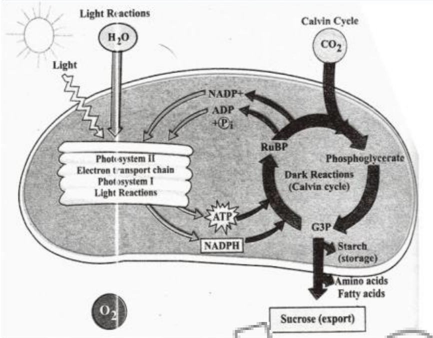


Chapter 11

Bioenergetics

11.0 INTRODUCTION

- Bioenergetics is the quantitative study of energy relationships and energy conversions in biological systems.
- Biological energy transformations obey the laws of thermodynamics.
- All organisms need free energy for keeping themselves alive and functioning.
- All life on this planet Earth is powered, directly or indirectly, by solar energy, but no organism can make direct use of sunlight as source of energy for metabolism; all can use chemical energy in the food such as sugars etc.
- The chloroplasts of the plants capture light energy coming from the sun and convert it into chemical energy that gets stored in sugar and then in other organic molecules.
- With the emergence of photosynthesis on earth, molecular oxygen began to accumulate slowly in the atmosphere.
- The presence of free oxygen made possible the evolution of respiration.
- Respiration releases great deal of energy, and couples some of this energy to the formation of adenosine triphosphate (ATP) molecules.
- **ATP is a kind of chemical** link between catabolism and anabolism.
- The process of photosynthesis helps understand some of the principles of energy transformation in living systems.
- Photosynthetic organisms (higher land plants for instance) use solar energy to synthesize organic compounds (Such as carbohydrates) that cannot be formed without the input of energy.
- Energy stored in these molecules can be used later to power cellular processes and can serve as the energy source for all forms of life.
- Whereas photosynthesis provides the carbohydrate substrate, glycolysis and respiration are the processes where by the energy stored in carbohydrate is released in a controlled manner.
- So the photosynthesis acts as an energy capturing while respiration as an energy releasing process.

11.1 PHOTOSYNTHESIS (CONVERSION OF SOLAR ENERGY INTO CHEMICAL ENEGY)

Photosynthesis can be defined as the process in which energy poor inorganic oxidized compounds of carbon (CO_2) and hydrogen (mainly H_2O) are reduced to energy rich carbohydrate i.e. glucose (sugar) using the light energy that is absorbed and converted into chemical energy by chlorophyll and some other photosynthetic pigments.

Chemical Equation

The processes of photosynthesis in green plants can be summarized as:

$$6CO_2 + 12H_2O + Light \xrightarrow{Chlorohyll} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

11.1.1 Photosynthetic Reactants and Products

Consider the following equation;

$$6CO_2 + 12H_2O + Light \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

This equation shows that carbon dioxide, water and light are the reactants while glucose and oxygen are the products. Water appears on both sides of the equation because water is used as reactant in some reactions and released as product in other. However because there is no net yield of H_2O, we can simplify the summary equation of photosynthesis for purpose of discussion:

$$6CO_2 + 6H_2O + Light \longrightarrow C_6H_{12}O_6 + 6O_2$$

Relation between Photosynthesis and Respiration and

- Chemical equation of photosynthesis is almost exactly opposite to the overall equation of aerobic respiration ($C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ + Energy).
- Photosynthesis uses the products of respiration and respiration uses the products of photosynthesis.
- Photosynthesis occurs only during daytime, whereas respiration goes on day and night.

Light Variations and Compensation Point

- During darkness, leaves and other actively metabolizing cells respire and utilize oxygen and release carbon dioxide.
- At dawn and dusk, when light intensity is low, the rate of photosynthesis and respiration may for a short time, equal one another. Thus oxygen released from photosynthesis is just the amount required for cellular respiration. Also the carbon dioxide released by respiration just equals the quantity required by photosynthesizing cells.

  At this moment there is no net gas exchange between the leaves and the atmosphere. This is termed as ***compensation point.***

  As the light intensity increases, so does the rate of photosynthesis and hence the requirement for more carbon dioxide increases which respiration alone cannot supply. Similarly the oxygen produced during photosynthesis is more than the need of the respiring cells, so the result is the net release of oxygen coupled with the uptake of carbon dioxide.

11.1.2 Water and Photosynthesis

Oxygen released during photosynthesis comes from water and is an important source of atmospheric oxygen, which most organisms need for ***aerobic respiration*** and thus for obtaining energy to live.

Discovery about Involvement of Water in Oxygen Production

- In 1930s, ***Van Niel*** hypothesized that plants split water as a source of hydrogen, releasing oxygen as a by-product. Neil's hypothesis was based on his investigations on photosynthesis in bacteria that make carbohydrate from carbon dioxide, but do not release oxygen.
- Neil's hypothesis was later confirmed by scientists during 1940s when first use of biological tracer (O^{18}) in biological research was made. Carbon dioxide and water containing heavy-oxygen isotopes O^{18} were prepared in the laboratory. Two groups of plants were made.

First Group

Experimental green plants of first group were supplied with H_2O containing O^{18} and with CO_2 containing common oxygen O^{16}.

These plants produced O^{18}.

Group – 1 plants: $CO_2 + 2H_2O^{18} \longrightarrow CH_2O + H_2O + {}^{18}O_2$

Second Group

Plants in the second group were supplied with H_2O containing common oxygen O^{16} but with CO_2 containing O^{18}.

These plants did not produce O^{18}.

Group 2 Plants: $CO_2^{18} + 2H_2O \longrightarrow CH_2O^{18} + H_2O^{18} + O_2$

- These experiments showed that oxygen produced during photosynthesis comes from water.

Formation of $NADPH_2$

Water is thus one of the raw materials of photosynthesis, other being carbon dioxide.

Hydrogen produced by splitting of water reduces NADPH to $NADPH_2$ ($NADPH + H^+$).

$NADPH_2$ is the "reducing power" which along with ATP also formed during **light reactions** is used to reduce CO_2 to form sugar during **dark reactions.**

QUESTION RELATED TO ABOVE ARTICLE

Discuss water photosynthesis relation with the help of Niel's Hypotheses (DGK 2022)
Write down the role of water in photosynthesis. (RWP 2022, GRW 2022)
Compare photosynthesis with respiration in plants. (Exercise Question vii)

11.1.3 CHLOROPLASTS-THE SITES OF PHOTOSYNTHESIS IN PLANTS

- All green parts of a plant have chloroplasts, but the leaves are the major sites of photosynthesis in most plants.
- Chloroplasts are present in very large number, about ***half a million per square millimeter*** of leaf surface.
- These are mainly present in the cells of mesophyll tissue inside the leaf. Each mesophyll cell has about ***20-100*** chloroplasts.
- Chloroplasts are present in plants photosynthetic cells.

Structure

- Chloroplast has a ***double membrane envelope***.
- This envelope encloses dense fluid filled region called ***the stroma***, which contains most of the enzymes required to produce carbohydrate molecules.
- Another system of membranes is suspended in the stoma. These membranes form an elaborate interconnected set of flat, disc like sacs called ***thylakoids***.
- The thylakoid membrane encloses a fluid-filled ***'thylakoid interior space'*** or 'lumen', which is separated from the stroma by thylakoid membrane.

In some spaces, the thylakoid sacs are stacked in columns called ***grana***.

Fig11.1: A plant possesses thick layer of mesophyll cells rich in chloroplasts. Thylakoids in chloroplasts are stacked into grana. Light reactions take place on the grana, and dark reactions in the stroma.

- ***Chlorophyll*** and other photosynthetic pigments are found embedded in the thylakoid membranes and impart green colour to the plant. Electron acceptors of 'Photosynthetic Electron Transport Chain' are also parts of these membranes.

Function

i) Thylakoid membranes are involved in ATP Synthesis by chemiosmosis

ii) Chlorophyll and other pigments absorb light energy, which is converted into chemical energy of ATP and NADPH, which are used to synthesize sugar in the stroma of chloroplast.

> Photosynthetic prokaryotes lack chloroplasts but they do have unstacked photosynthetic membranes, which work like thylakoid.

11.1.4 Photosynthetic Pigments

"Pigments are the substances that absorb visible light (***380-750 nm*** in wavelength)."

Types

- Light can work in chloroplasts if it is absorbed. Thylakoid membranes contain several kinds of pigments. Some important ones are;
- Chlorophyll, which is main photosynthetic pigment.
  Other accessory photosynthetic pigments present in the chloroplasts include yellow and orange to red ***carotenoids***.
- ***Xanthophylls*** are yellow.
- ***Carotenes*** are red to orange.
  These broaden the absorption and utilization of light energy.

Function

Different pigments absorb light of different wavelengths (colours) and the wavelengths that are absorbed disappear.

An instrument called ***Spectrophotometer*** is used to measure relative abilities of different pigments to absorb different wavelengths of light.

A graph plotting absorption of light of different wavelengths by a pigment is called ***absorption spectrum*** of the pigment.

QUESTION RELATED TO ABOVE ARTICLE

Explain the chloroplast as the "sites of photosynthesis" in plants (GRW 2017)

11.1.5 Chlorophylls

Chlorophylls are main photosynthetic pigments. These are insoluble in water but soluble in organic solvents such as carbon tetrachloride, alcohol etc.

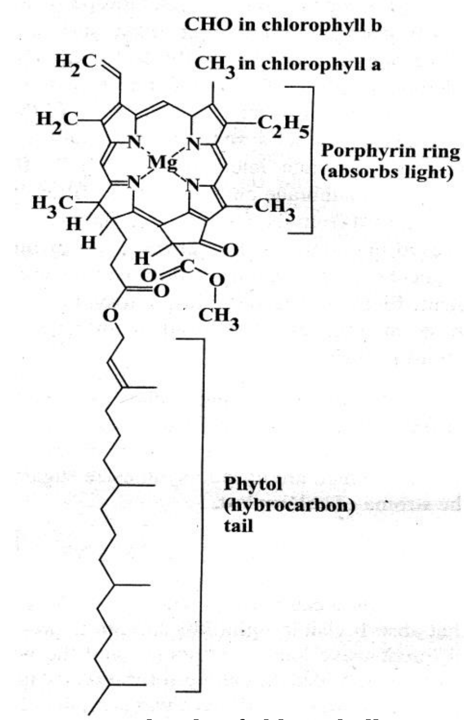


Fig 11.2 : A molecule of chlorophyll

Structure

A chlorophyll molecule has two main parts.

iii) One flat, square, light absorbing hydrophilic head.

iv) Other long, anchoring, hydrophobic, hydrocarbon tail.

i) Head

- It is complex porphyrin ring, which is made up of four joined smaller pyrrole rings composed of carbon and nitrogen atoms ***(tetrapyrrole ring structure)***.

