RESPIRATION IN PLANTS

Respiration is the process in which complex organisms are combined with oxygen and are broken down to simpler substances with consequent release of energy and production of carbon dioxide and water.

The term respiration was coined by Dutrochet. The breaking down of C-C bond of complex molecules by oxidation leading to the release of a lot of energy is called cellular respiration. Respiration is an amphibolic process (catabolic and anabolic process). Many respiratory intermediates are used for the synthesis of many other biomolecules.

Acetyl coenzyme A is used for the synthesis of fatty acid and Gibberellic acid.

Succinyl coenzyme A is used for the synthesis of chlorophyll, phytochrome and cytochrome.

Oxaloacetic acid and alpha ketoglutaric acid is used for the synthesis of amino acids such as glutamic acid, aspartic acid. Organic substances are oxidized during respiration and are called respiratory substrates. Classification of cellular respiration on the basis of types of substrates involved and are of two types

1. Floating respiration-Fat or carbohydrates are used as substrates and it is the common type.
2. Protoplasmic respiration- Proteins are used as substrates and occur in starved condition.

14.1 Do plants breathe?

Plants breathe and they require oxygen for respiration and gives our CO2. Plants don't have any special system for breathing or gaseous exchange. Stomata and lenticels allow gaseous exchange by diffusion. Only a very little transport of gases takes place from one part to another in plants.

Plants do not present great demands for gas exchange. During photosynthesis, large volumes of gases are exchanged. Availability of oxygen is not a problem because oxygen is released within the cell during photosynthesis. About 50% of the total energy released during respiration may be used for the synthesis of bio molecules and for other life activities. The carbon skeleton produced during respiration is used as a precursor for the biosynthesis of other cellular molecules.

Mitochondrion is the respiratory apparatus or site of respiration.

Types of respiration- On the basis of availability of oxygen cellular respiration are divided into two types-**Aerobic and anaerobic respiration.**

Salt respiration is the increased respiration taking place during active absorption in plants.

Climatic respiration takes place during ripening of fruits.

E.g.: Apple, Mango etc.

Aerobic respiration: The complete oxidation of food materials in the presence of oxygen and the formation of CO2 and Water as end products.

The equation for aerobic respiration is

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2870kJ$

It takes place in mitochondria and 2870kJ of energy is released.

The two main stages of aerobic respiration are **glycolysis and citric acid cycle.**

First discovered by **Kollicker** in striated muscles of insects.

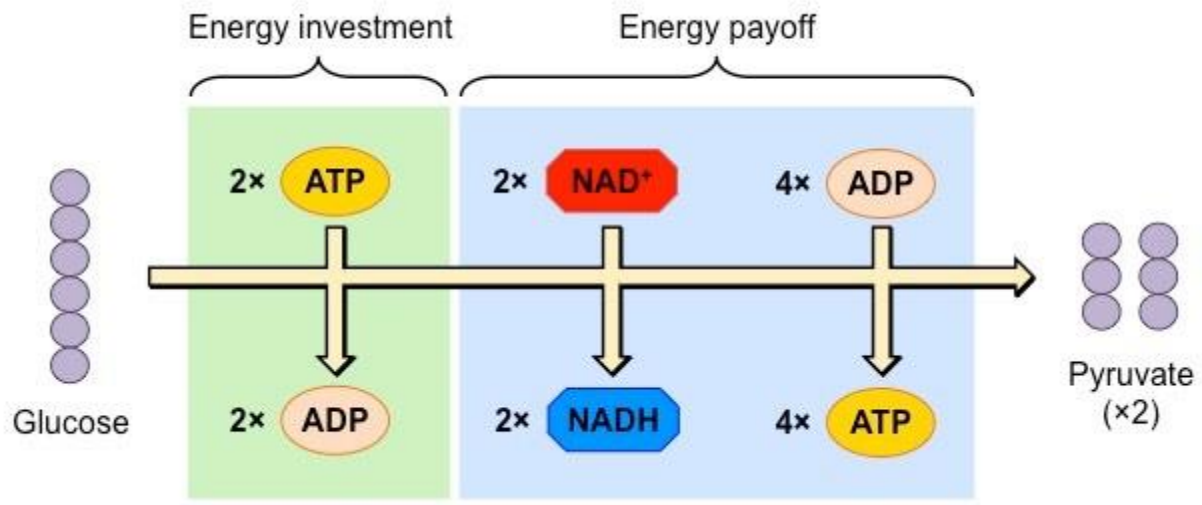
C.Benda coined the term Mitochondrion.

Hoyeboom proposed that mitochondria are the site of cellular respiration.

Mitochondria are a **semiautonomous organelle** due to the presence of circular DNA, RNA and ribosomes. They live inside the eukaryotic cell with symbiotic relationship (endosymbiont).

14.2 Glycolysis: Glycolysis is the first phase of both aerobic and anaerobic respiration. **It is the oxidation of glucose into pyruvic acid through a series of enzyme catalysed reactions.** The various steps were discovered by **Gustav Embden, Otto Meyerhof and J.Paranas. So is also called as EMP pathway.**

Glucose undergoes partial oxidation to form 2 molecules of pyruvic acid.



Glycolysis consists of two major phases.

- **Preparatory phase and cleavage**
- **Oxidative and payoff phase.**

The steps involved in both these phases are as follows.

Glucose is phosphorylated to glucose 6 phosphate in the presence of ATP and hexokinase.

Glucose 6 phosphate is converted into its isomeric form called fructose 6 phosphate by the enzyme phosphorgluco isomerase.

Subsequent steps of metabolism of glucose and fructose are the same.

Fructose 6 phosphate is phosphorylated with the help of one ATP molecule to form fructose 1,6 biphosphate.

