

## Respiration in Plants Class 11 Notes Biology Chapter 14

All living organisms require a continuous supply of energy for their survival. Energy is used to carry out various functions such as uptake of materials, absorption, growth, development, movement and even breathing. About 50% of the energy produced by the cell is utilized by these cellular activities and rest of it is changed into heat and get lost. Now, the question arises from where does this energy comes to carry out all these processes of life.

### **Topic 1 Respiration : The Basics**

We eat food in order to obtain energy. The food we eat in the form of macro molecules is oxidized to fulfill energy requirement of body for carrying out all the basic life processes.

As we have already studied in last chapter, that only green plants and cyanobacteria can prepare their own food by the process called photosynthesis. They use trapped energy in order to obtain their food by converting light energy into chemical energy, which thereby gets stored into the bonds of carbohydrates such as glucose, sucrose, starch, etc.

But all cells, tissues and organs in plants do not photosynthesise instead, photosynthesis takes place in only some parts of plants, i.e., only cells that contain chloroplasts (mostly areas located in superficial layers).

Hence, all other organs, tissues and cells in green plant that are non-green are need food for oxidation. Hence, food has to be translocated from the green parts to the non-green parts for oxidation processes.

#### Need of Photosynthesis

Animals on the other hand are heterotrophic in nature, i.e., they either obtain their food directly from the plants (herbivores) or indirectly, dependent on herbivores for their food (carnivores). Saprophytes are dependent on dead and decaying matter for their food (e.g., Fungi). Thus, it can be concluded that all the food that is respired for life processes ultimately comes from photosynthesis.

### **Cellular Respiration**

Cellular respiration or the mechanism of breakdown of food materials within the cell to release energy and trapping the same energy for synthesis of ATP.

Respiration is the process of breaking of the C-C bonds of complex compounds through oxidation within the cells, leading to release of considerable amount of energy.

It is to be noted that site of breaking down of complex molecules to yield energy is cytoplasm and mitochondria (also only in eukaryotes) which is different from the site of photosynthesis, which is chloroplast in plants.

### **Respiratory Substrates**

The compounds that are oxidised during the process of respiration are called respiratory substrates. Carbohydrates are used as major respiratory substrates are oxidised in high amounts, to release energy, but under some conditions in some plants, proteins, fats and organic acids are also used as respiratory substrates.

### **Differences between Respiration and Combustion**

<b>Respiration</b>	<b>Combustion</b>
It is the breakdown of complex compounds through oxidation within the cells, leading to release of considerable amount of energy.	Combustion is the complete burning of glucose, which produces $\text{CO}_2$ and $\text{H}_2\text{O}$ and yield energy which is given out as heat.
It is a controlled biochemical process.	It is an uncontrolled physico-chemical process.
Many chemical bonds break simultaneously releasing large amount of energy.	Chemical bonds break one after another to release energy.
Enzymes are involved.	Enzymes are not involved.
Only a part of energy is lost as heat.	Most of the energy is liberated as heat.
A number of intermediates are formed for the synthesis of different organic compounds.	No intermediates are produced in this case.

### ATP : Energy Currency of the Cell

During the process of oxidation of food within a cell, all the energy contained in the respiratory substrates is not released free into the cell, or in a single step. Instead it gets released in a series of step-wise reactions controlled by enzymes and is trapped as chemical energy in the form of ATP.

Hence, the energy released in respiration by the process of oxidation is not used directly but is used in synthesising ATP (which is utilised whenever energy needs to be utilised).

Thus, it is said that ATP acts as the energy currency of the cell. The energy trapped in ATP is utilised in many energy requiring processes of the organisms, and the carbon skeleton produced during respiration is used as precursors for the biosynthesis of other molecules in a cell.

### Do Plants Breathe : Exchange of Gases in Plants

For the process of respiration, plant takes  $\text{O}_2$  and releases  $\text{CO}_2$ . Plants have stomata and lenticles for gaseous exchange instead of specialised organs that are present in animals for exchange of gases.

### Following are the reasons which shows, how plants can get along without respiratory organs

(i) Every part of the plant has the ability to take care of its own needs of gas exchange and also very little transport of gases occur from one part of the plant to another.

(ii) It is only during the process of photosynthesis that large volumes of gases are exchanged and each leaf of the plant has ability to take care of its own needs during these periods.

Thus, when cells photosynthesis, availability of  $\text{O}_2$  is not a problem in these cells due to a continuous release of  $\text{O}_2$  that takes place within the cell.

(iii) Gases may easily diffuse in large, bulky plants as distance for diffusion is not so great because living cells in a plant are located quite close to the surface of the plant.

In case of stems, which are thick and woody in nature, the organisation of living cells is in the form of thin layers, which are found inside and beneath the bark. Like leaves which have stomata for gaseous exchange, these stems also have openings called lenticels. Internal cells are dead and provide only mechanical support to the plant.

This depicts that most cells of plant have atleast a part of their surface in contact with the air. The loose packing of parenchyma cells in leaves, stems and roots and provides an interconnected network of air spaces helps in facilitating this process.

### Types of Respiration

We know that during the process of respiration, utilisation of  $O_2$  takes place with the release of  $CO_2$ , water and energy as products.

According to the dependence of cells on oxygen, cellular respiration may be classified into two types as given below

### **1 Aerobic Respiration**

This is the type of respiration in which organism utilise oxygen for the complete oxidation of organic food into  $CO_2$  and water. It occurs inside the mitochondria.

Aerobic respiration yields more energy as the respiratory substrate gets completely oxidised in the presence of  $O_2$ .

### **2. Anaerobic Respiration**

This is the type of respiration in which organic food is oxidised incompletely without utilising energy as oxidant. It occurs in cytoplasm and often releases small amount of energy.

It is believed that the first cells on this planet lived in an oxygen free environment, i.e., they were anaerobes. Even among present day living organisms, several are adapted to anaerobic conditions. Some of them are facultative anaerobes (organisms that have capability of switching from aerobic to anaerobic conditions according to the availability of oxygen) while others are obligate anaerobes (organisms that are killed by normal atmospheric concentration of oxygen of 21%).

