**Respiration in plants**

In the body of organism different types of metabolic activities such as respiration, excretion, digestion and photosynthesis occur continuously. These processes require energy which is obtained by cellular respiration. During cellular respiration, oxygen enters into the cell where it reacts with carbohydrates and other food substances to produce energy, CO2 and water. Respiration is a catabolic process in which organic compounds are oxidized to produce energy.

Along with catabolic process, synthetic processes also occur which are known as anabolic processes for example Photosynthesis.In anabolic process, new products are formed and energy is consumed. Anabolic and catabolic processes are collectively called metabolism.

**Definition** respiration is a redox process, in which glucose undergoes oxidation to produce , CO2 and oxygen in reduced to form water. In simple words during the process of respiration, organisms absorb oxygen from atmosphere and oxidize glucose to produce carbon dioxide and water. In this process energy is also released. The entire process of respiration can be summarised in the following equation:

C6H12O6 + 6O2 6CO2 + 6H2O + 673 Kcal (energy)

**Important points of respiration:**

1. Organisms absorb oxygen during the process.
2. Glucose is oxidised and oxygen is reduced.
3. Oxygen oxidises food substances.
4. Energy produced is stored in the form of ATP.
5. Many intermediate products synthesized during the process of oxidation are used in other metabolic activities.
6. Carbon dioxide and water are ultimate products which are released out. This results in decreased biomass.
7. Breakdown of one molecule of glucose results in yield of 36 or 38 ATP molecules.
8. 40% of the total energy present in each glucose molecule is stored as ATP and the rest energy is released as heat which helps in the regulation of body temperature.

**Respiratory substrates** Carbohydrates, proteins and fats are the main respiratory substrates.

**Types of cellular respiration** Based on use and disuse of oxygen, cellular respiration are of following two types:**Anaerobic respiration** and **aerobic respiration**

**Anaerobic respiration**It is also called intermolecular respiration. It occurs in the absence of oxygen. In this substrate like carbohydrates, proteins, fats are partially oxidized and lesser energy is released. The final product of this respiration are carbon dioxide and alcohol. Oxidation of 1 gram glucose yields 28 kcal energy. Anaerobic respiration occurs in germinating seeds, stored seeds, fungi, bacteria,ascaris etc. Organisms which perform anaerobic respiration are called an anaerobes. Those which respire only in the absence of oxygen and die when oxygen is supplied are called obligate anaerobes for example *Clostridium*. facultative anaerobes are those organisms which although grow in the absence of oxygen but can also perform aerobic respiration for example Yeast (*Saccharomycescerevisiae.*

**Aerobic respiration** Organisms performing this type of respiration are called aerobes. It occurs in the presence of oxygen. The final products of aerobic respiration are carbon dioxide and water. Food products like carbohydrates proteins and lipids undergo complete oxidation during the process. Complete oxidation of one molecule of glucose yields 673 kcal energy. Oxygen is the final acceptor of electron which accepts electron and converts into water. 38 ATP are produced in the entire process. Organism which survive only in presence of Oxygen and dye in its absence are called obligate aerobes for example plants, human beings, flower, birds etc. Facultative aerobes are those organisms which although perform aerobic respiration using oxygen but can also perform anaerobic respiration in the absence of oxygen for example butyric acid bacteria. In entire respiratory process only 40% energy of substrate is conserved and rest is released as heat.

**Mechanism of aerobic respiration**In aerobic respiration food substances are oxidized in the presence of oxygen to produce carbon dioxide, water and large amount of energy. The entire process can be studied under following heads.

1. Glycolysis
2. Formation of acetyl Co A
3. Krebs cycle
4. Electron transport system

**Glycolysis** This process occurs in all organisms. It occurs in cytoplasm and is not dependent on the presence or absence of oxygen. Glycolysis was evolved before Krebs cycle and electron transport system in organisms. The reasons being, oxygen was not present in primitive environment. The steps of this process where discovered by three German scientists Embeden, Meyerhoff and Parnas. In their honour, glycolysis is also calledEmbeden, Meyerhoff and Parnas pathway for EMP pathway. In glycolysis six carbon molecule of glucose breaks up into two molecules of three carbon pyruvic acid. The process is studied under following heads:

