RESPIRATION

Introduction

All organisms require continuous input of energy to carry on life process. These energy comes from cellular activities. All the cellular activities can be grouped into two categories : **anabolism** (biosynthetic activities of the cell) and **catabolism** (breaking- up process of the cell). The anabolic activities are endergonic (utilizes energy in cellular activities), while the catabolic activities are usually exergonic (energy releasing process by oxidation of food material). The sum of total catabolic and anabolic reactions occurring at any time in a cell is called **metabolism**.

Respiration is a vital process, includes the intake of oxygen. Chemically it is catabolic and brings about the oxidation and decomposition of organic compounds like carbohydrate, fat, protein in the cells of plants and animals with the release of energy. Oxidation of organic compounds by respiration, resulting in the release of chemical energies water and carbon dioxide. The overall process may be states according to the following general equation:

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

In this reaction, six molecules of oxygen taken up and six molecules each of CO_2 and H_2O are formed with energy derived from respiration of each molecule of sugar oxidation. The plant cell is able to do chemical work in synthesizing energy- rich materials such as fat and hydrocarbon, osmotic work such as uptake and accumulation of salt and mechanical work such as involved in growth.

Respiration

Definition of respiration : 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.

(1) **Use of energy :** Cellular activities like active transport, muscle-contraction, bioluminescenes, 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.

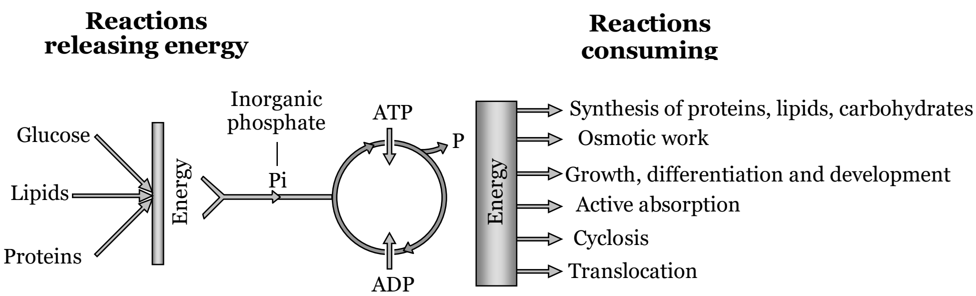


Fig. ATP cycle : ATP is an intermediate energy-transfer compound between energy-releasing and energy consuming

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.

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

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

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

(iii) It convert in soluble foods into soluble form.

(iv) 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).

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

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

(vii) It activates the different meristematic tissue of the plant.

(3) **Comparison between respiration and photosynthesis :** Photosynthesis associated with manufacturing of food, while respiration associated with releasing of energy from this food. Comparison between respiration and photosynthesis is given below :

Photosynthesis	**Respiration**
Occurs only in chlorophyll containing cells of plants.	Occurs in all plant and animal cells.
Takes place only in the presence of light.	Takes place continually both in light and in the dark.
During photosynthesis, radiant energy is converted into potential energy.	During respiration, potential energy is converted into kinetic energy.
Sugars, water and oxygen are products.	CO_2 and H_2O are products.
Synthesizes foods.	Oxidizeds foods.
CO_2 and H_2O are raw materials.	O_2 and food molecules are raw materials.
Photosynthesis is an endothermal process.	Respiration is an exothermal process.
Stores energy.	Releases energy.

It includes the process of hydrolysis, carboxylation etc.	It includes the process of the dehydrolysis, decarboxylation, etc.
Results in an increase in weight.	Results in a decrease in weight.
It is an anabolic process.	It is a catabolic process.
Require cytochrome.	Also require cytochrome.

(4) **Exchange of gases in photosynthesis and respiration :** Respiration is continually going on in all living cells and oxygen is being continually absorbed and carbon dioxide liberate. The intake of *oxygen* (Liberated by photosynthesis) and liberation of *carbon dioxide* (evolved in respiration) takes place through the stomata and lenticels. The real process of respiration consists in the oxidation of organic substances which takes place in the protoplasm of the living cells and the gaseous exchange is an outward manifestation and an accompaniment of respiration. The intensity of gaseous exchange depends upon the intensity of respiration. It is comparatively rapid in meristematic and growing tissues where the formation of new cells and cell wall material requires a large supply of energy and is comparatively slow in mature cells due to the slowness of metabolic activities.

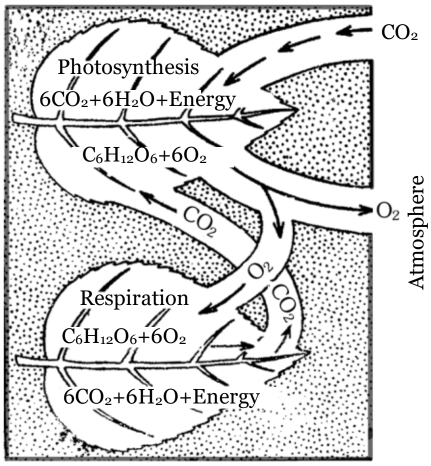


Fig. Showing gas exchange due to photosynthesis and respiration

❑ **Compensation point :** It is that value or point in light intensity and atmospheric CO_2 concentration when rate of photosynthesis is just equivalent to the rate of respiration in photosynthetic organs so that there is no net gaseous exchange. The value is 2.5- 100 ft candles/ 26.91-1076.4 lux in shade plants and 100-400 ft candles/ 1076.4-4305.6 lux in case of sun plants. It is called **light compensation point.** There is, similarly, a **CO_2 compensation point.** Its value is 25-100 *ppm* (25-100 $\mu l.l^{-1}$) in C_3 plants and 0-5 *ppm* **(**0-5 $\mu l.l^{-1}$) in C_4 plants. A plant cannot survive for a long at compensation point because the nonphotosynthetic parts and dark respiration will deplete organic reserve of the plant.

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

(5) **Comparison between respiration and combustion :** According **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:

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.

6.1 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.**

6.2 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**.

6.3 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 organism normally respire anaerobically which is their major ATP- yielding process. Such organisms are in fact killed in the presence of substantial amounts of oxygen (e.g., *Clostridium botulinum* and *C. tetan*i).

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

6.4 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 is given by Embden, Meyerhoff 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 (6*c*) breaks into two molecules of pyruvic acid (3*c*).

(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 converted into simplest form like glucose, glucose 6-phosphate or fructose 6-phosphate. Then these sugars are metabolized into the glycolysis. The flow chart that showing inter conversion of sugar are given below :

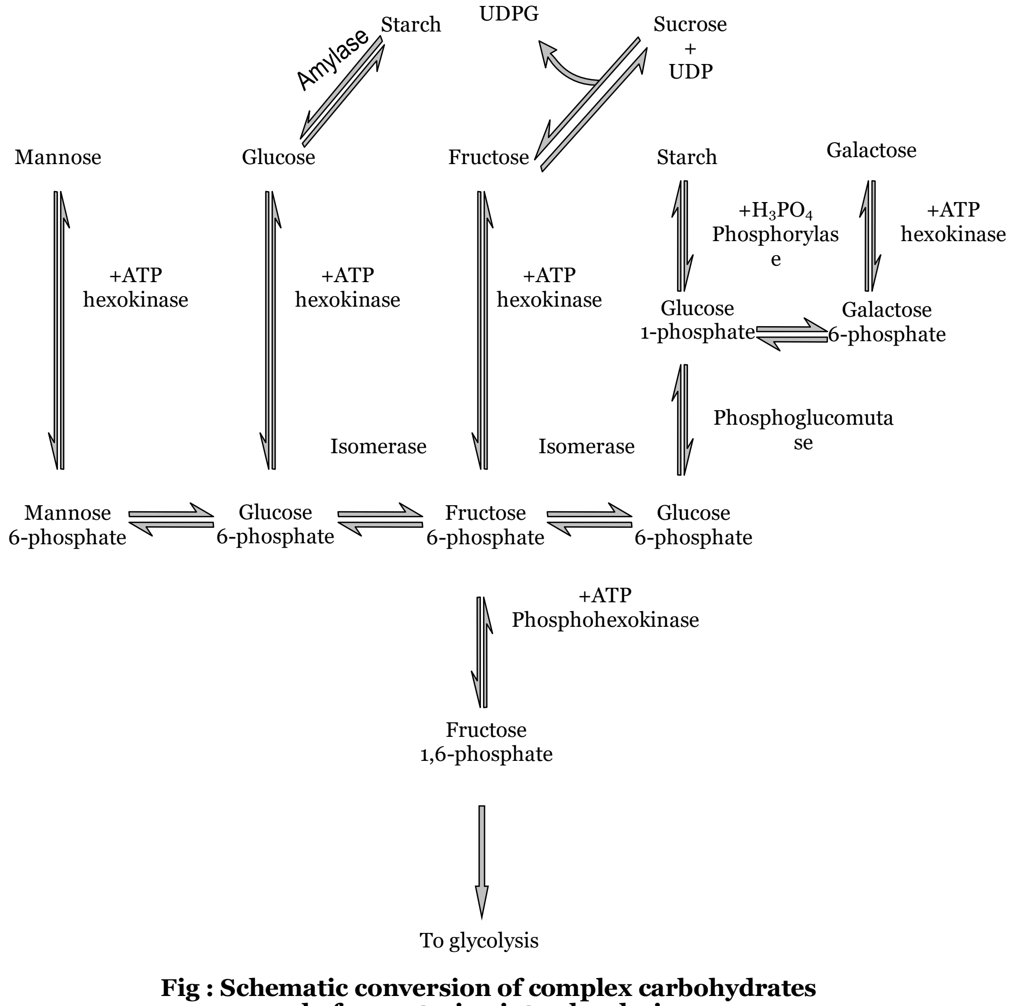


Fig : Schematic conversion of complex carbohydrates before entering into glycolysis

(5) **Glycolysis cycle**

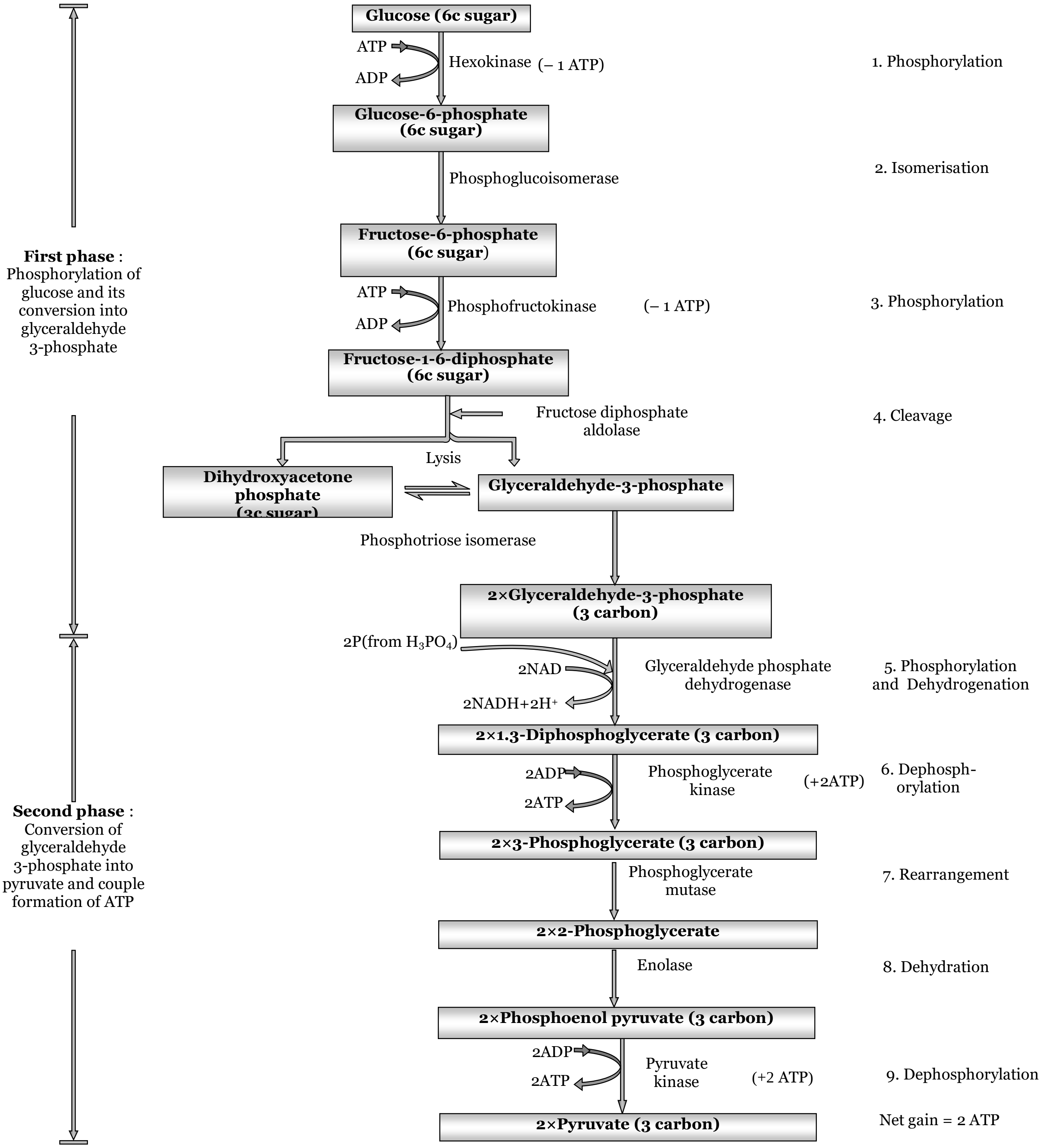


Fig : Glycolysis: A molecule of glucose breaks into two molecules of pyruvate in nine steps. Enzymes that catalyze the reactions 1-9 are sequentially listed on the right.

(6) **Enzymes of glycolysis and their co-factors**

S. No.	Enzyme	Coenzyme (s) and cofactor	Activator (s)	Inhibitor (s)	Kind of reaction catalyzed
(i)	Hexokinase	Mg^{2+}	ATP^{4-}, Pi	Glucose 6-phopshate	Phosphoryl transfer
(ii)	Phosphogluco-isomerase	Mg^{2-}	-	2-dioxyglucose 6-phosphate	Isomerization
(iii)	Phosphofructo-kinase	Mg^{2+}	Fructose 2, 6-diphosphate, AMP, ADP, cAMP, K^{+}	ATP $^{4-}$, citrate	Phosphoryl transfer
(iv)	Aldolase	Zn^{2+} (in microbes)	-	Chelating agents	Aldol cleavage
(v)	Phosphotriose isomerase	Mg^{2+}	-	-	Isomerization
(vi)	Glyceraldehyde 3-phosphate dehydrogenase	NAD	-	Iodoacetate	Phosphorylation coupled to oxidation
(vii)	Phosphoglycerate kinase	Mg^{2+}	-	-	Phosphoryl transfer
(viii)	Phosphoglycerate mutase	Mg^{2+} 2,3-diphos phoglycerate	-	-	Phosphoryl shift
(ix)	Enolase	Mg^{2+} , Mn^{2+}, Zn^{2+}, Cd^{2+}	-	Fluoride+ phosphate	Dehydration
(x)	Pyruvate kinase	Mg^{2+}, K^{+}	-	Acetyl CoA, analine, Ca^{2+}	Phosphoryl transfer

(7) **Steps of glycolysis :** Glycolysis consists of 9 steps. Each step is catalysed by a specific enzyme. Most of the reaction are reversible.

(i) **First phosphorylation :** The third phosphate group separates from adenosine triphospate (ATP) molecule, converting the latter into adenosine diphophate (ADP) and releasing energy. With this energy, the phosphate group combines with glucose to form glucose 6-phosphate, The reaction is catalysed by the enzyme, **hexokinase** or **glucokinase** in the presence of Mg^{2+}**.** Thus, a molecule of ATP is consumed in this step. This glucose 6-phosphate (phosphoglucose) is called active glucose.

$$\text{Glucose} + ATP \xrightarrow[Mg^{++}]{\text{Hexokinase}} \text{Glucose 6} - \text{phosphate} + ADP$$

(ii) **Isomerisation :** Glucose 6-phophate is changed into its isomer fructose 6-phophate by rearrangement. The rearrangement is catalysed by an enzyme, **phophoglucose-isomerase** or **phosphohexose isomerase.**

$$\text{Glucose 6-phosphate} \underset{\text{isomerase}}{\overset{\text{Phosphogluco}}{\rightleftharpoons}} \text{Fructose 6-phosphate}$$

Fructose 6-phosphate may be formed directly from free fructose by its phosphorylation in the presence of an enzyme **fructokinase,** Mg^{2+} and ATP

$$\text{Fructose} + ATP \xrightarrow[Mg^{2+}]{\text{Fructokinase}} \text{Fructose 6} - \text{phosphate} + ADP$$

(iii) **Second phosphorylation :** Fructose 6-phosphate combines with another phosphate group from another ATP molecule, yielding fructose 1, 6-diphosphate and ADP , The combination is catalysed by an enzyme **phosphofructokinase** in the presence of Mg^{2+} and appears to be irreversible. This phosphorylation, thus, consume another molecule of ATP. Excess of ATP inhibits phosphofructokinase.

$$\text{Fructose 6} - \text{phosphate} + ATP \xrightarrow[\text{kinase}, Mg^{2+}]{\text{Phosphofructo}-} \text{Fructose 1,6} - \text{diphosphat e} + ADP$$

phosphorylation reaction activate the sugar and prevent its excape from the cell. They go uphill, increasing the energy content of the products.

(iv) **Cleavage :** Fructose 1,6-diphosphate now splits into two 3-carbon, phosphorylated sugars : dihydroxyacetone phosphate (DHAP) and 3-phosphoglyceraldehyde (3-PGAL), or glyceraldehyde 3-phosphate (GAP). The reaction is catalyzed by an enzyme **aldolase**. DHAP is converted into PGAL with the aid of an enzyme **phosphotriose isomerase.**

$$\text{Fructose 1,6-diphosphate} \overset{\text{Aldolase}}{\rightleftharpoons} \text{3-phophoglyceraldehyde+Dihydroxyacetone phosphate}$$

$$\text{Dihydroxyacetone phosphate} \underset{\text{isomerase}}{\overset{\text{Phosphotriose}}{\rightleftharpoons}} \text{3- phosphoglyceraldehyde}$$

(v) **Phosphorylation and Oxidative dehydrogenation:** In phosphorylation, 3-phosphoglyceraldehyde combines with a phosphate group derived from inorganic phosphoric acid (H_3PO_4) found in cytosol, not form ATP, forming1, 3-diposphoglycerate, or diphosphoglyceric acid. The reaction occurs with the aid of a specific enzyme.

(a) In dehydrogenation, a pair of hydrogen atom separate from a molecule of 3-phosphoglyceraldehyde. Their separation releases a large amount of energy. A part of this energy is stored in newly formed phosphate bond of 1,3-diphosphoglycerate, making it a high energy bond. Separation of hydrogen is catalysed by an enzyme, **3-phosphoglyceraldehyde dehydrogenase.**

(b) As stated above, two hydrogen (H) atoms (2 proton and 2 electrons) separate from 3-phosphoglyceraldehyde. Of these, one complete hydrogen atom (proton and electron) and one additional electron are picked up by NAD^+ which gets reduced to NADH. The remaining one hydrogen proton or ion (H^+) remains free in the cytosol.

$$2H^+ + 2e^- + NAD^+ \rightarrow NADH + H^+$$

NADH is a high-energy substance, carrying the rest of the energy released by separation of hydrogen atoms from 3- PGAL. Energy is actually released by transfer of electrons from 3-PGAL to NAD. The NADH provides energy to convert ADP to ATP by passing its electrons over the electron transmitter system if oxygen is available.

