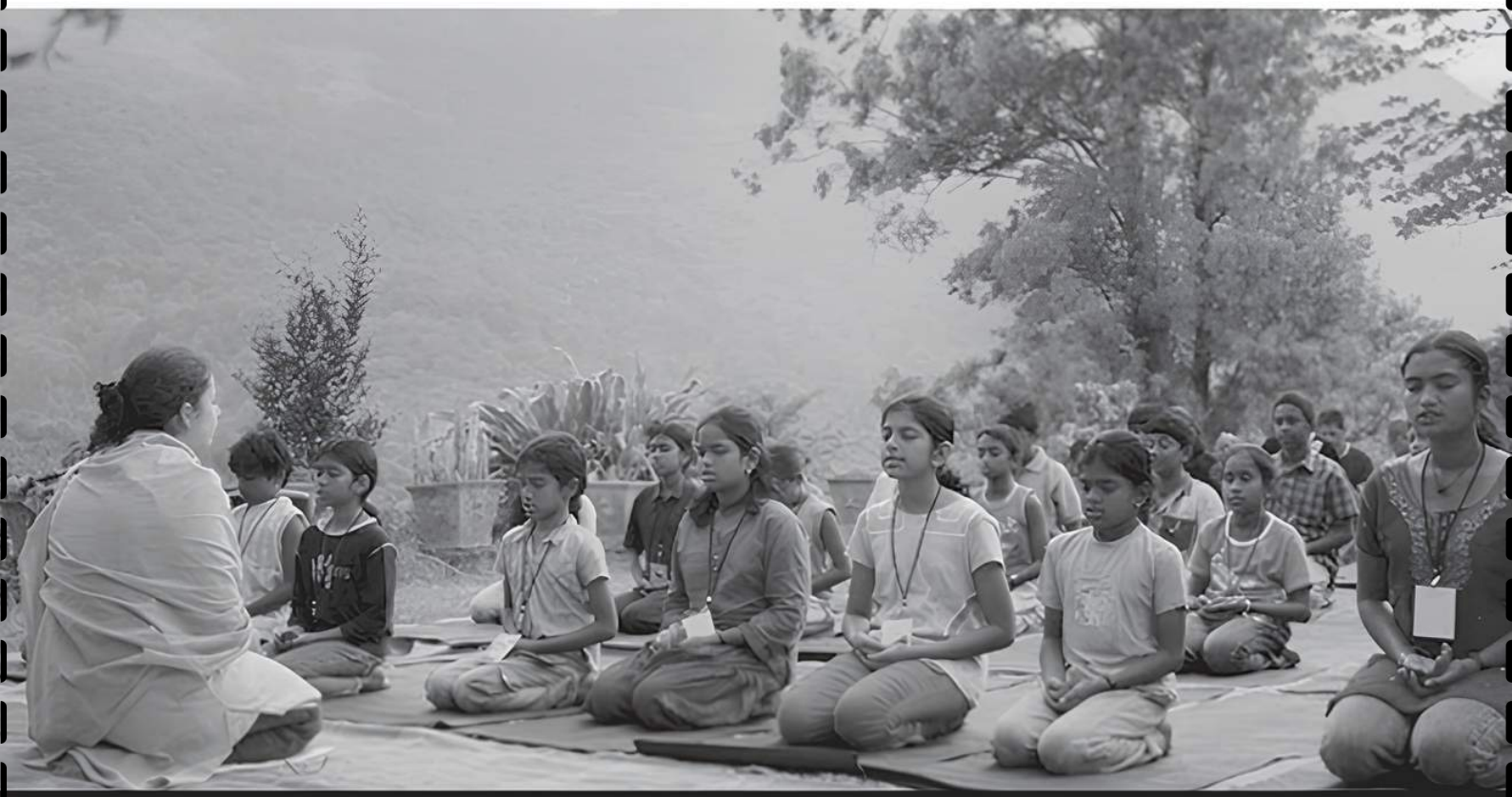
12

Respiration in Plants



We already know the health benefits that Yoga provides to the human organism as a result of extensive study and countless applications, we can conclude that we can utilise it as a tool for improving our health in the twenty-first century. Yoga is built on the foundation of breathing, which allows plants to play an important role in air purification.

Topic Notes

- *Respiration and Glucose*

RESPIRATION AND GLUCOSE 1

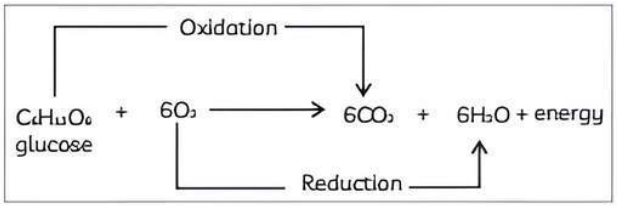
TOPIC 1

RESPIRATION

Respiration can be defined as an energy-releasing enzymatically controlled catabolic process which involves a step-wise oxidative breakdown of food substances inside the living cells.

Respiration refers to the breaking of the carbon-carbon bonds of the complex compounds by oxidation within the cells which leads to release of energy. This energy is utilised in the synthesis of ATP. Compounds that are oxidised during this process are known as respiratory substrates.

Plants need oxygen to breathe, yet they emit carbon dioxide. Stomata in the leaves and lenticels in the stems allow for gas exchange. There is a very little gas transmission from one section to another. There are no high demands for breathing as found in mammals. Plants have living cells that are near to the surface.



Oxidation of glucose

(1) In the presence of oxygen, during respiration carbon dioxide and water is released as by-products along with a high amount of energy.

(2) In absence of oxygen, all living things have the enzymatic equipment to partly oxidise glucose and very little amount of energy is produced.

Example 1.1: What are respiratory substrates? Name the most common respiratory substrate. [NCERT]

Ans. Respiratory substrates are organic compounds that are oxidised during respiration in order to release energy within living cells. Carbohydrates, proteins, lipids, and organic acids are the most prevalent respiratory substrates. Glucose is the most common respiratory substrate. It is a monosaccharide made up of hexose sugars.

Glycolysis

The word glycolysis stands for the splitting of sugar.

It is also called EMP pathway because it was discovered by three German scientists – Gustav Embden, Otto Meyerhof and J Parnas in 1930. Glycolysis is the process of partial oxidation of glucose or similar hexose sugar into two molecules of pyruvic acid through a series of 10 enzyme-mediated reactions releasing some energy (as ATP) and reducing power (as $NADH_2$). It occurs in cytosol or cytoplasm. Glycolysis is common in the both aerobic and anaerobic modes of respiration. So, this is called universal pathway of respiration.

It is the first stage of glucose breakdown in aerobic respiration and the only step in glucose breakdown in anaerobic respiration. Glycolysis has two phases, preparatory and payoff. In the preparatory phase, glucose is broken down to glyceraldehyde 3-phosphate. In payoff phase, the latter is changed into pyruvate producing NADH and ATP.

Steps of Glycolysis

(1) Glucose is derived from sucrose.

(2) Sucrose is converted into glucose and fructose by invertase (enzyme).

(3) These two monosaccharides enter to glycolysis pathway.

(4) Hexokinase phosphorylates glucose and fructose to produce glucose-6-phosphate.

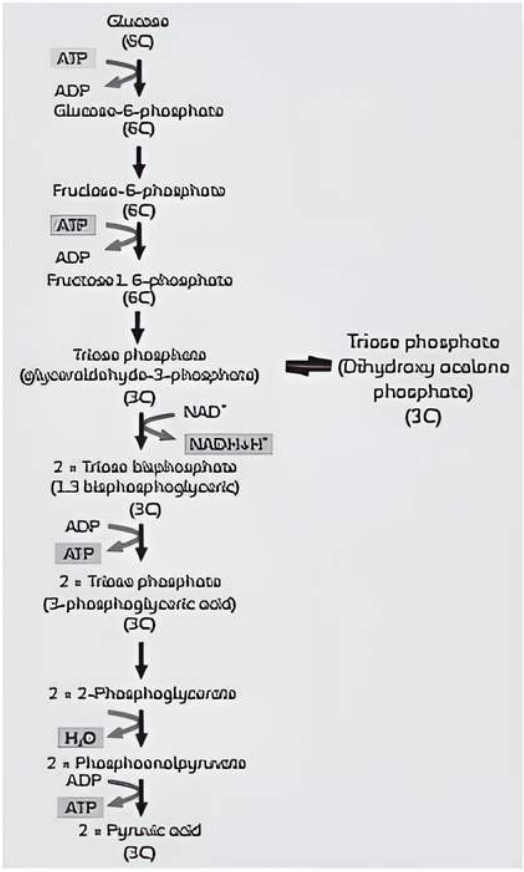
(5) This phosphorylated glucose isomerises to produce fructose-6-phosphate.

