14. Respiration In Plants

The gaseous exchange, i.e., intake of O_2 and release of CO_2 is called as breathing while respiration involves biological oxidation of organic molecules i.e., breaking up of $C-C$ bonds by using enzymes and results in the release of energy in the form of ATP. The oxidation of macromolecules that takes place inside the body is called as "respiration". In eukaryotes, photosynthesis takes place in chloroplast and respiration in cytoplasm and mitochondria.

1. Cellular Respiration

It is defined as the mechanism of breakdown of complex organic compounds with help of oxygen within a cell to release energy. During oxidation, within a cell energy is released in a series of slow step-wise reactions controlled by enzymes, and it is trapped as chemical energy in the form of ATP. ATP is broken down whenever (and wherever) energy needs to be utilized. Hence, ATP acts as the energy currency of the cell. This energy trapped in ATP is utilized in various energy-requiring processes of the organisms, and the carbon skeleton produced during respiration is used as precursors for biosynthesis of other molecules in the cell
The generalized chemical reaction representing cellular respiration is as follows.

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

During respiration, oxygen is utilized, on the other hand, carbon dioxide, water, and energy are released as products. This process can occur in the absence of oxygen also. Thus, in a cell, the breakdown of complex organic molecules can be aerobic (in presence of oxygen) or anaerobic (absence of oxygen).

2. Respiratory Substrate

The compounds subjected to biological oxidation are called respiratory substrate. These may be carbohydrates, fats, proteins or organic acids. Carbohydrates are the most preferred substrate for biological oxidation, other substrates are used under certain specific conditions. On the basis of respiratory substrate they used, (by Blackman) the respiration is of two types

- Floating respiration: When the respiratory substrate is fat or carbohydrate.
- Protoplasmic respssiration: When the respiratory substrate is protein.

3. Respiratory Quotient

During aerobic respiration, O_2 is consumed and CO_2 is released. The ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration is called the respiratory quotient (RQ) or respiratory ratio.

$$RQ = \frac{\text{volume of } CO_2 \text{ evolved}}{\text{volume of } O_2 \text{ consumed}}$$

The respiratory quotient depends upon the type of respiratory substrate used during respiration.

- When carbohydrates are used as a substrate and are completely oxidized, the RQ will be 1 because equal amounts of CO_2 and O_2 are evolved and consumed, respectively, as shown in the equation below :

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy},\ RQ = \frac{6CO_2}{6O_2} = 1$$

- When fats are used in respiration, the RQ is less than 1. Calculations for a fatty acid, tripalmitin, if used as a substrate is shown :

$$2(C_{51}H_{98}O_6) + 145\ O_2 \rightarrow 102\ CO_2 + 98\ H_2O + \text{energy},\ RQ = \frac{102\ CO_2}{145\ O_2} = 0.7$$

- When proteins are respiratory substrates the ratio would be about 0.9.
- RQ value is 4 for oxalic acid and 1.33 for malic acid. RQ value of organic acid is more than unity as organic acids contain high proportion of oxygen as compared to carbon and hydrogen, therefore, less oxygen is absorbed than CO_2 liberated.
- In case of the anaerobic condition. $\underset{\text{(Glucose)}}{C_6H_{12}O_6} \xrightarrow{\text{Zymase}} \underset{\text{(Alcohol)}}{2C_2H_5OH} + 2CO_2,\ RQ = \frac{2CO_2}{0O_2} = \infty(\text{infinite})$

Aerobic Respiration

It is the process by which organisms can carry out complete oxidation of glucose and extract the energy stored to synthesise a larger number of ATP molecules needed for cellular metabolism. This type of respiration is most common in higher organisms. The respiration is completed broadly in two phases Glycolysis and Breakdown of Pyruvic acid. For aerobic respiration glycolysis take place in cytoplasm and break down of Pyruvic acid takes place within the mitochondria the pyruvic acid formed during glycolysis is transported from the cytoplasm into the mitochondria. The crucial events in aerobic respiration are :

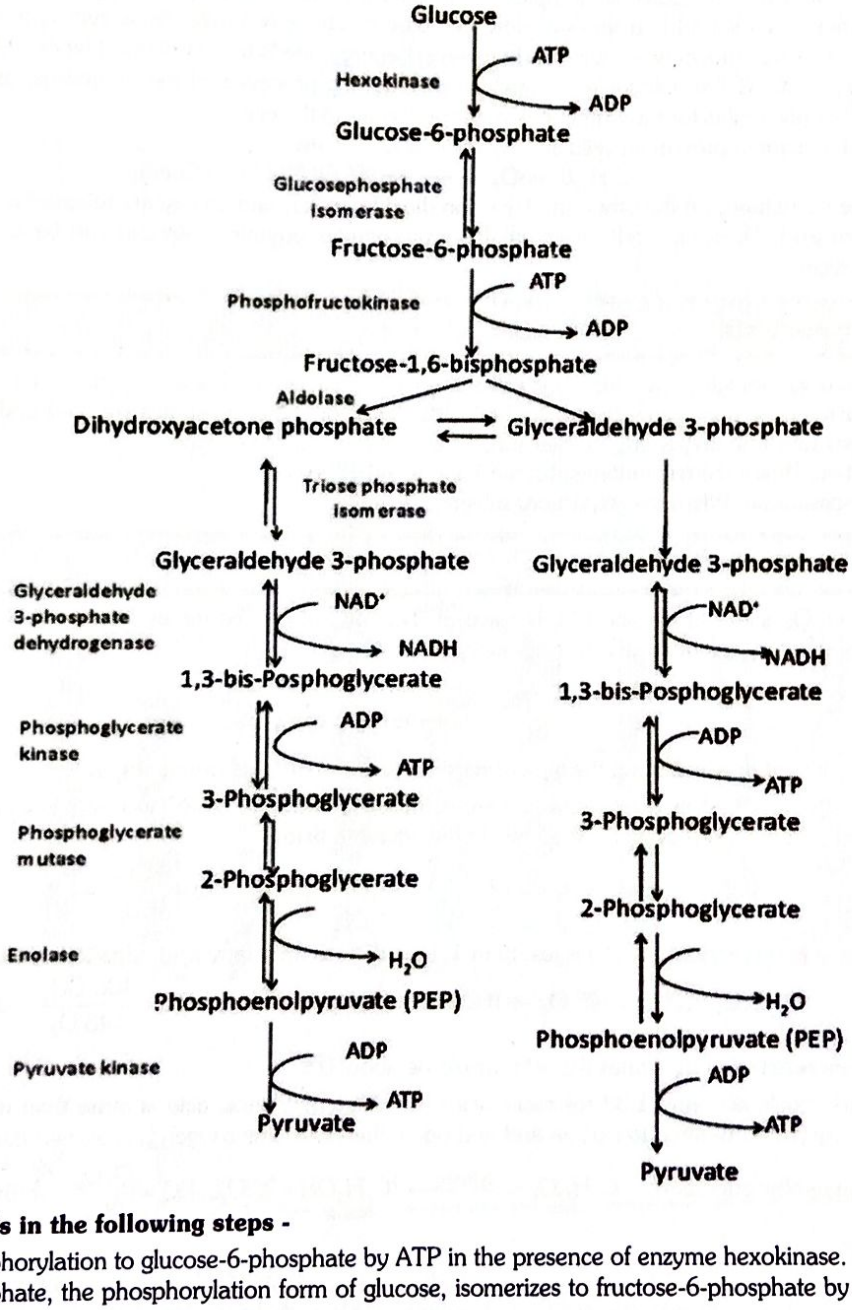
- **Glycolysis -**
- (Oxidative Decarboxylation of Pyruvic acid) Formation of acetyl coenzyme A.
- TCA cycle (Tricarboxylic acid cycle) or(Krebs cycle)or citric acid cycle.(This process takes place in the matrix of mitochondria.)
- (Oxidative Phosphorylation)The passing on the electrons removed as part of the hydrogen atoms to molecular O_2 with simultaneous synthesis of ATP.This process takes place on the inner membrane of the mitochondria

- **Glycolysis -**

It is a common step of both types of respiration. Glycolysis (Greek glycos – for sugar & lysis – for splitting) means splitting up of sugar. This scheme of glycolysis was given by Gustav Embden, Otto Meyerhof, and J. Parnas, and is often referred to as the EMP pathway. In anaerobic organisms, it is the only process in respiration.

Glycolysis occurs in cytoplasm of the cell and is present in all living organisms. Glycolysis is defined as the process of partial oxidation of glucose to form two molecules of pyruvic acid. Glycolysis does not require oxygen. In plants, the glucose is derived from sucrose, which is end product of photosynthesis, or from storage carbohydrates.Sucrose is converted into glucose and fructose by the enzyme, invertase, and these two monosaccharides readily enter the glycolytic pathway. In animals starch is digested into glucose and that is used in the glycolysis.

The first half of this pathway activates glucose (glucose activation phase). The second half extracts the energy (energy extraction phase).



Glycolysis proceeds in the following steps -

a) Glucose is phosphorylation to glucose-6-phosphate by ATP in the presence of enzyme hexokinase.

b) Glucose-6-phosphate, the phosphorylation form of glucose, isomerizes to fructose-6-phosphate by the action of the enzyme phosphohexose isomerase.

c) Fructose-6-phosphate is phosphorylated to form fructose-1, 6-phosphate in the presence of enzyme phosphofructokinase (Pacemaker enzyme of EMP pathway). During phosphorylation, ATP is converted to ADP thus this pathway of conversion of glucose to fructose-1,6-bisphosphate uses two ATP molecules.

d) The fructose-1, 6-bisphosphate splits into dihydroxyacetone phosphate and 3-phosphoglyceraldehyde (PGAL) by the action of aldolase.

e) The two triose phosphates formed are interconvertible. The enzyme that helps in this interconversion is Triose phosphate isomerase.

f) Glyceraldehyde-3-phosphate or 3-phosphoglyceraldehyde (PGAL) is converted into 1, 3 bisphosphoglycerate (BPGA). During this conversion NAD^+ is converted to $NADH+H^+$. i.e., two redox equivalents are removed (in the form of two hydrogen atoms) from PGAL and transferred to a molecule of NAD^+. PGAL is oxidised and with inorganic phosphate to get converted into BPGA. Enzyme that catalyses this reaction is Glyceraldehyde phosphate dehydrogenase.

g) Now 1, 3-bisphosphoglycerate is converted to 3-phosphoglycerate by the activity of enzyme phosphoglycerate kinase. During this reaction ADP is converted into ATP. The direct synthesis of ATP from metabolites is called substrate level phosphorylations.

h) 3-phosphoglycerate now by the action of phosphoglycerate mutase changes to 2-phosphoglycerate.

