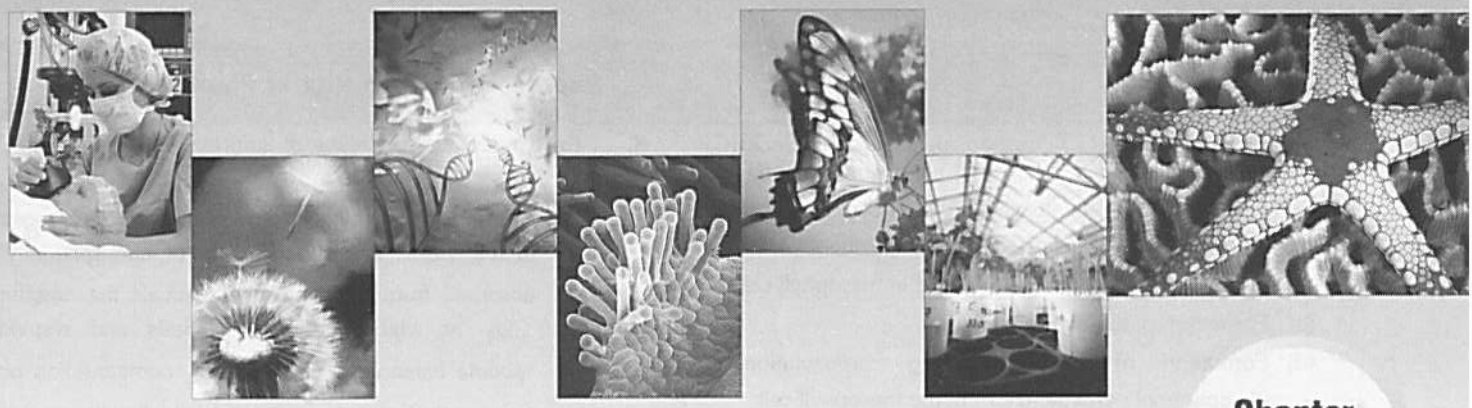


Chapter

4.4

Respiration in Plants

Cellular respiration is an enzyme controlled process of biological oxidation of food materials in a living cell, using molecular O_2, producing CO_2 and H_2O, and releasing energy in small steps and storing it in biologically useful forms, generally ATP.

So respiration is catabolic, exothermic and oxidative process.

$$\underset{\text{glucose}}{C_6H_{12}O_6} + 6O_2 \xrightarrow{\text{enzymes}} \underset{\text{carbondioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} + \underset{\text{(ATP)}}{\text{energy}}$$

Use of energy : Cellular activities like active transport, muscle-contraction, bioluminescence, homothermy, locomotion, nerve impulse conduction, cell division, growth, development, seed germination require energy. Main source of energy for these endergonic activities in all living organisms including plants, comes from the oxidation of organic molecules.

The energy released by oxidation of organic molecules is actually transferred to the high energy terminal bonds of ATP, a form that can be readily utilized by the cell to do work. Once ATP is formed, its energy may be utilized at various places in the cell to drive energy- requiring reactions. In these processes, one of the three phosphate groups is removed from the ATP molecule. Thus the role of ATP as an intermediate energy transforming compound between energy releasing and energy consuming reactions.

Significance of respiration : Respiration plays a significant role in the life of plants. The important ones are given below :

(1) It releases energy, which is consumed in various metabolic processes necessary for life of plant.

(2) Energy produced can be regulated according to requirement of all activities.

(3) It converts insoluble food into soluble form.

(4) Intermediate products of cell respiration can be used in different metabolic pathways *e.g.*,

Acetyl- CoA (in the formation of fatty acid, cutin and isoprenoids) ; α - ketoglutaric acid (in the formation of glutamic acid) ; Oxaloacetic acid (in the formation of aspartic acid, pyrimidines and alkaloids); Succinyl- CoA (synthesis of pyrrole compounds of chlorophyll).

(5) It liberates carbon dioxide, which is used in photosynthesis.

(6) Krebs cycle is a common pathway of oxidative breakdown of carbohydrates, fatty acids and amino acids.

(7) It activates the different meristematic tissues of the plant.

CO_2 intake in photosynthesis balanced with CO_2 release in respiration = Compensation point.

Comparison between respiration and combustion : According to Lavosier cell respiration resembles the combustion (*e.g.*, burning of coal, wood, oil etc.) in the breakdown of complex organic compounds in the presence of oxygen and production of carbon dioxide and energy, but there are certain fundamental differences between the two processes :

Table : 4.4-1

Differences between cell respiration and combustion

S.No.	Characters	Cell respiration	Combustion
(i)	Nature of process	Biochemical and stepped process.	Physico-chemical and spontaneous process.
(ii)	Site of occurrence	Inside the cells.	Non-cellular.
(iii)	Control	Biological control.	Uncontrolled.
(iv)	Energy release	Energy released in steps.	Large amount of energy is released at a time.
(v)	Temperature	Remain within limits.	Rises very high.
(vi)	Light	No light is produced.	Light may be produced.
(vii)	Enzymes	Controlled by enzymes.	Not controlled by enzymes.
(viii)	Intermediates	A number of intermediates are produced.	No intermediate is produced.

Phases of respiration

There are three phases of respiration :

(1) **External respiration :** It is the exchange of respiratory gases (O_2 and CO_2) between an organism and its environment.

(2) **Internal or Tissue respiration :** Exchange of respiratory gases between tissue and extra cellular environment .

Both the exchange of gases occur on the principle of diffusion.

(3) **Cellular respiration :** It is an enzymatically-controlled stepped **chemical process** in which glucose is oxidised inside the mitochondria to produce energy-rich ATP molecules with high-energy bonds.

So, respiration is a biochemical process.

Respiratory substrate or Fuel

In respiration many types of high energy compounds are oxidised. These are called respiratory substrate or respiratory fuel and may include carbohydrates, fats and protein.

(1) **Carbohydrate :** Carbohydrates such as glucose, fructose (hexoses), sucrose (disaccharide) or starch, insulin, hemicellulose (polysaccharide) etc; are the main substrates. Glucose are the first energy rich compounds to be oxidised during respiration. Brain cells of mammals utilized only glucose as respiratory substrate. Complex carbohydrates are hydrolysed into hexose sugars before being utilized as respiratory substrates. The energy present in one gram carbohydrate is 4.4 *Kcal* or 18.4 *kJ*.

(2) **Fats :** Under certain conditions (mainly when carbohydrate reserves have been exhausted) fats are also oxidised. Fat are used as respiratory substrate after their hydrolysis to fatty acids and glycerol by lipase and their subsequent conversion to hexose sugars. The energy present in one gram of fats is 9.8 *Kcal* or 41*kJ*, which is maximum as compared to another substrate.

The respiration using carbohydrate and fat as respiratory substrate, called floating respiration (Blackmann).

(3) **Protein :** In the absence of carbohydrate and fats , protein also serves as respiratory substrate. The energy present in one gram of protein is : 4.8 *Kcal* or 20 *kJ*. when protein are used as respiratory substrate respiration is called protoplasmic respiration.

Types of respiratory organism

Organism can be grouped into following four classes on the basis of their respiratory habit.

(1) **Obligate aerobes :** These organisms can respire only in the presence of oxygen. Thus oxygen is essential for their survival.

(2) **Facultative anaerobes :** Such organisms usually respire aerobically (*i.e.*, in the presence of oxygen) but under certain condition may also respire anaerobically (*e.g.*, Yeast, parasites of the alimentary canal).

(3) **Obligate anaerobes :** These organisms normally respire anaerobically which is their major ATP- yielding process. Such organisms are in fact killed in the presence of substantial amount of oxygen (*e.g.*, *Clostridium botulinum* and *C. tetani*).

(4) **Facultative aerobes :** These are primarily anaerobic organisms but under certain condition may also respire aerobically.

Types of respiration

On the basis of the availability of oxygen and the complete or incomplete oxidation of respiratory substrate. The respiration may be either of the following two types : Aerobic respiration and Anaerobic respiration

Aerobic respiration

It uses oxygen and completely oxidises the organic food mainly carbohydrate (Sugars) to carbon dioxide and water. It therefore, releases the entire energy available in glucose.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{enzymes}} 6CO_2 + 6H_2O + \text{energy (686 } Kcal)$$

It is divided into two phases : Glycolysis, Aerobic oxidation of pyruvic acid.

Glycolysis / EMP pathway

(1) **Discovery :** It was given by Embden, Meyerhof and Parnas in 1930. It is the first stage of breakdown of glucose in the cell.

(2) **Definition :** Glycolysis (Gr. *glykys*= sweet, sugar; *lysis*= breaking) is a stepped process by which one molecule of glucose (6c) breaks into two molecules of pyruvic acid (3c).

(3) **Site of occurrence :** Glycolysis takes place in the cytoplasm and does not use oxygen. Thus, it is an anaerobic pathway. In fact, it occurs in both aerobic and anaerobic respiration.

(4) **Inter conversions of sugars :** Different forms of carbohydrate before entering in glycolysis get converted into simplest form like glucose, glucose 6-phosphate or fructose 6-phosphate. Phosphorylation of glucose is the first step of glycolysis. Then these sugars are metabolized into the glycolysis.

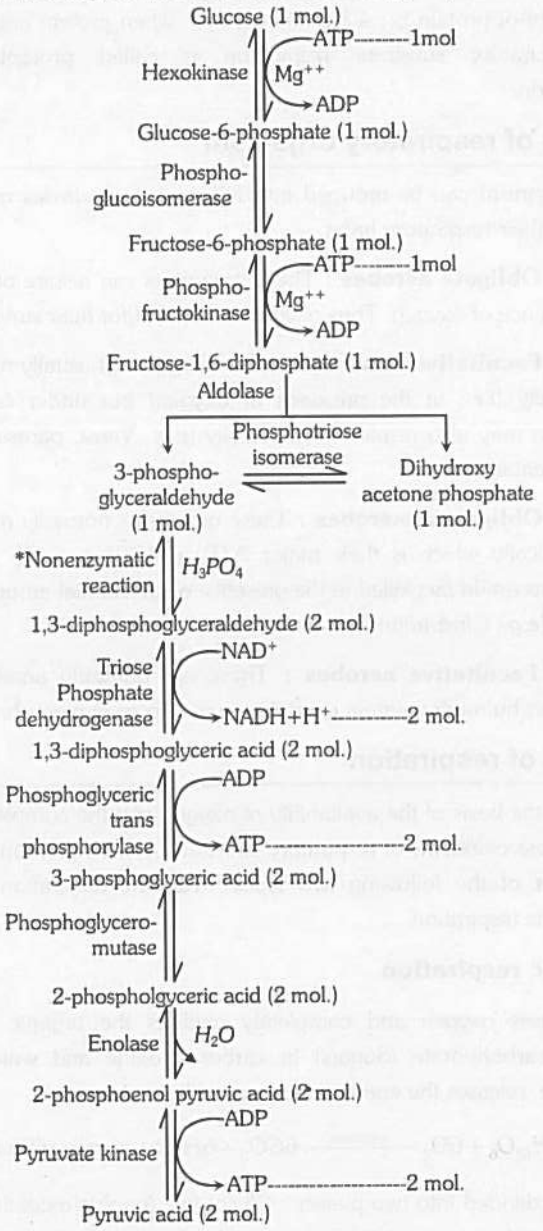


Fig : 4.4-1 Glycolysis or EMP-Pathway

(5) **Special features of glycolysis :** The special features of glycolysis can be summarised as follows :

(i) Each molecule of glucose produces 2 molecules of pyruvic acid at the end of the glycolysis.

(ii) The net gain of ATP in this process is two ATP molecules (four ATPs are formed in glycolysis but two of them are used up in the reaction).

(iii) During the conversion of 1, 3-diphosphoglyceraldehyde into 1, 3-diphosphoglyceric acid one molecule of $NADH_2$ is formed. As each molecule of glucose yields two molecules of 1,3-diphosphoglyceric acid, hence each molecule of glucose forms 2 molecules of $NADH_2$.

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

In this way during aerobic respiration there is additional gain of 6 ATP in glycolysis

$$\underset{\text{(net gain)}}{2ATP} + \underset{\text{(addition gain)}}{6ATP} \rightarrow \underset{\text{(total net gain)}}{8ATP}$$

(v) Reaction of glycolysis do not require oxygen and there is no output of CO_2.

(vi) Formation of 1, 3- diphosphoglyceraldehyde called non enzymatic phosphorylation.

(vii) Overall reaction of glycolysis represented by following reaction :

$$C_6H_{12}O_6 \rightarrow \underset{\text{Pyruvate}}{2C_3H_4O_3} + 4H$$

Table : 4.4-2 Total input and output materials in glycolysis

Total Input	Total Output
1 molecule of glucose (6 C)	2 molecules of pyruvate (2×3 C)
2 ATP	4 ATP
4 ADP	2 ADP
2 × NAD^+	2× NADH + $2H^+$
2 Pi	2 × H_2O

Aerobic oxidation of pyruvic acid

(1) **Oxidative decarboxylation of pyruvic acid :** If sufficient O_2 is available, each 3-carbon pyruvate molecule ($CH_3COCOOH$) enters the mitochondrial matrix where its oxidation is completed by aerobic means. It is called gateway step or link reaction between glycolysis and Kreb's cycle.

Decarboxylation and dehydration :

$$\underset{\text{(Pyruvic acid)}}{CH_3CO.COOH} + \underset{\text{(CoA)}}{CoA.SH} + NAD \xrightarrow[\substack{**TPP \\ **LAA}]{\text{Pyruvic dehydrogenase multienzyme complex}} \underset{\text{(acetyl-S-CoA)}}{CH_3.CO.S.CoA} + NAD.2H + CO_2$$

**TPP=Thiamine pyrophosphate

**LAA=Lipoic acid amide

Acetyl CoA is a common intermediate of carbohydrate and fat metabolism. Latter this acetyl CoA from both the sources enters Kreb's cycle. The formation of acetyle CoA is involved with some cofactors like Mg^{++}, thiamine pyrophosphate Vit B_1, NAD^+, CoA and lipoic acid. This reaction is not a part of Kreb's cycle.

(2) **Kreb's cycle / TCA cycle / Citric acid cycle**

Discovery : This cycle has been named after the German biochemist Sir Hans Krebs who discovered it in 1937. He won Noble Prize for this work in 1953. Krebs cycle is also called the citric acid cycle after one of the participating compounds. It takes place in the mitochondrial matrix.

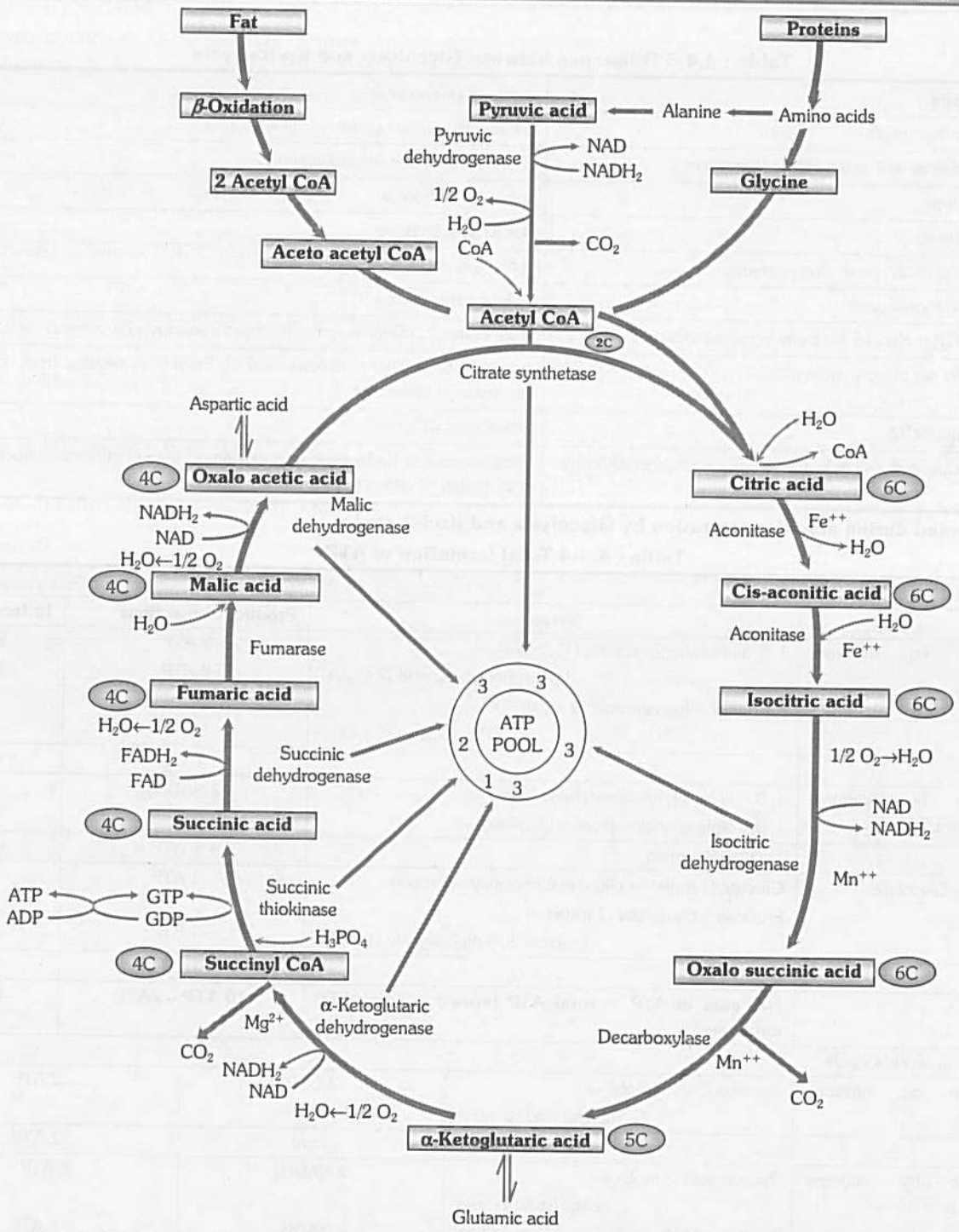


Fig : 4.4-2 Diagrammatic representation of oxidative decarboxylation of pyruvic acid and different chemical reactions in Kreb's cycle starting from Acetyl CoA

Summary of Kreb's cycle

(i) All the enzymes, reactants, intermediates and products of TCA cycle also are found in aqueous solution in the matrix, except the succinate dehydrogenase (mitochondrial marker enzyme) which is located in the inner mitochondrial membrane.

(ii) Oxidation of one mole of acetyl CoA uses 4 molecules of water and releases one molecule of water.

(iii) Liberates 2 molecules of carbon dioxide.

(iv) Gives off 4 pairs of hydrogen atoms.

(v) Produces one GTP/ ATP molecule during the formation of succinate.

(vi) One mole of acetyl CoA gives 12 ATP during oxidation in Krebs cycle.

(vii) Regenerates oxaloacetate used in last cycle for reuse.

The above summary is for one molecule of acetyl coenzyme A. There are two acetyl coenzyme A molecules formed from one molecule of glucose by glycolysis and oxidative decarboxylation of pyruvate.