(6) Fructose-6-Phosphate is converted into Fructose-1,6-Bisphosphate.

(7) Aldolase converts Fructose-1,6-Bisphosphate to GLAP (Glyceraldehyde-3-Phosphate) or DHAP (Dihydroxy acetone phosphate).

(8) Which is further converted into 1,3 Bisphospho -glycerate by GLAP Hydrogenase.

(9) 1, 3 Bisphosphoglycerate is converted into 3-Phosphoglycerate by Phosphoglycerate Kinase.



Steps of glycolysis

(10) Phosphoglycerate Mutase converts 3-Phosphoglycerate to 2-Phosphoglycerate, which is further converted by Enolase into Phosphoenol Pyruvate.

(11) Phosphoenol pyruvate is converted to Pyruvate by Pyruvate kinase.

(12) ATP is utilised in two steps:

(i) Conversion of glucose to glucose-6-phosphate.

(ii) Conversion of fructose-6-phosphate to fructose-1,6-bisphosphate.

Important

➥ *There are three fates of pyruvic acid which is produced during glycolysis. These are lactic acid fermentation, alcoholic fermentation and aerobic respiration. Pyruvic acid is the key product of glycolysis.*

Fermentation

Lactic acid is produced in muscles during heavy exercise. It is produced in large quantities in skeletal muscles in humans. The conversion of pyruvate into lactic acid in lack of oxygen during exercise is called lactic acid fermentation. This lactic acid is produced as a result of incomplete oxidation due to inadequate oxygen supply to the muscles. Incomplete oxidation of glucose occurs when anaerobic conditions are present. Pyruvate is broken down to produce ethanol and carbon dioxide in alcoholic fermentation. The amount of energy generated is really very low. If manufactured in uncontrolled quantities, the process is dangerous.

Important

➥ *Fermentation takes place in the absence of oxygen in bacteria (Rhizopus), some fungi and yeast, where Ethyl alcohol is produced. Whereas, LAB (Lactic Acid Bacteria -Lactobacillus) and muscles of humans do anaerobic respiration but form lactic acid as an end product.*

Example 1.2: Case Based:

Rahul was exercising after a long break after finishing his work. He felt pain in his muscles. He told his friend about the same in the evening. His friend told him not to worry it is just cramps and explained to him that there is the acid production in the skeletal muscles during exercise, due to an inadequate supply of oxygen to the muscles. It results in muscle pain commonly called cramps. But he did not know the exact name of the acid. Next day both friends went to school and enquired about it with the teacher. They asked the following questions to help the teacher in answering their doubts and made notes.

(A) Acid produced is:

(a) Lactic acid **(b) Acetic acid**

(c) Citric acid **(d) Pyruvic acid**

(B) Enzyme involved is:

(a) Lactate dehydrogenase

(b) Pyruvate dehydrogenase

(c) Hexokinase

(d) Isomerase

(C) Draw a rough flow chart showing the reaction of the above event.

(D) Give a reason for cramps.

(E) Assertion (A): Fermentation occurs in yeast.

Reason (R): Anaerobic respiration takes place in the absence of oxygen.

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true and R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

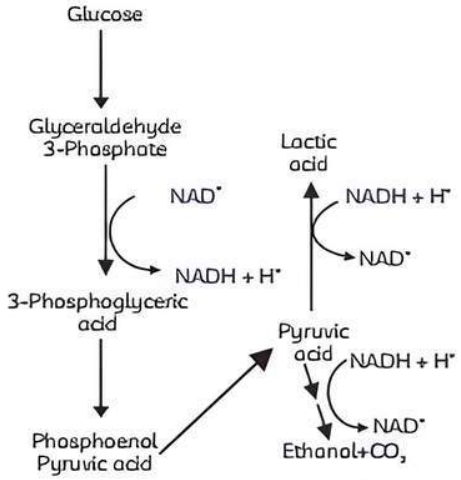
Ans. (A) *(a) Lactic acid*

Explanation: Lactic acid is produced due to less supply of oxygen in the skeletal muscles during heavy exercise.

(B) *(a) Lactate dehydrogenase*

Explanation: Pyruvic acid is reduced to lactic acid by the help of enzyme lactate dehydrogenase.

(C)



Lactic acid produced in skeletal muscle reaction

(D) In humans, after heavy exercise it causes cramps. It is due to the production of lactic acid in the muscles and its accumulation causes pain. This lactic acid is produced as a result of incomplete oxidation of glucose due to inadequate oxygen supply to the muscles.

(E) *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: Anaerobic respiration is a kind of respiration that allows cells to break down carbohydrates for energy production in the absence of oxygen. This is in contrast to aerobic respiration, which is a highly efficient energy-producing mechanism that relies on oxygen.

TOPIC 2

AEROBIC RESPIRATION

Having a glass of glucose in between playing, during summer gives instant energy to our body. Ever wondered why is it so? Why don't we instead have a sandwich? Because glucose is a monosaccharide which requires no digestion. When any person uses glucose, it directly absorb in our body and readily oxidises to give us energy in our cells.

It is an enzymatically controlled release of energy in a stepwise catabolic process of complete oxidation of organic food into CO_2 and H_2O with O_2 acting as a terminal oxidant.

The common pathway of aerobic respiration consists of three steps – glycolysis (common for both anaerobic and aerobic respiration), Krebs' cycle or TCA cycle, and Electron transport system and oxidative Phosphorylation.

Complete oxidation of organic substances or glucose molecules releases carbon dioxide, water and large amounts of energy.

Steps in Aerobic Respiration

Final product of glycolysis, *i.e.* pyruvate is transported from cytoplasm to mitochondria. Its two crucial steps are:

(1) Complete oxidation of pyruvate, leaving three molecules of carbon dioxide [occurs in matrix of mitochondria].

(2) Passing on of electrons to molecular oxygen, with production of ATP [occurs in inner membrane of mitochondria].

Oxidation of Pyruvate to Acetyl CoA:

$$\text{Pyruvate} + NAD^+ + CoA \xrightarrow[Mg^{2+}]{\text{Pyruvate dehydrogenase}} \text{Acetyl-CoA} + NADH + H^+ + CO_2 \uparrow$$

Conversion of pyruvate

Important

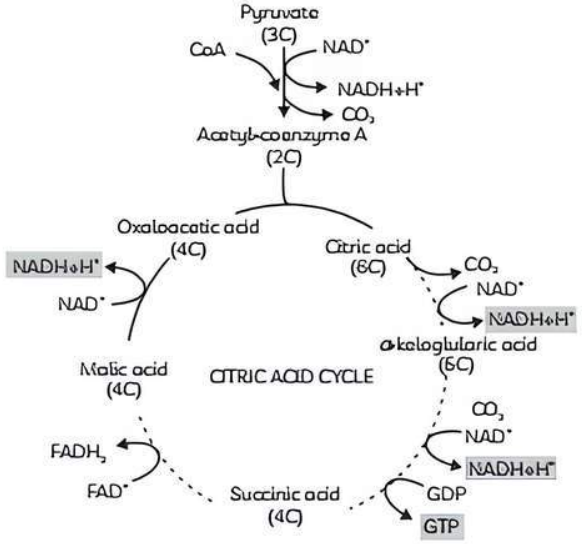
➥ *This reaction is also known as a link reaction as it links the glycolysis and TCA cycle.*

Tricarboxylic Acid Cycle (TCA Cycle)

Acetyl-CoA enters a cyclic pathway, *i.e.* Tricarboxylic Acid Cycle also known as Krebs' cycle as it was given by scientist Hans Krebs.