Thus, in any case, all living organisms retain the enzymatic machinery for partial oxidation of glucose in the absence of oxygen. And this breakdown of glucose to pyruvic acid is called glycolysis.

## **Topic 2 Respiration: The Mechanism**

Cellular respiration occurs inside the cell and proceeds with the help of enzymes. The first step in respiration (taking glucose as substrate) is the glycolysis (glucose oxidised to pyruvic acid). After which the pyruvic acid may enter the Krebs' cycle (aerobic respiration) or undergo fermentation (anaerobic respiration).

### **Glycolysis**

Glycolysis (Gr. Glycor-sugar; lysis-splitting), is a step-wise process by which one molecule of glucose (6C) breaks down into two molecules of pyruvic acid (3C).

The scheme of glycolysis was given by Gustav Embden, Otto Meyerhof and J Parnas and is often referred as the EMP pathway. It is a common pathway in both aerobic and anaerobic modes of respiration. But in case of anaerobic organisms, it is the only process of respiration.

Glycolysis occurs in the cytoplasm of the cell. During the process glucose gets partially oxidised. In plants this glucose is derived from sucrose (end product of photosynthesis) or from storage carbohydrates.

During the course of process in plant this sucrose is first converted into glucose and fructose by the action of invertase enzyme after this, these two monosaccharides enter the glycolytic pathway.

### **Steps Involved in Glycolysis**

In glycolysis, a chain of 10 reactions often reactions occur under the control of different enzymes.

### **It involves the following steps**

**Step I** Phosphorylation of glucose occur under the action of an enzyme hexokinase and  $Mg^{2+}$  that gives rise to glucose-6-phosphate by the utilisation of ATP.

**Step II** Isomerisation of this phosphorylated glucose-6-phosphate takes place to form fructose-6-phosphate with the help of an enzyme phosphohexose isomerase (Reversible Reaction).

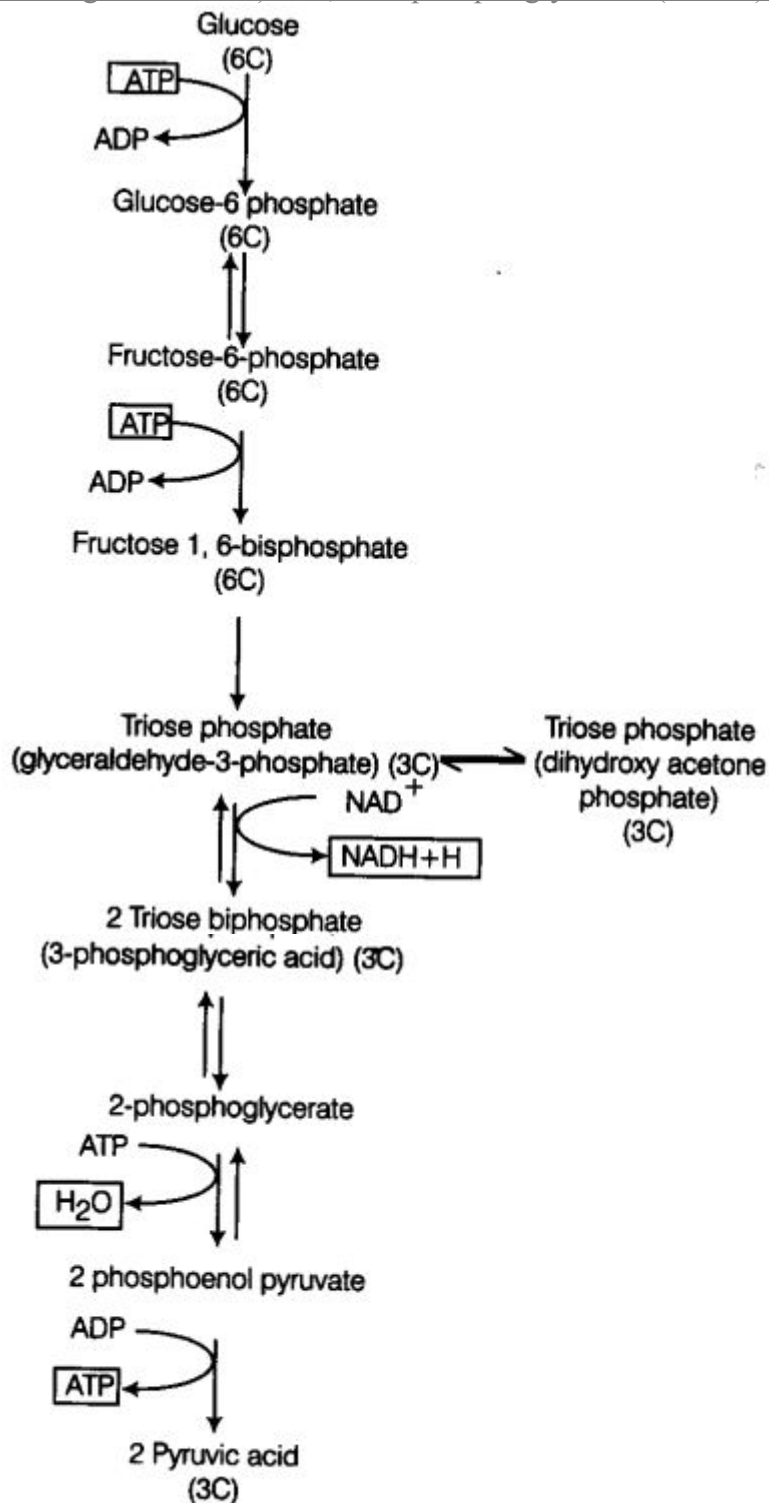
**Step III** This fructose-6-phosphate is again phosphorylated by ATP in order to form fructose 1, 6-bisphosphate in the presence of an enzyme phosphofructokinase and  $Mg^{2+}$ .

The steps of phosphorylation of glucose to fructose 1, 6-bisphosphate (i.e., from step 1 to 3) activates the sugar thus, preventing it from getting out of the cell.