(i) Enolase acts on 2-phosphoglycerate and converts it into phosphoenol pyruvate (PEP).

(ii) Phosphoenol pyruvate is acted upon by pyruvate kinase and gets converted into pyruvic acid. This step is also substrate level phosphorylation, therefore, ATP releasing step.

Special features of glycolysis can be summarized as follows :

a) Each molecule of glucose produces 2 molecules of pyruvic acid after partial oxidation, at the end of the glycolysis.

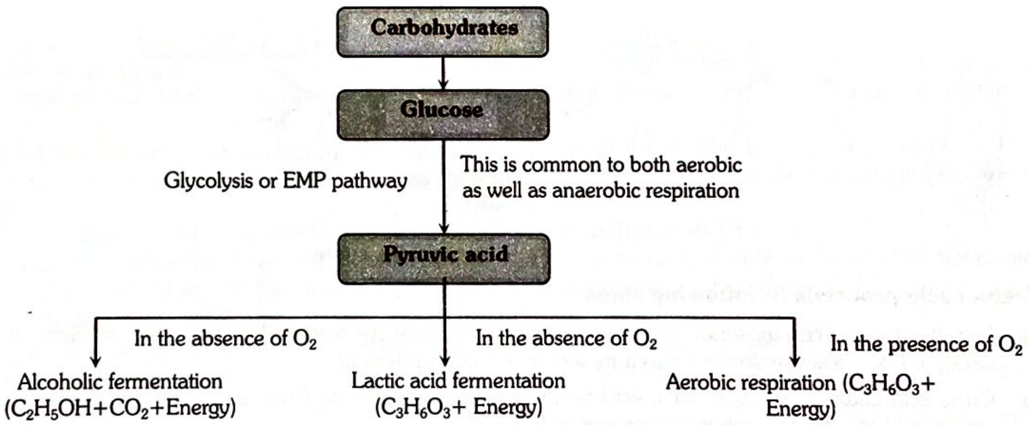
b) The net gain of ATP in this process is 2ATP molecules (four ATPs are formed but two are already used up in reaction)

c) During the conversion of glyceraldehydes 3-phosphate into 1, 3-bisphosphoglyceric acid, one molecule of $NADH+H^+$ is formed. As each molecule of glucose yields two molecules of 1, 3-bisphosphoglyceric acid, hence, each molecule of glucose forms 2 molecules of $NADH_2$.

d) During aerobic respiration (when oxygen is available) each $NADH_2$ forms 3ATP and H_2O through electron transport of mitochondria. In this process, ½ O_2 molecule is utilized for the synthesis of each water molecule.

Important -

Fate of pyruvic acid : Pyruvic acid is the key product of glycolysis. The fate of pyruvic acid depends upon the cellular needs. There are three major ways in which different cells handle pyruvic acid. These are lactic acid fermentation, alcoholic fermentation and aerobic respiration. Fermentation takes place under anaerobic conditions in many prokaryotes and unicelled eukaryotes. For the complete oxidation of glucose to CO2 and H2O, however, organisms adopt Krebs cycle, which is also called aerobic respiration. This requires O2 supply. Pfeffer-Kostychev scheme represents interrelationship between aerobic and anaerobic respiration.



- **Oxidative Decarboxylation of Pyruvic acid or Formation of Acetyl coenzyme A**

  Pyruvate, which is formed by the glycolytic catabolism of carbohydrates in the cytosol, after it enters mitochondrial matrix undergoes oxidative decarboxylation by a complex set of reactions catalysed by pyruvate dehydrogenase.

$$\underset{(3C)}{\text{Pyruvic acid}} + CoA + NAD^+ \xrightarrow{Mg^{2+}} \underset{(2C)}{\text{Acetyl}}\ Co-A + CO_2 + NADH + H^+ + (CO_2)$$

  Two molecules of pyruvic acid formed from one glucose molecule during glycolysis undergo the formation of two molecules of Acetyl CoA, $2CO_2$ and $2NADH+2H^+$. This reaction is called link reaction or transition reaction or gateway reaction of aerobic respiration. The $NADH_2$ molecule formed in this process enters the electron transport system of the mitochondria to release energy.

- **TCA cycle (Tricarboxylic acid cycle) or Krebs cycle or Citric acid cycle**

  Acetyl CoA enters a cyclic pathway called as Krebs cycle, Krebs cycle was named after the scientist Hans Kreb's who first elucidated it in fight muscles of pigeon in 1937. He was awarded a Nobel prize for his work in 1953. In these reactions hydrogen atoms are removed from the acetyl CoA and transferred to the coenzymes for further processing in the electron transport system.

  The cycle is also called citric acid cycle (CAC, because of the formation of citric acid in the first step of this cycle) or TCA cycle (because many intermediate compounds formed in the cycle have three carboxyl groups). The reactions of the Krebs cycle require the presence of oxygen and are confined to mitochondrial matrix. This cycle serves as a common oxidative pathway for carbohydrates, fats and proteins. All enzymes are soluble in mitochondrial matrix, but succinate dehydrogenase (SDH) is found attached to inner mitochondrial membrane.

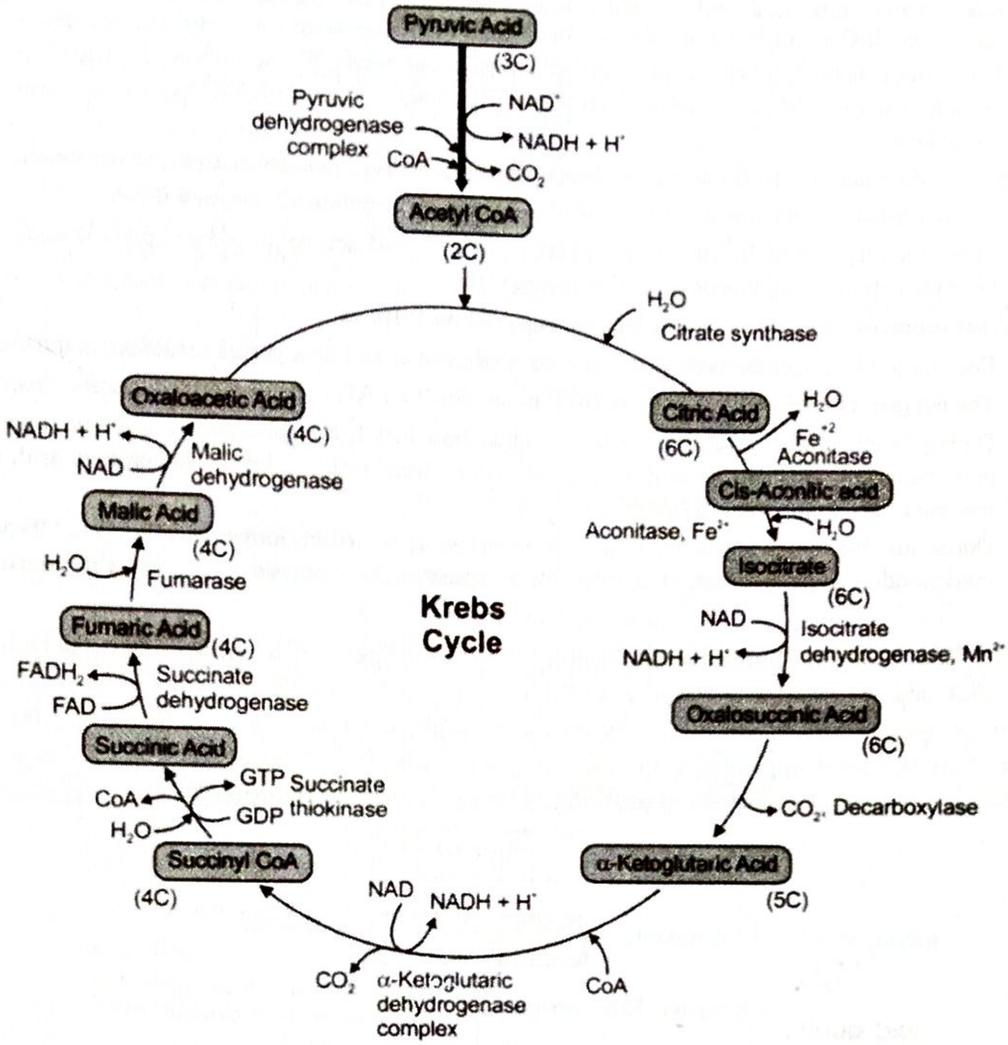


Fig. : Krebs cycle

Krebs cycle proceeds in following steps -

a) It starts with the condensation of Acetyl group with oxaloacetic acid (OAA) and water to yield citric acid and this reaction is catalyzed by citrate synthetase and a molecule of CoA is released.

b) Citric acid changes to cis-aconitic acid by the action of aconitase. Then, cis-aconitic acid changes to isocitrate by the same enzyme. In this manner citrate is isomerised to isocitrate.

c) Isocitrate is changed into oxalo-succinate. One molecule of $NADH_2$ also produced. Then, oxalosuccinate (6C) is converted into α -ketoglutaric acid (5C).

d) α -ketoglutaric dehydrogenase complex acts on α -ketoglutaric acid and converts it into a four carbon compound succinyl CoA. During this step CO_2 is released and NAD^+ is reduced to $NADH+H^+$.

e) In the next step, succinate thiokinase catalyzes the conversion of succinyl CoA to succinic acid. During this step CoA is released and one molecule of GTP is formed from GDP. This is a substrate level phosphorylation. In a coupled reaction GTP is converted to GDP with the simultaneous synthesis of ATP from ADP.

f) Fumaric acid is formed in the next step from succinic acid. This reaction is catalyzed by succinate dehydrogenase. During this reaction FAD molecule is reduced to $FADH_2$.

g) Malic acid is formed by the action of fumarase on fumaric acid. This step involves addition of water molecule.

h) Regeneration of oxaloacetic acid is the last step catalyzed by malic dehydrogenase which reduces NAD^+ to $NADH+H^+$ by removing hydrogen from malic acid.

One molecule of ATP (via direct GTP), three $NADH_2$, one $FADH_2$ and two molecules of CO_2 are released per molecule of acetyl CoA oxidised. However, as two molecules of pyruvic acid are formed from one glucose molecule, TCA cycle must occur twice for each molecule of glucose respired. Therefore, 2ATP, $8NADH_2$ and $2FADH_2$ are formed from 2 molecules of acetyl CoA (coming from one molecule of glucose.

The continued oxidation of acetyl CoA via the TCA cycle requires the continued replenishment of oxaloacetic acid, the first member of the cycle. In addition, it also requires regeneration of NAD^+ and FAD^+ from NADH and $FADH_2$ respectively.