The overall reaction is as under –

$$3 - PGAL + NAD^+ + P_i^{2-} \xrightarrow[\text{aldehyde dehydrogenase}]{\text{3-Phosphoglycer-}} \text{1,3-diphosphoglycerate} + NADH + H^+$$

(vi) **Dephosphorylation or ATP generation (First) :** High-energy phosphate group on carbon 1 of 1,3 diphosphoglycerate is transferred to a molecule of ADP, converting it into an ATP molecule. 1, 3-diphosphoglycerate changes to 3-phosphoglycerate due to loss of a phosphate group. The reaction is catalysed by an enzyme **diphosphoglycerokinase.** Formation of ATP directly from metabolites is known as **substrate level phophorylation.**

$$\text{1, 3-diphosphoglycerate +ADP} \xrightleftharpoons[\text{kinase} + Mg^{2+}]{\text{Diphosphoglycer}} \text{3-phosphoglycerate + ATP}$$

(vii) **Isomerisation/ Rearrangement :** The phosphate group on the third carbon of 3-phosphoglycerate shifts to the second carbon, producing 2-phosphoglycerate. This change is aided by the enzyme **phosphoglyceromutase.**

$$\text{3-phosphoglycerate} \xrightleftharpoons[\text{mutase}]{\text{Phosphoglycero-}} \text{2-phosphoglycerate}$$

(viii) **Dehydration :** 2-phosphoglycerate loses a water molecule in the presence of an enzyme, enolase and Mg^{2+}, and changes into phosphoenol pyruvate. The latter undergoes molecular rearrangement that transforms its phosphate group into a high-energy phosphate bond.

$$\text{2-phosphoglycerate} \xrightleftharpoons[Mg^{2+}]{\text{Enolase}} \text{Phosphoenol pyruvate} + H_2O$$

(ix) **Dephosphorylation or ATP generation (Second) :** High-energy phosphate group of phosphoenol pyruvate is transferred to a molecule of ADP with the help of an enzyme, **pyruvate <u>kinase</u>** in the presence of Mg^{2+} and K^+. This produces simple 3-carbon pyruvate and a molecule of ATP.

$$\sim \text{phosphoenol pyruvate +ADP} \xrightleftharpoons[Mg^{2+}, K^+]{\text{Pyruvate kinase}} \text{Pyruvate +ATP}$$

All enzymes, reactants, intermediates and products of glycolysis are dissolved in the cytosol. Their interaction depends on random collisions brought about by kinetic movements.

(8) **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) Overall reaction of glycolysis represented by following reaction :

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

(vii) Total input and output materials in glycolysis :

Total Inputs	**Total Outputs**
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

Important Tips

- 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.
- Glucose oxidation is very rapid process of complete oxidation of a glucose molecules takes only **one second.**
- Only 5% of total energy of glucose is released during glycolysis.
- **Utility of phosphorylation during glycolysis :** It traps glucose with in the cell as glucose 6-p is negatively charged.

- Splitting of fructose 1,6-diP into 3-PGAL and dihydroxyacetone P is called **rate determining step** of glycolysis.
- Glucose 6-phosphate called Rohinsonester, fructose 6-phosphate called Newberg's ester and fructose 1,6-diphosphate called Harden and Young's ester.
- R.B.Cs gets energy only by glycolysis because they lacks mitochondria.
- Phosphofructokinase called regulatory enzyme of glycolysis, it is inhibited by high concentration of ATP and is stimulated by ADP and Pi.
- **Preparatory phase of glycolysis** involves conversion of one molecule of glucose into two molecules of 3-PGAL and involves the use of 2 ATP molecules, while **pay-off phase of glycolysis** involves conversion of 2 molecules of 3-PGAL into two molecules of pyruvate and involves production of four ATP molecules. Preparatory phase causes activation of glucose, while pay-off phase involves extraction of energy from the activated glucose.
- Formation of 1,3-diphosphoglyceraldehyde called non enzymatic phosphorylation.

Aerobic oxidation of pyruvic acid

(1) Oxidative decarboxylation/ Formation of acetyl CoA.

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

(3) Electron transport system

(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. The pyruvate molecule gives off a molecule of CO_2 and releases a pair of hydrogen atoms from its carboxyl group ($–COOH$), leaving the 2 carbon acetyl group ($CH_3CO–$). The reaction is called oxidative decarboxylation, and is catalyzed by the enzyme pyruvate dehydrogenase complex (decarboxylase, TPP, lipolic acid, transacetylase, Mg^{2+}) . During this reaction, the acetyl group combines with the coenzyme A (CoA) to form acetyl coenzyme A with a high energy bond (CH_3CO~CoA). Most of the free energy released by the oxidation of pyruvate is captured as chemical energy in high energy bond of acetyl coenzyme A. From a pair of hydrogen atoms released in the reaction, to electrons and one H^+ pass to NAD^+, forming, $NADH^+$ H^+ . The NADH forms 3 ATP molecules by transferring its electron over ETS described ahead.

Decarboxylation and dehydration :

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

**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. This reaction is not a part of Kreb's cycle.

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

(i) **Discovery** : This cycle has been named after the German biochemist in England **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.

(ii) **Site of occurrence :** It takes place in the mitochondrial matrix.

(iii) **Kreb's cycle**

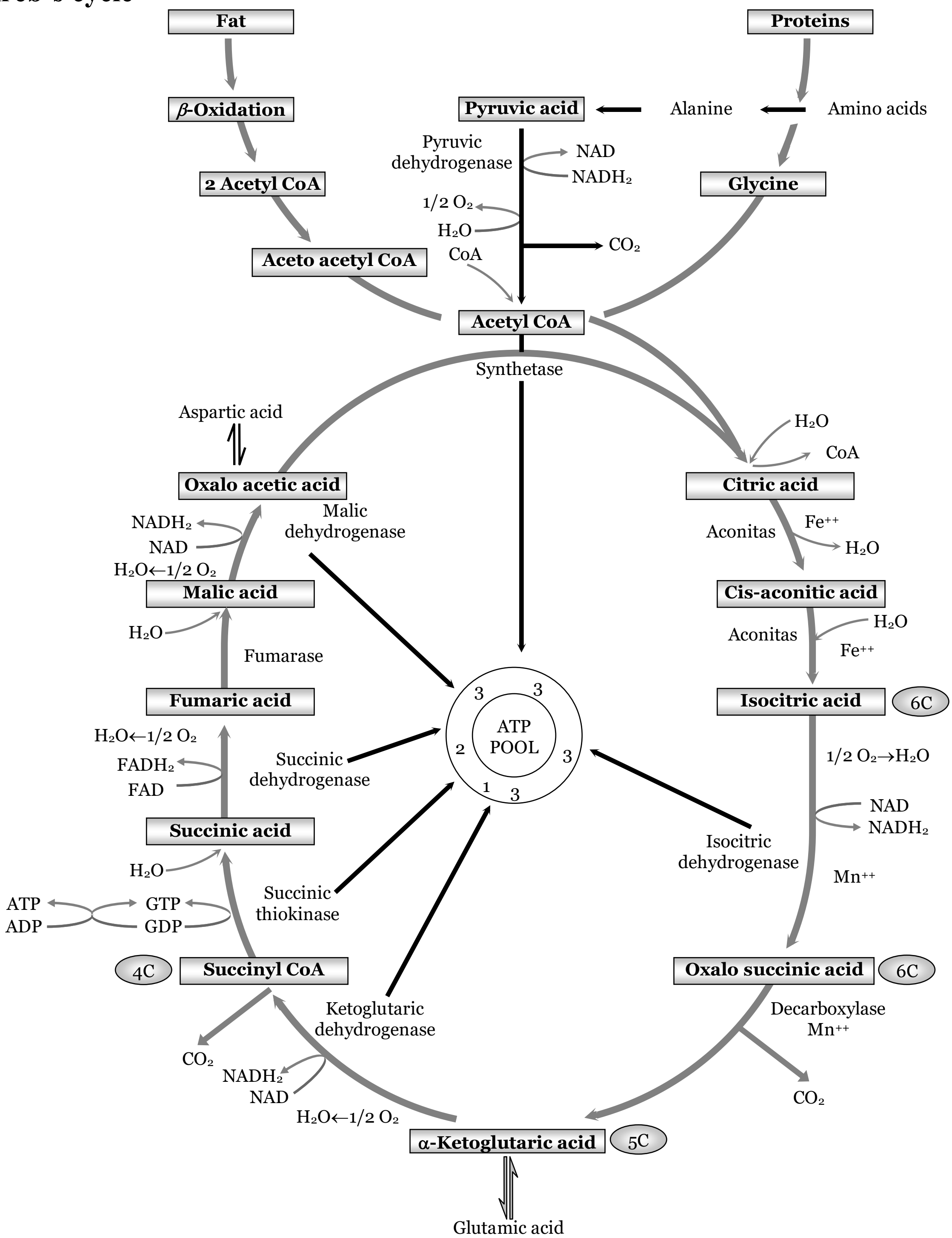


Fig : Diagramatic representation of oxidative decarboxylation of pyruvic acid and different chemical reactions in Kreb's cycle starting from Acetyl CoA

(iv) **Enzymes of Kreb's cycle**

Step	Enzyme	(Location in mitochondria)	Coenzyme(s) and cofactor (s)	Inhibitor(s)	Type of reaction catalyzed
(a)	Citrate synthetase	Matrix space	CoA	Monofluoro-acetyl- CoA	Condensation
(b)	Aconitase	Inner membrane	Fe^{2+}	Fluoroacetate	Isomerization
(c)	Isocitrate dehydrogenase	Matrix space	NAD^+, $NADP^+$, Mg^{2+}, Mn^{2+}	ATP	Oxidative decarboxylation
(d)	α -ketoglutarate dehydrogenase complex	Matrix space	TPP,LA,FAD, CoA, NAD^+	Arsenite,Succinyl-CoA, NADH	Oxidative decarboxylation
(e)	Succinyl-CoA synthetase	Matrix space	CoA	-	Substrate level phosphorylation
(f)	Succinate dehydrogenase	Inner membrane	FAD	Melonate, Oxaloacetate	Oxidation
(g)	Fumarase	Matrix space	None	-	Hydration
(h)	Malate dehydrogenase	Matrix space	NAD^+	NADH	Oxidation

(v) **Steps in Kreb's cycle :** Kreb's cycle consists of 8 cyclic steps, producing an equal number of organic acids. Each step is catalyzed by a specific enzyme. In Kreb's cycle, the **entrant molecule** is 2-carbon acetyl CoA and the **receptor molecule is** 4- carbon oxaloacetate.

(a) **condensation :** Acetyl coenzyme A reacts in the presence of water with the oxaloacetate normally present in a cell, forming 6-carbon citrate and freeing coenzyme A for reuse in pyruvate oxidation. The high-energy bond of acetyl CoA provides the energy for this reaction. The reaction is catalyzed by the **citrate synthetase** enzyme. The citrate has 3-carboxyl group. Hence, Krebs cycle is also called **tricarboxylic acid cycle**, or TCA cycle after its first product.

$$\text{Oxaloacetate} + \text{AcetylCoA} + H_2O \xrightarrow[\text{Synthetase}]{\text{Citrate}} \text{Citrate} + CoA\,(\text{Reused})$$

(b) **Reorganisation** (Dehydration) **:** Citrate undergoes reorganisation in the presence of an enzyme, **aconitase ,** forming 6-carbon cisaconitate and releasing water.

$$\text{Citrate} \xrightarrow{\text{Aconitase}} \text{Cisaconitate} + H_2O$$

(c) **Reorganisation (Hydration) :** Cisaconitate is further reorganised into 6-carbon isocitrate by the enzyme, **aconitase**, with the addition of water.

$$\text{Cisaconitate} + H_2O \xrightarrow{\text{Aconitase}} \text{Isocitrate}$$

(d) **Oxidative decarboxylation I :** This is a two stage process :

Stage I : Hydrogen atoms from isocitric acid react with NAD to form NAD. $2H$ forming oxalosuccinic acid. The pair of hydrogen atoms give two electrons and one H^+ to NAD^+ forming NADH $+H^+$**.** The enzyme **isocitrate dehydrogenase** catalyses the reaction in the presence of Mn^{2+}. NADH generates ATP by transferring its electron over the ETS.

$$\text{Isocitric acid} + NAD \xrightarrow[Mn^{2+}]{\text{Isocitric dehydrogenase}} \text{Oxalosuccinic acid} + NAD.2H(or\ NADPH.2H)$$

Stage II : Decarboxylation of oxalosuccinic acid occurs forming α-ketoglutaric acid, which is a first 5-C carbon molecule of Kreb's cycle.

$$\text{Oxalosuccinic acid} \xrightarrow[Mn^{2+}]{\text{Carboxylase}} \alpha - \text{Ketoglutaric acid} + CO_2$$

(e) **Oxidative decarboxylation II :** This is also a 2 stage process :

Stage I : Coenzyme A reacts with α-ketoglutarate, forming 4-carbon succinyl-coenzyme A and releasing CO_2 and a pair of hydrogen atoms. The reaction is catalysed by α-ketoglutarate dehydrogenase complex enzyme. the pair of hydrogen atoms pass two electrons and one H^+ to NAD^+, forming NADH + H^+

$$\alpha - \text{ketoglutarate} + CoA + NAD^+ \xrightarrow[\text{dehydrogenase}]{\alpha\text{-ketoglutarate}} \text{Succinyl} - CoA + CO_2 + NADH + H^+$$

Stage II : Succinyl –coenzyme A splits into 4-carbon succinate and coenzyme A with the addition of water. The coenzyme A transfers its high energy to a phosphate group that joins GDP (Guanosine diphosphate), forming GTP (Guanosine triphosphate). The latter is an energy carrier like ATP. This is the only high-energy phosphate produced in the Krebs cycle. The stage 2 reaction is catalysed by **succinyl-CoA synthetase** enzyme. The formation of GTP is called substrate level phosphorylation.

$$\text{Succinyl} - CoA + H_2O + GDP / ADP \xrightarrow[\text{Synthetase}]{\text{Succinyl}-CoA} \text{Succinate} + CoA + GTP / ATP$$

In a plant cell, this reaction produce ATP from ADP and GTP from GDP or ITP (Inosine triphosphate) in animals.

Oxygen to oxidize a carbon atom to CO_2 is taken in steps 4 and 5 from a water molecule.

(f) **Dehydrogenation :** This 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^+ (Flavin adenine dinucleotide), forming $FADH_2$._Hydrogen is carried by FAD in the form of whole atoms.

$$\text{Succinate} + FAD^+ \underset{\text{dehydrogenase}}{\overset{\text{Succinate}}{\rightleftharpoons}} \text{Fumarate} + FADH_2$$

(g) **Hydration :** This process changes fumarate into 4-carbon maltate in the presence of water and an enzyme, fumarase.

$$\text{Fumarate} + H_2O \overset{\text{Fumarase}}{\rightleftharpoons} \text{Maltate}$$

(h) **Dehydrogenation :** This process restores oxaloacetate by removing a pair of hydrogen atoms from maltate with the help of an enzyme **maltate dehydrogenase.** The pair of hydrogen atoms pass two electrons and one H^+ to NAD^+ , forming NADH+H^+.

$$\text{Maltate} + NAD^+ \underset{\text{dehydrogenase}}{\overset{\text{Maltate}}{\rightleftharpoons}} \text{Oxaloacetate} + NADH + H^+$$

Oxaloacetate combines with acetyl coenzyme A to form citrate, and so the cycle continues.

(vi) **Summary of Kreb's cycle**

(a) All the enzymes, reactants, intermediates and products of TCA cycle also are found in aqueous solution in the matrix, except the enzyme α-ketoglutarate dehydrogenase and succinate dehydrogenase which are located in the inner mitochondrial membrane. Both are called mitochondrial marker enzyme.

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

(c) Liberates 2 molecules of carbon dioxide.

(d) Gives off 4 pairs of hydrogen atoms.

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

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

(g) 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. The entire Krebs cycle may be represented by the following equation –

$$2\text{Acetylcoenzyme } A + 8H_2O + 6NAD^+ + 2FAD^+ + 2GDP/ADP + 2Pi$$

$$\rightarrow 4CO_2 + 2H_2O + 6\,NADH + 2FADH_2 + 2GTP/ATP + 6H^+$$

(vii) **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 oxidised 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.

(viii) **Product form during aerobic respiration by Glycolysis and Kreb's cycle.**

(a) **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) Phosphoenolpyruvic acid (2 moles) → Pyruvic acid (2 moles)	2 ATP 2 ATP	2 ATP 2 ATP
		Total	4 ATP
ATP formation by oxidative phosphorylation or ETC	1, 3 - disphosphoglyceraldehyde (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) Fructose 6 phosphate (1 mole) → Fructose 1, 6-diphosphate (1 mole)	– 1 ATP – 1 ATP	– 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) Isocitric acid (2 mols) → Oxalosuccinic acid (2 mols)	2 $NADH_2$ 2 $NADH_2$ 2 $NADH_2$	6 ATP 6 ATP 6 ATP

	α-Ketoglutaric acid (2 mols) → Succinyl CoA (2 mols)	2 $FADH_2$	4 ATP
	Succinic acid (2 mols) → Fumaric acid (2 mols)	2 $NADH_2$	6 ATP
	Malic acid (2 mols) → Oxaloacetic acid (2 mols)		
		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.

(b) **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)	**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) Cis aconitic acid (2 mols) $\xrightarrow{+H_2O}$ Isocitric acid (2 mols) Succinyl CoA (2 mols) $\xrightarrow{+H_2O}$ Succinic acid (2 mols) Fumaric acid (2 mols) $\xrightarrow{+H_2O}$ Malic acid (2 mols)	$2H_2O$ $2H_2O$ $2H_2O$ $2H_2O$
	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 – $10H_2O$)**	**$6H_2O$**

(c) **Evolution of carbon dioxide**

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

(d) **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	**$6O_2$**

(ix) **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.

(a) **Adenosine triphosphate** : An energy intermediate :

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 cells.

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

(a) A nitrogen contain purine base

(b) A five carbon sugar ribose

(c) Three inorganic phosphate groups

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.

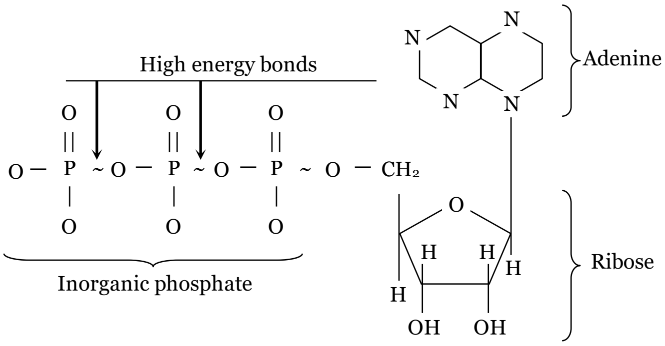


Fig : Structure of ATP

- **ATP hydrolysis :** The energy is usually released from ATP by hydrolysing the terminal phosphate groups. Each molecule on hydrolysis yields ADP, one inorganic phosphate group (Pi) and about 7.28 Kcal energy.

ADP further hydrolysed to AMP and inorganic phosphate, releasing 7.3 Kcal energy per molecule (of ATP). Above process represented by following reactions.

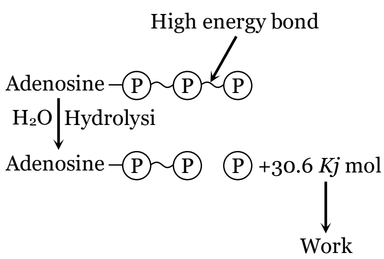


Fig : Hydrolysis of ATP

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

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

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

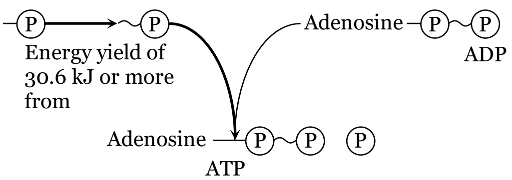


Fig : phosphorylation

The significant role of ATP as an intermediate energy transfer compound

- **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 :

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

(b) Translocation of organic food.

(c) Absorption of organic and inorganic food.

(d) Protoplasmic streaming.

(e) Growth.