  An atom of ***magnesium*** is present in the center of porphyrin ring and is coordinated with the nitrogen of each pyrrole ring. Magnesium deficiency causes yellowing in plants. Haeme portion of haemoglobin is also a porphyrin ring but containing an iron atom instead of magnesium atom in the center.

ii) Tail

Long hydrocarbon ($C_{20}H_{39}$), which is called ***phytol*** is attached to one of the pyrole rings.

Chlorophyll molecule is embedded in the hydrophobic core of thylakoid membrane by this tail

Absorption of Light by Chlorophyll

- Chlorophylls mainly absorb violet, blue, orange and red wavelengths.
- Green and yellow wavelengths are least absorbed by chlorophyils and are transmitted or reflected, although the yellow colour is often masked by darker green colour. Hence plants appear green.

Types of Chlorophyll

There are many known kinds of chlorophylls. Chlorophyll a, b, c and d are found in eukaryotic photosynthetic plants and algae, while others are found in photosynthetic bacteria and are known as ***bacteriochlorophylls***.

Of all the chlorophylls, chlorophyll a is most abundant and the most important photosynthetic pigment as it takes part directly in the light-dependent reactions, which convert solar energy to chemical energy.

Difference between chlorophyll 'a' and 'b'

Difference	Chlorophyll a	Chlorophyll b
Molecular formula	$C_{55}H_{72}O_5N_4Mg$	$C_{55}H_{70}O_6N_4Mg$
Functional group	$-CH_3$	-CHO
Occurrence	All photosynthetic organisms except photosynthetic bacteria.	In association with chlorophyll 'a' in all green plants and green algae.
Forms	Differ slightly in their red absorbing peaks e.g. 670,680,690,700 nm.	No such different forms exists.

11.1.6 Carotenoids-Accessory Pigments

Carotenoids are yellow and red to orange pigments.

Functions

- They absorb strongly the blue-violet range, different wavelengths than the chlorophyll absorbs. So they broaden the spectrum of light that provides energy for photosynthesis.
- These and chlorophyll b are called **accessory pigments** because they absorb light and transfer the energy to chlorophyll a, which then initiates the light reaction. It is generally believed that the order of transfer of energy is:

Carotenoids ⟶ Chlorophyll b ⟶ Chlorophyll a

- Some carotenoids protect chlorophyll from intense light by absorbing and dissipating excessive light energy, rather than transferring energy to chlorophyll.
- Similarly carotenoids protect human eye.

11.1.7 LIGHT-THE DRIVING ENERGY

Light is form of energy called electromagnetic energy or radiations. Light behaves as waves as well as sort of particles called photons. The radiations most important to life are the visible light that ranges from about 380 to 750 nm in wavelength.

Role of Light

It is the sunlight energy that is absorbed by chlorophyll, drives the photosynthetic process and is converted into chemical energy.

Not all the light falling on leaf is absorbed. Only about **one percent** of the light falling on the leaf surface is absorbed, the rest is either reflected or transmitted.

Spectrum of Light for Plants

There are two types of spectrum:

- Absorption spectrum
- Action spectrum

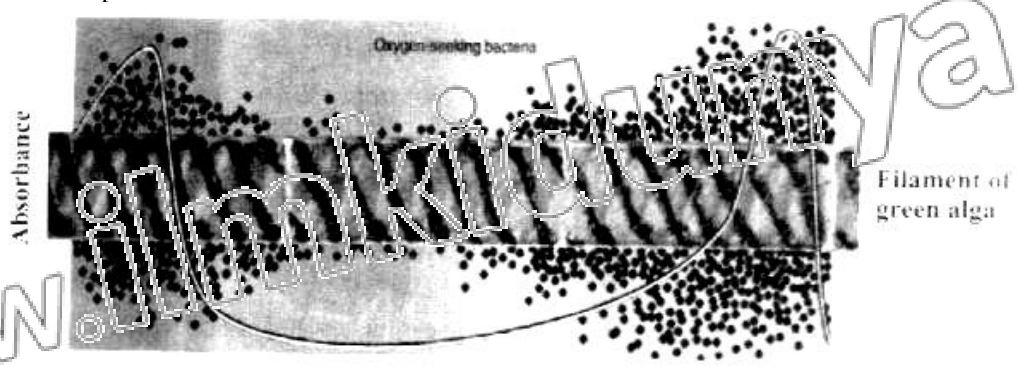


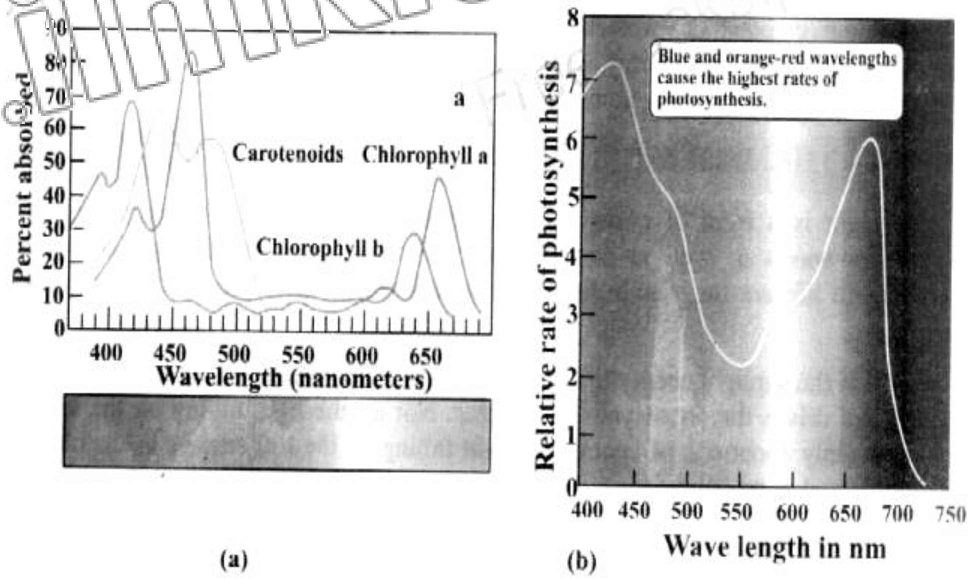
Fig. 11.3 Engelmann illuminated a filament of *Spirogyra* with light that had been passed through a prism. Aerobic bacteria moved toward the portions of the algal filament emitting the most oxygen, along the cells in blue and red portion of the spectrum.

1) Absorption Spectrum

- Graph showing relative absorption of different wavelengths (colours) of light is called absorption spectrum.
- Absorption spectrum for chlorophylls indicates that absorption is maximum in blue and red parts of the spectrum, two absorption peaks being at around 430 and 670 nm respectively.

Absorption peaks of carotenoids are different from those of chlorophylls.

> ***First action spectrum*** was obtained by German biologist ***T.W.Engelmann*** in 1883. He worked on Spirogyra.



Wave length in nm

Fig. 11.4 (a) Absorption spectrum of chlorophyll and carotenoids.
(b) Action Spectrum for photosynthesis.

2) Action Spectrum

- Graph showing relative effectiveness of different wavelengths (colours) of light in driving photosynthesis is called action spectrum.
- It can be obtained by illuminating plant with light of different wavelengths (colours) and then estimating relative CO_2 consumption or oxygen released during photosynthesis.

Relation between Absorption and Action Spectra of Plants

As is evident from above figure, action spectrum of photosynthesis corresponds to absorption spectrum of chlorophyll. The same two peaks and the valley are obtained for absorption of light as well as for CO_2 consumption. This also shows that chlorophyll is the photosynthetic pigment.

However, the action spectrum of photosynthesis does not parallel the absorption spectrum of chlorophyll exactly. Compared to the peaks in absorption spectrum the peaks in action spectrum are broader, and the valley is narrower and not as deep.

Information Provided by Spectra

These two spectra provide following information;

- Photosynthesis in the most absorbed range is more than the absorption itself.
- Photosynthesis in 500-600 nm (including green light) is more than the absorption of green light by the chlorophyll. This difference is due to accessory pigments (carotenoids), which absorb light in this zone and pass on some absorbed light to chlorophyll.
- When equal intensities of light are given, there is ***more photosynthesis in red than in blue part*** of spectrum.

11.1.8 ROLE OF CARBON DIOXIDE: A PHOTOSYNTHETIC REACTANT

Source of CO_2

- About ***10 percent*** of total photosynthesis is carried out by terrestrial plants, the rest occurs in oceans, lakes and ponds.
- Aquatic photosynthetic organisms use dissolved CO_2, bicarbonates and soluble carbonates that are present in water as carbon source.
- Photosynthesis occurring on land utilizes atmospheric CO_2. Air contains **0.03-0.04** percent of CO_2.

Passage of CO_2 to Enter in Plants

Carbon dioxide enters the leaves through stomata and gets dissolved in the water absorbed by the cell walls of mesophyll cells. Stomata are found in a large number in a leaf. Their number is proportional to the amount of gas diffusing into the leaf. ***Stomata*** cover only ***1-2%*** of the leaf surface but they allow proportionally much more gas to diffuse.

Effect of Opening and Closing of Stomata

The entry of CO_2 into the leaves depends upon the opening of stomata.

Stoma is an opening surrounded by guard cells. Because of peculiar structure and changes in their shape, they regulate the opening and closing of stomata.

Stomata are adjustable pores, which are;

- Open during daytime when CO_2 is required.
- Closed at night when photosynthesis stops.

> Daily rhythmic opening and closing of stomata is due to an internal clock located in the guard cells. Even if a plant is kept in a dark room, stomata will continue their daily rhythm of opening and closing.

Role of CO_2 in Photosynthesis

Reduction of CO_2 is done during light-independent reactions of photosynthesis by using ATP and NADH (products of light-dependent reaction). Due to this, sugar is formed. This shows that photosynthesis is not possible in the absence of CO_2.