**Step IV** Splitting of fructose 1, 6-bisphosphate takes place into two triose phosphate molecules, i.e., dihydroxyacetone 3-phosphate and 3-phosphoglyceraldehyde (i.e., PGAL). This reaction is

catalysed by an enzyme aldolase.

**Step V** Each molecule of PGAL removes two redox equivalents in the form of hydrogen atom and transfer them to a molecule of  $\text{NAD}^+$  (This  $\text{NAD}^+$  forms  $\text{NADH} + \text{H}^+$ ) and accepts inorganic phosphate ( $\text{P}_i$ ) from phosphoric acid. This reaction in turn leads to the conversion to PGAL (which gets oxidised) to 1, 3-bisphosphoglycerate (BPGA) (Reversible reaction).



**Fig 14.1 Steps of glycolysis**

**Step VI** 1, 3-bisphosphoglycerate is converted to 3-phosphoglycerate with the formation of ATP. This reaction is catalysed by an enzyme phosphoglycerate kinase. It is also known as energy yielding process. The formation of ATP directly from metabolites constitutes substrate level phosphorylation (Reversible reaction).

**Step VII** In the next step, 3-phosphoglycerate is subsequently isomerised to form 2-phosphoglycerate, catalysed by enzyme phosphoglyceromutase (Reversible reaction).

**Step VIII** In the presence of enzyme enolase and  $Mg^{2+}$ , with the loss of a water molecule, 2-phosphoglycerate is converted to Phosphoenol Pyruvate (PEP) (Reversible reaction).

**Step IX** High energy phosphate group of Phosphoenol Pyruvate (PEP) is transferred to a molecule of ADP, by the action of enzyme pyruvate kinase in the presence of  $Mg^{2+}$  and  $K^{+}$ . This in turn produces two molecules of pyruvic acid (pyruvate) and a molecule of ATP by substrate level phosphorylation. The pyruvic acid thus, produced is the key product of glycolysis.

### **Metabolic Fate of Glycolysis**

The overall reaction of glycolysis can be depicted as



\* Two molecules of NADH on oxidation produce 6 molecules of ATP. Therefore, a net gain of 8 ATP molecules occurs during glycolysis.

\* The fate of glycolysis depends upon the availability of oxygen in the cell. In the presence of oxygen, pyruvic acid will enter the mitochondrion and undergo complete oxidation of glucose to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  in aerobic respiration (Krebs' cycle).

\* On the other hand in the absence of oxygen, the pyruvic acid will undergo anaerobic respiration (lactic acid fermentation or alcoholic fermentation).

### **Note:**

\* Kostytscher (1902) coined the term anaerobic respiration.

\* Glycolysis has two phases, i.e., preparatory (glucose is broken down to glyceraldehyde-3-phosphate) and pay off phase (the GAL-3-PD4 is changed into pyruvate producing NADH and ATP).

### **Fermentation**

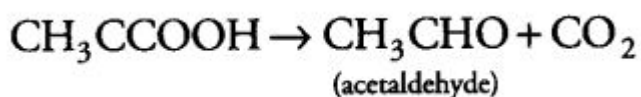
Various microorganisms, bacteria, animals and plants are known to catabolise pyruvic acid into various organic compounds depending upon the specific enzymes they possess.

### **Some of these types are as follows**

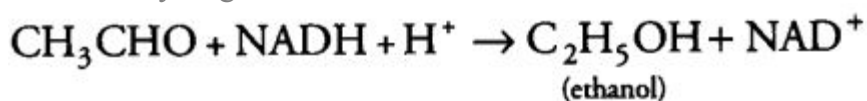
(i) During alcoholic fermentation, in fungi (e.g., yeast), and some higher plants, the incomplete oxidation of glucose is achieved under anaerobic condition by a series of reactions in which pyruvic acid is converted to  $\text{CO}_2$  and ethanol.

It is done under two steps

(a) Pyruvic acid is first decarboxylated to acetaldehyde in the presence of enzyme pyruvic acid decarboxylase.



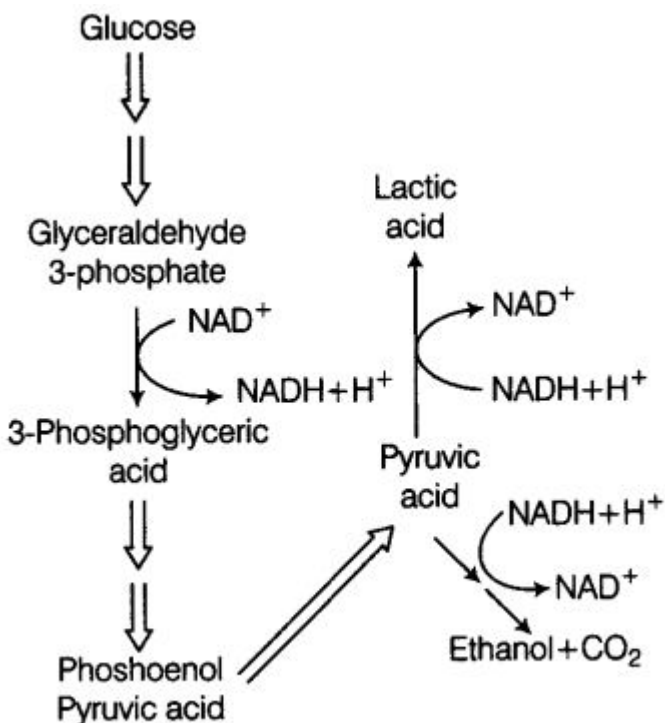
(b) This acetaldehyde is further reduced to ethyl alcohol or ethanol in the presence of enzyme, i.e., alcohol dehydrogenase.



(ii) During lactic acid fermentation, organisms like some bacteria produce lactic acid as an end product from pyruvic acid.

During the reduction, the pyruvic acid produced in glycolysis is reduced by  $\text{NADH}_2$  to form lactic acid.  $\text{CO}_2$  is not produced and  $\text{NADH}_2$  is oxidised to  $\text{NAD}^{+}$ .

This reaction is catalysed by an lactic acid dehydrogenase, FMN proteins and  $\text{Zn}^{2+}$  ions.