The summary equation for this space of respiration may be written as follows :

$$\text{Pyruvic acid} + 4NAD^+ + FAD^+ + 2H_2O + ADP + Pi \xrightarrow{\text{Mitochondrial matrix}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP + H_2O$$

Difference between Glycolysis and Krebs' cycle

Glycolysis	Krebs cycle
1. It takes place in the cytoplasm of the cell.	1. It takes place in the mitochondria.
2. It is a linear pathway.	2. It is a cyclic pathway.
3. Oxygen is not required for glycolysis	3. It takes place only in the presence of oxygen, used as terminal oxidant.
4. It is a pathway for both the aerobic and anaerobic respiration.	4. It occurs in the aerobic respiration only.
5. Carbon dioxide is not evolved.	5. Carbon dioxide is evolved during the cycle.
6. Glycolysis is the first step in the respiration.	6. Krebs cycle is the second stage in the respiration.
7. Glucose is the substrate used in glycolysis.	7. Acetyl coenzyme A is the substrate in Krebs cycle.
8. 2 ATP molecules are used up in this process.	8. No ATP molecules are consumed.
9. Produces 4 ATP molecule so net gain is 2 ATP.	9. Produces 2GTP molecules from 2 pyruvate molecules.
10. Pyruvic acid is the end product of glycolysis which undergoes oxidative decarboxylation and enters the Krebs cycle.	10. Oxalo acetic acid is the end product of Krebs cycle which again gets cycled by combing with acetyl CoA in the next cycle.
11. 1 molecule glucose yields 2NADH+ H^+.	11. 2 pyruvate molecules yield 6 NADH+ H^+ and $FADH_2$ molecules.

Significance of TCA (Krebs) Cycle -

a) Citric acid cycle is the final common oxidative pathway. Carbohydrates are entering this cycle as Pyruvate and Acetyl~coA. Fatty acids are Broken down into Acetyl~coA which then enters in this cycle. All amino acids after transamination enter into some or other point in this cycle.
b) In the body oxidation of fat need the help of oxaloacetate. One passage of cycle oxidizes acetyl~coA into two CO_2 molecules. Here oxaloacetate acts as true catalyst; it enters into the cycle but is regenerated in the end. The major source of OAA is Pyruvate.
c) Excess carbohydrates are converted as neutral fat and deposited in adipose tissue. The pathway is Glucose -> Pyruvate -> Acetyl~coA -> Fatty acid. However, fat can't be converted to Glucose because Pyruvate dehydrogenase reaction is an absolutely irreversible.
d) Fat is completely broken down in the cycle, and there is no net synthesis of carbohydrates from Fat.
e) Many amino acids after transamination enter into the citric acid cycle. E.g.: Glutamic acid enter at the level of alpha-ketoglutarate and aspartate enters at OAA level. Those amino acids which are converted as members of TCA cycle can enter the Gluconeogenesis pathway through OAA.
f) Some amino acids such as Leucine catabolized to Acetyl~coA or not converted to Glucose because Pyruvate to Acetyl~coA reaction is Irreversible. The acetyl~coA molecule either enter the TCA cycle and are completely oxidized, or are channeled into Ketone body formation. Hence, they are called as ketogenic amino acids.
g) All other pathways such as beta-oxidation of fat (or) glycogen synthesis are either catabolic or anabolic. But TCA cycle is truly amphibolic. It is also called amphiphatic in nature.
h) Citric acid cycle acts as a source of precursor of biosynthetic pathways. Example is HEME is synthesized from succinyl~coA and Aspartate from OAA. There is a continuous efflux of four carbon units from the cycle. To counter balance this loss, and to keep the concentrations of the four carbon unit in the cell, anaplerotic reactions are essential. This is called *Anaplerotic role* of TCA cycle. Anaplerotic reactions are "filling up" reactions or influx reactions, which supply 4 carbon units to the TCA cycle.

- **Electron Transport Chain**

Till now we have seen that glucose has been broken down completely but neither O_2 has been directly involved nor the large number of ATP molecules have been produced. The following steps in the respiratory process are to release and utilize the energy stored in NADH+H^+ and $FADH_2$. This is accomplished when they are oxidised through the electron transport system and the electrons are passed on to O_2 resulting in the formation of H_2O.

The metabolic pathway through which the electron passes from one carrier to another, is called the electron transport system (ETS). This process occurs in inner mitochondrial membrane. This process proceeds in following steps :

a) Electrons from NADH produced in the mitochondrial matrix during citric acid cycle are oxidised by an NADH dehydrogenase (complex I).
b) Electrons are then transferred to ubiquinone located within the inner membrane.
c) Ubiquinone also receives reducing equivalents via $FADH_2$ (complex II) that is generated during oxidation of succinate in the citric acid cycle.
d) The reduced ubiquinone (ubiquinol) is then oxidised with the transfer of electrons to cytochrome c via cytochrome bc_1 complex (complex III).
e) 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. Cytochrome c oxidase complex containing cytochromes a and a_3 and two copper centers is referred as complex IV.
f) Oxygen acts as terminal electron acceptor. It becomes reactive and combines with protons to form metabolic water

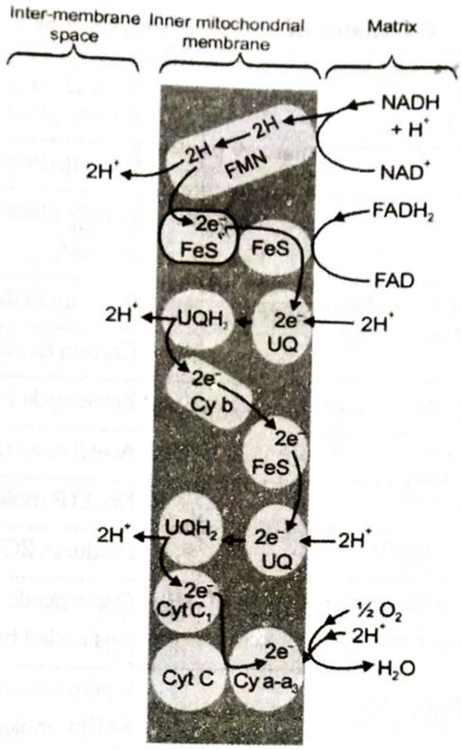


Fig. : Electron Transport System (ETS)

- **Oxidative Phosphorylation**
  a) When the electrons pass from one carrier to another via complex I to IV in the electron transport chain, they are coupled to ATP synthase (complex V) for the production of ATP from ADP and inorganic phosphate.
  b) Proton gradient or proton motive force (PMF) required for phosphorylation is obtained reduction. Therefore, it is called oxidative phosphorylation. Mechanism of membrane linked ATP synthesis is explained by chemiosmotic hypothesis, given by peter Mitchell.
  c) Inner mitochondrial membrane is permeable to protons only in the region of F_0-F_1 or elementary particles or ATP synthase.
  d) The energy released during the electron transport system is utilised in synthesising ATP with the help of ATP synthase (complex V). This complex consists of two major components F_1 and F_0.
  e) The F_1 headpiece is peripheral membrane protein complex and contains the site for synthesis of ATP from ADP and inorganic phosphate. F_0 is an integral membrane protein complex that forms the channel through which protons cross the inner membrane.
  f) The passage of protons through the channel is coupled to the catalytic site of the F_1 component for the production of ATP. For each ATP produced $2H^+$ passes through F_0 from the intermembrane space to the matrix down-the electrochemical proton gradient.
  g) Three pairs of protons are pushed during oxidation of each $NADH+H^+$ and two pairs of protons are pushed during oxidation of each $FADH_2$.

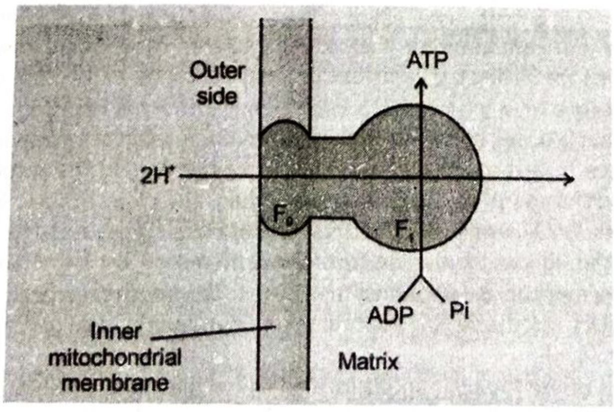


Fig. : Diagrammatic presentation of ATP synthesis in mitochondria

The Respiratory Balance Sheet

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.
- The NADH synthesised in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.

- None of the intermediates in the pathway are utilized to synthesise any other compound.
- Only glucose is being respired – no other alternative substrate are entering in the pathway at any of the intermediary stages.

ATP molecules produced during respiration

Stage of respiration	Source	Number of ATP molecules produced
Glycolysis	Direct 2-molecules of $NADH_2$ (one molecule of $NADH_2$ yields 2 molecules of ATP)	2×3=6
Pyruvic acid to acetyl-CoA	2 molecule of $NADH_2$	2×3=6
Citric acid cycle	6 $NADH_2$ 2$FADH_2$ ($FADH_2$ produces only 2 molecules of ATP Direct	6×3=18 2×2=4

Total net gain of ATP = 36 or 38 depending upon type of shuttle system used in aerobic respiration. In most eukaryotic cells the net gain of ATP is 36 molecules

Important -

Shuttles : The $NADH_2$ molecules produced during glycolysis cannot enter the mitochondria directly. They hand over their energy to other molecules. This entry of glycolytic energy inside mitochondria is performed using specific shuttles. Shuttles do not occur in prokaryotes. Two types of shuttles are described below :

a) **Glycerol-3-phosphate shuttle :** This explains that there is a loss of one ATP for each cytosolic $NADH+H^+$. Net ATP produced in respiration is 36 instead of 38 ATP. This shuttle occurs in fight muscle cells are brain.

b) **Malateaspartate shuttle :** Occurs in heart, kidney and other organs. 38 ATP are produced as net, in aerobic respiration.

4. Pentose Phosphate Pathway

Pentose phosphate pathway (PPP) or Hexose monophosphate shunt (HMS) occurs in cytoplasm and chloroplast, in presence of O_2. It is found in both eukaryotes and prokaryotes. It is also called as Warburg-Lipman-Dickens Pathway. In this pathway, complete oxidation of one glucose molecule would produce $6CO_2$ molecule and (6 × 2) = $2NADPH_2$ molecules. In terms of energy output of hexose monophosphate shunt is almost as efficient as aerobic pathway. This pathway is important in tissues like liver, adipose, germination seeds, ovary etc. It acts as a safety valve or shunt to EMP. It has very low activity in skeletal muscles.

