Plant Respiration

Complex organic food substances stored large amount of energy in the chemical bonds.The breaking of Complex organic substances through oxidation releases energy.This process is called respiration. All living organism required energy to carry out various activities. This energy is obtained through respiration which is a catabolic process. It occurs in all the living cells of all the organisms.

Respiration is defined as an intracellular process of oxidation in which complex organic substances are broken down into simpler ones with the release of energy which is immediately converted into usable form of energy ie. ATP.40% of released energy is converted in the form of ATP molecules and rest is lost in the form of heat, that maintains body temp. Of the living organism.Carbon dioxide and water is released as a byproduct.

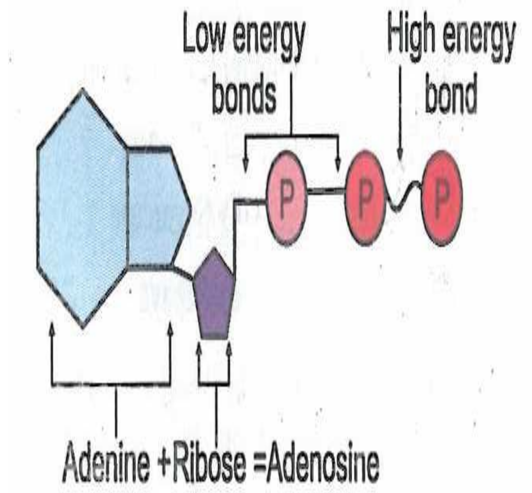
The Complex organic substances which are used for the release of energy during the process of respiration is called respiratory substrates.It includes carbohydrates, proteins , fats, and amino acids.Among these , carbohydrates are the main source of energy and glucose is the most preferred substrate because it is easily available and acceptable to all kinds of organisms.

ATP AS CURRENCY OF ENERGY : ATP or adenosine triphosphate is an energy-rich compound which stored energy in its high energy chemical bonds.This energy is made available for performing various cellular activities. The cell needs energy for its division , growth, movements, reproduction, various biosynthetic process etc. Whenever the cell needs energy , ATP is hydrolysed to produce ADP (adenosine diphosphate) and energy is released as a high energy phosphate bond is broken.

STRUCTURE OF ATP

1) ATP is a triphosphate ester of adenosine ribonucleoside.

2) It is made up of three chemical constituents ,viz. A nitrogenous base purine known as adenine , a pentose sugar ribose and three phosphate groups.



3) To the adenosine three phosphate groups are attached in the following three ways :

i) Adenosine + phosphate = Adenosine monophosphate (AMP)

ii) Adenosine monophosphate + phosphate = Adenosine diphosphate (ADP)

iii) Adenosine diphosphate + phosphate = Adenosine triiphosphate (ATP)

4)In ATP molecule , two terminal phosphate groups are linked to high energy bonds.

SITE FOR ATP SYNTHESIS OR ULTRAMICROSCOPIC STRUCTURE OF MITOCHONDRIA :

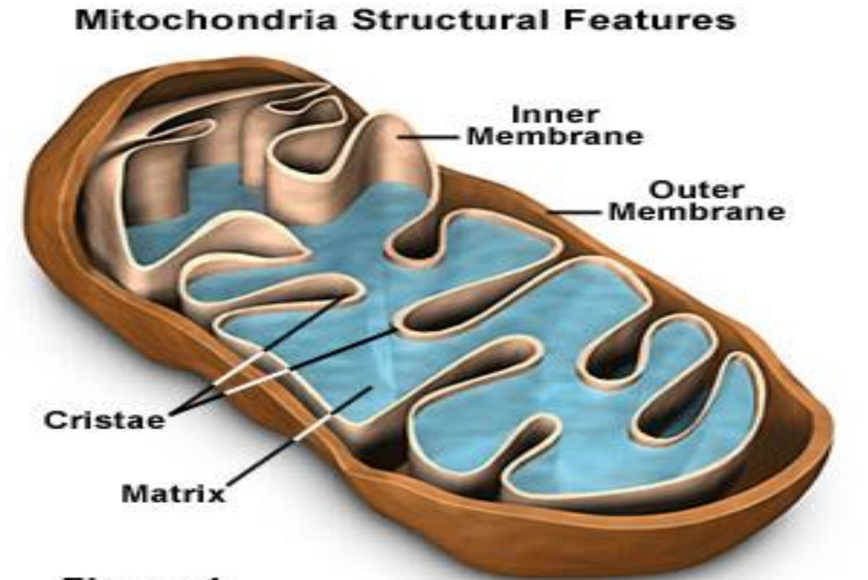


Figure 1

1)Mitochondria are cell organelle which is present in the cytoplasm of eukaryotic cell , but are totally absent in prokaryotic cells.

2) It is concerned with the aerobic respiration and supply of chemical energy ie. ATP for the maintainance of life, Therefore it is also called **" Power House of the Cell"** .

3) It is rod shaped, oval or spherical . its size is 0.5 micron in diameter and 1 to 2 micron in length. Its number is also varies from cell to cell.

4) Under electron microscope each mitochondrion appears to be bounded by two membrane namely an outer membrane and inner membrane .

