Chapter - 11
Respiration

All living organism needs energy to perform their daily work, which is achieved from food material. Food material is produced by plants. Plants produces such type of energy by the means of photosynthesis in the presence of sun light and with the help of chloroplasto in complex organic compound released by oxidation reaction. In this reaction complex organic compounds in the presence or absence of oxygen are decomposed in to $CO_2$and water and release energy. This reaction can be shown by the following equations

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Aerobic Respiration}} 6CO_2 + 6H_2O + 686 \text{ k.cal energy}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Anaerobic Respiration}} 2C_2H_5OH + 2CO_2 + 56 \text{ k.cal energy}$$

Hence respiration is the process of living cells in which high energy complex organic compounds are decomposed and form simple, low energy molecules and release energy. Generally, during this reaction carbon dioxide is released, oxygen is utilized and potential energy is converted into kinetic energy. The energy released in this way is utilized in various activities take place in a call. Respiration is a fundamental characteristics of living organisms and it is a continuous process. Most of the plants and animals use O_2 in the respiration process and release CO_2.

Respiratory Substrates

High energy compounds which take part in respiration and release energy by oxidation are called respiratory substrates. These substrates are stored in a cell in the form of carbohydrates, fats and protein molecules. Carbohydrates are the primary substrate, Haxose sugar carbohydrate is the first carbohydrate to be used in respiration. In the absence of carbohydrates fats are consumed and after consumption of fats oxidation of proteins begins. According to Blackman respiration occur from carbohydrate called floating respiration and respiration occur from protein is called protoplasmic respiration. It happens during starvation and diseases.

Types of Respiration

There are two types of respiration:-

(1) Aerobic Respiration

(2) Anaerobic Respiration

1. Aerobic Respiration : This type of respiration takes place in the presence of O_2 it means it happens by the use of oxygen in which organic food material completely breaks into carbon dioxide and water and more energy is generated.

This the normal process of respiration in all the plants and animals.

Aerobic respiration can be shown by chemical equation given below

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 686 \text{ k.cal energy}$$

2. Anaerobic respiration : This type of respiration take place without the use of oxygen hence O_2 is not used in this process so there is no complete oxidation of organic food material and alcohol or carbonic acid and CO_2 are formed. In this respiration very less energy generated. This is called intramolecular respiration Anaerobic respiration

can be shown by chemical equation given below :

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 56$ k.cal energy

Anaerobic respiration found constantly in fungi and bacteria and temporarily found stored and germinating seed, pulpy fruits.

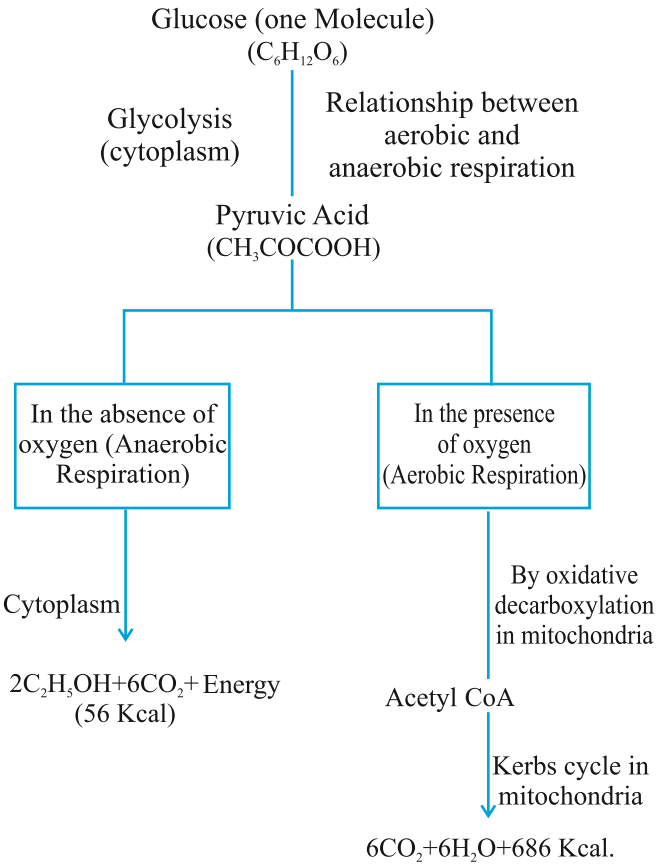


Fig. 11.0 Relationship between aerobic and anaerobic respiration

Table : Difference between aerobic and anaerobic respiration.

S. No.	Aerobic Respiration	Anaerobic Respiration
1.	In this O_2 is used	In this oxygen is not need.
2.	It takes place in all the living cells	It take place in only found in fungi, bacteria and germinating seeds
3.	In this respiration one molecule of glucose completely oxidized and form 38 ATP Molecules	Glucose molecule does not completely oxidized and form only 2 ATP
4.	In this respiration, glycolysis occurs in cytoplasm and Kreb's cycle occurs in mitochondria	All the reactions take place in cytoplasm
5.	Respiratory substrate is oxidized completely	Respiratory substrate is incompletely oxidized.
6.	End products are CO_2 , water and energy	End products are alcohol or organic acid, CO_2 and energy.

Site of Respiration

Main site for respiration in eukaryotic organisms is cell organells mitochondria.

Two major steps of aerobic respiration Kreb's cycle and electron transport system occur in it.

Mitochondria is a double membrane bound cell organelle which are respectively called external membrane and internal membrane. Both membranes are made up of lipoprotein, Space between both membrane is Called perimembrane space (40-70 A^0 Wide). Outer membrane is flat however internal membrane is distributed in the form of irregular in foldings in interstitial space of Mitochondria. These foldings are called cristae (Singular-Crista).

Internal space of Criste called inter criste space. Internal membrane or on the surface of criste many stakled particles are sticked which are called F1, Particles, elementary particles or oxysomes, Transportation of electron takes place in these particles by which ATP are formed.

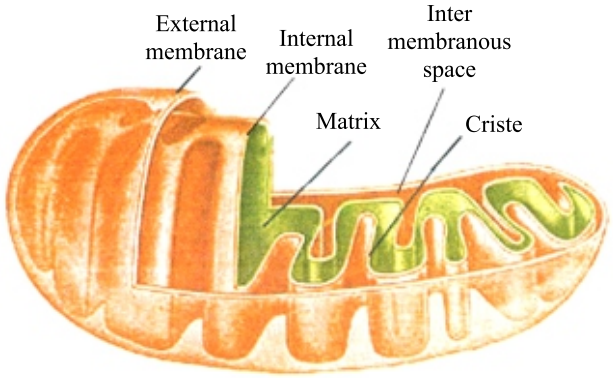


Fig. 11.1 Mitochondria-Respiration Site

Internal space of mitochondria is called

matrix. It is made up of liquid and semi liquid protein part. It has many respiration process related enzymes, co enzymes (NAD, NADD, ADP) electron carrier, ribosomes, RNA and DNA.

Mitochondria is known as the power house of the cell because it produce energy currency in the form of ATP.