It occurs inside the matrix of mitochondria. The cycle is also known as Citric Acid Cycle (CAC) after the name of the first stable product of the cycle which is citric acid. TCA cycle is stepwise oxidative and cyclic degradation of activated acetate derived from pyruvate.

Acetyl group of acetyl-CoA condenses with oxaloacetate and water to produce citric acid. Above reaction is catalysed by enzyme citrate synthase and a molecule of CoA is released.



Citric acid cycle

Important

➥ *Cycle requires continuous replenishment of Oxaloacetic acid, i.e. the first member of the cycle.*

➥ *Requires regeneration of NAD^+ and FAD^+ from NADH and $FADH_2$.*

➥ *Pyruvic acid + $4NAD^+$ + FAD^+ + $2H_2O$ + ADP + Pi*

$$\xrightarrow{\text{Mitochondrial Matrix}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

Example 1.3: Case Based:

In some schools, sports day was being organised. Rohan was a class 11^{th} student and also school sports captain. He was asked to make all the arrangements for the upcoming event since the sports teacher was on leave due to some emergency. He talked to the other respective teacher who was allotted the duty for the sports day and made the arrangements. He made a list of refreshments and included items like bananas, juices, glucose biscuits, glucose powder, etc. One of his friends came and told him why don't you add some tasty refreshments like samosa and some sweets that kids will like and enjoy. He said that they are making a list of refreshments for sports day and not for a party, everyone will be involved in physical activities and sitting under the sun would require high glucose for instant energy. His friend was confused and asked him certain questions, helping Rohan to address his classmate's doubts.

(A) Why are all glucose-based food items selected by Rohan?

(B) What does he mean by instant energy?

(C) Which process does our body follow?

(a) Anaerobic respiration
(b) Fermentation
(c) Aerobic respiration
(d) Transpiration

(D) Suggest him some more foods that can be added to his list.

(a) Samosa, coke
(b) Jalebi, laddoo
(c) Noodles, spring rolls
(d) Dry fruits, fruit juices

(E) Assertion (A): Glycolysis produces pyruvic acid from glucose.

Reason (R): Occurs in the cytoplasm of cell.

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true and R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

Ans. (A) All glucose-based food items are selected by him because these all have simple sugar that will readily break down and give energy to the body.

(B) Instant energy here means quick boost to energy levels since glucose is simplest sugar and is involved in first step of glycolysis, *i.e.* energy production. If he takes complex polysaccharides then first they will require to be broken into glucose and then only they will enter pathway since we give direct glucose liberating food it enters pathway instantly to give instant energy.

(C) *(c) Aerobic respiration*

Explanation: Aerobic respiration is the process of cellular respiration that produces energy from food in the presence of oxygen gas. Most plants and animals, including birds, humans, and other mammals, use this form of respiration. The final products of this process are water and carbon dioxide.

(D) *(d) Dry fruits, fruit juices*

Explanation: Honey, agave, molasses, dried fruit, fruits and fruit juices, etc., are all naturally high in pure glucose.

(E) *(b) Both A and R are true and R is not the correct explanation of A.*

Explanation: Glucose is converted into pyruvic acid through glycolysis, which takes place in cytoplasm. It refers to the splitting of sugar. It is also known as EMP pathway because it was discovered by three scientists named Embden, Meyerhof and Parnas in 1930. It occurs in all living organisms and forms the respiratory process in anaerobic and aerobic organisms. During glycolysis, glucose is partially oxidised, yielding two molecules of pyruvic acid.

Electron Transport System [ETS] and Oxidative Phosphorylation

These respiratory processes help to release and utilise energy stored in NADH + H^+ and $FADH_2$ molecules. The process is completed when these are oxidised through ETS and the electrons are transferred to O_2 to form H_2O.

It refers to the metabolic mechanism through which an electron is transferred from one carrier to another, it is present in the mitochondrial membrane.

Electrons from NADH (produced in the mitochondrial matrix during the TCA cycle) are oxidised by NADH Dehydrogenase (Complex I). Electrons are transferred to ubiquinone (inner mitochondrial membrane) and it also receives reducing equivalents *via* $FADH_2$ (Complex II) generated in TCA cycle. Reduced ubiquinone is oxidised with transfer of electrons to cytochrome c *via* cytochrome b and bc_1 complex (Complex III). Cytochrome c is a small protein acting as a mobile

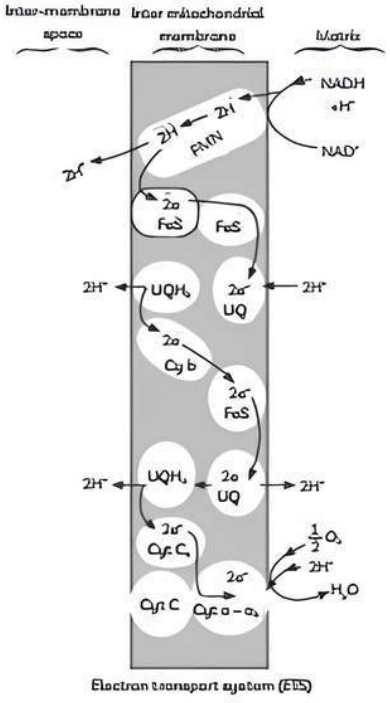
carrier for transfer of electrons between complex III and complex IV, its found attached to the outer surface of inner mitochondrial membrane. (Complex IV) is a cytochrome c oxidase complex containing cytochromes a and a_3 and two copper centres. Electrons pass from one carrier to another *via* Complex I to IV in ETC, they are coupled with ATP. Synthase (Complex V) thus producing ATP from ADP and inorganic phosphates.

Number of ATP molecules produced depends on the nature of the electron donor.

(1) One molecule of NADH gives 3 molecules of ATP.

(2) One molecule of $FADH_2$ produces 2 molecules of ATP.

Although the aerobic respiration takes place only in the presence of oxygen but the role of oxygen is limited, *i.e.* used in the terminal stage, but presence is vital. It drives the whole process by removing hydrogen from the system and acts as the final acceptor of hydrogen. Since energy of oxidation and reduction is utilised for producing a proton gradient which is essential for phosphorylation thus this process is termed as oxidative phosphorylation.



Example 1.4: What is oxidative phosphorylation? [NCERT]

Ans. Oxidative phosphorylation is the synthesis of an energy-rich molecule called ATP with the help of energy produced during the oxidation of reduced coenzymes (NADH, $FADH_2$) generated during respiration. ATP synthase is the enzyme which is responsible for ATP synthesis. ATP synthase is also considered as the fifth complex in electron transport chain. The ATP synthase is located in F_1 or head portion of F_0-F_1 or elementary particles. The particles are located in the inner membrane of mitochondria. For the functioning of ATP synthase, proton gradient is essential between intermembrane space and matrix of mitochondria. In other words, on the F_0 side, a higher concentration of H^+ or protons than on the F_1 side activates ATP synthase for ATP synthesis (chemiosmotic hypothesis of Peter Mitchell).

The pushing of protons with the assistance of energy freed by electrons passing from one carrier to another produces increased proton concentration in the outer chamber or outer surface of the inner mitochondrial membrane. Three pairs of protons are pushed to the outer chamber by electron transport from NADH through ETC, whereas two pairs of protons are propelled externally by electron flow from $FADH_2$. Protons flowing *via* the F_0 channel cause the F_1 particle to act as an ATP synthase. The energy of the proton gradient is utilised to form a high-energy bond between a phosphate radical and ADP. This results in the production of ATP. When one molecule of $NADH_2$ is oxidised, three ATP molecules are produced, but when $FADH_2$ is oxidised, two ATP molecules are produced.

The Respiratory Balance Sheet

Net gain of ATP can be calculated for every molecule of glucose broken down but it's just theoretical. The calculation of ATP synthesis from the complete oxidation of one molecule of glucose is based on assumption.