11.1.9 REACTIONS OF PHOTOSYNTHESIS

Photosynthesis is a ***'redox process'*** that can be represented by the following simplified summary equation:

Reduction

$$\underset{\text{Carbon Dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O} + \text{Light energy} \xrightarrow{\text{Chlorophyll}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} + 6H_2O$$

Oxidation

Phases of Photosynthesis

If we consider above equation that shows a simple relation, however photosynthesis is not a simple, single step process, but is a complex one that is completed by a series of simple steps or reactions. These reactions of photosynthesis consist of two parts:

1) ***The light-dependent reaction (Light reaction)*** which use light directly.
2) ***The light-independent reaction (dark reaction)*** which do not use light directly.

The light dependent reaction constitute that phase of photosynthesis during which light energy is absorbed by chlorophyll and other photosynthetic pigment molecules and converted into chemical energy.

- As a result of this energy conversion, reducing and assimilating power in the form of $NADPH_2$ ($NADPH + H^+$) and ATP, are formed, both temporarily storing energy to be carried along with H to the light independent reaction.
- $NADPH_2$ provides energized electron (and H^+) while ATP provides chemical energy for the synthesis of sugar by reducing CO_2, using reducing power and chemical energy of $NADPH_2$ and ATP respectively, produced by light reaction, the energy is thus stored in the molecules of sugar.
- This phase of photosynthesis is also called dark reactions because these reactions do not use light directly and can take place equally will both in light and dark provided $NADPH_2$ and ATP of light reaction are available.

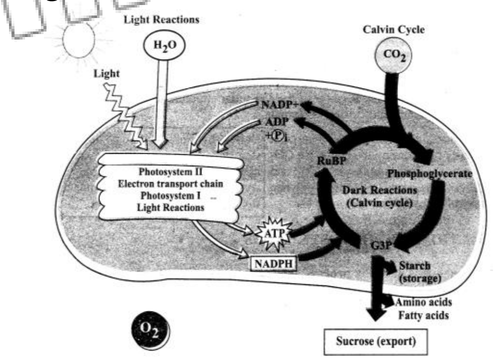


Fig 11.5. An overview of photosynthesis: Light – Dependent Reactions (Energy – conversion) and Light-Independent Reaction (Energy – conservation)

QUESTION RELATED TO ABOVE ARTICLE

Write down a note on photosystems. (GRW 2021)

11.1.10 Light Dependent Reactions: (Energy conversion phase; formation of ATP and NADPH)

Photosystems

Sunlight energy, which is absorbed by photosynthetic pigments drives the process of photosynthesis. Photosynthetic pigments are organized into clusters, called ***photosystems***, for efficient absorption and utilization of solar energy in thylakoid membranes.

Components of Photosystem

Each photosystem consists of two major components:

- Antenna complex
- Reaction center

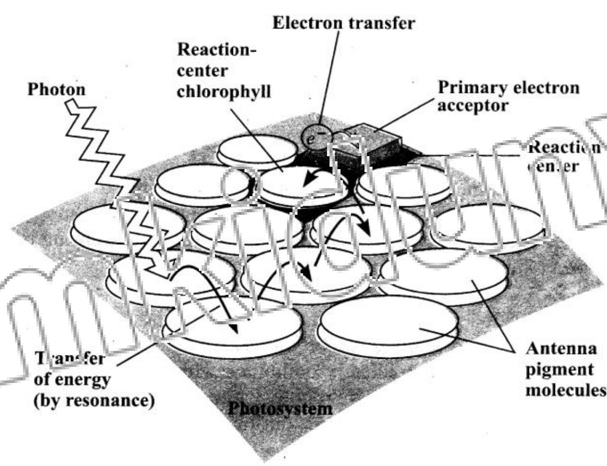


Fig 11.6 Light harvesting photosystem. Energy of light (photon) absorbed by photosynthetic pigment molecules is transferred from molecule to molecule, and finally reaches the reaction centre where actual energy conversion begins.

Antenna Complex

The antenna complex has ***many molecules of chlorophyll 'a', chlorophyll 'b',*** and ***carotenoids,*** most of them channeling the energy to reaction center.

Reaction Center

Reaction center has ***one or more molecules of chlorophyll 'a' along with a primary electron acceptor*** and associated electron carriers of '***electron transport system***'.

Chlorophyll a molecules of reaction center and associated proteins are closely linked to the nearby electron transport system. Electron transport system plays role in generation of ATP by chemiosmosis.

Light energy absorbed by the pigment molecules of antenna complex is transferred ultimately to the reaction center.

Types of Photosystems

There are two photosystems. These are named in order of their discovery. These are:

- Photosystem I (PS I)
- Photosystem II (PS II)

Photosystem I

Photosystem I has chlorophyll a molecule, which absorbs maximum light of ***700 nm*** and is called P_{700}.

Photosystem II

Photosystem II has chlorophyll a, which absorbs best the light of ***680 nm***, so called P_{680}.

A specialized molecule called, primary electron acceptor, is also associated nearby each reaction center. This acceptor traps the high-energy electrons from the reaction center and then passes them on to the series of electron carriers. During this transfer, energy is used to generate ATP by chemiosmosis.

Mechanism of Light-Dependent Reactions

In predominant type of electron transport called *non-cyclic electron flow*, the electrons pass through the two photosystems. In less common type of path called cyclic electron flow only photosystem I is involved. Formation of ATP during non-cyclic electron flow is called non-cyclic phosphoylation while that during cyclic electron flow is called *cyclic phosphorylation*.

11.1.10 (a) Non-cyclic Phosphorylation

In non cyclic phosphorylation, electrons are not reused. It involves both photosystem i.e photosystem II (involved first) and photosystem I (involved later), which are joined by electron transport chain.

The path of electrons through the two photosystems during non-cyclic photophosphorylation is known as ***Z-scheme*** from its shape.

1. Excitation of Electrons

When photosystem II absorbs light, two electrons are excited to a higher energy level from chlorophyll P_{680}. These electrons are accepted by primary electron acceptor of PS II. The oxidized chlorophyll is now a very oxidizing agent, which is ready to fill its electron holes.

2. Photolysis

- An enzyme splits water molecule into two hydrogen ions and oxygen atom, which immediately combines with another oxygen atom to form O_2. This water splitting step of photosynthesis is called photolysis.
- Electron produced fill the hole of chlorophyll. Oxygen produced is the main source of atmospheric oxygen.

3. Electron Transport Chain

- Each photoexcited electron passes from the primary electron acceptor of photosystem II to photosystem I via an electron transport chain. This chain consists of:
- An electron carrier called ***plastoquinone*** (Pq)
- A complex of two ***cytochromes***

  A copper containing protein called ***plastocyanin*** (Pc)

4. Photophosphorylation

As electrons move down the chain, their energy goes on decreasing and is used by thylakoid membrane to produce ATP.

Synthesis of ATP by light energy is called photophosphorylation. As it takes place during non-cyclic phase, so specifically called non-cyclic photophosphorylation.

ATP generated by these light reactions provide chemical energy for the synthesis of sugar during the Calvin Cycle (second major stage of photosynthesis).

5. Link between Photosystem II and I

The electrons reach the bottom of the electron transport chain and fill the electron holes in P_{700} (chlorophyll a molecule in reaction center of photosystem I). This hole is produced when light energy is absorbed by molecules of P_{700} and drives an electron from P_{700} to the primary acceptor of photosystem I.

INVOLVEMENT OF PHOTOSYSTEM I

- The primary electron acceptor of photosystem I passes the photoexcited electrons to a second electron transport chain, which transmits them to ***ferredoxin*** (Fd), an iron containing protein.

  An enzyme called NADP reductase then transfers the electrons from Fd to NADP. This is the redox reaction that stores the high energy electrons in NADPH. The NADPH will provide reducing power for the synthesis of sugar in the Calvin cycle.

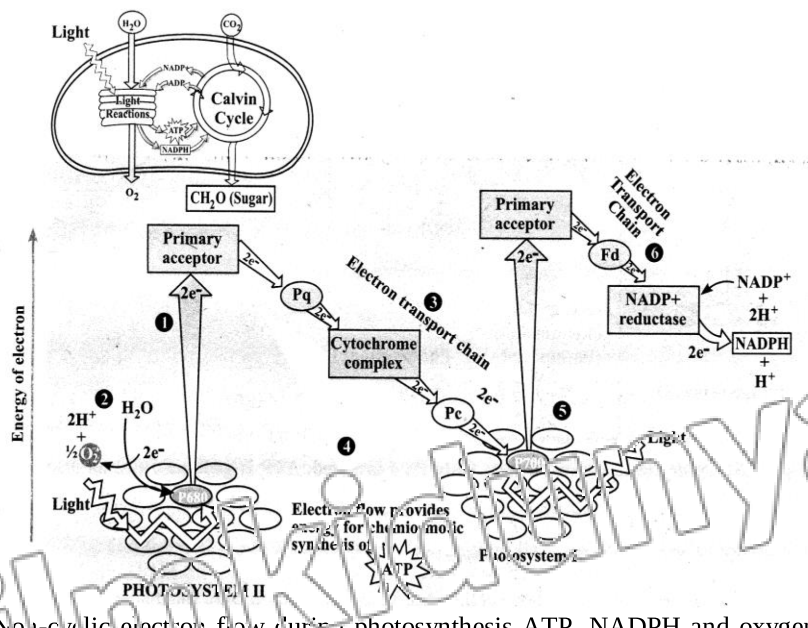


Fig 11.7: Non-cyclic electron flow during photosynthesis ATP, NADPH and oxygen are generated. The arrow trace the current of light-driven electrons from water to NADPH. Each photon of light excites single electron but the diagram tracts two electrons at a time, the number of electron required to reduce $NADP^+$. The numbered steps are described in the text.

QUESTION RELATED TO ABOVE ARTICLE

Sketch Non – cyclic phosphorylation with energy yielding steps. (SGD 2022)
Draw and label Z- scheme/non- cyclic phosphorylation. (LHR 2017)
Describe non-cyclic photo-phosphorylation. (DGK 2021)

11.1.10 (b) Cyclic Phosphorylation

Under certain conditions, photo excited electrons take an alternative path called ***cyclic electron flow***. This path uses photosystem I but not photosystem II.

Cause

Possibly it happens when the chloroplast runs low on ATP for the Calvin cycle, the cycle slows down and NADPH accumulate in chloroplast. This rise in NADPH may stimulate a temporary shift from non-cyclic to cyclic electron flow until ATP supply meets the demand.

Mechanism of Cyclic Phosphorylation

The cyclic flow is short circuit.