**Fig 14.2 Major pathways of anaerobic respiration**

Likewise, in case of animal cells also (such as muscles) during exercise, when there is inadequate amount of oxygen for cellular respiration, pyruvic acid is reduced to lactic acid by lactate dehydrogenase.

Thus, in both the processes reoxidation of reducing ( $\text{NADH} + \text{H}^+$ ) agent takes place.

### Energy Yield in Fermentation

In both alcoholic and lactic acid fermentation, the energy released is very less, i.e., not more than 7% of the energy is released from glucose and not all of it is trapped as high energy bonds of ATP. Also, the fermentation processes are proved to be hazardous in nature because either acid or alcohol is produced on oxidation. Apart from this, yeasts may also poison themselves to death if the concentration of alcohol reaches about 13%.

Drawback of this process is that organisms cannot carry out complete oxidation of glucose and are also unable to extract out the energy stored to synthesise a larger number of ATP molecules required for cellular metabolism.

### Differences between Glycolysis and Fermentation

<b>Glycolysis</b>	<b>Fermentation</b>
It is the first step of respiration which occurs without requirement of oxygen and is common to both aerobic and anaerobic mode of respiration.	It is anaerobic respiration which does not require oxygen.
It produces pyruvic acid.	Fermentation produces different products. The common ones are ethanol (and $\text{CO}_2$ ) and lactic acid.
It produces two molecules of NADH per glucose molecule.	It generally utilises NADH produced during glycolysis.
Glycolysis forms 2ATP molecules per glucose molecule.	It does not produce ATP.

## **Aerobic Respiration**

Aerobic respiration is the next step (after glycolysis) that leads to complete oxidation of organic substances. It occurs in the presence of oxygen. The oxygen acts as a final acceptor of electron and protons are removed from the substrate. For aerobic respiration to take place within the mitochondria, the final product of glycolysis, i.e., pyruvic acid is transported into from the cytoplasm mitochondria and thus, the second phase of respiration is initiated.

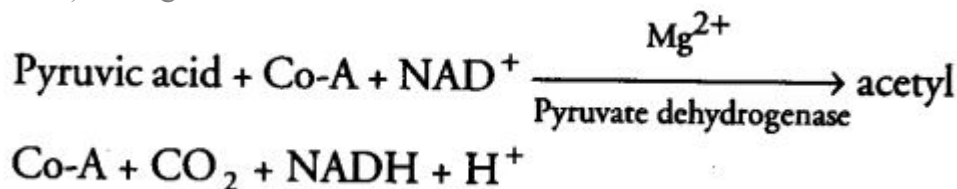
### **The process of aerobic respiration involves two crucial events**

(i) The complete oxidation of pyruvate occurs by the step-wise removal of all the hydrogen atoms, thereby, leaving three molecules of CO<sub>2</sub>. This occurs in the matrix of mitochondria.

(ii) The electrons removed as part of the hydrogen atoms are then passed on to molecular O<sub>2</sub> with the simultaneous synthesis of ATP. This on the contrary takes place on the inner membrane of the mitochondria.

### **Oxidative Decarboxylation of Pyruvic Acid**

In mitochondria, pyruvic acid (formed by the glycolytic catabolism of carbohydrates in cytosol) undergoes oxidative decarboxylation (i.e., removal of CO<sub>2</sub> in aerobic conditions) forming a key compound, i.e., acetyl Co-A by the action of pyruvic acid dehydrogenase (in mitochondrial matrix) through a series of reactions.



Thus, acetyl Co-A acts as a connecting link between glycolysis and citric acid cycle.

During this process, two molecules of NADH are produced from the metabolism of two molecules of pyruvic acid (produced from one glucose molecule during glycolysis).

### **Tricarboxylic Acid (TCA) Cycle**

The acetyl Co-A then enters a cyclic pathway, Krebs' cycle (or tricarboxylic acid cycle, TCA) in mitochondrial matrix. Various coenzymes including NAD<sup>+</sup> and Co-A also participates in the reaction catalysed by pyruvic acid dehydrogenase.

It was first elucidated by Sir Hans Krebs, a British Biochemist in 1940.

The whole cycle explains how pyruvate is broken down to CO<sub>2</sub> and water.

### **Following are the steps of Krebs' cycle**

(i) Condensation The Krebs' cycle starts with the condensation of acetyl group with oxaloacetic acid and water to yield citric acid, a 6C compound. This is the first stable product of the cycle.

This step is catalysed by an enzyme citrate synthetase. Co-A is liberated during this reaction.

(ii) Citric acid then undergoes reorganisation in two steps in order to form in the presence of an enzyme aconitase. intermediate

(iii) Oxidative decarboxylation Isocitrate is followed by two successive steps of oxidative decarboxylation, that leads to the formation of α-ketoglutaric acid, (a 5C compound in the presence of an enzyme isocitrate dehydrogenase and Mn<sup>2+</sup>) and then succinyl Co-A, catalysed by α-ketoglutarate dehydrogenase.