Following assumptions are made while making a respiratory balance sheet, which are enlisted below:

(1) 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.

(2) The NADH synthesised in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.

(3) None of the intermediates in the pathway are utilised to synthesise any other compound.

(4) Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.

But this kind of assumption does not work in living organisms, since substrates enter and leave the pathway as when needed. Approximately; breakdown of one molecule of glucose yields 36 ATP.

Difference between Fermentation and Aerobic Respiration.

Anaerobic Respiration / Fermentation	Aerobic Respiration
Takes place in absence of oxygen.	Takes place in presence of oxygen.

Occurs in cytoplasm.	Occurs in cytoplasm followed by mitochondria.
End products are ethanol and CO_2.	End products are water and CO_2.
Incomplete oxidation of substrate takes place.	Complete oxidation of substrate takes place.
Energy produced is low *i.e.*, only 2 ATP produced from each molecule of glucose.	High amount of energy produced, *i.e.* 36 ATP by one molecule of glucose.
Example: Yeast	Example: Higher plants and animals

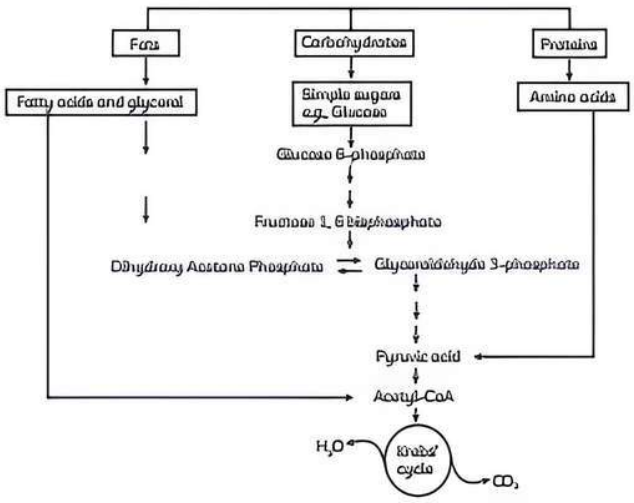
Amphibolic Pathway

Glucose is used as a substrate for respiratory pathway and energy synthesis, other molecules such as fats and proteins are also used but they cannot enter the respiratory pathway in the first step. All carbohydrates are converted into glucose, it can enter the very first step of the respiratory pathway.

Fats can enter the respiratory pathway, it needs to be broken into glycerol and fatty acids which are converted into acetyl-CoA and PGAL, respectively which then enters the respiratory pathway.

Proteins enter the pathway, first degraded into amino acids by proteases and amino acids enter the pathway after deamination, it then enters the respiratory pathway at some stage in Kreb's cycle, or as pyruvate or acetyl-CoA.

Respiratory pathway is termed as amphibolic pathway since substrates like carbohydrates, fats, and proteins the enter the respiratory pathway for synthesis, it is also withdrawn when there is a need for above-mentioned substrates. Thus, respiratory pathway is involved in both anabolism as well as catabolism, therefore it is known as an amphibolic pathway.



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

Respiratory Quotient

As we know, during aerobic respiration two things happen— O_2 is consumed and CO_2 is released.

Thus, respiratory quotient or respiratory ratio is given by:

$$RQ = \frac{\text{Volume of } CO_2 \text{ released}}{\text{Volume of } O_2 \text{ absorbed}}$$

Respiratory quotient or respiratory ratio for different substrates are as follows:

(1) For carbohydrates, RQ = 1, they are completely oxidised and equal amounts of oxygen and carbon dioxide are produced.

For example:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

$$RQ = \frac{6CO_2}{6O_2}$$

$$RQ = 1.0$$

(2) For proteins, RQ = 0.9 approximately.

(3) For fats and proteins, RQ is less than 1.

Example 1.5: Calculate the respiratory quotient for tripalmitin.

Ans.

$$\underset{\text{Tripalmitin}}{2(C_{51}H_{98}O_6)} + 145O_2 \longrightarrow 102CO_2 + 98H_2O + \text{energy}$$

$$RQ = \frac{102CO_2}{145O_2}$$

$$RQ = 0.7$$

Example 1.6: What is the significance of step-wise release of energy in respiration? [NCERT]

Ans. The utility of step-wise release of energy in respiration is given as follows:

A step-by-step release of chemical bond energy occurs, which is easily retained in the formation of ATP molecules. The temperature of the cells is not permitted to increase. Energy waste is decreased. A variety of intermediates can be utilised in the creation of a variety of biochemicals. Different compounds can undergo respiratory catabolism through their metabolic intermediates. Each phase of respiration has its own enzyme in charge. Specific substances can increase or decrease the activity of various enzymes. This aids in regulating the pace of breathing as well as the quantity of energy released.

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. Electron transport chain takes place in:
(a) Inner membrane space
(b) Inner mitochondrial membrane
(c) Matrix
(d) Cytoplasm

Ans. *(b) Inner mitochondrial membrane*

Explanation: It refers to the metabolic mechanism through which an electron is transferred from one electron carrier to another, it is present in the inner mitochondrial membrane.

Related Theory

These respiratory processes help to release and utilise the energy stored in $NADH+H^+$ and $FADH_2$. Process is completed when these are oxidised through ETS and the electrons are transferred to O_2 to form metabolic water. It refers to the metabolic mechanism through which an electron is transferred from one carrier to another, it is present in mitochondrial membrane.

2. Glycolysis occurs in:
(a) Cytoplasm
(b) Nucleus
(c) Mitochondria
(d) Endoplasmic reticulum
[NCERT Exemplar]

Ans. *(a) Cytoplasm*

Explanation: Glycolysis takes place in cytoplasm.

Related Theory

Glycolysis refers to the splitting of sugar. Scientists Gustav Embden, Otto Meyerhof, and J. Parnas presented it. Scientists have given it the term EMP Pathway. This substance is found in the cytoplasm of cells. It occurs in all living species and forms the respiratory process in anaerobic organisms. During glycolysis, glucose is partially oxidised, yielding two molecules of pyruvic acid.

3. Citric acid cycle occurs in:
(a) Cytoplasm
(b) Nucleus
(c) Mitochondrial matrix
(d) Intermembrane space

Ans. *(c) Mitochondrial matrix*

Explanation: Tricarboxylic Acid Cycle also known as citric acid cycle occurs in mitochondrial matrix. It is a part of aerobic respiration. This cycle uses the final product of glycolysis *i.e.*, pyruvate to produce NADH and $FADH_2$ that ultimately produces ATP after going through ETS.

Caution

Students usually get confused here, they should remember that ETS takes place in the inner mitochondrial membrane and Krebs' cycle in the mitochondrial matrix.

4. $FADH_2$ produces ..... molecules of ATP
(a) 2 **(b) 3**
(c) 5 **(d) 4**

Ans. *(a) 2*

Explanation: One molecule of $FADH_2$ produces 2 molecules of ATP through Electron Transport System.

Caution

Students usually make mistakes in such types of questions. They should remember that one molecule of NADH produces 3 molecules of ATP.

5. The ultimate electron acceptor of respiration in an aerobic organism is:
(a) Cytochrome **(b) Oxygen**
(c) Hydrogen **(d) Glucose**
[NCERT Exemplar]

Ans. *(b) Oxygen*

Explanation: The ultimate electron acceptor of respiration in an aerobic organism is oxygen.

6. Which of the following exhibits the highest rate of respiration?
(a) Growing shoot apex
(b) Germinating seed
(c) Root tip
(d) Leaf bud **[NCERT Exemplar]**

Ans. *(b) Germinating seed*

Explanation: Germinating seed exhibits the highest rate of respiration among the options provided.

7. Statement A: Fats yield less energy than carbohydrates or proteins.
Statement B: Fats have a higher carbon dioxide: oxygen ratio than do carbohydrates or proteins.
(a) Both A and B are correct.
(b) Both A and B are incorrect.
(c) Only A is correct.
(d) Only B is correct.