5) An outer membrane is smooth whereas an inner membrane shows many folds inside the cavity of the mitochondrion called cristae.

6) Inside the cavity of mitochondrion the colourless fluid or liquid are present called matrix. The matrix contain the enzymes for Kreb cycle.It also contain 70s type of ribosomes and single , circular DNA molecule. Thus mitochondria are self – duplicating , semi- autonomous cell organelles.

7) On the cristae some stalked particle are present called F_1 – particle or oxysomes or elementary

Particle .

8) Each oxysomesor F_1 – particle can be differentiated into the basal piece , stalk , and head .

9)Various co-enzymes and cytochromes which forms electron transport system are located on the cristae of the mitochondrion and elementary Particle .

10) Thus ATP formation takes place on the cristae of the mitochondrion and elementary Particles. Thus mitochondrion is said to be the site of electron transport system.

FUNCTIONS OF MITOCHONDRIA :

1) It is the power house of the cell.

2) It supply nearly all the required biological energy.

3) Only mitochondria are fully capable of converting pyruvate into CO_2 and H_2O.

4) The F_1 – particle which are present on the cristae of mitochondrion participate in ETS and terminal oxidation.

MECHANISM OF AEROBIC AND ANAEROBIC RESPIRATION : The primary process of respiration is the break-down of complex higher carbohydrates into simple form such as glucose . In cytoplasm glucose is broken –down into two molecules of pyruvic acid through a process called glycolysis.

Complex carbohydrate → Glucose → Pyruvic acid → Anaerobic respiration → $2C_2H_5OH$ $+2CO_2$

Pyruvic acid → Aerobic respiration → $6CO_2$ $+6H_2O$

The fate of Pyruvic acid depends upon presence or absence of oxygen. Under aerobic conditions, Pyruvic acid is completely oxidized to form $6CO_2$,$6H_2O$ and large amount of energy is generated.It occurs through Krebs cycle and ETS inside the mitochondrion and in all higher organisms.

Under anaerobic conditions , pyruvate undergoes reductive decarboxylation to yield CO_2 and ethyl alcohol.Very less amount of energy is generated through this type of respiration in the cytoplasm of living cells. This occurs in lower organisms , such as many bacteria and some fungi.

AEROBIC RESPIRATION

When free molecular oxygen is used in the respiratory break down of the substrate then it is called aerobic respiration.The mechanism of aerobic respiration includes three major phases. These are I – Glycolysis , II – Krebs cycle , III – Terminal oxidation or ETS.

GLYCOLYSIS : Glycolysis is the process during which one molecule of glucose is break-down into two molecules of pyruvic acid .This process takes place in cell cytoplasm therefore it is also called cytoplasmic respiration. Various steps of Glycolysis are controlled by specific enzymes. Every step of this pathway is worked out **by Embden ,Meyerhof , and Parnas** . **Therefore , Glycolysis is also called Embden -Meyerhof - Parnas pathway or EMP Pathway.**

Steps involved in Glycolysis : There are two major steps that are involved in Glycolysis. These are : A) preparatory phase and cleavage phase B)Oxidative or payoff phase.

A) Preparatory phase and cleavage phase : During this phase glucose molecule is activated by phosphorylation and then cleaved into two molecules of triose phosphates , namely 3-phosphoglyceraldehyde(3-c) or 3- PGAL and Dihydroxy acetone phosphate (3-C) or DHAP .In the next step only PGAL is participates and therefore DHAP gets converted into 3-PGAL . Thus, at the end of this phase two molecules of 3- PGAL are formed. It includes following reactions.

1) **Phosphorylation :** In this step , glucose molecule undergoes Phosphorylation during which it combines with ATP and forms glucose 6- phosphate in presence of enzyme hexokinase which requires Mg^{++} as a cofactor

$$\text{Glucose} + \text{ATP} \xrightarrow{\text{hexokinase}} \text{Glucose 6 phosphate} + \text{ADP}$$

2) **Isomerisation of Glucose 6 phosphate :** Glucose 6 phosphate undergoes isomerisation in presence of enzyme isomerase and converted into fructose 6 phosphate.

$$\text{Glucose 6 phosphate} \xrightarrow{\text{Isomerase}} \text{Fructose 6 phosphate}$$

3) **Phosphorylation of Fructose 6 phosphate :** The Fructose 6 phosphate undergoes further Phosphorylation and forms Fructose1, 6 diphosphate in presence of enzyme phosphofructokinase which required Mg^{++} as a cofactor.

$$\text{Fruct. 6 phosphate} + \text{ATP} \xrightarrow{\text{phosphofructokinase}} \text{Fructose1, 6 diphosphate} + \text{ADP}$$

4) **Cleavage of Fructose1, 6 diphosphate :** Fructose1, 6 diphosphate now undergoes Cleavage and forms one molecule of 3- phosphoglyceraldehyde (PGAL) and one molecule of dihydroxy acetone phosphate (DHAP) in presence of enzyme aldolase.

$$\text{Fructose1, 6 diphosphate} \xrightarrow{\text{Aldolase}} \text{3PGAL} + \text{DHAP}$$

5) **Isomerisation of Dihydroxy acetone phosphate :** Dihydroxy acetone phosphate and phosphoglyceraldehyde are isomers and are interconvertible. This reaction is catalysed by the enzyme phosphotriose isomerase. DHAP is converted to PGAL. Owing to the conversion of DHAP two molecules of PGAL are formed.