Fructose 1,6 biphosphate is then broken down into 2 molecules of triose phosphate (3 carbon compound) such as glyceraldehyde phosphate and dihydroxyacetone phosphate catalysed by the enzyme aldolase. Both are interconvertible.

Dihydroxy acetone phosphate is isomerised into glyceraldehyde 3 phosphate. Thus totally 2 molecules of Gleceraldehyde 3 phosphate are formed.

Each glyceraldehyde 3 phosphate molecule is then converted into a triose phosphate called 1,3 biphosphoglyceric acid by oxidation. During the oxidation, 2 protons and 2 electrons are released. Of these protons and electrons released, one proton and 2 electrons are added to the NAD and it is reduced into $NAD+H^+$. Each 1,3 biphosphoglyceric acid is then converted into a triose phosphate called 3 phospho glyceric acid .During this step an ATP molecule is also released. In this type of ATP generation, a phosphate group of the substrate molecule or metabolite is directly transferred to ADP to form ATP. Such a type of synthesis is called substrate level synthesis of substrate level phosphorylation. It is different from the ATP synthesis in chloroplast (phosphorylation) and in mitochondria (oxidative phosphorylation).

Each 3 phosphoglyceric acid is converted into 2 phosphoglycerate.

Each 2 phosphoglycerate is changed into 2 phosphoenol pyruvate by releasing one molecule of water. Phosphoenolpyruvate is a good donor for the formation of ATP.

Each 2 phosphoenol pyruvate is then converted into pyruvic acid in the presence of an enzyme pyruvate kinase. During this step, an ATP molecule is also released. Here a phosphate group of the substrate or metabolite is directly transferred to ADP to form ATP. So this type of ATP synthesis is also a substrate level ATP synthesis.

In EMP pathway the ATP molecules are produced in two ways.

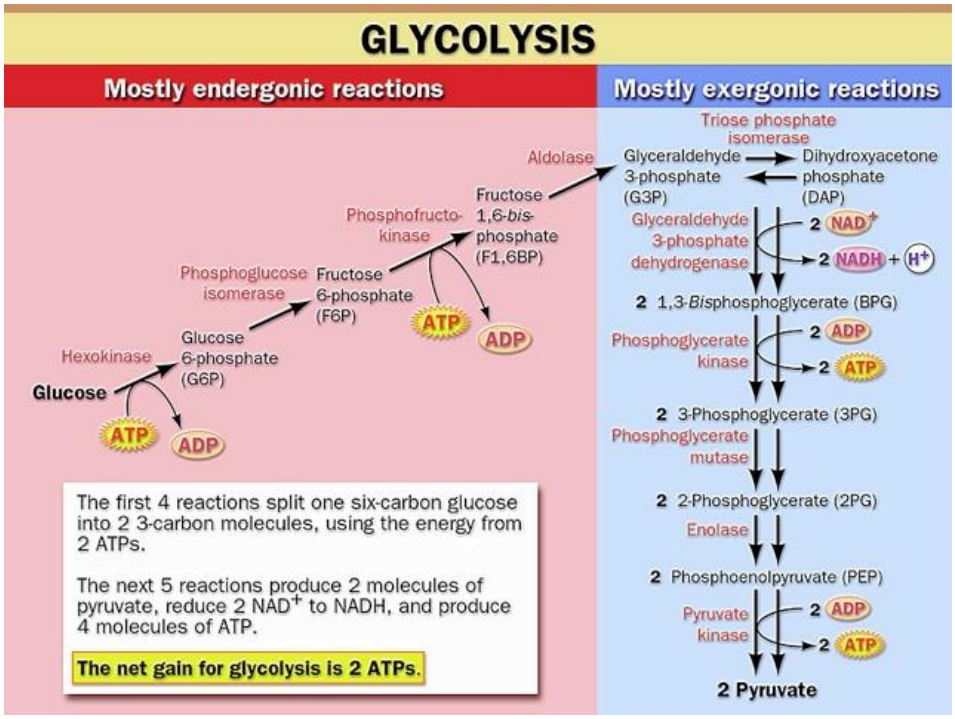
- Direct transfer of phosphate to ADP
- Oxidation of the NADH+H+ produced during glycolysis to NAD+

During glycolysis, from one molecule of glucose, 2 molecules of pyruvic acid and 4 molecules of ATP are formed.

2 ATP molecules are consumed in the phosphorylation reactions.

2 molecules of $NADH+H^+$, which can subsequently be oxidized to yield 6 molecules of ATP.

So the net gain of ATP molecules will be 8 instead of 2. As a result of glycolysis, 2 pyruvic acid molecules and 8 ATP molecules are produced.



The key product of glycolysis is pyruvic acid (pyruvate) .The metabolic fate of pyruvic acid is in 3 ways depending on the cellular need, availability of oxygen and the organism.

1. Aerobic respiration
2. Alcoholic fermentation
3. Lactic acid fermentation.

14.3 Fermentation: The incomplete oxidation of food materials in the absence of oxygen and the formation of CO2 and ethanol as end products is called anaerobic respiration. It is also called fermentation or zymosis. It is carried out by yeast. Fermentation was discovered by **Gay Lussac** .The term fermentation was coined by **Shank.**

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 + 210kJ$

Fermentation also takes place in many prokaryotes, unicellular eukaryotes and in germinating seeds under anaerobic condition. It is of two types-**Alcoholic fermentation and Lactic acid fermentation.**