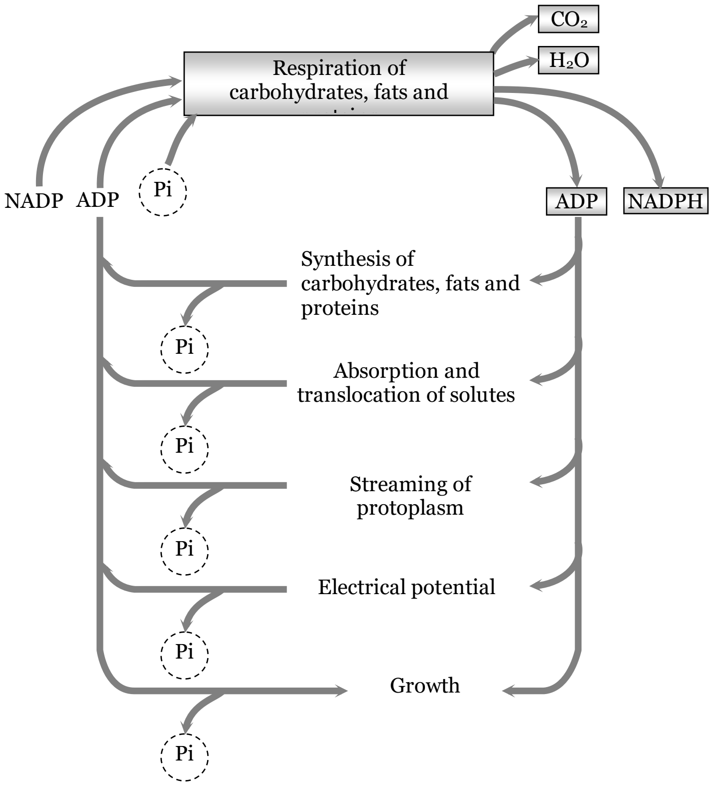


Fig : Schematic representation of the role of ATP

(b) **Nicotinamide dinucleotide phosphate/ Nicotinamide 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.

Structure of NAD = Nicotinamide-adenine-dinucleotide (formerly called coenzyme I or CO-I Diphosphopyridine dinucleotide = DPN) is shown below :

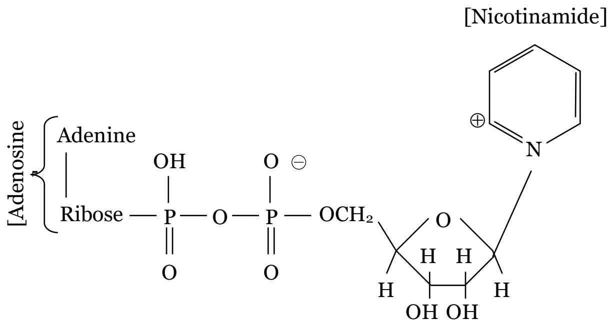


Fig : Reduced NAD

It 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.

Important Tips

- 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.
- Number of oxidation steps(dehydrogenation) for pyruvic acid is 5.
- In Kreb's cycle, acetyl CoA undergoes **two** decarboxylation and **four** dehydrogenation. Krebs cycle catabolises about 80-90% of glucose.
- ATP discovered by Lohmann (1929), term was coined by Lohmann (1931) while ATP cycle was discovered by Lipmann (1941).
- Allosteric inhibition or negative feedback by accumulation of $NADH_2$.
- Production of 36 ATP molecules from the oxidation of glucose is only an estimate as :

(i) $NADH_2$ may be used in some other metabolic pathway.

(ii) $NADH_2$ do not always produces 3 ATP molecules. More active muscle cells produces more while less active fat cell produce less ATP molecules.

(iii) Not all the proteins are routed through F_0 –F_1 channel.

(iv) So **realistic aerobic respiratory efficiency** ranges between **22% to 38%,** as realistic power limit is **21 ATP molecule.**

(3) **Electron transport system :** The electron transmitter system is also called electron transport chain (ETC), or cytochrome system (CS), as four out of these seven 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, $\alpha-$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 seven electron carriers (coenzyme) in the inner membrane of the mitochondrion, including the folds or cristae of this membrane. These seven 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, Cytochrome-a and Cytochrome-a_3,

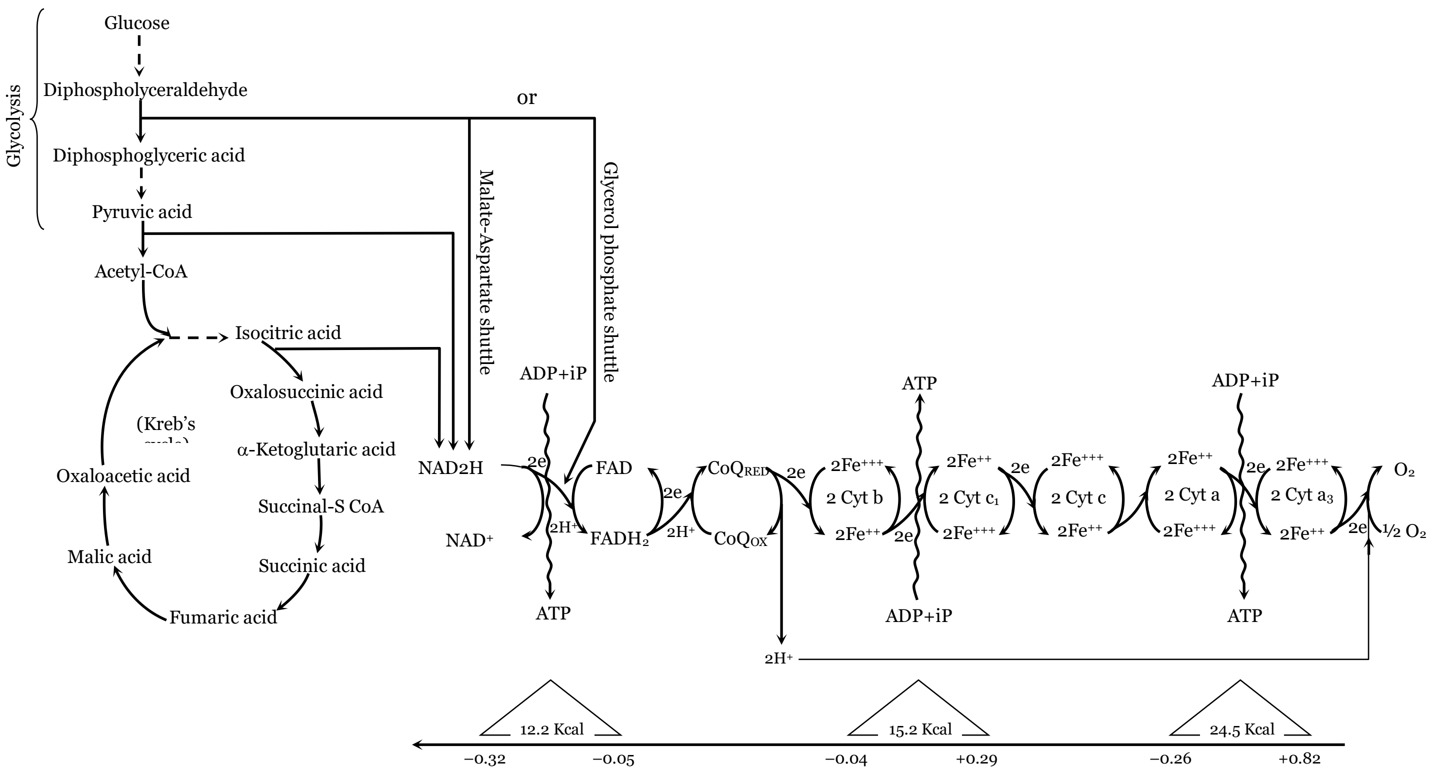


Fig : Electron Transport Chain (ETC) : Schematic representation of the electrons carrier group arranged in order of its edition-reduction potential and transport of electrons and hydrogen and synthesis of ATP. (On the left are shown origins of electrons and hydrogen)

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-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.**

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

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 crista. This process of ATP synthesis during oxidation of coenzyme is called **oxidative phosphorylation,** so ETS is also called **oxidative phosphorylation pathways.**

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

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* 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 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.

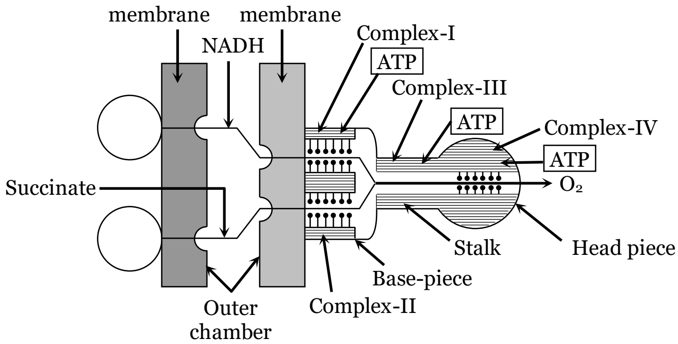


Fig. Four complexes of Oxysome

(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 syntheses 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.

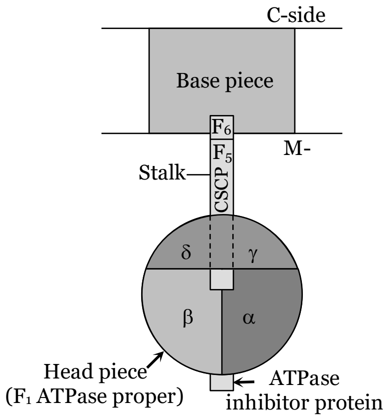


Fig. Five complexes of

(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

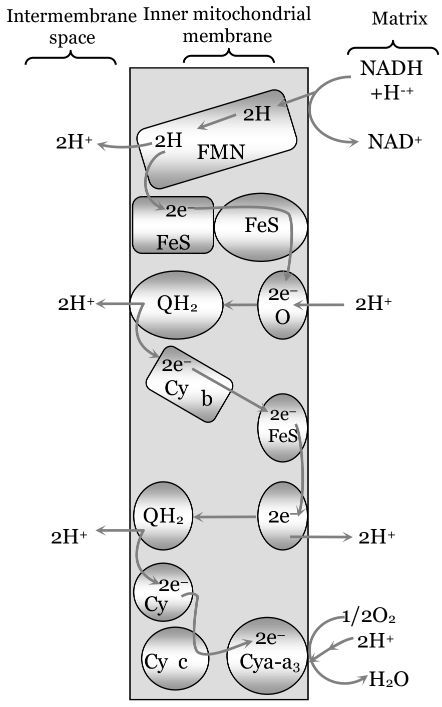


Fig : Proton

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.

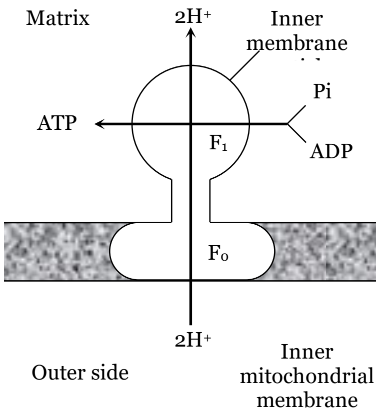


Fig : ATP synthesis by inner membrane particles of

Important Tips

- Cytochromes were discovered by **MacCunn** and term cytochrome given by **K.P.Kailin.**
- 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.
- **Cytochrome P-450 :** It occurs in E R and takes part in hydroxylation reaction.
- **ETC inhibitors**

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

(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 :** It is more efficient and results in the transfer of electron from NAD. 2*H* in cytosol to NAD inside the mitochondrion, via NAD. 2*H* dehydrogenase as follows :

Electrons are transferred from NAD. 2*H* in cytosol to malate which traverses the inner mitochondrial membrane and reoxidised to form NAD. 2*H* thus resulting in the formation of oxaloacetate . Oxaloacetate does not readily cross the inner mitochondrial membrane and so a transamination reaction is needed to form aspartate which does traverse this barrier. As a result 3 ATP molecules are generated for each pair of electrons. Thus if this shuttle is predominant there is a gain of **38 ATP** molecules by complete oxidation of one molecule of glucose.

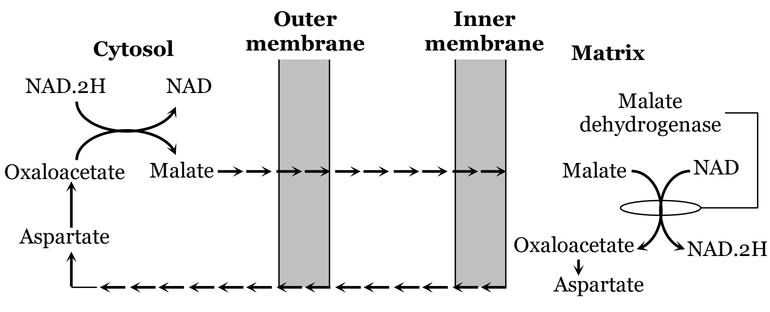


Fig : Malate-Aspartate shuttle

(b) **Glycerol-Phosphate shuttle :** It is less efficient and results in the reduction of FAD inside the mitochondrion.

If this shuttle predominates the electrons from NAD. 2*H* are transferred to FAD inside the mitochondrion as follows. NAD. 2*H* reacts with dihydroxyacetone phosphate (DHAP) in cytosol to form glycerol phosphate which diffuses through outer mitochondrial membrane to the outer surface of inner membrane. There glycerol phosphate reacts with membrane dehydrogenase to form dihydroxyacetone phosphate (DHAP) which returns to cytosol. In this process FAD is reduced to $FADH_2$. Electrons from $FADH_2$ directly pass to Q and other components of ETC and results in the synthesis of 2 ATP for each molecule of $FADH_2$. In this case complete oxidation of glucose will result in a gain of **36 ATP** molecule.

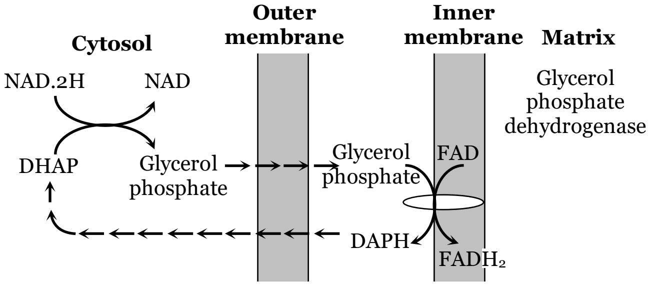


Fig : Glycerol-Phosphate shuttle

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 $NADH_2$.

6.5 Other pathways of glucose oxidation

(1) **Entner-Doudoroff pathway**

(i) **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.

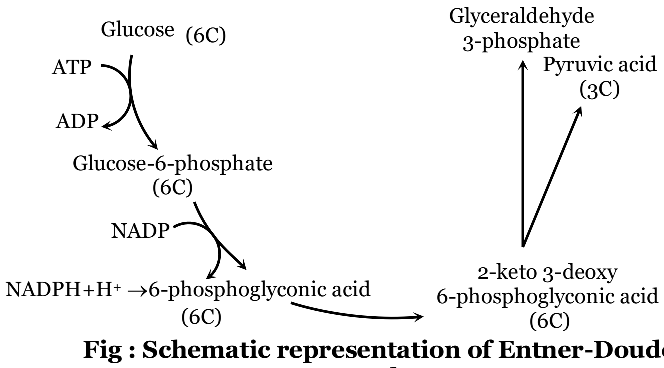


Fig : Schematic representation of Entner-Doudoroff

(ii) **Description :** In this pathway the glucose molecule first phosphorylated to Glucose-6-phosphate by ATP. Then it oxidised to 6-phosphogluconic acid by NADP which itself reduced to

$NADPH_2$ by the electrons released. The $NADPH_2$ is channeled through ETS system to produce 3-molecules of ATP per $NADPH_2$ molecule through ETS system to produce 3 molecules of ATP per $NADH_2$ molecule and 1,6-phosphogluconic acid is channeled to pyruvic acid. The main reaction are :

(a) $\text{Glucose - 6 - phosphate} + \text{NADP} \rightarrow \text{6 - Phosphoglu conolacton e} + \text{NADPH}_2$

(b) 6-phosphoglyconolactone $\rightarrow$ 2-Keto-3-deoxyphospho-6-gluconic acid

(c) 2-Keto-3-deoxyphosphogluconic acid $\rightarrow$ Pyruvic acid + Glyceraldehyde-3-phosphate

(d) Glyceraldehyde-3-phosphate $\rightarrow$ Pyruvic acid

The glyceraldehyde 3-phosphate by EMP pathway gets converted into pyruvic acid which can be further used up in the process.

(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 as **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.

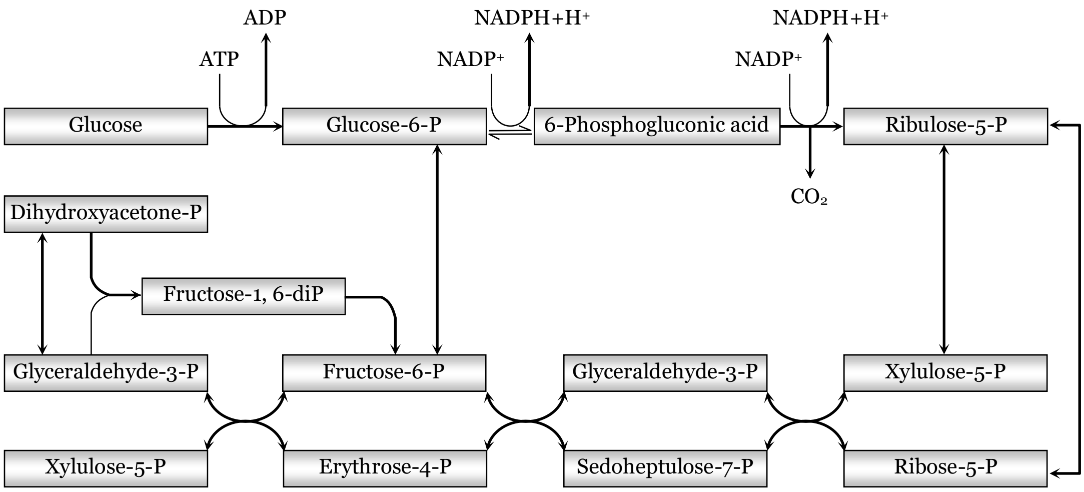


Fig : Hexose monophosphate shunt

(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.

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

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

The reaction can be summarised as follows :

- $6\ \text{Glucose} + 6\ \text{ATP} \xrightarrow{\text{hexokinase}} 6\ \text{Glucose - 6 - phosphate}$
- $6\ \text{Glucose - 6 - phosphate} + 6\ \text{NADP} + 6H_2O \xrightarrow{\text{dehydrogenase}} 6\ \text{phosphogluconic acid} + 6NADPH_2$
- $6\ \text{Phosphogluconic acid} + 6\text{NADP} \xrightarrow[\text{dehydrogenase}]{\text{oxidative decarboxylation}} 6\ \text{ribulose - 5 - phosphate} + 6\ CO_2 + 6NADPH_2$
- $2\ \text{Ribulose - 5 - phosphate} \xrightarrow{\text{isomerase}} 2\ \text{ribose - 5 - phosphate}$
- $5\ \text{Ribulose - 5 - phosphate} \xrightarrow{\text{isomerase}} 4\ \text{xylulose - 5 - phosphate}$
- $2\ \text{Xylulose - 5 - phosphate} + 2\ \text{ribose - 5 - phosphate}$

  $\xrightarrow{\text{transketolase}} 2\ \text{sedoheptulose} - 7\text{phosphate} + 2\ \text{glyceraldehyde - 3 - phosphate}$
- $2\ \text{Sedoheptulose - 7 - phosphate} + 2\ \text{glyceraldehyde 3 - phosphate}$

  $\xrightarrow{\text{transketolase}} 2\ \text{fructose - 6 - phosphate} + 2\ \text{erythrose - 4 - phosphate}$
- $2\ \text{Erythrose - 4 - phosphate} + 2\ \text{xylulose - 5 - phosphate}$

  $\xrightarrow{\text{transketolase}} 2\ \text{fructose - 6 - phosphate} + 2\ \text{glyceraldehyde 3 - phosphate}$
- $2\ \text{Glyceraldehyde - 3 - phosphate} + H_2O \xrightarrow{\text{aldolase}} \text{fructose - 6 - phosphate} + H_3PO_4$

Sum total of the reaction :

6 Glucose-phosphate + 12 $NADP$+7H_2O $\longrightarrow$ 5 Fructose-6-phosphate+6 CO_2 + 12$NADPH_2$ +H_2PO_4

(iv) **Significance of PPP**

- 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).
- 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.
- It is the major pathway by which necessary ribose and deoxyribose are supplied in the biosynthesis of nucleotides and nucleic acid.
- Erythrose 4 phosphate for the synthesis of lignin, oxine, anthocyanine and aromatic amino acid (phenylalanine, tyrosine, and tryptophan).