Mechanism of Aerobic Respiration :

The substrate in respiration process is carbohydrate. In the absence of carbohydrate fats and proteins are used respectively. Primary reaction of aerobic and anaerobic reactions takes place in cytoplasm, in which one molecule of glucose reduces to form 2 molecules of pyruvic acid and release energy. This is called glycolysis or EMP pathway. Oxygen is not need for this reaction. Pyruvic acid produced in glycolysis enters in mitochondria and produces acetyl co-A enzyms and by Kreb's cycle (or TCA cycle) takes place in mitochondria produces water, CO_2 and releases energy. In this reaction glucose is completely oxidized in the presence of O_2.

Overall mechanism of aerobic respiration can be divided in to 3 steps :-

1. Glycolysis
2. Krebs Cycle, Tricarboxylic acid cycle; TCA Cycle.
3. Electron Transport System

I. Glycolysis

Word glycolysis was originated from Greek word Glucose (sugar) + Lysis, analyatic (Dissolve or break down) it means break down of sugars. This is the complex biochemical reaction which is completed in 10 gradual steps. Different steps of it were discovered by 3 German scientist G. Embden, Otto Mayerh off, J. Parnas in 1930. This reaction is also known as EMP Pathway. This reaction takes place in cytoplasm without the use of oxygen hence oxygen is not required for this reaction. Glycolysis is completed in all the living in similar way and found in both aerobic and anaerobic respiration. Glycolysis is the process in which one molecule of glucose reduced to pyruvic acid through sequential biochemical reactions and release energy. For more clearity formation of 2 molecules of pyruvic acid from one molecule of fructose 1-5 diphosphate is called glycolysis.

10 biochemical reactions occur in glycolysis can be understood in three steps:

(a) Phosphorylation of glucose

(b) Splitting of phosphorylated glucose moleule in two molecules of phospho glyceraldehyde.

(c) Formation or two molecules of pyruvic acid.

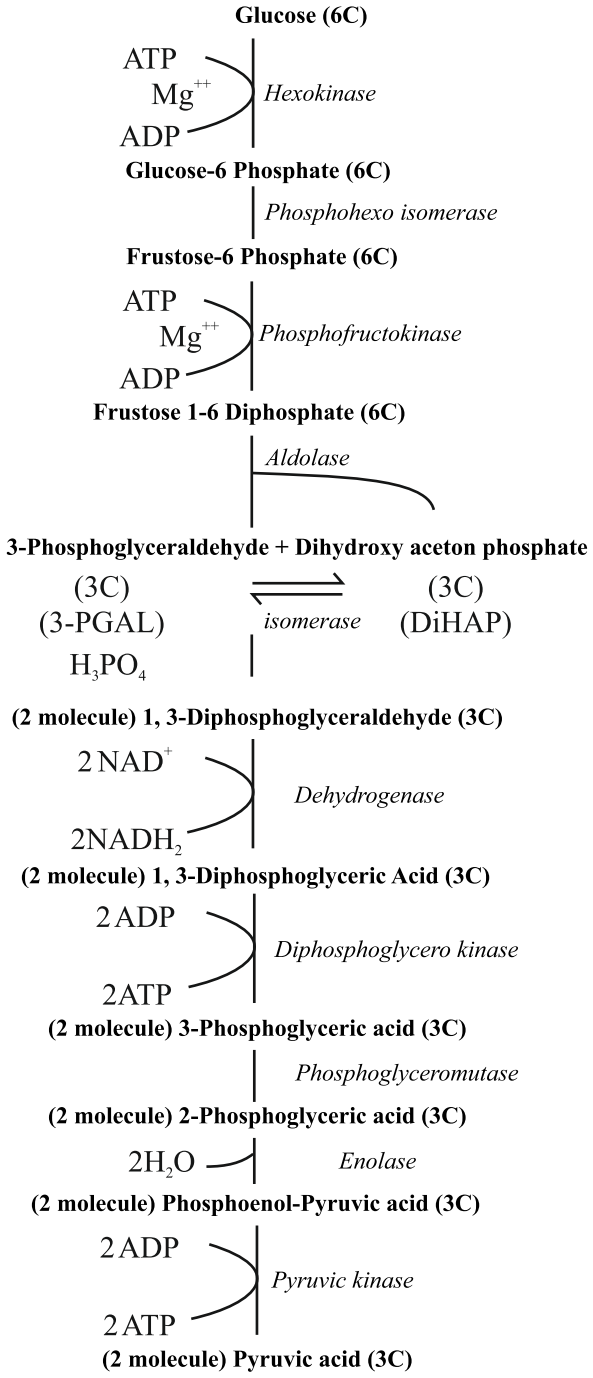


Fig. 11.2 Different Biochemical Reactions of Glycolysis

(A) Phosphorylation of Glucose

In the first step of glycolysis one molecule of glucose in the presence of hexokinase uses one molecule of ATP and form glucose 6-phosphate. This glucose 6-phosphate converts into fructose 6-phosphate in the presence of isomerase by isomerization. Fructose 6-phosphate again uses one molecule of ATP and forms fructose 1-6 diphosphate molecule in the presence of phosphofurectokinase.

The reactions that take part in the phosphorylation of glucose molecule are as follows:

$$\text{Glucose} + \text{ATP} \xrightarrow[Mg^{++}]{\text{Hexokinase}} \text{Glucose-6-phosphate} + \text{ADP} \quad (1)$$

$$\text{Glucose 6 phosphate} \xrightarrow{\text{Isomerase}} \text{Fructose-6-phosphate} \quad (2)$$

$$\text{Fructose 6 phosphate} + \text{ATP} \xrightarrow[Mg^{++}]{\text{Phosphofructokinase}} \text{fructose 1-6 Diphosphate} + \text{ADP} \quad (3)$$

(B) Splitting of Phosphorylated glucose molecule in two molecules of phosphoglyceraldehyde

In this reaction 6 carbon containing fructose-1, 6-diphosphate in the presence of aldolase enzyme converts into3-phosphoglyceraldehyde (3-PGAL) and dihydroxy acetone phosphate (3 carbon containing molecule) one molecule of each.

$$\text{Fructose 1, 6-diphosphate} \xrightarrow{\text{Aldolase}} \begin{cases} \text{3-phosphoglyceradehyde (3C) (3-PGAL)} \\ \rightleftharpoons \text{ Triose Phosphate Isomerase} \\ \text{Dihydroxy acetone phosphate (3C)(Di HAP)} \end{cases} (4)$$

Both these compounds are inter convertible in the presence of triose phosphate isomerase enzyme. Out of these compounds only 3-PGAL oxidizes. During the course of oxidation of 3-PGAL, dihydroxy acetone phosphate converts into 3-PGAL.

(C) Formation of two Molecules of Pyruvic acid

By the following reactions 2 molecules of 3-PGAL oxidize and form two molecules of pyruvic acid.