Table : 4.4-3 Difference between Glycolysis and Kreb's cycle

Glycolysis	Kreb's cycle
It takes place in the cytoplasm.	It takes place in the matrix of mitochondria.
It occurs in aerobic as well as anaerobic respiration.	It occurs in aerobic respiration only.
It consists of 9 steps.	It consists of 8 steps.
It is a linear pathway.	It is a cyclic pathway.
It oxidizes glucose partly, producing pyruvate.	It oxidises acetyl coenzyme A fully.
It consumes 2 ATP molecules.	It does not consume ATP.
It generates 2 ATP molecules net from 1 glucose molecules.	It generates 2 GTP/ATP molecules from 2 succinyl coenzyme A molecules.
It yields 2 NADH per glucose molecule.	It yields 6 NADH molecules and 2 $FADH_2$ molecules from 2 acetyl coenzyme A molecules.
It does not produce CO_2.	It produces CO_2.
All enzyme catalysing glycolytic reactions are dissolved in cytosol.	Two enzymes of Krebs cycle reactions are located in the inner mitochondrial membrane, all others are dissolved in matrix.

Product formed during aerobic respiration by Glycolysis and Kreb's cycle.

Table : 4.4-4 Total formation of ATP

ATP formation in Glycolysis			
	Steps	**Product of reactions**	**In terms of ATP**
ATP formation by substrate phosphorylation	1, 3-diphosphoglyceric acid (2 moles) → 3 phosphoglyceric acid (2 moles)	2 ATP	2 ATP
	Phosphoenolpyruvic acid (2 moles) → Pyruvic acid (2 moles)	2 ATP	2 ATP
		Total	4 ATP
ATP formation by oxidative phosphorylation or ETC	1, 3 - diphosphoglyceraldehyde (2 moles) 1, 3 – diphosphoglyceric acid (2 moles)	2 $NADH_2$	6 ATP
	Total ATP formed	4 + 6 ATP =	10 ATP
ATP consumed in Glycolysis	Glucose (1 mole) → Glucose 6 phosphate (1 mole)	– 1 ATP	– 1 ATP
	Fructose 6 phosphate (1 mole) → Fructose 1, 6-diphosphate (1 mole)	– 1 ATP	– 1 ATP
		Total	2 ATP
	Net gain of ATP = total ATP formed – Total ATP consumed	**10 ATP – 2ATP**	**8 ATP**
ATP formation in Kreb's cycle			
ATP formation by substrate phosphorylation	Succinyl CoA (2 mols) → Succinic acid (2 mols)	2 GTP	2 ATP
		Total	2 ATP
ATP formation by oxidative phosphorylation or ETC	Pyruvic acid (2 mols) → Acetyl CoA (2 mols)	2 $NADH_2$	6 ATP *
	Isocitric acid (2 mols) → Oxalosuccinic acid (2 mols)	2 $NADH_2$	6 ATP
	α-Ketoglutaric acid (2 mols) → Succinyl CoA (2 mols)	2 $NADH_2$	6 ATP
	Succinic acid (2 mols) → Fumaric acid (2 mols)	2 $FADH_2$	4 ATP
	Malic acid (2 mols) → Oxaloacetic acid (2 mols)	2 $NADH_2$	6 ATP
		Total	28 ATP
	Net gain in Kreb's cycle (substrate phosphorylation + oxidative phosphorylation)	2ATP + 28 ATP	30 ATP

Net gain of ATP in glycolysis and Kreb's cycle	Net gain of ATP in glycolysis + Net gain of ATP in Kreb's cycle	8 ATP + 30 ATP	38 ATP
Over all ATP production by oxidative phosphorylation or ETC	ATP formed by oxidative phosphorylation in glycolysis + ATP formed by oxidative phosphorylation or ETC.	6 ATP + 28 ATP	34 ATP

22 ATP produced by oxidation of $NADH_2$ and $FADH_2$ in Kreb's cycle and 6 ATP comes from oxidative decarboxylation of pyruvic acid.

* These ATPs are not included neither in glycolysis nor kreb's cycle.

Table : 4.4-5 Formation and use of water

Formation of water molecules		
Formation of water molecules in glycolysis	2 phosphoglyceric acid (2 mols) $\xrightarrow{-H_2O}$ 2 phosphoenol pyruvic acid (2 mols)	$2H_2O$
	1, 3-diphosphoglyceraldehyde $\xrightarrow{-H_2O}$ 1, 3 diphosphoglyceric acid	$2H_2O$
	Total water molecules formed in glycolysis	$4H_2O$
Formation of water molecules in kreb's cycle	One molecule of water in each of the five oxidation reactions (these reactions occur twice as there are two molecules of pyruvic acid).	$10\ H_2O$
	Other than oxidation reaction Citric acid (2 mols) → Cis-aconitic acid (2 mols)	$2H_2O$
	Total water molecules formed in Kreb's cycle	$12\ H_2O$
	Total water molecules formed in aerobic respiration (Glycolysis + Kreb's cycle including activation of pyruvates)	**$16\ H_2O$**
Use of water molecules		
Use of water in Glycolysis	3-phosphoglyceraldehyde (2 mols) $\xrightarrow{+H_2O}$ 1, 3 diphosphoglyceric acid (2 mols)	$2H_2O$
	Total water molecule used in glycolysis	$2H_2O$
Use of water in Kreb's cycle	Oxaloacetic acid (2 mols) $\xrightarrow{+H_2O}$ Citric acid (2 mols)	$2H_2O$
	Cis aconitic acid (2 mols) $\xrightarrow{+H_2O}$ Isocitric acid (2 mols)	$2H_2O$
	Succinyl CoA (2 mols) $\xrightarrow{+H_2O}$ Succinic acid (2 mols)	$2H_2O$
	Fumaric acid (2 mols) $\xrightarrow{+H_2O}$ Malic acid (2 mols)	$2H_2O$
	Total water molecules used is Kreb's cycle	$8H_2O$
	Total water molecules used in aerobic respiration (Glycolysis + Kreb's cycle)	$10H_2O$
Net gain of water molecules in aerobic respiration	**Number of water molecules formed – Number of water molecules used = ($16\ H_2O - 10H_2O$)**	**$6H_2O$**

Table : 4.4-6 Evolution of carbon dioxide

Pyruvic acid (2 mols) $\xrightarrow{-CO_2}$ Acetyl CoA (2 mols)	$2CO_2$
Oxalosuccinic acid $\xrightarrow{-CO_2}$ α ketoglutaric acid (2 mols)	$2CO_2$
α Ketoglutaric acid (2 mols) $\xrightarrow{-CO_2}$ Succinyl CoA (2 mols)	$2CO_2$
Total CO_2 molecules released in aerobic respiration	**$6CO_2$**

Table : 4.4-7 Use of O_2 (Oxygen)

Use of oxygen in Glycolysis	1, 3-diphosphoglyceraldehyde (2mols) $\xrightarrow{+\frac{1}{2}O_2}$ 1, 3-diphosphoglyceric acid (2 mols)	$1O_2$
Use of oxygen in Kreb's cycle	Five oxidation reactions of Kreb's cycle (2 times)	$5O_2$
	Total O_2 molecules required for aerobic respiration	**$6O_2$**

Energy storage and energy transfer : In respiration energy released takes in the form of chemical energy, stored in a form called ATP. Energy transfer of biological oxidation hinges on the formation of labile high energy phosphate bonds of ATP. Nicotinamide adenine dinucleotide phosphate (NAD), Flavin adenine dinucleotide (FAD), Guanosine triphosphate are also the product of respiration and converted to ATP by electron transport system.

Adenosine triphosphate

There are several compounds like NAD, FAD, GTP and ATP are known as energy yielding compounds. The best known, and probably the most important of these are adenosine triphosphate (ATP). It serves as the energy currency of the cell.

Structure of ATP : Adenosine triphosphate is a nucleotide consisting of three main constituents;

(i) A nitrogen contain purine base (Adenine).

(ii) A five carbon sugar ribose.

(ii) Three inorganic phosphate groups.

An ATP molecule is structurally most similar to a RNA molecule.

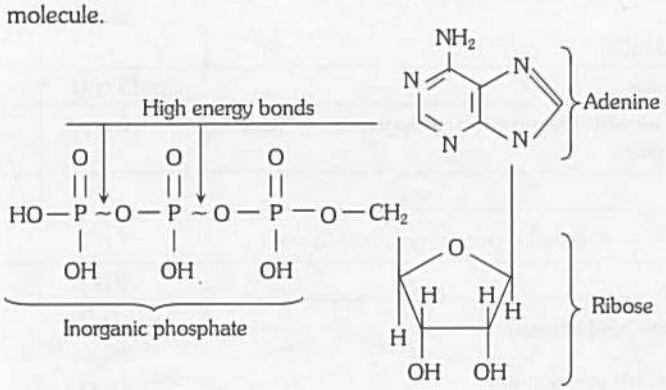


Fig : 4.4-3 Structure of ATP

The bonds attaching the last two phosphate to the rest of the molecule are high energy bonds (~) contain more than twice the energy of an average chemical bond.

ATP hydrolysis : The energy is usually released from ATP by hydrolysing the terminal phosphate groups.

$$\text{Adenosine triphosphate} \xrightarrow{\text{hydrolysis}} \text{Adenosine diphosphate}\,(ADP) + Pi + 7.3Kcal.....$$

$$\text{Adenosine diphosphate} \xrightarrow{\text{hydrolysis}} \text{Adenosine monophosphate}(AMP) + Pi + 7.3Kcal.$$

Phosphorylation : The ATP hydrolysis reactions are reversible because ATP are synthesized from ADP, Pi and energy (take up for the bond formation).

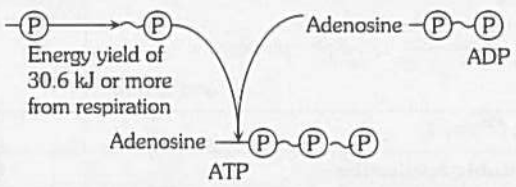


Fig : 4.4-4 Phosphorylation

The addition of phosphate group to ADP and AMP called phosphorylation. Energy required for the bond formation is equal to the energy released in hydrolysis. The significant role of ATP as an intermediate energy transfer compound.

Oxysomes acts as the unit of phosphorylation in respiration by the formation of ATP from ADP. These are present cristae of mitochondria.

Major functions of ATP : ATP molecules receive the energy, which released in exergonic reactions and make this energy available for various endergonic reactions. Some of the important process in which ATP is utilized are as follows :

(i) Synthesis of carbohydrates, proteins, fats, etc.

(ii) Translocation of organic food.

(iii) Absorption of organic and inorganic food.

(iv) Protoplasmic streaming.

(v) Growth.

Nicotinamide adenine dinucleotide phosphate/ Nicotinamide adenine dinucleotide (NADP/NAD) : It is called universal hydrogen acceptor, produced during aerobic respiration (glycolysis+ Kreb's cycle) and also in anaerobic respiration, work as coenzyme in ATP generation *Via* electron transport system. NADP have one additional phosphate.

NAD plays a crucial role in dehydrogenation processes. Some dehydrogenases do not work with NAD, but react with NADP (Nicotinamide adenine dinucleotide phosphate). Formerly called Coenzyme II or Triphosphopyridine nucleotide = TPN Nicotinamide is a vitamin of B group.

First NAD and NADP both functions as hydrogen acceptors. Later H ions and electrons (e-) from these are transported through a chain of carriers and after being released at the end of a chain react with O_2 and from H_2O (see Electron Transport chain). During the release of 2 electron from $2H^+$ atoms from NAD. $2H$ and their reaction with O_2 to form water, 3 ATP molecules are synthesized.

(3) **Electron transport system :** The electron transmitter system is also called electron transport chain (ETC), or cytochrome system (CS), as five out of these nine carriers are cytochrome. It is the major source of cells energy, in the respiratory breakdown of simple carbohydrates intermediates like phosphoglyceraldehyde, pyruvic acid, isocitric acid, α – ketoglutaric acid, succinic acid and malic acid are oxidised. The oxidation in all these brought about by the removal of a pair of hydrogen atoms ($2H$) from each of them. This final stage of respiration is carried out in ETS, located in the inner membrane of mitochondria (in prokaryotes the ETS is located in mesosomes of plasma membrane). The system consists of series of precisely arranged nine electron carriers (coenzyme) in the inner membrane of the mitochondrion, including the folds or cristae of this membrane. These nine electron-carriers function in a specific sequence and are :

Nicotinamide adenine dinucleotide (NAD), Flavin mononucleotide (FMN), Flavin adenine dinucleotide (FAD), Co-enzyme-Q or ubiquinone, Cytochrome-b, Cytochrome–c_1, Cytochrome-c, Cytochrome-a and Cytochrome-a_3,

The first carrier in the chain is a flavoprotein which is reduced by $NADH_2$. Coenzyme passes these electron to the cytochromes arranged in the sequence of b-c_1-c-a-a_3, finally pass the electron to molecular oxygen. In this transport, the electrons tend to flow from electro-negative to electro-positive system, so there is a decrease in free energy and some energy is released so amount of energy with the electrons goes on decreasing. During electron-transfer, the electron-donor gets oxidised, while electron-acceptor gets reduced so these transfers involve redox-reaction and are catalysed by enzymes, called reductases. Oxidation and reduction are complimentary. This oxidation-reductiion reaction over the ETC is called biological oxidation.

$$\text{Electron} - \text{donor} \xrightarrow{e^-} \text{electron} - \text{acceptor}$$

here, electron-donor and electron –acceptor form redox pair.

During the electron transfers, the energy released at some steps is so high that ATP is formed by the phosphorylation of ADP in the presence of enzyme ATP synthetase present in the head of F_1-particles present on the mitochondrial cristae. This process of ATP synthesis during oxidation of coenzyme is called oxidative phosphorylation, so ETS is also called oxidative phosphorylation pathways.

$$ADP + Pi \xrightarrow{\text{ATP Synthetase}} ATP$$

From the cytochrome a_3, two electrons are received by oxygen atom which also receives two proton (H^+) from the mitochondrial matrix to form water molecule. So the final acceptor electrons is oxygen. So the reaction

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ (called metabolic water) is made to occur in many steps through ETC, so the most of the energy can be derived into a storage and usable form.

(i) **Two route systems of ETC :** The pairs of hydrogen atoms from respiratory intermediates are received either by NAD^+ or FAD coenzymes which becomes reduced to $NADH_2$ and $FADH_2$. These reduced coenzyme pass the electrons on to ETC. Thus, regeneration of NAD^+ or FAD takes place in ETC. There are two routes ETC :

(a) **Route 1 :** $NADH_2$ passes their electrons to Co-Q through FAD . In route 1 FAD is the first electron carrier. 3 ATP molecules are produced during the transfer of electron on following steps :

NAD to *FAD*

Cyt b to *Cyt* c_1 and

Cyt a to *Cyt* a_3

(b) **Route 2 :** $FADH_2$ passes their electron directly to *FAD*. 2 *ATP* molecules are produced during the transfer of electron on following steps.

Cyt b to *Cyt* c_1 and

Cyt a to *Cyt* a_3

(ii) **Structure of mitochondria in relation to oxidative function :** On inner side of mitochondria elementary particles or F_0-F_1 complex of ATPase complex or elementary particle (oxysomes) are found. Previously it was considered that elementary particles contain all the enzyme of oxidative phosphorylation and electron transport chain.

Component of electron transport chain are located in the inner membrane in the form of respiratory chain complexes. For complexes following theories are given :

(a) **Four complex theory :** According to Devid green electron transport chain contains 4 complexes-

Complex I : Comprises *NADH* dehydrogenase and its 6 Iron Sulphur centers (Fe-S).

Complex II : Consists of Succinate dehydrogenase and its 3 Iron Sulphur centers.

Complex III : Consists of cytochrome *b* and *c*, and a specific Iron-Sulphur centers.

Complex IV : Comprises cytochromes *a* and a_3.

(b) **Five complex theory :** According to Hatefi, (1976), Complex I to Complex IV are related to the electron transport.

- Complex V related to mainly with ATP synthesis, so it is called ATPase /ATP synthesis complex.
- The head piece (F_1) of the oxysome consists of 5 hydrophobic subunits ($\alpha, \beta, \gamma, \delta, \varepsilon$), which are responsible for ATPase functioning.
- The stalk (F_0) contain F_5 (oligomycin sensitivity conferring protein) *i.e.*, CSCP and F_6. F_0 are related to the proton channel and embeded fully in thickness of inner mitochondrial membrane.
- Five complex *i.e.*, I, II, III, IV, V, have been isolated from mitochondrial membrane by chemical treatment.
- Complex I : NADH/NADPH : CoQ reductase

Complex II : Succinate : CoQ reductase

Complex III : Reduced CoQ ($CoQH_2$) : cytochrome *C* reductase

Complex IV : Cytochrome *C* oxidase

Complex V : ATPase

Cytochrome *C* and *Q* are mobile components of the respiratory chain.

(iii) **Oxidative phosphorylation :** The process of ATP synthesis during oxidation of reduced coenzymes in ETC is called oxidative phosphorylation.

Peter Mitchell (1961) proposed the chemiosmotic mechanism of ATP synthesis (Noble prize in 1978) which states that ATP synthesis occurs due to H^+- flow through a membrane. It involves two steps :

(a) **Development of proton gradient.** At each step of ETC, the electron-acceptor has a higher electron-affinity than the electron-donor. The energy from electron-transport is used to move the proton (H^+) from the mitochondrial matrix to inter-membranous or outer chamber. Three pairs of protons are pushed to outer chamber during the movement of electrons along route I while two pairs of protons are moved to outer chamber during the movement of electrons along route–II. This generates a pH-gradient across the inner mitochondrial membrane with protons (H^+) concentration higher in the outer chamber than in the mitochondrial matrix. This difference in H^+ concentration across the inner mitochondrial membrane is called proton-gradient(Δ pH). Due to proton gradient, an electrical potential ($\Delta\psi$) is developed across the inner mitochondrial membrane as the matrix is now electronegative with respect to the intermembranous (outer) chamber. The proton gradient and membrane electric potential collectively called proton motive force.

(b) **Proton flow :** Due to proton-gradient, the protons returns to the matrix while passing through proton channel of F_0-F_1 ATPase. This proton gradient activates the enzyme ATP synthetase or $F_0 - F_1$ ATPase.

ATP synthetase controls the formation of ATP from ADP and inorganic phosphate in the presence of energy.

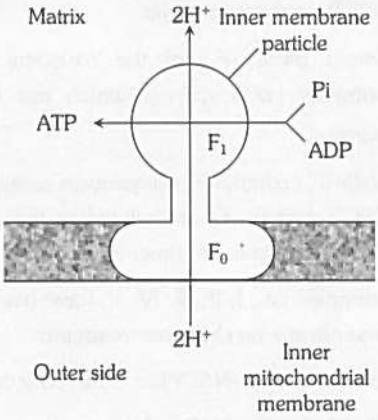


Fig : 4.4-5 ATP synthesis by inner membrane particles of mitochondria

(iv) **Role of shuttle system in energy production :** Glycolysis occurs in the cytoplasm outside the mitochondrion in which $2NADH_2$ molecules are produced but ETC is located along inner mitochondrial membrane, so $NADH_2$ of glycolysis must enter inside the mitochondrion to release energy. But the inner mitochondrial membrane is impermeable to $NADH_2$. In mitochondrial membrane, there are 2 shuttle-system, each formed of carrier-molecule.

