Revision Notes for Class 11 Biology

Chapter 12 – Respiration In Plants

Respiration: The process in which oxygen along with the complex organisms combine and break down to form simpler substances and result in the release of energy is called respiration. It leads to the production of water and carbon dioxide.

Dutrochet was the one who coined the term respiration. The respiration where the C-C bond is present in the complex molecules will undergo oxidation and will lead to the production of energy is called cellular respiration. Respiration is an amphibolic process (two types: catabolic and anabolic process). To synthesize other molecules several other respiratory intermediates are used.

To synthesize fatty acids and Gibberellic acid, acetyl coenzyme A is used, for chlorophyll, phytochrome, and cytochrome synthesis, Succinyl coenzyme A is used while for amino acids such as aspartic acid, glutamic acid, etc oxaloacetic acid and alpha-ketoglutaric acid is used. During the process of respiration respiratory substrates are formed, which are after the oxidation of organic substances. On the basis of types of substrates, cellular respiration is classified into two types:

1. **Floating Respiration:** It is a common type of respiration whereas substrate, fat, or carbohydrates are used.

2. **Protoplasmic Respiration:** This type occurs when plants are starved and here as substrate proteins are used.

12.1 Do Plants Breathe?

In the case of plants, no special system for gaseous exchange or breathing is present. The plants require oxygen during respiration and release carbon dioxide. The gaseous exchange occurs with the help of stomata and lenticels in the plants while a small number of gases travel from one plant part to another.

Plants do not require a large number of gases for exchange and do not require several demands to undergo respiration. They perform gaseous exchange mostly during the process of photosynthesis. The oxygen from the outside environment is not necessary since it is released during the process of photosynthesis along with energy. 50% of the total energy that is released during the process of respiration can be utilized for the synthesis of biomolecules and for other life activities. The carbon that is produced during respiration can be used as a precursor that helps in the biosynthesis of other cellular molecules.

The site of respiration or respiratory apparatus in the cell is the mitochondrion.

Types of Respiration:

Respiration is classified into two categories based on the presence of oxygen during cellular respiration. They are Aerobic and anaerobic respiration.

- When the plants show active absorption then the respiration of salt is increased.
- When the fruits undergo ripening then climatic respiration occurs.

E.g.: Apple, Mango, etc.

Aerobic Respiration:

It is the process of the formation of water and carbon dioxide from the utilization of raw materials including oxygen. The equation is given below:

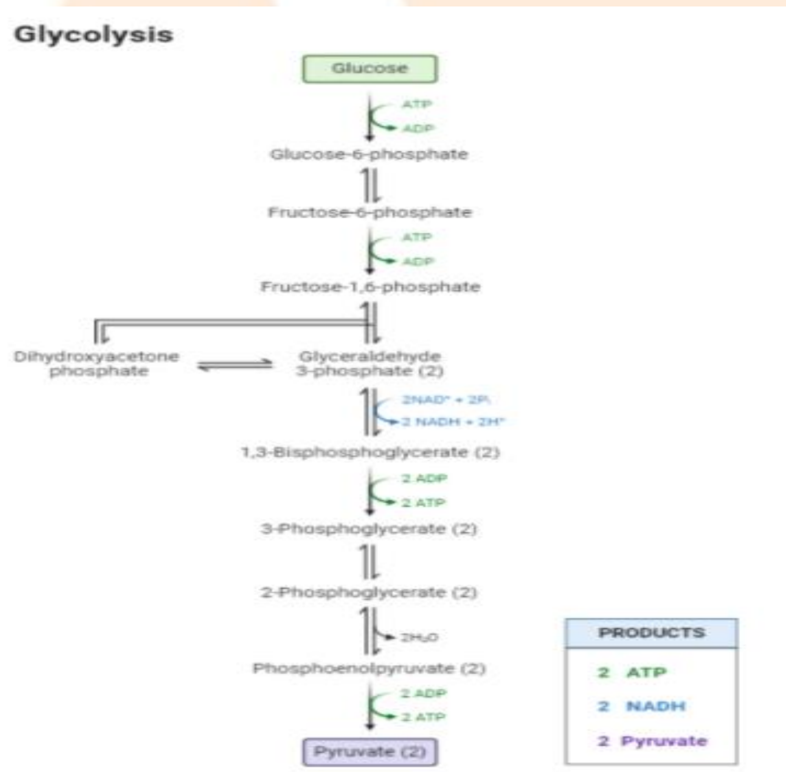
$$6CO_2 + 6H_2O \xrightarrow{Sunlight \quad Energy} C_6H_{12}O_6 + 6O_2 + 2870kJ\ .$$