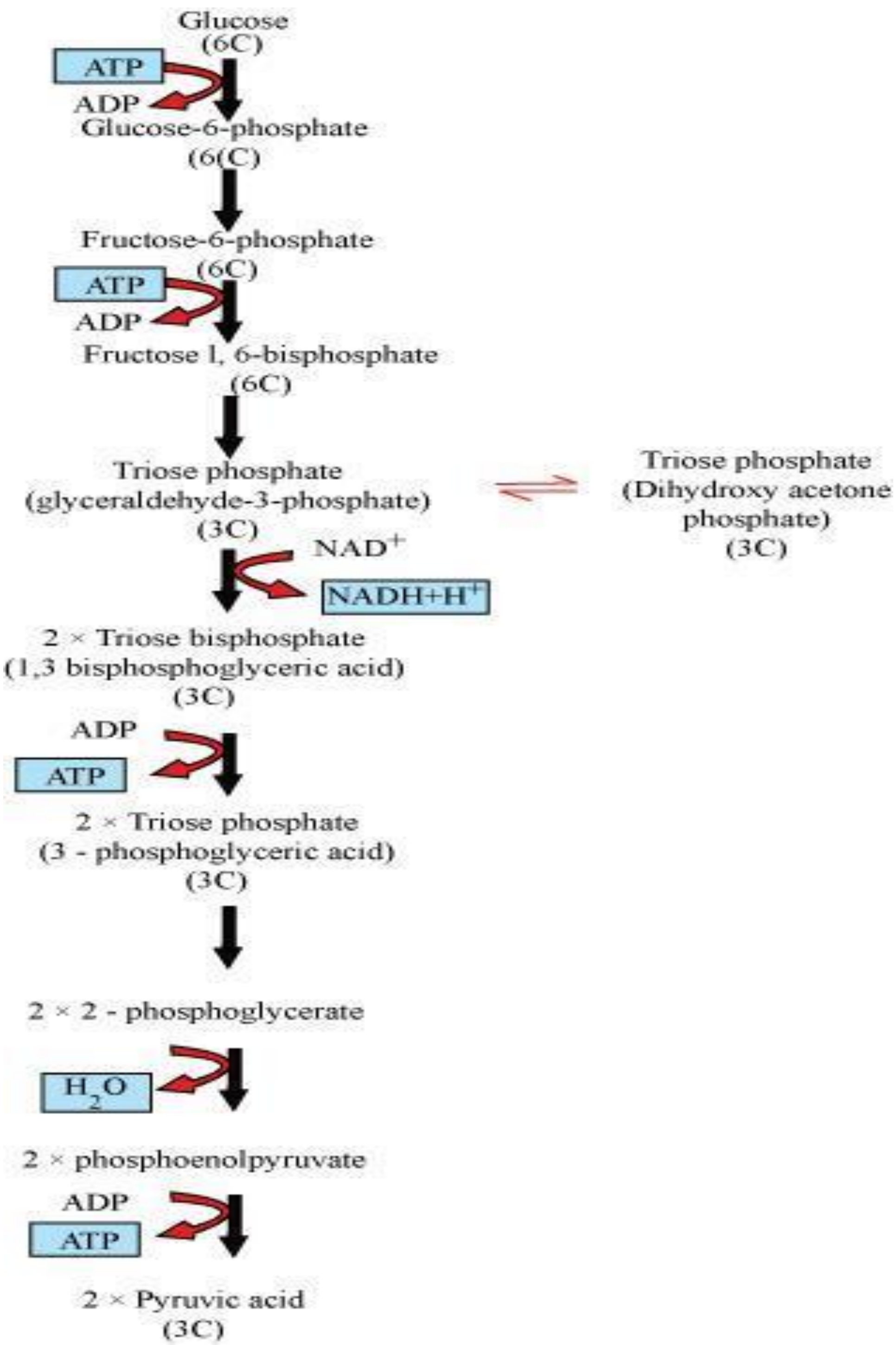
$$\text{DHAP} \xrightarrow{\text{Phosphotriose isomerase}} + \text{PGAL}$$

B) Oxidative and pay off phase : During this phase oxidation occurs by the removal of hydrogen which is accompanied by the generation of ATP. This phase is completed in the following steps.

6) **Oxidative Phosphorylation :** The phosphoglyceraldehyde (PGAL) undergoes oxidation and simultaneously , it undergoes phosphorylation forms 1 ,3 diphosphoglyceraldehyde (1,-3 diPGA) in presence of the enzyme phosphoglyceraldehyde dehydrogenase.During this reaction the coenzyme NAD takes up $H_2$and gets reduced to $NADH_2$.

$$\text{PGAL} + H_3PO_4 + \text{NAD} \xrightarrow{\text{Dehydrogenase}} \text{1,3-diPGA} + NADH_2$$

SCHEMATIC REPRESENTATION OF GLYCOLYSIS OR EMP PATHWAY :