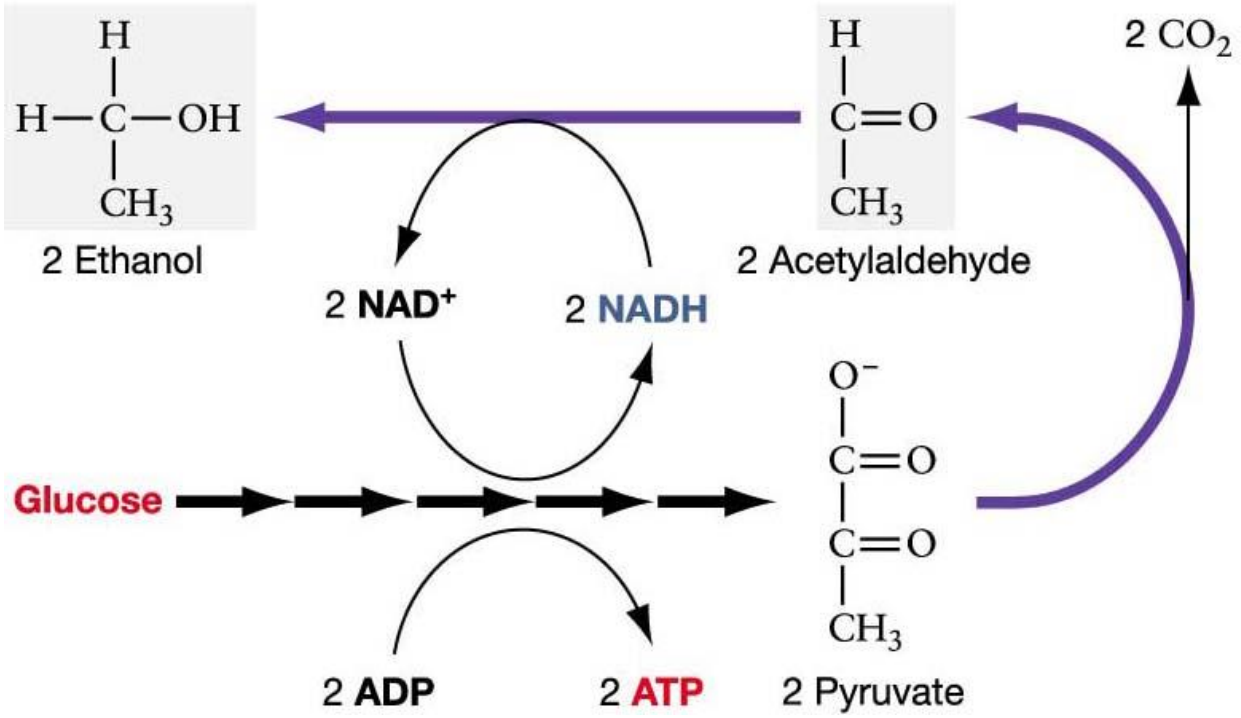
Alcoholic fermentation: CO2 and ethyl alcohol (ethanol) are the end products.

It has 2 series of steps. First reaction is glycolysis. The end product of glycolysis, pyruvic acid is then converted into CO2 and ethanol. This conversion has 2 steps.

1. Pyruvic acid is converted into acetaldehyde and CO2 in the presence of pyruvic acid dehycarboxylase enzyme.

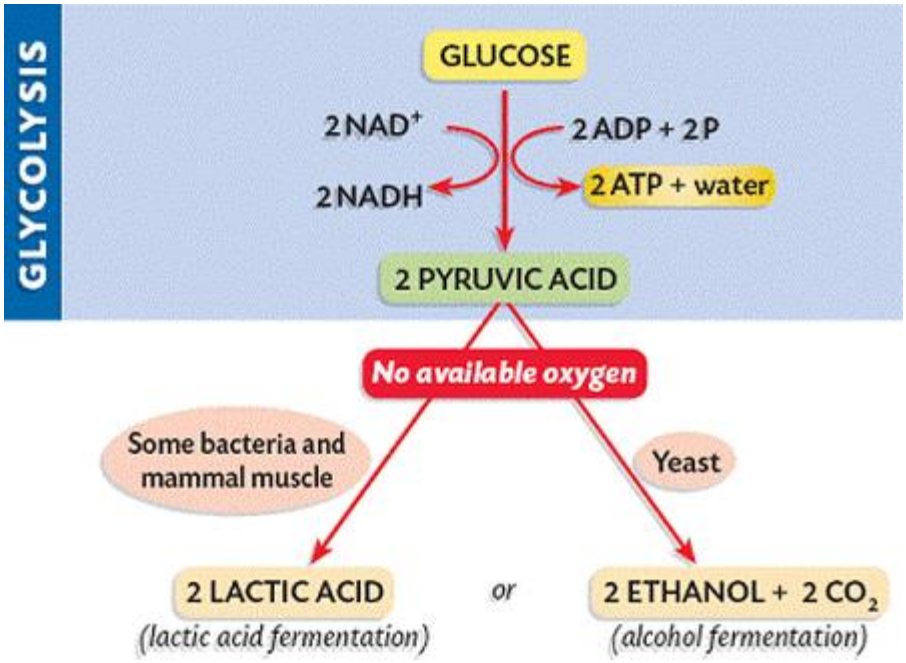
2. Acetaldehyde is converted into ethanol in the presence of alcoholdehydrogenase enzyme and a coenzyme. The end products are ethanol and CO2. As a result of glycolysis 8 ATP molecules are released. 2 NAADH+H^+ molecules (1 NADH+H^+=3 ATP) are utilized later. So the net gain is 2 ATP molecules in fermentation.

In animals anaerobic respiration takes place in skeletal muscles. The skeletal muscles derive energy by anaerobic respiration



Lactic acid fermentation: The end product is lactic acid. It is used in milk industry also occurs in muscle cells of vertebrates.

Lactobacillus bacteria cause curd formation. CO2 is not produced and $NADH+H^+$ is converted into NAD^+. The reaction is catalysed by lactate dehydrogenase enzyme. Net gain of ATP is 2.