1. **Phosphorylation** of glucoseIt is an Irreversible and endergonic reaction which requires ATP in the form of energy. The six carbon glucose molecule undergoes phosphorylation to produce glucose 6 phosphate. This reaction requires Mg++and one molecule of ATP and enzyme hexokinase.
2. **Isomerization** In the presence of the enzyme phosphoglucoisomerase, glucose 6 phosphate gets converted into Fructose 6 phosphate. Mg++ acts as cofactor.
3. **Second phosphorylation**In this reaction, phosphofructokinase uses Mg++as cofactor. It takes up one phosphate group from ATP and transfer it to first carbon of fructose 6 phosphate which gets converted into Fructose 1,6diphosphate. This is an endergonic reaction which requires energy in the form of ATP.
4. **Cleavage** In the presence of enzyme aldolase, Fructose 1,6diphosphate breaks up into one molecule each of glyceraldehyde 3-phosphate an aldose and dihydroxyacetone phosphate (a ketos). Both these are triphosphate molecules. Out of these two, only glyceraldehyde 3-phosphate proceeds further in glycolysis. Dihydroxyacetone phosphate molecule again in the presence of triose phosphate isomerase gets converted into three phosphoglyceraldehyde.
5. **3 phosphoglyceraldehyde** accepts inorganic phosphate molecule from phosphoric acid and gets converted into 1,3 diphosphoglyceraldehyde. This reaction does not require any enzyme.
6. **Dehydrogenation of 1,3 diphosphoglyceraldehyde** 1,3 diphosphoglyceraldehyde molecule get oxidized.It releases two electrons and two hydrogen ion and gets converted into 1,3diphosphoglyceric acid. Reaction occurs in the presence of enzyme diphosphoglyceraldehyde dehydrogenase and oxidized NAD+.NAD+accepts two hydrogen molecule and converts into NADH+ H+ .
7. **Synthesis of first ATPmolecule** The enzyme phosphoglycerate kinase removes 1 phosphate group from 1,3diphosphoglyceric acid by the process of the phosphorylation and converts it into 3-phosphoglyceric acid. The released phosphate group is accepted by ADP which converts into ATP.This is a reversible reaction in which magnesium ions act as cofactor.
8. **Isomerization** The phosphate group present on third carbon of 3-phosphoglyceric acid is shifted to 2nd carbon in the presence of enzyme phosphoglyceratemutase. This is a reversible reaction in which magnesium ion is required.
9. **Dehydration** In the presence of magnesium and enzymeenolase, 2phosphoglyceric acid through a reversible reaction gets converted to phosphoenolpyruvate. A molecule of water is released during the process.
10. **Synthesis of 2nd ATP molecule** This is the last step in glycolysis in which 2 phosphoenolpyruvic acid in the presence of magnesium and and pyruvate kinase enzyme gets converted into pyruvic acid.

**Summary of glycolysis**Glycolysis can be summarised as follows:

1. In this a six carbon glucose molecule gets oxidized to form 3 carbon pyruvic acid (two molecules).
2. In this process oxygen is not directly used rather at several steps hydrogen atoms are released.
3. This process occurs in the cytoplasm of all organisms (prokaryotes and eukaryotes).
4. The entire process has 10 steps and uses 10 enzymes.
5. Neither oxygen is accepted nor CO2 is discharged.
6. In all, two ATP molecules are used.First ATP is used at first step and second ATP at third step. Total 4 ATP are formed, two ATP molecules at the seventh step and another two ATP are formed at tenth step. Thus there is net gain of 2 ATP molecules.
7. At the seventh step of glycolysis 2 NADH+ H+are produced which get oxidised in the presence of oxygen. This process occurs in electron transport system where three ATP molecules are obtained from each NADH + H+molecule i.e. 6 ATP are formed from two NADH + H+. In this way in the presence of oxygen a total of eight ATP are produced in glycolysis.
8. All the initial 9 intermediate substances formed in glycolysis have phosphates whereas the last substance pyruvic acid does not have phosphate group.

**Fate of pyruvic acid**The further breakdown of the two molecules of pyruvic acid formed at the end of glycolysis depends on the availability of oxygen. In the absence of oxygen pyruvic acid undergoes anaerobic respiration or fermentation to produce CO2 and alcohol or lactic acid. In the presence of oxygen, pyruvic acid is oxidised to water and carbon dioxide.