1. Formation of 1-3 Di phosphoglyceric acid from 3 PGAL

At first 3 PGAL in the presence of enzyme dehydrogenase reacts with phosphoric acid (H_3PO_4) and forms 1,3-diphospho glyceraldehyde which on oxidates and forms 1-3-diphosphoglyceric acid. It is known as oxidation step. NAD^+ accepts the hydrogen atoms during the reaction and converts into $NADH_2$ which enters into election transport system and forms ATP. (2 Molecule)

$$\underset{\text{(2 Molecule)}}{\text{3-Phosphoglyceraldehyde}} + H_3PO_4 \xrightarrow{\text{Dehydrogenase}} \underset{\text{(2 Molecule)}}{\text{1,3-Diphosphoglygeraldehyde}} \quad (5)$$

$$\underset{\text{(2 Molecule)}}{\text{1, 3-Diphosphoglyceraldehyde}} \xrightarrow[2NAD \quad 2NADH+2H^+]{\text{Dehydrogenase}} \text{1, 3-Diphosphoglyeeric acid} \quad (6)$$

2. Formation of 3-Phosphoglyceric acid from 1,3-Diphosphoglyceric acid

In this reaction 1-3 di phosphoglyceric acid is combined with ADP in the presence of one phosphate group, di-phosphoglycero kinase molecules and form 2 molecules of 3-phosphoglyceric acid and 2 molecules of ATP.

$$\underset{\text{(2 Molecule)}}{\text{1, 3-Diphosphoglyceric acid}} + \underset{\text{(2 Molecule)}}{\text{ADP}} \xrightarrow[\text{kinase}]{\text{Dipshosphoglycero}} \underset{\text{(2 Molecule)}}{\text{3-Phosphoglyceric acid}} + \underset{\text{(2 Molecule)}}{\text{ATP}} \quad (7)$$

3.Conversion of 3-Phosphoglyceric acid into 2-Phosphoglyceric acid

3-Phosphoglyceric acid in the presence of phosphoglyceromutase converts acid, into its isomer 2-phosphoglyceric acid.

$$\underset{\text{(2 Molecule)}}{\text{3-phoshoglyceric acid}} \xrightarrow[\text{mutase}]{\text{Phosphoglycero}} \underset{\text{(2 Molecule)}}{\text{2-phosphoglyceric acid}} \quad (8)$$

4. Formation of 2-Phospheoneol pyruvate from 2-Phosphoglyceric acid

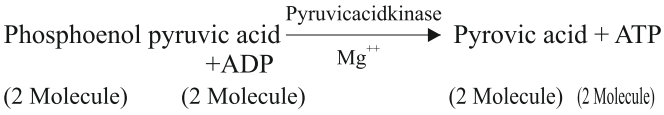
2-Phosphoglyceric acid by releasing 1 molecule of water in the presence of enolase enzyme converts into 2 phosphoneol pyruvate.

$$\underset{\text{(2 Molecule)}}{\text{2-phosphoglyceric acid}} \xrightarrow[-H_2O]{\text{Enolose}} \underset{\text{(2 Molecule)}}{\text{2-phosphoenolpyruvic acid}} \quad (9)$$

5. Formation of pyruvic acid from 2-Phosphoneol pyruvic acid

Phosphoenol pyruvic acid in the presence of

pyruvic acid kinas enzyme release 1 phosphate and form pyruvic acid and ATP



(10)

Process of glycolysis can be shown by the equation given below :

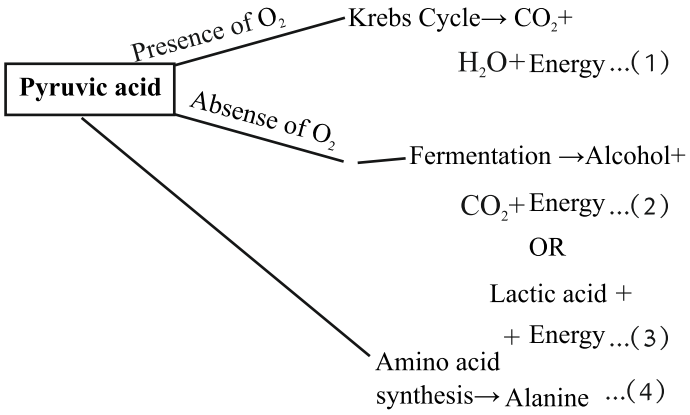
$$C_6H_{12}O_6 + 2ATP + 4ADP + 2P_2 + 2NAD^+ \rightarrow 2C_3H_4O_3 + 2ADP + 4ATP + 2NADH + 2H^+$$

Summary of Glycolysis

1. In the glycolysis 6 carbon containing glucose molecule splits into two molecules of pyruvic acid containing two carbon atoms.
2. In glycolysis four ATP molecules are formed by substrate level phosphorylation in which 2 ATP molecule spent and finally 2 ATP molecules are gained.
3. 1, 3-Diphosphoglyceric acid are formed by molecules of 1-3 di phosphoglyceraldehyde. At this time 2 molecule of NADH+H$^+$ form 3 ATP molecules by electron transport system, Hence total 6 ATP Molecules are formed.
4. In this reaction O_2 is not used and also CO_2 is not formed.
5. Few intermediate compounds of glycolysis are involved in other processes hence it is also known as catabolic resynthesis or oxidative anabolism. eg., PGAL used in synthesis Similarly phosphoglyceric acid used in the formation of various amino acids such as glycine, serein, cystein etc.

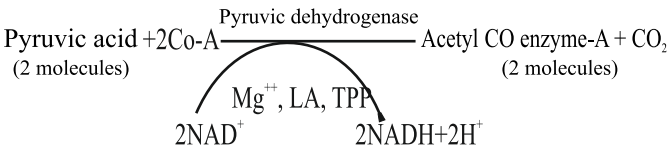
Fate of Pyruvic Acid

Pyruvic acid is the end product of EMP pathway. On the basis of availability and non availability of oxygen pyruvic acid can be further reduced along with differect circuit.



Aerobic Oxidation of Pyruvic Acid :

Second phase of respiration starts when pyruvic acid formed by glycolysis matrix in of cytoplasm enters into mitochondria. One carbon atom of pyruvic acid oxidized in to CO_2 in the matrix of mitochondria. This process is known as oxidative decarbosxylation. After this in the presence of pyruvic de hydrogenase enzyme first oxidation takes place and than it combines with co enzyme A and forms acetyl CoA. In this reaction 5 cofactors are important these are CoA, NAD+, Mg^{++} lipoic acid (LA) and thymine pyrophosphate (TPP). Reaction of formation of acetyl CoA connects glycolysis and Kreb's cycle. Hence it is called link reaction or gateway reaction. Conversion of pyruvic acid into acetyl Co enzyme A can be describe as below-



In this way the oxidation of 2 molecules of pyruvic acid 2 molecule of acetyl Co enzyme A and 2molecules of$NADH_2$, are formed, 2 $NADH_2$ form 6 ATP Molecules.

II. Kreb's Cycle, Citric Acid Cycle, TCA cycle, Tricarboxylic Acid Cycle

This Cycle is completed in Mitochondria and was discovered by British Biochemist Sir H.A. Kerb's in 1937 .In his regards it is known as Kreb's Cycle He was rewarded by a Nobel prize in 1953. First product of Kreb's cycle is Citric acid (CH_2COOH-C(OH)COOH-CH_2COO+H) so it is

also known as citric acid cycle because citric acid has 3 molecules of acidic group hence this cycle is also known as tri carboxylic acid cycle. At begning of Kreb's Cycle 2 carbon acetyl coenzyme A, transfers both the carbon molecules of acetyl group to oxaloacetic acid to from 6 carbon containing citric acid.