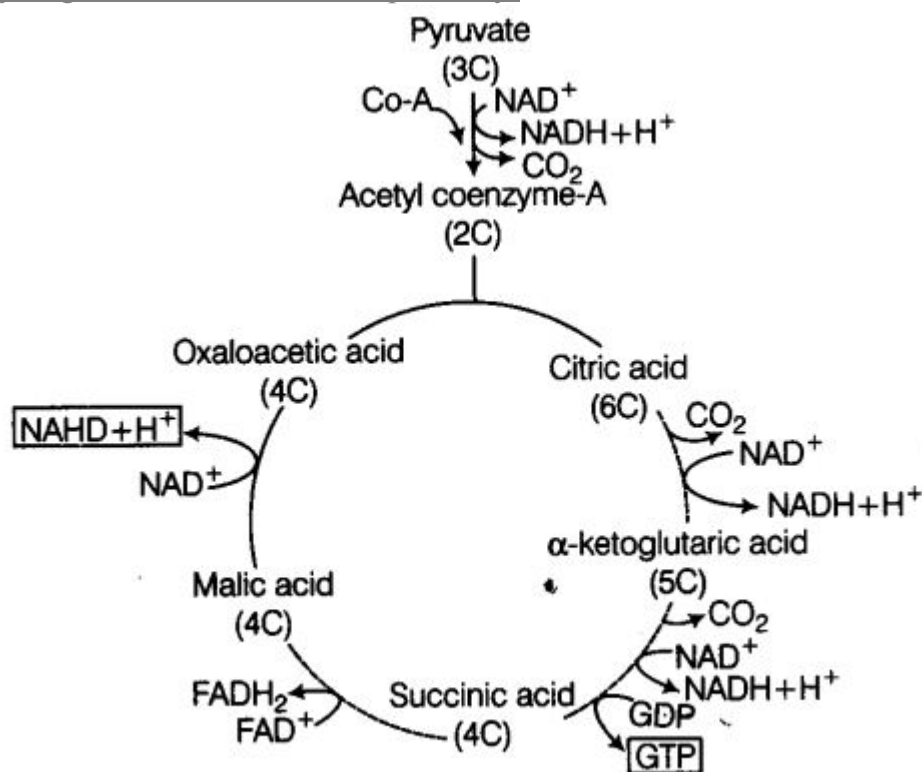
The succinyl Co-A then splits into a 4C compound succinic acid and Co-A with the addition of water. During this conversion, a molecule of GTP (guanosine triphosphate) is synthesised catalysed by an enzyme succinyl Co-A synthetase (this occurs when co-enzyme A transfers its high energy to a phosphate group that joins GDP forming GTP).

(i) GTP is also an energy carrier like ATP. Thus, this is the only high energy phosphate produced in the Krebs' cycle.

(ii) In plants cells, this reaction also produces ATP from ADP.

In the remaining steps of Krebs' cycle, succinyl Co-A is oxidised to oxaloacetic acid, a 4C compound following the formation of fumaric acid and malic acid catalysed by enzymes succinate dehydrogenase and malate dehydrogenase.

dehydrogenase and fumarate respectively.



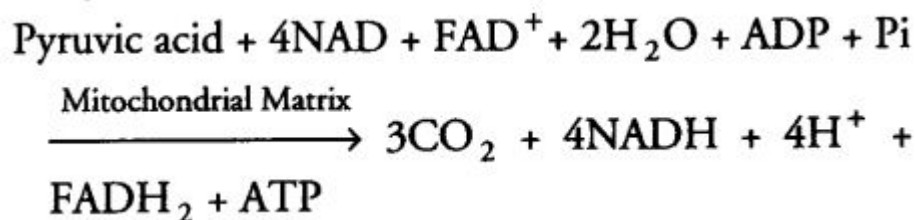
**Fig 14.3** The citric acid cycle

### Output of Krebs' Cycle or Citric Acid Cycle

During this cycle of reactions, 3 molecules of NAD<sup>+</sup> are reduced to NADH + H<sup>+</sup>, and one molecule of FAD<sup>+</sup> is reduced to FADH<sub>2</sub>. And also one molecule of ATP is reduced directly from GTP (by substrate level phosphorylation).

For continuous oxidation of acetyl Co-A, continued replenishment of oxaloacetic acid is necessary. In addition to this regeneration of NAD<sup>+</sup> and FAD<sup>+</sup> from NADH and FADH<sub>2</sub> respectively are also required.

The summary equation for this phase of respiration is as follows



Till now, glucose has been broken down to release CO<sub>2</sub> and 8 molecules of NADH+H<sup>+</sup>, two FADH<sub>2</sub> are synthesised and just two molecules of ATP.

### Importance of Citric Acid Cycle

The citric acid cycle is important in the following ways

- (i) This is the major pathway for the formation of ATP molecules.
- (ii) Many intermediate compounds of this cycle are used in the synthesis of other biomolecules.

### Differences between glycolysis and Krebs' cycle

<b>Glycolysis</b>	<b>Krebs' Cycle</b>
It takes place in the cytoplasm.	It takes place in the matrix of mitochondria.
It is a linear pathway.	It is a cyclic pathway.
It occurs in aerobic as well as anaerobic respiration.	It occurs in aerobic respiration only.
It consumes 2 ATP molecules.	It does not consume ATP.
It yields 2 NADH per glucose molecule.	It yields 6 NADH molecules and 2 FADH <sub>2</sub> molecules from 2 acetyl coenzyme-A molecules.
It generates 2 ATP molecules net from 1 glucose molecule.	It generates 2 GTP/ATP molecules from 2 acetyl coenzyme-A molecules.
It oxidises glucose partly, producing pyruvate.	It oxidises acetyl coenzyme-A fully.
It does not produce CO <sub>2</sub> .	It produces CO <sub>2</sub> .
All enzymes catalysing glycolytic reactions are dissolved in cytosol.	Two enzymes of Krebs' cycle reactions are located in the inner mitochondrial membrane, all others are dissolved in matrix.