- The electrons cycle back from primary electron acceptor to ***ferredoxin*** (Fd), then to ***cytochrome complex*** and from there continue on to the P_{700} chlorophyll.
- ATP is generated by the coupling of ETC by chemiosmosis. Cyclic flow generates only ATP, so called cyclic photophosphorylation.

There is no production of NADPH and no release of oxygen.

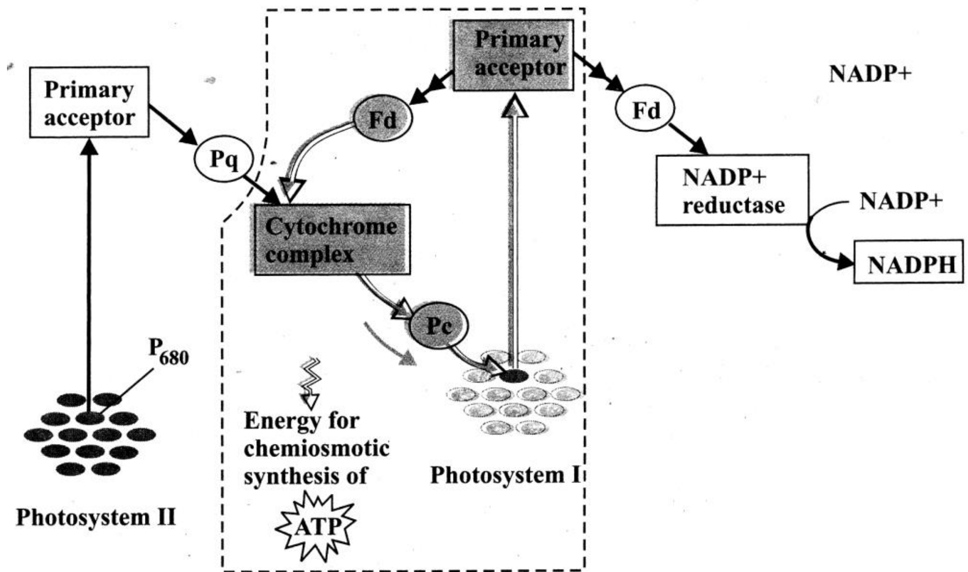


Fig11.8 Cyclic electron flow in box. Only PS I involved. ATP is generated but no NADPH and oxygen.

11.1.10 (c) CHEMIOSMOSIS

Process during cyclic and non-cyclic phosphorylation by using membranes to couple redox reactions to synthesize ATP is called chemiosmosis.

Site of Chemiosmosis during Photosynthesis

Chemiosmosis during photosynthesis takes place in ***thylakoid membranes***.

Mechanism

Different steps occurring during this process are:

- Electron transport pumps protons (H^+) across the membrane of thylakoids into thylakoid space.
- Energy for this pumping comes from the electrons moving through the electron transport chain. This energy is stored as potential energy in H^+, which are lifted up across the membrane.

Next, the hydrogen ions move down their gradient through special complexes called **ATP synthase**, which are built in the thylakoid membranes. During this diffusion of electrons the energy of electrons is used to make ATP.

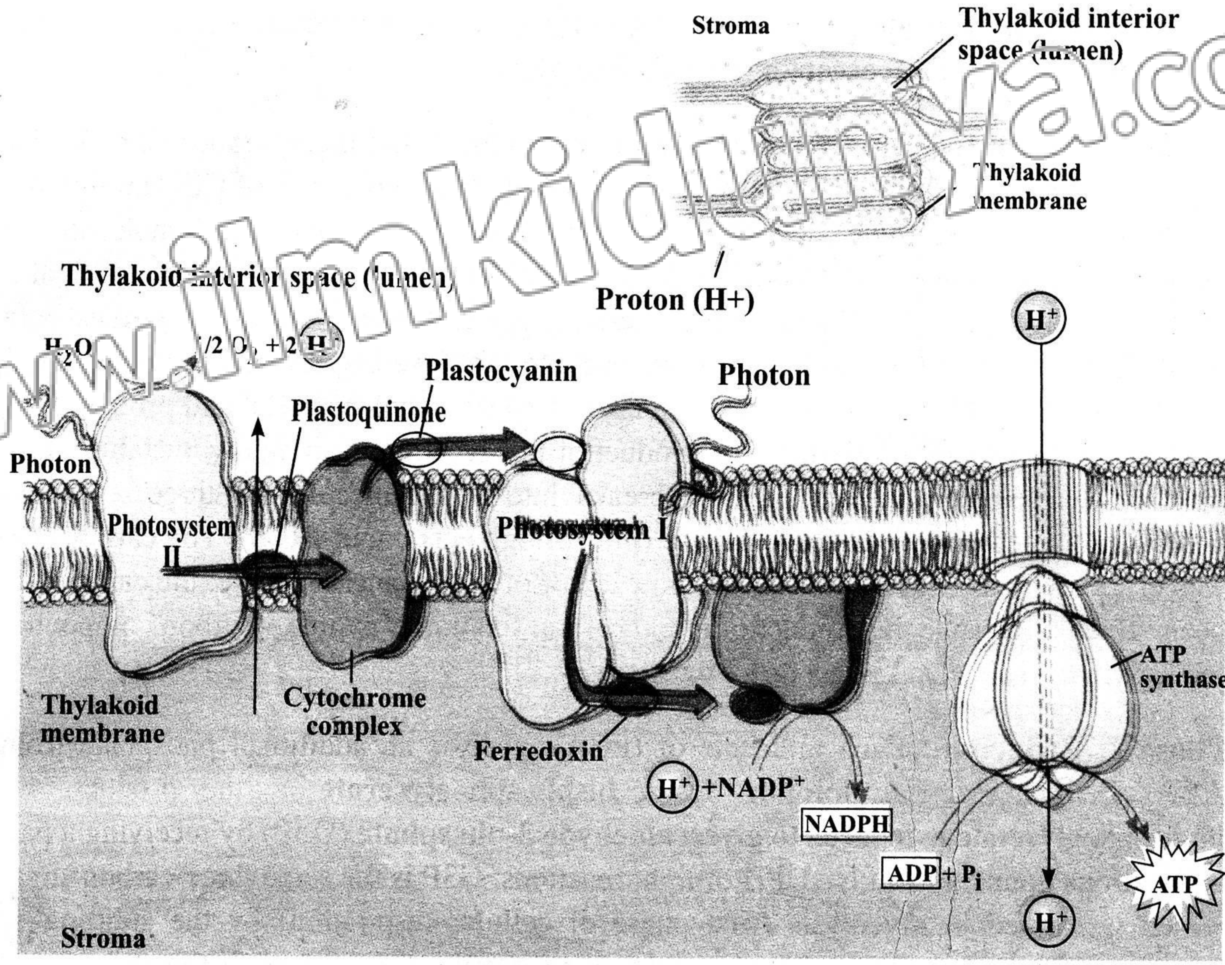


Fig. 11.9 Electron Transport chain and chemiosmosis, coupling of ETC and formation of ATP by chemiosmosis.

11.1.11 Light Independent (or Dark) Reactions: Calvin cycle: carbon fixation and reduction phase, synthesis of sugar

The **dark reactions** take place in the stroma of chloroplast. These reactions do not require light directly and can occur in the presence or absence of light provided the assimilatory power in the form of ATP and NADPH, produced during light reactions is available. Energy of these compounds is used in the formation of carbohydrates from CO_2 and thus stored there in. These reaction can be summarized as follows:

$$3CO_2 + 6NADPH + 9ATP \longrightarrow (CH_2O)_3 + 6NADP + 9ADP + 9Pi + 3H_2O$$

Discovery

The details of path of carbon in these reactions were discovered by Melvin Calvin and his collegues at the University of California. Calvin was awarded Nobel Prize in 1961.

Definition

The cyclic series of reactions, catalyzed by respective enzymes, by which the carbon is fixed and reduced resulting in the synthesis of sugar during the dark reactions of photosynthesis is called ***Calvin Cycle***.

Phases of Calvin Cycle

There are three important phases of dark reaction i.e.

3) Carbon fixation
4) Reduction
5) Regeneration of CO_2 acceptor

Phase 1: Carbon Fixation

- Carbon fixation refers to the initial incorporation of CO_2 into organic material.
- Keep in mind that we are following three molecules of CO_2 through the reaction (because 3 molecules of CO_2 are required to produce one molecule of carbohydrate, a triose).
- The Calvin cycle begins when a molecule of CO_2 reacts with a highly reactive phosphorylated five carbon sugar named ***ribulose bisphosphate (RUBP).***
- This reaction is catalyzed by the enzyme ***ribulose bisphosphate carboxylase,*** also known as ***Rubisco*** (it is the most abundant protein in chloroplasts, and probably the most abundant protein on Earth).
- The product of the reaction is a highly unstable, six carbon intermediate that immediately breaks into two molecules of three carbon compound called ***3–phosphoglycerate (phosphoglyceric acid –PGA)***.
- The carbon that was originally part of CO_2 molecule is now a part of an organic molecule; the carbon has been "fixed". Because the product of initial carbon fixation is a three – carbon compound, the Calvin cycle is also known as ***C_3 pathway.***

Phase 2: Reduction

- Each molecule of (PGA) receives an additional phosphate from ATP of light reaction, forming ***1,3 – bisphosphoglycerate*** as the product. 1,3 bisphoshoglycerate is reduced to ***glyceraldehydes 3- phosphate (G3P)*** by receiving a pair of electrons donated from NADPH of light reactions.
- G3P is the same three carbon sugar which is formed in glycolysis (first phase of cellular respiration) by the splitting of glucose.
- In this way fixed carbon is reduced to energy rich G3P with the energy and reducing power of ATP and NADPH (both the products of light dependent reaction), having the energy stored in it.
- Actually G3P**,** and not glucose, is the carbohydrate produced directly form the Calvin cycle, for every three molecules of CO_2 entering the cycle and combining with 3 molecules of five carbon RuBP, six molecules of G3P (containing 18 carbon in all) are produced.
- But only one molecule of G3P can be counted as a net gain of carbohydrate.
- Out of every six molecules of G3P formed, only one molecule leaves the cycle to be used by the plant for making glucose, sucrose, starch or other carbohydrates, and other organic compound; the other five molecules are recycled to regenerate the three molecules of five carbon RuBP, the CO_2 acceptor.