- It occurs in the mitochondria of the cell with the release of energy which is approximately 2870kJ.
- Aerobic respiration consists of two main stages which include glycolysis and the citric acid cycle.
- It was first discovered in the striated muscles of insects by Kollicker.
- While the word mitochondria was given by C. Benda.
- The mitochondria act as the site for cellular respiration was proposed by Hoyeboom.

- Mitochondria consist of their own DNA, RNA, and proteins along with ribosomes, thus they are called the semi-autonomous organelle. They are found inside the eukaryotic cell having a symbiotic relationship (endosymbiont).

12.2 Glycolysis:

It is the first step of both aerobic and anaerobic respiration. It includes the formation of pyruvic acid when the glucose undergoes oxidation and requires a series of reactions that are enzyme-catalyzed. It is also known as the EMP pathway based on the name of biologists who discovered it, they are Gustav Embden, Otto Meyerhof, and J.Paranas.



Glucose forms two molecules of pyruvic acid after it undergoes oxidation. Glycolysis includes two major phases.

- Preparatory phase and cleavage
- Oxidative and payoff phase.

The Steps Found in Both these Phases are as follows:

- Phosphorylation of glucose that requires energy in the form of ATP along with hexokinase enzyme that results in the formation of glucose 6 phosphatases.
- Conversion of glucose 6 phosphates into fructose 6 phosphate which is its isomeric form with the help of the enzyme called phosphorgluco isomerase.
- The rest of the steps for both the glucose and fructose metabolism are the same.
- With the help of only one molecule of ATP, the fructose 6 phosphate is converted into fructose 1,6 bisphosphate.
- Fructose 1,6 biphosphate is then broken down which results in the formation of two molecules of triose phosphate (3 carbon compounds) glyceraldehyde phosphate and dihydroxyacetone phosphate with the help of the aldolase enzyme it is catalyzed and both the compounds are interconvertible.
- Now glyceraldehyde 3 phosphate is formed by the isomerization of Dihydroxyacetone phosphate resulting in the production of two molecules of Glyceraldehyde 3 phosphate.
- Each molecule of the glyceraldehyde 3 phosphate molecule converts to form triose phosphate with the help of oxidation which is called 1,3 bisphosphoglyceric acid and will also produce two electrons and two protons of which one proton and two electrons are used in reducing NAd by adding to it and form $NAD+H^{+}$. Each molecule of 1,3 bisphosphoglyceric acid converts into a triose phosphate called 3 phospho glyceric acid along with the release of an ATP molecule. During this step of ATP generation, the group of substrates and other metabolites are added directly to ADP and will result in the formation of ATP, this type is called the substrate-level synthesis of the substrate-level phosphorylation. This ATP synthesis is different from the ATP synthesis that occurs in the chloroplast (phosphorylation) and in the mitochondria (oxidative phosphorylation).
- Every 3 phosphoglyceric acids convert to form 2 phosphoglycerate.
- Each 2 phosphoglycerate is then converted into 2 phosphoenol-pyruvate and results in the production of the water molecule and ATP as it is a good donor.

- Each 2 phosphoenol-pyruvate also converts into pyruvic acid with the help of an enzyme called pyruvate kinase. During this step, the phosphate group of the substrate will be converted directly into ATP from ADP along with the release of an ATP molecule which is also a substrate-level ATP synthesis.

The production of ATP molecules in the EMP pathway occurs in two ways.

- Transfer of phosphate to ADP directly.

- During the process of glycolysis, production of NAD^+ occurs with the help of oxidation of the NAD^+H^+.

During glycolysis, the formation of two molecules of pyruvic acid from one molecule of glucose along with the 4 molecules of ATP.

During the process of phosphorylation, the two molecules of ATP are utilized.

Production of six molecules of ATP by the oxidation of two molecules of NAD^+H^+.