These shuttle systems are :

(a) **Malate-Aspartate shuttle :** When this electron shuttle occurs, transfer of electrons from $NADPH_2$ in cytoplasm occurs to NAD inside the mitochondria. This is more efficient and result in production of 38 ATP molecules.

(b) **Glycerol-Phosphate shuttle :** In this shuttle transfer of electrons from $NADH_2$ in cytoplasm occurs to FAD inside mitochondria and it results in production of 36 ATP molecules. It is less efficient and results in the reduction of FAD inside the mitochondrion.

Which shuttle predominates depends on the particular species and tissues envolved, for example : 38 ATP are formed in kidney, heart and liver cell while 36 ATP molecules are formed in muscle cells and nerve cells. In these cells glycerol-phosphate shuttle is predominant and 2 ATP formed from $NADH_2$.

Other pathways of glucose oxidation

(1) **Entner-Doudoroff pathway**

Discovery : Entner-Doudoroff path discovered by Entner & Doudoroff. This pathway is also called glycolysis of bacteria.

Certain bacteria such as *Pseudomonas sacchorophila, P. fluorescens, P. lindeneri and P. averoginosa* lack phosphofructokinase enzyme. They can not degrade glucose by glycolytic process.

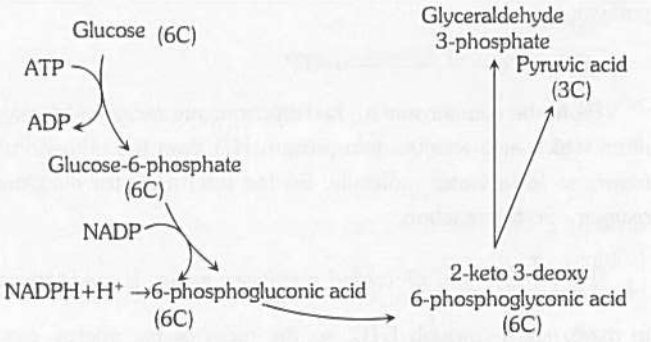


Fig : 4.4-6 Schematic representation of Entner-Doudoroff pathway

(2) **Pentose phosphate pathway**

(i) **Discovery :** It is also called as Hexose monophosphate (HMP) shunt or Warburg Dickens pathway or direct oxidation pathway. It provides an alternative pathway for breakdown of glucose which is independent of EMP pathway (glycolysis) and Krebs cycle. Its existence was suggested for the first time by Warburg *et al.* (1935) and Dickens (1938). Most of the reaction of this cycle were described by Horecker *et al.* (1951) and Racker (1954).

(ii) **Occurrence :** Pentose phosphate pathway that exists in many organisms. This pathway takes place in the cytoplasm and requires oxygen for its entire operation.

(iii) **Description :** There are two types of evidences is support of the existence of such an alternative pathway-works on the inhibiting action of malonic acid on the Krebs cycle and studies with the radioactive (C^{14}).

Twelve molecules of $NADH_2$ formed in the reaction can be oxidised back to 12 NADP with the help of the cytochrome system and oxygen of the air.

$$12\,NADPH_2 + 6O_2 \xrightarrow[System]{Cytochrome} 12H_2O + 12NADP$$

In this electron transfer process, 36 molecules of ATP are synthesized.

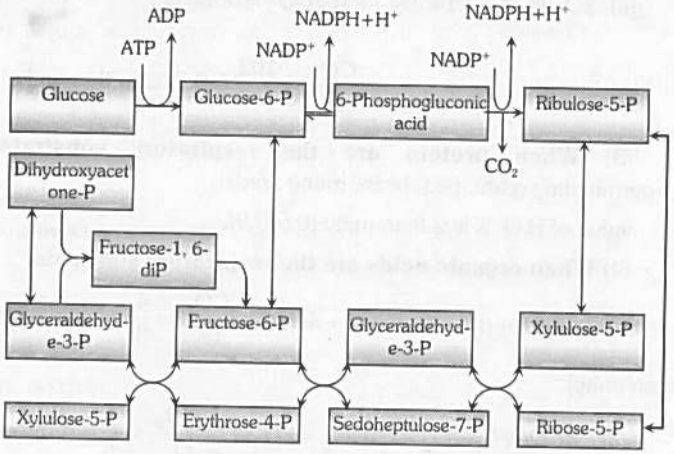


Fig : 4.4-7 Hexose monophosphate shunt

(iv) **Significance of PPP**

(a) It is the only pathway of carbohydrate oxidation that gives $NADPH_2$, Which is needed for synthetic action like synthesis of fatty acid (in adipose tissues) and amino acids (in liver).

(b) It synthesizes 3*C*-glyceraldehyde-3-P, 3*C*-dihydroxy acetone phosphate, 4*C*-erythrose-4-P, 5*C*-ribulose phosphate, 5*C*-xylulose phosphate, 5*C*-ribose phosphate, 6 *C*-Fructose 6-phosphate, 7*C*-sedoheptulose-7-phosphate.

(c) It is the major pathway by which necessary ribose and deoxyribose are supplied in the biosynthesis of nucleotides and nucleic acid.

(d) Erythrose 4 phosphate for the synthesis of lignin, oxine, anthocyanine and aromatic amino acid (phenylalanine, tyrosine, and tryptophan).

(e) Young growing tissues appears to use to the Krebs cycle as the predominant pathway for glucose oxidation, while aerial parts of the plants and other tissues seem to utilise the PPP as well as the Krebs cycle.

(f) It gives 6 CO_2, required for photosynthesis.

(g) Ribulose five phosphate is used in photosynthesis to produce RuBP which act as primary CO_2 acceptor in C_3 cycle.

(3) **Cyanide resistant pathway :** Cyanide-resistant respiration seems to be widespread in higher plant tissues. Cyanide prevents flow of electron from *Cyt* a_3 to oxygen, so called ETC inhibitor. In these plant tissues resistance is due to, a branch point in the ETS preceeding the highly cyanide-sensitive cytochromes. The tissues lacking this branch point, or alternate pathway and blockage of cytochromes by cyanide, inhibits the electron flow.

Significance

(i) The role of alternative pathway is that it may provide a means for the continued oxidation of *NADH* and operation of the tricarboxylic acid cycle, even through ATP may not be sufficiently drained off.

(ii) It is significant in respiratory climacteric of ripening fruits and leads to the production of hydrogen peroxide and super oxide, which in turn enhances the oxidation and breakdown of membranes.

(iii) Necessary activities in the ripening process because peroxides are necessary for ethylene biosynthesis.

Anaerobic respiration

Anaerobic respiration first studied by Kostychev (1902), Anaerobic respiration is an enzyme-controlled, partial break down of organic compounds (food) without using oxygen and releasing only a fraction of the energy. It is also called intra-molecular respiration (Pfluger, 1875). Anaerobic respiration occurs in the roots of some water-logged plants, certain parasitic worms (*Ascaris* and *Taenia*), animal muscle and some microorganisms (bacteria, moulds). In microorganisms anaerobic respiration is often called fermentation. Fermentation or anaerobic respiration is completed in cytoplasm.

Higher organism like plants can not perform anaerobic respiration for long. It is toxic because accumulation of end products, insufficient amount of available energy and causes stoppage of many active process.

Process of anaerobic respiration : In this process pyruvate which is formed by glycolysis is metabolised into ethyl alcohol or lactic acid and CO_2 in the absence of oxygen. Glycolysis is occurs in cytoplasm so the site of anaerobic respiration is cytoplasm.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 52\ Kcal/218.4\ kJ$$

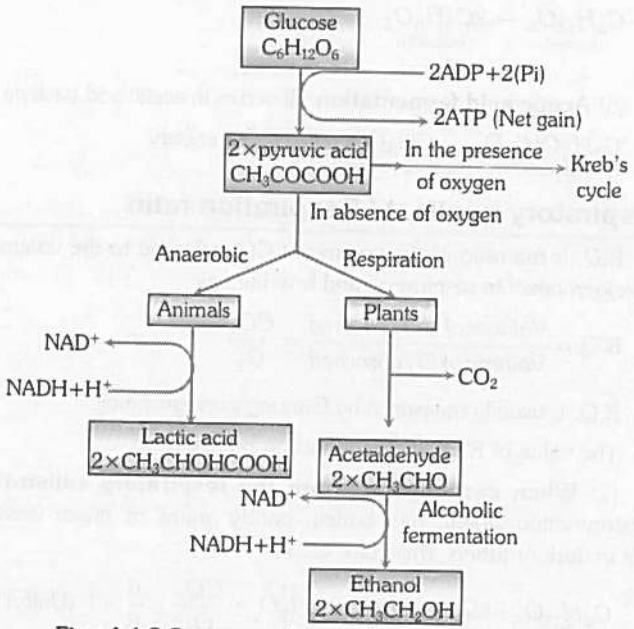


Fig : 4.4-8 Summary of anaerobic respiration pathways

(1) **Formation of ethyl alcohol :** When oxygen is not available, yeast and some other microbes convert pyruvic acid into ethyl alcohol.

$$\underset{\text{Pyruvic acid}}{2\,CH_3CO\,COOH} \xrightarrow{\text{Decarboxylase}} \underset{\text{Acetaldehyde}}{2\,CH_3CHO} + 2CO_2$$

$$2\,CH_3CHO + 2\,NADH_2 \xrightarrow[\text{drogenase}]{\text{Alcohol dehy-}} \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + 2NAD$$

(2) **Production of lactic acid :** In this process hydrogen atoms removed from the glucose molecule during glycolysis are added to pyruvic acid molecule and thus lactic acid is formed.

Lactic acid is produced in the muscle cells of human beings and other animals.

Pasteur effect : The process may be defined as *"the inhibition of sugar breakdown due to the presence of oxygen under aerobic condition"* and the reaction is called Pasteur reaction. Dixon (1937) stated that the Pasteur effect is the action of oxygen is checking the high rate of loss of carbohydrate and in suppressing or diminishing the accumulation of products of fermentation."

Fermentation : Fermentation is a kind of anaerobic respiration carried out by microorganisms fungi and bacteria. In microorganism the term anaerobic respiration is replaced by fermentation (Cruickshank, 1897) ; which is known after the name of its major product, *e.g.*, alcohol fermentation, lactic acid fermentation.

(1) **Butyric acid fermentation :** It occurs in bacteria *Clostridium butyricum*.

$$\underset{\text{(hexose)}}{C_6H_{12}O_6} \rightarrow \underset{\text{(butyric acid)}}{C_4H_8O_2} + 2H_2 + 2CO_2$$

$$\underset{\text{(lactic acid)}}{2C_3H_6O_3} \rightarrow \underset{\text{(butyric acid)}}{C_4H_8O_2} + 2H_2 + 2CO_2$$

(2) **Lactic acid fermentation :** It occurs in lactic acid bacteria and muscles.

$$\underset{\text{(lactose)}}{C_{12}H_{22}O_{11}} + H_2O \rightarrow \underset{\text{(glucose)}}{C_6H_{12}O_6} + \underset{\text{(galactose)}}{C_6H_{12}O_6}$$

$$\underset{\text{(hexose)}}{C_6H_{12}O_6} \rightarrow \underset{\text{(lactic acid)}}{2C_3H_6O_3}$$

(3) **Acetic acid fermentation :** It occurs in acetic acid bacteria.

$$\underset{\text{(ethyl alcohol)}}{C_2H_5OH} + O_2 \rightarrow \underset{\text{(acetic acid)}}{CH_3COOH} + H_2O + \text{energy}.$$

Respiratory quotient / Respiration ratio

R.Q. is the ratio of the volume of CO_2 released to the volume of oxygen taken in respiration and is written as

$$\text{R.Q.} = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ absorbed}} = \frac{CO_2}{O_2}$$

R.Q. is usually measured by Ganong's respirometer.

The value of R.Q. at compensation point is zero.

(1) **When carbohydrates are the respiratory substrate** (=germinating wheat, oat, barley, paddy grains or green leaves kept in dark or tubers, rhizomes, etc.)

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + 6O_2 \rightarrow 6CO_2 + 6H_2O \;;\; \frac{CO_2}{O_2} = \frac{6}{6} = 1 \text{ (Unity)}$$

(2) **When fats are the respiratory substrate** (=germinating castor, mustard, linseed, til seeds) for fatty substances R.Q. is generally less than one .

(i) $\underset{\text{Stearic acid}}{C_{18}H_{36}O_2} + 26O_2 \rightarrow 18CO_2 + 18H_2O$;

$$\frac{CO_2}{O_2} = \frac{18}{26} = 0.7 \text{ (Less than unity)}$$

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

$$\frac{CO_2}{O_2} = \frac{102}{145} = 0.7 \text{ (Less than unity)}$$

(3) **When protein are the respiratory substrate** (=germinating gram, pea, bean, mung seeds)

value of R.Q. is less than unity (0.5-0.9).

(4) **When organic acids are the respiratory substrate**

(i) $\underset{\text{Malic acid}}{C_4H_6O_5} + 3O_2 \rightarrow 4CO_2 + 3H_2O$; $\frac{CO_2}{O_2} = \frac{4}{3} = 1.33$ (More than unity)

(ii) $\underset{\text{Oxalic acid}}{2(COOH)_2} + O_2 \rightarrow 4CO_2 + 2H_2O$; $\frac{CO_2}{O_2} = \frac{4}{1} = 4$ (More than unity)

Some other organic acids and their R.Q. are – Succinic acid (1.14), Taurtric acid (1.6) and Acetic acid (1).

(5) **When there is incomplete oxidation of carbohydrates** (In the respiration of succulents *i.e., Bryophyllum, Opuntia*).

$$2C_6H_{12}O_6 + 3O_2 \rightarrow 3C_4H_6O_5 + 3H_2O\,;$$

$$\frac{CO_2}{O_2} = \frac{0}{3} = 0 \text{ (Zero)}$$

(6) **Respiration in the absence of O_2** (in anaerobic respiration)

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2\,;$$

$$\frac{CO_2}{O_2} = \frac{2}{0} = \infty \text{ (Infinite)}$$

Factors affecting rate of respiration

Many external and internal factors affecting the rate of respiration are as follows :

(1) **External factors**

(i) **Temperature :** With every 10°C rise of temperature from 0°C to 30°C the rate of respiration increases 2 to 2.5 times (*i.e.*, temperature coefficient (Q_{10}°) is = 2 to 2.5), following Vant Hoff's Law. Maximum rate of respiration takes place at 30°C, there is an initial rise, soon followed by a decline. Higher the temperature above this limit, more is the initial rise but more is the decline and earlier is the decline in the rate of respiration. Probably this is due to denaturation of enzymes at high temperature.

Below 0°C the rate of respiration is greatly reduced although in some plants respiration takes place even at-20°C. Dormant seeds kept at –50°C survive.

(ii) **Supply of oxidisable food :** Increase in soluble food content readily available for utilization as respiratory substrate, generally leads to an increase in the rate of respiration upto a certain point when some other factor becomes limiting.

(iii) **Oxygen concentration of the atmosphere :** The amount of oxygen in the environment of plants is increased or reduced upto quite low values the rate of respiration is not effected. On decreasing the amount of oxygen to 1.9% in the environment aerobic respiration become negligible (extinction point of aerobic respiration) but anaerobic respiration takes place.

(iv) **Oxygen poisoning :** The significant fall in respiration rate was observed in many tissues in pure O_2, even at *N.T.P.* This inhibiting effect was also observed in green peas when they are exposed to pure oxygen exerting a pressure of 5 atm- the respiration rate fall rapidly. The oxygen poisoning effect was reversible, if the exposure to high oxygen pressure was not too prolonged.

(v) **Water :** With increase in the amount of water the rate of respiration increases. In dry seeds, which have 8-12% of water the rate of respiration is very low but as the seeds imbibe water the respiration increases. As water is necessary for activity of enzymes.

(vi) **Light :** Respiration takes place in night also which shows that light is not essential for respiration. But light effects the rate of respiration indirectly by increasing the rate of photosynthesis due to which concentration of respiratory substrates is increased. More the respiratory substrate more is the rate of respiration.

(vii) **Carbon dioxide (CO_2) :** If the amount of CO_2 in the air is more than the usual rate of respiration is decreased. Germination of seeds is reduced and rate of growth falls down. Heath, (1950) has shown that the stomata are closed at higher conc. of CO_2, due to which oxygen does not penetrate the leaf and rate of respiration is lowered.

(viii) **Inorganic salts :** The chlorides of alkali cations of *Na* and *K*, as also the divalent cations of *Li*, and *Ca* and *Mg*, generally increase the rate of respiration as measured by the amount of CO_2 evolved. Monovalent chlorides of *K* and *Na* increases the rate of respiration, while divalent chlorides of *Li*, *Ca* and *Mg* causes less increase in respiration.

(ix) **Injury and effects of mechanical stimulation :** Wounding or injury almost invariably results in an increase in the rate of respiration.

(x) **Effect of various chemical substances :** Certain enzymatic inhibitors like cyanides, azides, carbon monoxide, iodoacetate, malonate etc. reduce the rate of respiration even if they are present in very low concentration.

However, various chemical substances such as chloroform, ether, acetone, morphine, etc., brings about an increase in respiratory activity.

(xi) **Pollutants :** High concentration of gaseous air pollutants like SO_2 , NO_X and O_3 inhibit respiration by damaging cell membrane. These gaseous pollutant causes increase in pH which in turn affects the electron transport system thus inhibiting respiration.

Heavy metal pollutant like lead (*Pb*) and cadmium (*Cd*) inhibit respiration by inactivating respiratory enzymes.

(2) **Internal Factors**

(i) **Protoplasm :** The meristematic cells (dividing cells of root and shoot apex) have more protoplasm than mature cells. Hence, the meristematic cells have higher rate of respiration than the mature cells. Respiration rate high at growing regions like floral and vegetative buds, germinating seedlings, young leaves, stem and root apices.

(ii) **Respiratory substrate :** With the increase in the amount of respiratory substrate, the rate of respiration increases.

Tips & Tricks

- Lavosier (1783) found that respiration in animals involves intake of O_2 and liberation of CO_2. Dutrochet is belived to have used the term of respiration for the first time, while book "cellular respiration" was written by Meldrum.
- Energesis : An old term of respiration.
- One glucose molecule contain about 686 *K* cal of energy and 38 ATP molecules provide 288.8 *K* cal of energy. Therefore about 40% (288.8/686) energy of the glucose molecule is gained during aerobic breakdown and the rest is lost as heat.
- Glucose oxidation is very rapid process of complete oxidation of a glucose molecules takes only one second.
- Glucose 6-phosphate called Rohinsonester, fructose 6-phosphate called Newberg's ester and fructose 1,6-diphosphate called Harden and Young's ester.
- Phosphofructokinase called regulatory enzyme of glycolysis, it is inhibited by high concentration of ATP and is stimulated by ADP and Pi.
- Formation of 1,3-diphosphoglyceraldehyde called non enzymatic phosphorylation.
- Krebs cycle is the central pathway of the cell respiration where the catabolic pathways converge upon it an anabolic pathways diverge from it, so called amphibolic pathway.
- Acetyl Co~A, also called active acetate.
- In Kreb's cycle, acetyl CoA undergoes two decarboxylation and four dehydrogenation. Krebs cycle catabolises about 80-90% of glucose.
- ATP discovered by Karl Lohmann (1929), term was coined by Lohmann (1931) while ATP cycle was discovered by Lipmann (1941).
- Allosteric inhibition or negative feedback by accumulation of $NADH_2$.
- Cytochromes were discovered by MacCunn and term cytochrome given by K.P.Kailin.
- Ganong's respiroscope is used to demonstrate production of CO_2 during aerobic respiration.