7) Synthesis of ATP : 1,-3 diPGA undergoes dephosphorylation, i.e. it loses one molecule of phosphate which is accepted by ADP to form ATP . During this reaction 1,-3 diPGA is converted into 3- PGA in presence of the enzyme phosphoglycerokinase which requires Mg^{++} as a cofactor.

$$1,3\text{- diPGA} + ADP \xrightarrow[Mg^{++}]{\text{Phosphoglycerokinase}} 3\text{-PGA} + ATP$$

8) Isomerisation of 3-PGA : The 3-PGA undergoes Isomerisation and forms 2-PGA by changing the position of phosphate group from 3rd to 2nd carbon. This reaction is catalysed by the enzyme phosphoglyceromutase.

$$\text{3-PGA} \xrightarrow{\text{Phosphoglyceromutase}} \text{2-PGA}$$

9) Dehydration of 2-PGA : The 2-PGA undergoes Dehydration i.e. loses a molecule of water and forms phosphoenol pyruvate (PEPA). This reaction is catalysed by the enzyme enolase which requires Mg^{++} as cofactor.

$$\text{2-PGA} \xrightarrow{\text{Enolase, } Mg^{++}} \text{PEPA} + H_2O$$

10) Formation of pyruvate and synthesis of ATP : The phosphoenol pyruvate (PEPA) undergoes hydrolysis and dephosphorylation to form pyruvate . During this process ADP is converted into ATP . This reaction is catalysed by the enzyme pyruvate kinase which needs Mg^{++} as cofactor.

$$\text{PEPA} + \text{ADP} + H_2O \xrightarrow{\text{Pyruvate kinase , } Mg^{++}} \text{Pyruvate} + \text{ATP}$$

From the above reactions, it is obvious that two molecules of pyruvate are formed from one molecule of glucose , besides the formation of four molecules of ATP and two molecules of $NADH_2$.

The over –all equation for glycolysis may be written as :

$$\text{Glucose} + 2NAD + 2ADP + 2ip \xrightarrow[\text{Glycolysis}]{\text{Enzymes}} 2 \text{ pyruvate} + 2NADH_2 + 2ATP$$

Significance of glycolysis

1) Two molecules of pyruvic acid are produced from one molecules of glucose.

2) During glycolysis 8 molecules of ATP are gain from one molecule of glucose.

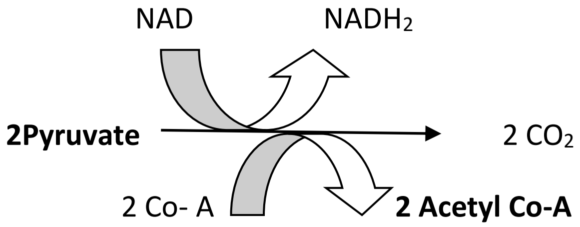
3) Glycolysis is a common pathway to both aerobic and anaerobic respiration.

Phase II of respiration : The Phase II of respiration involves following two process.

1) Oxidative decarboxylation of pyruvic acid .
2) Krebs cycle

1)Oxidative decarboxylation of pyruvic acid : The pyruvic acid which is the end product of glycolysis does not enter directly in the Kreb cycle.The three carbon atom molecule of pyruvic acid is first converted into two carbon atom molecule of acetyl Co-A .One carbon atom is lost by in the form of CO_2.

The two hydrogen atom are released during the process of dehydrogenation which are accepted by NAD and gets reduced to $NADH_2$. This reaction required three enzymes and 6-coenzymes.At the end of this reaction acetyl Co-A is produced which enter in the kerb cycle.



Krebs cycle OR TCA cycle : Krebs cycle is named after sir Hans Kreb who first analysed it in 1937and for this he was awarded Nobel prize in Biochemistry in 1953. In this cycle acetyl Co-A is completly oxidized and CO_2 is released in step wise manner. This is also known as Tricarboxylic acid cycle (TCA) because the first stable compound form during this cycle contain 3 carboxylic groups.It is also called citric acid cycle because the first stable acid form during this cycle is citric acid. It takes place in the matrix of mitochondria, in presence of several enzymes, and coenzymes. Steps involved in Krebs cycle are as follows

1)Formation of citric acid (citrate) : In this step acetyl Co-A combines with oxaloacetate to form citric acid. During this reaction one molecule of water is utilized. The enzyme citrate synthetase catalyses the reaction.

$$\text{OAA} + \text{Acetyl Co-A} + H_2O \xrightarrow{\text{Citrate synthetase}} \text{Citric acid} + \text{Co-A}$$