So the ATP net gain will be 8 in place of 2. Thus, during glycolysis, there is a production of two molecules of pyruvic acid along with the 8 molecules of ATP.

During glycolysis, the main product formed is pyruvic acid (pyruvate). The metabolic fate of pyruvic acid will take place in three different ways that depend on the presence of oxygen, the cellular need, and the organism.

12.3 Fermentation:

The process that occurs when oxygen is absent and involves the incomplete oxidation of food materials that result in the formation of CO_2 along with ethanol in the form of end products is called anaerobic respiration, or fermentation or zymosis. The process is carried out with the help of yeast. Gay Lussac was the first to discover the process of fermentation while Shank was the one to coin the term fermentation.

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

In various organisms that include many prokaryotes, unicellular eukaryotes along seeds that are germinating under anaerobic conditions, the process of fermentation occurs. There are two types of fermentation processes: Alcoholic fermentation and Lactic acid fermentation.

Alcoholic Fermentation:

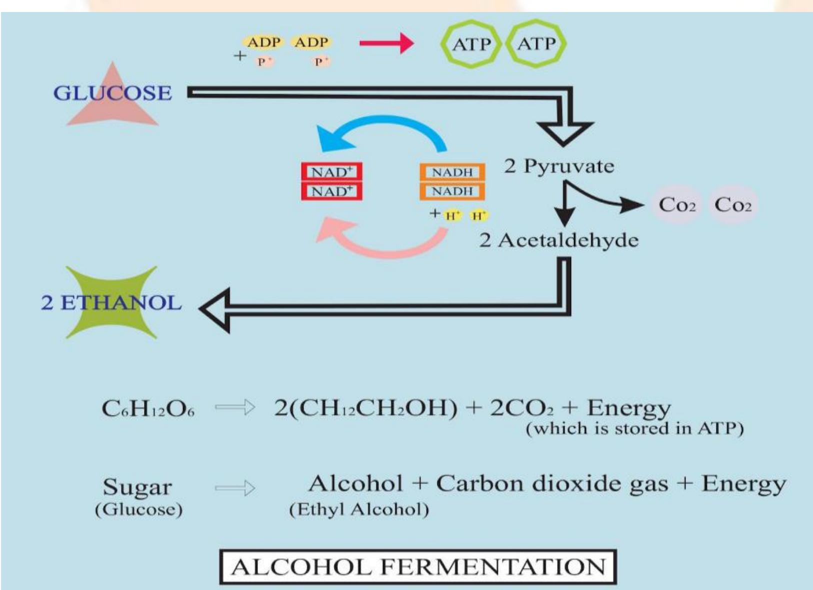
It results in the formation of carbon dioxide and ethanol (ethyl alcohol).

It involves two steps, the first one is glycolysis that results in the formation of pyruvic acid from the glucose molecules and it then converts and forms carbon dioxide and ethanol. The two steps are:

1. The conversion of Pyruvic acid is converted into carbon dioxide and acetaldehyde with the help of an enzyme called pyruvic acid decarboxylase.

2. With the help of an enzyme called alcohol dehydrogenase along with coenzyme the process of acetaldehyde occurs that results in the formation of ethanol along with carbon dioxide. In this process, a total of 8 ATP are released while two molecules of $NADH + H^{+}$ are utilized which is equal to three molecules of ATP. So, the net gain in the process of fermentation is two molecules of ATP.

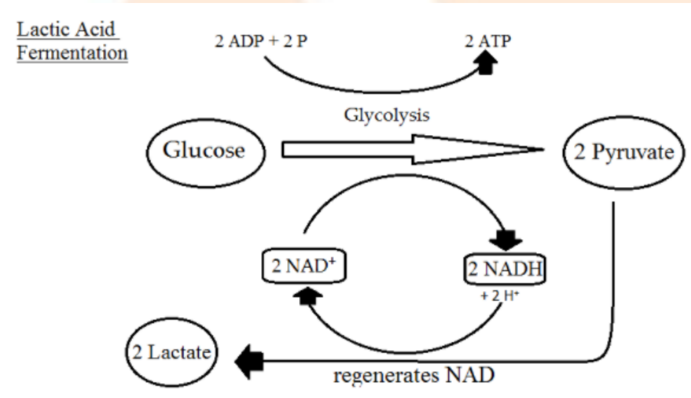
In the case of animals, the process of anaerobic respiration occurs in the skeletal muscles that utilize energy by the process of anaerobic respiration.