- 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.
- It gives 6 CO_2, required for photosynthesis.
- Ribulose five phosphate is used in photosynthesis to produce RuBP which act as primary CO_2 acceptor in C_3 cycle.

(3) **Comparison of the different pathway of glucose metabolism**

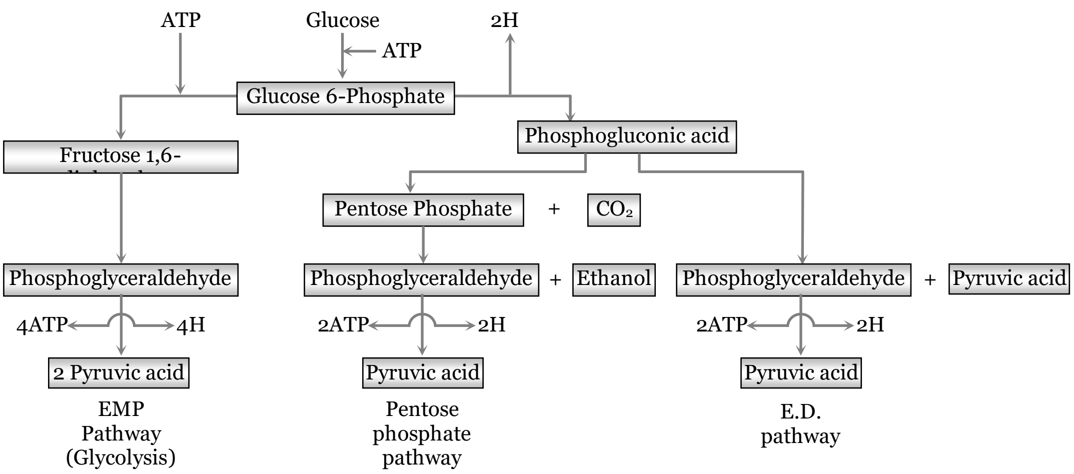
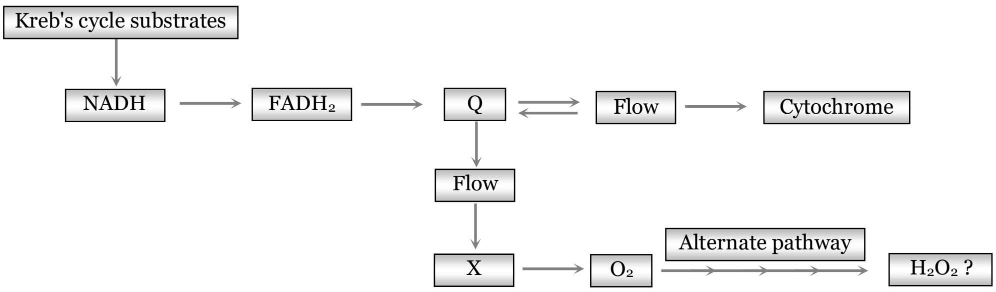


Fig : A comparison of the different pathways of glucose

(4) **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

(a) 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.



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

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

6.6 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.

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.

(1) **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

(i) **Formation of ethyl alcohol** : When oxygen is not available, yeast and some other microbes convert pyruvic acid into ethyl alcohol. This is two step process as explained below

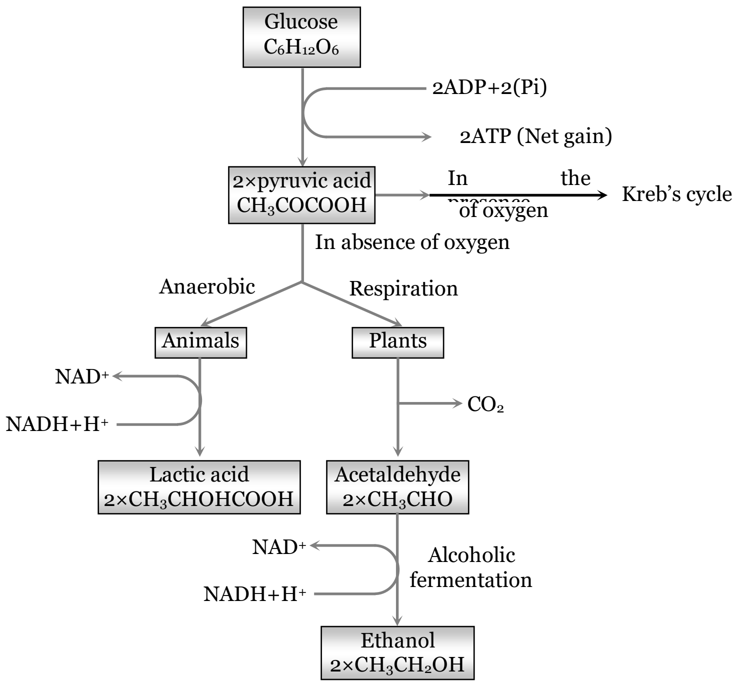


Fig : Summary of anaerobic respiration

(a) In the first step pyruvic acid is decarboxylated to yield acetaldehyde and CO_2. In the presence of Mg^{++} and *TPP* (Thiamine pyrophosphate) pyruvate carboxylase.

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

(b) In the second step acetaldehyde is reduced to ethyl alcohol by $NADH_2$ formed in the glycolysis.

$$\underset{\text{(Acetaldehyde)}}{CH_3CHO} + NADH_2 \xrightarrow[\text{dehydrogenase}]{\text{Alcoholic}} \underset{\text{(Ethyl alcohol)}}{C_2H_5OH} + NAD$$

(ii) **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.

$$\underset{\text{(Pyruvic acid)}}{CH_3COCOOH} \rightarrow \underset{\text{(Lactic acid)}}{CH_3CHOH.COOH} + NAD$$

Lactic acid is produced in the muscle cells of human beings and other animals. During strenuous physical activity such as running, the amount of oxygen delivered to the muscle cells may be insufficient to keep pace with that of cellular respiration. Under such circumstances lactic acid is formed which accumulates in the muscle cells and causes muscle fatigue.

(2) **Pasteur effect :** Two types of respiration –anaerobic and aerobic respiration produce carbon dioxide in the ratio of 1:3 as shown in the equation.

Anaerobic Respiration : $\underset{\text{(Two molecules of } CO_2 \text{ are produced)}}{C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2}$

Aerobic Respiration : $\underset{\text{(Six molecules of } CO_2 \text{ are produced)}}{C_6H_{12}O_4 + 6O_2 \rightarrow 6H_2O + 6CO_2}$

Pasteur noted that when oxygen is given to the running anaerobic respiration the output of CO_2 is not similar to aerobic respiration, i.e. during aerobic respiration the ratio 1:3 does not always appear to be true. In several cases the amount of carbon dioxide is much less in comparison to normal aerobic respiration as shown above. For such cases it is considered that the presence of oxygen may sometimes lower down the rate of breakdown of sugar. The phenomenon is named as 'Pasteur's effects' after the name of great scientist and 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."

Pasteur's effect is said to occur due to many reasons. Some of them are :

(i) Pasteur reaction inhibits some glycolytic enzyme and stops glycolysis.

(ii) Formation of excess of CO_2 from degradation of compounds other than respiratory substrate.

(iii) Increased glycolysis with decreased oxygen tension.

(iv) Occurrence of partial oxidative glycolytic products and oxidative anabolism (resynthesis, a process corresponding HMP pathway).

(3) **Connection between aerobic and anaerobic respiration**

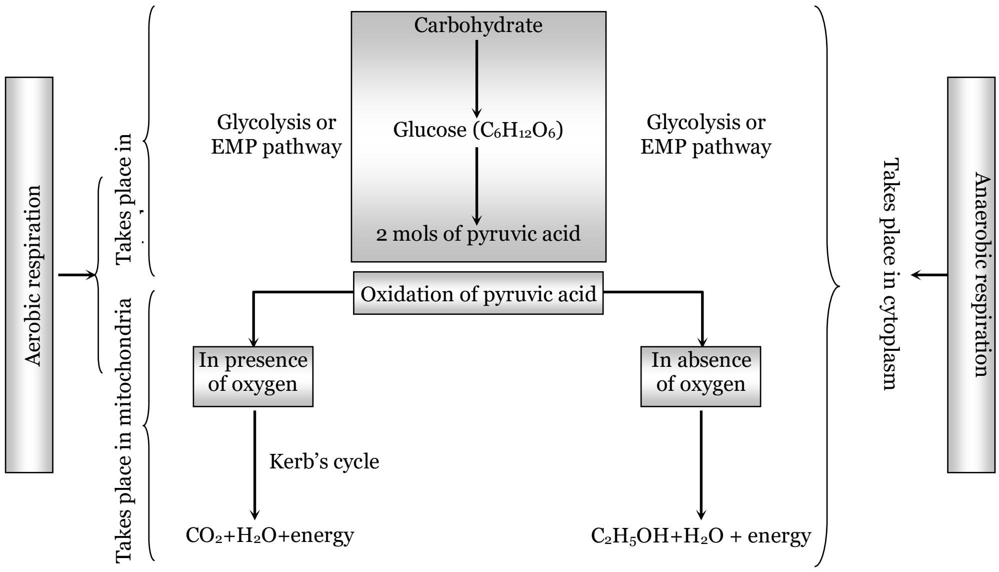


Fig : Pyruvic acid as a intermediate of aerobic and anaerobic

The glycolysis is the common phase and its products pyruvic acid is the common intermediate of the aerobic and anaerobic respiration.

(4) **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.

Gay Lussac was the first to provide following reaction for the fermentation of sugar.

$$C_6H_{12}O_6 = 2CO_2 + 2CH_3CH_2OH + 52\ Kcal$$

Louis Pasteur (1822-1895) supported Gay Lussacs reaction and concluded that fermentation occurred and concluded that fermentation occurred only when living Yeast cells were present. **Buchner** (1897) found that yeast extract could perform fermentation of sugary solution. The enzyme complex present in yeast which could perform fermentation was named as zymase. Because of the latter, fermentation is also called zymosis. Besides zymase yeast cells also contain enzymes like sucrose and maltose which can ferment sucrose and maltose respectively. Direct fermentation of starch by yeast is not possible as it lacks amylase enzyme.

The fermentation is of two types : Homofermentive (one product) and **heterofermentive** (two or more than two types of products). Alcoholic fermentation may occur in almost, any moist sugar containing medium or sugar solution, such as fruit juice, which is inoculated with yeast or which is left exposed to air. The examples of fermentation :

(i) **Butyric acid fermentation :** It occurs in butter which has turned rancid. Bacteria like *Clostridium butyricus* and *Bacillus butyricus* are responsible for fermenting sugars and lactic acid into butyric acid to the following equation :

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

$$\underset{\text{(lacticacid)}}{2C_3H_6O_3} \rightarrow \underset{\text{(butyricacid)}}{C_4H_8O_2} + 2H_2 + 2CO_2$$

(ii) **Lactic acid fermentation :** In this process the lactose sugar, present in the milk, is converted into lactic acid which provides a distinctive sour taste to the milk. Two bacteria viz., *Bacterium lactic acidi and B.acidi lactici* take part in this process.

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

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

(iii) **Acetic acid fermentation :** It is different from other types of fermentation as it utilises atmospheric oxygen. Acetic acid fermentation is catalysed by *Acetabacter aceti,* and *A. xylinum* which oxidised ethyl alcohol into acetic acid.

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

(iv) **Importance of fermentation :** Anaerobic respiration is advantageous in many ways :

(a) It supplement, the energy provided by aerobic respiration during intense muscular activity.

(b) Brewing industry produces beers and wines by fermentation of sugary solution with yeast (*saccharomyces cerevisiae*).

(c) Baking industry uses CO_2 released by Yeast cells in alcoholic fermentation in raising the dough and making bread spongy.

(d) Dairy industry produces yogurt, cheese and butter by fermenting milk sugar lactose to lactic acid with lactic acid bacteria (*Streptococcus lactis*). Lactic acid coagulates the milk protein casein and fuses droplets of milk fat.

(e) Tea and tobacco leaves are cured (freed of bitterness and imparted pleasant flavours) by fermentation with certain bacteria.

(f) Vinegar is produced by fermenting molasses with yeast to ethyl alcohol which is then oxidised to acetic acid with aerobic acetic acid bacteria (*Acetobacter aceti*).

(g) Bacterial fermentation is also used for tanning hides (removal of fat, hair and other tissues).

(h) Retting of hemp fibers is achieved by fermentation with *Pseudomonas fluroscense.*

(i) Ensilase, a nutritive fodder for cattle, is prepared by fermentation with bacteria in air-tight-chambers called silos.

(5) **Efficiency of respiration**

(i) **Efficiency of aerobic respiration :** We used the generally accepted amount of 12,000-14,000 calories per mole of ATP approximately 456,000-532,000 calories are generated from one mole of glucose. One mole of glucose contains about 686,000 calories(686 *Kcal*) of energy in the form of bonds. When one molecule of glucose is oxidised to carbon dioxide and water 673,000 calories of energy released.

However the actual amount of energy available from each ATP (rest of energy is lost as heat, and so on) is approximately 7,3000 calories (7.28 *Kcal*) or–34 *kJ*.

Therefore, actual energy yield from one mole of glucose is :

$$= 38 \times 7.3 = 277.4\ Kcal$$

So the percent of aerobic respiration = $\frac{277.4}{686} \times 100$

= 40.43%

Thus, efficiency of aerobic respiration = 40% approx.

Out of 686 Kcal. of one mole glucose, only 277.4 Kcal. is trapped in the form of ATP.

(ii) **Efficiency of anaerobic respiration :** In anaerobic respiration of carbohydrate by glycolysis apparently 2ATP molecules are formed per glucose molecule. Therefore, efficiency of anaerobic respiration will be :

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 52\ Kcal.$$

Percent of anaerobic respiration = $\frac{2 \times 7.3}{52} \times 100 = 28.07\%$

(iii) **Efficiency of alcoholic fermentation :** By Yeast only two molecules of ATP are generated per glucose molecule and efficiency will be, therefore,

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 56\ Kcal.$$

Percent of fermentation = $\frac{2 \times 7.3}{56} \times 100 = 26.07\%$

(6) **Difference between respiration and fermentation**

Respiration	**Fermentation**
It may occur both in the presence and absence of oxygen.	It does not require oxygen.
Occurs only in living cells.	It does not occur with in the living cells. It requires only enzymes and substrate.
Sugar is oxidised and CO_2 and H_2O are formed as end products.	Different substances oxidise to form alcohol or organic acids.
Complete oxidation of substrate occurs, hence produces large amount of energy.	Incomplete oxidation of substrate occurs and hence less energy is produced.
It can occur in any living cell.	It occurs mainly with the help of yeast or bacterial cells.

Many microbiologists have distinguished Aerobic respiration, Anaerobic respiration and Fermentation from one another principally by the means through which hydrogen is removed from various substrates (the hydrogen donor) and by nature of ultimate substrate accepting this hydrogen (the hydrogen acceptor).

Aerobic Respiration	**Anaerobic Respiration**	**Fermentation**
Molecular oxygen is the ultimate electron acceptor for biological oxidation. The ETS serves to transfer electrons from oxidisable donor to molecular oxygen. The early	The ultimate electron acceptor is an inorganic compound other than oxygen. The compounds accepting the hydrogen (electrons) are nitrates, sulphates, carbonates or CO_2.	The final electron acceptors are organic compounds. Both electron donors (oxidizable substrate) and electron acceptors (oxidizing agent) are organic compounds and

enzymatic steps involve dehydrogenation whereas the final steps are mediated by a group of enzyme called cytochromes. Ultimately the electrons are transferred to oxygen which is reduced to water. During aerobic respiration ATP is generated by coupled reaction	Anaerobic respiration produces ATP through phosphorylation reaction involving electron transfer systems. (mechanism not known)	usually both substrates arise from same organic molecules during metabolism. Thus part of the nutrient molecule is oxidised and part reduced and the metabolism results in intramolecular electron rearrangement. ATP is generated by substrate level phosphorylation. This reaction differs from oxidative phosphorylation because oxygen itself is not required for ATP generation.

6.7 Fat, Protein and Salt respiration

(1) **Fat respiration :** Fats are stored as triglycerides in cells, (in animal-adipose tissues and in plants-seeds). They break up into fatty acids and glycerol in the cytoplasm before use in respiration. Glycerol converted into Dihydroxy acetonephosphate and enters into glycolysis. The conversion of fatty acid into carbohydrate is called β oxidation. It convert in acetate units of acetyl CoA to glyoxylate and malate (malic acid) takes place in microbodies, termed glyoxysomes. The glyoxysomes are contain all the necessary enzymes for β oxidation of fatty acid to acetyl CoA and subsequent conversion of the acetate units to malic acid (malate) and succinic acid (succinate), the cycle is known as Glyoxylate cycle.

(i) **Energy output :** A molecule of 18-carbon stearic acid on complete oxidation produces 147 high-energy phosphates. A 6-carbon glucose molecule yields 36 or 38 ATP. With this rate, an 18-carbon molecule is expected to give 3 times more energy (36 or 38×3=108 or 114 ATP) but it provides about 4 times more energy (36 or 38 ×4=144 or 152 ATP) than 6-carbon glucose produces.

(ii) **Glyoxylate cycle**

(a) **Discovery : Kornberg** and **Krebs** discovered first this cycle in the bacterium *Pseudomonas.* Later, the reaction of β-oxidation of fatty acids and its conversion of acetyl CoA to glyoxylate and malate occurs in glyoxysomes given by **Beevers.**

(b) **Occurrence :** It occurs in seed rich in fats convert stored fats to carbohydrates during germination. The cycle does not appears to be present in those seeds that store starch rather than fat. Glyoxylate activity in germination seeds ceases as soon as the fat reserves have been used up. The fact that plants convert fatty acid to carbohydrates is due to operation of two unique glyoxysome enzyme not known to be present in animals : isocitrate lyase and malate synthetase.

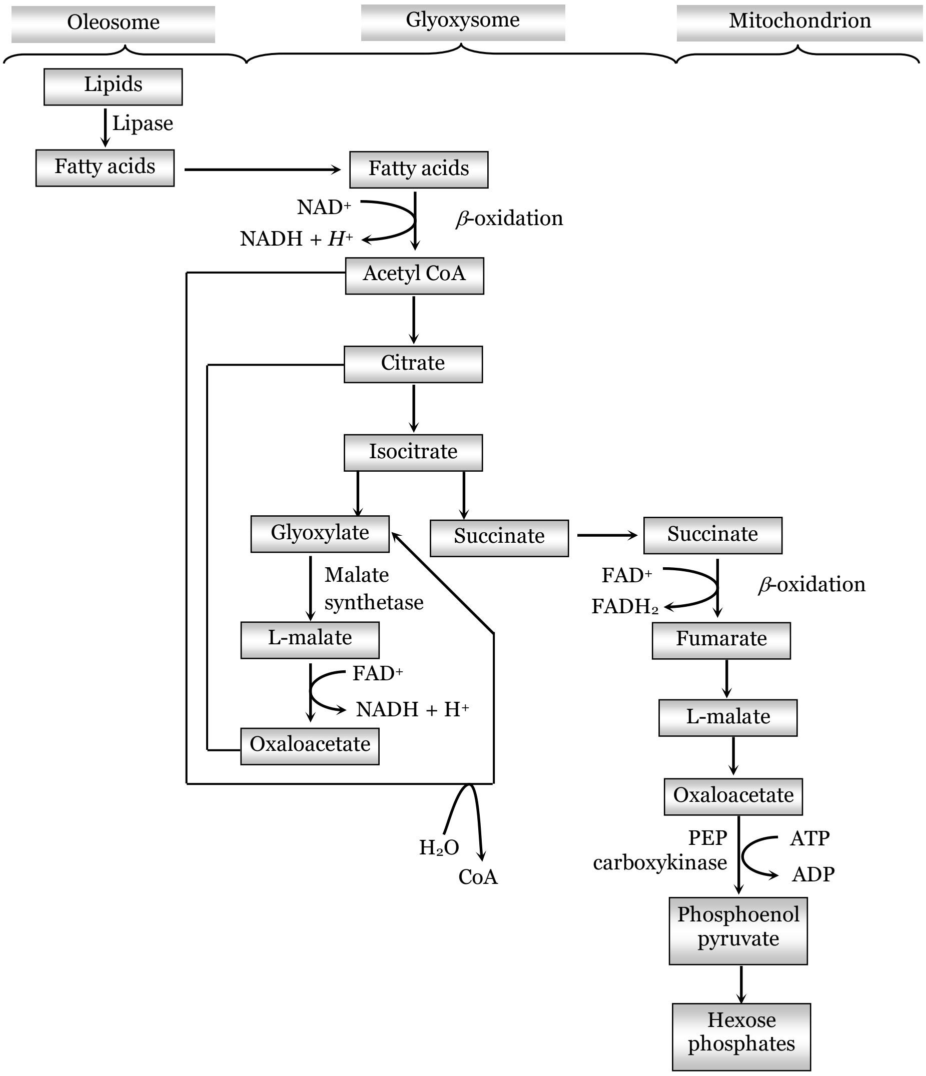


Fig : Conversion of storage fat to carbohydrates in germinating seed *via* glyoxylate cycle.