✍ Iron-Sulphur is the component of ETC (complex I, II, III) and helps in transfer of electrons from $FMNH_2$ to coenzyme Q. Thus, deficiency of iron direct affect ETC or oxidative phosphorylation.

✍ Cytochromes are Iron-containing (Iron porphyrin protein) electron transferring (electrons picked up and release by Fe) except cytochrome a_3. Cytochrome a_3 contains both Iron and Copper, in this Fe picks the electrons and through *Cu* it hands over electron to oxygen, so cytochrome a_3 called terminal electron donar.

✍ *ETC inhibitors*

(i) Dinitrophenol (2,4-DNP) : It prevents synthesis of ATP from ADP because it directs electrons from *CoQ* to O_2.

(ii) Cyanide : It prevents flow of electrons from *Cyt* a_3 to oxygen.

(iii) Carbon monoxide : It functions like cyanide.

(iv) Antimycin A: Transfer of electron from *Cyt b* to *Cyt* c_1 is prevented.

(v) Rotenone : It checks flow of electrons from *NADH* /$FADH_2$ to *CoQ*.

✍ *Action of ATPase needed* Na^+ *and* K^+.

✍ *Amount of energy released in ETC :*

(i) 12.2 Kcal during transfer of electrons from NAD to FMN.

(ii) 15.2 Kcal during transfer of electrons from *Cyt* b to *Cyt c*.

(iii) 24.5 Kcal during transfer of electrons from *Cyt a* to *Cyt* a_3.

✍ Glyoxylate cycle is called adaptation of Kreb's cycle.

✍ Effect of cyanide poisoning can be minimised by immediate supply of ATP.

✍ In prokaryotes aerobic cell respiration of glucose always produces 38 ATP molecules, as $NADH_2$ molecules formed during glycolysis are not enter the mitochondria.

✍ Pentose phosphate pathway called connective link between photosynthesis and fat synthesis.

✍ The potato growing in hilly areas are bigger in size because in hilly areas temperature is low. Respiration decreases on low temperature therefore in potato complete oxidation of carbohydrate not takes place and carbohydrate/ starch in potato tuber accumulates and increases the size.

✍ The R.Q. at compensation point $= \frac{CO_2}{O_2} =$ Zero (CO_2 and O_2 equal at compensation point).

✍ Temperature affects germinating seeds because hydration makes enzyme more sensitive to temperature.

✍ Glucose before converting glycogen in muscles and liver converted into glucose 6-phosphate needed ATP. Glycogen also before utilization converted into glucose –6-phosphate process called glycogenolysis.

✍ Thiamine pyrophosphate is the active form of vitamin B_1 (Thiamine) work as coenzyme of pyruvate carboxylase dehydrogenase.

✍ Climacteric fruits : Those fruits which show a high rate of respiration during their ripening *e.g.*, Apple, Banana. In these fruits rise of respiration called climacteric rise.

✍ Aldolase and triose phosphate isomerase enzyme are common for EMP and C_3 pathway.

✍ In fermentation yeast secrets the enzyme zymase.

✍ Universal hydrogen acceptor in NAD.

Ordinary Thinking

Objective Questions

Anaerobic respiration

1. The energy releasing process in which the substrate is oxidised without an external electron acceptor is called **[CBSE PMT 2008; CBSE PMT (Pre.) 2010]**

Or

Lactic acid converted into alcohol in process called **[HPMT 2005; DPMT 2007]**

(a) Aerobic respiration (b) Glycolysis
(c) Fermentation (d) Photorespiration

2. During anaerobic conditions, the rate of glycolysis increases is called as

Or

The process by which there is inhibition of aerobic respiration by atmospheric O_2 is **[DPMT 2004]**

(a) Compensation point (b) Extinction point
(c) Warburg effect (d) Pasteur effect

3. How many ATP molecules are obtained from fermentation of 1 molecule of glucose **[WB JEE 2009; KCET 2011]**

(a) 2 (b) 4
(c) 3 (d) 5

4. In anaerobic respiration, from one glucose molecule how many net ATP molecules are formed

(a) 2 (b) 8
(c) 6 (d) 4

5. Pasteur effect is concerned with the shifting of environmental conditions from **[KCET 2001]**

(a) Light to dark (b) Aerobic to anaerobic
(c) Anaerobic to aerobic (d) Light to anaerobic

6. The incomplete breakdown of sugars in anaerobic respiration results in the formation of

Or

End product of anaerobic respiration is **[AFMC 1995; RPMT 1999]**

Or

The end products of fermentation when sugars are used as raw material **[CBSE PMT 1997]**

(a) Fructose and water (b) Glucose and CO_2
(c) Alcohol and CO_2 (d) Water and CO_2

7. Which of the following plant is widely accepted to respire in absence of oxygen **[MHCET 2003; MP PMT 2004]**

(a) Yeast (b) Potato
(c) *Chlorella* (d) Grass

8. Cyanide resistant pathway is **[DPMT 2004]**

(a) Anaerobic respiration (b) Aerobic respiration
(c) Both (a) and (b) (d) None of these

9. When a molecule of pyruvic acid is subjected to anaerobic oxidation and forms lactic acid, there is

(a) Loss of 3 ATP molecules (b) Loss of 6 ATP molecules
(c) Gain of 2 ATP molecules (d) Gain of 4 ATP molecules

10. During cellulose fermentation by anaerobic bacteria in rumen and reticulum, cellulose is majorly converted into **[BHU 2012]**

(a) Lactic acid (b) Ethyl alcohol
(c) Volatile fatty acids (d) CO_2

11. Fermentation is **[AFMC 1997, 99; MP PMT 2003; BHU 2006; Odisha JEE 2011]**

(a) Anaerobic respiration after glycolysis

(b) Incomplete oxidation of carbohydrates

(c) Complete oxidation of carbohydrates

(d) None of the above

12. Which of the following minerals activate the enzymes involved in respiration **[Kerala PMT 2011]**

(a) Nitrogen and phosphorus

(b) Magnesium and manganese

(c) Potassium and calcium

(d) Sulphur and iron

(e) Copper and boron

13. During anaerobic respiration in yeast **[CPMT 1992; BVP 2002; AIEEE Pharmacy 2003]**

(a) Water and CO_2 are end products

(b) CO_2, C_2H_5OH and energy are end products

(c) H_2S, $C_6H_{12}O_6$ and energy are the end products

(d) H_2O, CO_2 and energy are the only end products

14. Fermentation is represented by the equation **[MP PMT 1994, 96]**

(a) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 673\ k\ cal$

(b) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 18\ k\ cal$

(c) $6CO_2 + 12H_2O \xrightarrow[Chlorophyll]{Light} C_6H_{12}O_6 + 6H_2O + 6O_2$

(d) $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

15. During anaerobic respiration the conversion of pyruvate into acetaldehyde, along with co-enzyme TPP, the cofactor required is **[MHCET 2015]**

(a) Mg^{++} (b) Mn^{++}

(c) Fe^{++} (d) Zn^{++}

16. Continuous addition of sugars in 'fed batch' fermentation is done to **[CBSE PMT (Pre.) 2011]**

(a) Degrade sewage (b) Produce methane

(c) Obtain antibiotics (d) Purify enzymes

17. Anaerobic products of fermentation are **[CBSE PMT 1996; JIPMER 2001]**

(a) Alcohol and lipoprotein

(b) Ether and nucleic acid

(c) Protein and nucleic acid

(d) Alcohol, lactic acid and similar compound

18. During lactic acid fermentation, ... **[KCET 2010; CBSE PMT 2014]**

(a) O_2 is used, CO_2 is liberated

(b) Neither O_2 is used, nor CO_2 is liberated

(c) O_2 is used, CO_2 is not liberated

(d) O_2 is not used, CO_2 is liberated

19. Anaerobic respiration was first of all reported by

(a) Maguenne (b) Kostychev

(c) Klein (d) Pfeffer

20. What is the total gain of energy during anaerobic respiration

(a) One molecule of ATP (b) Two molecules of ATP

(c) Four molecules of ATP (d) Eight molecules of ATP

21. In fermentation, yeast secrets one of the following enzyme

(a) Invertase (b) Zymase

(c) Dehydrogenase (d) Anolase

22. Select a suitable name for the following process

$C_6H_{12}O_6 + 2ADP + 2Pi \rightarrow 2C_2H_5OH + 2ATP + 2CO_2 \uparrow$ **[KCET 2012]**

(a) Alcoholic fermentation (b) Photorespiration

(c) Lactate fermentation (d) Aerobic respiration

Introduction and types of respiration

1. Which of the following is the phosphorylating unit **[AFMC 2000]**

(a) Oxysome (b) Mesosome

(c) Peroxisome (d) Mitochondria

2. Aerobic respiratory pathway is appropriately termed **[NCERT; CBSE PMT 2009]**

(a) Catabolic (b) Parabolic

(c) Amphibolic (d) Anabolic

3. Which of the following show higher rate of respiration **[NCERT]**

(a) Collenchyma (b) Leaf

(c) Dry seeds (d) Germinating seeds

4. How many ATP molecules will be generated in a plant system during complete oxidation of 40 moles of glucose **[WB JEE 2012]**

(a) 190 (b) 380

(c) 1520 (d) 3040

5. Which one is product of aerobic respiration **[WB JEE 2009]**

(a) Malic acid (b) Ethyl alcohol

(c) Lactic acid (d) Pyruvic acid

6. The energy consumed during the conversion of ADP into ATP is **[Pb. PMT 2000]**

(a) 73000 *cal/mole* (b) 686000 *cal/mole*

(c) 8000 *cal/mole* (d) 7300 *cal/mole*

7. Which of the substrate is used in protoplasmic respiration

(a) Fat (b) Carbohydrate

(c) Protein (d) All the above

8. How much of the energy released during aerobic respiration is approximately conserved in the form of ATP **[MHCET 2015]**

(a) 20% (b) 40%

(c) 60% (d) 100%

9. Heat energy of plants is measured in **[MP PMT 1996]**

(a) Grams (b) Pounds

(c) Decibels (d) Calories

10. Chemiosmotic theory of ATP synthesis in the chloroplasts and mitochondria is based on **[CBSE PMT 1997, 2005; KCET 2012]**

(a) Proton gradient (b) Accumulation of K ions

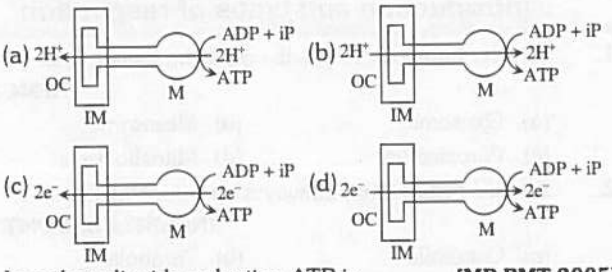
(c) Accumulation of Na ions (d) Membrane potential

11. Which of the option is correct for photorespiration **[GUJCET 2014]**

(a) In chloroplast, glycerate forms glycine
(b) In peroxisome, glycerate forms phosphoglycolate
(c) In mitochondrion, glycine forms serine
(d) In bundle sheath, serine form glycine

12. Which diagram represents the ATP synthesis in mitochondria through chemiosmosis

I.M = Inner membrane
M = Matrix
O. C = Outer Chamber **[NCERT]**



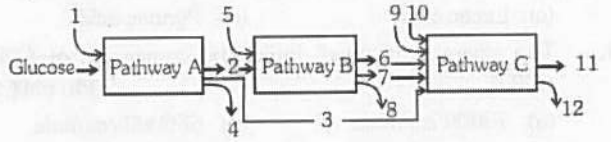
13. In carbon dioxide reduction ATP is **[MP PMT 2005]**

(a) Used (b) Unused
(c) May be used or not used (d) None

14. In submerged hydrophytes entry of CO_2 is through **[DPMT 2004]**

(a) Epidermis as dissolved CO_2
(b) Epidermis as carbonates only
(c) Epidermis as bicarbonates only
(d) Both (b) and (c)

15. 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 **[NEET 2013]**

(a) FAD^+ or $FADH_2$ (b) NADH
(c) ATP (d) H_2O

16. Respiration differs from the process of combustion in the fact that

(a) All the energy stored in glucose is released at once due to combustion and enzymes are involved
(b) All energy stored in glucose is gradually released due to combustion
(c) Comparatively large quantity of energy is produced due to combustion
(d) The carbohydrates act as the combustion substance

17. Adenosine diphospate contains **[CPMT 1995]**

(a) One high energy bond
(b) Two high energy bond
(c) Three high energy bond
(d) Four high energy bond

18. "*Mitchell's chemiosmotic theory*" belongs to

(a) Kreb's cycle
(b) Oxidative phosphorylation
(c) Glycolysis
(d) None of the above

19. Which of the following is involved in the catalysis of link reaction during aerobic respiration **[DPMT 2004]**

(a) Vitamin A (b) Vitamin B_1
(c) Vitamin B_6 (d) Vitamin K

20. Ganong's respiroscope is used to demonstrate..... **[KCET 2004]**

(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

21. ATP was discovered by **[KCET 2004]**

(a) Blackman (b) Bowman
(c) Lipmann (d) Karl Lohman

22. Mechanism of aerobic respiration was discovered by **[AFMC 2004]**

(a) Kreb's (b) Calvin
(c) Hatch and Slack (d) Pasteur

23. Cell respiration (Internal Respiration) is carried out by **[CPMT 1998; Odisha JEE 2004; Pb. PMT 2004]**

Or

Aerobic respiration which yields maximum ATP molecules is completed on **[BHU 1999]**

(a) Ribosome (b) Mitochondria
(c) Chloroplast (d) Golgi bodies

24. In mitochondria, cristae act as sites for **[Pb. PMT 1999; AFMC 2000; CBSE PMT 2000]**

(a) Protein synthesis
(b) Oxidation-reduction reaction (respiration)
(c) Breakdown of macromolecules
(d) Phosphorylation of flavoproteins

25. Which of the following forms the connecting link between glycolysis and Kreb's cycle **[Kerala CET 2003; Wardha 2005]**

(a) Glucose (b) Ethyl alcohol
(c) Lactic acid (d) Pyruvic acid

26. Enzymes related with cristae are related with **[CPMT 1996]**

(a) Anaerobic respiration (b) Aerobic respiration
(c) CO_2 formation (d) Reduction of pyruvic acid

27. Which of the following is a more accurate statement about respiration

(a) O_2 must always be available for respiration
(b) O_2 combines with carbon to form CO_2
(c) O_2 combines with hydrogen to form H_2O
(d) Air is inhaled and exhaled only from stomata

28. In the respiratory process, energy is released and is used to synthesise energy rich molecules of ATP from ADP, thereby storing energy for future use. This process of output of these molecules in the aerobic phase is known as **[DPMT 1993]**

(a) Kreb's cycle (b) Glycolysis
(c) Phosphorylation (d) Ornithine cycle

29. How many ATP are formed from $NADPH^+$ to NAD^+ **[KCET 2000; AFMC 2004; Bihar CECE 2006; Kerala PMT 2010; Odisha JEE 2010; J & K CET 2012]**

(a) 2 ATP (b) 3 ATP
(c) 6 ATP (d) 4 ATP

30. An ATP molecule is structurally most similar to a molecule of **[Kerala CET 2003; Odisha JEE 2009]**

(a) RNA molecule (b) DNA molecule
(c) Amino acid (d) Fatty acid

31. Aerobic respiration is called

(a) Fermentation (b) Chemosynthesis
(c) Bio–oxidation (d) Photorespiration

32. Which of the following is utilized first in respiration **[BVP 2003]**

(a) Fat (b) Protein
(c) Sucrose (d) Hexose

33. Degradation of sugar and fat to Acetyl *CoA* will not take place if the following organelle is not present in a eukaryotic cell **[AIEEE Pharmacy 2003]**

(a) Golgi apparatus (b) Mitochondrion
(c) Ribosome (d) Nucleus

34. Salt respiration is also called as **[J & K CET 2002]**

(a) Anion respiration (b) Cation respiration
(c) Photorespiration (d) None of the above

35. Leaves of annual plants obtain O_2 through

(a) Cell walls (b) Cuticle and leaf scars
(c) Stomata (d) Lenticels

36. Respiratory exchange in seeds occur through

(a) Testa (b) Stomata
(c) Micropyle (d) Hilum

37. The aerobic respiration yields **[MHCET 2002]**

(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

38. Protein is used as respiratory substrate only when

(a) Carbohydrates are absent
(b) Fats are absent
(c) Both exhausted
(d) Fats and carbohydrates are abundant

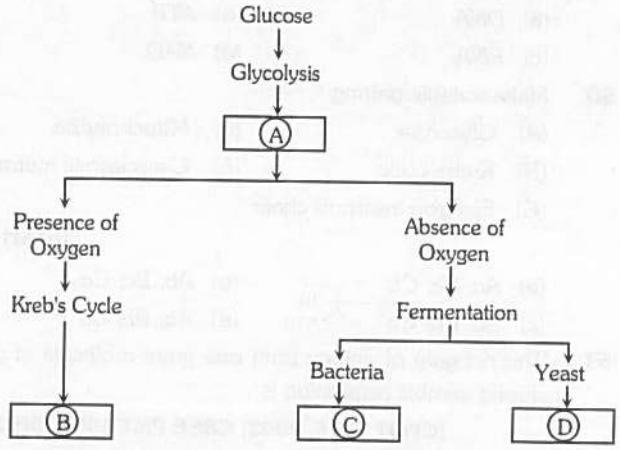
39. Which of the scientific paper would you assign to plant physiology

(a) Evergreen forest of India
(b) Embryo culture of plants
(c) Respiratory activities in plants
(d) Cell and cell division

40. Chemiosmotic mechanism of ATP synthesis was proposed by **[MHCET 2001; KCET 2011]**

(a) Warberg (b) Dickens
(c) Kreb's (d) P. Mitchell

41. 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 **[KCET 2006]**



(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

42. The rate of respiration could be checked by

(a) Malonate (b) CO_2
(c) Chloroform and cynides (d) All the above

43. If a starved plant is provided with glucose, the rate of respiration would

(a) Decrease (b) Increase
(c) Become constant (d) First rise and than fall

44. The high-energy bonds of ATP are between **[AIIMS 2001]**

(a) *C-C* (b) *C-O*
(c) *C-N* (d) *O-P*

45. Respiration initiated in chloroplasts and occurs in light is called **[J & K CET 2005]**

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

46. Which of the following is formed during respiration **[MP PMT 1999]**

(a) O_2 (Oxygen) (b) CO_2 (Carbon dioxide)
(c) NO_2 (Nitrogen dioxide) (d) SO_2 (Sulphur dioxide)