## Exercices

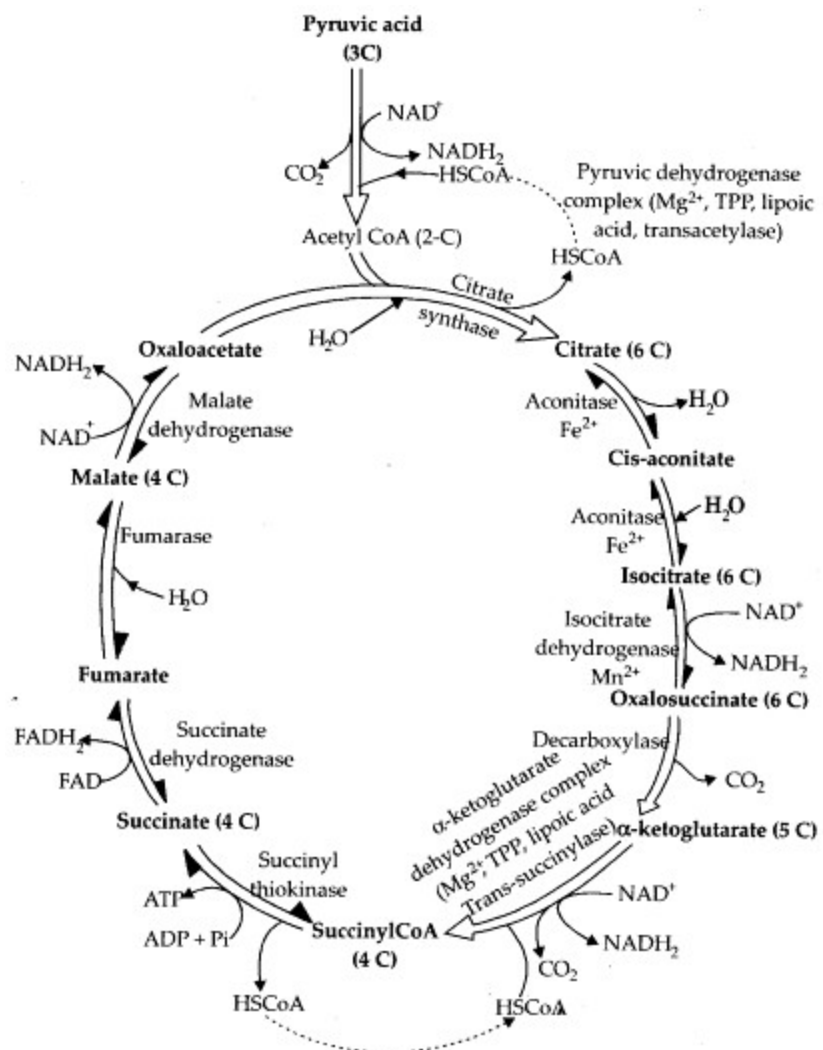


Fig.: Schematic representation of Krebs' cycle

	<b>Respiration</b>	<b>Combustion</b>
(i)	It occurs inside living cells.	It is a noncellular process.
(ii)	Respiration is a biochemical process.	Combustion is a physio-chemical process.
(iii)	Energy is released in stages as chemical bonds are broken in steps.	Energy is released in a single step as all chemical steps occur simultaneously.
(iv)	Most of the energy is trapped in ATP molecules.	ATP is not formed.
(v)	Oxidation occurs at the end of reaction (terminal oxidation) between reduced coenzymes and oxygen.	The substrate is directly oxidised in combustion.
(vi)	A number of intermediates are formed. They are used in the synthesis of different organic compounds	No intermediates are produced in combustion.
(vii)	A number of enzymes are required, one for each step or reaction.	Burning is a non-enzymatic process.
(viii)	Less than 50% energy is liberated in the form of heat energy. Light is rarely produced.	Energy is liberated in the form of both light and heat energy.
(ix)	Temperature is not allowed to rise.	Temperature becomes very high.

	<b>Glycolysis</b>	<b>Krebs' cycle</b>
(i)	It occurs inside the cytoplasm.	Krebs' cycle operates inside mitochondria.
(ii)	Glycolysis is the first step of respiration in which glucose is broken down to the level of pyruvate.	Krebs' cycle is the second step in respiration where an active acetyl group is broken down completely.
(iii)	The process is common to both aerobic and anaerobic modes of respiration.	It occurs only in aerobic respiration.
(iv)	It degrades a molecule of glucose into two molecules of an organic substance, pyruvate.	It degrades pyruvate completely into inorganic substances ( $\text{CO}_2 + \text{H}_2\text{O}$ ).
(v)	Glycolysis consumes 2 ATP molecules for the initial phosphorylation of substrate molecule.	It does not consume ATP.

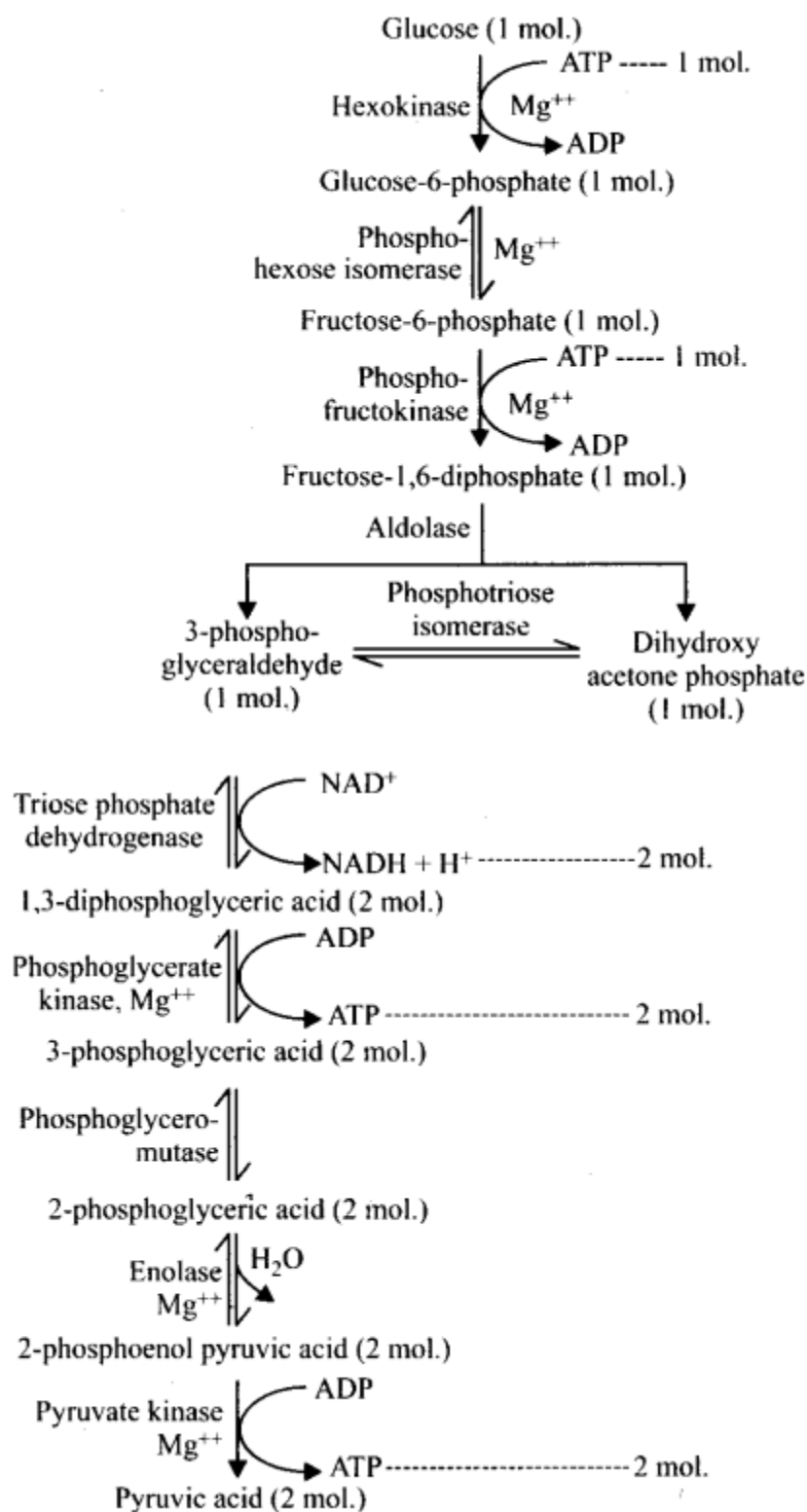
	<b>Aerobic respiration</b>	<b>Fermentation</b>
(i)	It uses oxygen for breaking the respiratory material into simpler substances.	Oxygen is not used in the breakdown of respiratory substrate.
(ii)	Respiratory material is completely oxidised.	Respiratory material is incompletely broken.
(iii)	The end products are inorganic.	At least one of the end products is organic. Inorganic substances may or may not be produced.
(iv)	Aerobic respiration is the normal mode of respiration of plants and animals.	It is the normal mode of respiration in some parasitic worms and microorganisms. In others, anaerobic respiration is a stop-gap arrangement.
(v)	Aerobic respiration consists of three steps –glycolysis, Krebs' cycle and terminal oxidation.	Anaerobic respiration or fermentation consists of two steps – glycolysis and incomplete breakdown of pyruvic acid.
(vi)	Every carbon atom of the food is oxidised and a large quantity of carbon dioxide is evolved.	Less quantity of carbon dioxide is evolved.
(vii)	Water is formed.	Water is usually not formed.
(viii)	686 kcal of energy are produced per gm mole of glucose.	Only 39-59 kcal of energy are formed per gm mole of glucose.
(ix)	It continues indefinitely.	It cannot continue indefinitely (except in some micro-organisms) because of the accumulation of poisonous compounds and less availability of energy per gm mole of food broken.