(c) **Description :** The cycle starts with fatty acids are derived from lipase-mediated enzymolysis of triglycerides occurring in lipid bodies called oleosomes. The fatty acids undergo β oxidation in the glyoxysome with the formation of acetyl CoA.

The acetyl CoA reacts with oxaloacetate to form citrate and then isocitrate. The isocitrate is cleaved to succinate and glycoxylate. This reaction is catalyzed by isocitrate lyase. The glyoxylate combines with acetyl CoA to form malate, the reaction being catalyzed by malate synthetase. The malate in the glyoxysome is oxidized to oxaloacetate, which initiates the cycle again by combining with acetyl CoA derived from β oxidation of fatty acids. The succinate produced moves out of the glyoxysome and into the mitochondrion, where it is converted through the conventional Krebs cycle reactions to oxaloacetate.

The increase of oxaloacetate (OAA) provides ample substrate for amino acid production and carbohydrate formation by reverse glycolysis. Conversion of OAA to phosphoenolpyruvic acid and other glycolytic intermediates takes place in the cytoplasm.

(2) **Protein respiration :** The proteins split into amino acids in the cytoplasm for use in respiration. The amino acids enter respiratory routes in two ways : Deamination and Transamination.

(i) **Deamination :** In deamination, an amino acid loses its amino group (-NH_2) and changes into a keto acid. The latter may further change into a pyruvic acid or acetyl coenzyme A. Pyruvic acid is oxidised to acetyl coenzyme A. The latter enters the Krebs cycle.

(ii) **Transamination :** In transamination, an amino group of an amino acid is transferred to an appropriate keto acid, forming a new amino acid and a new keto acid. The keto acids so formed are normal participants of glycolysis or Krebs cycle. Of the all amino acids of plant cell only glutamic acid is believed to be oxidised directly by the enzyme, glutamic acid dehydrogenase into α-ketoglutaric acid and ammonia in the presence of *NAD*. α-ketoglutaric acid enters the Kreb's cycle to undergo cyclic degration and oxidation.

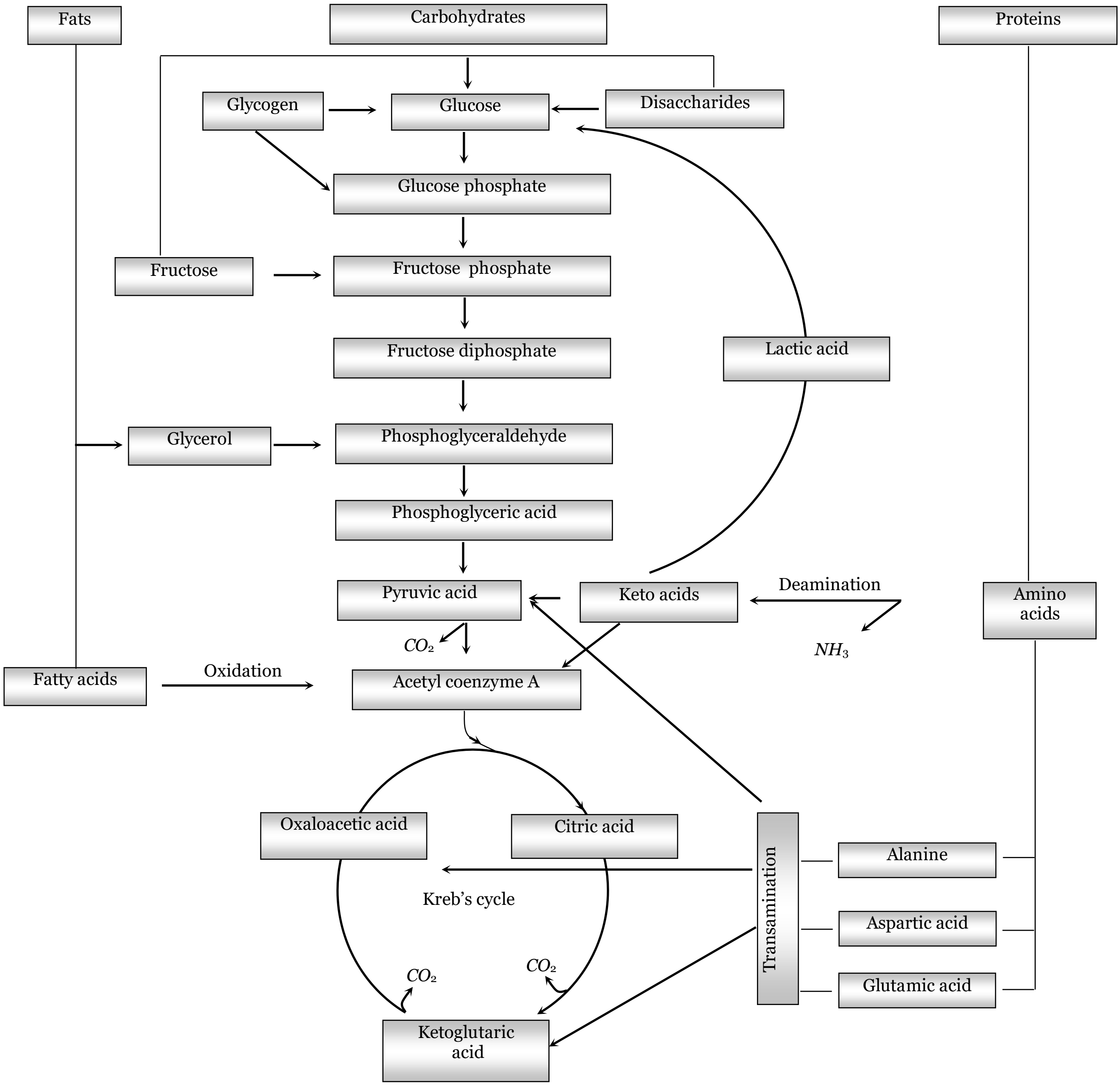


Fig. Summary of cell respiration showing metabolic pathways in the use of carbohydrates, fats and proteins in cell respiration

(3) **Salt respiration :** This respiration is discovered by **Lundegarth** and **Burstram** monovalent chlorides of *Na*, *K* and divalant chlorides of *Li*, *Ca* and *Mg* are responsible for salt respiration. 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.

When a fresh water plant transferred to the salty water the rate of respiration increase due to salt respiration. The cause of increase in the rate of respiration during absorption of minerals by roots is also salt respiration.

6.8 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

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

Value of R.Q. varies with substrate. Thus the measurement of R.Q. gives some idea of the nature of substrate being respired in a particular tissue.

When carbohydrates are completely oxidised the value of R.Q. is unity (=one). If fats and proteins are the substrate the value of R.Q. is less than unity (0.5 to 0.9) and when organic acids are substrate the value is more than unity (1.3 to 4.0).

In succulent like *Opuntia*, *Bryophyllum* where there is incomplete oxidation of carbohydrates no CO_2 is produced, hence the value of R.Q. is zero.

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

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

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

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

(i) $\underset{\text{Stearic acid}}{C_{18}H_{36}O_2}+26\,O_2\rightarrow 18\,CO_2+18\,H_2O\ ;\ \frac{CO_2}{O_2}=\frac{18}{26}=0.7$ (Less than unity)

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

Organic acid	R.Q.
Succinic acid	1.14
Taurtric acid	1.6
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)

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2 \; ; \; \frac{CO_2}{O_2} = \frac{2}{0} = \infty \text{ (Infinite)}$$

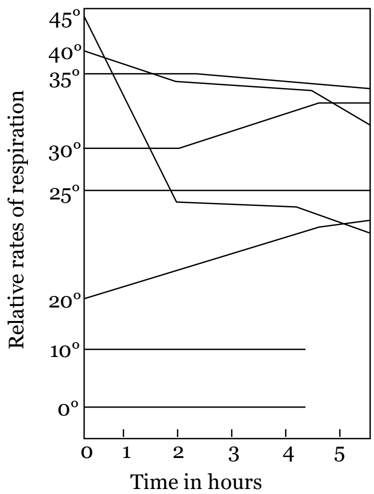


Fig : Interrelationship between respiratory rates of germinating pea seeds, temperature and time

6.9 Factors affecting rate of respiration

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

(1) **External factors**

(i) **Temperature :** Temperature is the most important factor for respiration. Most of the plants respire normally between 0^oC to 30^oC. With every 10^0C rise of temperature from 0^oC to 30^oC the rate of respiration increases 2 to 2.5 times (*i.e.*, temperature coefficient (Q_{10}^o) is = 2 to 2.5), following Vant Hoff's Law. Maximum rate of respiration takes place at 30^oC, 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^oC the rate of respiration is greatly reduced although in some plants respiration takes place even at -20^oC. Dormant seeds kept at -50^oC survive.

(ii) **Supply of oxidisable food :** Increase in soluble food content readily available for utilization as respiratory substrate,

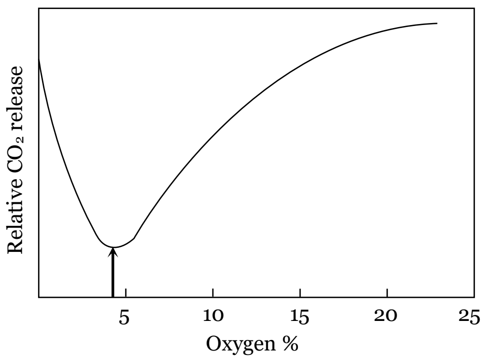


Fig : Effect of oxygen concentration on the rate of respiration. On the right of arrow – Rate of respiration increases with increases in oxygen concentration. On the left of arrow -Rate of anaerobic respiration increases again with decrease in oxygen concentration and ethyl alcohol produced and CO_2 is released

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 :** Respiration is aerobic or anaerobic depending upon the presence or absence of oxygen. Air has 20.8% oxygen which is more than enough keeping in view the requirements of plants. Due to this if 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.

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.

(iv) **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. The life of seeds decreases with increase of water. This increase is slow at first but very rapid later. This is very clearly seen in the tissues of many xerophytes. As the water contents of such plants is increased, often there is no great immediate effect upon the rate of respiration. Minor variation in water content of well-hydrated plant cell do not appear to have very great influence upon the rate of respiration.

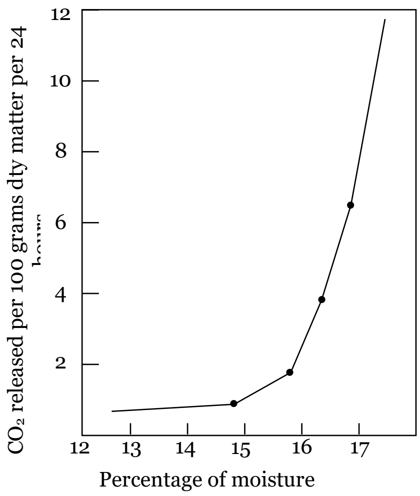


Fig : Effect of moisture on the rate of respiration of germinating wheat

Figure shows that in wheat grains rate of respiration increases with increase of water to 16-17%. The rate of respiration of seeds increase with increase of water because water causes hydrolysis, and activity of respiratory enzymes is increased. Also oxygen enters the seed through the medium of water.

(v) **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.

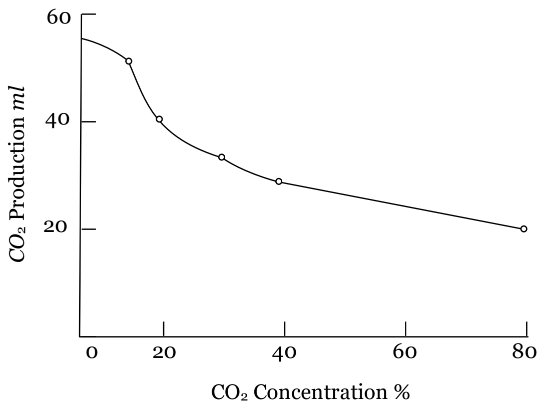


Fig : Effect of CO_2 concentration on the rate of respiration of germinating mustard seeds

In case of blue green algae (*Anabaena*) respiration rate was found to depend upon light and the effect was also influenced by O_2-concentration.

(vi) **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 cone. of CO_2, due to which oxygen does not penetrate the leaf and rate of respiration is lowered.

This fact is made use of in storage of fruits. Air containing 10% CO_2 (in atmosphere it is only 0.03%) retards respiratory break down and therefore reduces sugar consumption and thus prolongs the life of the fruit.

(vii) **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.

(viii) **Injury and effects of mechanical stimulation :** Wounding or injury almost invariably results in an increase in the rate of respiration . Whenever a plant tissue is wounded the sugar content of the wounded portion is suddenly increased. This increase in the sugar content is responsible for the observed temporary increase in the respiration rate.

A purely mechanical stimulation of respiration has been demonstrated in leaves of a number of species by Audus (1939,40,46). A gentle rubbing, touching, handling and bending of the leaf blade was sufficient to induce a marked rise in the respiration rate (20 to 183%) which persisted for several days. If the treatment was repeated at intervals, the stimulus gradually lost its effect in increasing the rate of respiration.

(ix) **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. Ripening fruits produce ethylene and this is accompanied by an increase in respiration rate. Other volatile products responsible for the flavour (aroma) e.g., methyl, ethyl, amyl, esters of formic, acetic, caproic and caprylic acid also associated with increased respiration rate, reach a maximum during ripening of fruits.

(x) **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 rate of respiration depends on quality and quantity of 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 of in the amount of respiratory substrate, the rate of respiration increases.

6.10 Experiments of respiration

(1) **Demonstration of aerobic respiration in plant tissues :** Experimentally, aerobic respiration is proved by respiroscope. As a result of this experiment water column arises (also mercury) due to absorption of evolved CO_2 in respiration by *KOH*.

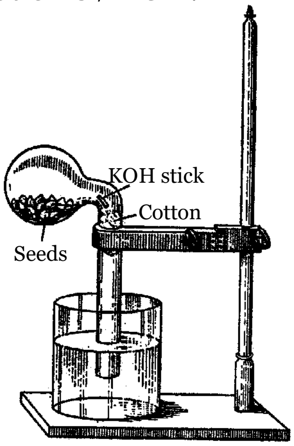


Fig : Respiroscope for demonstration of aerobic respiration in

(2) **Demonstration of anaerobic respiration :** In this experiment anaerobic condition created by filling the test tube with mercury. After completion of experiment the level of mercury goes down, because CO_2 evolved by the respiration push the mercury level down. When *KOH* is introduced mercury level will again rise up to top.

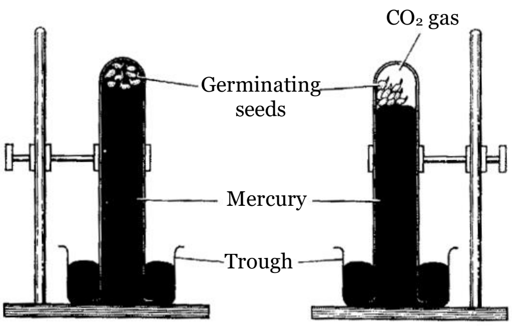


Fig : Demonstration of the evolution of CO_2 in anaerobic respiration

(3) **To prove that CO_2 is evolved in aerobic respiration :** In following apparatus, when suction pump is started it pulls air through absorbed by *KOH* of U-tube. CO_2 of air free of CO_2 enters bottles C. If the calcium hydroxide water does not turns milky it

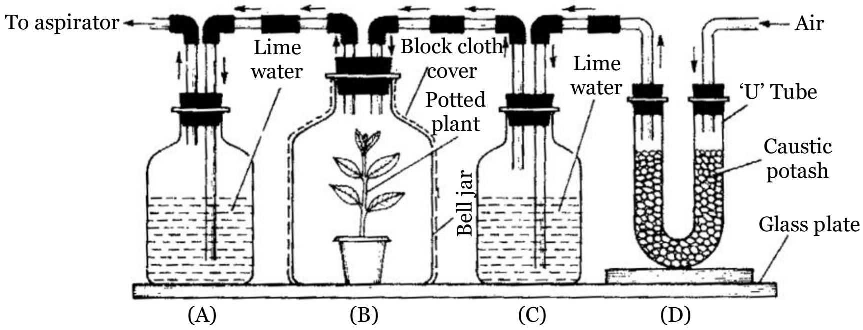


Fig : Apparatus to demonstrate that CO_2 is evolved in aerobic respiration

is an indication that all CO_2 has been absorbed by *KOH*. The results shows that lime water in bottle A turns milky proved that liberation of CO_2 takes place in aerobic respiration

(4) **Demonstration of liberation of heat energy during respiration :** In this experiment bottle A filled with boiled seed and bottle B filled with germinating seed. After 24 hours temperature of both thermometer noted. Observation shows rise in temperature in bottle B because these seeds are respiring.

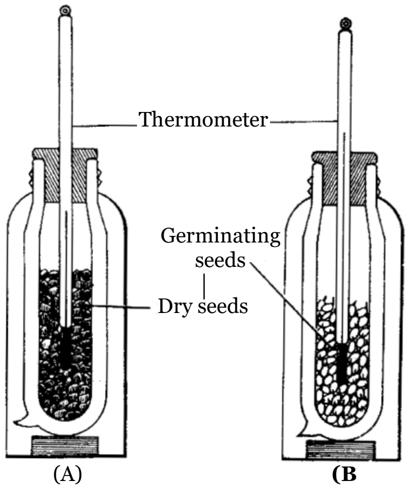


Fig : Demonstration of evolution of heat in respiration (A) Dry seeds

(5) **Measurement of rate of respiration by Ganong's respirometer :** The apparatus consists of three parts :

(i) A bulb for the respiring material, with stopper.

(ii) A graduated manometer tube.

(iii) A levelling or reservoir tube connected with manometer tube by a stout rubber tubing.

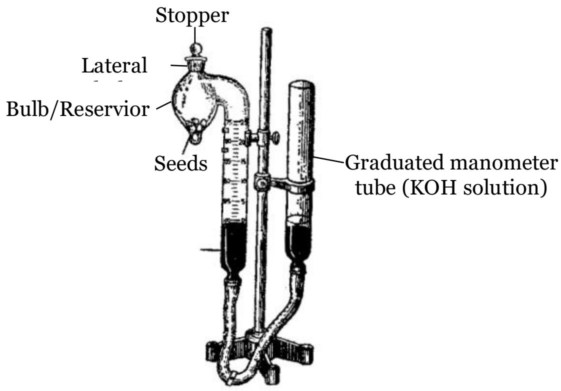


Fig : Ganong's respirometer

2 *ml* of respiring material are put into the bigger bulb of the respirometer and 10% *KOH* in placed in the manometer tube. Experiment start with the turning the glass stopper at the top. Respiration now takes place in a closed space and the absorption of CO_2 liberated shown by rise in *KOH* solution in the graduated tube.

[For the measurement of R.Q. saturated solution of *NaCl* is first place in manometer tube. (Pure water not used, as it absorbed CO_2)].