- **Anaerobic Cellular Respiration :** Organic food is broken down incompletely to release energy in absence of oxygen. The products are CO_2, ethyl alcohol and lactic acid.

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2CO_2 + 2C_2H_5OH \text{ (ethyl alcohol)}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2C_3H_6O_3 \text{ (lactic acid)}$$

- **Fermentation :** Fermentation is a kind of anaerobic respiration, carried out primarily by fungi and bacteria. Although people had been using this process in the preparation of wines since prehistoric times but failed in their attempts to understand the alcoholic fermentation. Gay Lussac was the first to discover fermentation.
- **Alcoholic Fermentation :** In fermentation, say by yeast, incomplete oxidation of glucose is achieved under anaerobic conditions by sets of reactions, where pyruvic acid is converted to CO_2 and ethanol.

  (1) In the first step, pyruvic acid is decarboxylated resulting in the formation of acetaldehyde and CO_2

$$\underset{\text{(Pyruvic acid)}}{2CH_3COCOOH} \xrightarrow[Mg^{++}]{\text{Pyruvic decarboxylase}} \underset{\text{(Acetaldehyde)}}{2CH_3CHO} + 2CO_2$$

  (2) In the second step, acetaldehyde is reduced to alcohol by $2NADH+H^+$

$$\underset{\text{(Acetaldehyde)}}{2CH_3CHO} + 2NADH + H^+ \xrightarrow[\text{dehydrogenase}]{\text{Alcohol}} \underset{\text{(Ethanol)}}{2C_2H_5OH} + 2NAD^+$$

  Example : This is commonly seen in yeast and certain bacteria.

  Ethyl alcohol does not stay inside micro-organisms but is excreted. Accumulation of alcohol beyond a certain limit can, however, kill the microorganisms. Yeasts poison themselves to death when the concentration of alcohol reaches about 13%. A higher concentration of alcohol in a beverage is achieved through distillation.

- **Lactic acid fermentation :** Pyruvic acid formed at the end of glycolysis is reduced to lactic acid by homo fermentative lactic acid bacteria (*lactobacillus lacti*).

$$\underset{\text{(Pyruvic acid)}}{CH_3COCOOH} \xrightarrow[FMN,\,Zn^{2+}]{\text{Lactic acid dehydrogenase}} \underset{\text{(Lactic acid)}}{CH_3CHOHCOOH}$$

  During vigorous exercise, when oxygen is inadequate for cellular respiration Pyruvic acid is reduced to lactic acid by using the enzyme lactate dehydrogenase.

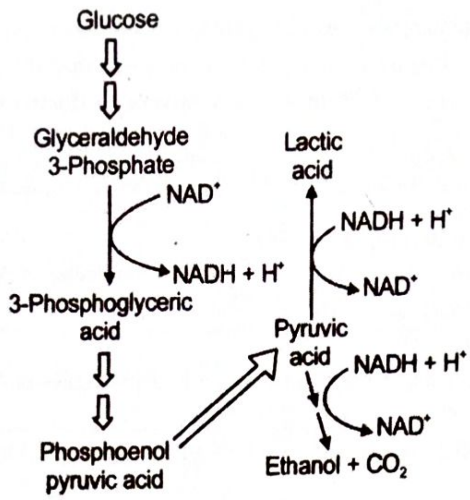


Fig. : Major pathways of anaerobic respirtation

- **Acetic acid fermentation :** This pathway is common in acetic acid bacteria. The oxygen is used in this fermentation process. The end products are ethyl alcohol and acetic acid.
- **Butyric acid fermentation :** This pathway is common in *Clostridium butyricum*. This type of fermentation is normally occurs in rotten butter due to which it gives fowl smell.

Special features of alcohol and lactic acid fermentation :

- In both lactic acid and alcohol fermentation not much energy is released; less than seven percent of the energy in glucose is released and not all of it is trapped as high energy bonds of ATP.
- Both the processes are hazardous – either acid or alcohol is produced.
- Net gain in both the types of fermentation is 2ATP.
- Alcohol fermentation results in the release of CO_2 along with ethanol while lactic acid fermentation releases lactic acid only.
- The reducing agent is $NADH+H^+$ which is reoxidised to NAD^+ in both the processes.

Energy Yield in Fermentation - Fermentation yields only about 5% of the energy obtained by aerobic respiration. This small amount of energy is sufficient to maintain the life of organisms such as yeasts, many bacteria and other anaerobes (organisms that normally live or can live in the absence of oxygen).Vast majority of organisms are, however, aerobes, i.e., need oxygen for respiration. They die within minutes in the total absence of oxygen. Fermentation can supplement the aerobic energy in them.

Anaerobic respiration yields much less energy than aerobic respiration because - The end products of anaerobic respiration still contain energy which remains untapped and is wasted. NAD is not regenerated from NADH in the absence of O_2. This deprives the cell of energy likely to be produced by transfer of hydrogen electrons from $NADH_2$ over ETS.

Difference Between Aerobic Respiration and Anaerobic Respiration

Aerobic Respiration	Anaerobic Respiration
Oxygen is present when this form of respiration takes place.	Oxygen is absent when this form of respiration takes place.
Gases are exchanged in this form of respiration.	Gases are not exchanged in this form of respiration.
It can be found in the cytoplasm and the mitochondria.	It can be found only in the cytoplasm.
Glucose breaks down into carbon-di-oxide and water.	Glucose breaks down into ethyl alcohol, carbon dioxide, and energy.
All organisms such as mammals have this type of respiration.	Lower organisms such as bacteria and yeast use this type. In other organisms, it occurs during heavy activities.

5. Respiration As Amphibolic Pathway

Glucose is the favoured substrate for respiration. All carbohydrates are usually first converted into glucose before they are used for respiration. Other substrates can also be respired, but then they do not enter the respiratory pathway at the first step. Fats are first broken down into glycerol and fatty acids. Fatty acids are degraded into acetyl CoA and enter the pathway. Glycerol would enter the pathway after being converted to PGA (phosphoglyceraldehyde). Proteins are degraded by proteases into amino acids and depending on their structure would enter the pathway at some stage within the Krebs cycle or even as pyruvate or acetyl CoA. Breaking down processes within the living organisms is catabolism and synthesis of molecules within the living organism is anabolism. Respiratory pathway is mainly a catabolic process which serves to run the living system by providing energy.

The pathway produces a number of intermediates. These intermediates of the pathway are precursors of various compounds e.g.,

- Acetyl CoA → raw material for carotenoids, terpenes, gibberellins etc.
- Succinyl CoA → raw material for chlorophyll, cytochrome.

- Oxaloacetic acid → raw material for alkaloids, pyrimidines.
- α -ketoglutaric acid → raw material for amino acid synthesis.

Thus, 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.

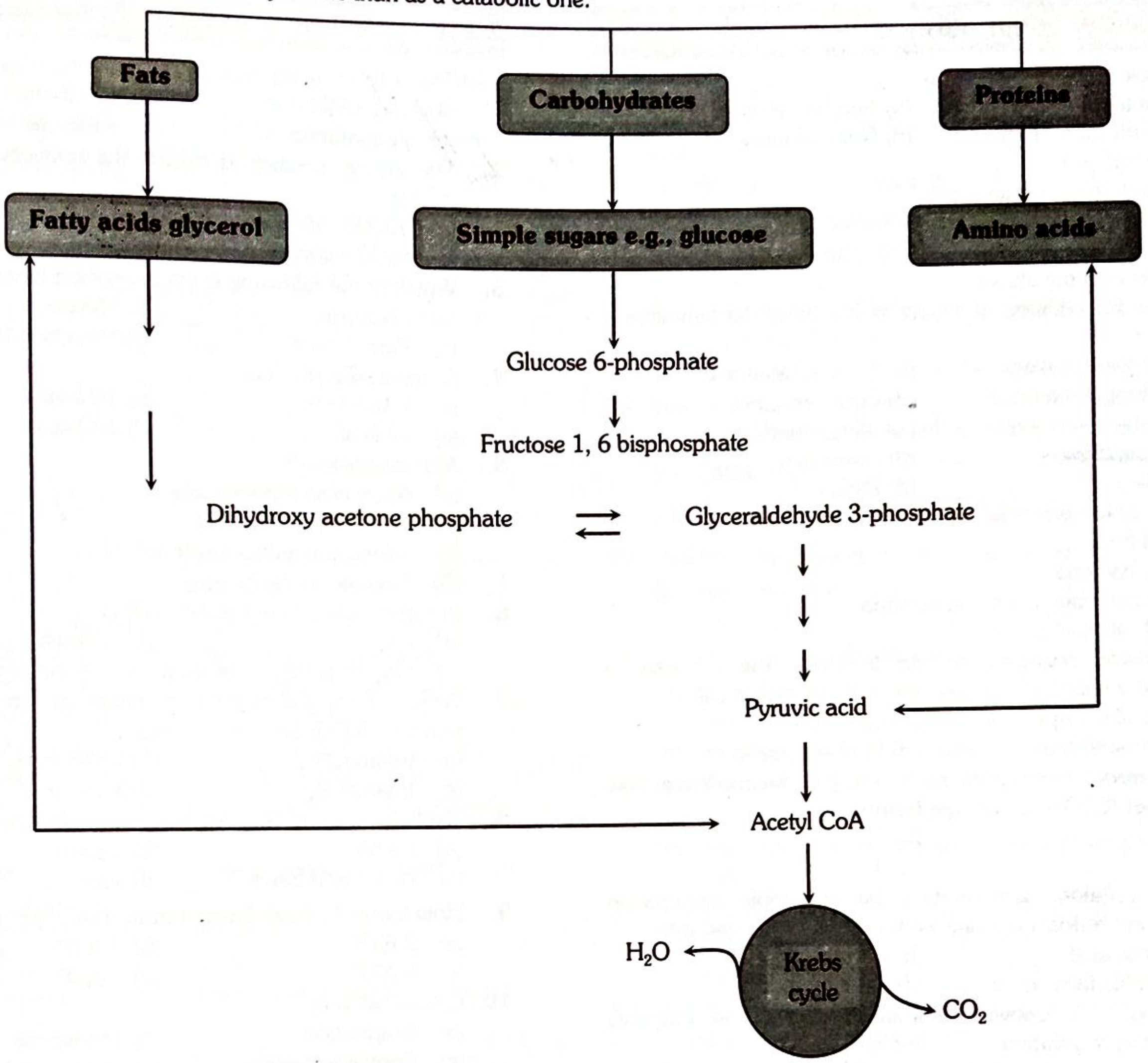


Fig. : Interrelationship among metabolic pathways showing respiration mediated breakdown of different organic molecules to CO_2 and H_2O

Important -

Trapping of energy in ATP is highly useful as -It makes any amount of energy available immediately. ATP is mobile inside the cell so that energy is made available away from the site of respiration. 8.15 kcal or 34 kJ of energy is liberated upon hydrolysis of one molecule of ATP into ADP. The cell is not required to consume all the respiratory energy immediately.Wastage of energy is minimised.