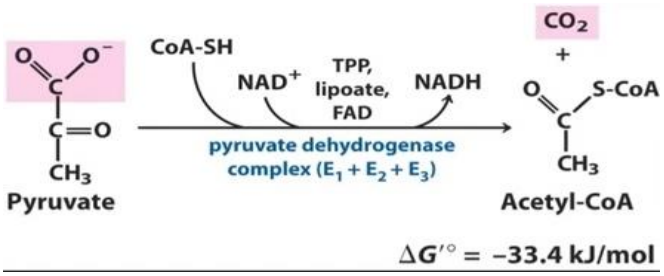
14.4 Aerobic respiration: The end products of glycolysis are a 3 carbon compound called pyruvic acid. It is formed by the glycolytic catabolism of carbohydrates in the cytoplasm or cytosol.

The crucial events are

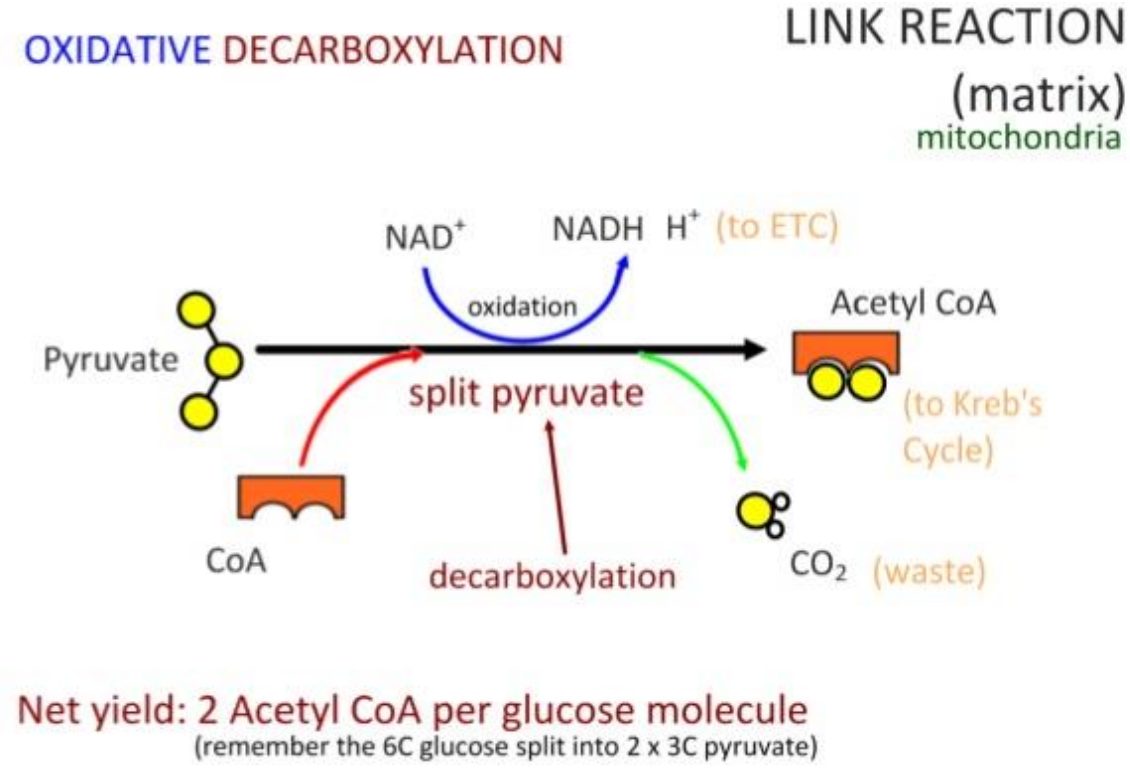
- The complete oxidation of pyruvic acid by the stepwise removal of all the hydrogen atoms.

- The electrons move to the molecular oxygen with simultaneous synthesis of ATP. It takes place on the inner membrane of the mitochondria.
- The removal of CO2 molecules. It takes place in the matrix of the mitochondria.

After pyruvic acid enters into the mitochondria for citric acid cycle one of the 3 carbon atoms of pyruvic acid is oxidized to CO2.This reaction is called **oxidative decarboxylation**.In this reaction, pyruvic acid is first decarboxylated and then oxidized by the enzyme, pyruvate dehydrogenase. The remaining part of pyruvic acid combines with Coenzyme A to form acetyl coenzyme A in the presence of Mg^{2+}. Co A is a sulphur containing compound. **Acetyl Co A is the connecting link between glycolysis and citric acid cycle.**



The aerobic oxidation of pyruvic acid is called link reaction. During this process NAD+ is reduced to $NADH+H^+$. The 2 pyruvic acid molecules are produced from one molecule of glucose by glycolysis are oxidized during this aerobic oxidation. Thus 2NADH+H+ molecules are formed. As a result there is a net gain of 6 ATP molecules (2NADH+H+=2X 3 =6 ATP).



14.4.1 Tricarboxylic Acid Cycle: TCA cycle is the complete oxidation of pyruvic acid into CO2 and water through a series of reactions in the presence of oxygen and it takes place in the mitochondria.

The steps were traced by Hans Krebs and so it is also known as **Krebs cycle.** The first compound formed is tricarboxylic acid –citric acid, so it is also known as **Citric acid cycle**. It is a tricarboxylic acid as it contains 3 acid groups, so known as **tricarboxylic acid cycle.**

In TCA cycle the respiratory substrate is acetyl coenzymeA. The acceptor molecule is a 4 carbon compound called Oxalo Acetic acid. It involves 4 dehydrogenation (removal of hydrogen) reactions and two decarboxylation (removal of CO2) reactions. In citric acid cycle the coenzymes are reduced and CO2 is evolved.

One molecule of acetyl coenzyme A combines with 4 carbon oxaloacetic acid to form a 6 carbon compound, citric acid. This reaction is catalysed by an enzyme citrus synthase. The reaction utilizes one molecule of water and release CoA

Citric acid is then isomerised to isocitric acid with a molecule of water.

