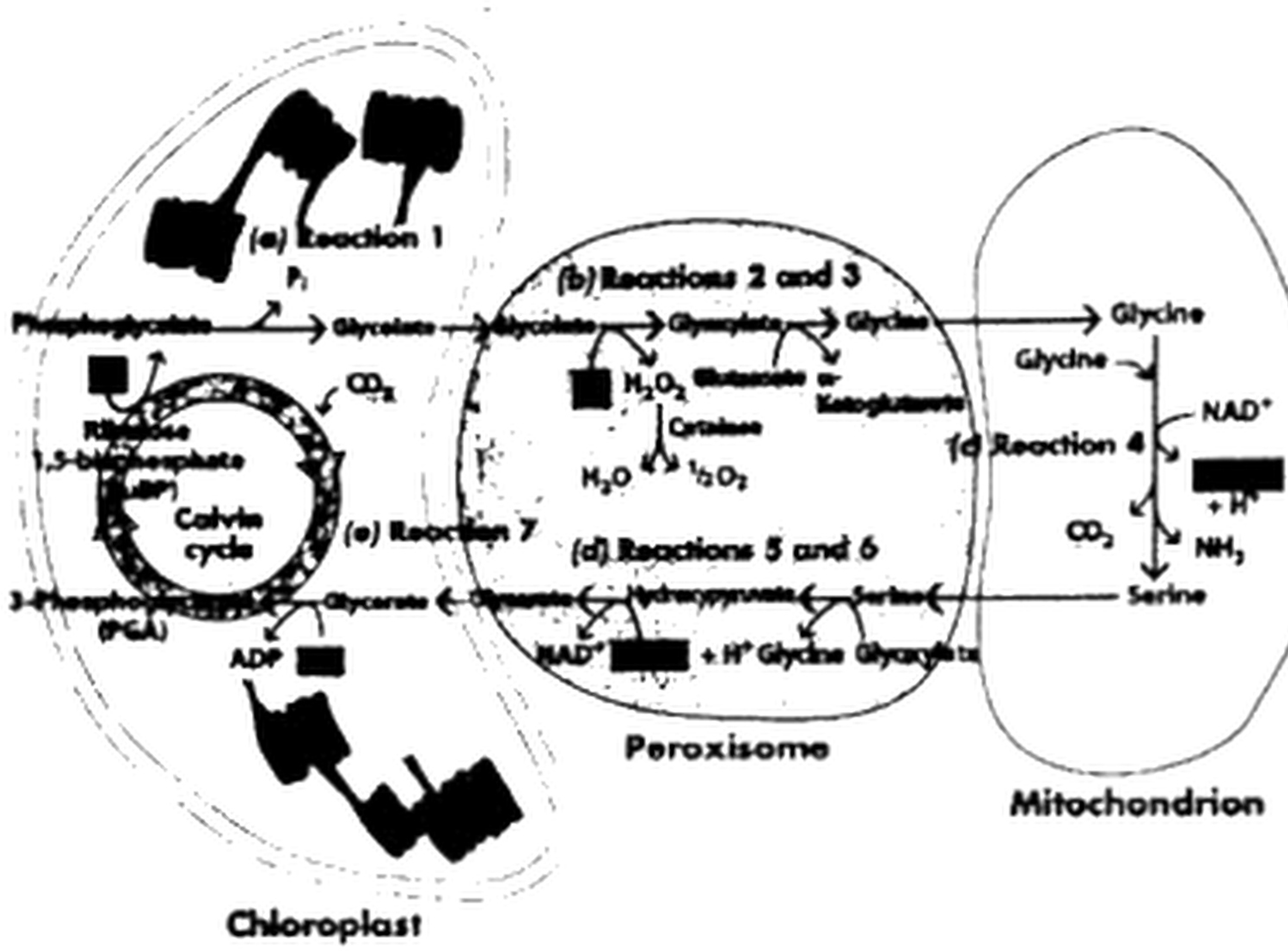
i. Photorespiration costs the plant energy and results in the net loss of CO_2 fixation from the plant. Thus , reduces the rate of photosynthetic process. In most plants, photorespiration reduces the amount of carbon fixed into carbohydrate during photosynthesis by 25 percent.

ii. Photorespiration is not essential for plant. It is also observed that if photorespiration is inhibited chemically, the plant can still grow.

iii. Furthermore , some plants are naturally resistant to photorespiration.