Pasteur effect -It is the reduction in the amount of consumption of respiratory substrate and evolution of CO2 on being switched over from anaerobic to aerobic mode of respiration.

14. Respiration In Plants – Multiple Choice Questions

1. Anaerobic respiration

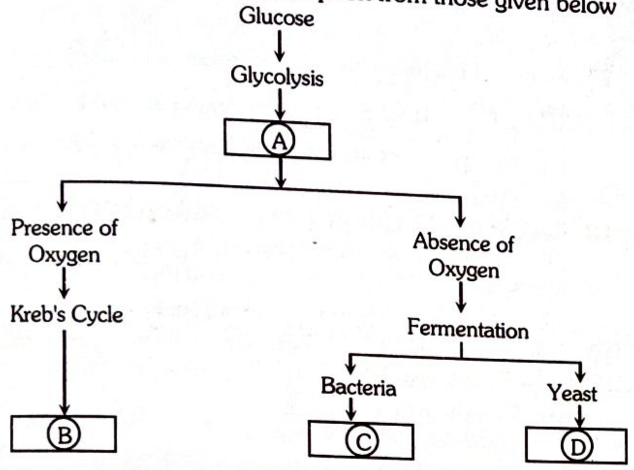
1. Cyanide-resistant pathway is
   (a) Anaerobic respiration (b) Aerobic respiration
   (c) Both (a) and (b) (d) None of these
2. Fermentation is
   (a) Anaerobic respiration
   (b) Incomplete oxidation of carbohydrates
   (c) Complete oxidation of carbohydrates
   (d) None of the above
3. Continuous addition of sugars in 'fed batch' fermentation is done to
   (a) Degrade sewage (b) Produce methane
   (c) Obtain antibiotics (d) Purify enzymes
4. Anaerobic respiration was first of all reported by
   (a) Maguenne (b) Kostychev
   (c) Klein (d) Pfeffer
5. Fermentation is conducted by
   (a) All fungi
   (b) All bacteria
   (c) Some fungi and some bacteria
   (d) All micro-organisms
6. The energy releasing process in which the substrate is oxidized without an external electron acceptor is called
   (a) Aerobic respiration (b) Glycolysis
   (c) Fermentation (d) Photorespiration
7. In anaerobic respiration, from one glucose molecule how many net ATP molecules are formed
   (a) 2 (b) 8
   (c) 6 (d) 4
8. During cellulose fermentation by anaerobic bacteria in rumen and reticulum, cellulose is majorly converted into
   (a) Lactic acid (b) Ethyl alcohol
   (c) Volatile fatty acids (d) CO_2
9. Which of the following minerals activate the enzymes involved in respiration
   (a) Nitrogen and phosphorus
   (b) Magnesium and manganese
   (c) Potassium and calcium
   (d) Sulfur and iron
   (e) Copper and boron
10. The anaerobic process after glycolysis is called
    (a) *TCA* (b) Calvin cycle
    (c) Kreb's cycle (d) Fermentation
11. During lactic acid fermentation
    (a) O_2 is used, CO_2 is liberated
    (b) Neither O_2 is used, nor is CO2 liberated
    (c) O_2 is used, CO_2 is not liberated
    (d) O_2 is not used, CO_2 is liberated
12. Anaerobic products of fermentation are
    (a) Alcohol and lipoprotein
    (b) Ether and nucleic acid
    (c) Protein and nucleic acid
    (d) Alcohol, lactic acid, and similar compound
13. In alcohol fermentation
    (a) Oxygen is the electron acceptor
    (b) Triose phosphate is the electron donor while acetaldehyde is the electron acceptor
    (c) Triose phosphate is the electron donor while pyruvic acid is the electron acceptor
    (d) There is no electron donor

2. Introduction and types of respiration

1. The aerobic respiratory pathway is appropriately termed
   (a) Catabolic (b) Parabolic
   (c) Amphibolic (d) Anabolic
2. The energy consumed during the conversion of ADP into ATP is
   (a) 73000 *cal/mole* (b) 686000 *cal/mole*
   (c) 8000 *cal/mole* (d) 7300 *cal/mole*
3. Which of the following is the phosphorylating unit
   (a) Oxysome (b) Mesosome
   (c) Peroxisome (d) Mitochondria
4. A single ATP produce
   (a) 8 *kcal* (b) 10 *kcal*
   (c) 12 *kcal* (d) 100 *kcal*
5. ATP stands to
   (a) Adenosine triphosphate
   (b) Adenine diphosphate
   (c) Adenosine tetraphosphate
   (d) Adenine triphosphate
6. In carbon dioxide reduction ATP is
   (a) Used (b) Unused
   (c) May be used or not used (d) None of the above
7. Which of the following is involved in the catalysis of link reaction during aerobic respiration
   (a) Vitamin A (b) Vitamin B_1
   (c) Vitamin B_6 (d) Vitamin K
8. Mechanism of aerobic respiration was discovered by
   (a) Kreb's (b) Calvin
   (c) Hatch and Slack (d) Pasteur
9. How many ATP are formed from $NADPH^+$ to NAD^+
   (a) 2 ATP (b) 3 ATP
   (c) 6 ATP (d) 4 ATP
10. Cristae helps in
    (a) Respiration (b) Transpiration
    (c) Photosynthesis (d) Photo-oxidation
11. Degradation of sugar and fat to Acetyl *CoA* will not take place if the following organelle is not present in a eukaryotic cell
    (a) Golgi apparatus (b) Mitochondria
    (c) Ribosome (d) Nucleus
12. The aerobic respiration yields
    (a) $8NADH_2$, $2FADH_2$, 2ATP
    (b) $10NADH_2$, $2FADH_2$, 38ATP
    (c) $12NADH_2$, 30ATP, H_2O
    (d) $10NADH_2$, $2FADH_2$, 2GTP, 2ATP
13. Respiration is an
    (a) Endothermic process (b) Exothermic process
    (c) Anabolic process (d) Endergonic process
14. An indispensable role in energy metabolism is played by
    (a) Sodium (b) Phosphorus
    (c) Calcium (d) Potassium
15. How many ATP molecules will be generated in a plant system during complete oxidation of 40 moles of glucose
    (a) 190 (b) 380
    (c) 1520 (d) 3040
16. The process by which there is inhibition of aerobic respiration by atmospheric O_2 is
    (a) Pasteur's effect (b) Calvin's effect
    (c) Darwin's effect (d) None of these

17. Ganong's resectoscope is used to demonstrate
(a) Production of carbon dioxide during aerobic respiration
(b) Production of heat during aerobic respiration
(c) Evolution of oxygen during photosynthesis
(d) Evolution of carbon dioxide during fermentation

18. The following is a simplified scheme showing the fate of glucose during aerobic and anaerobic respiration. Identify the end products that are formed at stages indicated as A, B, C and D. Identify the correct option from those given below



(a) A= carbon dioxide and water, B= pyruvic acid, C= ethyl alcohol and carbon dioxide, D= lactic acid
(b) A= pyruvic acid, B= carbon dioxide and water, C= lactic acid, D= ethyl alcohol and carbon dioxide
(c) A= pyruvic acid, B= carbon dioxide and water, C= ethyl alcohol and carbon dioxide, D= lactic acid
(d) A= pyruvic acid, B= ethyl alcohol and carbon dioxide, C= lactic acid, D= carbon dioxide and water

19. The net gain of energy, from one molecule of sucrose in aerobic respiration, is
(a) 18 ATP (b) 38 ATP
(c) 60 ATP (d) 80 ATP

20. Common immediate source of energy in a cellular activity or Energy currency of the cell is
(a) *DNA* (b) *ATP*
(c) *RNA* (d) *NAD*

21. Who among the following can be said to be the "Father of Indian Physiology"
(a) B.P. Pal (b) K.C. Mehta
(c) M.S. Swaminathan (d) J.C. Bose

22. Make suitable pairing
(A) Glycolysis (p) Mitochondria
(B) Kreb's cycle (q) Cytoplasmic matrix
(C) Electron transport chain
(a) Ap, Bp, Cq (b) Aq, Bp, Cp
(c) Ap, Bq, Cq (d) Aq, Bq, Cp

23. Cristae are associated with which of the following
(a) Cytoplasm (b) Protoplasm
(c) Mitochondria (d) Ribosomes

24. If CO_2 is given off in respiration, why does the amount of CO_2 in the atmosphere remains relatively constant
(a) CO_2 forms carbonate rocks
(b) CO_2 is buffer
(c) CO_2 is converted in photosynthesis to carbohydrates
(d) CO_2 splits up during photosynthesis

25. During 24 hours there is a time when plants neither give O_2 nor CO_2. This is the time of
(a) Night (b) Daylight
(c) Twilight (d) None of these

26. Aerobic respiration is more advantageous to a large organism than anaerobic respiration because of aerobic respiration
(a) Does not require sunlight
(b) Produces oxygen as a waste product
(c) Does not require molecular oxygen and hydrogen
(d) Releases more energy from an equal amount of nutrients

27. Respiration differs from the process of combustion in the fact that
(a) All the energy stored in glucose is released gradually due to combustion and enzymes are involved
(b) All energy stored in glucose is gradually released due to combustion
(c) The comparatively large quantity of energy is produced due to combustion
(d) The carbohydrates act as the combustion substance

28. Pyruvic acid, the key product of glycolysis can have many metabolic fates. Under aerobic condition, it forms
(a) Lactic acid (b) $CO_2 + H_2O$
(c) Acetyl $CoA + CO_2$ (d) Ethanol + CO_2

29. Which of the following exhibits the highest rate of respiration
(a) Growing shoot apex (b) Germinating seed
(c) Root tip (d) Leaf bud

30. Mitochondria called powerhouses of the cell. Which of the following observations support this statement
(a) Mitochondria synthesis ATP
(b) Mitochondria have a double membrane
(c) The enzymes of the Krebs cycle and the cytochromes are found in mitochondria
(d) Mitochondria are found in almost all plants and animal cells