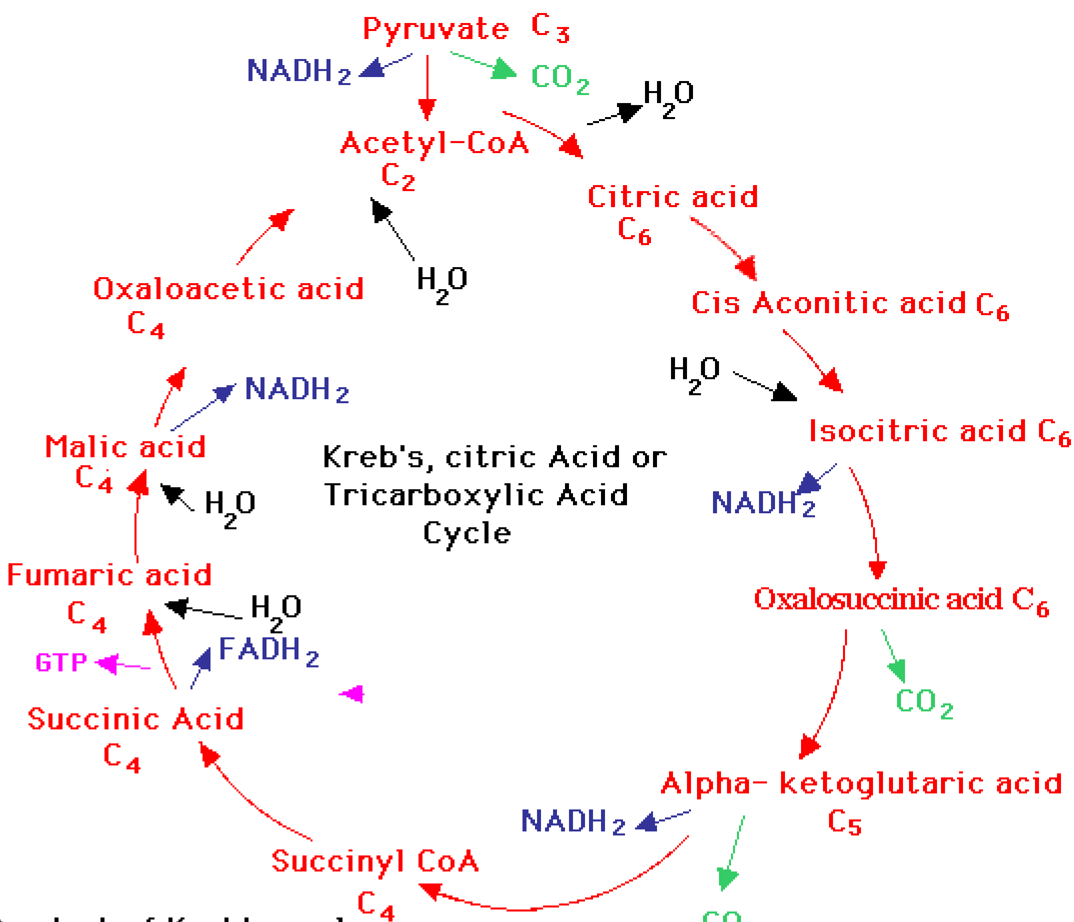
2)Isomerisation of citrate to isocitrate : The citrate undergoes Isomerisation to form isocitrate. This Isomerisation reaction is carried out in the following two steps

i)First of all the citrate undergoes dehydraton i.e. it loses one molecule of water and forms cis-aconitate under the influence of enzyme aconitase.

$$\text{Citrate} \xrightarrow{\text{Aconitase}} \text{cis-aconitate} + H_2O$$

ii)The cis-aconitate undergoes hydration during which it takes back a molecule of water and forms isocitrate in presence of enzyme aconitase

$$\text{cis-aconitate} + H_2O \xrightarrow{\text{Aconitase.}} \text{Isocitrate}$$



Product of Kreb's cycle

	One Cycle	Two Cycles	Energy
1.	Three CO_2	Six CO_2	
2.	4 $NADH_2$	8 $NADH_2$	24 ATP
3.	1 $FADH_2$	2 $FADH_2$	4 ATP
4.	3 H_2O	6 H_2O	
5.	1 GTP	2 GTP	2 ATP
		Total	30 ATP for Kreb
		Glycoloysis	8 ATP 6 are from NADH

$$C_6H_{12}O_6 + 6O_2 + 6H_2O \rightleftharpoons 6CO_2 + 12\,H_2O$$

3)Oxidation of Isocitrate : The isocitrate undergoes oxidation and forms oxalosuccinate. During this reaction two hydrogen atoms are released which is accepted by NAD and gets reduced to $NADH_2$, the reaction is catalysed by the enzyme isocitrate dehydrogenase.

$$\text{Isocitrate} + \text{NAD} \xrightarrow[\text{Mn}^{++}]{\text{Dehydrogenase}} \text{Oxalosuccinate} + NADH_2$$

4)Decarboxylation of Oxalosuccinic acid : The Oxalosuccinate undergoes Decarboxylation in presence of enzyme decarboxylase to form α – ketoglutarate . During this reaction one molecule of co_2 is released.

$$\text{Oxalosuccinate} \xrightarrow{\text{Decarboxylase}} \alpha - \text{ketoglutarate} + co_2$$

5)Oxidative Decarboxylation of α – ketoglutarate : The α – ketoglutarate undergoes Oxidative Decarboxylation to form succinyl co-A , the reaction is catalysed by the enzyme α – ketoglutarate dehydrogenase

$$\alpha\text{ – ketoglutarate} + NAD + \text{Co-A} \xrightarrow{\text{Dehydrogenase}} \text{Succinyl Co-A} + NADH_2 + CO_2$$

The reaction is carried out with the help of NAD and co-A accompanied by the removal of hydrogen and carbon dioxide.