Lactic Acid Fermentation:

The process will lead to the formation of lactic acid and is used in the milk industry and in the muscle cells of vertebrates.

The process of formation of curd occurs due to the presence of a bacteria called Lactobacillus which results in the formation of NAD^+ from $NADH^+H^+$ while no carbon dioxide is produced. This reaction occurs with the help of an enzyme called the dehydrogenase enzyme. The total net gain of ATP is found to be two.



12.4 Aerobic respiration:

During glycolysis, glucose will form end products in the form of The end product of glycolysis is pyruvic acid which is a 3-carbon compound that occurs in the cytoplasm of the cell.

The Main Events are:

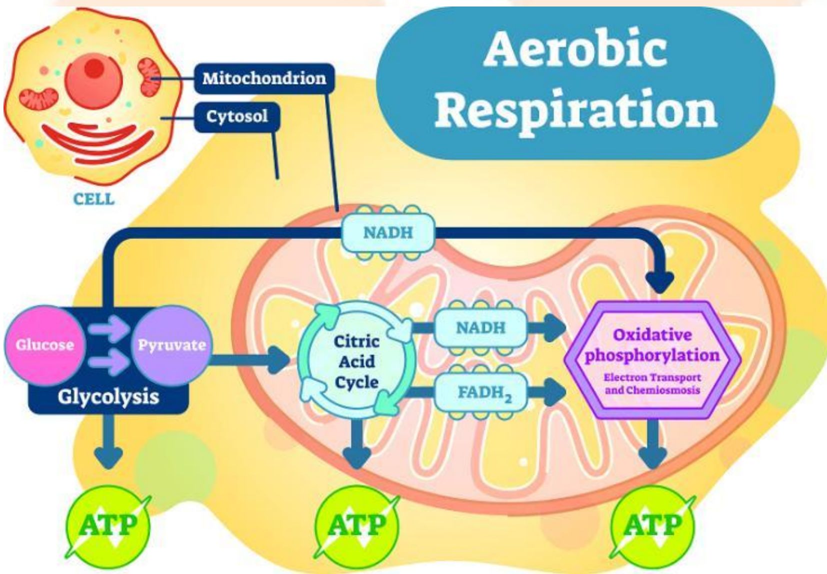
- The pyruvic acid is oxidized completely by the removal of the hydrogen atoms from it in a stepwise manner.
- The electrons after the production of ATP will then move towards the oxygen molecules and this process takes place in the inner mitochondrial membrane of the cell.
- Then the molecules of carbon dioxide are removed which occurs in the mitochondrial matrix of the cell.

When the pyruvic acid enters the mitochondria, it then takes part in the citric acid cycle and undergoes oxidation to form carbon dioxide. This process is called oxidative decarboxylation.

In this reaction, the pyruvic acid first undergoes decarboxylation and then is oxidized with the help of an enzyme called pyruvate dehydrogenase. While the rest of the pyruvic acid molecules will combine with the coenzyme A and result in the formation of acetyl coenzyme A in the presence of Mg^{2+}. Co A is a sulfur-containing compound and acetyl CoA acts as the connecting link between the glycolysis and citric acid cycle.

$$Pyruvicacid + CoA + NAD^{+} \xrightarrow[Pyruvatedehydrogenase]{Mg^{2+}} AcetylCoA + CO_2 + NADH + H^{+}$$

The process of aerobic oxidation of pyruvic acid is named the link reaction and its results in the formation of $NADH^{+}H^{+}$ by the reduction of NAD^{+}. During glycolysis, two molecules of pyruvic acid are formed from one molecule of glucose when it undergoes oxidation during aerobic oxidation. Thus two molecules of $NADH^{+}H^{+}$ are formed. Therefore, the net gain of energy will be 6 molecules of ATP $2NADH + H^{+} = 2X3 = 6ATP$.



12.4.1 Tricarboxylic Acid Cycle:

This cycle involves the formation of carbon dioxide and water after the complete oxidation of pyruvic acid occurs in a step-wise series of reactions and requires oxygen. This process takes place in the mitochondria of the cell.