31. A molecule of ATP is structurally similar to the molecule of
(a) DNA (b) RNA
(c) Protein (d) AMP

32. When ATP molecule is hydrolyzed in ADP, then the quantity of energy released is about
(a) 750 *cal* (b) 7, 500 *cal*
(c) 75,000 *cal* (d) 7, 50,000 *cal*

3. Glycolysis

1. Decarboxylation is not involved in
(a) Electron transport system (b) Glycolysis
(c) Kreb's cycle (d) Alcoholic fermentation

2. Which is not true for glycolysis
(a) The end product is CO_2, H_2O
(b) Substrate level phosphorylation
(c) Production of ATP
(d) Expenditure of ATP

3. Which one is correct sequence in glycolysis
(a) G 6–P → PEP → 3–PGAL → 3–PGA
(b) G 6–P → 3–PGAL → 3–PGA → PEP
(c) G 6–P → PEP → 3–PGA → 3 – PGAL
(d) G 6–P → 3–PGA → 3–PGAL → PEP

4. Which one of the following is the first step of glycolysis
(a) Breakdown of glucose
(b) Phosphorylation of glucose
(c) Conversion of glucose into fructose
(d) Dehydrogenation of glucose

5. Glycolysis (EMP Pathway) takes place in

Or

Anaerobic respiration takes place in the
(a) Mitochondria
(b) Cytoplasm
(c) Both mitochondria and cytoplasm
(d) Vacuole

6. During respiration, pyruvic acid is formed by
(a) Glycolysis (b) Kreb's cycle
(c) HMP pathway (d) None of the above

7. What is the other name of glycolysis
(a) EMP pathway (b) TCA pathway
(c) HMS pathway (d) None of the above

8. The number of molecules of pyruvic acid formed from one molecule of glucose at the end of glycolysis is
(a) 1 (b) 2
(c) 3 (d) 4

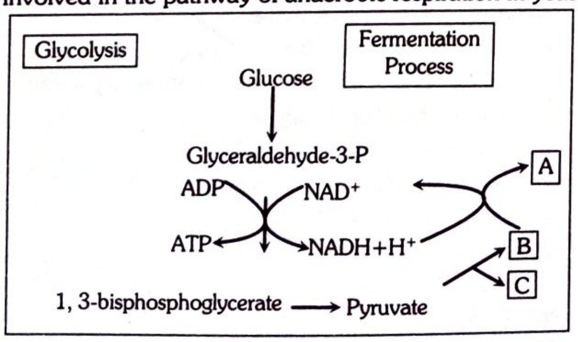
9. The formula for the process of glycolysis is
(a) $C_6H_{12}O_6 \rightarrow 2C_3H_4O_3 + 4H$
(b) $C_6H_{12}O_6 + 6CO_2 \rightarrow 6CO_2 + 6H_2O$
(c) $6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$
(d) None of these

10. Which group of the following scientists discovered the EMP pathway of glycolysis
(a) Embden, Meyerhof, and Parnas
(b) Emerson, Hoffman, and Peterson
(c) Embden, Morrison, and Pitcher
(d) Avery, McLeod, and McCarthy

11. Glycolysis occurs in
(a) Generally in all the cells (b) In only eukaryotes
(c) Only in prokaryotes (d) only in higher animals

12. In which of the following reaction of glycolysis, a molecule of water is removed from the substrate
(a) Fructose – 6 – phosphate → fructose 1, 6 – bisphosphate
(b) 3 – phosphate glyceraldehyde → 1, 3-bisphosphoglyceric acid
(c) PEP → pyruvic acid
(d) 2 – Phosphoglycerate → PEP
(e) Glucose → glucose 6 – phosphate

13. Choose the correct combination of labeling the molecules involved in the pathway of anaerobic respiration in yeast



(a) A – Ethanol B – CO_2 C – Acetaldehyde
(b) A – CO_2 B – Ethanol C – Acetaldehyde
(c) A – CO_2 B – Acetaldehyde C – Ethanol
(d) A – Acetaldehyde B – CO_2 C – Ethanol
(e) A – Ethanol B – Acetaldehyde C – CO_2

14. Glycolysis term has originated from Greek words
(a) Glycose and lysis (b) Glycos and lysis
(c) Glyco and lysis (d) Glucose and lysis

15. In glycolysis, during oxidation electrons are removed by
(a) NAD^+
(b) Molecular oxygen
(c) ATP
(d) Glyceraldehyde-3-phosphate

16. In glycolysis, the end product is
(a) Protein is converted to glucose
(b) Glucose is converted into fructose
(c) Starch is converted into glucose
(d) Glucose is converted into pyruvic acid

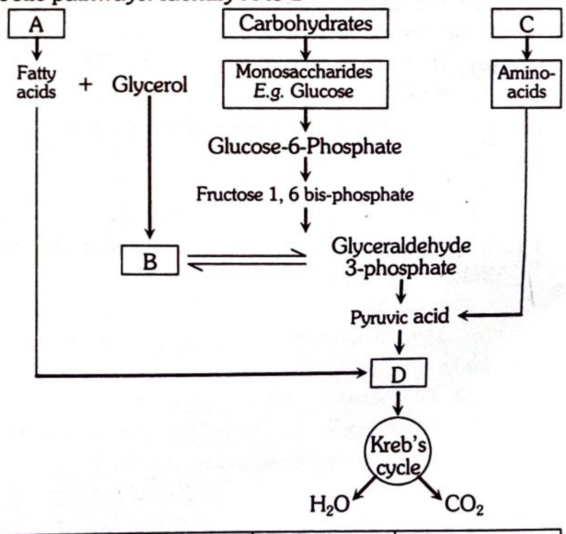
17. Which of the following is the product of phosphorylation
(a) PGA
(b) Fructose 1, 6 diphosphate
(c) DPGA
(d) Pyruvic acid

18. Besides the net gain of 2 ATP molecules in glycolysis which other molecules are simultaneously formed
(a) $FADH_2$ (b) $NADPH_2$
(c) $NADH_2$ (d) $FAMH_2$

19. The common phase between aerobic and anaerobic respiration is called
(a) Tricarboxylic acid cycle
(b) Oxidative phosphorylation
(c) Embden, Meyerhof, Parnas cycle (Glycolysis)
(d) Kreb's cycle

20. ATP formation in glycolysis is
(a) Oxidative phosphorylation
(b) Photophosphorylation
(c) Reductive phosphorylation
(d) Substrate level phosphorylation

21. The given figure indicates the interrelationship among metabolic pathways. Identify A to D



	A	B	C	D
(a)	Fat	DHAP	Acetyl CoA	Protein
(b)	Acetyl CoA	Fat	DHAP	Protein
(c)	Fat	DHAP	Protein	Acetyl CoA
(d)	Protein	Acetyl CoA	Fat	DHAP

22. Which process does the following equation represent

$$C_6H_{12}O_6 + 2NAD + 2ADP + 2Pi$$
$$\rightarrow 2CH_3 - CO - COOH + 2NADH_2 + 2ATP$$

(a) Complete glycolysis
(b) Complete aerobic respiration
(c) Complete anaerobic respiration
(d) Complete fermentation

23. Phosphorylation of glucose during glycolysis is catalyzed by
(a) Phosphoglucomutase (b) Phosphoglucoisomerase
(c) Hexokinase (d) Phosphorylase

24. The first phase in the breakdown of glucose in animal cell is
(a) Glycolysis (b) Electron transport system
(c) Fermentation (d) Kreb's cycle

4. Kreb's cycle and ETS

1. In the electron transport system present in the inner mitochondrial membrane, complexes I and IV are respectively
(a) *NADH* dehydrogenase and $FADH_2$
(b) $FADH_2$ and *NADH* dehydrogenase
(c) *NADH* dehydrogenase and cytochrome oxidase complex
(d) *NADH* dehydrogenase and *ATP* synthase
(e) Cytochrome *bc* 1 complex and *NADH* dehydrogenase

2. Pyruvic acid is converted into a compound before the formation of oxaloacetic acid in the citric acid cycle, this compound is

Or

Which of the following metabolites enter the TCA cycle during glucose oxidation
(a) Acetyl *CoA* (b) Acetoacetic acid
(c) Lactic acid (d) *cis* aconitic acid

3. Chemiosmotic theory of ATP synthesis in the chloroplasts and mitochondria is based on
(a) Proton gradient (b) Accumulation of K ions
(c) Accumulation of Naions (d) Membrane potential

4. Which of the following forms the connecting link between glycolysis and Kreb's cycle
(a) Glucose (b) Ethyl alcohol
(c) Lactic acid (d) Pyruvic acid

5. The reaction of Kreb's cycle (TCA cycle) take place
(a) In cytoplasm
(b) In endoplasmic reticulum
(c) In the matrix of mitochondria
(d) On the surface of the mitochondrion

6. Oxidative phosphorylation occurs in
(a) The outer membrane of mitochondria
(b) The inner membrane of mitochondria
(c) Stroma of chloroplast
(d) Grana of chloroplast

7. The cycle in which pyruvic acid is broken down in presence of oxygen is known as
(a) Glycolysis (b) Kreb's cycle
(c) Anaerobic respiration (d) None of the above

8. In an electron transport chain in terminal oxidation, the cytochrome which donates electrons to O_2 is
(a) Cytochrome *b* (b) Cytochrome *c*
(c) Cytochrome a_3 (d) Cytochrome *a*

9. The last or terminal cytochrome in the respiratory chain is
(a) Cyt *b* (b) Cyt a_3
(c) Cyt *a* (d) Cyt *c*

10. The correct sequence of electron acceptor in ATP synthesis is
(a) Cyt *aa bc* (b) Cyt *b ca* a_3
(c) Cyt *bc* a_3 *a* (d) Cyt *cb an* a_3

11. Cytochromes are
(a) Lipid
(b) Glycoprotein
(c) Metalloporphyrins
(d) Fe^{++} containing with porphyrin pigment

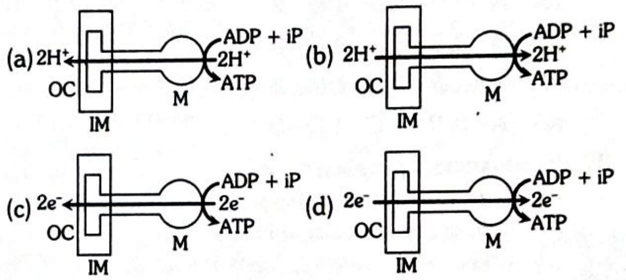
12. Cytochromes occur in
(a) Cristae of mitochondria
(b) Matrix of mitochondria
(c) Outer mitochondrial membrane
(d) Entire inner mitochondrial membrane