Phase 3: Regeneration of CO_2 Acceptor, RuBP

- Through a complex series of reactions, the carbon skeletons of five molecules of three-carbon G3P are rearranged into three molecules of five –carbon ribulose phosphate (RuP).
- Each RuP is phosphorylated to ribulose bisphosphate (RuBP), the very five carbon CO_2 acceptor with which the cycle started.
- Again three more molecules of ATP of light reactions are used for this phosphorylation of three RuBP molecules.

  These RuBP are now prepared to receive CO_2 again and the cycle continues.

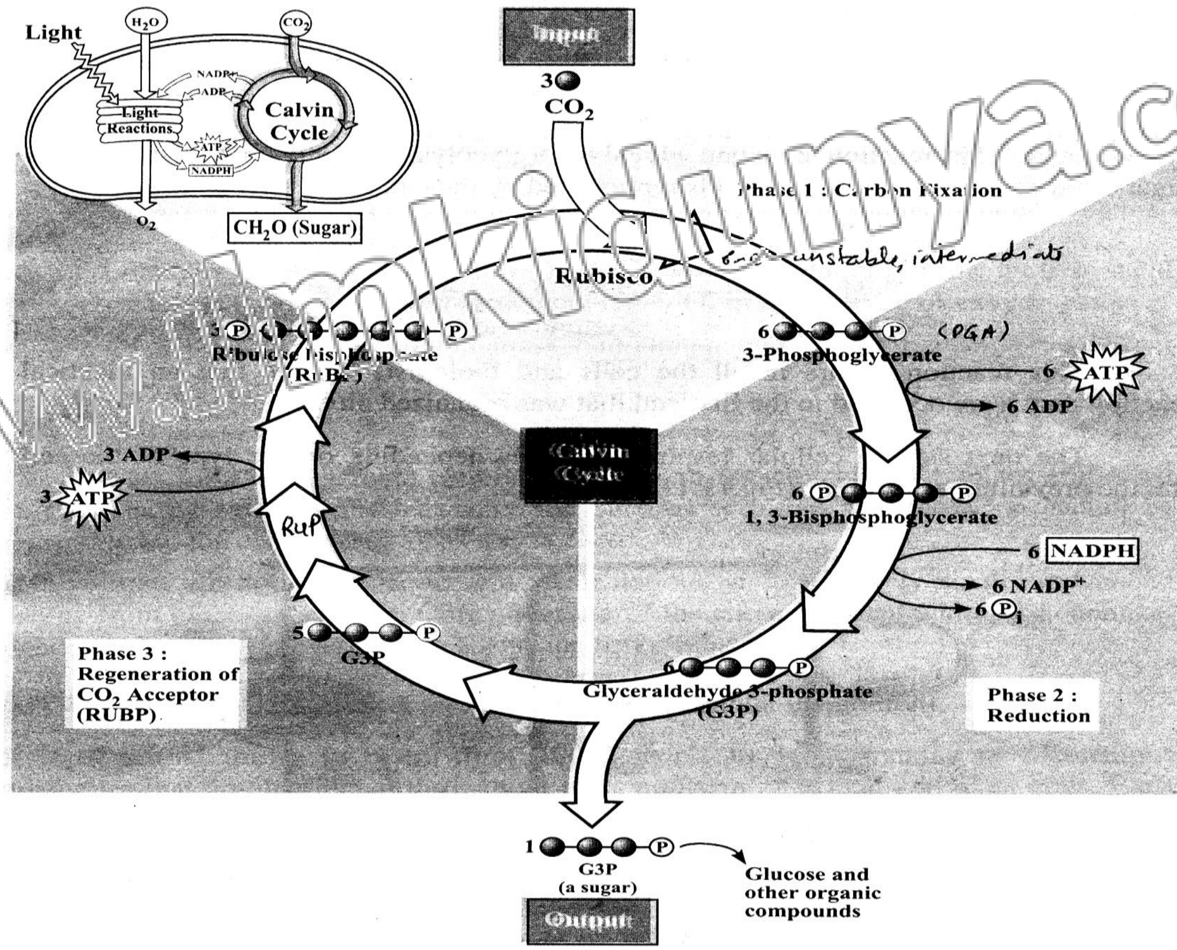


Fig. 11.10 The Calvin cycle occurs in stroma of chloroplast. Carbon is fixed and reduced to sugar

QUESTION RELATED TO ABOVE ARTICLE

What is photophosphorylation?
Define Bioenergetics. Also describe the role of photosynthesis and respiration.
Give an account of light independent reactions of Photosynthesis.
the Z – scheme.
Sketch and explain Calvin cycle in plants. (SWL 20219, MLT 2021)
Draw labelled sketch of Calvin cycle. (DGK-2021)

11.2 RESPIRATION

Living organisms need energy to carry on their vital activities. This energy is provided from within the cells by the phenomenon of respiration.

Definition

"Respiration is the universal process by which organism's breakdown complex compounds containing carbon in a way that allows the cells to harvest a maximum of usable energy". In biology, the term respiration is used in two ways.

External respiration

- More familiarly, the term respiration means the ***exchange of respiratory*** gases (CO_2 and O_2 between the organism and its environment). This exchange is called ***external respiration***.

Cellular respiration

- The cellular respiration is the process by which energy is made available to cells in a step-by-step breakdown of C-chain molecules in the cells.

11.2.1 Aerobic and Anaerobic Respiration

- The most common fuel used by the cell to provide energy by cellular respiration is glucose.
- The way glucose is metabolized depends on the availability of oxygen. Prior to entering a mitochondrion, the glucose molecule is split to form two molecules of pyruvic acid.
- This reaction is called ***glycolysis*** (glycolysis literally means splitting of sugar), and occurs in the cytosol and is represented by the equation:

$$\overset{2NAD \quad\quad 2NADH_2}{C_6H_{12}O_6 \longrightarrow C_6H_{12}O_6 + \text{Energy}}$$

Glucose → Pyruvic acid

- This reaction occurs in all the cells and biologists believe that an identical reaction may have occurred in the first cell that was organized on earth.
- The next step in cellular respiration varies depending on the type of the cell and the prevailing conditions.

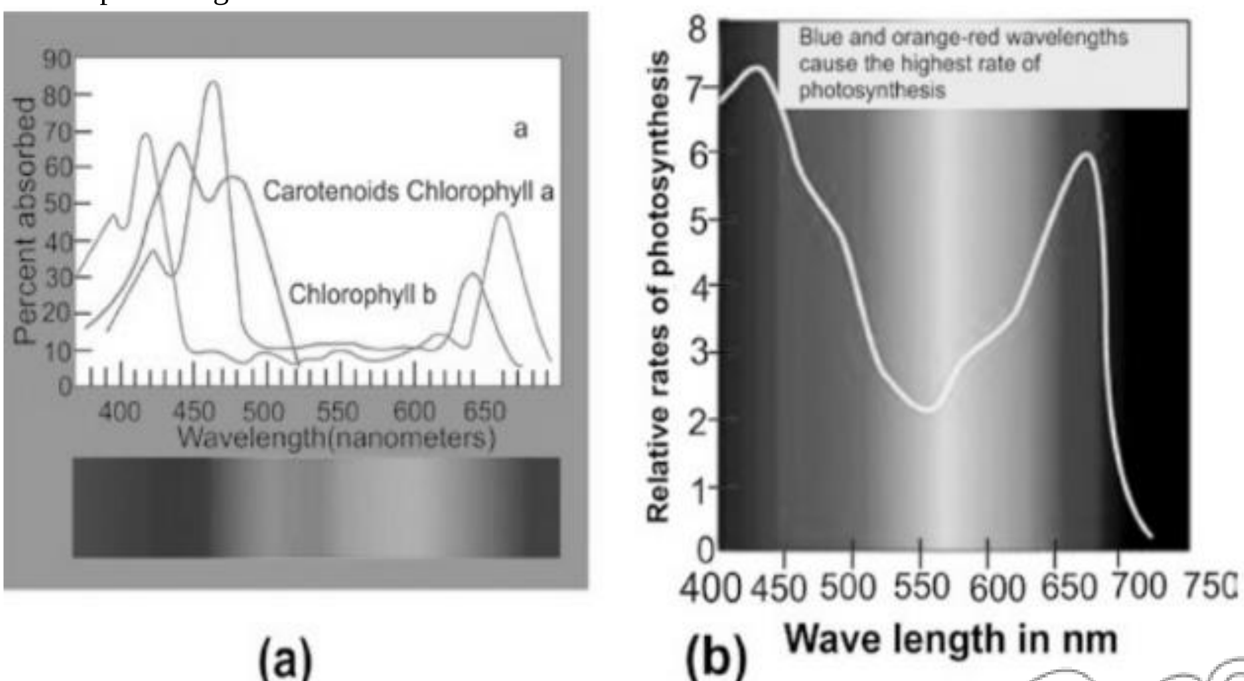


Fig 11.11: Pyruvate, the end product of glycolysis, follows different catabolic pathways depending on the organism and the metabolic condition.

- Cell processes pyruvic acid in three major ways, ***alcoholic fermentation, lactic acid fermentation*** and ***aerobic respiration.***
- The first two reactions occur in the absence of oxygen and are referred to as anaerobic (without oxygen).
- The complete breakdown of glucose molecule occurs only in the presence of oxygen, i.e. in aerobic respiration. During aerobic respiration glucose, is oxidized to CO_2 and water and energy is released.

11.2.2 Anaerobic Respiration

(i) Alcoholic Fermentation

In ***primitive cells*** and in ***some eukaryotic cells*** such as yeast, pyruvic acid is further broken down by alcoholic fermentation into alcohol (C_2H_5OH) and CO_2.

$$2(C_3H_4O_3) \xrightarrow{2NADH_2 \;\rightarrow\; 2NAD} 2(C_2H_5OH) + 2CO_2$$

Pyruvic acid → Ethyl Alcohol

(ii) Lactic acid fermentation

In lactic acid fermentation, each pyruvic acid molecule is converted into lactic acid $C_3H_6O_3$ in the absence of oxygen gas:

$$2(C_3H_4O_3) \xrightarrow{2NADH_2 \;\rightarrow\; 2NAD} 2(C_3H_6O_3)$$

Pyruvic acid → Lactic acid

- This form of anaerobic respiration ***occurs in muscle cells*** of humans and other animals during extreme physical activities, such as sprinting, when oxygen cannot be transported to the cells as rapidly as it is needed.
- Both alcoholic and lactic acid fermentations yield relatively small amounts of energy from glucose molecule.
- Only about ***2%*** of the energy present within the chemical bonds of glucose is converted into adenosine triphosphate (ATP).