### **3. What are respiratory substrates? Name the most common respiratory substrate.**

**Solution:** Respiratory substrates are those organic substances which are oxidised during respiration to liberate energy inside the living cells. The common respiratory substrates are carbohydrates, proteins, fats and organic acids. The most common respiratory substrate is glucose. It is a hexose monosaccharide.

#### 4. Give the schematic representation of glycolysis.

**Solution:**



**Fig.:** Glycolysis or EMP-pathway.

#### 5. Explain ETS.

**Solution:** An electron transport chain or system (ETS) is a series of coenzymes and cytochromes that take part in the passage of electrons from a chemical to its ultimate acceptor. Reduced coenzymes participate in electron transport chain. Electron transport takes place on cristae of mitochondria [oxysomes (  $F_0$ - $F_1$  particles) found on the inner surface of the membrane of mitochondria]. NADH formed in glycolysis and citric acid

cycle are oxidised by NADH dehydrogenase (complex I) and the electrons are transferred to ubiquinone. Ubiquinone also receives reducing equivalents via FADH<sub>2</sub> through the activity of succinate dehydrogenase (complex II). The reduced ubiquinone is then oxidised by transfer of electrons of cytochrome c via cytochrome Fc, complex (complex III). Cytochrome c acts as a mobile carrier between complex III and complex IV. Complex IV refers to cytochrome c oxidase complex containing cytochromes a and a<sub>3</sub> and two copper centres. When the electrons are shunted over the carriers via complex I to IV in the electron transport chain, they are coupled to ATP synthetase (complex V) for the formation of ATP from ADP and Pi. Oxygen functions as the terminal acceptor of electrons and is reduced to water along with the hydrogen atoms. Reduced coenzymes (coenzyme I, II and FAD) do not combine directly with the molecular O<sub>2</sub>. Only their hydrogen or electrons are transferred through various substances and finally reach O<sub>2</sub>. The substances useful for the transfer of electron are called electron carriers. Only electrons are transferred through cytochromes (Cyt F<sub>1</sub>, Cyt c, C<sub>2</sub>, a, a<sub>3</sub>) and finally reach molecular O<sub>2</sub>. Both cytochrome a and a<sub>3</sub> form a system called cytochrome oxidase. Copper is also present in Cyt a<sub>3</sub> in addition to iron. The molecular oxygen that has accepted electrons now receives the protons that were liberated into the surrounding medium to give rise to a molecule of water. The liberated energy is utilised for the synthesis of ATP from ADP and Pi.

#### **6. What are the main steps in aerobic respiration? Where does it take place?**

**Solution:** Aerobic respiration is an enzymatically controlled release of energy in a stepwise catabolic process of complete oxidation of organic food into carbon dioxide and water with oxygen acting as terminal oxidant. It occurs by two methods, common pathway and pentose phosphate pathway. Common pathway is known so because its first step, called glycolysis, is common to both aerobic and anaerobic modes of respiration. The common pathway of aerobic respiration consists of three steps – glycolysis, Krebs' cycle and terminal oxidation. Aerobic respiration takes place within mitochondria. The final product of glycolysis, pyruvate is transported from the cytoplasm into the mitochondria.

#### **7. What are the assumptions made during the calculation of net gain of ATP?**

**Solution:** It is possible to make calculations of the net gain of ATP for every glucose molecule oxidised; but in reality this can remain only a theoretical exercise. These calculations can be made only on certain assumptions that:

- There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway following one after another. transferred into the mitochondria and undergoes oxidative phosphorylation.
- None of the intermediates in the pathway are utilised to synthesise any other compound.
- Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.