Hans Krebs traced the step thus the cycle was named after him as Krebs cycle. The tricarboxylic acid –citric acid is the first compound of the cycle thus the cycle is also known as the citric acid cycle, it consists of three acids thus it is a tricarboxylic acid and thus the cycle is also named the tricarboxylic acid cycle. The respiratory substrate in the TCA cycle is acetyl coenzyme A while the 4-carbon compound is named oxalo Acetic acid is the acceptor molecule. This cycle consists of 4 dehydrogenations (the removal of hydrogen) reactions and two decarboxylations (the removal of CO_2) reactions. Here the reduction of coenzymes will result in the formation of carbon dioxide.

- In the formation of citric acid which is a 6-carbon compound, there is a combination of one molecule of acetyl coenzyme A along with 4 carbon oxaloacetic acids. This reaction occurred with the help of an enzyme called citrus synthase. This reaction requires a water molecule and leads to the formation of CoA.

- The isomerization of isocitric acid occurs to form citric acid with the help of a water molecule.

- By the process of dehydrogenation, the conversion of isocitric acid occurs which leads to the formation of oxaloacetic acid. In this process, there is a reduction of NAD+ which forms NAD^+ H^+.

- Then the formation of alpha-ketoglutaric acid occurs which is a five-carbon compound by the process of decarboxylation of the oxalosuccinic acid.

- Then there will be the formation of the four-carbon compound called succinyl CoA by the process of decarboxylation resulting in the reduction of NAD^+ to form NAD^+ H^+.

- This reaction requires CoA.

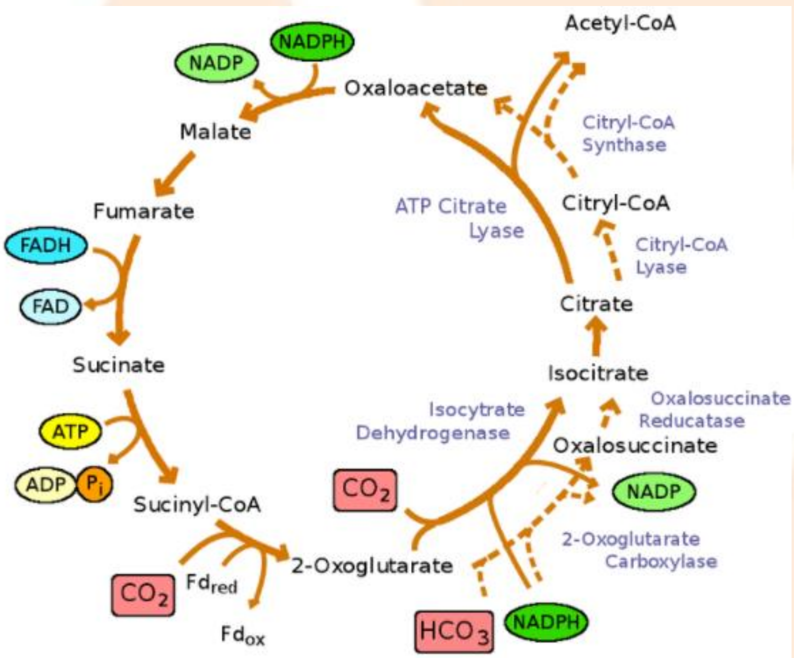
- There will be the formation of GTP along with succinic acid due to the loss of CoA from the succinyl and the GTP formed will then be transferred to one of the phosphates of ADP resulting in the formation of ATP.

- By the process of dehydrogenation, there will be the conversion of succinic acid into the fumaric acid which is a four-carbon compound while there will be a reduction of FAD that forms $FADH_2$.

- The next step involves the formation of malic acid from the fumaric acid after the addition of a water molecule.

- Finally, there will be the conversion of malic acid into oxaloacetic acid and there will be a reduction of NAD^+ that forms $NADH^+$.

- The oxaloacetic acid formed will now combine with the acetyl CoA and will lead to the start of a new cycle.
- With the help of the citric acid cycle there will be the oxidation of acetyl Co-A that results in the replenishment of oxaloacetic acid and also the regeneration of NAD^+ and FAD^+ from $NADH^+$ and $FADH_2$ respectively.
- Since during glycolysis, two molecules of pyruvic acid only one molecule of glucose is required along with the formation of two molecules of acetyl CoA.