Isocitric acid is converted into oxaloacetic acid by dehydrogenation. Here NAD^+ is reduced to $NADH+H^+$.

Oxalosuccinic acid is then decarboxylated to form a 5 carbon compound alpha ketglutaric acid (5C).

Alpha ketoglutaric acid is dexcarboxylated to form a 4 carbon compound to form a 4 carbon compound succinyl Co A by dehydrogenation. NAD^+ is reduced to $NADH+H^+$. CoA is required in this reaction.

Succinyl Co A loses its CoA and reacts with GDP to form succinic acid and GTP. Later GTP transfers its one phosphate to ADP and thus ATP is formed.

Succinic acid is converted into fumaric acid (4C) by dehydrogenation reaction. FAD is reduced to $FADH_2$.

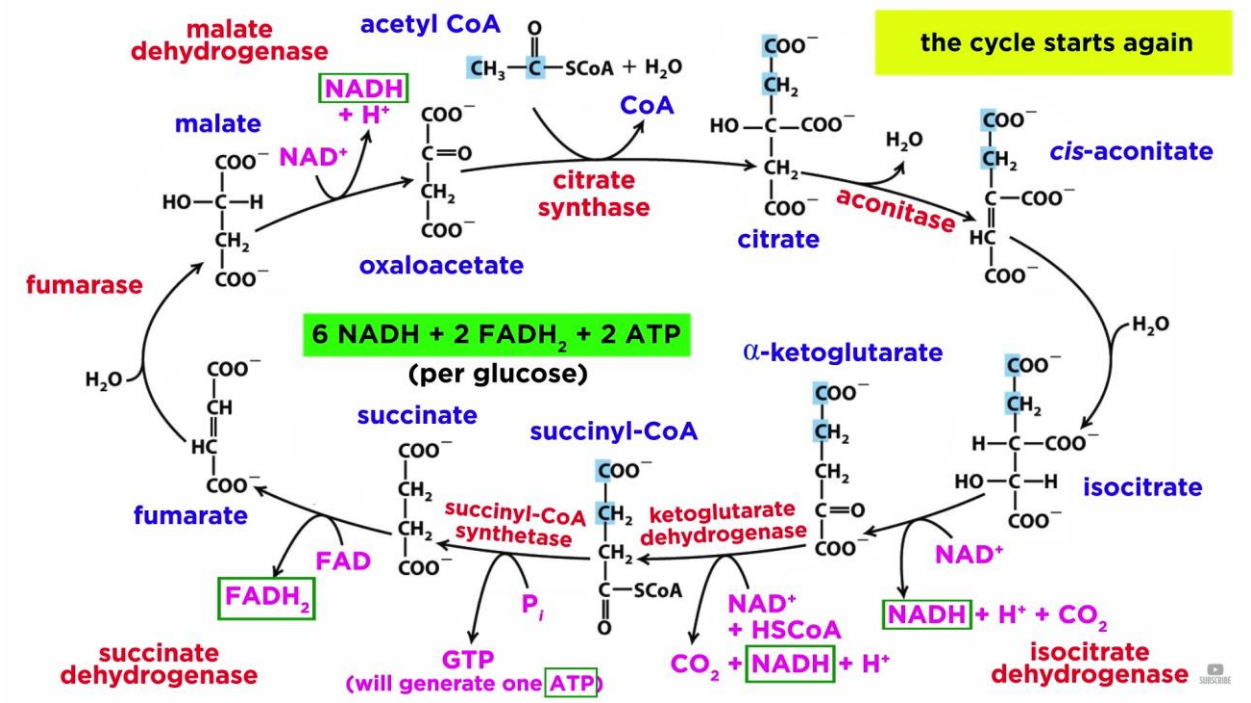
A water molecule is added to fumaric acid to form malic acid.

Finally malic acid is converted into oxaloacetic acid by dehydrogenation reaction. NAD^+ is reduced to $NADH+H^+$.

Oxaloacetic acid produced in this reaction becomes available to combine with acetyl CoA to start a new cycle.

The oxidation of acetyl Co A through citric acid cycle requires the continued replenishment of oxaloacetic acid and it requires the regeneration of NAD^+ and FAD^+ from $NADH+H^+$ and $FADH_2$ respectively.

Since 2 pyruvic acid molecules are formed from one molecule of glucose by glycolysis, 2 molecules of acetyl CoA are also formed.



During aerobic oxidation of pyruvic acid to acetyl Co A, 2 $NADH+H^+$ are formed. In one citric acid cycle 3 $NADH+H^+$, 1 $FADH_2$ and 1ATP are formed. Subsequently each $NADH+H^+$ is oxidized aerobically to yield 3 ATP molecules, each $FADH_2$ is oxidized to yield 2 ATP by oxidative phosphorylation. So the net gain of ATP molecules in each citric acid cycle is 12 ATP. There is a net gain of 38 ATP molecules during aerobic respiration of one molecule of glucose.

In most eukaryotic cells, for transporting the NADH produced in glycolysis into mitochondria for further oxidation, 2 ATP molecules are required. Hence net gain of ATP is 36 molecules. Thus 45% of energy released during the oxidation of 1 molecule of glucose is stored in 38 ATP molecules. Rest of the energy generated during aerobic respiration is lost in the form of heat.