11.2.3 Aerobic respiration

Role of mitochondria in respiration: Mitochondria are large granular or filamentous organelles that are distributed throughout the cytoplasm of animal and plant cells.

- Each mitochondrion is constructed of an outer enclosing membrane and an inner membrane with elaborate folds or **cristae** that extend into the interior of the organelle.
- Mitochondria play a part in cellular respiration by transferring the energy of the organic molecules to the chemical bonds of ATP.
- A large "battery" of enzymes and coenzymes slowly release energy from the glucose molecules. Thus mitochondria are the ***"Power houses"*** that produce energy necessary for many cellular functions.

Adenosine triphosphate and its importance:

Adenosine triphosphate, generally abbreviated 'ATP' is a compound found in every living cell and is one of the essential chemicals of life. It plays the key role in most biological energy transformations.

- Conventionally, 'P' stands for the entire phosphate group. The second and the third phosphate represent the so called "high energy" bonds. If these are broken by hydrolysis, far more free energy is released as compared to the other bond in the ATP molecule.
- The breaking of the terminal phosphate of ATP releases about ***7.3 K cal.*** of energy.
- The high energy 'P' bond enables the cell to accumulate a great quantity of energy in a very small space and keeps it ready for use as soon as it is needed.
- The ATP molecule is used by cells as a source of energy for various functions, for example, ***synthesis of more complex compounds, active transport across the cell membrane, muscular contraction, and nerve conduction, etc.***

11.2.3 (a) Biological Oxidation

- The maintenance of living system requires a continual supply of free energy which is ultimately derived from various oxidation reduction reactions.
- Except for photosynthetic and some bacterial chemosynthetic processes, which are themselves oxidation reduction reactions, all other cells depend ultimately for their supply of free energy on oxidation reactions in respiratory processes.
- In some cases biological oxidation involves the removal of hydrogen, a reaction catalyzed by the ***dehydrogenases*** linked to specific coenzymes.
- Cellular respiration is essentially an ***oxidation process***.

11.2.4 Cellular Respiration

Cellular respiration may be sub-divided into 4 stages:

(i) **Glycolysis** **(ii)** **Pyruvic acid oxidation**
(iii) **Krebs cycle or citric acid cycle** **(iv)** **Respiratory chain**

Out of these stages the first occurs in the cytosol for which oxygen is not essential, while the other three occur within the mitochondria where the presence of oxygen is essential.

11.2.4 (a) Glycolysis

Definition

"Glycolysis is the breakdown of glucose upto the formation of pyruvic acid".

- Glycolysis can take place both in the absence of oxygen (anaerobic condition) or in the presence of oxygen (aerobic condition).
- In both, the end product of glucose breakdown is ***pyruvic acid***.
- The breakdown of glucose takes place in a series of steps, each catalyzed by a specific enzyme.
- ***All these enzymes are found dissolved in the cytosol.*** In addition to the enzymes, ATP and ***coenzyme NAD (nicotinamide adenine dinucleotide)*** are also essential.
- Glycolysis can be divided into two phases, a ***preparatory phase*** and ***an oxidative phase***.
- In the preparatory phase breakdown of glucose occurs and energy is expended. In the oxidative phase high energy phosphate bonds are formed and energy is stored.

Preparatory phase

The first step in glycolysis is the transfer of a phosphate group from ATP to glucose. As a result a molecule of ***glucose-6-phosphate*** is formed.

- An enzyme catalyzes the conversion of glucose-6-phosphate to its isomer, ***fructose-6-phosphate***. At this stage another ATP molecule transfers a second phosphate group.
- The product is ***fructose 1,6-bisphosphate.*** The next step in glycolysis is the enzymatic splitting of ***fructose 1,6-bisphosphate*** into two fragments. Each of these molecules contains three carbon atoms.
- One is called ***3-phospo-glyceraldehyde (3-PGAL)*** or **glyceraldehyde** ***3-phosphate (G3P)*** while the other is ***dihydroxyacetone*** phosphate. These two molecules are isomers and in fact, are readily interconverted by yet another enzyme of glycolysis.

Oxidative (payoff) phase

The next step in glycolysis is crucial to this process, Two electrons or two hydrogen atoms are removed from the molecule of ***3-phosphoglyceraldehyde (PGAL)*** and transferred to a molecule of NAD.

- This is of course, an oxidation-reduction reaction, with the PGAL being oxidized and the NAD being reduced. During this reaction, a second phosphate group is donated to the molecule from inorganic phosphate present in the cell. The resulting molecule is called ***1,3 Bisphosphoglycerate (BPG).***
- The oxidation of PGAL is an energy yielding process. Thus a "high energy" phosphate bond is created in this molecule.

- At the very next step in glycolysis this phosphate group is transferred to a molecule of adenosine diphosphate (ADP) converting it into ATP.
- The end product of this reaction is ***3-phosphoglycerate (3-PG).***
- In the next step 3-PG is converted to ***2-phosphoglycerate (2PG).*** From 2PG a molecule of water is removed and the product is ***phosphoenol pyruvate (PEP).***
- PEP then gives up its 'high energy' phosphate to convert a second molecule of ADP to ATP.
- The product is pyruvate, ***pyruvic acid*** ($C_3H_4O_3$). It is equivalent to half glucose molecule that has been oxidized to the extent of losing two electrons (as hydrogen atoms).

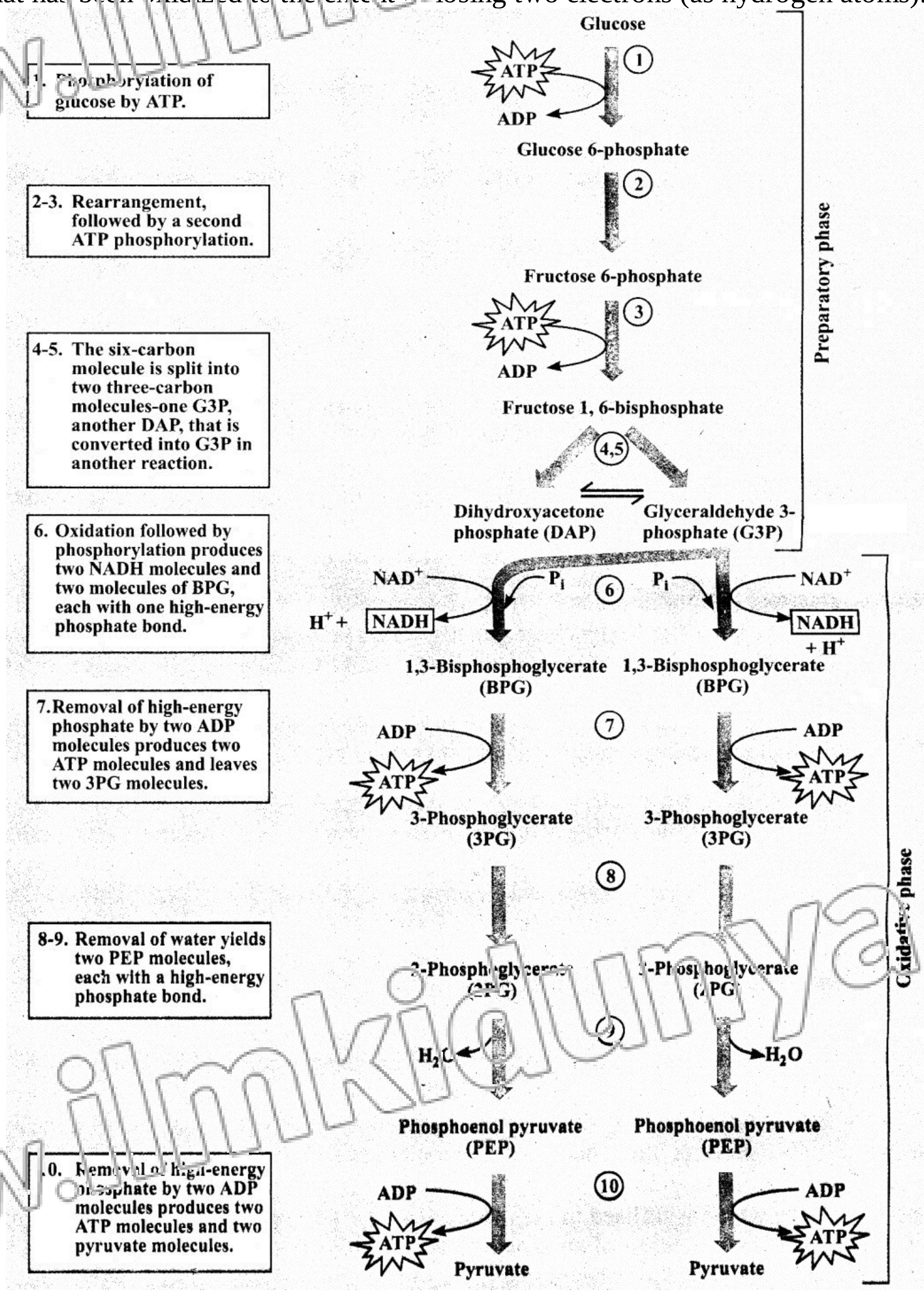


Fig 11.12 Two phases of glycolysis. All of these reaction take place in the cytosol.

QUESTION RELATED TO ABOVE ARTICLE

Describe various steps involved in oxidative breakdown of glucose to pyruvate.
Sketch the process of glycolysis. (No description required) (FSD 2022)
Discus glycolysis. Give scheme of reactions as well. (BWP 2022)
Sketch two phases of glycolysis. (LHR 2019)
What is glycolysis? Draw its scheme of reactions. (DGK 2019)
Make a complete sketch of glycolysis (SWL 2021)
Sum up how much energy (as ATP) is made available to the cell from a single glucose molecule by the operation of glycolysis, the formation of acetyl CoA, the citric acid cycle and the electron transport chain. (Exercise Question ii)
Trace the fate of hydrogen atoms removed from glucose during glycolysis when oxygen is present in muscle cells; compare this to the fate of hydrogen atom removed from glucose when the amount of the available oxygen is insufficient to support aerobic respiration. (Exercise Question iii)

11.2.4 (b) Pyruvic acid Oxidations

- Pyruvic acid (pyruvate), the end product of glycolysis, does not enter the Krebs cycle directly. The pyruvate (3- carbon molecule) is first changed into 2-carbon ***acetic acid*** molecule.
- One carbon is released as CO_2 ***(decarboxylation)***.
- Acetic acid on entering the mitochondrion unites with coenzyme-A (CoA) to form acetyl-CoA ***(active acetate)***. In addition, more hydrogen atoms are transferred to NAD.