During the process of aerobic oxidation, the pyruvic acid will form acetyl CoA along with two molecules of $NADH^+$. Thus, in the case of one citric acid cycle, there will be the formation of 3 molecules of $NADH^+$, one molecule of $FADH_2$, and one molecule of ATP. During anaerobic oxidation, every $NADH^+$ molecule will produce 3 ATP molecules, and each $FADH_2$ will produce 2 molecules of ATP, this process is called oxidative phosphorylation. So, in the citric acid cycle, the net gain of energy will be 12 ATP. So, when one molecule of glucose undergoes aerobic respiration there will be a net gain of 38 ATP molecules.

In the case of many eukaryotic cells, there will be a requirement of 2 molecules of ATP for the transfer of NADH into the mitochondria that were produced during the process of glycolysis and it will further be used to undergo oxidation. Thus, the total net gain of energy now becomes 36 molecules of ATP. This will lead to the release of 45% of the energy that is stored in the 38 molecules of ATP for oxidizing one molecule of glucose while the remaining energy will be lost as heat during aerobic respiration.

Aerobic Respiration ATP Production

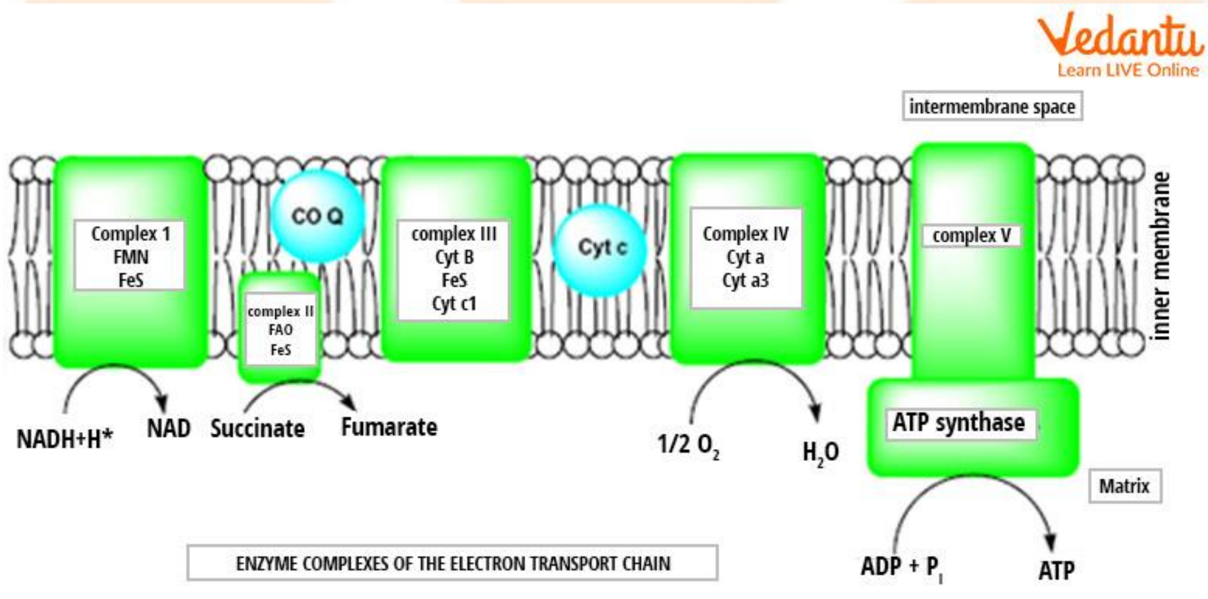
Steps in Respiration	**Takes place in the...**	**Result**
Glycolysis	Cytoplasm	2ATP+NADH
Krebs cycle	Mitochondrial matrix	2ATP+NADH+ $FADH_2$
Electron transport chain and Cytoplasm ATP synthesis	In and across the mitochondrial membrane	34ATP

12.4.2 Electron Transport System and Oxidative Phosphorylation:

By the process of dehydrogenation, the electrons along with the hydrogen ions are removed from the substrates that including glyceraldehyde 3 phosphate, pyruvic acid, isocitric acid, alpha-ketoglutaric acid, succinic acid, and malic acid during aerobic respiration. This leads to the removal of energy. Then removed hydrogen ions and electrons will then combine with coenzymes like NAD^+ and FAD. This results in the formation of $NADH^+$ or $FADH_2$ while the energy released from the electrons gets stored in the bonds that are formed between NADH and H and FAD and H.