13. Enzymes found attached to the inner membrane of mitochondria instead of the matrix is/are
(a) Succinic dehydrogenase (b) Cytochrome oxidase
(c) Both (a) and (b) (d) Malic dehydrogenase

14. How many ATP will be produced during the production of 1 molecule of acetyl *CoA* from 1 molecule of pyruvic acid
(a) 3 ATP (b) 5 ATP
(c) 8 ATP (d) 38 ATP

15. The amount of energy released incomplete oxidation of one molecule of glucose is
(a) 628 *kcal* (b) 668 *kcal*
(c) 686 *kcal* (d) 697 *kcal*

16. Which diagram represents the ATP synthesis in mitochondria through chemiosmosis
I.M = Inner membrane
M = Matrix
O. C = Outer Chamber



17. During Krebs' cycle energy from glucose is mostly transferred to
(a) NADH & FADH (b) NADPH
(c) ADP (d) Water

18. The details of the tricarboxylic acid path were worked out by
(a) Meischer (b) Hans Krebs
(c) Pasteur (d) None of these

19. Which one of the following is complex V of the ETS of the inner mitochondrial membrane
(a) NADH dehydrogenase (b) Cytochrome c oxidase
(c) Ubiquinone (d) Succinate dehydrogenase
(e) ATP synthase

20. The overall goal of glycolysis, the Krebs cycle and the electron transport system is the formation of
(a) ATP in small stepwise units
(b) ATP in one large oxidation reaction
(c) Sugars
(d) Nucleic acids

21. In citric acid, cycle decarboxylation occurs when
(a) Citric acid converts to α – ketoglutaric acid
(b) Succinic acid converts to malic acid
(c) Malic acid converts to oxaloacetic acid
(d) Oxaloacetic acid converts to citric acid

22. During one of Krebs' cycle number of CO_2 molecules released is
(a) 1 (b) 2
(c) 3 (d) 4

23. Kreb's cycle was discovered by Krebs in pigeon muscles in 1940. Which step is called a gateway step. Link reaction/transition reaction in respiration
(a) Glycolysis (b) Formation of acetyl-*coA*
(c) Citric acid formation (d) ETS terminal oxidation

24. Synthesis of ATP in mitochondria require
(a) Oxygen (b) NADP
(c) FMN (d) Pyruvic acid

25. Which of these steps in Kreb's cycle indicates substrate level phosphorylation
(a) Conversion of succinic acid to α – ketoglutaric acid
(b) Conversion of succinic acid to malic acid
(c) Conversion of succinyl Co. A to succinic acid
(d) Conversion of malic acid to oxalo acetic acid
(e) Conversion of citric acid to α – ketoglutaric acid

26. Match the number of carbon atoms given in List – I with that of the compounds given in List – II and select the correct option

	List – I		List - II
A.	4C Compound	1.	Acetyl CoA
B.	2C Compound	2.	Pyruvate
C.	5C Compound	3.	Citric acid
D.	3C Compound	4.	α – ketoglutaric acid
		5.	Malic acid

(a) $A-2, B-5, C-3, D-1$
(b) $A-5, B-1, C-4, D-2$
(c) $A-3, B-1, C-4, D-2$
(d) $A-5, B-3, C-1, D-2$
(e) $A-3, B-4, C-1, D-5$

27. In respiration, pyruvic acid is
(a) Formed only when oxygen is available
(b) One of the products of Kreb's cycle
(c) Broken down into two-carbon fragments and CO_2
(d) A result of protein breakdown

28. During which stage in the complete oxidation of glucose are the greatest number of ATP molecules formed from ADP
(a) Conversion pyruvic acid to acetyl CoA
(b) Electron transport chain
(c) Glycolysis
(d) Kreb's cycle

29. Which of the following observation most strongly support the view that mitochondria contain electron transfer enzymes aggregated into compact associations
(a) A contractile protein capable of utilizing ATP has been obtained from mitochondria
(b) Mitochondria have highly folded inner wall
(c) Disruption of mitochondria yields membrane fragments which are able to synthesize ATP
(d) Mitochondria in animal embryos have a tendency to concentrate in cells which are to become part of locomotory structures

30. Respiratory enzymes are located in
(a) Mitochondrial matrix (mitochondria)
(b) Perimitochondrial space
(c) Cristae
(d) Outer membrane

31. Oxidation of succinate to fumarate in the Kreb's cycle is due to
(a) Loss of electron from it
(b) Removal of hydrogen from it
(c) Addition of oxygen to it
(d) None of the above

32. Cytochrome helps in
(a) Oxidation of glucose (b) Release of energy
(c) Electron transport (d) Growth

33. The formation of acetyl coenzyme–A from pyruvic acid is the result of its
(a) Reduction
(b) Dehydration
(c) Dephosphorylation
(d) Oxidative decarboxylation

34. Aerobic respiration which yields maximum ATP molecules is completed on
(a) Mitochondria
(b) General cytoplasm
(c) General cytoplasm and mitochondria
(d) Somewhere else

35. Oxidative phosphorylation is the formation of
(a) $NADPH_2$ in respiration
(b) ATP in respiration
(c) $NADPH_2$ in photosynthesis
(d) ATP in photosynthesis

36. How many *ATP* molecules could maximally be generated from one molecule of glucose, if the complete oxidation of one mole of glucose to CO_2 and H_2O yields 686 kcal and the useful chemical energy available in the high energy phosphate bond of one mole of *ATP* is 12 *kcal*
(a) Fifty-seven (b) One
(c) Two (d) Thirty

37. In ETS, electron combines to
(a) Cytochrome (b) H_2
(c) O_2 (d) H_2O

38. Kreb's cycle begins with
(a) Pyruvic acid (b) Hydrochloric acid
(c) Corticosteroids (d) Lysine

39. Kreb's cycle involves the formation of
(a) Lactic acid from glucose
(b) Change of pyruvic acid to energy transformation
(c) Pyruvic acid from glucose
(d) ATP from ADP

40. In Kreb's cycle, the FAD participates as an electron acceptor during the conversion of
(a) Succinyl *CoA* to succinic acid
(b) α-ketoglutarate to succinyl *CoA*
(c) Fumaric acid to malic acid
(d) Succinic acid to fumaric acid

41. The pyruvic acid formed in Glycolysis is oxidized to CO_2 and H_2O in a cycle called
(a) Calvin cycle (b) Hill reaction
(c) Kreb's cycle (d) Nitrogen cycle

42. In which one of the following do the two names refer to one and the same thing
(a) Tricarboxylic acid cycle and urea cycle
(b) Kreb's cycle and Calvin cycle
(c) Tricarboxylic acid cycle and citric acid cycle
(d) Citric acid cycle and Calvin cycle

43. Which of the following does not function as an electron carrier
(a) Coenzyme Q (b) Cytochrome-c
(c) Cytochrome-a (d) Cytochrome-a_3
(e) H_2O

44. The ultimate electron acceptor of respiration in anaerobic organisms is
(a) Cytochrome (b) Oxygen
(c) Hydrogen (d) Glucose

45. Electron Transport System (ETS) is located in mitochondrial
(a) Outer membrane (b) Intermembrane space
(c) Inner membrane (d) Matrix

46. Choose the correct statement
(a) Pyruvate is formed in the mitochondrial matrix
(b) During the conversion of succinyl Co-A to succinic acid, a molecule of ATP is synthesized
(c) Oxygen is vital in respiration for removal of hydrogen
(d) There is a complete breakdown of glucose in fermentation

47. The end product of oxidative phosphorylation is
(a) NADH (b) Oxygen
(c) ADP (d) ATP + H_2O

48. Match the compounds given in Column I with the number of carbon atoms present in them which are listed under Column II. Choose the answer which given the correct combination of alphabets of the two columns

Column-I		Column-II	
(A)	Oxaloacetate	(p)	6-C compound
(B)	Phosphoglycrealdehyde	(q)	5-C compound
(C)	Isocitrate	(r)	4-C compound
(D)	α -ketoglutarate	(s)	3-C compound
		(t)	2-C compound

	A	B	C	D
(a)	s	t	q	r
(b)	r	s	p	q
(c)	r	t	p	q
(d)	q	s	p	t

49. In respiration, the energy is produced during the process of
(a) Glycolysis (b) Krebs cycle
(c) Glycolysis and Kreb's cycle (d) Ornithine cycle

50. The chemiosmotic coupling hypothesis of oxidative phosphorylation proposes that adenosine triphosphate (ATP) is formed because
(a) A proton gradient forms across the inner membrane
(b) There is a change in the permeability of the inner mitochondrial membrane toward adenosine diphosphate (ADP)
(c) High energy bonds are formed in mitochondrial proteins
(d) ADP is pumped out of the matrix into the intermembrane space

51. Select the wrong statement
(a) When tripalmitin is used as a substrate in respiration, the R.Q. is 0.7
(b) The intermediate compound which links glycolysis with Kreb's cycle is malic acid
(c) One glucose molecule yields a net gain of 36 *ATP* molecules during aerobic respiration
(d) One glucose molecule yields a net gain of 2 *ATP* molecules during fermentation
(e) The scheme of glycolysis was given by Embden, Meyerhof, and Parnas

52. Hibernating animals have tissues containing mitochondria with a membrane protein that accelerates electron transport while blocking the synthesis of ATP. What is the consequence of this
(a) Hibernating animals can synthesize fat instead of wasting the energy of respiration
(b) Energy is saved because glycolysis and the citric acid cycle shut down
(c) Pyruvate is converted to lactic acid by anaerobic fermentation
(d) The energy of respiration is converted into heat

53. Which of the following processes make direct use of oxygen
(a) Glycolysis (b) Fermentation
(c) Electron transport (d) Kreb's citric acid cycle
(e) Hydrolysis

5. Pentose phosphate pathway

1. Pentose phosphate pathway, an alternative pathway of respiration was elucidated by
(a) Horecker (b) Warburg and Dickens
(c) Blackman (d) Kelvin

2. The reactions of pentose phosphate pathway (PPP) take place in
(a) Mitochondrion
(b) Cytoplasm
(c) Chloroplast, peroxisome, and mitochondrion
(d) Chloroplast, glyoxysome, and mitochondrion
(e) Chloroplast, lysosome, and mitochondrion

3. The substrate for the pentose phosphate pathway is
(a) Glucose–6–phosphate (b) Glucose–1–phosphate
(c) Fructose–6–phosphate (d) Fructose–1–phosphate

4. Which of the following statements is/are not true
A. One ATP molecule yields 30.5 *kJ* of energy
B. Pentose Phosphate Pathway was discovered by Dickens
C. When tripalmitin is used as a substrate, the R.Q. is 0.7
D. The energy released by one molecule of glucose on complete oxidation corresponds to 1195 *kJ*
(a) *A, B* and *D* only (b) *C* and *D* only
(c) *A* and *D* only (d) *A, C* and *D* only
(e) *C* only