47. From substrate level phosphorylation ATP are produced **[BHU 2000]**

(a) 2 (b) 6
(c) 10 (d) 8

48. The net gain of energy, from one molecule of sucrose in aerobic respiration, is **[CBSE PMT 2001]**

(a) 18 ATP (b) 38 ATP
(c) 60 ATP (d) 76 ATP

49. Common immediate source of energy in cellular activity or Energy currency of the cell is **[CPMT 1994; MP PMT 2002]**

Or

To a living organism which of the following has the greater amount of available energy per molecule

(a) *DNA* (b) *ATP*
(c) *RNA* (d) *NAD*

50. Make suitable pairing

(*A*) Glycolysis (*a*) Mitochondria
(*B*) Kreb's cycle (*b*) Cytoplasmic matrix
(*C*) Electron transport chain

[RPMT 1997]

(a) *Aa, Ba, Cb* (b) *Ab, Ba, Ca*
(c) *Aa, Bb, Cb* (d) *Ab, Bb, Ca*

51. The net gain of energy from one gram molecule of glucose during aerobic respiration is

[CPMT 1996, 2002; CBSE PMT 1999; BHU 2000; KCET 2001; RPMT 2002; MP PMT 2012; AIIMS 2012]

Or

Net gain of ATP in prokaryotes from a molecule of glucose when oxidized is **[RPMT 2005]**

(a) 2 ATP (b) 36 ATP
(c) 38 ATP (d) 15 ATP

52. If the CO_2 content of atmosphere is as high as 300 parts per million

(a) All plants will be killed
(b) The plants would not grow properly
(c) Plants would grow for sometime and then die
(d) The plants would thrive well

53. Different steps in respiration are controlled by **[DPMT 1992; CPMT 2002]**

(a) Auxin (b) Sugar
(c) Enzyme (d) Kinetin

54. Highest calories is obtained from **[CPMT 1996]**

(a) Fats (b) Proteins
(c) Carbohydrates (d) Vitamins

55. Aerobic respiration of glucose produces energy **[MP PMT 1993]**

(a) 637 *kcal* (b) 640 *kcal*
(c) 673 *kcal* (d) 693 *kcal*

56. Cytochrome is related to

(a) Cellular digestion (b) Protein synthesis
(c) Cell division (d) Cellular respiration

57. Energy given by one molecule of ATP is **[MP PMT 2005]**

(a) 7.3 *kcal* (b) 721 *kcal*
(c) 760 *kcal* (d) 1000 *kcal*

58. Respiration is an **[NCERT]**

(a) Endothermic process (b) Exothermic process
(c) Anabolic process (d) Endergonic process

59. 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

60. The energy yield as a result of total oxidation of one glucose molecule during cellular respiration is to convert **[CBSE PMT 1992]**

(a) 38 molecules of ADP into 38 molecules of ATP
(b) 30 molecules of ADP into 30 molecules of ATP
(c) 36 molecules of ADP into 36 molecules of ATP
(d) 32 molecules of ADP into 32 molecules of ATP

61. Cut surfaces of fruit and vegetables often become dark because

(a) Dirty knife makes it dark
(b) Oxidation of tannic acid in the presence of trace of iron from the knife makes it dark
(c) Dust of the air makes it dark
(d) None of the above

62. Oxidative phosphorylation occurs during the process of **[MP PMT 1994, 98; HPMT 2005]**

(a) Protein synthesis (b) N_2 fixation
(c) Respiration (d) Transpiration

63. The connecting link among glycolysis, Kreb's cycle and beta–oxidation of fatty acid is **[MP PMT 1994, 98, 2001; CBSE PMT 1997, 2000; BHU 2000; CPMT 2001; BVP 2001; MHCET 2004; DUMET 2010]**

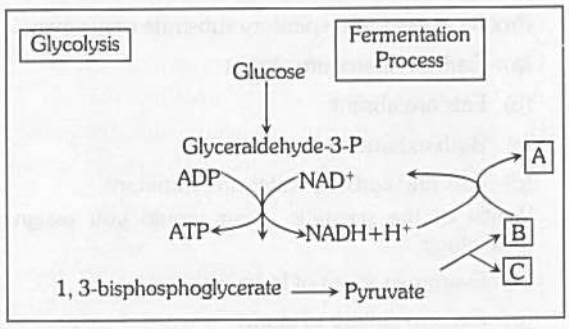
Or

Which of the metabolites is common to respiration mediated breakdown of fats, carbohydrates and proteins **[NEET 2013]**

(a) Pyruvic acid (b) Acetyl *CoA*
(c) Acetaldehyde (d) Citric acid

Glycolysis

1. Choose the correct combination of labelling the molecules involved in the pathway of anaerobic respiration in yeast **[Kerala PMT 2008; KCET 2015]**



(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

2. In which of the following reaction of glycolysis, a molecule of water is removed from the substrate **[Kerala PMT 2008]**
(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

3. Which process does the following equation represent
$C_6H_{12}O_6 + 2NAD + 2ADP + 2Pi \rightarrow 2CH_3 - CO - COOH + 2NADH_2 + 2ATP$
[MHCET 2015]
(a) Complete glycolysis
(b) Complete aerobic respiration
(c) Complete anaerobic respiration
(d) Complete fermentation

4. How many ATP are used in glycolysis or For complete phosphorylation of a glucose molecule, how many ATP molecules are required

Or

The net gain of ATP during glycolysis is **[KCET 2007]**
(a) 4 (b) 2
(c) 6 (d) 8

5. Which of the following substances yield less than 4 Kcal/mol when its phosphate bond is hydrolysed **[WB JEE 2009]**
(a) Creatine phosphate (b) ADP
(c) Glucose-6-phosphate (d) ATP

6. Which is not true for glycolysis **[NCERT; Manipal 2005]**
(a) End product is CO_2, H_2O
(b) Substrate level phosphorylation
(c) Production of ATP
(d) Expenditure of ATP

7. Glycolysis term has originated from Greek words **[NCERT; AMU (Med.) 2012]**
(a) *Glycose* and *lysis* (b) *Glycos* and *lysis*
(c) *Glyco* and *lysis* (d) *Glucose* and *lysis*

8. Consider the following statements with respect to respiration
A. Glycolysis occurs in the cytoplasm of the cell
B. Aerobic respiration takes place within the mitochondria
C. Electron transport system is present in the outer mitochondrial membrane
D. $C_{51}H_{98}O_5$ is the chemical formula of Tripalmitin, a fatty acid
E. Respiratory quotient $= \frac{Volume\ of\ O_2\ evolved}{Volume\ of\ CO_2\ consumed}$
Of the above statements **[Kerala PMT 2012]**
(a) A, B, and D alone are correct
(b) B, C and D alone are correct
(c) C, D and E alone are correct
(d) B, D and E alone are correct
(e) A, C and E alone are correct

9. Decarboxylation is not involved in **[DPMT 2004]**
(a) Electron transport system (b) Glycolysis
(c) Kreb's cycle (d) Alcoholic fermentation

10. Which one is correct sequence in glycolysis **[MHCET 2004]**
(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

11. In glycolysis, during oxidation electrons are removed by **[CBSE PMT 2004]**
(a) NAD^+
(b) Molecular oxygen
(c) ATP
(d) Glyceraldehyde-3-phosphate

12. In glycolytic pathway which of the following steps shows reduction of co-enzyme **[Odisha JEE 2010]**
(a) 1, 3-diphosphoglycerate to 3-phosphoglycerate
(b) Glucose 6-phosphate to fructose 6-phosphate
(c) Glyceraldehyde 3-phosphate to 1,3-diphosphoglycerate
(d) 3-phosphoglycerate to 2-phosphoglycerate

13. First stage in respiration is
(a) Aerobic oxidation of pyruvic acid
(b) Liberation of CO_2
(c) Glycolysis
(d) Electron transport system

14. Besides the net gain of 2 ATP molecules in glycolysis which other molecules are simultaneously formed **[CPMT 1995]**
(a) $FADH_2$ (b) $NADPH_2$
(c) $NADH_2$ (d) $FAMH_2$

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

16. In glycolysis, the end product is **[NCERT; CPMT 1996, 2001, 03 MP PMT 1996, 2003; KCET 1998; MHCET 2001; PET (Pharmacy) 2013]**
(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. Total ATP production during EMP pathway is **[CBSE PMT 1990]**
(a) 24 ATP molecules (b) 8 ATP molecules
(c) 38 ATP molecules (d) 6 ATP molecules

18. Glycolysis (EMP Pathway) takes place in **[KCET 1994; MP PMT 1996, 2004, 05; BVP 2001; Odisha PMT 2002; RPMT 2002; CPMT 2004; Bihar CECE 2006; Odisha JEE 2008; J & K CET 2012]**

Or

Anaerobic respiration takes place in the **[DPMT 1992; MP PMT 2002, 06]**
(a) Mitochondria
(b) Cytoplasm
(c) Both mitochondria and cytoplasm
(d) Vacuole

19. Which one of the following is the first step of glycolysis **[NCERT; DPMT 2004]**

(a) Breakdown of glucose
(b) Phosphorylation of glucose
(c) Conversion of glucose into fructose
(d) Dehydrogenation of glucose

20. Glycolysis occurs in **[NCERT; BVP 2001; AFMC 2003]**

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

21. 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

22. What is the other name of glycolysis **[Pune CET 1998; CPMT 1998]**

(a) EMP pathway (b) TCA pathway
(c) HMS pathway (d) None of the above

23. During respiration ..... **[GUJCET 2015]**

(a) 2 PGAL during glycolysis and none of the PGAL produced in Kreb's cycle
(b) 2 PGAL during glycolysis and 4 Pyruvic acid are produced in Kreb's cycle
(c) 2 PGAL during glycolysis and 2 Pyruvic acid are produced in Kreb's cycle
(d) PGAL is not produced during respiratory events

24. During respiration, pyruvic acid is formed by **[BHU 1995; MP PMT 2011]**

Or

The first phase in the breakdown of glucose in animal cells is **[BVP 2002; AIEEE Pharmacy 2004]**

(a) Glycolysis (b) Kreb's cycle
(c) HMP pathway (d) None of the above

25. The common phase between aerobic and anaerobic respiration is called **-[NCERT; MP PMT 1992, 2009; BHU 2008]**

(a) Tricarboxylic acid cycle
(b) Oxidative phosphorylation
(c) Embden, Meyerhof, Parnas cycle (Glycolysis)
(d) Kreb's cycle

26. The formula for the process of glycolysis is **[KCET 1994]**

(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

27. Which group of the following scientists discovered the EMP pathway of glycolysis **[NCERT; MP PMT 1995; BVP 2002]**

(a) Embden, Meyerhof and Parnas
(b) Emerson, Hoffman and Peterson
(c) Embden, Morrison and Pitcher
(d) Avery, McLeod and McCarthy

28. Which one of the following products is formed during glycolysis of glucose **[MP PMT 1995, 2000, 02; AIIMS 2002]**

(a) Pyruvic acid (b) Carbon dioxide
(c) Citric acid (d) Ethanol

29. Column I contains some enzymes and Column II contains reactions. Match them properly and choose the right answer **[MP PMT 1996; AIIMS 1999; Pb PMT 1999, 2000]**

	Column I		Column II
A.	Hexokinase	1.	Conversion of fructose-6-phosphate to fructose-1-6-diphosphate
B.	Triose Phosphate dehydrogenase	2.	Conversion of glucose to glucose-6-phosphate
C.	Phosphoglycero-mutase	3.	Conversion of 1, 3-diphosphoglyceraldehyde to 1, 3-diphosphoglyceric acid
D.	Phosphofructo-kinase	4.	Conversion of 3-phosphoglyceric acid to 2-phosphoglyceric acid

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

30. ATP formation in glycolysis is **[AMU (Med.) 2006; MP PMT 2012]**

(a) Oxidative phosphorylation
(b) Photophosphorylation
(c) Reductive phosphorylation
(d) Substrate level phosphorylation

31. Given below are some reactions and the enzymes involved. Identify the correct pairs

I		II	
1.	Fructose 1,6 diphosphate → 3 PGAL + DHAP	A.	Enolase
2.	Citrate → Cis – aconitate	B.	Thiokinase
3.	Succinyl Co. A → Succinate	C.	Aconitase
4.	2 PGA → PEPA	D.	Aldolase

[MHCET 2015]

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

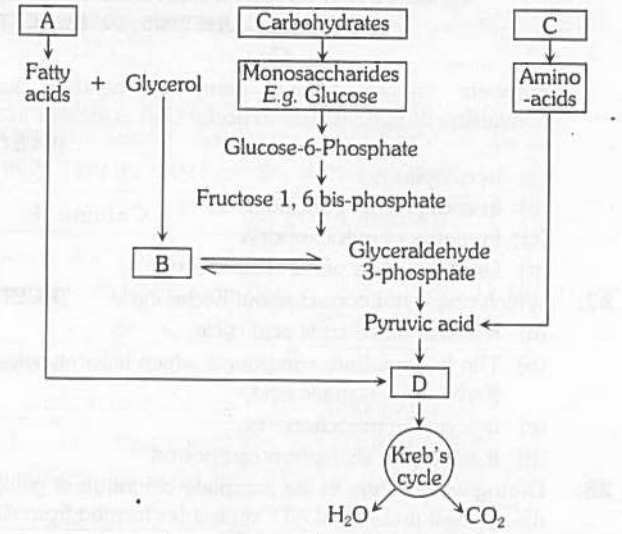
32. In muscles from three molecules of glucose, two are completely oxidized and one is incompletely oxidized (anaerobic) then, what will be the number of total NAD^+ molecules utilized **[GUJCET 2014]**

(a) 10 (b) 20
(c) 14 (d) 08

33. Which of the following process occurs in glycolysis **[JIPMER 2002]**

(a) Oxidation (b) Reduction
(c) Hydrogenation (d) Fixation

34. The given figure indicates the interrelationship among metabolic pathways. Identify A to D **[NCERT]**



	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

35. Glucose is **[MP PMT 2013]**

(a) Pyranose pentose sugar (b) Furanose pentose sugar
(c) Ketose hexose sugar (d) Aldose hexose sugar

36. Which of the following biomolecules is common to respiration-mediated breakdown of fats, carbohydrates and proteins **[NEET (Phase-II) 2016]**

(a) Acetyl CoA
(b) Glucose-6-phosphate
(c) Fructose 1, 6-bisphosphate
(d) Pyruvic acid

Kreb's cycle and ETS

1. The details of tricarboxylic acid path was worked out by **[Odisha JEE 2008; AFMC 2012]**

(a) Meischer (b) Hans Krebs
(c) Pasteur (d) None of these

2. The product formed by malic dehydrogenase is

(a) Malic acid (b) Fumaric acid
(c) Oxaloacetic acid (d) Succinic acid

3. During Krebs' cycle energy from glucose is mostly transferred to **[Odisha JEE 2009]**

(a) NADH & FADH (b) NADPH
(c) ADP (d) Water

4. The number of carbon atom in citric acid is **[Odisha JEE 2008]**

(a) 8 (b) 6
(c) 10 (d) 2

5. Hydrogen of malate is accepted by

(a) FAD (b) FMN
(c) COQ (d) NAD

6. During aerobic respiration maximum ATP is synthesized by **[Odisha JEE 2009]**

(a) ETS (b) Krebs' cycle
(c) Glycolysis (d) Fermentation

7. Which one of the following is complex V of the ETS of inner mitochondrial membrane **[Kerala PMT 2009]**

(a) NADH dehydrogenase (b) Cytochrome c oxidase
(c) Ubiquinone (d) Succinate dehydrogenase
(e) ATP synthase

8. Which intermediate compound is involved in the synthesis of amino acids

(a) Malic acid (b) Citric acid
(c) α-ketoglutaric acid (d) Isocitric acid

9. During one Krebs' cycle number of CO_2 molecules released is **[MH CET 2005; AMU (Med.) 2009]**

(a) 1 (b) 2
(c) 3 (d) 4

10. During movement of electron through ETC **[BHU 2012]**

(a) *pH* of matrix increases
(b) Electrons are transported by active transport
(c) Electrons are resonated
(d) Electrons show fluorescence

11. In citric acid cycle decarboxylation occurs when **[AMU (Med.) 2010]**

(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

12. The overall goal of glycolysis, Krebs cycle and the electron transport system is the formation of **[CBSE PMT 2007]**

(a) ATP in small stepwise units
(b) ATP in one large oxidation reaction
(c) Sugars
(d) Nucleic acids

13. In the electron transport system present in the inner mitochondrial membrane, complexes I and IV are respectively **[Kerala PMT 2011]**

(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

14. Kreb's cycle was discovered by Krebs in pigeon muscles in 1940. Which step is called gateway step. Link reaction/transition reaction in respiration **[NCERT; AFMC 2006]**

(a) Glycolysis (b) Formation of acetyl-*coA*
(c) Citric acid formation (d) ETS terminal oxidation

15. In Kreb's cycle formation of **[RPMT 2001, 06; Bihar CECE 2006]**

(a) 34 ATP takes place
(b) 38 ATP takes place
(c) 15 ATP from each acetyl *Co–A* takes place
(d) 12 ATP from each acetyl *Co–A* takes place (24 ATP)

16. All enzymes of TCA cycle are located in the mitochondrial matrix except one which is located in inner mitochondrial membranes in eukaryotes and in cytosol in prokaryotes. This enzyme is **[AIIMS 1994; CBSE PMT 2007]**
(a) Lactate dehydrogenase (b) Isocitrate dehydrogenase
(c) Malate dehydrogenase (d) Succinate dehydrogenae

17. Cytochrome oxidase is a/an **[MP PMT 2007]**
(a) Exoenzyme (b) Endoenzyme
(c) Proenzyme (d) Coenzyme

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

19. Which of these steps in Kreb's cycle indicates substrate level phosphorylation **[Kerala PMT 2011]**
(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

20. Most of the energy in the cell is liberated by oxidation of carbohydrate when
(a) Pyruvic acid is converted into CO_2 and H_2O
(b) Pyruvic acid is converted into Acetyl *CoA*
(c) Sugar is converted into pyruvic acid
(d) Glucose is converted in alcohol and CO_2

21. Complete oxidation of 1 *gm* molecule of glucose gives rise to **[RPMT 1997]**
(a) 68,60,000 *cal* (b) 6,86,000 *cal*
(c) 68,600 *cal* (d) 6,800 *cal*

22. Pyruvic acid is converted into a compound before formation of oxaloacetic acid in the citric acid cycle, this compound is **[MP PMT 2002]**

Or

Which of the following metabolites enter the TCA cycle during glucose oxidation **[WB JEE 2016]**
(a) Acetyl *CoA* (b) Acetoacetic acid
(c) Lactic acid (d) *cis* aconitic acid

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

24. 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 – keto glutaric acid
		5.	Malic acid

[NCERT; Kerala PMT 2007, 08]
(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) $A-3, B-4, C-1, D-5$

25. In Kreb's cycle OAA accepts acetyl CoA to form **[Odisha JEE 2010]**
(a) Citric acid (b) Oxalosuccinate
(c) Fumarate (d) Succinyl CoA

26. The reaction of Kreb's cycle (TCA cycle) take place **[CPMT 1994; CBSE PMT 1996; MP PMT 1997; BVP 2001; JIPMER 2001; MHCET 2002; AIEEE Pharmacy 2003; Odisha JEE 2005, 10, 12; KCET 2012]**