Different respiratory substrates (carbohydrate, fat seed) are taken. In the graduated tube will remain more or less and unaltered showing that the volumes of CO_2 evolved and oxygen absorbed are the same and R.Q. =1. If solid *KOH* pellets than added to salt solution in the tube, the accumulated CO_2 is absorbed and can be measured from the reading in the tube.

(6) **Demonstration of fermentation :** For this experiment glucose, baker's yeast and water are taken in Kuhne's tube. As a result the level of solution falls in the upright arm and the solution gives alcoholic smell, proves that alcoholic fermentation of glucose takes place.

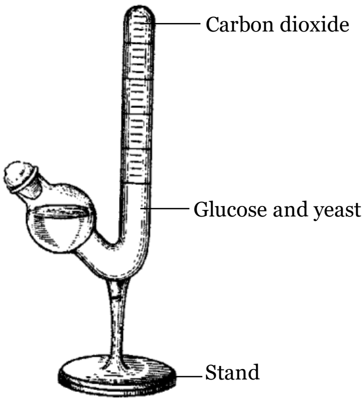


Fig : Fermentation vessel (Kuhne's vessel)

Important Tips

- Glyoxylate cycle is called adaptation of Kreb's cycle.
- Effect of cyanide poisoning can be minimised by immediate supply of ATP.
- **Cut fruit and vegetable :** They often turn brownish due to oxidation of tannins or orthodihydroxyphenols to orthoquinones/polyphenols by means of phenolases and Laccase(e.g., Apple, Potato, Cauliflower, Cabbage, Banana, Peach). This can be prevented by sprinkling ascorbic acid (vit.C), vacuum packing, sugar syrup, steam boiling water or potassium metabisulphite.
- In prokaryotes aerobic cell respiration of glucose **always produces 38 ATP** molecules, as $NADH_2$ molecules formed during glycolysis are not enter the mitochondria.
- The main place of metabolism is cytoplasm, maximum reaction like glycolysis, fat oxidation into acetyl CoA, protein oxidation into α-ketoglutaric acid, ED pathway and pentose phosphate pathway occurs in cytoplasm. Only Krebs cycle and ETC occurs in mitochondria.
- Pentose phosphate pathway called connective link between photosynthesis and fat synthesis.
- The low temperature and high CO_2 concentration used in cold storage of fruits and tubers increases the rate of respiration.
- 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.
- Animals cells respire anaerobically during straneous condition forms lactic acid, and fungi respire anaerobically so the requirement for respiration of fungi considered similar to the animal cells.

- 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.
- **Climateric fruits :** Those fruits which show a high rate of respiration during their ripening e.g., Apple, Banana. In these fruits rise of respiration called climatric rise.
- NADH produces during the glycolysis are utilized in formation of ethyl alcohol from acetaldehyde during anaerobic respiration. The net gain of ATP is 2 ATP in anaerobic respiration which comes from the process of glycolysis.
- Aldolase and triose phosphate isomerase enzyme are common for EMP and C_3 pathway.
- In white muscles fibers lactic acid accumulated more faster than red muscle fiber because red muscle fiber have more myoglobin (O_2 storing pigment) as compared to white muscles fiber so white muscle get fatigued soon.

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ASSIGNMENT

INTRODUCTION AND TYPES OF RESPIRATION

Basic Level

1. With which of the following fatty acid value of R.Q. is one

(a) Acetic acid (b) Oleic acid (c) Stearic acid (d) Palmitic acid

2. 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

3. Which of the following process may be toxic to plants

(a) Photolysis of water (b) Photosynthesis

(c) Aerobic respiration (d) Anaerobic respiration

4. Which of the following substrate is used during floating respiration

(a) Fat (b) Protein (c) Carbohydrate (d) None of the above

5. On which substrate found enzyme lipase works

(a) Fat (b) Protein (c) Carbohydrate (d) All the above

6. Anaerobic synthesis found in bacteria is

(a) Endergonic (b) Exergonic (c) Isothermal (d) None of the above

7. Which of the substrate is used in protoplasmic respiration

(a) Fat (b) Carbohydrate (c) Protein (d) All the above

8. Which of the following leaves will show maximum rate of respiration

(a) Young leaves (b) Mature leaves (c) Senescent leaves (d) None of the above

9. The energy yield as a result of total oxidation of one glucose molecule during cellular respiration is to convert

(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

10. The main place of metabolism in a cell is

(a) Nucleus (b) Mitochondria (c) Cytoplasm (d) Lysosome

11. *Pseudomonas saccharophila* shows which of the following pathway

(a) Glycolysis (b) Krebs cycle

(c) Entner-Deudoroff pathway (d) None of the above

12. The rate of respiration depends upon the

(a) Quantity of protoplasm in cell (b) Quality of protoplasm in cell

(c) Both (a) and (b) (d) None of the above

13. Value of Q^{0}_{10} for respiration is

(a) One (b) Two (c) Three (d) Four

14. If oxygen contents is reduced to 1%, the rate of respiration becomes

(a) Optimum (b) Minimum (c) Maximum (d) None of the above

15. CO_2 concentration has which relation with respiration

(a) Directly proportional (b)Inversely proportional

(c) Both (a) and (b) (d)No relation

16. Substrate phosphorylation is the formation of

(a) ATP (b) AMP (c) ADP (d) Pyruvic acid

17. The R.Q. of a plant organ depends upon the nature of the substrate which is

(a) Reduced (b) Oxidized (c) Catabolized (d) Metabolized

18. Storage of carbohydrate in memmalian muscles taken place in which form

(a) Glucose (b) Lactic acid (c) Glycogen (d) Pyruvic acid

19. The process of phosphorylation takes place in

(a) Glycolysis (b) Krebs cycle (c) HMP pathway (d) All the above

20. The intermediate compound common for aerobic and anaerobic respiration

(a) Citric acid (b) Pyruvic acid

(c) Acetyle COA (d) succinic acid

21. In presence of dilute salt solution, rate of respiration in a respiring tissue

(a) Increases (b) Decreases (c) Remains constant (d) None of the above

22. Salt respiration is also called as

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

23. The synthesis of ATP in photosynthesis and respiration is essentially an oxidation-reduction process involving removal of energy from

(a) Oxygen (b) Phytochrome (c) Cytochrome (d) Electrons

24. In presence of TPP and carboxylase, pyruvic acid in transformed into

(a) Acetaldehyde and CO_2 (b)Ethyl alcohol and CO_2

(c)Citric acid and CO_2 (d) None of the above

25. Releasing of energy from oxidation of food material is called

(a) Catabolism (b) Metabolism (c) Constructive step (d) Dehydrogenation

26. ATP stands for

(a) An enzyme which brings about oxidation (b) A hormone

(c) A protein (d) A molecule which contains high phosphate

27. ATP stands for

(a) Adenosine triphosphate (b)Adenine triphosphate

(c) Adenosine diphosphate (d) Adenosine tetraphosphate

28. Common immediate source of energy in cellular activity or Energy currency of the cell is

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

29. 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

30. Upon the oxidation of one mole of pyruvate by mitochondrial respiration, the mole of ATP generated are

(a) 38 (b) 30 (c) 8 (d) 15

31. Which of the following is required for the formation of ATP outside the mitochondria

(a) Oxygen (b) Nitrogen (c) Hydrogen (d) None of the above

32. Evolution of CO_2 is more than intake of oxygen when

(a) Sucrose is respired (b) Glucose is respired

(c) Organic acids are respired (d) Fats are respired

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

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

34. The organism in which Krebs cycle does not occur in mitochondria is

(a) Yeast (b) *E . coli* (c) *Ulothrix* (d) Mould

35. ATP synthesis occurs on the

(a) Outer membrane of mitochondrion (b) Inner membrane of mitochondrion

(c) Matrix (d) None of the above

36. Plants whose requirement for respiration is similar to animals are

(a) Algae (b)Fungi (c) Lichens (d) Cyanobacteria

37. The most common organism which can respire is absence of O_2 is

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

38. What is active glucose

(a) FAD- glucose (b)NAD-glucose (c) Phosphoglucose (d) Glycerophosphate

39. In aerobic respiration

(a) Glucose is the only substrate (b)Glucose is a preferred substrate

(c) Glucose cannot be uses directly

(d)Any material which burns in air can be used as substrate

40. Energy given by one molecule of ATP is

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

41. Fermentation is

(a) Anaerobic respiration (b) Incomplete oxidation of carbohydrates

(c) Complete oxidation of carbohydrates (d) None of the above

42. Conversion of pyruvic acid into ethyl alcohol is facilitated by the enzymes

(a) Carboxylase (b) Dehydrogenase

(c) Carboxylase and dehydrogenase (d) Phosphatase

43. Respiration is an

(a) Endothermic process (b)Exothermic process

(c) Anabolic process (d) Endergonic process

44. In *Opuntia*, in night the R.Q. will be

(a) One (b) Less than one (c) More than one (d) Zero

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

(a) Invertase (b) Zymase (c) Dehydrogenase (d) Anolase

46. Which of the following is the source of respiration

(a) Stored food (b) RNA (c) DNA (d) ATP

47. In the process of respiration the potential energy stored in the organic compounds is released in the form of

(a) Kinetic energy (b) Physical energy (c) Chemical energy (d) Radiant energy

48. If the nacked pea seed are kept in four respiratory flasks, they would germinate best in the flask which contains

(a) Carbon dioxide (b) Oxygen (c) Hydrogen (d) Nitrogen

49. Which of the following is the site of respiration within the cell

(a) Ribosomes (b) Nucleus (c) Golgi body (d) Mitochondria

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

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

51. Which of the following show higher rate of respiration

(a) Collenchyma (b) Leaf (c) Dry seeds (d) Germinating seeds

52. Lowest rate of respiration will be in

(a) Collenchyma (b) Leaf (c) Dry seeds (d) Germinating seeds

53. During injury and infection, the rate of O_2 consumption

(a) Increases (b) Decreases (c) Remains unchanged (d) Becomes zero

54. After respiration, the conversion of energy is mainly in the form of

(a) ADP (b) ATP (c) AMP (d) Glucose

55. Which of the following is formed during respiration

(a) O_2 (Oxygen) (b) CO_2 (Carbon dioxide)

(c) NO_2 (Nitrogen dioxide) (d) SO_2 (Sulphur dioxide)

56. Heat energy of plants is measured in

(a) Grams (b) Pounds (c) Decibels (d) Calories

57. R.Q. of malic acid is

(a) 0.7 (b) 1 (c) 1.33 (d) 4

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

59. In an organism utilizing carbohydrates as its source of energy anaerobically, the R.Q. is likely to be
(a) 0.7 (b) 1.0 (c) 0.9 (d) infinity

60. To a living organism which of the following has the greater amount of available energy per molecule
(a) *ATP* (b) *ADP* (c) CO_2 (d) H_2O

61. In a mango tree, metabolic energy is most extensively used in
(a) Cambium (b) Cork (c) Xylem (d) Root parenchyma

62. Instantaneous source of energy is
(a) Glucose (b) Fats (c) Proteins (d) Amino acids

63. R.Q. is zero when the respiratory substrate is
(a) Completly oxidized (b) Incompletly oxidized (c) Not oxidized at all (d) Reduced

64. Cytochrome is related to
(a) Cellular digestion (b) Protein synthesis (c) Cell division (d) Cellular respiration

65. Apparatus used to measure respiration is called
(a) Potometer (b) Auxanometer (c) Autometer (d) Respirometer

66. Aerobic respiration is called
(a) Fermentation (b) Chemosynthesis (c) Bio-oxidation (d) Photorespiration

67. Leaves of annual plants obtain O_2 through
(a) Cell walls (b) Cuticle and leaf scars (c) Stomata (d) Lenticels

68. Old trees obtain O_2 from
(a) Stomata (b) Lenticels (c) Leaf scars (d) All the above

69. Apple and Potato obtain O_2 through
(a) Stomata (b) Cork (c) Lenticels (d) Epidermis

70. Respiratory exchange of gases in hydrophytes occur through
(a) Stomata (b) Cuticle (c) Lenticels (d) General surface

71. Roots can take oxygen when it is in
(a) Gaseous form (b) Solution with water
(c) Chemical combination with other compounds (d) Liquid form

72. The incomplete breakdown of sugars in anaerobic respiration results in the formation of
(a) Fructose and water (b) Glucose and CO_2 (c) Alcohol and CO_2 (d) Water and CO_2

73. If carbon dioxide contents of the atmosphere is as high as 300 *ppm*
(a) All plants will be killed (b)The plants would not grow properly
(c) Plants would grow for some times and then die (d)The plants would thrive well

74. R.Q. is represented by
(a) $\frac{C}{N}$ (b) $\frac{CO_2}{O_2}$ (c) $\frac{O_2}{CO_2}$ (d) $\frac{N}{C}$

75. Energy produce per gram is highest for

(a) Wheat starch (b) Rice starch (c) Potato starch (d) All equally

76. Anaerobic respiration was first of all reported by

(a) Maguenne (b) Kostychev (c) Klein (d) Pfeffer

77. Different steps in respiration are controlled by

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

78. Both respiration and photosynthesis require the following

(a) Sunlight (b) Chlorophyll (c) Glucose (d) Cytochrome

79. The amount of energy released in complete oxidation of one molecule of glucose is

(a) 628 *kcal* (b) 668 *kcal* (c) 686 *kcal* (d) 697 *kcal*

80. Anaerobic process after glycolysis is called

(a) *TCA* (b) Calvin cycle (c) Krebs cycle (d) Fermentation

81. When 100% carbon is oxidized to CO_2, the efficiency of such a respiration is

(a) 40% (b) 60% (c) 90% (d) 100%

82. In succulents respiratory quotient is always less than one because of

(a) Complete oxidation (b) Complete reduction

(c) Incomplete oxidation (d) Incomplete reduction

83. 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

84. R.Q. is highest when respiratory substance is

(a) Fat (b) Malic acid (c) Glucose (d) Protein

85. In germinating castor seeds, the R.Q. is

(a) One (b) More than one (c) Less than one (d) Zero

86. When ATP is converted into ADP, it releases

(a) Electricity (b) Energy (c) Enzymes (d) Hormones

87. The mechanism of *ATP* formation both in chloroplast and mitochondria is explained by

(a) Relay pump theory of Godlewski (b)Cholodny-Wont's model

(c) Chemiosmotic theory (d) Munch's hypothesis (mass flow model)

88. The value of RQ at compensation point is

(a) Unity (b) Infinity (c) >1 (d) Zero

89. 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

90. Which of the enzymes is responsible for converting pyruvic acid to acetaldehyde

(a) Aldolase (b) Pyruvic kinase

(c) Pyruvic acid decarboxylase (d) Pyruvic dehydrogenase

91. Anaerobic respiration takes place in the

(a) Mitochondria (b) Cytoplasm (c) Lysosomes (d) ER

92. Respiration occurs

(a) Only in non-green cells in light

(b) Only in non-green cells both in light and dark

(c) In all living cells both in light and dark (d) In all living cells only in light

93. Which of the following is necessary for respiration in plants

(a) Carbon dioxide (b) Oxygen (c) Chlorophyll (d) Light

94. In plants, energy is produced during the process

(a) Transpiration (b) Respiration (c) Photosynthesis (d) Water absorption

95. Adenosine diphospate contains

(a) One high energy bond (b)Two high energy bond

(c) Three high energy bond (d) Four high energy bond

96. Enzymes related with cristae are related with

(a) Anaerobic respiration (b)Aerobic respiration

(c) CO_2 formation (d) Reduction of pyruvic acid

97. Highest calories is obtained from

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

98. Anaerobe products of fermentation are

(a) Alcohol and lipoprotein (b) Ether and nucleic acid

(c) Protein and nucleic acid (d) Alcohol, lactic acid and similar compound

99. 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*

100. If the temperature is increased (above 35^0C)

(a) Rate of decline of respiration will be earlier than decline of photosynthesis

(b) Rate of decline of photosynthesis will be earlier than decline respiration

(c) Both decline simultaneously

(d) Both do not show any fixed pattern

101. Oxidative phosphorylation is the formation of

(a) $NADPH_2$ in respiration (b)ATP in respiration

(c) $NADPH_2$ in photosynthesis (d) ATP in photosynthesis

102. Why do fishes in an aquarium thrive better if green plants are growing there because they

(a) Inhale oxygen released by green plants

(b) Inhale carbon dioxide released by green plants

(c) Can feed of them (d) Like green surrounding

103. 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

104. Aerobic respiration is more advantageous to a large organism than anaerobic respiration, because aerobic respiration

(a) Does not require sunlight (b) Produces oxygen as a waste product

(c) Does not require molecular oxygen and hydrogen

(d) Releases more energy from an equal amount of nutrients

105. Intake of CO_2 and outlet of O_2 is equal in photosynthesis and respiration, then the condition is known as

(a) Red drop (b) Solarization (c) Null point (d) Compensation point

106. Fermentation is conducted by

(a) All fungi (b) All bacteria

(c) Some fungi and some bacteria (d) All micro-organisms

107. During 24 hours there is a time when plants neither give O_2 nor CO_2 . This is the time of

(a) Night (b) Daylight (c) Twilight (d) None of these

108. 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

109. 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 k*cals* of energy

(d) 528 *gms* of CO_2, 216 *gms* of water and 1348 *kcals* of energy

110. If CO_2 is given off in respiration, why does the amount of CO_2 in the atmosphere remains relatively constant

(a) CO_2 forms carbonate rocks (b)CO_2 is buffer

(c) CO_2 is converted in photosynthesis to carbohydrates

(d) CO_2 split up during photosynthesis

111. 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

(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

112. Zymase was discovered by

(a) Lipmann (b) Pasteur (c) Buchner (d) Altman

113. When the $NADH_2$ formed in glycolysis reacts with an inorganic element the nature of respiration is
(a) Aerobic / oxy respiration (b) Anaerobic respiration
(c) Fermentation (d) Photorespiration

114. High energy compounds
(a) Are sugars that release large amount of energy during respiration
(b) Are produced when ATP loses two terminal phosphate groups
(c) Are produced in respiration only
(d) Are referred as those compounds which link exergonic to endergonic reactions

115. The energy which can be utilized by an organism respiring aerobically from 1g of glucose is
(a) 686 *kcal* (b) 380 *kcal* (c) 227.4 *kcal* (d) 666 *kcal*

116. The fundamental law of physics applicable to living system is law of
(a) Electrical energy (b) Conservation of energy
(c) Maintenance of energy (d) Segregation

117. Maximum molecules of ATP produced under aerobic conditions in eukaryotes is
(a) 0 (b) 36 (c) 38 (d) 46

118. In the normal resting state of humans, most of the blood glucose burnt as 'fuel' is consumed by
(a) Brain (b) Liver (c) Kidney (d) Adipose tissue

119. Which one forms of ATP
(a) *Fe* and *P* (b) *N* and *P* (c) *Fe* and *Mo* (d) *Mg* and *Mn*

120. Metabolism of one palmitic acid yields ATP
(a) 36 ATP (b) 56 ATP (c) 136 ATP (d) 48 ATP

121. Maximum amount of energy/ ATP is liberated on oxidation of
(a) Fats (b) Proteins (c) Starch (d) Vitamins.

122. In liver conversion of glucose to glycogen shall require
(a) *ATP* (b) *AMP* (c) *UTP* (d) *CTP*

123. Before entering respiratory pathway, amino acids are
(a) Decarboxylated (b) Hydrolysed (c) Deaminated (d) Phosphorylated

124. Metabolic water is the one
(a) Used during transamination
(b) Used during photosynthesis
(c) Produced during aerobic utilisation of glucose
(d) Produced during condensation or polymerisation

125. ATP is injected cyanide poisoning because it is
(a) Necessary for cellular function (b) Necessary for Na^+ -K^+ pump
(c) Na^+–K^+ pump operates at the cell membranes (d) ATP breaks down cyanide

126. Fat has two components, glycerol and fatty acids. They enter common pathway of respiration as
(a) DiHAP and α-ketoglutarate (b)DiHAP and acetyl CoA
(c) Glyceric acid and acetyle CoA (d)Glyceric acid and α-ketoglutarate

127. RQ is more than one indicating

(a) Aerobic respiraton (b) Anaerobic respiration

(c) Both (a) and (b) (d) None of the above

128. The most concentrated form in which the potential energy can be stored is

(a) Triacylglycerol (b) Long chain of fatty acids

(c) Galactose (d) Polypeptides rich in arginine.