Ans. *(d) Only B is correct.*

Explanation: Fat molecules provide more energy than carbohydrates and are a significant

source of energy for the human body because one triglyceride molecule creates three fatty acid molecules, each of which can contain up to 16 carbons.

8. During Krebs' cycle isocitrate is converted into oxalo-succinate in the presence of enzyme isocitrate dehydrogenase and one of the following:

(a) Fe^{++} **(b)** Mn^{++}

(c) Mg^{++} **(d)** Na^{+} **[Diksha]**

Ans. *(b)* Mn^{++}

Explanation: Manganese has a big impact on idiophase metabolism. Cell growth rises, sugar intake lowers, and acidogenesis reduces dramatically when manganese is present.

9. Due to an inadequate supply of oxygen in animals, pyruvic acid is converted to:

(a) Lactic acid **(b) Ethanol + CO_2**

(c) Acetyl-CoA **(d) Glucose**

Ans. *(a) Lactic acid*

Explanation: Due to an inadequate supply of oxygen in muscles in animals, pyruvic acid is converted to lactic acid that causes muscle pain known as muscle cramps. It occurs due to accumulation of lactic acid in the muscle cells.

Caution

Students have a misconception that it occurs due to sudden extra exercise. Accumulation of lactic acid is the real scientific answer.

10. Glucose is converted into glucose-6-phosphate by:

(a) Hexokinase

(b) Isomerase

(c) Phosphofructokinase

(d) Kinase

Ans. *(a) Hexokinase*

Explanation: Glucose is converted into Glucose-6-phosphate by hexokinase during glycolysis. Hexokinase phosphorylates glucose and fructose to produce glucose-6-phosphate. This phosphorylated glucose isomerises to produce fructose-6-phosphate.

11. Conversion of glucose into acetyl-CoA releases:

(a) CO_2 **(b)** O_2

(c) SO_2 **(d)** N_2

Ans. *(a)* CO_2

Explanation: Conversion of glucose into acetyl-CoA releases CO_2. Final product of glycolysis, *i.e.* pyruvate is transported from cytoplasm to mitochondria. Complete oxidation of pyruvate, leaving three molecules of carbon dioxide (occurs in matrix of mitochondria).

12. Statement A: Fermentation is a wasteful process.

Statement B: It yields only 60% of the energy provided by aerobic respiration.

(a) Both A and B are correct.

(b) Both A and B are incorrect.

(c) Only A is correct.

(d) Only B is correct.

Ans. *(c) Only A is correct.*

Explanation: Fermentation is wasteful because only less than 7% of the energy that is present is liberated and converted to ATP. Additionally, it creates dangerous alcohol or acid.

13. What would happen if organisms need to synthesise fatty acids which had already broken down into acetyl-CoA?

(a) Acetyl-CoA would be withdrawn from the pathway

(b) Acetyl-CoA would be further broken down

(c) Ethanol would be released

(d) Glycerol would be released

Ans. *(a) Acetyl-CoA would be withdrawn from the pathway*

Explanation: When fatty acids are to be used as substrates, then they would be broken down to acetyl-CoA before entering the respiratory pathway, but when organisms need to synthesise fatty acids, acetyl-CoA would be withdrawn from the respiratory pathway for it.

14. Do all the respiratory pathways work simultaneously?

(a) No, not at all

(b) They take place one after the other

(c) Yes, they work simultaneously

(d) Sometimes they work independently

Ans. *(c) Yes, they work simultaneously*

Explanation: The assumptions made in the respiratory balance sheet are not valid for the living system. All pathways work simultaneously and do not take place one after another.

15. Statement A: For a complete breakdown of respiratory substrate, Krebs' cycle is essential.

Statement B: Krebs' cycle is associated with step-wise removal of all the hydrogen and O_2 molecules.

(a) Both A and B are correct.

(b) Both A and B are incorrect.

(c) Only A is correct.

(d) Only B is correct.

Ans. *(c) Only A is correct.*

Explanation: The Krebs' cycle, also known as the TCA cycle or the citric acid cycle, is a series of enzyme-catalysed reactions that take place in the mitochondrial matrix and involve the oxidation of acetyl-CoA to produce carbon dioxide and the reduction of coenzymes to produce ATP for the electron transport chain. It is associated with step-wise removal of all the hydrogen and CO_2 molecules.

The acetyl group of acetyl-CoA is oxidised to make two molecules of CO_2 in a succession of eight steps, while also producing one ATP. Additionally, reduced high-energy molecules like NADH and $FADH_2$ are created.

16. **Statement A: RQ value for fermentation is zero.**

Statement B: In fermentation, carbon dioxide is produced but no oxygen is used.

(a) Both A and B are correct.

(b) Both A and B are incorrect.

(c) Only A is correct.

(d) Only B is correct.

Ans. *(d) Only B is correct.*

Explanation: Carbon dioxide is exhaled while oxygen is ingested during aerobic respiration. The respiratory quotient (RQ) or respiratory ratio is the ratio of the volume of carbon dioxide exhaled to the volume of oxygen taken during breathing. RQ is infinite in anaerobic respiration because CO_2 is evolved but O_2 is not used.

17. **Final product of glycolysis is:**

(a) Pyruvic acid

(b) Ethanol

(c) Carbon dioxide

(d) Glyceraldehyde 3-phosphate

Ans. *(a) Pyruvic acid*

Explanation: Final product of glycolysis is Pyruvic acid. This substance is found in the cytoplasm of cells. It occurs in all living species and forms the respiratory process in anaerobic organisms. During glycolysis, glucose is partially oxidised, yielding two molecules of pyruvic acid.

18. **A unicellular organism was found in the garden, on observing it carefully, it was found that it respired anaerobically and produced carbon dioxide. It is a type of anaerobic respiration which takes place in a unicellular organism widely used by baking and brewery industries. Name the process.**

(a) Fermentation **(b) TCA cycle**

(c) Pyruvic acid **(d) Aerobic respiration**

Ans. *(a) Fermentation*

Explanation: Fermentation is the process which takes place in yeasts and it refers to incomplete oxidation of glucose. It takes place in anaerobic conditions. Pyruvate is converted into ethanol and carbon dioxide. In animal cells, during exercise, inadequate oxygen supply converts pyruvic acid into lactic acid. Energy produced is very less.

19. **Cytoplasm is a viscous liquid that fills each cell and is surrounded by the cell membrane. Water, salts, and proteins make up the majority of it. The cytoplasm of eukaryotic cells contains all of the material inside the cell and outside of the nucleus. Name the process that takes place in this part of the cell.**

(a) Glycolysis **(b) Krebs' cycle**

(c) ETS **(d) Fermentation**

Ans. *(a) Glycolysis*

Explanation: Glycolysis refers to the splitting of sugar. Scientists Gustav Embden, Otto Meyerhof, and J. Parnas presented it. Scientists have given it the term EMP Pathway. It occurs in all living species and is the common respiratory process in both aerobic and anaerobic organisms. It takes place in the cytoplasm of the cell. During glycolysis, glucose is partially oxidised, yielding two molecules of pyruvic acid.

Assertion-Reason (A-R)

Given below are two statements labelled as Assertion (A) and Reason (R). Select the most appropriate answer from the options given below:

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true and R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

20. **Assertion (A): Glycolysis is the breakdown of glucose into pyruvate.**

Reason (R): It occurs in mitochondria.

Ans. *(c) A is true but R is false.*

Explanation: Glycolysis means splitting of sugar which produces two molecules of pyruvate at the end. It was given by scientists Gustav Embden, Otto Meyerhof and J. Parnas. It is also referred to as EMP Pathway. It occurs in cytoplasm of the cells.

Related Theory

Scientists have given it the term EMP Pathway. This is found in the cytoplasm of cells. It occurs in all living species. During glycolysis, glucose is partially oxidised, yielding two molecules of pyruvic acid.