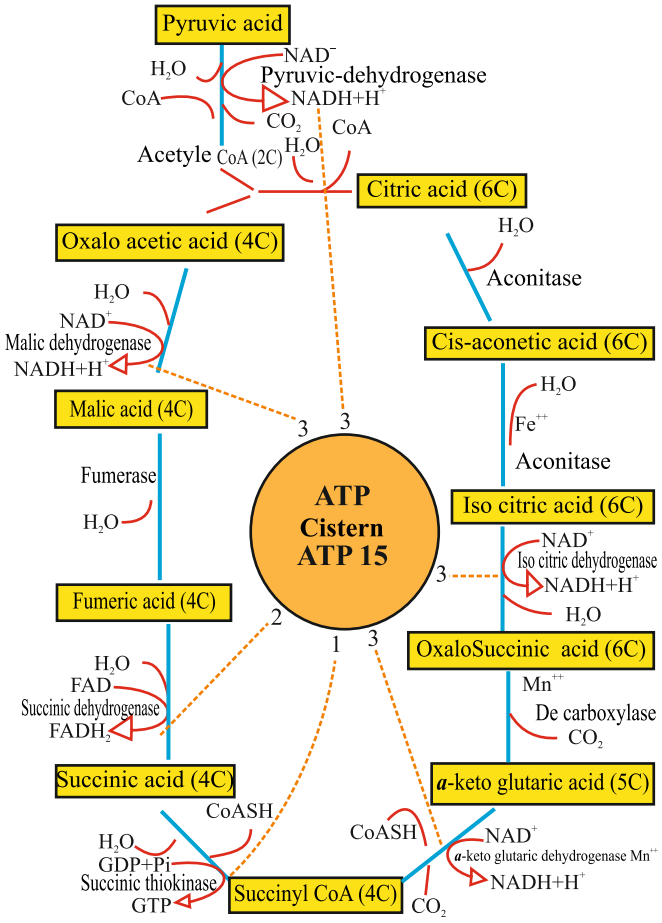


Fig. 11.3 Main Reactions of Krebs Cycle or Citric Acid Cycle

The main steps of Kreb's cycle can be explained as follows:

(1) Formation of Citric Acid : 2 carbon containing acetyl CoA enters into mitochondria and in presence of condensing enzyme citrate synthatase reacts with 4C containing oxaloacetic acid by hydration forms 6C containing citric acid. In this reaction co enzyme is being released.

Acetyl-CoA + Oxalo Acetic Acid $\xrightarrow[H_2O]{\text{Condensing Enzyme, Citrate synthatase}}$ Citric acid+CoA

(2) Formation of cis-Aconitic acid : Citric Acid in the presence of aconitase enzyme release 1 water molecule and form cis-aconitic acid

Citric Acid $\xrightarrow[-H_2O]{\text{Aconitase}}$ cis aconitic acid

(3) Formation of Isocitric acid : Cis aconetic acid in the presence of aconitase enzyme rehydrate and forms isocitric acid.

Cis aconitic acid $\xrightarrow[H_2O]{\text{Aconitase}}$ Isocitric acid

(4) Formation of Oxalo Succinnic acid : Iso citric acid in the presence of de hydrogenase enzyme by oxidation forms oxalo succinic acid.2 hydrogen atoms released during this reaction accepted by NAD^+ and it converts into NADH + H^+. CO_2, is released in this reaction

Isocitric acid $\xrightarrow[NAD^+ \rightarrow NADH+H^+]{\text{Isocitric dehydrogenase}}$ Oxalo succinic acid

(5) Formation of *a*-Keto Glutaric Acid : Oxalo succinic acid in the presence of decarboxylase enzyme release containing carbon di oxide and form 5 carbon containing α- keto glutaric acid.

This is the only 5 carbon containing acid in whole Kreb's Cycle.

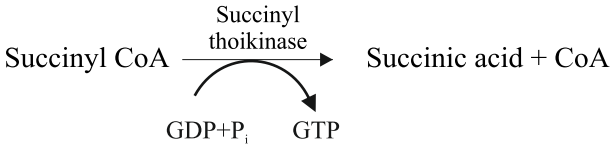
Oxalo succinic acid $\xrightarrow{\text{decarboxylase enzyme}}$ α- Keto glutaric acid + CO_2

(6) Formation of Succinyl Coenzyme A : 5 C containing α- keto glutaric acid in the presence of Dehydrogenase enzyme through oxidative decarboxylation forms succinyl coenzyme A. Two hydrogen atoms released during this reaction reduce NAD + into NADH +H, CO_2 is released during this process.

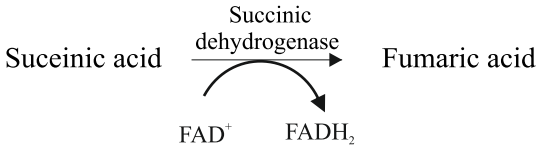
α- keto glutaric acid + CoA $\xrightarrow[NAD^+ \rightarrow NADH+H^+]{\text{α- keto glutaric dehydrogenase}}$ succinyl CoenzymeA + CO_2

(7) Formation of Succinic Acid : In the presence of succinyl thiokinase enzyme by hydrolysis of succinic acid is formed and Co-A is

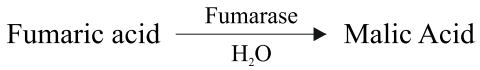
released. In this reaction energy is released in it form of GTP which later converts into ATP.



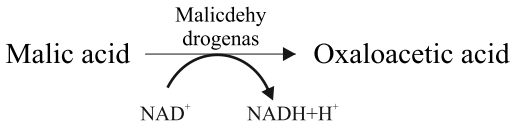
(8) Formation of Fumaric acid : In the presence of succinic de hydrogenase enzyme succinic acid oxidized and form fumaric acid. The hydrogen atoms released in this reaction are reduce FAD^+ into $FADH_2$.



(9) Formation of Malic Acid : In the presence of fumerase enzyme by hydration fumaric acid converts into malic acid



(10) Formation of Oxaloacetic acid : In the last reaction of Kreb's Cycle malic acid oxidized in the presence of malic de hydrogenase enzyme and form oxaloacetic acid. In this reaction two hydrogen atom are released and reduce NAD^+ into $NADH+H^+$.



Summary of Aerobic Respiration of glucose

S.No.	Process		Energy Produced
1.	Glycolysis Glucose ($C_6H_{12}O_6$)	(Site-Cytoplasm) Pyruvic acid $+2H_2$	8 or 6 ATP
2.	Middle reaction 2 Pyruvic Acid (COA)	(Site perimitochondrial) 2 acetyl CoA + $4H^+$ $2CO_2$	6 ATP
3.	Krebs Cycle (Site Matrix) 2 Acetyl Co enzyme $+6H_2O$ $24H^+ + 6O_2$	$CoA+16H^+ + 4CO_2$ $12H_2O$	24 ATP
	$C_6H_{12}O6 + 6O_2$	$6CO_2 + 6H_2O$	38 or 36 ATP

Oxaloacetic acid again accepts acetyl co-enzyme and enters into Krebs cycle

In this way in Krebs cycle 3 molecules of CO_2 formed from 1 molecule of pyruvic acid.

Since 2 molecules of pyruvic acid formed from one molecule of glucose hence by complete oxidation of glucose 6 molecules of CO_2 are formed.