5. Which of the following is produced in oxidative pentose phosphate pathway
(a) Pyruvic acid (b) Acetyl CoA
(c) $NADH_2$ (d) *NAD (P) H*
(e) ATP

6. R.Q.

1. Substance whose *RQ* is less than one is
(a) Carbohydrate (b) Protein
(c) Organic acid (d) All the above

2. R.Q. for glucose (Carbohydrates) is
(a) 1 (b) 0.5
(c) 2 (d) 0.05

3. R.Q. in anaerobic respiration is
(a) 0 (b) ∞
(c) 1 (d) > 1

4. In germinating castor seeds, the R.Q. is
(a) One (b) More than one
(c) Less than one (d) Zero

5. R.Q. of malic acid is
(a) 0.7 (b) 1
(c) 1.33 (d) 4

6. Which of the following option is correct for the given statements, 'X', 'Y' and 'Z'
Statement 'X' – R.Q. of fat containing palmitic acid is less than one, whereas RQ of glucose is 1
Statement 'Y' – Fat containing palmitic acid need less O_2 for respiration and glucose to need more oxygen for respiration
Statement 'Z' – Fat containing palmitic acid has much less oxygen in its constitution as compared to glucose
(a) Statement 'X', 'Y' and 'Z' are correct. Statement 'Y' and 'Z' is the correct explanation for 'X'
(b) Statement 'X' and 'Y' are correct and the statement 'Z' is an incorrect statement, 'Y' is the correct explanation for 'X'
(c) Statement 'X' and 'Z' is correct and the statement 'Y' is an incorrect statement, 'Z' is the correct explanation for 'X'
(d) Statement 'X' and 'Z' are incorrect and the statement 'Y' is correct

7. Which of the following respiratory substrates requires the highest number of O_2 molecules for its complete oxidation
(a) Tripalmitin (b) Triolein
(c) Tartaric acid (d) Oleic acid

8. The energy content in Kcal/g of carbohydrate: protein: triglycerol respectively is approximately in the ratio of
(a) 1:2:2 (b) 1:1:2
(c) 2:1:1 (d) 2:2:1

9. R.Q. of fatty substances is generally
(a) Unity (b) Less than one (Approx 0.7)
(c) Greater than one (d) Zero

10. In succulents, respiratory quotient is always less than one because of
(a) Complete oxidation (b) Complete reduction
(c) Incomplete oxidation (d) incomplete reduction

11. R.Q. is more than one in case of
(a) Fat (b) Fructose
(c) Glucose (d) Organic acid

12. RQ (respiratory quotient) is defined as
(a) The volume of CO_2 the evolved = volume of O_2 consumed
(b) $\frac{\text{Volume of } O_2 \text{ consumed}}{\text{Volume of } CO_2 \text{ evolved}}$
(c) $\frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$
(d) $\frac{\text{Volume of } O_2 \text{ evolved}}{\text{Volume of } CO_2 \text{ consumed}}$

13. When the respiratory substances are more than one then which respiratory substrates are not used
(a) Pure Protein (b) Lipid
(c) Carbohydrate (d) (a) and (b) both

7. Factor affecting respiration

1. Which of the following is necessary for respiration in plants
(a) Carbon dioxide (b) Oxygen
(c) Chlorophyll (d) Light

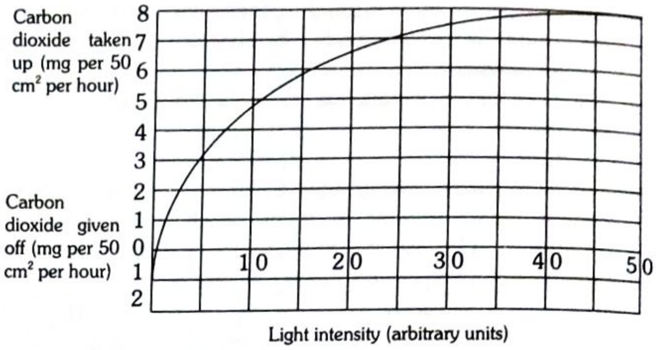
2. The rate of respiration of young maturing seeds is quite high but as water contents decrease during further maturation, respiration
(a) Remains high (b) Stops completely
(c) Increases steadily (d) Decreases steadily

3. Different steps in respiration are controlled by
(a) Auxin (b) Sugar
(c) Enzyme (d) Kinetin

4. In presence of cyanide, azide and carbon monoxide, the rate of respiration
(a) Decreases (b) Increases
(c) Remains the same (d) None of the above

5. Vant Hoff's law states that
(a) The respiration rate increases two or three times for every rise of 5° C
(b) The respiration rate decreases two or three times for every rise of 10° C
(c) The respiration rate does not increase or decrease with a change in temperature
(d) The respiration rate increases two or three times for every rise of 10° C

6. The graph shows the relationship between light intensity and the giving off and taking up carbon dioxide from the leaves of a plant. Why is most carbon dioxide given off when the light intensity is zero units



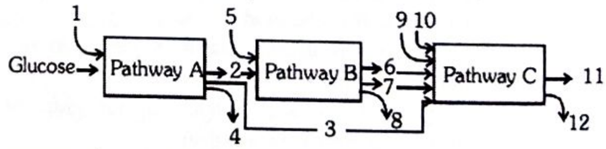
(a) Because it is just the start of the experiment
(b) Only respiration is taking place at this intensity of Light
(c) Only photosynthesis is taking place at this intensity of light
(d) The rate of photosynthesis is equivalent to the rate of respiration
(e) The rate of photosynthesis is more than the rate of respiration

7. If the temperature is increased (above 35° C)
(a) The rate of decline of respiration will be earlier than the decline of photosynthesis
(b) The rate of decline of photosynthesis will be earlier than the decline of respiration
(c) Both decline simultaneously
(d) Both do not show any fixed pattern

8. NEET- AIPMT/ CBSC-PMT

1. Oxygen is not produced during photosynthesis by **[2018]**
(a) Chara (b) Cycas
(c) Nostoc (d) Green sulphur bacteria

2. The three boxes in this diagram represent the three major biosynthetic pathways in aerobic respiration. Arrows represent net reactants or products



Arrow numbered 4, 8 and 12 can all be **[2013]**
(a) FAD^+ or $FADH_2$ (b) NADH
(c) ATP (d) H_2O

3. The connecting link among glycolysis, Kreb's cycle and beta–oxidation of fatty acid is **[1997, 2000]**

Or

Which of the metabolites is common to respiration mediated breakdown of fats, carbohydrates, and proteins **[2013]**
(a) Pyruvic acid (b) Acetyl CoA
(c) Acetaldehyde (d) Citric acid

9. AIIMS

1. The high-energy bonds of ATP are between **[2001]**
(a) C-C (b) C-O
(c) C-N (d) O-P

2. The net gain of energy from one gram molecule of glucose during aerobic respiration is [2012]
(a) 2 ATP (b) 36 ATP
(c) 38 ATP (d) 15 ATP

3. The enzyme which converts glucose to glucose–6–phosphate is [1999]
(a) Phosphorylase (b) Glucose–6–phosphate
(c) Hexokinase (d) Glucose synthetase

4. Which one of the following products are formed during glycolysis of glucose [2002]
(a) Pyruvic acid (b) Carbon dioxide
(c) Citric acid (d) Ethanol

5. Glycolysis is found in the cytoplasm of virtually all types of aerobic/anaerobic cells. In this process, glucose is converted into a compound which is [2002]
(a) PEP (b) Pyruvic acid
(c) Acetyl *CoA* (d) Citric acid

6. The process by which ATP is produced in the inner membrane of a mitochondrion. The electron transport system transfers protons from the inner compartment of the outer, as the protons flow back to the inner compartment, the energy of their movement is used to add phosphate to ADP, forming ATP [2009]
(a) Chemiosmosis (b) Phosphorylation
(c) Glycolysis (d) Fermentation

7. All enzymes of the TCA cycle are located in the mitochondrial matrix except one which is located in inner mitochondrial membranes in eukaryotes and in the cytosol in prokaryotes. This enzyme is [1994]
(a) Lactate dehydrogenase (b) Isocitrate Dehydrogenase
(c) Malate dehydrogenase (d) Succinate dehydrogenase

8. The enzyme mediating the reaction of Kreb's cycle during cellular respiration in animal found in [1993]
(a) Cytoplasm (b) Ribosome
(c) Lysosome (d) Mitochondria

9. In hexose monophosphate shunt, the number of CO_2 molecules evolved is [1990]
(a) Same as in glycolysis
(b) Less than glycolysis
(c) More than glycolysis
(d) Much lesser than glycolysis

10. Assertion & Reason

Read the assertion and reason carefully to mark the correct option out of the options given below :

(a) If both the assertion and the reason are true and the reason is a correct explanation of the assertion
(b) If both the assertion and reason are true but the reason is not a correct explanation of the assertion
(c) If the assertion is true but the reason is false
(d) If both the assertion and reason are false
(e) If the assertion is false but reason is true

1. Assertion : Glycolysis occurs in the cytoplasm.
Reason : Enzymes for glycolysis are found in the cytoplasm. It is common in aerobic / anaerobic respiration.

2. Assertion : Cytochrome oxidase enzyme contains copper.
Reason : Cyanide combines with copper of cytochrome oxidase and prevents oxygen from combining with it

3. Assertion : During the hydrolysis of typical chemical bonds, about 3000 calories per mole are liberated.
Reason : ATP also yields about 3000 calories per mole
after the release of any one of the two terminal phosphates.

4. Assertion : In alcoholic fermentation, the hexose molecule is converted into glucose and fructose.
Reason : Alcoholic fermentation is anaerobic respiration
brought about by enzyme zymase.

5. Assertion : Both hexokinase and glucokinase require divalent cation Mg^{++} or Mn^{++}.
Reason : The divalent cations act as catalysts.

6. Assertion : Substrate-level phosphorylation is present in glycolysis.
Reason : Substrate level phosphorylation causes the synthesis of ATP.

7. Assertion : Terminal oxidation occurs both in aerobic and anaerobic conditions.
Reason : Terminal oxidation occurs at the terminal Step of respiration.

8. Assertion : Fructose-1, 6 diphosphates is converted into glyceraldehyde-3-phosphate and dihydroxyacetone-3-phosphate.
Reason : Conversion of fructose-1,6 diphosphate into 3- phosphoglyceraldehyde and dihydroxyacetone - 3-phosphate is facilitated by the enzyme Aldolase