Or

Pyruvate dehydrogenase complex, needed for the conversion of pyruvic acid to acetyl CoA is located in ..... **[KCET 2010]**
(a) In cytoplasm
(b) In endoplasmic reticulum
(c) In matrix of mitochondria
(d) On the surface of mitochondrion

27. Which one is not correct about Krebs' cycle **[KCET 2007]**
(a) It is also called citric acid cycle
(b) The intermediate compound which links glycolysis with Krebs' cycle is malic acid
(c) It occurs in mitochondria
(d) It starts with six carbon compound

28. During which stage in the complete oxidation of glucose are the greatest number of ATP molecules formed from ADP **[CBSE PMT 2005]**

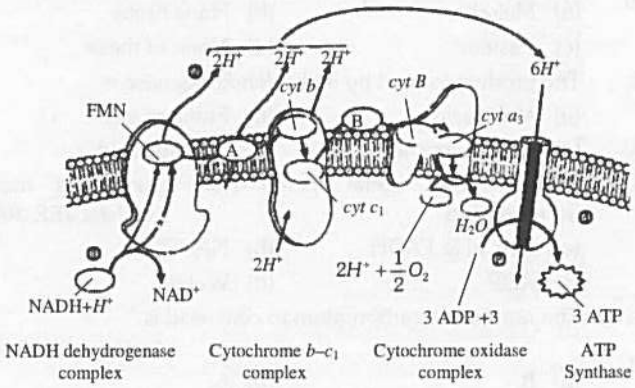
Or

Largest amount of phosphate bond energy is produced in the process of respiration during **[BHU 2002]**
(a) Conversion pyruvic acid to acetyl CoA
(b) Electron transport chain
(c) Glycolysis
(d) Kreb's cycle

29. Choose the correct statement **[KCET 2015]**
(a) Oxygen is vital in respiration for removal of Hydrogen
(b) Pyruvate is formed in the mitochondrial matrix
(c) There is complete breakdown of glucose in fermentation
(d) During the conversion of Succinyl CoA to Succinic acid a molecule of ATP is synthesized

30. In Kreb's cycle the hydrogen atoms removed at succinate level are accepted by
(a) FAD (b) ADP
(c) ATP (d) NAD

31. The following is a scheme showing the electron transport system. Identify the electron carrier molecules indicated as *A* and *B*. Choose the correct option **[KCET 2010]**



(a) A = coenzyme Q, B = cytochrome c
(b) A = cytochrome c, B = coenzyme Q
(c) A = Fe-S protein, B = FMN
(d) A = FMN, B = Fe-S protein

32. Oxidative phosphorylation occurs in **[RPMT 1995; Pune CET 1998; JIPMER 2001]**
(a) Outer membrane of mitochondria
(b) Inner membrane of mitochondria
(c) Stroma of chloroplast
(d) Grana of chloroplast

33. The enzymes for electron transport system are located in the **[Kerala PMT 2004]**

Or

Cellular energy is provided through respiration and oxidation by
(a) Plastid (b) Endoplasmic reticulum
(c) Ribosomes (d) Mitochondria
(e) Golgi bodies

34. Respiratory enzymes are located in **[RPMT 1995; Bihar MDAT 1995; MP PMT 2001; AFMC 2003; AMU (Med.) 2005; BHU 2008; WB JEE 2009; Odisha JEE 2011]**
(a) Mitochondrial matrix (mitochondria)
(b) Perimitochondrial space
(c) Cristae
(d) Outer membrane

35. Food is converted to energy in
(a) Chloroplast (b) Nucleus
(c) Mitochondria (d) None of the above

36. ATP molecules produced respectively by NADH(H^+) and $FADH_2$ during electron transport are **[MP PMT 2013]**
(a) 3 and 2 (b) 1 and 1
(c) 2 and 3 (d) 3 and 3

37. Which of the following is correct sequence in Kreb's cycle
(a) Isocitric acid → Oxalosuccinic acid → α-ketoglutaric acid
(b) Oxalosuccinic acid → Isocitric acid α-ketoglutaric acid
(c) α-ketoglutaric acid → Isocitric acid → Oxalosuccinic acid
(d) Isocitric acid → α-ketoglutaric acid → Oxalosuccinic acid

38. In how many steps, CO_2 is released in aerobic respiration of pyruvic acid
(a) One (b) Six
(c) Three (d) Twelve

39. Activity of succinic dehydrogenase involves the following in TCA cycle **[DPMT 2004]**
(a) NAD (b) FAD
(c) GDP (d) ATP

40. The formation of acetyl coenzyme-A from pyruvic acid is the result of its **[Kerala PMT 2004; AFMC 2009; KCET 2011]**
(a) Reduction
(b) Dehydration
(c) Dephosphorylation
(d) Oxidative decarboxylation

41. Oxidation of succinate to fumerate 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

42. Oxidative phosphorylation and photophosphorylation both require the electron carrier
(a) Cytochrome (b) Oxygen
(c) Carbon dioxide (d) Water

43. Cytochrome helps in **[AFMC 1994; MP PMT 1996]**
(a) Oxidation of glucose (b) Release of energy
(c) Electron transport (d) Growth

44. In oxidative photophosphorylation, the last 3 steps are as follows **[Odisha JEE 2004]**
$Q \rightarrow C \rightarrow aa_3 \rightarrow O_2$
(a) $Q \rightarrow C$ is H^+ absorbing site
(b) $aa_3 \rightarrow O_{2+}H^+$ yielding site
(c) $Q \rightarrow C$ is H^+ yielding site and $aa_3 \rightarrow O_2$ is H^+ absorbing site
(d) No H^+ is absorbed or released

45. In which one of the following do the two names refer to one and the same thing **[CBSE PMT 2003]**
(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

46. By the reaction of α-ketoglutaric acid with ammonia, through which of the process glutamic acid is formed **[GUJCET 2007]**
(a) Oxidative amination (b) Reductive amination
(c) Ammonification (d) Transamination

47. Biological oxidation in Kreb's cycle involves **[MP PMT 1994; Odisha JEE 2011]**
(a) N_2 (b) CO_2
(c) O_2 (d) SO_2

48. Oxidative phosphorylation is the formation of **[CBSE PMT 1992, 96; BHU 1994, 99; Odisha JEE 2009]**
(a) $NADPH_2$ in respiration
(b) ATP in respiration
(c) $NADPH_2$ in photosynthesis
(d) ATP in photosynthesis

49. Mineral activator needed for the enzyme carboxylase of TCA cycle is
(a) Mg^{++} (b) Fe^{+++}
(c) Mo^{++} (d) Mn^{++}

50. 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

51. In the electron transport system, the reduced coenzymes are regenerated by
(a) Loss of hydrogen (b) Loss of electron
(c) Addition of oxygen (d) None of the above

52. Which of the following does not function as an electron carrier **[Kerala PMT 2004]**
(a) Coenzyme Q (b) Cytochrome-c
(c) Cytochrome-a (d) Cytochrome-a_3
(e) H_2O

53. Kreb's cycle begins with **[CBSE PMT 1991]**
(a) Pyruvic acid (b) Hydrochloric acid
(c) Corticosteroids (d) Lysine

54. In ETS, electron combines to **[CPMT 1994]**
(a) Cytochrome (b) H_2
(c) O_2 (d) H_2O

55. 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* **[CBSE PMT 2006]**
(a) Fifty-seven (b) One
(c) Two (d) Thirty

56. Each molecule of pyruvic acid entering the Kreb's cycle produces
(a) 2 *molecules* of CO_2 (b) 3 *molecules* of CO_2
(c) 1 *molecules* of CO_2 (d) 5 *molecules* of CO_2

57. The last or terminal cytochrome in respiratory chain is **[CBSE PMT 1992; RPMT 1997]**
Or
In an electron transport chain in terminal oxidation the cytochrome which donates electrons to O_2 is
(a) Cyt *b* (b) Cyt a_3
(c) Cyt *a* (d) Cyt *c*

58. Upon the oxidation of one mole of pyruvate by mitochondrial respiration, the moles of ATP generated are **[BHU 1994; KCET 1998]**
(a) 38 (b) 30
(c) 8 (d) 15

59. Kreb's cycle is also called **[EAMCET 1995; MHCET 2003; WB JEE 2009]**
(a) TCA cycle (b) Citric acid cycle
(c) Tricarboxylic cycle (d) All the above

60. Kreb's cycle is found in **[AFMC 1996]**
(a) Anaerobic respiration (b) Photorespiration
(c) Photosynthesis (d) Aerobic respiration

61. The importance of Kreb's cycle is in the production of **[MP PMT 1996]**
(a) Acetyl *CoA* (b) Water
(c) ATP (d) ADP

62. The correct sequence of electron acceptor in ATP synthesis is **[CBSE PMT 1997; MHCET 2002, 06]**
(a) Cyt *a a b c* (b) Cyt *b c a* a_3
(c) Cyt *b c* a_3 *a* (d) Cyt *c b a* a_3

63. In Kreb's cycle, the FAD participates as electron acceptor during the conversion of **[CBSE PMT 1997; MHCET 2002; AMU (Med.) 2009; WB JEE 2009; AFMC 2010]**
(a) Succinyl *CoA* to succinic acid
(b) α-ketoglutarate to succinyl *CoA*
(c) Fumaric acid to malic acid
(d) Succinic acid to fumaric acid

64. Which transfer electrons in E.T.S. (Electron Transport System) **[CPMT 1998]**
(a) Phytochrome (b) F_1 particles
(c) *Fe* – S (d) None of these

65. The pyruvic acid formed in Glycolysis is oxidised to CO_2 and H_2O in a cycle called **[NCERT; MP PMT 1999; J & K CET 2008]**
(a) Calvin cycle (b) Hill reaction
(c) Kreb's cycle (d) Nitrogen cycle

66. Which one of the following energy storing compound is formed when succinyl *CoA* is converted into succinic acid **[BHU 2000]**
(a) ADP (b) ATP
(c) AMP (d) GTP

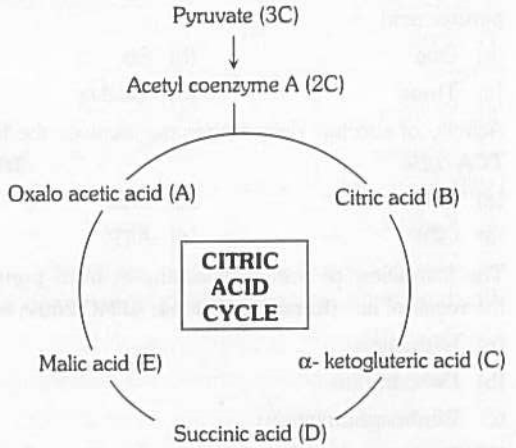
67. Which of the following is not an electron transferring molecule **[KCET 2001]**
(a) ATP (b) NAD^+
(c) Fe-S protein (d) Co-enzyme *Q*

68. Cytochromes are **[CBSE PMT 2001]**
(a) Lipid
(b) Glycoprotein
(c) Metalloporphyrins
(d) Fe^{++} containing with porphyrin pigment

69. Cytochromes occur in **[BHU 2001; AIPMT (Cancelled) 2015]**
(a) Cristae of mitochondria
(b) Matrix of mitochondria
(c) Outer mitochondrial membrane
(d) Entire inner mitochondrial membrane

70. Final electron acceptor in ETS is **[Kerala CET 2002; CPMT 2003; BHU 2004; RPMT 2006; Odisha JEE 2009; MH CET 2015]**
(a) H_2O (b) O_2
(c) Cyt a_3 (d) Cyt a

71. Choose the correct combination of labelling the number of carbon compounds in the substrate molecules, involved in the citric acid cycle



[NCERT; Kerala PMT 2006]
(a) (*A*) 4*C*, (*B*) 6*C*, (*C*) 5*C*, (*D*) 4*C*, (*E*) 4*C*
(b) (*A*) 6*C*, (*B*) 5*C*, (*C*) 4*C*, (*D*) 3*C*, (*E*) 2*C*
(c) (*A*) 2*C*, (*B*) 5*C*, (*C*) 6*C*, (*D*) 4*C*, (*E*) 4*C*
(d) (*A*) 4*C*, (*B*) 6*C*, (*C*) 4*C*, (*D*) 4*C*, (*E*) 5*C*
(e) (*A*) 4*C*, (*B*) 6*C*, (*C*) 4*C*, (*D*) 4*C*, (*E*) 4*C*

72. Oxidative phosphorylation is **[NEET (Phase-II) 2016]**
(a) Formation of ATP energy released from electrons removed during substrate oxidation
(b) Formation of ATP by transfer of phosphate group from a substrate to ADP
(c) Oxidation of phosphate group in ATP
(d) Addition of phosphate group to ATP

73. Which statement is wrong for Krebs' cycle **[NEET 2017]**
(a) There are three points in the cycle where NAD^+ is reduced to $NADH+H^+$
(b) There is one point in the cycle where FAD^+ is reduced to $FADH_2$
(c) During conversion of succinyl CoA to succinic acid, a molecule of GTP is synthesised
(d) The cycle starts with condensation of acetyl group (acetyl CoA) with pyruvic acid yield citric acid

Pentose phosphate pathway

1. The reactions of pentose phosphate pathway (PPP) take place in **[Kerala PMT 2009]**
(a) Mitochondrion
(b) Cytoplasm
(c) Chloroplast, peroxisome and mitochondrion
(d) Chloroplast, glyoxysome and mitochondrion
(e) Chloroplast, lysosome and mitochondrion

2. Which of the following is a direct oxidation pathway being performed without glycolysis
(a) TCA cycle (b) HMP pathway
(c) Both (a) and (b) (d) None of the above

3. In which of the following process 36 ATP molecules are produced by per hexose molecule
(a) Glycolysis (b) Kreb's cycle
(c) Direct oxidation pathway (d) None of the above

4. The substrate for pentose phosphate pathway is **[BHU 2012]**
(a) Glucose–6–phosphate (b) Glucose–1–phosphate
(c) Fructose–6–phosphate (d) Fructose–1–phosphate

5. Shikimic acid can be made from
(a) Xylulose (b) Erythrose–4–phosphate
(c) Ribulose (d) None of the above

6. HMP shunt is an alternative to
(a) Kreb's cycle (b) Aerobic glycolysis
(c) Calvin cycle (d) C_4 pathway

7. Which of the following statements is / are not true
A. One ATP molecule yields 32 *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. Energy released by one molecule of glucose on complete oxidation corresponds to 1292 *kJ*
[Kerala PMT 2006]
(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

8. HMP shunt is a set of reactions
(a) Called pentose phosphate pathway
(b) Which bypasses EMP route of glucose oxidation
(c) Either of the above
(d) Which converts glucose to phosphoglycerate

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

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

11. Which of the following is produced in oxidative pentose phosphate pathway **[Kerala PMT 2007]**
(a) Pyruvic acid (b) Acetyl *CoA*
(c) $NADH_2$ (d) *NAD(P)H*
(e) ATP

R.Q.

1. R.Q. for glucose (Carbohydrates) is **[AFMC 1993; CPMT 1998; Bihar CECE 2005; J & K CET 2008]**
(a) 1 (b) 0.5
(c) 2 (d) 0.05

2. If R. Q. is less than 1.0 in a respiratory metabolism, it would mean that **[Kerala PMT 2008]**
(a) Carbohydrates are used as respiratory substrate
(b) Organic acids are used as respiratory substrate
(c) The oxidation of the respiratory substrate consumed more oxygen than the amount of CO_2 released
(d) The oxidation of the respiratory substrate consumed less oxygen than the amount of CO_2 released
(e) The reaction is anaerobic

3. Which of the following respiratory material may show the unit value of R.Q.
(a) Stem of wheat (b) Leaf of barley
(c) Leaf of oat (d) All the above

4. Which of the following respiratory substrates requires the highest number of O_2 molecules for its complete oxidation **[EAMCET 2009]**
(a) Tripalmitin (b) Triolein
(c) Tartaric acid (d) Oleic acid

5. Substance whose *RQ* is less than one is **[CPMT 1994]**
(a) Carbohydrate (b) Protein
(c) Organic acid (d) All the above

6. When the respiratory substances are more than one then which respiratory substrates are not used **[GUJCET 2015]**
(a) Pure Protein (b) Lipid
(c) Carbohydrate (d) (A) and (B) both

7. What is the value of *RQ* of castor seeds, if the imaginary values of Ganong's respirometer are as follows
(i) First rise of saline = 10 *ml*
(ii) Second rise of saline after adding *KOH* = 30 *ml*
(a) 0.33 (b) 0.75
(c) 0.85 (d) 3.00

8. The energy content in Kcal/g of carbohydrate : protein : triglycerol respectively is approximately in the ratio of **[AMU (Med.) 2010, 12]**
(a) 1:2:2 (b) 1:1:2
(c) 2:1:1 (d) 2:2:1

9. The respiratory quotient during cellular respiration would depend on **[KCET 2009]**
(a) The nature of enzymes involved
(b) The nature of the substrate
(c) The amount of carbon dioxide released
(d) The amount of oxygen utilised

10. R.Q. in anaerobic respiration is **[JIPMER 1998; Wardha 2005]**
(a) 0 (b) ∞
(c) 1 (d) > 1

11. The R.Q. of a plant organ depends upon the nature of the substrate which is
(a) Reduced (b) Oxidized
(c) Catabolized (d) Metabolized

12. R.Q. of fatty substances is generally **[RPMT 1999, 2002; KCET 1999; AMU (Med.) 2012]**
(a) Unity (b) Less than one (Approx 0.7)
(c) Greater than one (d) Zero

13. Which of the following option is correct for the given statements, 'X', 'Y' and 'Z'
Statement 'X' – R.Q. of fat containing palmatic acid is less than one, whereas R.Q. of glucose is 1
Statement 'Y' – Fat containing palmatic acid need less O_2 for respiration and glucose need more oxygen for respiration
Statement 'Z' – Fat containing palmatic acid has much less oxygen in its constitution as compared to glucose **[GUJCET 2014]**
(a) Statement 'X', 'Y' and 'Z' are correct. Statement 'Y' and 'Z' are correct explanation for 'X'
(b) Statement 'X' and 'Y' are correct and statement 'Z' is incorrect statement, 'Y' is correct explanation for 'X'
(c) Statement 'X' and 'Z' are correct and statement 'Y' is incorrect statement, 'Z' is correct explanation for 'X'
(d) Statement 'X' and 'Z' are incorrect and statement 'Y' is correct

14. In *Opuntia*, in night the R.Q. will be
(a) One (b) Less than one
(c) More than one (d) Zero

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

16. The R.Q. value of oxalic acid is **[Kerala PMT 2009]**
(a) 1.0 (b) 0.7
(c) 4 (d) ∞
(e) 1.5

17. In germinating castor seeds, the R.Q. is **[BHU 1995, 2003; CBSE PMT 2002; MHCET 2003; MP PMT 2011]**
Or
A mixture containing equal quantity of germinating maize and groundnut seeds are taken. The RQ of this mixture would be
(a) One (b) More than one
(c) Less than one (d) Zero

18. R.Q. of malic acid is **[RPMT 1995]**
(a) 0.7 (b) 1
(c) 1.33 (d) 4

19. The correct relationship of value of Respiratory Quotient is **[RPMT 1997]**
(a) Glucose symbol > Fats symbol > Organic acid
(b) Glucose symbol < Fats symbol < Organic acid
(c) Fats symbol > Glucose symbol > Organic acid
(d) Fats symbol < Glucose symbol < Organic acid