Then why photorespiration eixists? The common simple answer to this question is that the active site of RuBisCO is evolved to bind both carbon dioxide and oxygen.

Originally ot was not a problem as there was no oxygen in the atmostphere at the time of establishment of earth so the carbon dioxide binding activity was the only one used. The photorespiration started when the oxygen began to accumulate in the atmosphere.



Schematic representation of pathway involved in photorespiration in chloroplast peroxisomes and mitochondria

41. Explain that C4 photosynthesis in an adaptation to the problem in photorespiration.

Ans: C4 photosynthesis:

An adaptation to the problem in photorespiration:

Some plants which grow in tropical climate have an adaptation to the problem of photorespiration. They have an additional metabolic pathway in light independent phase of photosynthesis beside Calvin cycle. This metablic pathway is called Hatch-Slack cycle of C4 pathway in which phosphoenal pyruvate (PEP) carboxylases is used instead of RuBisCO to fix CO2 to phosphoenal pyruvate (a C3 molecule), and the result is oxaloacetate , a C4 molecule. It takes place in cytoplasm of mesophyll cells.

$$\textbf{PEP} + \textbf{CO2} \xrightarrow{\textbf{PEP carbocylase}} \textbf{Oxaloacetate}$$

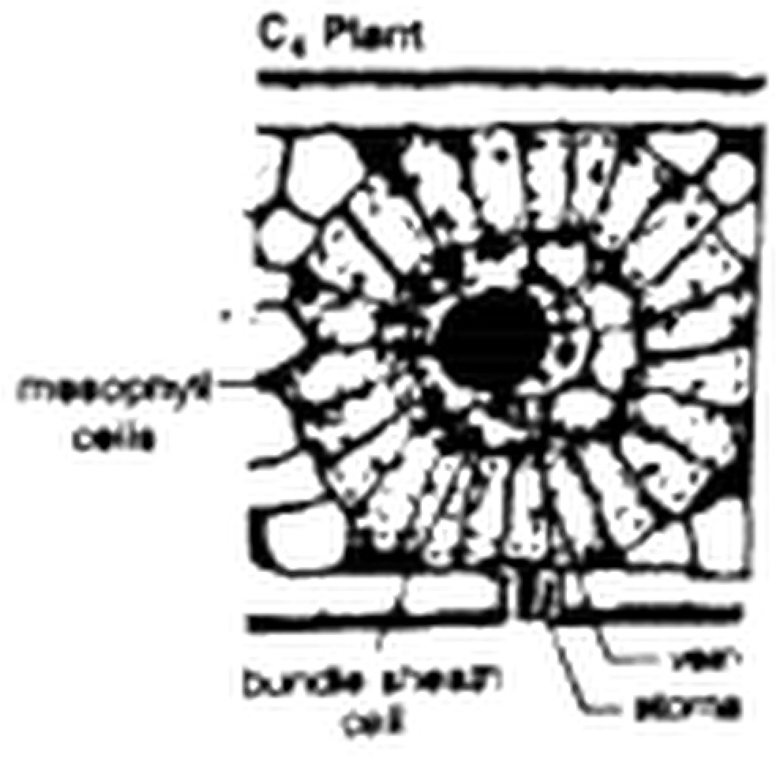
As the first product of CO2 fixation is a 4-carbon compound ocaloacetate, so that plants are called C4 plants e.g , maize , sugarcane , sorghum, etc.

Role of Oxaloacetate:

Oxaloacetate is then transported to the chloroplasts of mesophyll cells. It is then converted to another 4-C compound , the malate with the help of NADH.

Produced in the photochemical phase. The malate is then transported to the chloroplasts of bundle sheath cells. Here malate is converted to pyuvate (C3) with the release of CO2. Thus concentration of CO2 increases in the bundle sheath cells. These cells contain enzymes of Calvin cycle. B ecause of high concentration ofCO2,RuBP carboxylase participates in Calvin cycle and not in photorespiration. Sugarformed in Calvin cyvle transported into the phloem. Pyuvic acid (pyruvate) generated in the bindle sheath cells re-enters mesophyll cells and regenerates phosphoenol pyruvic acid (PEP) by consuming one ATP.