11.2.4 (c) Krebs Cycle or Citric Acid Cycle

Acetyl CoA now enters a cyclic series of chemical reactions during which oxidation process is completed. This series of reactions is called the Krebs cycle (after the name of the biochemist who discovered it), or the citric acid cycle.

- The first step in the cycle is the union of acetyl CoA with oxaloacetate to form ***citrate***. In this process, a molecule of CoA is regenerated and one molecule of water is used. Oxaloacetate is a 4-carbon acid. Citrate thus has 6 carbon atoms.
- After two steps that simply result in forming an isomer of citrate, ***isocitrate,*** oxidation takes place. This is accompanied by the removal of a molecule of CO_2. The result is ***α-ketoglutarate***.
- It, in turn, undergoes further oxidation ($NAD + 2H \rightarrow NADH_2$) followed by decarboxylation (-CO2) and addition of a molecule of water.
- The product then has one carbon atom and one oxygen atom less. It is ***succinate***.
- The conversion of α-ketoglutarate into succinate is accompanied by a free energy change which is utilized in the synthesis of an ATP molecule.
- The next step in the Krebs cycle is the oxidation of succinate to ***fumarate***.
- Once again, two hydrogen atoms are removed, but this time the oxidizing agent is a coenzyme called ***flavin adenine dinucleotide (FAD)***, which is reduced to ***$FADH_2$.***

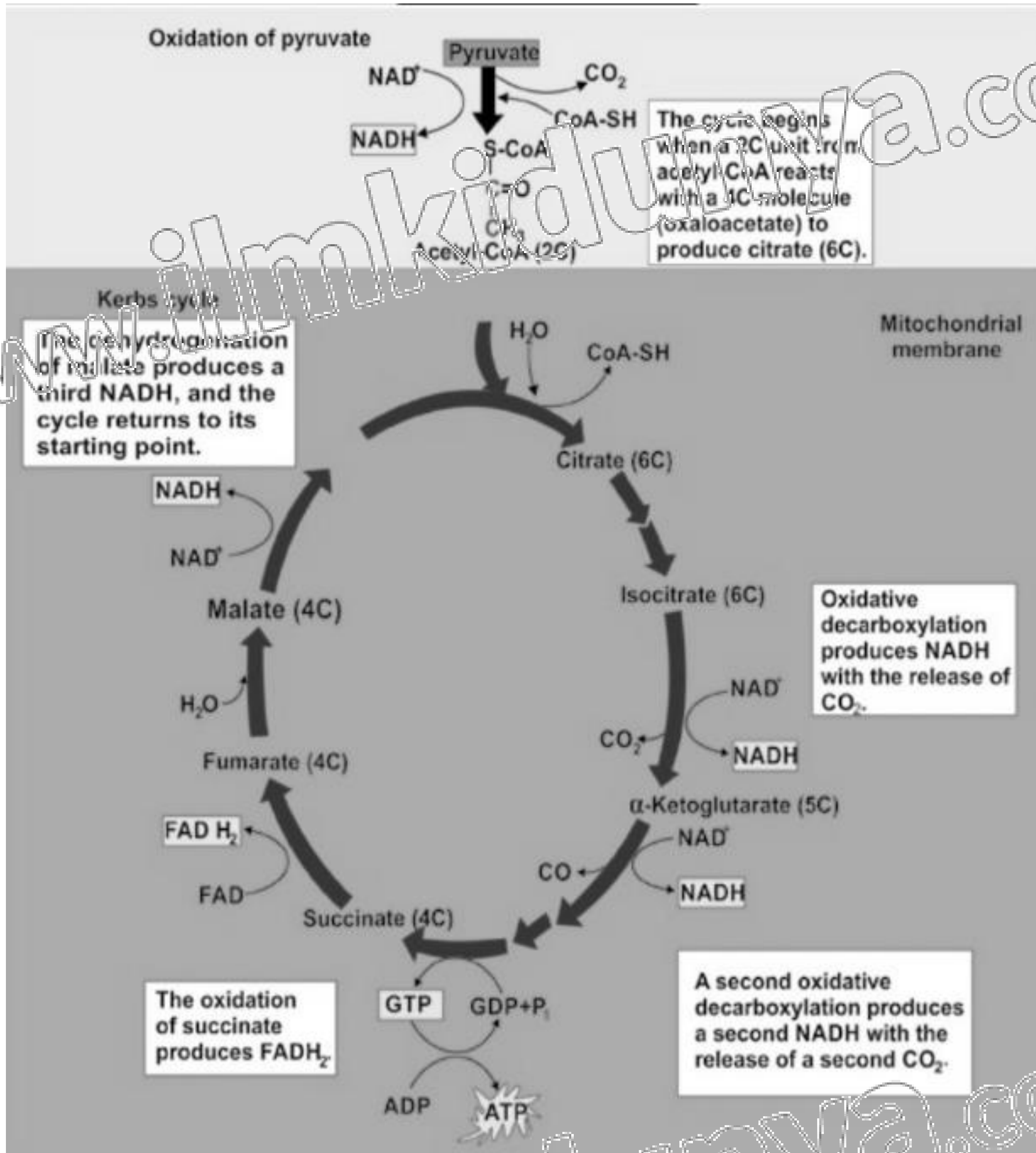


Fig11.13: Outline of the Krebs cycle. The brackets give the number of carbon atom in each intermediate of the cycle.

- With the addition of another molecule of water, fumarate is converted to ***malate***.
- Another NAD mediated oxidation of malate produces ***oxaloacetate***, the original 4-carbon molecule. This completes the cycle.
- The oxaloacetate may now combine with another molecule of acetyl-CoA to enter the cycle and the whole process is repeated.

QUESTION RELATED TO ABOVE ARTICLE

Sketch Krebs cycle and discuss its energy yielding steps

Sketch Calvin Cycle (no description). (LHR 2018)

Write note on Calvin Cycle. (LHR 2019)

Explain Kreb's cycle in detail. Draw flow sheet diagram of its reaction. (MLT 2019)

Draw and describe the Calvin Cycle. (LHR 2021)

Sketch and explain Calvin cycle in plants. (LHR 2021)

Draw and label Calvin cycle. (Description is not required) (GRW 2021)

Draw the outlines of Kreb's Cycle. (BWP 2021, LHR 2022)

Explain the roles of the following in aerobic respiration (a) NAD+ (b) FAD (c) Oxygen.

Sketch Kreb's cycle and discuss its energy yielding steps. (Exercise Question iv)

Describe various steps involved in oxidative breakdown of glucose to pyruvate.

(Exercise Question v)

11.2.4 (d) Respiratory Chain

In the Krebs cycle, NADH and H^+ are produced form NAD^+. NADH then transfers the hydrogen atom to the respiratory chain (also called electron transport system) where electrons are transported in a series of oxidation reduction steps to react, ultimately, with molecular oxygen.

The oxidation reduction substances which take part in respiratory chain are:

(i) A coenzyme called coenzyme Q

(ii) A series of cytochrome enzymes (b,c,a,a_3)

(iii) Molecular oxygen (O_2)

- ***Cytochromes*** are electron transport intermediates containing haem or related prosthetic groups that undergo valency changes of iron atom. Haem is the same iron containing group that is oxygen carrying pigment in haemoglobin.
- The path of electrons in the respiratory chain appears to be as follows;

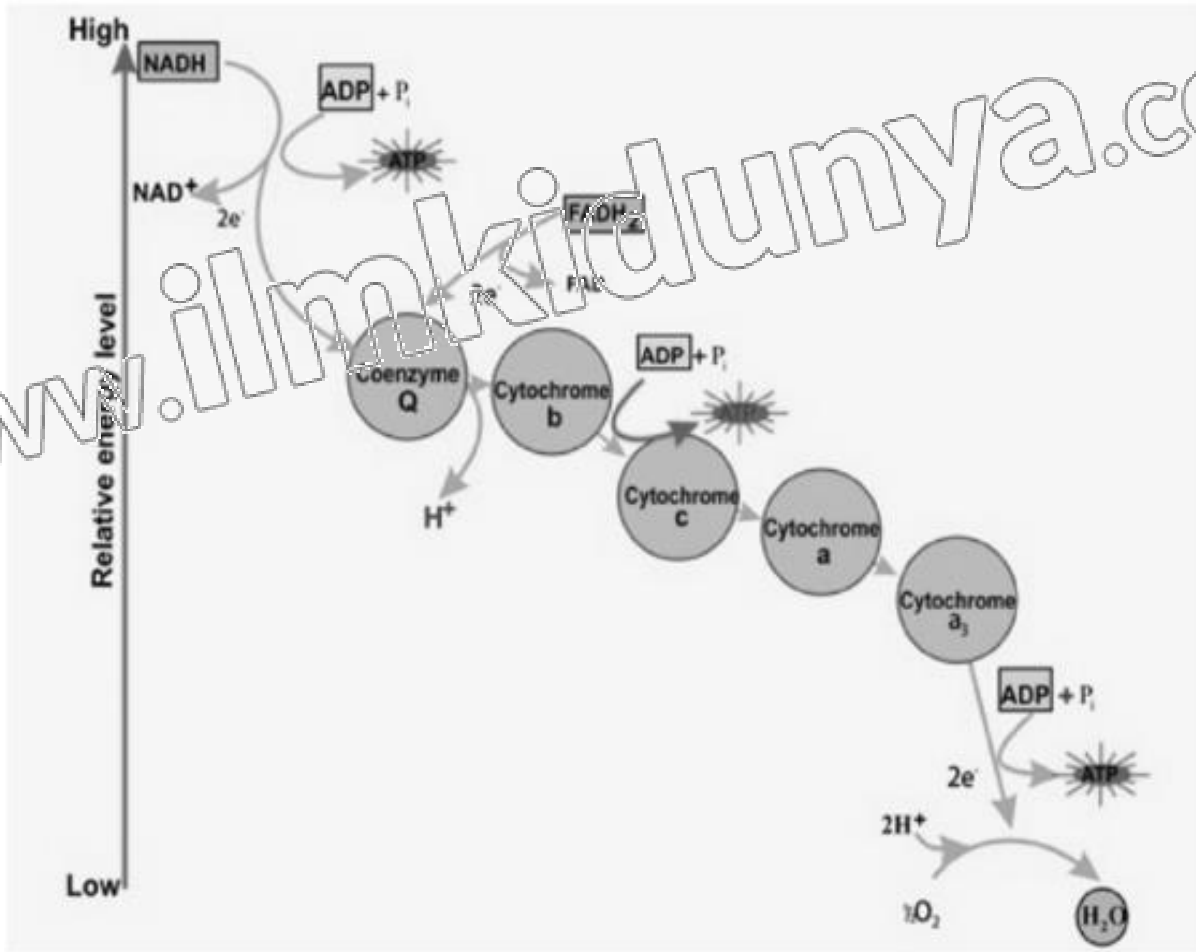


Fig. 11.14 The respiratory electron transport chain and its coupling with oxidative phosphorylation.