21. **Assertion (A):** **Citric Acid Cycle takes place in mitochondrial matrix.**

Reason (R): **The above-mentioned cycle starts with condensation of acetyl group with oxaloacetic acid and water.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: Acetyl group of acetyl-CoA condenses with oxaloacetate and water to produce citric acid. This reaction is catalysed by enzyme citrate synthase and a molecule of CoA is released.

22. **Assertion (A):** **Cytochrome-c is a small protein.**

Reason (R): **Cytochrome-c acts as a mobile carrier for transfer of electrons.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: Cytochrome-c is a small protein acting as a mobile carrier for transfer of electrons between complex III and complex IV. It is found attached to the outer surface of the inner mitochondrial membrane.

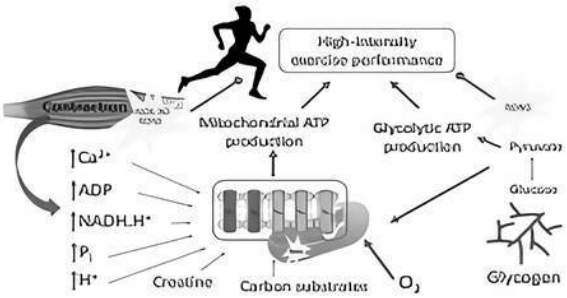
23. **Assertion (A):** **In oxidative phosphorylation, oxygen acts as final hydrogen acceptor.**

Reason (R): **Proton gradient required for phosphorylation is produced by energy of oxidation-reduction.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: Role of oxygen is limited, *i.e.* used in terminal stage, but presence is vital. It drives the whole process by removing hydrogen from the system and acts as the final acceptor of hydrogen. Since energy of oxidation and reduction is utilized for producing a proton gradient which is essential for phosphorylation thus this process is termed as oxidative phosphorylation.

24. **During exercise, muscle ATP demand increases with intensity, and at the highest power output, ATP consumption may increase more than 100-fold above the resting level. The rate of mitochondrial ATP production during exercise depends on the availability of O_2, carbon substrates, reducing equivalents, ADP, Pi, free creatine, and Ca^{2+}.**



Assertion (A): **More ATPs are produced during aerobic respiration than anaerobic respiration.**

Reason (R): **Site for aerobic respiration is mitochondria and that of anaerobic respiration is cytoplasm.**

[Mod. Delhi Gov. QB 2022]

Ans. *(b) Both A and R are true and R is not the correct explanation of A.*

Explanation: Aerobic respiration takes place in mitochondria. Anaerobic respiration takes place in the cytoplasm. Aerobic respiration makes much more energy in the form of ATP from glucose molecules than anaerobic respiration does. Aerobic respiration makes 36 to 38 ATP per glucose molecule whereas anaerobic respiration makes only 2 ATP per glucose molecule.

Caution

Generally speaking, aerobic respiration transforms about 40 per cent of the available energy of glucose into ATP. The remaining 60 per cent is lost as heat and helps to generate your relatively high body temperature.

CASE BASED Questions (CBQs)

[**4** & **5** marks]

Read the following passages and answer the questions that follow:

25. *Schools are an important food environment to cultivate and promote healthy food choices*

and practices among children and adolescents. The school food environment has a potentially significant impact on a child's dietary practices as they spend more time in school than in any other environment away from home and consume almost half of their total daily energy in the school setting.

(A) What will be the possible substrate mentioned in the question?

(a) Fat **(b) Protein**

(c) Both (a) and (b) **(d) Vitamin**

(B) Formula for RQ:

(a) $\frac{\text{Volume of } CO_2 \text{ released}}{\text{Volume of } O_2 \text{ absorbed}}$

(b) $\frac{\text{Volume of } O_2 \text{ absorbed}}{\text{Volume of } CO_2 \text{ released}}$

(c) $\frac{\text{Volume of } CO_2 \text{ absorbed}}{\text{Volume of } O_2 \text{ released}}$

(d) $\frac{\text{Volume of } O_2 \text{ released}}{\text{Volume of } CO_2 \text{ absorbed}}$

(C) The respiratory quotient in succulent plants is always less than one. The reason is:

(a) complete reduction

(b) complete oxidation

(c) incomplete reduction

(d) incomplete oxidation

(D) In germinating seeds of castor, respiratory quotient is:

(a) zero **(b) less than one**

(c) greater than one **(d) one**

Ans. (A) *(c) Both (a) and (b)*

Explanation: Respiratory quotient or respiratory ratio for different substrates are the following:

For carbohydrates R.Q = 1, they are completely oxidised and equal amounts of oxygen and carbon dioxide are produced.

For proteins R.Q = 0.9 approximately.

For fats and proteins, R.Q is less than 1.

(B) *(a)* $RQ = \frac{Volume\ of\ CO_2\ released}{Volume\ of\ O_2\ absorbed}$

Explanation: The respiratory quotient is the actual ratio of the volume of carbon dioxide expelled to the volume of oxygen consumed during cellular respiration. The respiratory ratio is another name for it. RQ is the abbreviation for it.

(C) *(d) incomplete oxidation*

Explanation: The respiratory quotient is the actual ratio of the volume of carbon dioxide expelled to the volume of oxygen consumed during cellular respiration. The respiratory quotient is less than one in succulent plants at night. This is due to the incomplete oxidation of carbohydrates which leads to the production of acids (malic acid, oxalic acid) and in extreme cases; no CO_2 is evolved at all. This makes the RQ less than 1.

(D) *(b) less than one*

Explanation: The respiratory substrate produced during the germination of the castor seed is fat. The respiratory quotient value of fats is always less than one. It means, when fat is consumed during respiration, the volume of CO_2 evolved is less than the volume of O_2 consumed.

26. *It refers to the final process while the organism is respiring in the presence of oxygen. It requires the transfer of electrons to produce ATP. Different molecules produce different numbers of ATP while we proceed through this process. The process takes place within the membrane of some important organelle of the cell. Many complexes are involved in the transport of electrons, they pass via complex I to V. Small proteins are attached to its outer membrane that acts as a mobile carrier for transfer of electrons from complex III to IV.*

(A) Identify the above event.

(B) Where does this event occur in the cell? Give another name for this organelle and also give a reason why it is called so.

(C) Identify the protein involved and name it.

Ans. (A) The event is the electron transport chain. It is a set of four protein complexes that link redox processes to create an electrochemical gradient that results in the production of ATP in a process known as oxidative phosphorylation. In both cellular respiration and photosynthesis, it occurs in mitochondria.

Related Theory

➥ *Oxidation of one molecule of NADH produces 3 ATP whereas one molecule of $FADH_2$ produces 2 ATP.*

(B) It occurs in the inner mitochondrial membrane of the cell. Mitochondria is

also known as the "powerhouse of the cell" because it is in charge of cellular respiration which is the process of obtaining energy from oxidation of food. Adenosine triphosphate is used to release the energy (ATP). It is called energy currency of the cell.

(C) Protein involved is cytochrome c. It is a small protein acting as a mobile carrier for transfer of electrons between complex III and complex IV, it is found attached to the outer surface of the inner mitochondrial membrane.

27. *Electron transport chain is the final stage of aerobic respiration which is located on the mitochondrial membrane. There are two mitochondrial membranes, outer and inner. All proton pumps are located on the inner mitochondrial membrane which is arranged into folds called cristae. These folds increase the surface area available for the transport chain. Electron transport chain is the series of redox reactions in which there is transfer of electrons from electron donors to electron acceptors. The energy is released and stored within the reduced hydrogen carriers which are then used to synthesise ATP. This is called oxidative phosphorylation. Oxidative phosphorylation occurs in distinct steps. First, the proton pumps create an electrochemical gradient called as proton motive force, second, ATP synthase uses the subsequent diffusions of protons, this step is called chemiosmosis.*

ATP is synthesised in this step. Third and final, oxygen accepts electrons and protons to form water. **[Delhi Gov. QB 2022]**

(A) The correct series of electron acceptors present in mitochondrial membrane is:

(a) Cyt-c, b, a, a_3

(b) Cyt-b, c, a, a_3

(c) Cyt-a, a, b, c

(d) Cyt-b, c, a_3, a

(B) How many ATPs will be produced from three molecules of NADPH and two molecules of $FADH_2$?