But these kind of assumptions are not really valid in a living system; all pathway work simultaneously and do not take place one after another; substrates enter the pathways and are withdrawn from it as and when necessary; ATP is utilised as and when needed; enzymatic rates are controlled by multiple means. Hence, there can be a net gain of 36 ATP molecules during aerobic respiration of one molecule of glucose.

#### **8. Distinguish between the following:**

**(a) Aerobic respiration and Anaerobic respiration.**

**(b) Glycolysis and Fermentation.**

**(c) Glycolysis and Citric acid cycle.**

**Solution:** (a) Differences between aerobic and anaerobic respiration are as follows:

Aerobic respiration	Anaerobic respiration
Aerobic respiration is a type of respiration in which foodstuffs (usually carbohydrates) are completely oxidised to carbon dioxide and water, with the release of chemical energy, in a process requiring atmospheric oxygen. The reaction can be summarized by the equation: $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}$	Anaerobic respiration is a type of respiration in which foodstuffs (usually carbohydrates) are partially oxidised, with the release of chemical energy, in a process not involving atmospheric oxygen. Since the substrate is never completely oxidised the energy yield of this type of respiration is lower than that of aerobic respiration. It occurs in some yeasts and bacteria and in muscle tissue when oxygen is absent.

(b) Differences between glycolysis and fermentation are as follows:

	Glycolysis	Fermentation
(i)	It is the first step of respiration which occurs without requirement of oxygen and is common to both aerobic and anaerobic modes of respiration.	It is anaerobic respiration or respiration which does not require oxygen.
(ii)	Glycolysis produces pyruvic acid.	Fermentation produces different products. The common ones are ethanol (and $\text{CO}_2$ ) and lactic acid.
(iii)	It produces two molecules of NADH per glucose molecule.	It generally utilises NADH produced during glycolysis.
(iv)	It forms 2 ATP molecules per glucose molecule.	It does not produce ATP.

### 9. Discuss “The respiratory pathway is an amphibolic pathway”.

**Solution:** Amphibolic pathway is the one which is used for both breakdown (catabolism) and build-up (anabolism) reactions. Respiratory pathway is mainly a catabolic process which serves to run the living system by providing energy. The pathway produces a number of intermediates. Many of them are raw materials for building up both primary and secondary metabolites. Acetyl CoA is helpful not only in Krebs' cycle but is also raw material for synthesis of fatty acids, steroids, terpenes, aromatic compounds and carotenoids,  $\alpha$ -ketoglutarate is organic acid which forms glutamate (an important amino acid) on amination. OAA (Oxaloacetic acid) on amination produces aspartate. Both aspartate and glutamate are components of proteins. Pyrimidines and alkaloids are other products. Succinyl CoA forms cytochromes and chlorophyll. Hence, fatty acids would be broken down to acetyl CoA before entering the respiratory pathway when it is used as a substrate. But when the organism needs to synthesise fatty acids, acetyl CoA would be withdrawn from the respiratory pathway for it. Hence, the respiratory pathway comes into the picture both during breakdown and synthesis of fatty acids. Similarly, during breakdown and synthesis of proteins too, respiratory intermediates form the link. Breaking down processes within the living organism is catabolism, and synthesis is anabolism. Because the respiratory pathway is involved in both anabolism and catabolism, it would hence be better to consider the respiratory pathway as an amphibolic pathway rather than as a catabolic one.

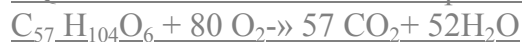
### 10. Define RQ. What is its value for fats?

**Solution:** Respiratory quotient (RQ) is the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed in respiration over a period of time. Its value can be one, zero, more than 1 or less than one.

$$\text{RQ} = \frac{\text{Volume of CO}_2 \text{ evolved}}{\text{Volume of O}_2 \text{ consumed}}$$

Volume of CO<sub>2</sub> evolved    Volume of O<sub>2</sub> consumed

RQ is less than one when the respiratory substrate is either fat or protein.



$$\text{RQ} = 57\text{CO}_2 / 80\text{O}_2 = 0.71$$

RQ is about 0.7 for most of the common fats.

### **11. What is oxidative phosphorylation?**

**Solution:** Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH, FADH<sub>2</sub>) produced in respiration. The enzyme required for this synthesis is called ATP synthase. It is considered to be the fifth complex of electron transport chain. ATP synthase is located in FT or head piece of F<sub>0</sub>-F<sub>1</sub> or elementary particles. The particles are present in the inner mitochondrial membrane. ATP synthase becomes active in ATP formation only where there is a proton gradient having higher concentration of H<sup>+</sup> or protons on the F<sub>0</sub> side as compared to F<sub>1</sub> side (chemiosmotic hypothesis of Peter Mitchell).

Increased proton concentration is produced in the outer chamber or outer surface of inner mitochondrial membrane by the pushing of proton with the help of energy liberated by passage of electrons from one carrier to another. Transport of the electrons from NADH over ETC helps in pushing three pairs of protons to the outer chamber while two pairs of protons are sent outwardly during electron flow from FADH<sub>2</sub>. The flow of protons through the F<sub>0</sub> channel induces F<sub>1</sub> particle to function as ATP-synthase. The energy of the proton gradient is used in attaching a phosphate radical to ADP by high energy bond. This produces ATP. Oxidation of one molecule of NADH<sub>2</sub> produces 3 ATP molecules while a similar oxidation of FADH<sub>2</sub> forms 2 ATP molecules.

### **12. What is the significance of step-wise release of energy in respiration?**

**Solution:** The utility of step-wise release of energy in respiration are given as follows :

- (i) There is a step-wise release of chemical bond energy which is very easily trapped in forming ATP molecules.
- (ii) Cellular temperature is not allowed to rise.
- (iii) Wastage of energy is reduced.
- (iv) There are several intermediates which can be used in production of a number of biochemicals.
- (v) Through their metabolic intermediates different substances can undergo respiratory catabolism.
- (vi) Each step of respiration is controlled by its own enzyme. The activity of different enzymes can be enhanced or inhibited by specific compounds.

This helps in controlling the rate of respiration and the amount of energy liberated by it.

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