- NADH is oxidized by coenzyme Q. This oxidation yields enough free energy to permit the synthesis of a molecule of ATP from ADP and inorganic phosphate.
- Coenzyme Q is in turn oxidized by cytochrome b which is then oxidized by cytochrome c.
- This step also yields enough energy to permit the synthesis of a molecule of ATP. Cytochrome c then reduces a complex of two enzymes called cytochrome a and a_3 (for convenience the complex is referred as cytochrome a).
- Cytochrome is oxidized by an atom of oxygen and the electrons arrive at the bottom end of the respiratory chain.
- Oxygen is the most electronegative substance and the final acceptor of the electrons. A molecule of water is produced. In addition, this final oxidation provides enough energy for the synthesis of a third molecule of ATP.

QUESTION RELATED TO ABOVE ARTICLE

Explain the roles of the following in aerobic respiration (a) NAD^+ (b) FAD (c) Oxygen.
Sketch respiratory electron transport chain. Discuss the significance of ETC.
Describe respiratory electron transport chain. (GRW 2019)
Explain Electron transport chain in Mitochondria. (DGK 2019)
Sketch respiratory election transport chain. (MLT 2021)
Sketch respiratory electron transport chain. Discuss the significance of ETC. (Exercise Question vi)

11.2.5 Oxidative Phosphorylation

Synthesis of ATP in the presence of oxygen is called oxidative phosphorylation.

- Normally, oxidative phosphorylation is coupled with the respiratory chain. As already, described ATP is formed in three steps of the respiratory chain.
- The equation for this process can be expressed as follows:
  $NADH + H^+ + 3ADP + 3Pi + ½ O_2 \rightarrow NAD^+ + H_2O + 3ATP$
  Where Pi is inorganic phosphate.
- The molecular mechanism of oxidative phosphorylation takes place in conjunction with the respiratory chain in the inner membrane of the mitochondrion.
- Here also, as in photosynthesis, the mechanism involved is chemiosmosis by which electron transport chain is coupled with synthesis of ATP.
- In this case, however the pumping/movement of protons (H^+) is across the inner membrane of mitochondrion folded into cristae, between matrix of mitochondrion and mitochondrion's intermembrane space.
- The coupling factors in respiration are also different from those in photosynthesis.

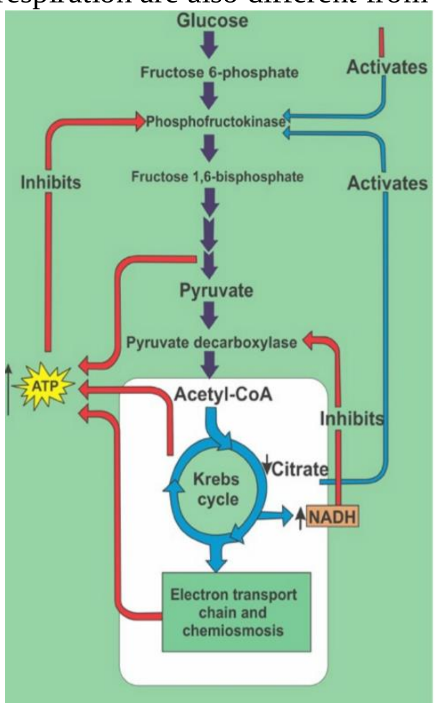


Fig. 11.15 Stages in aerobic respiration. Stage 1: Formation of acetyl-CoA form pyruvate. Stage2: The Krebs cycle. Stage 3: Respiratory chain and oxidative phosphorylation. Each pair of H atoms entering the respiratory chain as NADH yield 3 ATPs.

QUESTION RELATED TO ABOVE ARTICLE

Compare photosynthesis with respiration in plants.

What is oxidative phosphorylation? Discuss. **(GRW 2018)**

KEY POINTS

Oxidation:

The addition of oxygen or removal of electron from a compound is called oxidation. The compound which release electrons said to be oxidized.

Oxidizing Agent:

The compound which has capability to remove an electron form a compound is called oxidizing agent. NAD is a strong oxidizing agent, as it can remove electrons (H^+) from a compound.

Reduction:

The addition of electron or hydrogen into a compound is called reduction. The removal of oxygen is also called reduction. The compound which adds electron is said to be reduced.

Reducing Agent:

The compound which has capability to add electron in a compound is called reducing agent. The $NADH_2$ is a strong reducing agent, as it can give or add electron to any compound.

$$CO_2 + H_2O \longrightarrow C_6H_{12}O_6 + O_2$$

Accept of electrons by NAD and NADP:

Two hydrogen atoms are removed during oxidation in respiration and photosynthesis from substrates.

- One hydrogen atom removes an electron from the other hydrogen atom. This hydrogen atom with an additional electron is called Hydride ion. This hydride ion has one proton and two electrons. This Hydride ion has now become anion. This hydride ion reacts with NAD^+ or $NADP^+$ to form NADH and NADPH.
- The other hydrogen atom has only one proton. It has no electron. It may be called Hydrogen nucleus. It is written as H^+. It remains in free form along with NADH, till it receives its lost electron during oxidation of NADH to NAD. This discussion shows that the reduced NAD or NADP should be written as NADH + H, or NADH + H. It should not be written as $NADH_2$ or $NADPH_2$.

Chemiosmosis:

Word chemiosmosis is formed of two Greek word, Chemo means-chemical reaction and osmosis means push. The coupling reaction in which synthesis of ATP molecule takes during movement of H^+ across an H^+ gradient is called chemiosmosis.

Isomers:

The compounds, having same general formula but different structural formula are called isomers, e.g. glucose, fructose.

EXERCISE

Q.1. Encircle the correct answer from the multiple choices.

i) Magnesium is an important nutrient ions in green plants as it is an essential component of:
(a) Cell sap
(b) Protein
(c) Chlorophyll
(d) Glucose

ii) When a green plant performs photosynthesis at its maximum rate?
(a) The rate of water loss is low
(b) The water content of the plant will be low
(c) The energy content of plant will be low
(d) The energy content will be unaffected.

iii) During the dark reaction of photosynthesis, the main process which occurs is:
(a) Release of oxygen
(b) Energy absorption by chlorophyll
(c) Adding of hydrogen to carbon dioxide
(d) Formation of ATP

iv) Which statement about ATP is not true?
(a) It is used as an energy currency by all cells
(b) It is formed only under aerobic conditions
(c) Some ATP is used to drive the synthesis of storage compounds
(d) It provides the energy for many different biochemical reactions

v) Glycolysis:
(a) Produces no ATP
(b) Is the same as fermentation?
(c) Takes place in mitochondria
(d) Reduces two molecules of NAD^+ for every glucose molecule processed

vi) The citric acid cycle:
(a) Takes place in the mitochondrion
(b) Takes place in cytoplasm
(c) Takes place in chloroplast
(d) None of these

vii) Which statement about the chemiosmotic mechanism is not true?
(a) Protons return through the membrane by way of a channel protein
(b) Protons are pumped across a membrane
(c) Proton pumping is associated with the respiratory chain
(d) The membrane in question is the inner mitochondrial membrane

viii) Which statement about oxidative phosphorylation is not true?
(a) Its function can be served equally well by fermentation
(b) In eukaryotes, it takes place in mitochondria
(c) It is brought about by the chemiosmotic mechanism
(d) It is the formation of ATP during operation of the respiratory chain

ix) Before pyruvate enters the citric acid cycle, it is decarboxylated, oxidized and combined with coenzyme A, forming acetyl CoA, carbon dioxide and one molecule of:
(a) NADH **(b)** $FADH_2$
(c) ATP **(d)** ADP

x) In the first step of citric acid cycle, acetyl CoA reacts with oxaloacetate to form:
(a) Pyruvate **(b)** Citrate
(c) NADH **(d)** ATP

xi) When deprived of oxygen, yeast cells obtain energy by fermentation, producing carbon dioxide, ATP and___________?
(a) Acetyl CoA **(b)** Ethyl alcohol
(c) Lactate **(d)** Pyruvate

Answers Key:

Q.2.

i	c	vi	a	xi	b
ii	b	vii	a		
ii	c	viii	a		
iv	b	ix	a		
v	d	x	b		

Write whether the statement is 'true' or 'false' and write the correct statement, if it is false.

i) Hydroponics are the plants grown in water culture.

ii) Calcium is essential element for chlorophyll formation.

Magnesium is essential element for chlorophyll formation.

iii) Chlorosis means yellowing of leaves due to deficiency of certain essential element of plant nutrition.

Ans: i) True ii) False iii) True

Q.3. Short Questions

Ans: (For answer to short questions consult KIPS Objective Series)

Q.4. Extensive Questions.

i) Explain the roles of the following in aerobic respiration

(a) NAD+ (b) FAD (c) Oxygen.

Ans: (See article 11.2.4.d)

ii) Sum up how much energy (as ATP) is made available to the cell from a single glucose molecule by the operation of glycolysis, the formation of acetyl CoA, the citric acid cycle and the electron transport chain.

Ans: (See article 11.2)

iii) Trace the fate of hydrogen atoms removed from glucose during glycolysis when oxygen is present in muscle cells; compare this to the fate of hydrogen atom removed from glucose when the amount of the available oxygen is insufficient to support aerobic respiration.

Ans: (See article 11.2.4 a)

iv) Sketch Kreb's cycle and discuss its energy yielding steps.

Ans: (See article 11.2.4 c)

v) Describe various steps involved in oxidative breakdown of glucose to pyruvate.

Ans: (See article 11.2.4 a)

vi) Sketch respiratory electron transport chain. Discuss the significancWe of ETC.

Ans: (See article 11.2.4 d)

vii) Compare photosynthesis with respiration in plants.

Ans: (See article 11.1 & 11.2)