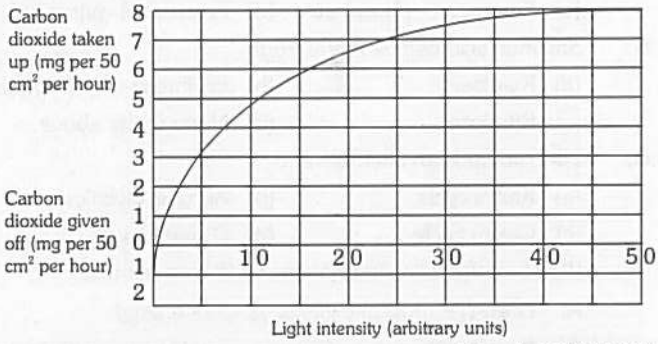
20. R.Q. is more than one in case of **[MP PMT 2000]**
Or
If the volume of CO_2 liberated during respiration is more than the volume of O_2 used, the respiratory substance will be
(a) Fat (b) Fructose
(c) Glucose (d) Organic acid

21. R.Q of sprouting potato tubers will be **[BVP 2002]**
(a) 1 (b) < 1
(c) > 1 (d) 0

22. RQ (respiratory quotient) is defined as **[NCERT; DPMT 2003, 04; KCET 2004; BVP 2004; Kerala PMT 2006]**
(a) Volume of CO_2 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) $\frac{\text{Volume of } O_2 \text{ evolved}}{\text{Volume of } CO_2 \text{ consumed}}$

Factor affecting respiration

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



[Kerala PMT 2004]
(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

2. The potato growing in hilly areas is bigger in size due to
   (a) High rate of photosynthesis at high altitude
   (b) Low rate of respiration at high altitude
   (c) Due to formation of more fat
   (d) None of the above
3. When an unripe banana is sealed in a polythene bag, it remains green for many days. But if an apple is also sealed in the same bag, the banana ripens and turns yellow within a few days. The reason is that apple **[BHU 1994]**
   (a) Removes O_2 released by the banana and thus promotes ripening
   (b) Produces CO_2 which promotes ripening
   (c) Removes CO_2 which inhibits ripening
   (d) Releases ethylene which promotes ripening
4. If the temperature is increased (above 35° C)
   (a) Rate of decline of respiration will be earlier than decline of photosynthesis
   (b) Rate of decline of photosynthesis will be earlier than decline of respiration
   (c) Both decline simultaneously
   (d) Both do not show any fixed pattern
5. CO_2 concentration has which relation with respiration
   (a) Directly proportional (b) Inversely proportional
   (c) Both (a) and (b) (d) No relation
6. Which statement is wrong
   (a) Stomatal opening is influenced by many factors and potassium
   (b) All enzymes are proteins but all proteins are not enzymes
   (c) All angiosperms are with seeds but all seed plants are not angiosperms
   (d) Factors which effect the respiration influence the photosynthesis but reverse is not possible
7. Which of the following is necessary for respiration in plants
   (a) Carbon dioxide (b) Oxygen
   (c) Chlorophyll (d) Light
8. The rate of respiration of young maturing seeds is quite high but as water contents decreases during further maturation, respiration
   (a) Remains high (b) Stops completely
   (c) Increases steadily (d) Decreases steadily
9. 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

NCERT Exemplar Questions

1. The ultimate electron acceptor of respiration in an aerobic organisms is **[NCERT]**
   (a) Cytochrome (b) Oxygen
   (c) Hydrogen (d) Glucose
2. Phosphorylation of glucose during glycolysis is catalysed by **[NCERT]**
   (a) Phosphoglucomutase (b) Phosphoglucoisomerase
   (c) Hexokinase (d) Phosphorylase
3. Pyruvic acid, the key product of glycolysis can have many metabolic fates. Under aerobic condition it forms **[NCERT]**
   (a) Lactic acid (b) $CO_2 + H_2O$
   (c) Acetyl Co A + CO_2 (d) Ethanol + CO_2
4. Electron Transport System (ETS) is located in mitochondrial **[NCERT]**
   (a) Outer membrane (b) Inter membrane space
   (c) Inner membrane (d) Matrix
5. Match the following and choose the correct option from those given below

Column A	Column B
A. Molecular oxygen	i. α – Ketoglutaric acid
B. Electron acceptor	ii. hydrogen acceptor
C. Pyruvate dehydrogenase	iii. Cytochrome C
D. Decarboxylation	iv. acetyl Co A

   Options **[NCERT]**
   (a) A-ii, B-iii, C-iv, D-i
   (b) A-iii, B-iv, C-ii, D-i
   (c) A-ii, B-i, C-iii, D-iv
   (d) A-iv, B-iii, C-i, D-ii
6. Choose the correct statement **[NCERT]**
   (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 complete breakdown of glucose in fermentation
7. Mitochondria are called power houses of the cell. Which of the following observations support this statement **[NCERT]**
   (a) Mitochondria systhesise 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
8. The end product of oxidative phosphorylation is **[NCERT]**
   (a) NADH (b) Oxygen
   (c) ADP (d) ATP + H_2O

Critical Thinking Objective Questions

1. The chemiosmotic coupling hypothesis of oxidative phospohorylation proposes that adenosine triphosphate (ATP) is formed because **[CBSE PMT 2008; DUMET 2009]**
   (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

2. How many molecules of ATP and NADPH are require in formation of two molecules of glucose? How many calvin cycles are required **[GUJCET 2015]**

(a) 36 ATP, 24 NADPH, 12 Calvin cycles
(b) 18 ATP, 12 NADPH, 6 Calvin cycles
(c) 36 ATP, 24 NADPH, 6 Calvin cycles
(d) 24 ATP, 36 NADPH, 12 Calvin cycles

3. Four respiratory enzymes are given below. Arrange them in increasing order of the carbon number of the substrates on which they act

(I) Enolase (II) Aconitase
(III) Fumerase (IV) Alcohol dehydrogenase
[EAMCET 2009]

(a) II, IV, III, I (b) IV, I, II, III
(c) I, IV, III, II (d) IV, I, III, II

4. 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

[KCET 2009]

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

5. In respiration the energy is produced during the process of

(a) Glycolysis (b) Krebs cycle
(c) Glycolysis and Kreb's cycle (d) Ornithine cycle

6. 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 **[KCET 2015]**

(a) Hibernating animals can synthesize fat instead of wasting energy of respiration
(b) Energy is saved because glycolysis and the citric acid cycle shuts down
(c) Pyruvate is converted to lactic acid by anaerobic fermentation
(d) The energy of respiration is converted into heat

7. Production of glucose from amino acids, fatty acids and glycerol is called **[MP PMT 2009]**

Or

Synthesis of glucose from sources other than Carbohydrate is called **[WB JEE 2016]**

(a) Glycogenesis (b) Gluconeogenesis
(c) Glycogenolysis (d) Glycolysis

8. Net yield of aerobic respiration during Krebs' cycle per glucose molecule is **[WB JEE 2009]**

(a) 2 ATP molecules (b) 8 ATP molecules
(c) 36 ATP molecules (d) 38 ATP molecules

9. Which of the following is non-enzymatic phosphorylation

(a) Formation of fructose 1, 6-diphosphate
(b) Formation of dihydroxyacetone phosphate
(c) Formation of 1, 3-diphosphoglyceraldehyde
(d) All the above

10. In alcohol fermentation **[CBSE PMT 2003]**

(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

11. The number of glucose molecules required to produce 38 ATP molecules under anaerobic conditions by a yeast cells is **[Kerala PMT 2004; AFMC 2009]**

(a) 2 (b) 4
(c) 19 (d) 25
(e) 38

12. Harden and Young's ester is formed during glycolysis from

(a) Fructose–6–phosphate (b) Glucose–6–phosphate
(c) Glucose (d) None of the above

13. Select the wrong statement **[Kerala PMT 2010, 11]**

(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

14. Which among the following is the most appropriate reason for storing green coloured apples at low temperature (Refrigerator)

(a) The rate of photosynthesis is reduced
(b) Respiration and photosynthesis are completely inhibited
(c) The rate of respiration is reduced
(d) The rate of photosynthesis and respiration are reduced

15. In the process of respiration in plants 180 *gms* of sugar plus 192 *gms* of oxygen produce

(a) Large amount of CO_2, no water and no energy
(b) 132 *gms* of CO_2, 54 *gms* of water and 337 *kcals* of energy
(c) 264 *gms* of CO_2, 108 *gms* of water and 674 *kcals* of energy
(d) 528 *gms* of CO_2, 216 *gms* of water and 1348 *kcals* of energy

16. When ATP molecule is hydrolysed in ADP, then the quantity of energy released is about

(a) 120 *cal* (b) 1, 200 *cal*

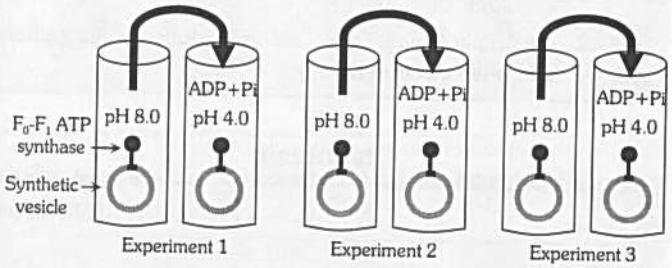
(c) 12,000 *cal* (d) 1,20,000 *cal*

17. The R.Q. (Respiratory quotient) of $C_{39}H_{72}O_6$ is

(a) 2.71 (b) 1.34

(c) 0.72 (d) 3.250

18. Experiments 1, 2 and 3 were conducted wherein synthetic vesicles containing F_0 - F_1 ATP synthase were prepared and incubated overnight in a tube. Subsequently, the vesicles were transferred to another tube which also contained ADP and Pi (inorganic phosphate)



A. A proton gradient across the vesicular membrane will be present in both experiments 1 and 2 at the time of transfer

B. As a consequence of the proton gradient, ATP will be synthesized in both experiments 1 and 2

C. ATP will be synthesized in experiment 3 because F_0 –F_1 ATP synthase has the inherent property to catalyse the synthesis of ATP from ADP and Pi

D. ATP will be synthesized in experiment 2 because the proton has to flow out of the vesicles through the F_0 - F_1 ATP synthase for ATP synthesis **[NCERT]**

(a) A and D (b) C and D

(c) B and C (d) A and B

19. The time taken from the fixation of CO_2 to the formation of one glucose molecules is about _____ seconds **[MHCET 2015]**

(a) 20 (b) 40

(c) 60 (d) 90

20. In an experiment demonstrating the evolution of oxygen in *Hydrilla*, sodium bicarbonate is added to water in the experimental set-up. What would happen if all other conditions are favourable **[KCET 2009]**

(a) Amount of oxygen evolved decreases as carbon dioxide in water is absorbed by sodium bicarbonate

(b) Amount of oxygen evolved increases as the availability of carbon dioxide increases

(c) Amount of oxygen evolved decreases as the availability of carbon dioxide increases

(d) Amount of oxygen evolved increases as carbon dioxide in water is absorbed by sodium bicarbonate

A R 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 : In alcoholic fermentation, the hexose molecule is converted into glucose and fructose.

Reason : Alcoholic fermentation is anaerobic respiration brought about by enzyme zymase. **[AIIMS 1996]**

2. Assertion : Glycolysis occurs in cytoplasm.

Reason : Enzymes for glycolysis are found in cytoplasm. It is common in aerobic/anaerobic respiration. **[AIIMS 2002]**

3. Assertion : In electron transport chain, there is a gain of energy at each step.

Reason : At each step of ETC, there are electron carriers.

4. Assertion : The inner membrane of mitochondria contains systems involving electron transport.

Reason : The mitochondrial matrix contains enzymes of Kreb's cycle.

5. Assertion : Both hexokinase and glucokinase require divalent cation Mg^{++} or Mn^{++}.

Reason : The divalent cations act as catalysts.

6. Assertion : One way of indicating the ATP yield from oxidative phosphorylation is the *P/O* ratio.

Reason : The cell stores 40% of the chemical energy.

7. Assertion : Cytochromes are a group of copper containing electron transferring proteins.

Reason : The terminal cytochrome reacts with oxygen.

8. Assertion : Cytochrome oxidase enzyme contains copper.

Reason : Cyanide combines with copper of cytochrome oxidase and prevents oxygen combining with it **[AIIMS 2010]**

9. Assertion : Substrate level phosphorylation is present in glycolysis.
Reason : Substrate level phosphorylation causes synthesis of ATP.

10. Assertion : Under aerobic conditions, pyruvate gives rise to lactate.
Reason : Under anaerobic condition, pyruvate gives rise to acetyl *CoA*.

11. Assertion : Terminal oxidation occurs both in aerobic and anaerobic conditions.
Reason : Terminal oxidation occurs at terminal step of respiration.

12. 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.

13. Assertion : Fructose-1, 6 diphosphate is converted into glyceraldehyde-3-phosphate and dihydroxy -acetone-3-phosphate.
Reason : Conversion of fructose-1,6 diphosphate into 3-phosphoglyceraldehyde and dihydroxyace -tone-3-phosphate is facilitated by the enzyme aldolase. **[AIIMS 2010]**

Answers

Anaerobic respiration

1	c	2	d	3	a	4	d	5	c
6	c	7	a	8	a	9	a	10	c
11	a	12	b	13	b	14	b	15	d
16	d	17	d	18	b	19	b	20	b
21	b	22	a						

Introduction and types of respiration

1	a	2	c	3	d	4	c	5	a
6	d	7	c	8	b	9	d	10	a
11	c	12	b	13	a	14	d	15	c
16	a	17	a	18	b	19	b	20	a
21	d	22	a	23	b	24	b	25	d
26	b	27	c	28	c	29	b	30	a
31	c	32	d	33	b	34	a	35	c
36	c	37	d	38	c	39	c	40	d
41	b	42	d	43	b	44	d	45	c
46	b	47	b	48	d	49	b	50	b
51	c	52	d	53	c	54	a	55	c
56	d	57	a	58	b	59	d	60	a
61	b	62	c	63	b				

Glycolysis

1	e	2	d	3	a	4	b	5	c
6	a	7	b	8	a	9	b	10	b
11	a	12	c	13	c	14	c	15	b
16	d	17	b	18	b	19	b	20	a
21	b	22	a	23	a	24	a	25	c
26	a	27	a	28	a	29	b	30	d
31	a	32	b	33	a	34	c	35	d
36	a								

Kreb's cycle and ETS

1	b	2	c	3	a	4	b	5	d
6	a	7	e	8	c	9	b	10	a
11	a	12	a	13	c	14	b	15	d
16	d	17	b	18	a	19	c	20	a
21	b	22	a	23	c	24	b	25	a
26	c	27	b	28	d	29	a, d	30	a
31	a	32	b	33	d	34	a	35	c
36	a	37	a	38	c	39	b	40	d
41	b	42	a	43	c	44	c	45	c
46	b	47	c	48	b	49	a	50	b
51	b	52	e	53	a	54	b	55	a
56	b	57	b	58	d	59	d	60	d
61	c	62	b	63	d	64	c	65	c
66	d	67	a	68	d	69	a	70	b
71	a	72	a	73	d				

Pentose phosphate pathway

1	b	2	b	3	c	4	a	5	b
6	b	7	c	8	c	9	b	10	c
11	d								

R.Q.

1	a	2	c	3	d	4	b	5	b
6	d	7	b	8	b	9	b	10	b
11	b	12	b	13	c	14	d	15	c
16	c	17	c	18	c	19	d	20	d
21	a	22	c						

Factor affecting respiration

1	b	2	b	3	d	4	b	5	b
6	d	7	b	8	d	9	a		

NCERT Exemplar Questions

1	b	2	c	3	c	4	b	5	a
6	c	7	a	8	d				

Critical Thinking Questions

1	a	2	a	3	d	4	b	5	c
6	d	7	b	8	a	9	c	10	d
11	c	12	a	13	b	14	c	15	c
16	c	17	c	18	a	19	d	20	b

Assertion and Reason

1	e	2	a	3	e	4	b	5	c
6	b	7	e	8	b	9	b	10	d
11	e	12	c	13	b				

AS Answers and Solutions

Anaerobic respiration

2. (d) *Pasteur's effect* : The increase of rate of glycolysis in absence of O_2 is due to the non-availability of those enzymes which are easily available in presence of O_2.

6. (c) $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + 21\,Kcal$

8. (a) Cyanide is deadly poison which inhibit the activity of cytochrome oxidase enzyme of electron transport chain. As in case of aerobic respiration there is no electron transport chain involved, therefore, anaerobic respiration is cyanide resistant pathway.

11. (a) In absence of O_2, fermentation or anaerobic respiration occurs.

13. (b) During anaerobic respiration in yeast glucose formed CO_2, C_2H_5OH and energy.

16. (d) Continuous addition of sugar in 'fed batch' fermentation is done to purify enzymes.

19. (b) Anaerobic respiration first studied by Kostychev (1902).

20. (b) Number of ATP mol. evolved in one complete cycle of anaerobic respiration is 2.

21. (b) In yeast fermentation, the enzymatic reactions are as follows

(1) $C_{12}H_{22}O_{11} + H_2O \xrightarrow[\text{in yeast}]{\text{Invertase}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}$

(2) $C_6H_{12}O_6 \xrightarrow[\text{Yeast}]{\text{Zymase}} 2C_2H_5OH$

$+2CO_2 + 21\,kcal$ energy.

Introduction and types of respiration

1. (a) Oxysome acts as the unit of phosphorylation in respiration by the formation of ATP from ADP occur on oxysome. These are present on cristae of mitochondria.

3. (d) Respiration rate high at growing regions like floral and vegetative bud, germinating seedlings, young leaves stem and root apices.

11. (c) Two molecules of glycine form a molecule of serine, CO_2 and NH_3 in mitochondria.

14. (d) In submerged hydrophytes (plants which remain completely dipped in the water) CO_2 enters through epidermis as both carbonates and bicarbonates.

17. (a) ADP $\xrightarrow{\text{hydrolysis}}$ AMP + Pi + 7.3kcal.

18. (b) Chemiosmotic hypothesis of ATP synthesis or oxidative phosphorylation given by Petel mitchell's.

19. (b) In aerobic respiration glycolysis is linked with, kreb's cycle through acetyl Co-A because pyruvic acid (end product of glycolysis) first converted into acetyl Co-A. Acetyl Co-A enter in the kreb's cycle. The formation of acetyl Co-A is involved with some cofactors like. Mg^{++} ions thiamine pyrophosphate, (Vit-B_1) NAD^+, Co-A and lipoic acid.

21. (d) ATP was discovered by Lohmann (1926) and ATP cycle by Lipmann (1941) who won Nobel prize in 1953.

23. (b) Cellular respiration is an enzyme controlled process of biological oxidation of food materials in a living cell. Using molecular O_2, producing CO_2 and H_2O and releasing energy in small step and storing it in biologically useful forms generally ATP. It occurs in mitochondria.

24. (b) Kreb's cycle takes place in the matrix and ATP formation takes place on oxysome of cristae in mitochondria.