Complete Krebs Cycle can be explained by equation given below :

Acetyl Co-A + $3H_2O$ + $3NAD^+$ + FAD^+ + GDP + Pi → $2CoA + 3CO_2 + 3NADH + 4H^+ + FADH_2 + GTP$

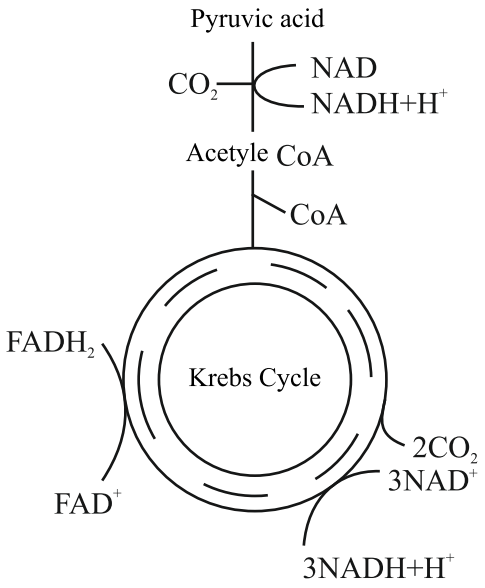


Fig. 11.4 Krebs Cycle

Molecules of NADH+H^+ formed during glycolysis if enter in ETS takes place in mitochondria through malate asspartate shuttle they form 6 ATP molecules, In aerobic respiration total 38 ATP molecules are formed

If 2 molecules of NADH +H^+ enters in to mitochondria through glycerol phosphate shuttle then they reduce FAD in which 4 ATP molecules are formed however in aerobic respiration 36 ATP molecules are formed.

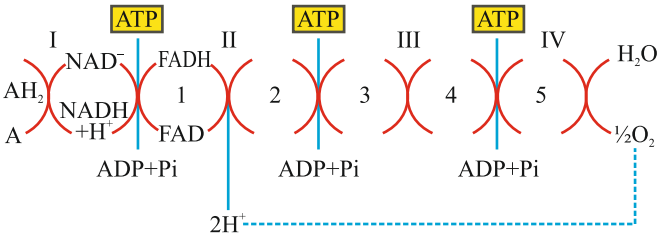
Importance of Kreb's Cycle

I. In Kreb's Cycle ATP molecules are formed and they provide energy to do different functions.

II. In this cycle many intermediate compounds are formed which are used in other bio molecular synthesis. e.g. succynyl co enzyme A is initial molecule for synthesis of chlorophyll. Amino acids are formed by *a*-keto glutaric acid, pyruvic acid and oxaloacetic acid.

III. Electron Transport System, ETS

At the end of the Kreb's cycle glucose oxidized completely but energy released only after oxidation of $NADH_2$ and $FADH_2$. In electron transport system electron transfer from one electron carrier to another in a uniform chain. Electron transfer from high energy level to low energy level. All the enzymes take part in this reacton associated with the internal membrane of mitochondria.



1. Flavoprotein 2. Cytochronic b
3. Cytochrome C 4. Cytochrome a 5. Cytochrome a_3

Fig. 11.5 Electron transport system

Carrier and Factors of ETS are graded as given below. These are called complexes :

S.No.	Name of the complex	Components of complex
1.	Complex I	FMN, Fe-S
2.	Complex II	Fe-S
3.	Complex III	Cytochrome-b-Cyt C_1
4.	Complex IV	Cytochrome-a-Cytochrome-a_3
5.	Complex V	ATP synthatase

Apart from this electron has 2 molecule carriers cytochrome C and CoQ/UQ (ubiquinone) are also involved in this process.

Oxidation of NADH + H^+ and $FADH_2$ in electron transport system takes place in a fixed sequence. Which can be understood as follows:

(1) In Kreb's cycle NADH + H^+ formed in matrix of mitochondria oxidized into NAD^+ by NADH de hydrogenase and the electrons released in this reaction are accepted by components of complex I which are found on the internal membrane of mitochondria. In these components mainly NADH ubiquinon oxido reductase and flavin mono nucleotide (FMN) are found.

Components of complex II (succinate ubiquinone oxidoreductase) accepts electrons released from succinic acid which are accepted by $FADH_2$.

(2) In this way reduced ubiquinone transfers the electrons to components of complex III (Cytochrome b and c_1) This cytochrome C is a mobile protein related to outer.layer of internal membrane of mitochondria which transfers the electron from complex II to complex IV.

Cytochrome C-oxidase complex in which cytochrome a and a_3 and two copper centers are found that form complex IV.

(3) In electron transport chain elecrons are transferred from complex I to complex IV and through ATP synthatase complex form ADP and inorganic phosphate by which they form ATP.

(4) Formation of Number of ATP Molecules in this reaction depends of nature of electron donor. One NADH + H^+ forms 3 ATP molecules and 2 ATP molecules are formed from $FADH_2$.

(5) Oxygen acts as last electron receptor in this reaction.

(6) This reaction of phosphorylation takes place in the presence of oxygen hence, it is known as

oxidativephosphorylation.

Chemiosmotic Theory of ATP Synthesis :

In cellular reactions like photosynthesis and respiration energy converts into ATP molecules. Due to the disintegration of ATP high Energy, ADP and Pi are formed. This energy is used to perform different biochemical reactions. This is the reason that ATP is called the universal energy currency of the cells. In respiration ATP is formed by oxidative phosphorylation and in photosynthesis it is formed by photophosphorylation.

Peter Mitchell in 1961 propounded the Chemiosmotic Theory of ATP Synthesis. This principle shown the Process of ATP synthesis in mitochondria and chloroplast.

According to this theory positively charged protons (H^+ ions) move across the bacteria membranes, chloroplast and mitochondria under the controls of flow of electrons in enzyme chains used in respiration and photosynthesis. Due to this on both sides of membrane on electrochemical proton gradient develops. There are two components of electrochemical proton gradient.

(i) Difference between hydrogen ion concentration or pH values across the membrane.

(ii) Difference between electrode potentials across the membrane.

These two components together generate proton motive force due to this proton moves as per concentration gradient and enter and ATPase acid enzyme synthesize ATP by ADP and inorganic phosphate.

Break down of pyruvic acid in the absence of Oxygen :

The end product of glycolysis i.e. pyruvic acid can decomposes in the both condition of presence of oxygen or absence of oxygen. In presence of oxygen it oxidizes completely and CO_2 and maximum energy releases. In absence oxygen incomplete oxidation of pyruvic acid takes place which is called anaerobic respiration. In this reaction acetaldehyde forms either by decarboxylation or by fermentation and CO_2 is released. Acetaldehyde reduces itself and produces alcohol and NADH+ H^+ oxidizes into NAD^+. Both of these reactions are catalysed by decarboxylasc and dehydrogenase enzymes.

Fernmentation

Fermentation is the process takes place in most bacteria and fungi which completes in the absence of oxygen i.e. O_2 is not utilized in this process .In this sugar is partially oxidized and alcohol and carboxylic acids are formed and carbon di oxide is released. In 1857 Pasture proved that alcoholic fermentation takes place by the metabolic reaction of yeast cell. In 1897 Buchner isolate the zymase enzyme which is capable of doing fermentation even without living cells.