129. In anaerobic fermentation 15% of the energy is stored as ATP and 50% of it is lost as heat. The remaining energy is used in

(a) Doing work (b) Growth and reproduction or yeast cells

(c) Fast locomotion (d) Production of oxygen

130. Why carbohydrates are more efficient in providing energy than fats and proteins

(a) Carbohydrates have high molecular weight

(b) They have less oxygen content than fats, therefore, require less molecular oxygen

(c) Fats have less molecular weight

(d) They have more oxygen content and therefore, require less molecular oxygen to provide energy

131. Select the correct match for the following

(A) Net ATP produced in glycolysis (B) Positive Benedict's test

(C) Genes unable to express in presence of their alleles

(D) A character controlled by many genes.

(a) 36, glucose, recessive, polygenic (b)8, glucose, recessive, polygenic

(c) 32, sucrose, recessive, polygenic (d)8, fructose, dominant, polygenic

132. Who is credited with study of external respiration for the first time

(a) Dutrochet (b) Pasteur (c) Cruick Shank (d) Lavosier.

133. External respiration is

(a) Respiration is skin cells

(b) Gaseous exchange between organism and external environment

(c) Gaseous exchange between cells and tissue fluid

(b) Both (b) and (c)

134. Tissue respiration denotes

(a) Respiration by tissues

(b) Gaseous exchanges between cell and tissue fluid

(c) Cell respiration (d) Both (b) and (c)

135. Respiratory substrate yielding maximum number of ATP molecules is

(a) Ketogenic amino acids (b)Glucose (c) Amylose (d) Glycogen

136. As compared to anaerobic respiration, the energy gained during aerobic respiration is

(a) 8 times (b) 12 times (c) 19 times (d) 36 times

137. Which of the following is the site of respiration in bacteria

(a) Episome (b) Ribosome (c) Mesosome (d) Microsome

138. One of the following cells do not respire

(a) Cortical cells (b) Epidermal cells (c) RBC (d) Xylem cells

139. Vinegar is synthesized from alcohol by

(a) Mycobacterium aceti (b)Acetobacter aceti (c) Lactobacillus (d) Both (a) and (b)

140. The term respiration was given by

(a) Lavosier (b) Dutrochet (c) Sachs (d) Krebs

141. A very important feature of respiration is the

(a) Synthesis of complex compounds (b) Utilization of CO_2

(c) Liberation of oxygen (d) Liberation of energy

142. Amino acids enter respiratory pathway

(a) After deamination (b)As fumarate and oxaloacetate

(c) Acetyl CoA, succinyl CoA and α-ketoglutarate (d)All the above

143. Incomplete breakdown of glucose in muscles results in the formation of

(a) Alcohol and water (b) Alcohol and lactic acid (c)CO_2 and water (d) Lactic acid

144. The end product of fermentation of sugars by *psuedomonas* bacteria is

(a) Lactic acid and alcohol (b)CO_2 (c)Ethyl alcohol + CO_2 (d) butyl alcohol

145. A bottle containing germinating seeds is connected to a tube having lime water. After sometime, the lime water turns

(a) Red (b) Brown (c) Green (d) White

146. Plants but not animals can convert fatty acids to sugars by a series of reaction known as the

(a) Glyoxylate cycle (b) Photorespiration (c) Kreb's cycle (d) Glycolysis

147. The respiratory substrates used during respiration are carbohydrates, proteins, organic acids and fats which are used in the order of

(a) Fats, carbohydrates, protein, organic acids (b) Carbohydrates, fats, proteins, organic acids

(c) Carbohydrates, proteins, organic acids, fats, (d) Protein, organic acids, carbohydrates

148. What would you suggest an athelete to take before going to participate in an event

(a) Butter (b) Sugar (c) Bread (d) Cheese

149. Alcoholic beverages such as wine and beer are produced by fermentation. However, Brandy and Whisky, which contain higher alcohol contents, are produced by fermentation followed by distillation. This is because

(a) Distillation prolongs storage period

(b) Distillation is cheaper

(c) Distillation improve quality

(d) Fermentation does not occur when alcohol content exceeds 14-18%

150. It is not advisable to sleep under the trees at night because

(a) They release oxygen during night (b) They release carbon dioxide during night

(c) They release both carbon dioxide and oxygen during night

(d) None of these

151. Seed can be preserved if they are stored

(a) After drying in steam (b)Absolutely fresh

(c) After boiling in water (d)With minimum moisture

152. RQ is measured with Ganong's respiroscope. If in it level remains constant during experiment, the RQ value comes to unity. When it shows rise in Hg level the

(a) RQ value will be infinity (b) Value of RQ will be 0

(c) Value of RQ will be <1 (d) RQ value will be unity

Advance Level

153. Match the given below organelles with their function

I	II
(A)Krebs cycle	(i) Stalked particles of mitochondria
(B)Photorespiration	(ii) Cytoplasm
(C)Oxidative phosphorylation	(iii)Peroxisomes
(D)Glycolysis	(iv)Inner surface of membrane of mitochondria

	A	B	C	D
(a)	(ii)	(iii)	(iv)	(i)
(b)	(i)	(ii)	(iii)	(iv)
(c)	(iv)	(iii)	(i)	(ii)
(d)	(iii)	(ii)	(iv)	(i)

154. Match the name of scientist with his work

I	II
(A)PPP (Pentose phosphate pathway)	(i) Kuhne
(B)Demonstration of fermentation	(ii) Krebs
(C)TCA cycle	(iii)Warburg – Dichens pathway
(D)Glycolysis	(iv)Embden, Mayerhoff, Parnas

	A	B	C	D
(a)	(i)	(ii)	(iii)	(iv)
(b)	(ii)	(iv)	(iii)	(i)
(c)	(i)	(ii)	(iv)	(iii)
(d)	(iii)	(i)	(ii)	(iv)

155. Match the correct answers with type of respiration and respiratory substrates

Respiration	Type of substrate
(A) Floating respiration	(i) Proteins
(B) Cytoplasmic respiration	(ii) Starch
(C) Protoplasmic respiration	(iii) Carbohydrates
(D) Lactic acid fermentation	(iv) Lactose

	A	B	C	D
(a)	(iii)	(ii)	(i)	(iv)
(b)	(ii)	(iii)	(iv)	(i)
(c)	(i)	(ii)	(iii)	(iv)
(d)	(ii)	(iv)	(i)	(iii)

156. During anaerobic respiration, one molecule of pyruvic acid

(a) Losses 3 molecules of ATP
(b) Losses 6 molecules of ATP
(c) Gains 2 molecules of ATP
(d) Gains 4 molecules of ATP

157. Anaerobic respiration is also known as

(a) Intramolecular respiration
(b) Intermoleculer respiration
(c) Extramolecular respiration
(d) Molecular respiration

158. Vant Hoff's law states that

(a) The respiration rate increases two or three times for every rise of 5^o C
(b) The respiration rate decreases two or three times for every rise of 10^o 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^o C

159. Slow respiring plants or plant tissues are

(a) Promeristems
(b) Cambium
(c) Leaf primordia and young plant
(d) Adult plants and matured tissues

160. The tissue of highest respiratory activity is

(a) Meristems
(b) Ground tissue
(c) Phloem
(d) Mechanical tissue

161. Why do fruit juices turn bitter if kept in an open place for sometime

(a) Juices have something inside them which makes it bitter
(b) It is due to fermentation brought about by yeast cells
(c) It is due to the activity of fungi present in the atmosphere
(d) All the above

162. Fermentation is represented by the equation

(a) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 673 kcal$
(b) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 18 kcal$
(c) $6CO_2 + 12H_2O \xrightarrow[Chlorophyll]{Light} C_6H_{12}O_6 + 6H_2O + 6O_2$
(d) $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

163. The RQ (Respiratory quotient) of $C_{39}H_{72}O_6$ is

(a) 2.71 (b) 1.34 (c) 0.72 (d) 3.250

164. Roots of a plant when kept in a phenolphthalein containing weak alkaline solution, decolorises it. This is due to

(a) Absorption of phenolphthalein (b) Absorption of alkali

(c) Respiration of roots (d) Utilization of O_2

165. Make suitable pairing

(A)Glycolysis (a) Mitochondria

(B) Krebs cycle (b) Cytoplasmic matrix

(C) Electron transport chain

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

166. The correct relationship of value of Respiratory quotient is

(a) Glucose>Fats>Organic acid (b)Glucose<Fats<Organic acid

(c) Fats> Glucose>Organic acid (d) Fats< Glucose< Organic acid

167. The net gain of energy from one molecule of sucrose in aerobic respiration is

(a) 8 ATP (b) 38 ATP (c) 40 ATP (d) 80 ATP

168. What is the last substrate to be used in respiration

(a) Glucose (b) Fats (c) Organic acid (d) Proteins

169. How much usable energy is available during oxidative combustion of 1 *gm mole* of glucose in the body

(a) 686000 *cal* (b) 304000 *cal* (c) 277400 *cal* (d) 686 *cal*

170. What is the common in NAD, ATP and FMN

(a) *Zn* (b) *P* (c) *Ca* (d) *Mg.*

171. The number of glucose molecules required to produce 38 ATP molecules under anaerobic conditions by any yeast cell is

(a) 2 (b) 1 (c) 19 (d) 38

172. R.Q. of 4 is obtained when respiratory substrate is

(a) Oxalic acid (b) Malic acid (c) Tartaric acid (d) Glucose

173. Link between glycolysis, Krebs cycle and β- oxidation of fatty acid or carbohydrate and fat metabolism is

(a) Oxaloacetic acid (b) Succinic acid (c) Citric acid (d) Acetyl CoA

174. In metabolism of glycogen, first to be formed is

(a) Glucose 1 phosphate (b)Glucose 6 phosphate

(c) Glucose (d) Dextrin

GLYCOLYSIS

Basic Level

175. Which group of the following scientists discovered the EMP pathway of glycolysis

(a) Embden, Mayerhoff and Parnas (b)Emerson, Hoffman and Peterson

(c) Embden, Morrison, and Pitcher (d)Avery, McLeod and McCarthy

176. The enzyme which converts glucose to glucose 6- phosphate is

(a) Phosphorylase (b) Glucose 6-phosphate

(c) Hexokinase (d) Glucose synthetase

177. Which of the following is the product of phosphorylation

(a) PGA (b) Fructose 1, 6 diphosphate (c)DPGA (d) Pyruvic acid

178. In glycolysis, the end product is

(a) Protein is converted to glucose (b)Glucose is converted into fructose

(c) Starch is converted into glucose (d) Glucose is converted into pyruvic acid

179. Glycolysis takes place in

(a) Mitochondria (b)Cytoplasm

(c) Both mitochondria and cytoplasm (d) Vacuole

180. Which of the following process should not operate when organic acids are used as respiratory substrates

(a) Glycolysis (b) Krebs cycle (c) Terminal oxidation (d) Phosphorylation

181. First stage in the breakdown of glucose in cell is

(a) Aerobic oxidation of pyruvic acid (b) Liberation of CO_2

(c) Glycolysis (d) Electron transport system

182. 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

183. Which of the following is formed in presence of pyruvate kinase

(a) Phosphoenol pyruvic acid (b) Pyruvic acid

(c) Both (a) and (b) (d) None of the above

184. The enzyme used in formation of 2-phosphoglyceric acid from 3-phosphoglyceric acid is

(a) Phosphoglycerol mutase (b) Triose phophate isomerase

(c) Phosphohexo isomerase (d) Glyceric acid

185. In glycolysis besides the formation of 2 ATP, two molecules of other compound are also formed. The name of that compound is

(a) $NADH_2$ (b) $NADPH_2$ (c) ADP (d) *H*-atom

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

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

187. The common phase between aerobic and anaerobic respiration is called

(a) Tricarboxylic acid cycle (b) Oxidative phosphorylation

(c) Embden, Mayerhoff, Parnas cycle (d) Krebs cycle

188. 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

189. For the enzyme enolase, the substrate is

(a) Succinic acid (b) 2 PGA (c) PEP (d) Fumaric acid

190. Net gain of ATP in glycolysis is

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

191. How many water molecules are used in glycolysis

(a) One (b) Two (c) Three (d) Four

192. During glycolysis ATP and Mg^{2+} coenzymes function

(a) For phosphoglucoisomerase (b) For glucokinase

(c) For pyruvic kinase

(d) For phosphoglyceraldehyde-3-phosphate dehydrogenase

193. The formation of acetyl coenzyme A from pyruvic acid is the result of its

(a) Reduction (b) Dehydration

(c) Dephosphorylation (d) Oxidative decarboxylation

194. The reactions of glycolysis are

(a) Reversible (b) None reversible (c) Both (a) and (b) (d) None of these

195. Number of CO_2 molecules evolved in glycolysis is

(a) 2 (b) 1 (c) 3 (d) 0

196. The intermediate of glycolysis which undergoes lysis or splitting is

(a) Dihydroxyacetone 3-phosphate (b) Fructose 1,6-diphosphate

(c) Glyceraldehyde 3-phosphate (d) Glucose 6-phosphate

197. Formation of phosphoenol pyruvate from 2-phosphoglycerate is

(a) Dehydration (b) Dehydrogenation (c) Oxidation (d) Hydration

198. Which product of glycolysis is consumed in alcoholic fermentation

(a) $NADH_2$ (b) ATP (c) ATP and $NADH_2$ (d) CO_2

199. A complex enzyme system of mitochondria functional outside Krebs cycle is

(a) Pyruvate kinase (b) Pyruvate dehydrogenase

(c) Enolase (d) α - Ketoglutarate dehydrogenase

200. Enzyme pair common to both EMP and C_3 cycle is
(a) Aldolase and enolase
(b) Aldolase and triose phosphate isomerase
(c) Phosphoglyceromutase and triose phosphate isomerase
(d) Cytochrome oxidase and enolase

201. In glycolysis, glucose splits into compounds which are
(a) 5-C (b) 4-C (c) 2-C (d) 3-C

202. The reaction involved in reduction of NAD^+ is
(a) Glucose $\rightarrow$Glucose 6–*P*
(b) (b) Fructose 1,6-diphosphate $\rightarrow$ PGAL+DiHAP
(c) Glucose 6-P $\rightarrow$ Fructose 6-*P* (d) PGAL $\rightarrow$ PGA

Advance Level

203. 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

204. *Robinson's ester* is
(a) Glucose 1, 6 diphosphate (b) Glucose-6-phosphate
(c) Fructose-6-phosphate (d) None of the above

205. Isomerization step takes place in
(a) Glycolysis (b) Krebs cycle
(c) Oxidative phosphorylation (d) None of the above

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

207. Which of the following is called *Newberg's ester*
(a) Glucose-6-phosphate (b)Fructose-6-phosphate
(c) Fructose 1, 6 diphosphate (d) All the above

208. Conversion of fructose - 6-phosphate to fructose 1,6 diphosphate is catalysed by
(a) Phosphofructose kinase (b)Aldolase (c) Hexokinase (d) None of the above

209. Oxidation of glyceraldehyde phosphate is accompanied by
(a) Oxidation of NAD^+ (b) Substrate level phosphorylation
(c) Reduction of NAD^+ (d) Oxidative phosphorylation

210. Excess of ATP inhibits
(a) Phosphofructokinase (b)Pyruvic dehydrogenase
(c) Triose phosphate isomerase (d) Glyceraldehyde phosphate

211. Glycolysis occurs in

(a) Anaerobic organisms (b)Muscle cells (c) Prokaryotic cells (d) Almost the cells

212. Which one of the following is wrong about glycolysis

(a) It uses ATP (b) It produces ATP

(c) End products are CO_2 and H_2O (d) NADH (H^+) is produced

213. Glycolysis is

(a) 10 step enzymatic reaction leading to formation of four carbon pyruvate

(b) 8 step enzymatic reaction leading to formation of four carbon pyruvate

(c) 10 step enzymatic reaction leading to formation of three carbon pyruvate

(d) 8 step enzymatic reaction leading to formation of three carbon pyruvate

214. Blood glucose level is not dependent upon muscle glycogen because of the absence of

(a) Phosphorylase (b) Branching enzyme (c) Glucose-6-phosphatase (d) aldolase

215. All reactions in glycolysis are reversible except

(a) Glucose to glucose-6-phosphate

(b) Glucose 6-phosphate to fructose-6 phosphate

(c)Reaction catalysed by kinases

(d) Fructose-6-phosphate to fructose 1,6 diphosphate

216. Respiratory formation of ATP during the reactions 1, 3-diphosphoglyceric acid $\rightarrow$ 3-phosphoglyceric acid and phosphoenol pyruvate $\rightarrow$ Pyruvate is

(a) Oxidative phosphorylation (b) Substrate level phosphorylation

(c) Respiratory phosphorylation (d) Chemical phosphorylation

217. All of the following are prosthetic groups in pyruvate to acetyl CoA reaction, except

(a) *Mn* (b) Thiamine pyrophosphate and coenzyme A

(c) Lipoic acid (d) *NAD*

218. Number of *ATP* molecules formed during complete oxidation of fructose 1,6-diphosphate is

(a) 20 (b) 32 (c) 36 (d) 40

219. Glyceraldehyde 3-phosphate is oxidised to 1-3 biphosphoglyceric acid along with

(a) Release of electrons for reducing NAD^+ (b) *ATP* synthesis

(c) Release of phosphate group (d) Release of H^+ and e^- for forming *NADH*

220. In glycolysis during oxidation, electrons are removed by

(a) NAD^+ (b) Molecular oxygen

(c) *ATP* (d) Glyceraldehyde 3- phosphate

KERB'S CYCLE AND ETS

Basic Level

221. TPP means

(a) Thiamine pyrophosphate (b) Tymine pyrophosphate

(c)Thymine pentaphosphate (d) None of the above

222. Hydrogen of malate is accepted by

(a) *FAD* (b) *FMN* (c) *NAD* (d) *CoQ*

223. Which of the coenzyme is used in acetylation reaction

(a) *CoA* (b) *FAD* (c) *FMN* (d) None of the above

224. In cellular respiration O_2 is used as a final receptor of

(a) *ATP* and *NADH* (b) *H* and *e* (c) *Fe* (d) Cytochrome

225. Krebs cycle is also known as

(a) Glyoxylate cycle (b) EMP pathway (c) Citric acid cycle (d) Glycolate cycle

226. The pyruvic acid formed in Glycolysis is oxidised to CO_2 and H_2O in a cycle called

(a) Calvin cycle (b) Hill reaction (c) Krebs cycle (d) Nitrogen cycle

227. In ETS, electron combines to

(a) Cytochrome (b) H_2 (c) O_2 (d) H_2O

228. Which of the follwoing is correct sequence in Krebs cycle

(a) Isocitric acid $\rightarrow$ Oxalosuccinic acid $\rightarrow$ α - ketogluteric acid

(b) Oxalosuccinic acid $\rightarrow$ Isocitric acid $\rightarrow$ α - ketogluteric acid

(c) α -ketogluteric acid $\rightarrow$ Isocitric acid $\rightarrow$ Oxalosuccinic acid

(d) Isocitric acid $\rightarrow$ α - ketogluteric acid $\rightarrow$ Oxalosuccinic acid

229. In respiration, pyruvic acid is

(a) Formed only when oxygen is available (b) One of the product of Krebs cycle

(c) Broken down into two carbon fragments and CO_2

(d) A result of protein breakdown

230. How many molecules of ATP are produced per molecule of FpH_2 or $FADH_2$ oxidised

(a) One (b) Two (c) Three (d) Four

231. Vitamin B_1 is present in one of these molecules

(a) *TPP* (b) *FMN* (c) *NAD* (d) *ATP*

232. The reaction of Krebs cycle take place

(a) In cytoplasm (b) In endoplasmic reticulum

(c) In matrix mitochondria (d) On the surface of mitochondrion

233. The importance of Krebs cycle is in the production of

(a) Acetyl CoA (b) Water (c) ATP (d) ADP

234. The number of steps required for oxidation of one molecule of pyruvic acid is

(a) 5 (b) 6 (c) 3 (d) 12

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

(a) Oxaloacetic acid (b) Citric acid (c) α - ketogluteric acid (d) Isocitiric acid