6)Hydration and phosphorylation of Succinyl co-A : Succinyl Co-A undergoes hydrolysis to form succinate with the release of Co-A. This reaction is catalysed by the enzyme succinyl thiokinase. The energy released during this reaction is utilized in the synthesis of GTP (Guanosine triphosphate) from GDP (Guanosine diphosphate) and ip . GTP thus formed reacts with ADP to form ATP . This type of ATP synthesis known as substrate level phosphorylation.

$$\text{Succinyl Co-A} + H_2O \xrightarrow[\text{Thiokinase}]{\text{GDP} \quad \text{GTP}} \text{succinate} + \text{Co-A}$$

7)Oxidation of succinate : The succinate undergoes Oxidation to form fumarate.The hydrogen removed during this reaction is accepted by FAD (Flavin Adenine Dinucleotide) to form $FADH_2$. This reaction is catalysed by the enzyme succinate dehydrogenase which requires Fe^{++} as cofactor.

$$\text{Succinate} + FAD \xrightarrow{\text{Succinate dehydrogenase}} \text{Fumarate} + FADH_2$$

8)**Hydration of Fumarate :** Fumarate undergoes Hydration i.e. it combines with water molecule to form malate in presence of enzyme fumarase.

$$\text{Fumarate} + H_2O \xrightarrow{\text{Fumarase}} \text{Malate}$$

9)Oxidation of Malate : The Malate undergoes Oxidation to form oxaloacetate in the presence of enzyme malate dehydrogenase. Hydrogen removed during this reaction is accepted by NAD gets reduced to $NADH_2$.

$$\text{Malate} + NAD \xrightarrow{\text{Malate dehydrogenase}} \text{Oxaloacetate} + NADH_2$$

The Oxaloacetate is thus regenerated to combine with acetyl Co-A again to keep the cycle going.

Significance of Kreb cycle

1) Kreb cycle is a very efficient energy releasing process as 30 ATP molecules are produced from one molecule of glucose during Kreb cycle

2) Pyruvic acid is completly oxidised to form CO_2 and H_2O .

3) It is common respiratory pathway for breakdown of carbohydrates , fats and proteins.

4) Different organic acids are form as intermediate compound during Kreb cycle , these acids may be used in the synthesis of other organic compounds.

Amphibolic pathway :

1) The term Amphibolic pathway is used to describe the biochemical pathway which involves both anabolic and catabolic reactions, for example, Krebs cycle of respiration.

2) When fats are used as respiratory substrates, they are first broken down to fatty acids and glycerol.

3) glycerol thus formed is first converted into dihydroxy acetone phosphate (DHAP) then into PGAL which is further degraded to acetyl Co-A which enters the Krebs cycle.

4)The proteins are degraded to amino acids by the enzymes proteases.

5) Individual amino acids after deamination enter the pathway at some stage of the Krebs cycle or as pyruvate or as acetyl co-A.

6) Earlier , since the respiration involves the breakdown of substrates , it was considered as catabolic pathway.

7) But as present day plant physiologists consider respiration as amphibolic pathway as the intermediates can be withdrawn from the pathway and are utilized for the synthesis of fatty acids or glycerol or proteins.

8) The respiratory intermediates form the link both during the synthesis and breakdown.

9) The acids of Krebs cycle serve as precursors of amino acids which are used as building blocks of proteins . From this it is obvious that respiratory pathway is an amphibolic pathway.

TERMINAL OXIDATION (ELECTRON TRANSPORT SYSTEMOR RESPIRATORY CHAIN)

1) The oxidation of reduced coenzymes, viz. $NADH_2$ and $FADH_2$ into their oxidized forms is called terminal oxidation.
2) Terminal oxidation involves ETS(electron transport system) consisting of NAD (nicotinamide adenine dinucleotide) FMN(Flavin mononucleotide) coenzyme Q or uboquinone , cytochromes-b, c a and a_3.
3) Electron transfer is the last step during which water is formed with the release of energy.
4) When $NADH_2$ transfers H_2 to FMN it is oxidized to NAD.
5) The coenzyme ubiquinone takes up only electrons and protons from FMN and release them into them in mitochondrial matrix.
6) Each hydrogen atom undergoes ionization to form a proton and an electron.
7) The protons are released into the mitochondrial matrix while the electrons are channelized into an electron transport system (ETS) OR respiratory chain.
8) NAD , FMNand ubiquinone behave as coenzymes while cytochromes act as electron carriers.
9) Cytochromes are proteins containing iron which oscillates between its ferrous and ferric form by oxidation –reduction reactions and brings about the transferof an electron.
10) The cytochromes (electron carriers) are arranged in a definite sequence along the inner surface of the mitochondrial membrane(cristae)
11) The electron carriers are arranged on the cristae according to their decreasing energy potential.
12) When the potential difference between the two electron carriers is more than 0.27ev , the energy released is utilized in the synthesis of ATP from ADP and ip.
13) When the potential difference between the two electron carriers is less than 0.27ev , the energy released as heat.
14) ATP synthesis occurs at three places during the ETS. One ATP molecule is synthesized during the transfer of hydrogen from $NADH_2$ to FMN. The second ATP molecule is synthesized during the transfer of electrons from cytochrome –b to cytochrome –c_1 and third ATP is synthesized when the electrons transferred from cytochrome –c to cytochrome –a , a_3.
15) The oxidation of one molecule of $NADH_2$ produces three ATP molecules , while oxidation of one molecule of $FADH_2$ produces 2 ATP molecules. No ATP synthesis occurs when $FADH_2$ is reoxidized to FAD. This process of ATP formation is called oxidative phosphorylation.
16) From yhe above account it is obvious that the released energy during electron transfer is utilized for the synthesis of ATP.
17) cytochrome - a_3 is the last electron carrier. It transfers the de-energized electron to the molecular oxygen which is activated. The activated oxygen combines with protons in the mitochondrial matrix resulting in the formation of water molecule. This formation of water molecule by combining the activated oxygen with proton in the mitochondrial matrix is known as terminal oxidation.