Types of Fermentation

On the basis of product formed during fermentation it is of following types:

1. Alcoholic Fermentation : This reaction found in yeast, few fungi and higher class plants. This reaction is the general form of anaerobic oxidation. Formation of alcohol from pyruvic acid formed during glycolysis is completed in two steps:

In first phase acetaldehyde is formed by the decarboxylation of pyruvic acid and release CO_2.

$$\text{Pyruvic acid} \xrightarrow[\text{decarboxylase}]{\text{Pyruvic}} \text{Acetaldehyde} + CO_2 \quad ...(i)$$

In second step in the presence of alcohol de hydrogenase and NADH+H^+, acetal+dehylde reduces to alcohol and NAD^+ forms.

$$\text{Acetaldehyde} \xrightarrow[\text{Dehydrogenase}]{\text{Alcohol}} \text{Ethyle Alcohol}$$

$NADH+H^+$ NAD^+

2. Lactic Acid Fermentation : This reaction takes place in Bacteria (*Lactobacillus, Clostridium*) and Muscles. In this reaction in the presence of Lactic de hydrogenase and NA DH+H^+ pyruvic acid reduces to lactic acid.

$$\text{Pyruvic Acid} + \text{NADH} + H^+ \xrightarrow[\text{dehydrogenase}]{\text{Lactic}} \text{Lactic acid} + NAD^+$$

3. Acetic Acid Fermentation : This reaction takes place in the presence of *Aceto+bacter acetic* bacteria. In this reaction acetaldehyde formed from pyruvic acid and than acetic acid is formed.

$$\text{Pyruvic Acid} \rightarrow \text{Acetaldehyde} + CO_2$$

$$\text{Acetaldehyde} \xrightarrow[-2H]{+H_2O} \text{Acetic Acid}$$

4. Butyric Acid Fermentation : This reaction takes place in *Butyricus* and *Closteridium butyricus* bactria. In this reaction pyruvic acid form aceto acetic acid first and than butyric acid is formed

$$\text{Pyruvic acid} \xrightarrow[-CO_2]{+H_2O} \text{Acetoacetic acid}$$

$$\text{Aectoacetic acid} \xrightarrow[+4H^+]{-H_2O} \text{Butyric acid}$$

Difference between Respiration and Fermentation

S. No.	Respiration	Fermentation
1	It occurs in the presence of oxygen	It occurs in the absence of oxygen
2	This reaction takes place in all the living cells	The present of living cells is not necessary for this reaction.
3	It the end of this reaction glucose is completely oxidized into CO_2 and H_2O.	In this reaction due to the partial oxidation alcohol, carbonic acid and CO_2 are formed. Water is not formed in it.
4	Very high energy released during this reaction	Very less energy is released during this reaction

Some other pathways of Glucose Breakdown

1. Hexose Monophosphate pathway or Pentose Phosphate Pathway, HMP or PPP: Generally aerobic respiration completed by normal pathway (Glycolysis and Krebs cycle). But in few living organism optional pathway found for the oxidation of glucose. Which is called pentose phosphate path. In this process hexose sugar decomposes to intermediate 5 carbon containing sugar. This is the reason it is called pentose phosphate pathway. It was first to studied by Warburg and Dickons in 1938 on animal tissues. Different reaction of this path was studied in detailed by Racker and his coworkers in 1954. This pathway occur in cytoplasm in the presence of oxygen.

This process can be understood in following steps :

1. Phosphorylation of Glucose Molecule : First phosphorylation of 6 molecules of glucose takes place in the presence of ATP and glucose is produced 6-phosphate.

$$\underset{\text{(6 Molecules)}}{\text{Glucose} + 6\text{ATP}} \xrightarrow{\text{Hexokinase}} \underset{\text{(6 Molecules)}}{\text{Glucose-6-Phosphate} + \text{ADP}}$$

2. Oxidation of glucose 6-phosphate : Glucose 6-phosphate oxidizes in the presence of glucose 6-phosphate de hydrogenase enzyme and forms 6-phosphogluconic Acid

$$\underset{\text{(6 Molecules)}}{\text{Glucose 6-phosphate} + \text{NADP}} \xrightarrow{\text{Glucose 6-phosphate dehydrogenase enzyme}} \underset{\text{(6 Molecules)}}{\text{6-Phosphogluconic Acid} + 6\text{NADPH} + 6H^+}$$

3. Oxidative de carboxylation of Phosphogluconic Acid : In the presence of 6-phosphogluconic acid, de hydrogenase enzyme, 6 phosphogluconic acid by oxidative de carboxylation forms ribulose 5-phosphate and NADP reduced to NADPH+H$^+$ and oxygen is released.

$$\underset{\text{(6 Molecules)}}{\text{6-Phosphogluconic acid} + \text{NADP}^+} \xrightarrow{\text{Phosphogluconic acid dehydrogenase enzyme}} \underset{\text{(6 Molecules)}}{\text{Ribulose 5-phosphate} + 6\text{NADPH} + H^+ + CO_2}$$

By this from ribulose 5-phosphate consecutive by many isomeric reactions phosphorylated intermediate products are formed. Its main objective is to breakdown glucose phosphate completely. Two NADPH + H$^+$ molecules are formed with each molecule of carbon di oxide. By its complete breakdown 6 molecules of carbon di oxide and 12 molecules of NADPH+ H$^+$ are formed. These 12 molecules of NADPH +H$^+$ by electron transport system form 36 ATP molecules we know that one NADPH+H$^+$ molecule form 3ATP Molecules. From ribulose 5 phosphate formed in this cycle (HMP Pathway) different substances like DNA, RNA,

ATP, FAD, Co-A etc. are synthesized.

II. Entner Doudoroff Pathway:

This pathway mostly found in few bacteria. This path shows breakdown of glucose to pyruvic acid. Intermediate substances formed in this path are generally different from the substances formed in glycolysis. It was first studied on *Pseudomonas* bacterium.

Interrelation of Respiratory substrates in Respiration process :

Generally livings use carbohydrate as respiratory substrate in respiration process. But in few plants in exclusive condition protein, fats and organic acids are also used as respiratory substrates. If fat is the substrate for respiration than it reduces to fatty acid and glycerol. Fatty acid converts into acetyl CoA and enters in the kreb's cycle (Fig 11.6) and glycerol first convert into PGAL and enters into Glycolysis. If protein is the substrate for respiration than it breaks by protease enzyme in the form of amino acids with pyruvic acid and enters to respiration path.

Respiratory substrates sequence on the basis of use in respiration are charbohydrate, then fat, carbonic acid and in last it is protein.

Respiration is an amphibolic Process :

In Living Organism Process of breakdown of organic material is called catabolism and synthesis is called anabolism. In Respiration path both anabolic and catabolic process are take place, Hence it is called amphibolic.