236. Synthesis of ATP in mitochondria require

(a) Oxygen (b) *NADP* (c) *FMN* (d) Pyruvic acid

237. Krebs cycle is termed as the aerobic phase of respiration because

(a) It consumes oxygen

(b) Oxygen acts as a catalyst

(c) Aerobic condition are essential for the continued operation of electron transport system

(d) All the above

238. Which of the following is not a part of Krebs cycle

(a) Dehydrogenation (b) Acetylation

(c) Oxidative phosphorylation (d) Decarboxylation

239. Mitochondria are the sites of

(a) Oxidative phosphorylation (b) Photolysis

(c) Photophosphorylation (d) Starch synthesis

240. O_2 maintains the operation of Krebs cycle by

(a) Combining with the acids of the cycle (b) Producing CO_2

(c) Both the above (d) By regenerating *NAD* and *FAD*

241. Cytochrome helps in

(a) Oxidation of glucose (b)Release of energy (c) Electron transport (d) Growth

242. Ferredoxin is a

(a) Protein (b) Fat (c) Phenol (d) None of the above

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

(a) Krebs cycle (b) Oxidative phosphorylation

(c) Glycolysis (d) None of the above

244. Krebs cycle starts with the formation of six carbon compounds by reaction between

(a) Maleic acid and acetyl CoA (b) Succinic acid and pyruvic acid

(c) Fumaric acid and pyruvic acid (d) Acetyle CoA and oxaloacetic acid

245. Oxidation of succinate to fumerate in the Krebs 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

246. The last or terminal cytochrome in respiratory chain is

(a) *Cyt b* (b) *Cyt* a_3 (c) *Cyt* a_1 (d) *Cyt c*

247. Which of the following is directly affected by deficiency of *Fe*

(a) Glycolysis (b) Calvin cycle

(c) DPD of cell (d) Oxidative photophosphorylation

248. Mineral activator needed for the enzymes carboxylase of TCA cycle is

(a) *Mg* (b) *Fe* (c) *Mo* (d) *Mn*

249. Mineral activator needed for the enzymes aconitase of TCA cycle is

(a) *Mn* (b) *Fe* (c) *Mg* (d) *Cu*

250. Which of the following involves the loss of two protons and two electrons

(a) Deamination (b) Dehydrogenation (c) Carboxylation (d) None of these

251. When a cell is treated with citrate and malonate

(a) Oxaloacetic acid is accumulated

(b) Aerobic respiration is enhanced

(c) Krebs cycle is suppressed half way and succinic acid accumulates

(d) RQ becomes more than one

252. How many ATP will be produced during the production of 1 molecule of acetyl CoA from 1 Molecule of pyruvic acid

(a) 3 ATP (b) 5 ATP (c) 8 ATP (d) 38 ATP

253. Oxidative phosphorylation occurs in

(a) Outer membrane of mitochondria (b) Inner membrane of mitochondria

(c) Stroma of chloroplast (d) Grana of chloroplast

254. Krebs cycle begins with

(a) Pyruvic acid (b) Hydrochloric acid (c) Corticosteroids (d) Lysine

255. Oxidative phosphorylation occurs during the process of

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

256. Last acid formed in Kreb cycle is

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

257. Krebs has been awarded Noble Prize in 1953 for explaining

(a) Energy forming process in the cell (b) ATP metabolism

(c) Respiration chain (d) Oxidation of cytoplasm

258. The product formed by malic dehydrogenase is

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

259. In how many steps, CO_2 is released in aerobic respiration of pyruvic acid

(a) One (b) Six (c) Three (d) Twelve

260. During respiration, 38 ATP molecules per glucose molecule are produced in respiratory chain, 22 molecules of these 38 ATP molecules are produced from $NADH_2$ / $FADH_2$ produced during

(a) Embden-Mayerhoff pathway (b) Oxidative decarboxylation

(c) Kreb's cycle (d) Respiratory chain itself

261. The first compound of TCA cycle is

(a) Oxalosuccinic acid (b) Oxaloacetic acid (c) Citric acid (d) Cis-aconitic acid

262. The inhibitor of oxidative phosphorylation is

(a) Azide (b) Cyanide (c) 2,4-Dinitrophenol (d) Both (b) and (c)

263. The universal hydrogen acceptor

(a) NAD (b) FAD (c) ATP (d) CoA

264. In Krebs' cycle FAD participates as electron acceptor during conversion of

(a) Succinyl CoA to succinic acid (b) α-ketoglutarate to succinyl CoA

(c) Succinic acid to fumaric acid (d)Fumaric acid to Malic acid

265. Number of cytochrome molecules required for the transfer of a pair of electrons through ETS is

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

266. Which one is the final electron carrier

(a) OAA (b) $NADP^+$ (c) Cytochrome oxidase (d) Pyruvate

267. Which of the following happens in mitochondria

(a) $O_2 + ADP + H_3PO_4 \xrightarrow{M} H_2O + ATP + CO_2$ (b) $O_2 + ADP + H_3PO_4 \xrightarrow{M} H_2O + AMP + CO_2$

(c) $CO_2 + ADP + H_3PO_4 \xrightarrow{M} H_2O + AMP + O_2$ (d) $CO_2 + ADP + H_3PO_4 \xrightarrow{M} H_2O + ATP + O_2$

268. In electron transport system a carrier holds electron at

(a) Higher energy level than the previous carrier

(b) Lower energy level than the previous carrier

(b) Same energy level as the adjacent ones

(d) Initially holds it at higher level but the electron loses energy during its contact with carrier

269. In respiration, most of ATP is synthesised during

(a) Electrons transport (b) Glycolysis

(c) Krebs cycle (d) Oxidation of pyruvate

270. Cytoplasmic NADH is oxidatively phosphorylated inside mitochondrion. Mitochondrion is impermeable to NADH. Entry into mitochondrion is effected through

(a) Shuttle system (b) Facilitated diffusion

(c) Active absorption (d) F_0 tunnel of elementary particles.

271. In muscles and nerves, cytoplasmic NADH yeilds

(a) 3 ATP (b) 2 ATP (c) 1 ATP (d) No ATP

272. Energy is released during

(a) Citric acid $\rightarrow$ Isocitric acid (b) Isocitric acid $\rightarrow$ cis-Aconitic acid

(c) Glucose 1-P $\rightarrow$ glucose 6-P (d) Pyruvate $\rightarrow$ Acetyl CoA

273. What is the produced when succinyl CoA is changed to succinate

(a) ATP (b) GTP

(c) CTP (d) ATP in plants and GTP in animals

274. In electron transport chain, $FADH_2$ is oxidised to FAD, the electrons are passed to cytochrome proteins whereas hydrogen ions are released into

(a) Matrix (b) Cytosol (c) Outer membrane (d) Inner membrane

275. In cytochromes, electrons are picked up and released by

(a) *Fe* (b) *Mo* (c) *Cu* (d) *Zn*

276. Which of the following enzymes is absent in mitochondria

(a) Aconitase (b) Malic dehydrogenase (c) Fumarase (d) Hexokinase

277. A single turn of Krebs cycle yields

(a) 1$FADH_2$, 1 NADH and 1 ATP
(b)1 $FADH_2$, 2NADH and 1 ATP
(c) 1 $FADH_2$, 3NADH and 1 ATP
(d)2 $FADH_2$, 2 NADH and 2 ATP

278. In aerobic respiration, first CO_2 is liberated during

(a) Oxidation of pyruvate
(b)Decarboxylation of oxalosuccinate
(c) Decarboxylation of α-ketoglutarate
(d) Alcoholic fermentation

279. A complex enzyme system functional in Krebs cycle is

(a) Citrate synthetase
(b) Isocitrate dehydrogenase
(c) Oxalosuccinate decarboxylase
(d) α-ketoglutarate dehydrogenase

280. When a pair of electrons from NADH(H^+) is transported through respiratory ETS, it result in the formation of

(a) 2 mol. of ATP (b) 4 mol. of ATP (c) 3 mol. of ATP (d) 5 mol. of ATP

281. Iron-porphyrin protein complex occurs in

(a) Cytochrome (b) Chlorophyll (c) Phytochrome (d) Both (a) and (b)

282. An amphibolic pathway is

(a) TCA cycle (b) Calvin cycle
(c) Terminal oxidation (d) Electron transport chain

283. Conversion of oxaloacetic acid to citric acid requires one molecules of

(a) CO_3 (b) CO_2 (c) CO (d) H_2O

284. The first 5-C dicarboxylic acid in Krebs cycle is

(a) Acetyl CoA (b) Citric acid (c) α-Ketoglutaric acid (d) OAA

Advance Level

285. The correct sequence of electron acceptor in ATP synthesis is

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

286. In Krebs cycle, the FAD precipitates as electron acceptor during the conversion of

(a) Succinyl CoA to succinic acid
(b)α-ketoglutarate to succinyl CoA
(c) Fumaric acid to malic acid
(d) Succinic acid to fumaric acid

287. Krebs 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

288. Pyruvate (pyruvic acid) dehydrogenase is used in converting

(a) Pyruvate to glucose
(b) Glucose to pyruvate
(c) Pyruvic acid to lactic acid
(d) Pyruvate (pyruvic acid) to acetyl CoA

289. Which of the following observation most strongly support the view that mitochondria contain electron transfer enzymes aggregated into compact associations

(a) A contractile protein capable of utilizing ATP has been obtained from mitochondria

(b) Mitochondria have highly folded inner wall

(c) Disruption of mitochondria yields membrane fragments which are able to synthesize ATP

(d) Mitochondria in animal embryos have a tendency to concentrate in cell which are to become part of locomotory structures

290. Between which of the following stages GTP is formed by substrate level phosphorylation

(a) Succinate to fumarate (b)Ketoglutarate to succinate

(c) Oxalosuccinate to glutarate (d) Fumarate to malate

291. Which transfer electrons in E.T.S. (electron transport system)

(a) Phytochrome (b) F_1 particles (c) Fe-S (d) Cytochrome

292. The membrane bound enzyme involved in Krebs cycle is

(a) Malate dehydrogenase (b)Fumarase

(c) Cis acotinase (d) Succinic dehydrogenase

293. Krebs cycle is

(a) Oxidation of glucose to alcohol and water

(b) Oxidation of acetyl CoA to carbon dioxide and water involving electron transport

(c) Complete oxidation of acetyl CoA without electron transport

(d) Complete reduction of acetyl CoA to carbon dioxide and water

294. Who gave the term cytochrome

(a) C.A. Mummoon (b) W.J. Young (c) A. Harden (d) K.P. Keilin

295. The mobile electron carrier of mitochondrial membrane is

(a) Cyt a_3 (b) FeS (c) CoQ (d) Cyt c_1

296. Which one is absent in erythrocytes

(a) Krebs cycle (b) Enzymes (c) Biomembrane (d) Hyaloplasm

297. Which is wrong about cytochrome P- 450

(a) Contains iron (b) Is a coloured cell

(c) Is an enzyme (d) Plays an important role in metabolism

298. Isocitric acid is changed to α - ketoglutaric acid by

(a) Oxidative carboxylation (b) Oxidative decarboxylation

(c) Dehydrogenation (d) Hydrogenation and decarboxylation

299. Number of carbon atoms present in citric acid, oxaloacetic acid and pyruvic acid are respectively

(a) 6, 3 and 3 (b) 6, 4 and 3 (c) 5, 4 and 3 (d) 6, 4 and 2

300. Enzymes located in mitochondrial membrane are

(a) Enolase and catalase (b) Flavoproteins and cytochromes

(c) Hexokinase and zymase

(d) Citrate synthetase and glutamate dehydrogenase

301. Mitochondrial marker enzyme is

(a) Pyruvate dehydrogenase (b) Aldolase

(c) Amylase (d) Succinic dehydrogenase

302. Action of ATPase needs the presence of

(a) Mg^{++} and K^{+} (b) Cu^{++} and Fe^{++} (c) Na^{+} and K^{+} (d) Ca^{++} and Mg^{++}

303. Flow of electrons in ETS is $NADH_2 \rightarrow$ FMN $\rightarrow$ FeS protein $\rightarrow$ CoQ $\rightarrow$ Cyt b $\rightarrow$ Cyt $C_1 \rightarrow$ Cyt C $\rightarrow$ Cyt a $\rightarrow$ Cyt $a_3 \rightarrow$ O. At three steps ATP is formed (oxidative phosphorylation) where does II ATP is formed

(a) Cyt C_1 and C (b) Cyt a and Cyt a_3

(c) Cyt b and cyt C_1 (d) Between $NADH_2$ and FMN

304. In Krebs' cycle, the conversion of succinyl CoA to succinic acid and requires:

(a) Acetyl CoA + GDP + ip (b) CoA + GTP + ip

(c) Acetyl CoA +GTP + ip (d) GDP + ip

305. In Krebs' cycle, how many water molecules are used ?

(a) 2 (b) 8 (c) 10 (d) 16

306. How many ATP molecules should be produced from the complete oxidation of a mole of active acetate or acetyl CoA

(a)38 ATP (b) 15 ATP (c) 12 ATP (d) 19 ATP

307. The proton pumps provide energy to cell through

(a) pH gradient and electropotential gradient (b) ATP and ADP

(c) Auxins and hormones (d) Carbohydrates and lipids

308. Dehydrogenation process in Kreb's cycle complete in

(a) 5 Step (b) 4 Step (c) 8 Step (d) 10 Step

PENTOSE PHOSPHATE PATHWAY

Basic Level

309. Photorespiration takes place only in

(a) Green parts of the plant (b)All the living cells of plant

(c) Mitochondria (d) Root

310. Discovery of photorespiration is based on

(a) Warburg effect (b) Pasteur effect

(c) Richmond- Lang effect (d) Cholodny-Went effect

311. Photorespiration is characteristic of

(a) CAM plants (b) C_3 plants (c) C_4 plants (d) None of the above

312. Which cell organelle is required in photorespiration

(a) Chloroplast (b) Mitochondria (c) Peroxisome (d) All the above

313. Substrate for photorespiration is

(a) Glycolate (b) Glyoxalate (c) Amino acid (d) None of these

314. Pentose phosphate pathway, an alternative pathway of respiration was elucidated by

(a) Horecker (b) Warburg and Dickens (c) Blackmann (d) Calvin

315. In which of the following process 36 ATP molecules are produced by per hexose molecule

(a) Glycolysis (b) Krebs cycle

(c) Direct oxidation pathway (d) None of the above

316. Starting point of photorespiration in C_4 plants is

(a) Glycerate (b) Glycolate (c) Glyoxylate (d) None of these

317. How many ATP and $NADH_2$ are produced in photorespiration

(a) 2 and 4 (b) 1 and 2 (c) 4 and 6 (d) Zero

318. A reduction of NADP to $NADPH_2$ is associated with

(a) EMP (b) HMP (c) Calvin cycle (d) Glycolysis

319. Enzymes of PPP of aerobic respiration are found in

(a) Mitochondria (b) Mitochondria and cytosol

(c) Cytosol (d) Cytosol and E.R.

320. Which one undergoes decarboxylation in hexose monophosphate shunt

(a) Glucose 6- phosphate (b)6-glucono γ - lactone

(c) 6- phosphogluconate (d)Fructose 6-phosphate

321. Hexose-monophosphate shunt occurs in one of the following

(a) Most of the plants and adipose tissue of animals (b)Only in bacteria

(c) Only in fungi (d)Only in yeast.

322. In pentose phosphate shunt, the number of NADPH formed per glucose molecule is

(a) 12 (b) 6 (c) 2 (d) 10

323. Which one of the following processes release larger amount of usable energy per-molecule of glucose broken down

(a) Fermentation (b) Lactic acid cycle in muscle

(c) Glycolysis in living cells (d) Pentosephosphate shunt in liver

Advance Level

324. Photorespiration is favoured by

(a) Low light and high O_2 (b) Low O_2 and high CO_2

(c) Low temperature and high O_2 (d) High O_2 and low CO_2

325. 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

326. HMP shunt is an alternative to

(a) Krebs cycle (b) Aerobic glycolysis (c) Calvin cycle (d) C_4 pathway

327. 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

328. The significance of pentose phosphate pathway (PPP) is

(a) To produce intermediates for CO_2 fixation

(b) To synthesize carbohydrates with 3, 4, 5 and 7 carbon atoms

(c) Both (a) and (b) (d) To produce more ATP

FACTORS AFFECTING RESPIRATION

Basic Level

329. A characteristic feature of ripening of some fruits (like banana) is sudden increase in respiration which is known as

(a) Climactric (b) Anthesis (c) Climatic (d) Photorespiration

330. High temperature does not affect the dry seeds as much as they affect germinating seeds because

(a) Hydration makes the enzyme more sensitive to temperature

(b) The seedlings are tender

(c) Dry seeds are hard and therefore are resistant to heat

(d) Dry seeds have more reserve food

331. 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

332. Respiratory rate is an organism is:

(a) Increased by a rise in temperature (b) Decreased by a rise in temperature

(c) Remains unaffected by temperature (d) None of the above

333. Cyanide resistant respiration is found in

(a) Plants (b) Bacteria (c) Viruses (d) Animals

334. Rate of energy formation in mitochondria is not directly dependent on

(a) PO_4 (b) ATP (c) GTP (d) O_2

335. The wrong statement amongst the following is

(a) The phenomenon of inhibition of glycolysis by O_2 is Pasteur effect

(b) TCA is amphibolic in nature

(c) HMP is alternate pathway of glycolysis

(d) Anaerobic oxidative reaction (glycolysis) may be increased by aeration.

336. KCN (potassium cyanide) stops cell activity by

(a) Coagulation protein carriers (b)Blocking trachea

(c) Preventing transfer of e from cytochrome a_3 to O_2(d)Preventing diffusion of O_2

337. When night temperature is low during winter season the size of potato tuber will

(a) Decrease (b) Increase

(c) No effect (d) Increase and decrease

338. 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

339. 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

340. The potato growing in hilly areas in 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

341. When a man enters a seed godown, the feeling is that of

(a) Freshness (b) Suffocation

(c) Freshness in the beginning and suffocation afterwards

(d) Suffocation in the beginning and freshness afterwards

***

ANSWER

ASSIGNMENT (BASIC & ADVANCE LEVEL)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
a	d	d	c	a	a	c	a	a	c	c	c	b	b	b	a	b	c	d	b
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
a	a	d	a	a	d	a	b	b	d	a	c	c	b	b	b	c	c	b	a
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
a	c	b	d	b	a	c	b	d	d	d	c	a	b	b	d	c	b	d	a
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
a	a	b	d	d	c	c	d	c	d	a	c	d	b	d	b	c	d	c	d
81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
a	c	d	b	c	b	c	d	c	c	b	c	b	b	b	b	a	d	c	b
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
b	a	c	d	d	c	c	b	c	c	b	c	a	b	c	b	b	a	b	c
121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140
a	a	c	c	a	b	c	a	b	d	b	d	b	d	b	d	c	c	b	b
141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160
d	d	d	a	d	a	b	b	d	b	d	c	c	d	a	a	a	d	d	a
161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
b	b	c	c	b	d	d	c	c	b	c	a	d	b	a	c	b	d	b	a
181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
c	c	b	a	a	b	c	b	b	d	b	b	d	a	d	b	a	a	b	b
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220
d	d	a	b	a	a	b	a	c	a	d	c	d	c	d	b	a	d	d	a
221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240
a	c	a	b	c	c	c	a	c	b	a	c	c	a	c	a	c	c	a	d
241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260
c	a	b	d	b	b	d	a	b	b	c	a	b	a	c	d	a	c	c	c
261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280
c	d	a	c	d	c	a	b	a	a	b	d	d	d	a	d	c	a	d	c
281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
a	a	d	c	b	d	b	d	c	b	c	d	b	d	c	a	b	b	b	b
301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320
d	c	c	d	b	c	a	a	a	a	b	d	a	b	c	d	d	b	c	c
321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340
a	a	d	d	c	b	c	c	a	a	a	a	a	c	d	c	b	c	d	b
341																			
c																			