Aerobic Respiration ATP Production

Step in Respiration	Takes Place in the...	Result
Glycolysis	Cytoplasm	2ATP + NADH
Krebs cycle	Mitochondrial Matrix	2ATP + NADH + FADH2
Electron transport chain and ATP synthesis	In and across the mitochondrial membrane	34 ATP

Net Result: 38 ATP

Summary of Respiration

Characteristic	Starting materials	1st step	Uses oxygen	Cell location	Products	Number of ATP produced	Net Gain of ATP
Aerobic Respiration	Glucose	Glycolysis	Yes	Mitochondria	CO_2, H_2O, energy (ATP)	38 ATP	36 ATP
Lactic Acid Fermentation	Glucose	Glycolysis	No	Cytoplasm	Lactic acid, ATP	4 ATP	2 ATP
Alcoholic Fermentation	glucose	Glycolysis	No	cytoplasm	Ethyl alcohol, CO_2, ATP	4 ATP	2 ATP

14.4.2 Electron transport system and Oxidative phosphorylation: During aerobic respiration, hydrogen ions and electrons are removed from respiratory substrates such as glyceraldehyde 3 phosphate, pyruvic acid, isocitric acid, alpha ketoglutaric acid, succinic acid, and malic acid by dehydrogenation reaction. The removal of electrons means that energy is removed. These hydrogen ions and electrons are now fused with coenzymes such as NAD^+ and FAD. As a result, $NAADH+H^+$ or $FADH_2$ is formed. The energy of the electrons is stored in the form of chemical energy in bonds between NADH and H and FAD and H.

During oxidation of NADH and $FADH_2$, the electrons of the hydrogen atoms are transported to the oxygen through different kinds of electron carriers which are arranged in a specific order called **electron transport chain or mitochondrial respiratory chain or electron transport system.**

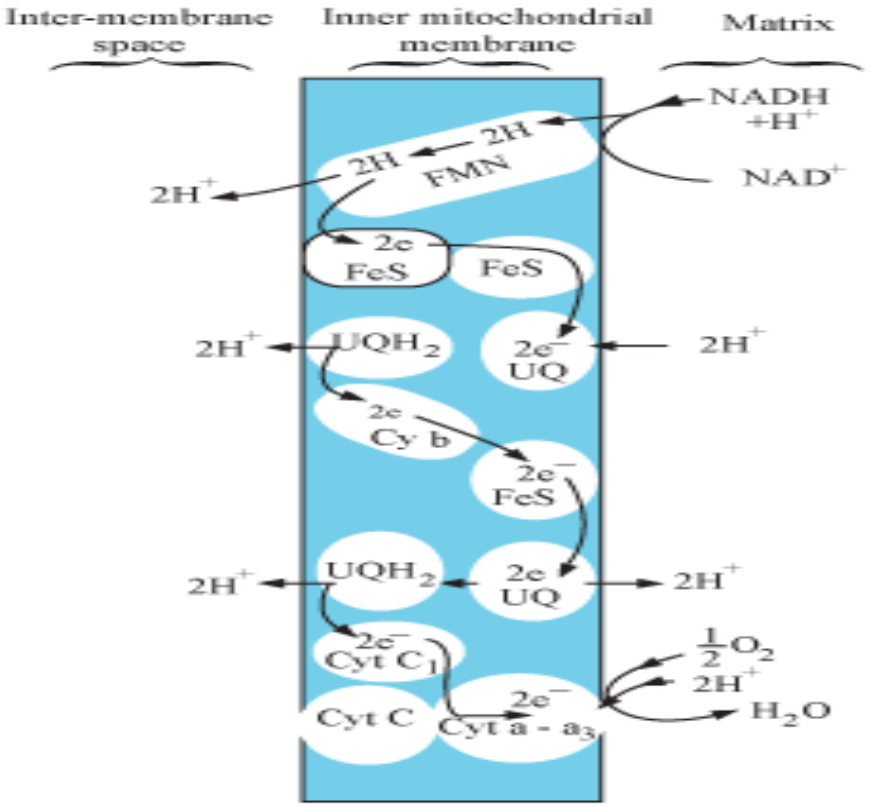
The electron transport system is located in the inner mitochondrial membrane. The individual members of the ETS are called **electron carriers**. They are **Flavin, FeS protein, quinines, and cytochromes**. Flavin is FMN (Flavin mononucleotide). FeS is an iron sulphur protein. Quinones are mobile electron carriers in the membrane. The common quinine is ubiquinone. Ubiquinone is a phenolic compound. Cytochromes are enzymes as well as electron carriers. Cytochromes involved in ETS are **Cyt b, Cyt c1, Cyt c, Cyt a, and Cyt a3**. All these cytochromes contain iron as activator. **Cyt a3 additionally contains copper**.

For each dehydrogenation reaction during aerobic respiration, $NADH+H^+$ is formed in the mitochondrial matrix. On oxidation, $NADH+H^+$ donates 2 hydrogen atoms to FMN seen in the inner mitochondrial membrane and FMN becomes $FMNH_2$. It takes place in the presence of NADH dehydrogenase enzyme. Then $FMNH_2$ breaks up and release protons into the inter membrane space and 2 electrons to FeS in the inner mitochondrial space. From FeS, the electrons are picked up by ubiquinone (UQ) of the enzyme. UQ also picks 2 protons from the matrix to form UQH_2.

Some times UQ picks up 2 protons directly from $FADH_2$. During the citric acid cycle, $FADH_2$ is formed in the mitochondrial matrix from FAD and succinic acid in the presence of an enzyme succinate dehydrogenase.

Ubiquinone is a mobile electron carrier in the inner mitochondrial membrane. So UQ carries H2 from the inner side to the outer side of the membrane. Here it discharges 2 protons into the inner membrane space and donates its electrons to Cyt b.

Cyt b hands over its electrons to FeS. FeS passes its electrons to UQ of another enzyme. Now UQ becomes UQH_2 and carries H_2 from inner side to the outer side of the membrane. Here it liberates 2 protons to the inner membrane space and donates its 2 electrons Cyt c1 .From Cyt c1 the electrons are transported to Cyt C, Cyt a and Cyt a3.Cyt c is also a mobile electron carrier seen in the inner mitochondrial membrane. From Cyt a3, the electron pass into the matrix. Hence 2 electrons recombine with 2 protons in the matrix to form two hydrogen atoms. These hydrogen atoms are accepted by molecular oxygen and they fuse to form a molecule of metabolic water. Thus oxygen acts as the final hydrogen acceptor.