When NADH and $FADH_2$ undergo oxidation, then the electrons of the hydrogen atoms will be transported with the help of different kinds of electron carriers to the oxygen that is arranged in a specific order called electron transport chain or it is also named as mitochondrial respiratory chain or electron transport system.

The electron transport system is found to be placed in the inner mitochondrial membrane. Each member of ETS individually will be called electron carriers which are Flavin, FeS protein, quinines, and cytochromes. Flavin is FMN (Flavin mononucleotide), FeS is an iron-sulfur protein, quinones are present in the membrane and are mobile electron carriers while the ubiquinone is the common quinine and is a phenolic compound, and lastly, the cytochromes act as both the enzymes as well as the electron carriers. The cytochromes that are present in the ETS are Cyt b, Cyt c1, Cyt c, Cyt a, and Cyt a3 and are all containing iron that acts as their activator except Cyt a3 that along with iron also contains copper.



The Respiratory Balance Sheet

Stage of Respiration	Source	Number of ATP Molecules Produced
Glycolysis	Direct	2
	2-molecules of $NADH^{+}\ H^{+}$ (one molecule of $NADH^{+}\ H^{+}$ yields 3 molecules of ATP)	6
Link reaction	2 molecules of $NADH^{+}\ H^{+}$	6
Citric acid cycle	6 $NADH^{+}\ H^{+}$	18
	2 $FADH_2$ ($FADH_2$ produces only 2 molecules of ATP)	4
	Direct	2
Total		**38 ATP molecules.**

Amphibolic Pathway

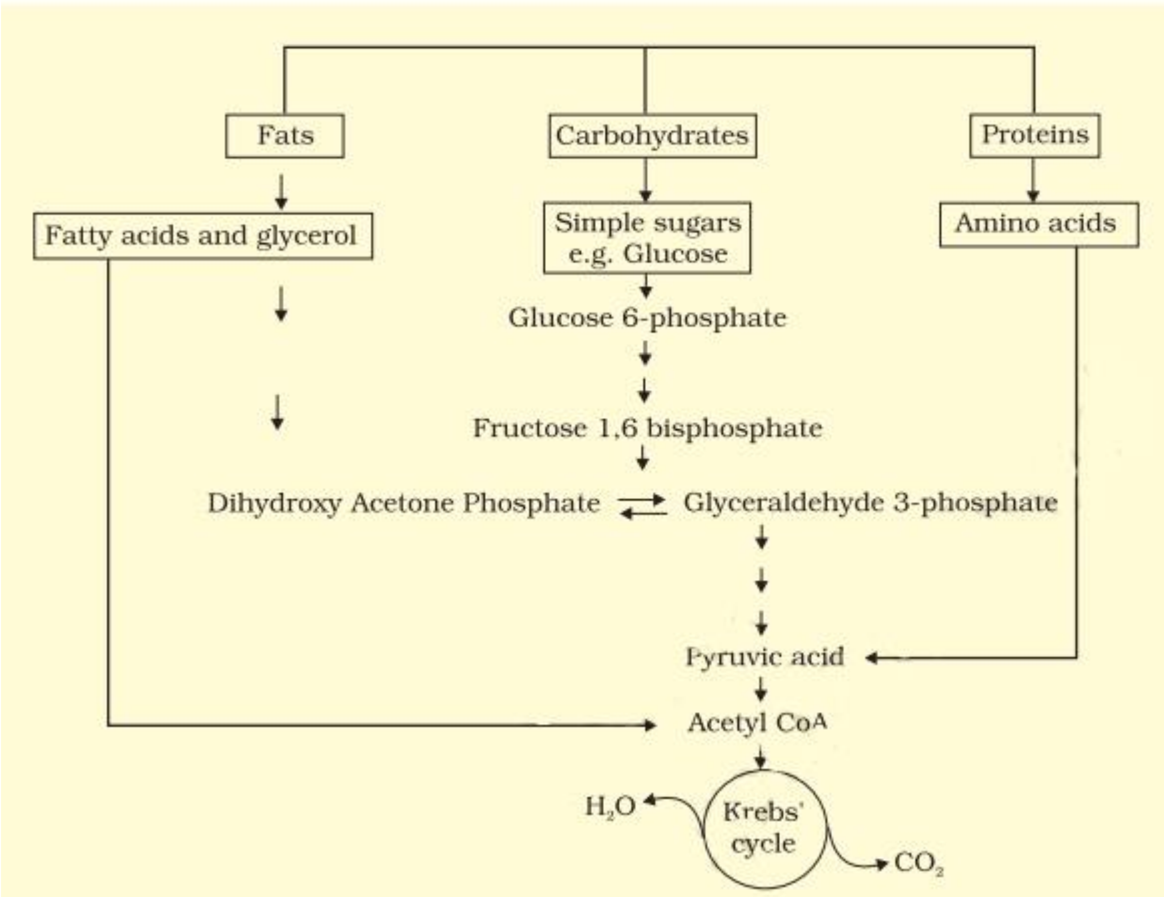
The term "amphibolic pathway" refers to a metabolic pathway that serves both catabolic (breakdown) and anabolic (biosynthesis) processes. Cellular respiration, particularly the Krebs Cycle (Citric Acid Cycle), is a prime example of an amphibolic pathway.