(a) 5 **(b) 9**

(c) 13 **(d) 18**

(C) In amphibolic pathway, fatty acids will produce:

(a) Glucose-6-phosphate

(b) Glucose-1-6-phosphate

(c) Pyruvate

(d) Acetyl-CoA

(D) The F_0-F_1 complex acts as a site for ATP synthesis when protons enter inner membrane space.

(a) True

(b) False

(c) Cannot say

(d) Protons are not involved.

(E) Ubiquinone (UQ) transfers its electrons to:

(a) Cytochrome b in complex III

(b) Cytochrome a in complex IV

(c) FAD in Complex II

(d) Mitochondrial matrix

Ans. (A) *(b) Cyt-b, c, a, a_3*

Explanation: Cytochromes are the electron carriers in the different electron transport complexes in the membrane of the mitochondria which helps in the formation of ATP by the process of oxidative phosphorylation. The sequence of the movement of the electrons includes cytochromes b, cytochrome c, cytochrome a, and cytochrome a_3.

(B) *(c) 13*

Explanation: Three molecules of NADH will produce 9 ATP molecules and two molecules of $FADH_2$ will produce 4 ATP. Total ATP produced is 9 + 4 = 13.

Related Theory

The oxidation of one molecule of NADH thus leads to the synthesis of three molecules of ATP, whereas the oxidation of FADH2 yields only two ATP molecules.

(C) *(d) Acetyl-CoA*

Explanation: In amphobolic pathway, fatty acids are converted to acetyl-CoA by beta oxidation.

Caution

Fatty acids are converted to acetyl-CoA whereas glycerol is transformed into 3-phosphoglyceraldehyde (PGAL) which then enters the respiratory pathway.

(D) *(a) True*

Explanation: The ATP synthase is also sometimes referred to as complex V of the electron transport system.

It consists of two components:

(1) A transmembrane protein complex is known as F_0.

(2) A peripheral protein complex is known as F_1.

The F_1 headpiece present peripherally contains the site of ATP synthesis. F_0

is a channel protein and allows the diffusion of protons through it, down the electrochemical gradient.

(E) *(a) Cytochrome b in complex III*

Explanation: Ubiquinone receives reducing equivalents *via* $FADH_2$(complex II) that is generated during the oxidation of succinate in the citric acid cycle.

The reduced ubiquinone (ubiquinol) is then oxidised with the transfer of electrons to cytochrome c *via* cytochrome bc_1 complex (complex III).

Related Theory

Cytochrome c is a small protein attached to the outer surface of the inner membrane and acts as a mobile carrier for transfer of electrons between complex III and IV.

VERY SHORT ANSWER Type Questions (VSA)

[**1** mark]

28. Why does a person with sufficient white fibres get fatigued in a short period? **[Delhi Gov. QB 2022]**

Ans. Since the white fibres depend mainly on anaerobic glycolysis for energy production, they accumulate lactic acid in considerable amounts during strenuous work and soon get fatigued.

29. Different substrates get oxidized during respiration. How does Respiratory Quotient (RQ) indicate which type of substrate, *i.e.*, carbohydrate, fat or protein is getting oxidized?

RQ= A/B

What do A and B stand for? What type of substrates has RQ of 1, < 1 or > 1? **[NCERT Exemplar]**

Ans. $RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$

Thus, A stands for volume of CO_2 evolved and B stands for volume of O_2 consumed.

For fats and protein, RQ is less than 1, *i.e.* 0.7 and 0.9, respectively.

RQ of organic acid is more than 1.

For carbohydrates RQ is 1.

30. "Krebs' Cycle is an amphibolic pathway". Justify the statement. **[Diksha]**

Ans. Term amphibolic refers to both anabolic and catabolic.

Krebs' cycle is mainly catabolic but it produces many intermediates that are raw materials for anabolic process. For example, acetyl-CoA is also used for building steroids and carotenoids. α-keto - glutaric acid is utilised for the synthesis of glutamic acid which is an amino acid.

31. What is the full name of PGAL?

Ans. Glyceraldehyde-3-phosphate is the full name for PGAL.

32. Energy is released during the oxidation of compounds in respiration. How is this energy stored and released as and when it is needed? **[NCERT Exemplar]**

Ans. In respiration, the energy generated during the oxidation of substances is instantly stored in the form of chemical bonds in ATP.

ATP = ADP + P*i* + energy

This connection energy is broken and used as and when required.

ADP + P*i* + energy → ATP

33. Define fermentation.

Ans. Fermentation occurs in yeast cells and bacteria, as well as in animal muscles. It is an anaerobic mechanism that breaks down the glucose.

34. How will you explain cellular respiration?

Ans. Cellular respiration is a process during which respiratory substrates are oxidised within cells. In this process, chemical bonds are broken during oxidation. Due to the breakdown of chemical bonds, energy is liberated which is utilised in the synthesis of ATP.

Related Theory

It occurs in the cell's cytoplasm and mitochondria.

SHORT ANSWER Type-I Questions (SA-I)

[**2** marks]

35. (A) Discuss the relationship between Glycolysis, Krebs' Cycle and ETC.

(B) Write about the total net gain of ATP as a result of complete oxidation of one molecule of glucose. **[Diksha]**

Ans. (A) Interlink for the process showing the product of one being the starting point of the other, for example, end product of glycolysis is pyruvate which is the starting product for the TCA cycle or the Krebs' cycle, the NADH and $FADH_2$ produced during Krebs' cycle is an intermediate product for the electron transport system. These three are inter-related, and function together to produce a large amount of energy during aerobic respiration in the presence of oxygen to produce ATP.

(B) Role of ETC in yielding ATP from NADH and FADH formed in this process.

Glycolysis produces 8 ATP as (2 ATP + 2 NADH = 6 ATP, *i.e.* 3 ATPs per NADH molecule)

Decarboxylation of pyruvate to acetyl-CoA produces 6 ATP as (2 NADH = 6 ATP, *i.e.* 3 ATP per NADH molecule)

Krebs' cycle produces 24 ATP as (6 NADH = 18 ATP, 2 $FADH_2$ = 4 ATP (2 ATP per $FADH_2$) and 2 ATP)

So, total ATP are 8 + 6 + 24 = 38 ATP.

36. Describe crucial events in aerobic respiration.

Ans. Aerobic respiration is commonly found in higher plants and animals. Final product of glycolysis *i.e.*, pyruvate is transported from cytoplasm to mitochondria. Its two crucial steps are:

(1) Complete oxidation of pyruvate, leaving three molecules of carbon dioxide (occurs in matrix of mitochondria).

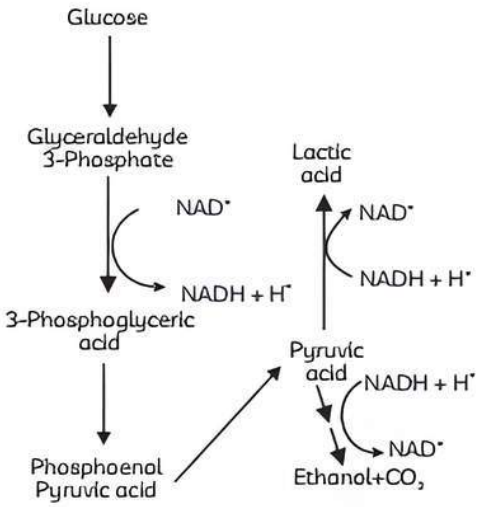
(2) Passing on of electrons to molecular oxygen, with production of ATP (occurs in inner membrane of mitochondria).

Related Theory

Aerobic respiration takes place within mitochondria, and requires presence of oxygen. Complete oxidation of organic substances or glucose molecules releases carbon dioxide, water and large amounts of energy.

37. Draw a well-labelled diagram showing major pathways of anaerobic reaction.

Ans.