Electron Transport System (ETS)

In citric acid cycle , it get oxidized into two molecules of CO2 while capturing the electrons in the form of 6 NADH molecules and two molecules of $FADH_2$.These reduced molecules contain a pair of electrons with a high transfer potential.

These electrons are transferred by a system of electron carriers to form H2O.This process occurs in the mitochondria and is the major source of energy to produce ATP by oxidative phosphorylation. The 6 $NADH_2$ and 2 $FADH_2$ formed in Krebs cycle provide about 22 ATP molecules of ATP in the electron transport chain.

The electron transport chain is the third stage of cellular respiration.

Five protein complexes in the inner mitochondrial membrane form the electron transport chain. These complexes exist in a descending order of energy. Each complex contains several different electron carriers.

Complex I also known as the NADH coenzyme Q reductase or NADH Dehydrogenase.

Complex II also known as succinate coenzyme Q reductase or Succinate dehydrogenase.

Complex III also known as cytochrome c reductase.

Complex IV also known as cytochrome c reductase.

Complex V also known as ATP synthase.

Complex I accepts electrons from NADH and serve as the link between glycolysis, the citric acid cycle, fatty acid oxidation and the electron transport chain.

Complex II contains succinate dehydrogenase and serves as a direct link between the citric acid cycle and the electron transport chain.

Complex I and II both produce reduced coenzyme Q, CoQH2 which is the substrate for complex III.

Complex III transfers the electrons from cytochrome c to reduce molecular oxygen into water.

Complex V is an enzyme which produce ATP by converting mechanical work into chemical energy, which powers most cellular reactions. A small amount of ATP is available from substrate level phosphorylation for example in glycolysis.

Each of these complexes are large, multi subunit embedded in the inner mitochondrial membrane.

Here the electron carriers drop off all their electrons and protons that they picked up during the glycolysis and citric acid cycle stages. NADH+H+ and FADH2 become oxidized, donating electrons to the first and second protein complex, respectively. These complex proteins now become electron carriers themselves and are now reduced. They become oxidized as they pass these electrons down the electron transport chain. A single oxygen molecule accepts two electrons and two protons from the final protein complex. This produces a molecule of water.

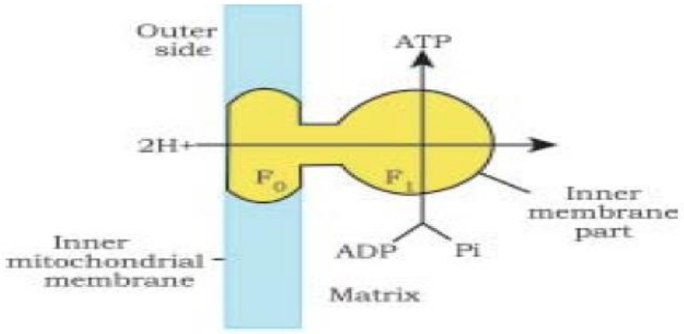
Oxidative phosphorylation: The ATP molecules are synthesised with the help of energy liberated by oxidation of reduced coenzymes NADH+H+ and FADH2) produced during respiration is called oxidative phosphorylation. The inner surface of the inner mitochondrial membrane bears many small outgrowths called **oxysomes or Fo-F1 particles or elementary particles or inner membrane sub units.**

The base of oxysome has 3 parts- a base, a stalk, and a head piece. The base of oxysome is called F0. F0 is embedded in the inner mitochondrial membrane. The head piece is called F1.The enzyme required for ATP synthesis is ATP synthase. It is present in F1 head piece of oxysomes. F1 contains the site for ATP synthesis from ADP and inorganic phosphate. F0 forms the proton channel through which protons cross the inner mitochondrial membrane.ATP synthesis is explained by chemiosmotic theory (coupling hypothesis). It was proposed by **Peter Mitschell**.

According to chemiosmotic theory, during ETS, the oxidation of one molecule of $NADH+H_+$ push 3 proton pairs into the intermembrane space and the oxidation of one molecule of $FADH_2$ push 2 proton pairs into the inter membrane space of the mitochondria. As a result proton concentration increases in the inter membrane space compared to the matrix. The difference in the proton concentration on the 2 sides of a system is called proton gradient.

As a result of proton gradient an electrochemical potential difference occurs across the inner mitochondrial membrane. This push protons back towards the mitochondrial matrix. But the inner mitochondrial membrane is impermeable to protons except in the region of elementary particle (F0-F1 particle). F0-F1 particle functions as proton channel. The flow of electron back to mitochondrial matrix is driven by electrochemical proton gradient.

During this back flow of protons the energy released is used for the synthesis of ATP from ADP and inorganic phosphate in F1. One molecule of ATP is formed in the F1 as a result of two protons transported back through F0 from the intermembrane space to mitochondrial matrix. Oxidation of one $NADH+H_+$ through ETS forms 3 ATP molecules and oxidation of one $FADH_2$ forms 2 ATP molecule.



14.5 Respiratory balance sheet: The net gain of ATP from glucose molecule can be calculated on the following assumptions:

- All steps of Glycolysis, Citric acid cycle and Electron transport system occur in sequential and orderly manner.
- In glycolysis, the NADH undergo oxidative phosphorylation inside the mitochondria.
- The intermediates produced in the pathway are not utilized to make any other compound.

Only glucose molecules are broken down during respiration.

These assumptions are not valid:

- All the pathways are working simultaneously .It does not take place one after the other.
- Substrates entering the pathway are withdrawn as and when necessary.
- ATP is utilized whenever needed.
- By multiple means the enzymatic rates are controlled.