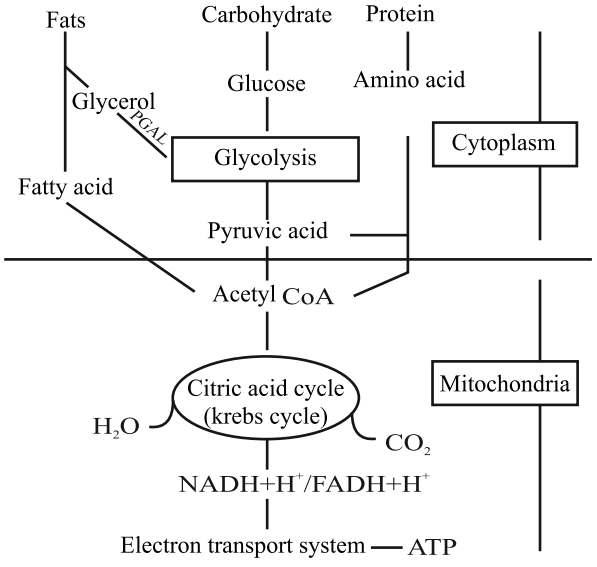


Fig. 11.6 Digramatic representation showing interrelations among different substrates

Respiratory Quotient (RQ)

Different organic substances are oxidized in respiration process as for which oxygen is absorbed and carbon dioxide is released. Ratio of CO_2 and O_2 used is known respiratory oxygen quotient.

Respiratory quotient measured by Ganong's respirometer.

$$\text{Respiratory Quotient} = \frac{\text{Volume of carbon di oxide evolved}}{\text{Volume of oxygen absorbed}}$$

Respiratory quotient is helpful to determine the substrate used in respiration and type of respiration.Different substrates used in respiration have different respiratory quotient which can be understood by the followings :

(I) Respiratory quotient of Carbohydrate : If carbohydrate is the respiraory substrate which is completely oxidized than respiratory quotient is always an unit because volume of evolved carbon di oxide and used oxygen is always the same .

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

$$\text{Respiratory Quotient} = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ absorbed}} = \frac{6CO_2}{6O_2} = 1.0$$

(ii) Respiratory quotient of Fats : Fat is the Respiratory substrate during the germination of oily seeds like Mustard, Ground Nuts, Cotton. Molecule of fat has less oxygen in comparison to carbohydrate, Hence for the oxidation of fats more of the environmental oxygen is required. Hence respiratory quotient of fat is always less than one.

$$2C_{51}H_{98}O_6 + 145O_2 \rightarrow 102CO_2 + 98H_2O$$
Tripamiten

$$\text{Respiratory Quotient} = \frac{102}{145} = 0.7$$

(iii) Respiratory quotient of Proteins : Protein molecules also have the less amount of oxygen in comparison to carbon like fats. In respiration process proteins works as respiratory substrate only in the absence of carbohydrate and

fats. If humans keep fasting for long time without food protein used as respiratory substarte which is a indication of death in humans if continue. Respiratory quotient of protein is less than one mostly 0.7-0.9 which is little more than R.O. of fat.

(iv) Respiratory quotient of Carboxylic Acids : In few plants respiratory substrates are carboxylic acid which has more oxygen in comparison to carbon in its molecule. That is why for the oxidation of these substances need of external oxygen is less and CO_2 is released in high amount. Hence respiratory quotient is always more then one for them.

$$2(COOH) + O_2 \rightarrow 4CO_2 + H_2O$$

Oxylic acid

$$\text{Respiratory cuotient} = \frac{4CO_2}{O_2} = 4.0$$

Respiratory quotients of citric acid and malic acid are 1.14 and 1.33 respectively.

(v) Respiratory quotient of succulent plants: Succulent plants like *Opuntia* etc. has carbohydrate as respiratory substrate however it is not completely oxidized by which intermediate substances are formed but $CO_2$is not formed. Hence respiratory quotient of these plants is zero.

$$2C_6H_{12}O_6 + 3O_2 \rightarrow 3C_4H_6O_5 + 3H_2O$$

Glucose Malic Acid

$$\text{Respiratory Quotient} = \frac{\text{Zero } CO_2}{3O_2} = 0 \text{ (Zero)}$$

(vi) Respiratory Quotient in Anaerobic Respiration : In anaerobic respiration carbon di oxide is released however, oxygen is not absorbed. Hence respiratory quotient in these reactions is infinite.

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2 + \text{Energy}$$

Ethyl Alcohol

$$\text{Respiratory cuotient} = \frac{2CO_2}{\text{Zero } O_2} = \text{infinite } (\propto)$$

Lower the respiratory quotient of substrate, the higher the amount of energy released in that condition. In this way one molecule of fats release higher energy however, the energy released from one molecule of organic acid or anaerobic respiration releases small amount of energy.

Importance of Respiration

1. Energy released during respiration is used in different anabolic reactions.
2. As a result of this reaction many intermediate chemical substance are formed which are necessary for the metabolism of a cell.
3. CO_2 released in this reaction maintains the gaseous balance of the environment.
4. In this reaction complex insolubale food substance convert into soluble food substances.
5. This process convert potential energy into kinetic energy.

Factors Affecting Respiration

Rate of respiration affected by many factors. Rate of respiration is highest in actively deviding meristematic cells. Factors affecting rate of respiration are classified into two groups.

(I) External Factors

(II) Internal Factors

(I) External or Environmental Factors :

External factors affecting respiration are given below:

1. Temperature : Temperature is the main factors that affects rate of respiration. Generally at a fixed limit increases in temperature (5-30 °C) rate of respiration increases. Rate of respiration increased in this limit is according to Vont Hoffs rule. According to this every 10 °C in temperature rate of respiration becomes double.(Q_{10}=**2**). Temperature more than 35°C distorts the enzymes and reduces the rate of respiration. An enzyme vegetables gets kept inactive at very low temperature which reduces the rate of respiration. Due to this fruits and vegetables kept in good condition without deteriorating for long time in cold storage.

2. Oxygen : Oxygen is necessary for aerobic respiration because oxygen is the end electron acceptor in aerobic respiration. Aerobic and anaerobic respiration both type of respiration can occur in low oxygen concentration. When

concentration of oxygen is reaches to zero than only anaerobic respiration occurs. Respiratory quotient at this stage is infinite.

3. Water : water works as mediator for anabolic reactions in protoplasm. Protoplasm of plants contains 90-95% water. Water plays an important role in transport system of plants, activation of enzymes, exchange of gases.

Due to less amount of water in dry seeds and fruits the respiration rate is low. That's why these can be stored for longer periods. In the presence of water carbohydrate coverts into the soluble sugar and increases the respiration rate.

4. Light : In the presence or absence of light respiration process occur uniformly in both the phases. Hence, light do not affect directly the process of respiration. However indirectly light affects respiration in the following ways:

(a) Temperature increases due to light which increase rate of respiration.

(b) Sugars are formed due to the process of photosynthesis which is an important respiratory substrate.

(c) Exchange of gases occurs because stomata are open during day time.

5. Carbon Di Oxide (CO_2) : As the concentration of carbon di oxide increases rate of respiration decreases hence, its adverse effect seen on germination of seeds and the growth of plants. Heath proved by his experiment that stomata gets closed due to excess CO_2thereby rate of respiration is reduced due to lack of O_2

Internal or Plants Factors :

Protoplasm of the cell and respiratory substance are the main internal factors which affect respiration.

1. Protoplasm : In meristematic cells protoplasm is active and found in excess by which rate of respiration in these cells is comparatively more than the rate of respiration in mature cells.

2. Respiratory Factor : Different types of sugar present in a cell like glucose, fructose, Maltose are used immediately in respiration. In comparision of these conversion of starch and fats into sugars is necessary before use. Due to this reason the process of respiration is delayed. That is the reason that in the diet of a healthy person contains more starch (Potato, rice and chapati) and fat (Oil. ghee). However, a patient diet gets solution of glucose directly in hospitals.