Schematic diagram of Electron Transport System

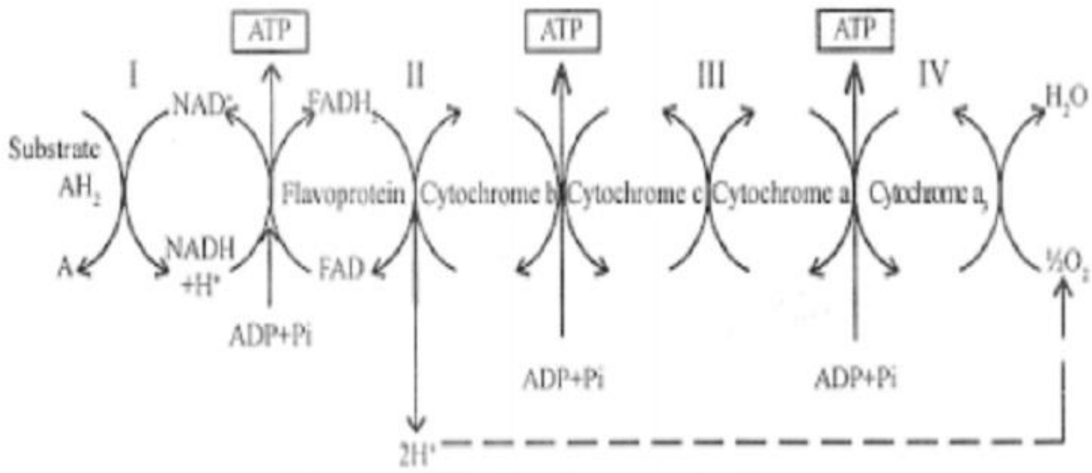


Fig. Electron transport system

Significance of ETS :

1) In ETS, there is complete oxidation as O_2 is available to accept the H_2 released during the process of respiration.

2) The energy released during ETS is gradual in a stepwise mannerso that the cell is in a position to utilize this energy more efficiently.

3) During ETS, each hydrogen electron generates three molecules of ATP. Out of total 38 ATP molecules of ATP , 34 molecules are produced during ETS.

4) The energy released during ETS is made available to the cell to perform various life activities.

5) ETS generates oxidized coenzymes like NAD and FAD from $NADH_2$ and $FADH_2$ for recycling.

6) The energy is released in a stepwise manner for preventing the damage of cells.

7) Most of the energy released during ETS , is conserved in the form of energy rich molecules called adenosine triphosphate (ATP) .

ATP Account of Aerobic Respiration

I) GLYCOLYSIS :

a) ATPs formed (by substrate level phosphorylation)

i) 1,3 diPGA to 3 PGA =2 ATPs
ii) PEPA to Pyruvic acid = 2 ATPs

Total = 4 ATPs

b) ATPs used :

i) Gl to GL- 6 PO_4 =1 ATP
ii) Fr- 6 PO_4 to Fr- 1,6 PO_4 =1 ATP

Total = 2 ATPs

II) Krebs cycle :

ATPs formed (by substrate level phosphorylation)

i) Succinyl Co-A to Succinate = 1× 2 = total 2ATPs

III) TERMINAL OXIDATION (through ETS) :

i) From NADH2 : 10 NADH2 ×3 ATP = 30 ATP
ii) From FADH2 : 2FADH2 × 2ATP = 4 ATP

Total = 34 ATP

Total ATPs formed (4+ 2+ 34) = 40 ATPs s

Total ATPs used = 2 ATPs

Net gain = 38 ATPs

ANAEROBIC RESPIRATION

Respiration that takes place in the absence of free molecular oxygen is called Anaerobic Respiration **.**

Mechanism of Anaerobic Respiration :

Anaerobic Respiration occurs in the following three steps :

1)**Glycolysis :** during glycolysis , glucose is broken down to two molecules of pyruvate, two molecules of NADH2 and two molecules of ATP along EMP pathway as shown below :

$$C_6H_{12}O_6 + 2NAD + 2ADP + 2ip \longrightarrow 2CH_3\text{-}CO\text{-}COOH + 2NADH_2 + 2\ ATP$$

2)**DECARBOXYLATION :** The pyruvate undergoes decarboxylation to form acetaldehyde. This reaction occurs in the presence of pyruvate decarboxylase enzyme which requires TPP (Thymine phosphate) as coenzyme and Zn++ as cofactor as shown below :

$$2CH_3\text{-}CO\text{-}COOH\ (\text{pyruvate}) \xrightarrow{\text{Pyruvate decarboxylase}} 2CH_3\text{-}CHO\ (\text{Acetaldehyde}) + CO_2$$