Kranz anatomy: the special structure of lein C4 plants (e.g maize) where the tissue equivalent to the spongy mesophyll cells is clustered in a ring around the leaf veins, outside the bundle-sheath cells. (the term **"Kranz" means** wreath or ring in German).



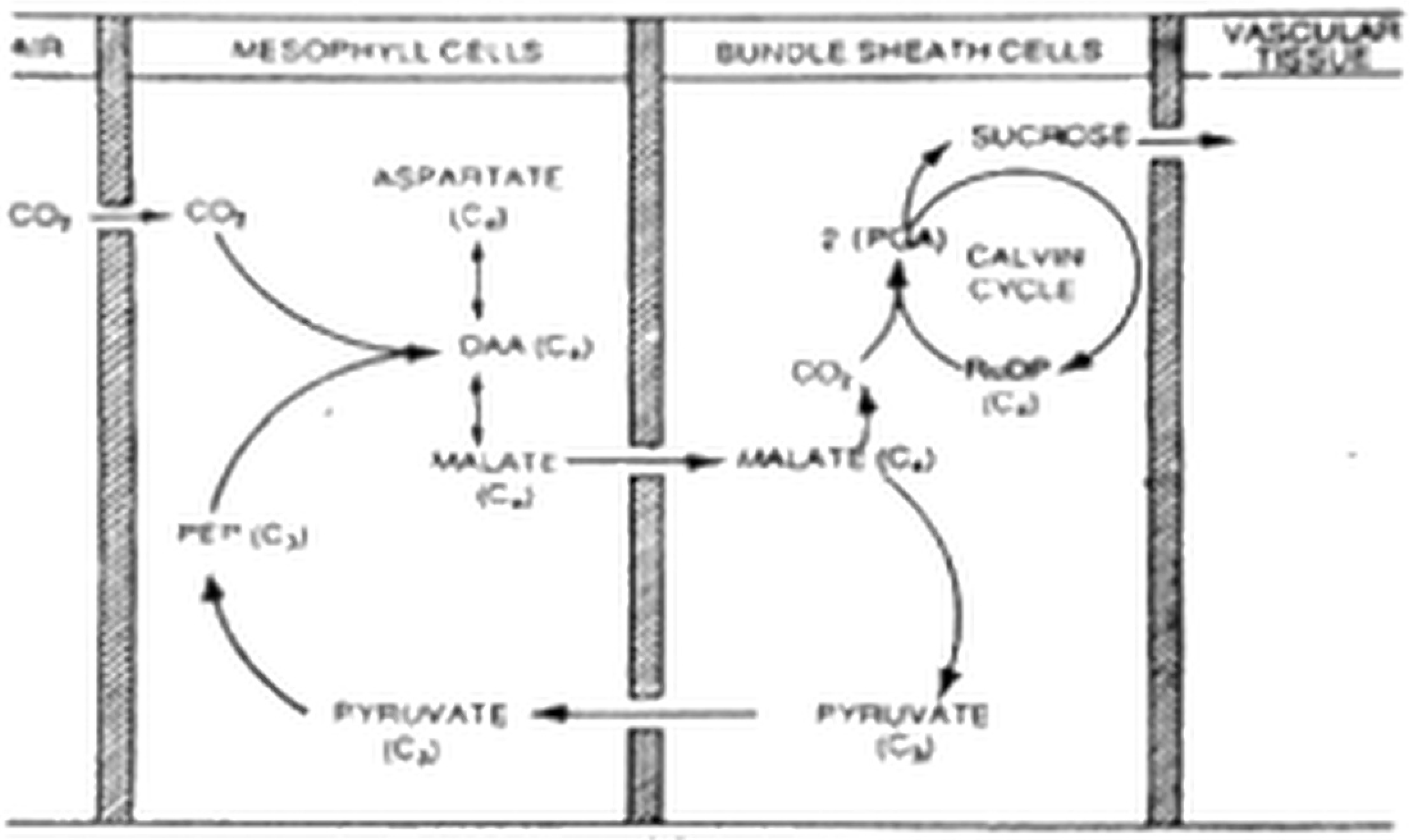


Fig: In C4 plants with Kranz anatomy ,CO2 is initially fixed in mesophyll cells by the ezyme PEP-carboxylase, 4-carbon compound, malic acid (malate), transfers CO2 to bundle sheath cells where it is further transferred to the Calvin cycle. Bundle sheath cells transfer the sugar they make to phoem tube transported through the body.