3. Age of the cell : Rate of respiration is high in young cells and in adult and old cells rate of respiration is lees.

4. Injury and Wound : Rate of respiration is increased in injured and damaged tissues.

Important Points

1 Respiration is an important process which occurs in livings continuously, In this process complex organic compounds dissociate into simple compounds and release energy.

2. Complex compounds oxidized in the process of respiration are called the respiratory substrate. Glucose (carbohydrate) is the first respiratory substrate of respiration.

3. Mainly respiration is of two type (i) Aerobic respiration occurs in the presence of oxygen (ii)Anaerobic respiration occurs in the absence of oxygen

4 Initial phase of respiration begins in cytoplasm which is known as glycolysis. Pyruvic acid is the end product of glycolysis.

5. In glycolysis reaction one molecule of glucose form 2 molecules of $NADH+H^+$ and two molecules of pyruvic acid and 4 molecules of ATP , 2 molecules of ATP are spent.

6. In anaerobic respiration by the incomplete oxidation of glucose molecule alcohol and CO_2 are formed and two molecules of ATP are generated.

7. Oxidation of pyruvic acid end product of glycolysis takes place in mitochondria which is called Kreb's cycle.

8. By oxidation of pyruvic acid first acetyl co enzyme (CoA) is formed which is the link between glycolysis and Kreb's Cycle. Acetyl Co enzyme A enters in Kreb's Cycle and completely oxidized and form Carbon di oxide and water. In the Kreb's cycle energy is

released in the form of molecules (ATP GTP, $FADH+H^+$ and $NADH+H^+$)

9. $2\ H^+$ Molecules of $NADH+H^+$ and $FADH+H^+$ enters into electron transport system of Mitochondria and form 3 and 2 ATP Molecules respectively. This Reaction is known as oxidative phosphorylation.
10. 2 molecules of $NADH + H^+$ formed during glycolysis in aerobic respiration enters into electron transport chain through Malate Asperate shuttle form 38 ATP molecules and if enters through glycerol phosphate then form 36 ATP molecules.
11. Advance principle of oxidative phosphorylation was given by Peter Mitchel which is kown as the chemiosmotic theory of oxidative phosphorylation.
12. The process of the formation of alcohol and carboxylic acids by the incomplete oxidation of sugars in the absence of oxygen is called fermentation.
13. Instead of glycolysis and Kreb's cycle respiration also occurs in cells by pentose phosphate Pathway. In which 36 ATP molecules are formed.
14. Ratio of evolved CO_2 and absorbed O_2 in respiration is known as respiratory quotient. (RQ)
15. The value respiratory quotient depends on the nature of respiratory substance used in the process. Generally RQ of carbohydrate is 1, fats and proteins has less than 1, organic acids, are more than 1 and for anaerobic respiration it is infinite.
16. Rate of respiration constantly increase between temperature 5^0C-30^0C.In this range of temperature if temperature exceeds by 10°C, then rate of respiration become double.
17. Respiration process is affected by many external factors like temperature, oxygen, water, light, carbon dioxide and internal factors like protoplasm, respiratory substrate, injury and age.

Practice Questions

Multiple choice questions

1. In a cell Krebs cycle occurs in
   (a) Nucleus (b) Cytoplasm
   (c) Chloroplast (d) Mitochondria
2. In anaerobic respiration how many ATP molecules are profited?
   (a) Three (b) Four
   (c) Eight (d) Two
3. In protoplasmic respiration respiratory substrate is
   (a) Fat (b) Protein
   (c) Sugar (d) All of the above.
4. Universal energy currency of cell is called
   (a) ATP (b) DNA
   (c) RNA (d) AMP
5. Net gain of energy in glycolysis is
   (a) 2ATP (b) 8ATP
   (c) 4ATP (d) Zero
6. Conversion of pyruvic acid to acetyl coenzyme occurs in
   (a) Cytoplasm
   (b) Matrix
   (c) External membrane of mitochondria
   (d) Internal membrane
7. How many molecules of ATP are formed if 2 molecules of $NADH+H^+$ formed during glycolysis enter into the ETS through malate Aspartate shuttle
   (a) Two (b) Four
   (c) Six (d) Eight
8. How many ATP molecules are formed by oxidation of one molecule of glucose in pentose phosphate path
   (a) 36 (b) 38
   (c) 40 (d) 8
9. Who demonstrate the chemiosmotic theory of oxidative phosphorylation
   (a) Krebs (b) Gibbs
   (c) Peter Mitchel (d) Dickens

10. First and only five carbon containing compound formed during Kreb's cycle is
    (a) Cis-Aconetic Acid
    (b) Oxalo succinic acid
    (c) α-Keto glutaric acid (d) Fumaric acid
11. In Respiration respiratory quotient is less than 1 in
    (a) Glucose (b) Sucrose
    (c) Starch (d) Protein
12. Value of respiration Q_{10} is
    (a) Three (b) Two
    (c) Four (d) Six
13. Pentose phosphate path occurs at which site in a cell
    (a) Mitochondria (b) Peroxisomes
    (c) Cytoplasm (d) Nucleus

Very Short Answer Questions

1. What is the end product of glycolysis ?
2. Aerobic respiration in a cell occurs at which site ?
3. Why is Kreb's cycle also called TCA cycle ?
4. Give the name of optional path for oxidation of glucose.
5. What do you understand by protoplasmic respiration ?
6. What is fermentation?
7. What is mean by respiratory substrates.
8. Write the name of end products of complete oxidation of glucose.
9. Define respiratory quotient.
10. Why is the respiratory quotient infinite in anaerobic respiration ?
11. Which is the connecting link between glycolysis and Kreb's cycle ?
12. What is the respiratory quotient of germinating castor seeds?
13. Who propounded chaemiosmotic theory ?
14. What are the main factors which affect respiration ?
15. Which are the expected products formed by fermentation ?

Short Answer Questions

1. What is difference between protoplasmic respiration and floating respiration?
2. Explain the difference between aerobic and anaerobic respiration
3. Fruits and vegetables are kept in good condition for long time in cold storage. Why?
4. Write a comment on pentose phosphate path.
5. Draw a labelled diagram of Interrelation between respiratory substrates.
6. Write a short note on.
    (I) Fermentation
    (ii) Oxidative breakdown of pyruvic acid
    (iii) Respiratory Quotient
    (iv) Chameiosmotic Theory of Mitchel
7. How do respiratory substrates affect respiratory quotient? Explain.

Essay Type Questions

1. What do you understand by glycolysis? Explain in detail the different reactions and energy relations of this process.
2. Define Respiration. Differentiate between aerobic and anaerobic respiration. Give detailed explanation of aerobic respiration,
3. What do you understand by oxidative phosphorylation. Explain electron transport system in detail.
4. Write a short note on factors affecting respiration.
5. What is called respiratory quotient? Give respiratory quotient of different respiratory substances.

Answer Key

1. (D)	2. (D)	3. (B)	
4. (A)	5. (B)	6. (B)	
7. (C)	8. (A)	9. (C)	
10. (C)	11. (D)	12. (B)	13. (C)