3)**REDUCTION :** The Acetaldehyde is finally reduced to ethyl alcohol by accepting hydrogen atoms from $NADH_2$ produced during glycolysis. This reaction occurs in the presence of the enzyme ethanol dehydrogenase as shown below :

$$2CH_3\text{-}CHO + 2NADH_2 \xrightarrow{\text{Dehydrogenase}} 2C_2H_5OH\ (\text{ethyl alcohol}) + 2\ NAD$$

During this process , Since ethyl alcohol is produced , as end product , it is used in the fermentation industries for the production of alcohol from molasses. It is also used in bakeries.

FERMENTATION :

The term fermentation is derived from Greek word fervos meaning bubbling. Fermentation is the breakdown of organic compounds by living organisms or living cells especially by microorganisms or enzymes produced by them under anaerobic conditions . Fermentation is of two types :

1) Alcoholic Fermentation
2) Lactic acid Fermentation

Alcoholic Fermentation : When main end product of Fermentation is alcohol then it is called alcoholic Fermentation. It takes place in presence of unicellular fungi called yeast.During alcoholic fermentation yeast cell release the enzyme called zymase. This enzyme brings about the fermentation of sugar to form ethyl alcohol . The process of Alcoholic Fermentation is represented by following chemical equation

$$\underset{(\text{Sucrose})}{C_{12}H_{22}O_{11}} + H_2O \longrightarrow \underset{(\text{Glucose})}{C_6H_{12}O_6} + \underset{(\text{Fructose})}{C_6H_{12}O_6}$$

$$\underset{(\text{glucose})}{C_6H_{12}O_6} \xrightarrow[\text{Yeast}]{\text{Enzyme Zymase}} \underset{(\text{ethyl alcohol})}{2\ C_2H_5OH} + 2CO_2 + 2ATP$$

Lactic acid Fermentation : When the main end product of fermentation is lactic acid then it is called Lactic acid Fermentation. It takes place in presence of lactic acid bacteria . During Lactic acid Fermentation the enzyme lactose dehydrogenase is released which convert milk sugar i.e. lactose into lactic acid , it is completed in two steps.

Step I – In this step lactose is hydrolysed to form the hexose sugar.

$$\text{Lactose} + H_2O \xrightarrow{\text{Lactic acid bacteria}} \text{Glucose} + \text{Galactose}$$

Step II – In this step hexose sugar , is converted into lactic acid in presence of enzyme lactose dehydrogenase which is secreted by lactic acid bacteria , it is represented by following chemical equation .

$$C_6H_{12}O_6 \text{ (hexose sugar)} \xrightarrow{\text{Lactose dehydrogenase}} 2CH_3\text{-}CHOH – COOH \text{ (lactic acid)}$$

Commercial uses of Fermentation :

1) Fermentation help in the production of alcoholic beverages like Rum, Whisky, Brandy.
2) It also help in the production of organic acid like lactic acid, butyric acid, acetic acid.
3) It also help in the production of antibiotics and vitamins.
4) It helps in the production of butter , cheese , and other dairy milk products,

Respiratory Quotient :

1) The ratio of the volume of CO_2 given out to the volume of O_2 consumed in respiration is called Respiratory Quotient (RQ) .
2) When carbohydrates are respiratory substrates, the RQ is one as shown below :

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

$$RQ = \frac{6\ CO_2}{6O_2} = 1$$

3)When fats are used as respiratory substrate, the RQ is 0.7 as shown below:

$$2(\ C_{51}H_{98}O_6) + 145O_2 \longrightarrow 102CO_2 + 98H_2O\ \text{Energy}$$

$$RQ = \frac{102CO_2}{145O_2} = 0.7$$

4)When proteins are used as respiratory substrate, the RQ is about 0.9
5) In case of anaerobic respiration, RQ is always infinity. In such respiration , CO_2 is evolved without taking O_2.

$$C_6H_{12}O_6 \longrightarrow 2\ C_2H_5OH \text{ (ethyl alcohol)} + 2CO_2 + \text{Energy}$$

$$RQ = \frac{2CO_2}{\text{Zero } O_2} = \text{Infinity.}$$

Significance of Respiration

1)Energy released during this process is utilized in various synthetic activities like synthesis of proteins, fats, oils, carbohydrates, , vitamins, pigments, alkaloids, etc.

2) During respiration Energy is liberated in stepwise manner as a result of which most of the energy is properly utilized for cellular activity like cell division , growth, repairs, movements, and locomotion etc.

3) During Respiration CO_2 liberated which is used by green plants during photosynthesis , thus it maintain the CO_2 and O_2 balance in the atmosphere.

4)NADH2 which is produced during respiration is used for the synthesis of fatty acid.

5) various intermediate compounds formed during Kreb cycle are used as building blocks for the synthesis of other complex compounds.

6) Anaerobic respiration(fermentation) is used in various industries such as dairies, bakeries, distilleries, leather industries, paper industries , etc. It is used in the commercial production of alcohol, organic acids, vitamins, antibiotics.