Key Points of Amphibolic Pathway:

1. **Dual Functionality**:
    - **Catabolic Role**: The pathway breaks down complex molecules like carbohydrates, fats, and proteins into simpler compounds, releasing energy in the form of ATP.
    - **Anabolic Role**: The same pathway also provides intermediates that serve as building blocks for synthesizing essential molecules like amino acids, nucleotides, and fatty acids.
2. **Krebs Cycle as an Amphibolic Pathway**:
    - **Energy Production**: During the Krebs Cycle, acetyl-CoA is oxidized, resulting in the production of ATP, NADH, and $FADH_2$, which are used to generate energy.
    - **Biosynthesis**: Intermediates from the Krebs Cycle, such as citrate, α-ketoglutarate, and oxaloacetate, are diverted for the synthesis of fatty acids, amino acids, and glucose (via gluconeogenesis).
3. **Versatility**:
    - The amphibolic nature of the pathway allows cells to adapt to varying metabolic needs. For instance, when energy is plentiful, intermediates are diverted for biosynthesis. When energy is required, the pathway prioritizes the breakdown of molecules to release ATP.

Importance:

- The amphibolic pathway is crucial for maintaining metabolic balance in cells, ensuring that both energy production and biosynthesis occur efficiently according to the cell's needs.
- It highlights the interconnectedness of metabolism, where the same pathways contribute to both energy generation and the synthesis of vital cellular components.



The Respiratory Quotient (RQ) is a ratio used to measure the relative amounts of carbon dioxide (CO_2) produced to oxygen (O_2) consumed during the process of cellular respiration. The RQ value provides insight into which type of substrate (carbohydrates, fats, or proteins) is being metabolized for energy.

RQ Values for Different Substrates:

1. **Carbohydrates**:
   - When carbohydrates are metabolized, the RQ is typically **1**.
   - Example: Glucose ($C_6H_{12}O_6$) oxidation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ Here, 6 molecules of CO_2 are produced and 6 molecules of O_2 are consumed, so RQ = 1.

2. **Fats**:

   - The RQ for fats is usually **0.7**.
   - Fats require more oxygen for oxidation compared to the amount of CO_2 produced.
   - Example: Palmitic acid ($C_{16}H_{32}O_2$) oxidation: $C_{16}H_{32}O_2 + 23O_2 \rightarrow 16CO_2 + 16H_2O$ Here, 16 molecules of CO_2 are produced and 23 molecules of O_2 are consumed, so RQ = 0.7.

3. **Proteins**:

   - The RQ for proteins is approximately **0.8**.
   - Proteins have a mixed composition of carbon, hydrogen, nitrogen, and oxygen, leading to an intermediate RQ value.

RQ in Special Conditions:

- **RQ > 1**: Occurs during lipogenesis (fat synthesis), where excess carbohydrates are converted to fat, leading to more CO_2 production than O_2 consumption.
- **RQ < 0.7**: This can indicate conditions like ketosis or starvation, where fats are the primary energy source, and very little carbohydrate metabolism is occurring.