Major Pathways of Anaerobic Respiration

38. It is known that red muscle fibres in animals can work for longer periods of time continuously. How is this possible? [NCERT Exemplar]

Ans. Myoglobin is a red-coloured oxygen-storing pigment found in muscle. Some muscles have a high myoglobin concentration, giving them a reddish hue. The red fibres are the muscles that make up this type of muscle. These muscles also include a significant number of mitochondria, which may use the oxygen stored in them to produce ATP. As a result, these muscles are also known as aerobic muscles.

SHORT ANSWER Type-II Questions (SA-II)

[3 marks]

39. How does a tree trunk exchange gases with the environment although it lacks stomata? [NCERT Exemplar]

Ans. Inside and under the bark, the 'alive' cells in stems are organised in thin layers. They also contain a lens-shaped aperture called lenticels. These are the area of gaseous exchange and transpiration. The internal cells are lifeless and simply give mechanical support. As a result, most plant cells have at least a portion of their surface in touch with the air. The loose packing of parenchyma cells in leaves, stems, and roots, create an interconnected network of air gaps, which also helps.

40. Explain the Tri-Carboxylic acid cycle.

Ans. The TCA cycle, also known as the Kreb's cycle or the Citric Acid Cycle, is the series of chemical reactions through which all aerobic organisms release stored energy through the oxidation of acetyl-CoA obtained from carbohydrates, proteins and fats into ATP.

The matrix of mitochondria is where the second step of cellular respiration takes place. The citric acid cycle's enzymes are all water-soluble. It is an aerobic pathway because the electrons produced by NADH and $FADH_2$ are transferred to the following process, which uses oxygen. There is no oxidation if the transport of electrons does not take place. During the process, very little ATP is directly created.

The TCA cycle is an example of a closed loop. The pathway's last step regenerates the pathway's starting molecule indicate that it is a cyclic process.

41. Differentiate between Fermentation and Aerobic respiration.

Ans.

Fermentation	Aerobic Respiration
Takes place in absence of oxygen.	Takes place in presence of oxygen.
Occurs in cytoplasm.	Occurs in cytoplasm followed by mitochondria.
End products are ethanol and CO_2.	End products are water and CO_2.
Incomplete oxidation of substrate takes place.	Complete oxidation of substrate takes place.
Energy produced is low, *i.e.* only 2 ATP is produced for each molecule of glucose.	High amount of energy is produced, *i.e.* 36 ATP by one molecule of glucose.
Example: Yeast	Examples: Higher plants and animals

42. Respiration is an energy-releasing and enzymatically controlled catabolic process which involves a step-wise oxidative breakdown of organic substances inside living cells. In this statement explain the meaning of:

(A) Step-wise oxidative breakdown.

(B) Organic substances (used as substrates).

(C) In a way green plants and cyanobacteria have synthesised all the food on the earth. Comment. [NCERT Exemplar]

Ans. (A) **Step-wise oxidative breakdown:** During oxidation within a cell, all of the energy contained in respiratory substrates is not delivered freely or in a single step into the cell. It is released as chemical energy in the form of ATP through a sequence of slow stepwise processes regulated by enzymes. As a result, it is critical to understand that the energy released during respiration is not (or rather cannot be) consumed immediately, but rather is used to synthesise ATP, which is then broken down whenever (and anywhere) energy is required.

(B) **Organic substances (used as substrates):** Respiratory substrates are the chemicals that are oxidised during this process. In most plants, carbohydrates are oxidised to release energy, but under specific conditions, proteins, lipids, and even organic acids can be employed as respiratory agents.

(C) The oxidation of certain macromolecules that we name 'food' provides all of the energy necessary for 'life' activities. Only green plants and cyanobacteria can manufacture their own food; they trap light energy and turn it into chemical energy, which is stored in the bonds of carbohydrates like glucose, sucrose, and starch, through the process of photosynthesis.

43. Pyruvic acid is the end product of glycolysis. What are the three metabolic fates of pyruvic acid under aerobic and anaerobic conditions? [Delhi Gov. QB 2022]

Ans. Lactic acid – Formed by oxidation of pyruvic acid in skeletal muscles under anaerobic conditions.

Ethanol – Formed by oxidation of pyruvic acid under anaerobic conditions in yeasts.

Acetyl-CoA – Formed by the oxidation of pyruvic acid occurring within the mitochondria under aerobic conditions.

LONG ANSWER Type Questions (LA)

[**4** & **5** marks]

44. Give an account of Glycolysis. Where does it occur? What are the end products? Trace the fate of these products in both aerobic and anaerobic respiration. [NCERT Exemplar]

Ans. Glycolysis is a process that happens in the cytoplasm of all living organisms.

Glucose is partially oxidised to produce two molecules of pyruvic acid. This glucose comes from either the end result of photosynthesis, sucrose, or stored carbohydrates in plants. The enzyme invertase converts sucrose into glucose and fructose, and these two

monosaccharides easily enter the glycolytic pathway. Hexokinase is an enzyme that phosphorylates glucose and fructose to produce glucose-6-phosphate. Fructose-6-phosphate is formed when this phosphorylated form of glucose is isomerized. The following stages in glucose and fructose metabolism are identical. A cascade of ten processes takes place in glycolysis to create pyruvate from glucose, all of which are controlled by various enzymes. The main result of glycolysis is the pyruvic acid. Pyruvate's metabolism is dictated by cellular requirements.

The pyruvic acid generated by glycolysis is handled in three ways by distinct cells. Lactic acid fermentation, alcoholic fermentation, and aerobic respiration. These are the three major ways in which different cells use pyruvic acid produced by glycolysis. In many prokaryotes and unicellular eukaryotes, fermentation happens in anaerobic environments. Organisms, on the other hand, use Krebs' cycle, commonly known as aerobic respiration, to complete the oxidation of glucose to CO_2 and H_2O. A supply of O_2 is required.

45. Rohan recently attended a seminar in his school which about various steps of respiration in plants. One of these steps that he found interesting was electron transport system. Explain this system as Rahul.

Ans. These respiratory processes help to release and utilise energy stored in $NADH+H^+$ and $FADH_2$. Process is completed when these are oxidized through ETS and the electrons are transferred to O_2 to form metabolic H_2O.

It refers to the metabolic mechanism through which an electron is transferred from one electron carrier to another. These electron carriers are located on inner mitochondrial membrane.

(1) Electrons from NADH (produces in mitochondrial matrix during TCA cycle) are oxidised by NADH Dehydrogenase (Complex I).

(2) Electrons are transferred to ubiquinone (inner mitochondrial membrane), it also receives reducing equivalents *via* $FADH_2$ (Complex II) generated in TCA cycle.

(3) Reduced ubiquinone is oxidized with transfer of electrons to cytochrome c *via* cytochrome b, c_1 complex (Complex III). Cytochrome c is a small protein acting as a mobile carrier for transfer of electrons between complex III and complex IV, it is found attached to the outer surface of the inner mitochondrial membrane.

(4) Complex IV is a cytochrome c oxidase complex that contains cytochromes a and a_3 and two copper centres.

(5) Electrons pass from one carrier to another *via* Complex I-IV in ETC, they are coupled with ATP Synthase (Complex V) thus producing ATP from ADP and inorganic phosphates. Complex V is a proton carrier which is responsible for breaking proton gradient.

Number of ATP molecules produced depends on the nature of the electron donor.

(1) One molecule of NADH gives 3 molecules of ATP.

(2) One molecule of $FADH_2$ produces 2 molecules of ATP.

46. Mention the important series of events of aerobic respiration that occurs in the matrix of the mitochondrion as well as one that takes place in the inner membrane of the mitochondrion. [NCERT Exemplar]

Ans. Pyruvate, the last result of glycolysis, is carried from the cytoplasm into the mitochondria for aerobic respiration to take place. The full oxidation of pyruvate by the progressive removal of all hydrogen atoms, leaving three molecules of CO_2, is the most important event in aerobic respiration.

The electrons extracted as part of the hydrogen atoms are transferred to molecular oxygen. At the same time, ATP is also synthesised. It is worth noted that the first step occurs in the matrix of the mitochondria, while the second takes place on the inner membrane of the mitochondria.