There is a net gain of 36 ATP molecules during aerobic respiration of one molecule of glucose.

Comparison of aerobic respiration and fermentation:

In aerobic respiration glucose is completely broken down to CO2 and water but in fermentation only partial breaking down of glucose takes place.

More ATP molecules are produced in aerobic respiration, but only 2 ATP molecules are produced in fermentation when each molecule of glucose gets degraded to pyruvic acid.

In aerobic respiration NADH is oxidized to NAD^+ very fast but in fermentation it is a slow process.

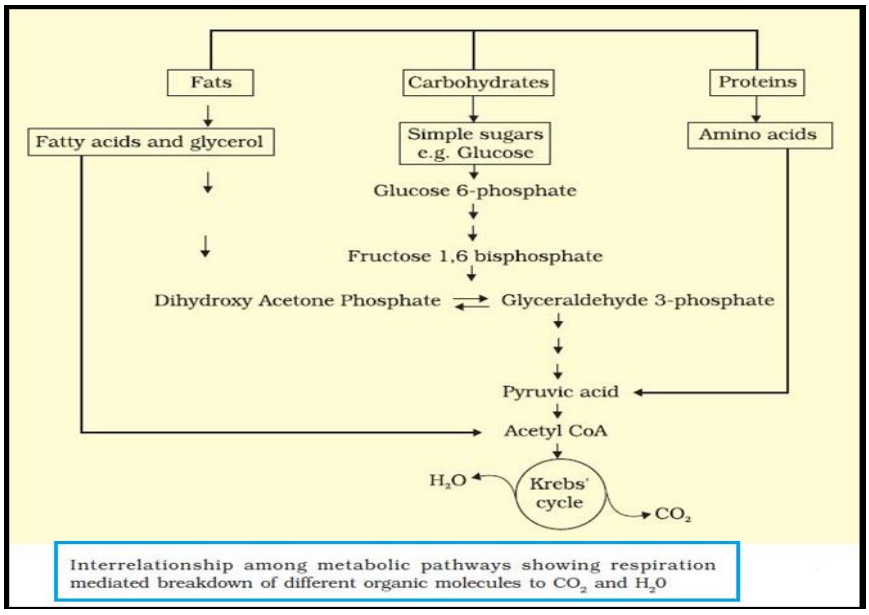
14.6 Amphibolic pathway: **Breaking down process within living organism is called catabolism and synthesis is called anabolism. Both anabolism and catabolism are involved in respiratory pathway it is called amphibolic pathway.**

Carbohydrates, fats, and proteins are the respiratory substrates. They do not enter the respiratory pathway at the first step. The points of entry of different substrates may be varied. Before entering into the respiratory pathway these substrates become converted into the simple forms.

Carbohydrates are converted into glucose before respiration. Fats would be broken down into glycerol and fatty acids. Glycerol would enter the respiratory pathway after being converted to PGAL. Fatty acids would enter the pathway after being degraded to acetyl CoA. The proteins would be degraded into amino acids after deamination by protease enzyme. These would enter the pathway at some stage within the Kreb's cycle or as pyruvic acid or as acetyl CoA depending on their structure.

Since the respiratory substrates are broken down during respiratory processes, traditionally it is considered as a catabolic process (catabolism) and the respiratory pathway is considered as a catabolic pathway. At certain points in the respiratory pathway, different substrates would enter to be respired and used to derive energy. Those compounds would be withdrawn from any point of the respiratory pathway in order to synthesize the above substrates.

E.g: Fatty acids would be broken down to acetyl CoA before entering the respiratory pathway when it is used as substrate. Acetyl CoA would be withdrawn from the respiratory pathway when the organism need to synthesize fatty acids. So respiratory pathway includes both break down and synthesis of fatty acid.



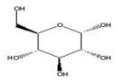
Interrelationship among metabolic pathways showing respiration mediated breakdown of different organic molecules to CO_2 and H_2O

14.7 Respiratory quotient: During aerobic respiration Oxygen is consumed and Carbon dioxide is released. Respiratory quotient is the ratio of the volume of CO2 evolved to the volume of O2 consumed in respiration. The R.Q value depends on the type of the substrate molecule. Respiratory quotient is determined with the help of an apparatus called **respirometer.**

RQ= volume of CO2 evolved /volume of O2 consumed

For carbohydrates the respiratory quotient is 1, for fats and proteins it is less than 1.

Carbohydrate (Glucose):



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

$RQ = 6CO_2 / 6O_2 = \underline{1.00}$

Fat (Palmitic Acid):

$C_{16}H_{32}O_2 + 23O_2 \rightarrow\rightarrow\rightarrow 16CO_2 + 16H_2O + Energy$

$RQ = 16CO_2 / 23O_2 = \underline{0.70}$

FAST TRACK REVISION:

It is a characteristic process of every living cell.

Respiration is the process in which glucose is broken down to release energy.

It is an intracellular oxidation of organic compounds with release of carbon dioxide and energy.

In respiration, substrate is enzymatically broken down in a step wise manner.

Phase 1 is glycolysis (EMP pathway). It is completed in cytoplasm. These reaction involves further breakdown of pyruvic acid to form end products of respiration.

Pyruvic acid metabolism can be aerobic or anaerobic.

Phase II of aerobic respiration is completed in mitochondria. The oxidation of substrate is complete and the end products re CO2, H2O and 38 ATP molecules for every molecule of glucose.

Phase II of anaerobic respiration is completed in cytoplasm only. The end products are ethyl alcohol, CO2 and energy.

Fermentation is an anaerobic respiration. It is commonly found in saprophytic microorganisms like bacteria and fungi. End products are sometimes very useful. Alcoholic fermentation and lactic acid fermentation are the two most common type.