**Oxidation of pyruvic acid in presence of oxygen**Both the molecules of pyruvic acid undergo oxidation in the following manner:

1. **Formation of acetyl Co A** pyruvic acid enters mitochondria where, in the presence of oxygen, it forms acetyl Co A. In this process pyruvic acid in the presence of enzyme pyruvate dehydrogenase, NAD+ and Co A undergoes oxidative decarboxylation to produce a two carbon compound acetyl Co A with the release of one molecule of carbon dioxide. At the same time NAD+ gets reduced to NADH + H+. This reaction is called transition reaction or Gateway step because as a result of this process glycolysis is linked to Krebs cycle.Through acetyl Co A. Pyruvate dehydrogenase is an enzyme Complex. This enzyme is present in the mitochondria of Eukaryotic cells and protoplasm of prokaryotic cells.

**Krebs cycle**Hans Krebs (1937) discovered the process in pigeon breast muscles for which he along with Fritz Lipmann(father of ATP) was awarded Nobel Prize in 1953.

The process occurs in the matrix of Mitochondria, where all the required enzymes are present except succinic dehydrogenase which is present as integral protein Complex in the inner membrane of Mitochondria. Krebs cycle is also called citric acid cycle because the first product formed is citric acid. It is also known as tricarboxylic acid or TCA cycle because citric acid has three carboxyl groups. There are in all 8 steps in Krebs cycle which have been given in the following diagram.

**Summary of Krebs cycle**Krebs cycle can be summarised as follows:

1. The process occurs in the matrix of Mitochondria.
2. It occurs in aerobic conditions that is oxygen is required.
3. The process is a cyclic process.
4. For each molecule of glucose Krebs cycle occurs twice. This is because two molecules of pyruvic acid are produced from one molecule of glucose and Krebs cycle utilizes one molecule of pyruvic acid at a time.

Entry of one molecule of pyruvic acid in kerbs cycleresults into:

1. Release of two carbon dioxide molecules.
2. Release of four hydrogen atoms, out of which three hydrogen atoms are utilised in the reduction of NAD+ into NADH + H+and one hydrogen atom reduces FAD+ into FADH + H+.
3. Four electrons are released which pass through electron transport system and finally reduce one oxygen molecule into two molecules of water.
4. One molecule of ATP is formed through GTP.

The entire reaction can be demonstrated as follows: Acetyl Co A + 2H2O + FAD+ + 3NAD+ + GDP + Pi

2Co A + 2CO2+ 3NADH + H++ FADH + H++ GTP

A total of 24 ATP molecules are produced from one Acetyl Co A in Krebs cycle.

**Significance of Krebs cycle**

1. In this, Complex molecules disintegrate to release energy and carbon dioxide.
2. This energy is utilised in different activities by the organisms where as carbon dioxide is used in photosynthesis.
3. Besides energy several intermediate compounds are formed during Krebs cycle which are important for organisms due to whichKrebs cycle is also called amphibolic cycle.
4. It provides reducing power in the form of hydrogen atoms.
5. Electron transport system (ETS) Electron transport system is composed of electron acceptor protein molecules. When electron passes through these carrier molecules energy is evolved whichis accepted by ADP to form ATP.This system is found in the inner membrane and oxisomes of Mitochondria. The NADH formed during Krebs cycle in the mitochondrial matrix is oxidized in the presence of enzyme NADH dehydrogenase into NAD+ (Complex 1). Later the released electron is transferred to the proteinubiquinone present in the inner membrane. Reduced ubiquinone is obtained by FADH2 which is formed during oxidation of succinic acid in Krebs cycle. Reduced ubiquinone transfers electron to cytochrome B then cytochrome C 1 and next to cytochrome C and gets oxidized. Cytochrome C is a small protein which is attached to the outer surface of inner membrane and transfers electron to Complex 4. Complex 4 is cytochrome C oxidase Complex in which cytochrome A3 and two copper centres are present.When electrons pass through the electron transport system from one carrier to another passing from Complex 1 to Complex 4, they combine with ATP synthase Complex 5 form ATP from ADP and inorganic phosphate. The number of ATP molecules formed depends on Donor electrons. By the oxidation of one NADH molecules 3 ATP molecules are synthesized whereas from 1 FADH2 molecule 2 ATP molecules are formed. The aerobic process of respiration occurs in the presence of oxygen. Oxygen is essential because it liberates hydrogen from the entire system and regulate the process. Oxygen acts as the last hydrogen acceptor. As against photophosphorylation where solar energy is responsible for development of proton potential in respiration the energy is provided by oxidative reduction. As a result it is also called oxidative phosphorylation.