25. (d) Pyruvic acid is the end product of glycolysis. This pyruvic acid forms acetyl *CoA*. Acetyle *CoA* is a initial compound of Kreb's cycle.

28. (c) Respiration is a biological enzymatic reaction while combustion is a chemical process.

30. (a) ATP is a higher nucleotide resembling to ribonucleotide having adenine base, ribose sugar and three phosphate groups.

31. (c) Because it takes place in living beings (biological matter).

33. (b) Because kreb's cycle occurs in matrix of mitochondria.

34. (a) According to Lundegarth amount of anion absorbed by plant cells rather than to the absorption of cations of salts so it is also called anion respiration.

37. (d) Aerobic respiration yields $10NADH_2$, $2FADH_2$, 2GTP and 2ATP resulting into

$10NADH_2 = 10 \times 3 = 30$ ATP

$2FADH_2 = 2 \times 2 = 4$ ATP

$2GTP = 2 \times 1 = 2$ ATP

$2ATP = 2 \times 1 = 2$ ATP

38 ATP

38. (c) Primary respiratory substrate is carbohydrate and secondary respiratory substrate is fat.

52. (d) As 300 ppm is normal concentration of CO_2, hence there is no effect on plant.

53. (c) Cellular respiration is an enzyme controlled process of biological oxidation of food materials in living cell.

54. (a) The energy present in one gram of fats is 9.8kcal or 41kJ, which is maximum as compared to another substrate.

57. (a) $ATP \xrightarrow{hydrolysis} ADP + Pi + 7.3$ kcal

58. (b) Because it is an energy liberating process.

Glycolysis

4. (b) Two molecules of ATP are consumed in glycolysis during phosphorylation of glucose to fructose 1, 6-diphosphate.

6. (a) Pyruvic acid is end product of glycolysis.

9. (b) Decarboxylation is the removal of carbon from a compound by using carbon to make CO_2. During kreb's cycle the acetyl group pass round the cycle and the two carbon atoms are lost in the form of carbon dioxide in two decarboxylation reactions.

10. (b) Glucose – 6-phosphate → 3-phosphoglyceraldehyde → 3-phosphoglyceric acid → phosphoenol pyruvate → pyruvic acid.

13. (c) Breakdown of glucose into 2 molecules of pyruvic acid is known as glycolysis.

17. (b) The net reaction of glycolysis would be

$$C_6H_{12}O_6 + 2ADP + 2Pi + 2NAD + \xrightarrow{Glucose}$$

$$\underset{Pyruvate}{2C_3H_4O_3} + 2NADH(+H^+) + 2ATP + 2H_2O$$

$$\underset{Glucose}{C_6H_{12}O_6} + 8ADP + 8Pi \longrightarrow \underset{Pyruvate}{2C_3H_4O_3} + 8ATP + 2H_2O$$

18. (b) Glycolysis takes place in the cytoplasm and does not use Oxygen. In anaerobic respiration only glycolysis is found, in which there is no need of mitochondria.

19. (b) Glucose is converted into glucose 6-phosphate is first step of glycolysis.

20. (a) Glycolysis occurs in all the living cells because this is common process in both aerobic and anaerobic respiration.

21. (b) Six carbon glucose molecule forms two molecules of three carbon pyruvic acid.

$C_6H_{12}O_6 \rightarrow 2C_3H_4O_3 + 4H$

22. (a) Glycolysis was discovered by Embden, Meyerhof and Parnas.

24. (a) Two molecules of pyruvic acid are formed by one molecule of glucose by glycolysis.

26. (a) $C_6H_{12}O_6$ is glucose and $C_3H_4O_3$ is pyruvic acid.

27. (a) EMP pathway is most common which was discovered by Embden, Meyerhof and Parnas (1930).

29. (b) Fructose 6-phosphate $+ATP \xrightarrow{Phosphofructokinase, Mg^{2+}}$ Fructose 1, 6-diphosphate +ADP. Glucose is converted into glucose 6-phosphate by ATP in the presence of enzyme hexokinase.

32. (b) Complete oxidation of one molecule of glucose produce 10 molecules of $NADH_2$.

Kreb's cycle and ETS

2. (c) Malate is dehydrogenated or oxidised through the agency of malate dehydrogenase to produce oxaloacetate.

8. (c) Amino acid like aspartate and glutamate on deamination from organic acids like OAA and α. Ketoglutaric acid respectively which enter into kreb's cycle.

14. (b) If O_2 is not available pyruvic acid undergo anaerobic respiration/fermentation, but under aerobic condition the pyruvic acid enter into mitochondria and converted to Acetyl *Co-A*. Acetyl *CoA* functions as substrate entrant for Krebs cycle. So, a connecting link between glycolysis and Krebs cycle.

21. (b) 1 molecule of glucose yields 56kcal/2ATP in anaerobic respiration and 686000 calories (686 kcal)/total of 38 ATP in aerobic respiration.

22. (a) Under aerobic condition pyruvate is converted into acetyl co-enzyme-A and CO_2 is released. Acetyl co-enzyme-A combines with oxaloacetic acid and form citric acid.

26. (c) In eukaryotes the entire site of reaction of kreb's cycle occur in the matrix of mitochondria.

28. (d) Largest amount of ATP is produced during aerobic respiration (38 ATP). It includes 8 ATP in glycolysis and 30 ATP in kreb's cycle.

30. (a) Dehydrogenation process converts succinate into 4-carbon fumarate with the aid of an enzyme, succinate dehydrogenase and liberates a pair of hydrogen atoms. The latter pass to FAD^+ forming $FADH_2$.

38. (c) In aerobic respiration, CO_2 is produced at 3 step :
(i) During acetyl Co-A formation.
(ii) During formation of a-ketoglutaric acid in kreb's cycle.
(iii) During succinic acid formation in kreb's cycle.

39. (b) During sixth step succinate is oxidised into fumarate by the enzyme succinate dehydrogenase and two hydrogens are transferred to FAD to form $FADH_2$.

46. (b) Reductive amination is the method of amino-acid synthesis in plants. In this method, α–keto glutaric acid reacts with ammonia (NH_3) and forms the amino acid called glutamic acid. The enzyme glutamate dehydrogenase enhances the reaction.

57. (b) Cytochrome a_3 is terminal cytochrome of ETC. It has Fe^{+++} and Cu^{++} both. With Fe^{+++}, it picks up electrons and through Cu^{+} it passes electrons to oxygen.

61. (c) Kreb's cycle is an important step of aerobic respiration in which largest molecules of ATP are formed.

62. (b) These are arranged in order of their increasing redox potential and electron flow through the chain in step wise manner from the more electronegative compound to the more electropositive O_2. On the basis of redox potential cytochrome acceptor order is cyt b c a a_3.

64. (c) Fe-S complex is responsible for passing electrons (also protons) from mitochondria NADH/NADPH to ubiquinone.

65. (c) In aerobic conditions pyruvic acid formed in glycolysis enters in the matrix of mitochondria.

66. (d) Succinyl $CoA \xrightarrow[GDP + ip \quad GTP]{H_2O}$ succinic acid.

67. (a) ATP is not electron transferring molecule. It is a energy storing molecule. So it is called as currency of energy.

68. (d) Cytochromes contain *Fe* with porphyrin pigment. The electrons pass through the cytochromes reducing their Fe^{+3} into Fe^{+2} $(Fe^{+3} + e^- \rightarrow Fe^{+2})$.

69. (a) Cytochromes occur in cristae of mitochondria because all cytochromes involved in electron transport system.

70. (b) The oxygen is the terminal acceptor of electrons which forms a water molecule in presence of protons in ETS

$$\left(\frac{1}{2}O_2 + 2e^- \rightarrow O^{-2}, 2H^+ + O^{-2} \rightarrow H_2O\right)$$

Pentose phosphate pathway

3. (c) The complete oxidation of one glucose molecule forms 12NADPH which are equivalent to 36 ATP molecules.

5. (b) PPP provides erythrose– 4 - phosphate which is required for the synthesis of shikimic acid. The latter is a precursor of aromatic ring compounds.

6. (b) HMP is an alternate method of aerobic respiration and occurs in cytoplasm.

9. (b) PEP was described by Warburg (1935) and Dickens (1938).

R.Q.

1. (a) $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$

$$\text{R.Q.} = \frac{\text{Vol. of } CO_2}{\text{Vol of } O_2} = \frac{6}{6} = 1$$

3. (d) In the above green organs the value of R.Q. is always one because in them for respiration hexose molecule is needed, in which CO_2 and O_2 molecules are equal.

5. (b) Since amount of CO_2 released is less than absorbed O_2, therefore the value of $RQ\left(\frac{CO_2}{O_2}\right)$ is less than unity.

7. (b) $$\frac{Vol.\text{ of } CO_2}{\text{Vol. of } O_2} = \frac{V_2\ cc}{V_1\ cc + V_2\ cc}$$

$$\Rightarrow R.Q. = \frac{30\ cc}{10\ cc + 30\ cc} = 0.75.$$

10. (b) During anaerobic respiration, due to the absence of O_2 the value of R.Q. is infinite (or more than one).

$C_6H_{12}O_6 \longrightarrow 2CO_2 + 2C_2H_5OH$

$$\text{R.Q.} = \frac{2}{0} = (\text{infinite}).$$

11. (b) Respiratory quotient depends upon the type of substrate participating in respiration.

13. (c) Carbohydrate

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

$$\text{RQ} = \frac{6CO_2}{6O_2} = 1$$

Fats : The value of RQ is less than 1. This would mean that there is much less oxygen in the constitution of fat as compared to that in carbohydrates. Thus, they need more O_2 for respiration.

As an example, the equation for respiration of Tripalmitin is as under

$2(C_{51}H_{98}O_6) + 145\,O_2 \rightarrow 102\,CO_2 + 98\,H_2O$ Energy

$$RQ = \frac{102CO_2}{145O_2} = 0.7.$$

14. (d) In some succulent or fleshy plants *e.g.*, *Opuntia*, carbohydrates are incompletely oxidized to organic acids in dark without the evolution of CO_2

$$\underset{\text{glucose}}{2C_6H_{12}O_6} + 3O_2 \longrightarrow \underset{\text{malic acid}}{3C_4H_6O_5} + 3H_2O$$

$$\text{R.Q.} = \frac{CO_2}{O_2} = \frac{0}{0} = 0 \text{ (less than one)}$$

17. (c) In germinating castor seeds, respiratory substrate is fat. Maize contains carbohydrate and groundnut seed contains fatty acid. R.Q. of these substances are respectively less than 1. Thus total R.Q. will be less than one.

18. (c) $C_4H_6O_5 + 3O_2 \longrightarrow 4CO_2 + 3H_2O$

$$\text{R.Q.} = \frac{4}{3} = 1.3 \text{ (more than one).}$$

Factor affecting respiration

3. (d) In apple, gaseous hormone ethylene is produced which helps in ripening of banana to convert it yellow.

5. (b) If the amount of CO_2 in the air more than usual rate of respiration is decreased.

7. (b) Oxygen is essential for aerobic respiration it is the ultimate acceptor of electrons in electron transport system (E.T.S).

8. (d) Water is essential for accelerating enzyme activity. In conditions of water stress therefore the respiration decreases that's why in dry fruits and seeds in respiratory enzyme least active, show minimum respiration.

9. (a) Cyanides, azides and carbon monoxide work as enzyme inhibitors, thus the rate of respiration decreases.

Critical Thinking Questions

14. (c) At low temperature in green apple, the galactose sugar consumption reduces in respiration due to which they remain as such fresh for long time.

15. (c) Reaction of respiration is

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 674\ kcal$

In this reaction considering molecular weight of each element, we get

$C_6H_{12}O_6$ = 6 times 12 +12 times 1 + 6 times 16 = 180 *gm*

O_2 = 6 times 32 = 192 *gm*

Now we consider products of this reaction i.e. $6CO_2$ and $6H_2O$

$6CO_2 = 6\ (12 + 32) = 264\ gm$

$6H_2O = 6\ (2 + 16) = 108\ gm$

17. (c) $2C_{39}H_{72}O_6 + 108O_2 \rightarrow 78\ CO_2 + 72\ H_2O$

$$\therefore \text{R.Q.} = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ used up}} \frac{78}{108} = .072$$

Assertion and Reason

1. (e) Alcoholic fermentation is the respiration in absence of O_2. In this process, hexose molecule is changed to ethyl alcohol and CO_2. In presence of zymase enzyme. In this less amount of energy is released as compared to aerobic respiration.

2. (a) Glycolyis occurs in cytoplasm as all necessary enzymes are found in it. This process is common in aerobic/anaerobic respiration. In this process, one glucose molecule is converted into 2 molecules of pyruvic acid.

3. (e) The passage of electrons from one enzyme or cytochrome to the next is a downhill journey with a loss of energy at each step. At each step the electron carriers include flavins, iron sulphur complexes, quinones and cytochromes.

4. (b) The inner membranes of mitochondria contain all systems involving electron transport. The mitochondrial matrix contains all the soluble enzymes of the citric acid or Kreb's cycle and those involved in the oxidation of fatty acids.

5. (c) Both kinases require a divalent cation (Mg^{2+} or Mn^{2+}), which first combines with ATP to form the true substrate, $MgATP^{2-}$ or $MnATP^{2-}$

6. (b) One way of indicating the ATP yield from oxidative phosphorylation is the P/O ratio, which is expressed as the moles of inorganic phosphate used per oxygen atom consumed. The cell stores 40% of the chemical energy liberated by the combustion of glucose in the form of ATP. The rest of the energy is dissipated as heat or used for other cell functions.

7. (e) The cytochromes are a group of iron containing electron-transferring proteins of aerobic cells that act sequentially to transfer electrons from flavoprotein to molecular oxygen. The terminal cytochrome of the electron transport chain, which can react with oxygen, is called cytochrome oxidase.

8. (b) The final stage of respiratory chain involves cytochrome oxidase which contains copper. This stage can be specifically inhibited by cyanide or carbon monoxide. Cyanide combines with the copper and prevents oxygen combining with it.

9. (b) One of the two phosphates of diphosphoglycerate is linked by high energy bond. It can synthesize ATP and form 3-phosphoglycerate. The enzyme is phosphoglycerate kinase. The direct synthesis of ATP from metabolites is called substrate level phosphorylation.

During formation of phosphoenol pyruvate the phosphate radical pick up energy. It helps in the production of ATP by substrate level phosphorylation.

10. (d) Under aerobic conditions, the products are pyruvate and coenzyme *NADH*. Pyruvate directly enters the mitochondrial matrix and is converted into acetyl-*CoA*. Under anaerobic conditions, pyruvate is used as a hydrogen acceptor and converted into lactate. In anaerobic conditions, pyruvate remains in the cytosol.

11. (e) Terminal oxidation is the name of oxidation found in aerobic respiration that occurs towards the end of catabolic process and involves the passage of both electrons and protons of reduced coenzymes to oxygen.

12. (c) During the hydrolysis of typical chemical bonds, about 3000 calories per mole are liberated. The release of any one of the two terminal phosphates of ATP yields about 7300 calories per mole, instead of the 3000 calories from common chemical bonds. The standard free energy of hydrolysis of ATP to ADP and phosphate is – 7.30 *K cal* at *pH* 7.0 and temperature 37°*C* in the presence of excess Mg^{2+}.

13. (b) Fructose 1, 6-diphosphate in the presence of enzyme aldolase is converted into a glyceraldehyde-3-phosphate and a dihydroxy acetone-3-phosphate molecules.

Fructose 1, 6-diphosphate $\xrightleftharpoons{\text{aldolase}}$ $3PGA + DiHAP$.

Respiration in Plants

SET Self Evaluation Test

1. Enzymes found attached to inner membrane of mitochondria instead of matrix is/are **[AFMC 2006]**
   (a) Succinic dehydrogenase (b) Cytochrome oxidase
   (c) Both (a) and (b) (d) Malic dehydrogenose
2. Anaerobic respiration is also known as
   (a) Intramolecular respiration
   (b) Intermolecular respiration
   (c) Extramolecular respiration
   (d) Molecular respiration
3. 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 **[AIIMS 2009]**
   (a) Chemiosmosis (b) Phosphorylation
   (c) Glycolysis (d) Fermentation
4. Which of the following processes make direct use of oxygen **[Kerala PMT 2006; CPMT 2010]**
   (a) Glycolysis (b) Fermentation
   (c) Electron transport (d) Kreb's citric acid cycle
   (e) Hydrolysis
5. What is active glucose
   (a) FAD–glucose (b) NAD–glucose
   (c) Phosphoglucose (d) Glycerophosphate
6. High fatty acids are breaking by **[RPMT 1999]**
   (a) β-oxidation (b) α-oxidation
   (c) Glycolysis (d) All of these
7. How many ATP will be produced during the production of 1 molecule of acetyl *CoA* from 1 molecule of pyruvic acid **[MP PMT 1996, 2006]**
   (a) 3 ATP (b) 5 ATP
   (c) 8 ATP (d) 38 ATP
8. Fruit keep better in refrigeration, this is due to
   (a) Non-availability of O_2 (b) Absence of moisture
   (c) Accumulation of O_2 (d) Inactivation of respiration
9. Vant Hoff's law states that **[KCET 1994]**
   (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 change in temperature
   (d) The respiration rate increases two or three times for every rise of 10° *C*
10. A characteristic feature of ripening of some fruits (like banana) is a sudden increase in respiration which is known as
    (a) Climacteric (b) Anthesis
    (c) Climatic (d) Photorespiration
11. R.Q. is highest when respiratory substance is
    (a) Fat (b) Malic acid
    (c) Glucose (d) Protein
12. An indispensable role in energy metabolism is played by
    (a) Sodium (b) Phosphorus
    (c) Calcium (d) Potassium
13. Fermentation is conducted by **[NCERT]**
    (a) All fungi
    (b) All bacteria
    (c) Some fungi and some bacteria
    (d) All micro-organisms

* * *

AS Answers and Solutions

1	c	2	a	3	a	4	c	5	c
6	a	7	a	8	d	9	d	10	a
11	b	12	b	13	c				

1. (c) All the enzymes of Kreb's cycle, fatty acid synthesis and amino acid synthesis are found in matrix but succinic dehydrogenese and cytochrome oxidase are present on inner membrane of mitochondria.
3. (a) Chemiosmosis is the diffusion of ions across a selectively-permeable membrane. More specifically, it relates to the generation of ATP by the movement of hydrogen ions across a membrane during cellular respiration
6. (a) Fats hydrolyse in fatty acids and glycerol. Fatty acids after β-oxidation forms to acetyl *CoA* and glycerol forms to triose phosphates.
7. (a) During acetyl *CoA* formation by pyruvic acid, only one $NADH_2$ is formed by which 3 molecules of ATP are formed.
8. (d) Respiratory rate is low in refrigeration.
9. (d) The respiration rate increases two or three times for every rise of 10°C called or Vant Hoff's law which is between 2 to 2.5.
10. (a) Some fruits (*e.g.*, banana and apple) show high rates of respiration during their ripening. This rise in respiratory rate is called climacteric.
11. (b) Because malic acid is an organic acid, which after oxidation produces more CO_2, due to which the value of R.Q. is four.
12. (b) Because phosphorus produces energy coins ATP.
13. (c) Fermentation is anaerobic breakdown of carbohydrates into alcohol, organic acids with the help of microorganisms (fungi, bacteria).