XI 14

RESPIRATION IN PLANTS

SYLLABUS

Exchange gases; Cellular respiration-glycolysis, fermentation (anaerobic), TCA cycle and electron transport system (aerobic); Energy relations-Number of ATP molecules generated; Amphibolic pathways; Respiratory quotient.

KEY CONCEPTS

INTRODUCTION

* The catabolic processes that convert the energy in the chemical bonds of nutrients to chemical energy stored in ATP(Adenosine triphosphate, energy currency of cell) then occur inside cells,usually through a process known as cellular respiration.
* The term cellular respiration is used to distinguish it from organismic respiration, the exchange of oxygen and carbon dioxide with the environment by animals that have special organs,such as lungs or gills,for gas exchange.
* The compounds that are oxidised during this process are known as respiratory substrates (like carbohydrates, fats).
* Respiration is a multistep enzymatic process.
* Cellular respiration may be either aerobic or anaerobic. Aerobic respiration requires molecule oxygen (O_2) ,whereas anaerobic pathways , which include anaerobic respiration and fermentation , do not require oxygen .
* All three pathways - aerobic respiration,anaerobic respiration and fermentation- are exergonic and release free energy.

TYPES OF RESPIRATION

(i) **Aerobic respiration :** The complete oxidation of food with the use of oxygen and when entire carbon released, as CO_2 is called as aerobic respiration.

$$C_6H_{12}O_6 + 6O_2 + 6H_2O \xrightarrow[\text{cyto. \& mito.}]{\text{Enzyme in}} 6CO_2 + 12H_2O + 686 \text{ Kcal energy}$$

(ii) **Anaerobic respiration :** This is an incomplete oxidation. When food is oxidized into alcohol or organic acids without use of oxygen.

During it most of the energy is lost in form of heat. It occurs in cytoplasm and only 2ATP are produced.

$$C_6H_{12}O_6 \xrightarrow[\text{cytoplsam}]{\text{Enzyme in}} 2C_2H_5OH + 2CO_2 + 21 \text{ Kcal (2ATP)}$$

* Anaerobic respiration may takes place in bacteria, some lower parasitic animals (Ascaris, Taenia) plants, RBCs & muscles of human body. When oxygen is not available, then food is incompletely oxidised in to some organic compounds like ethanol, acetic acid, lactic acid.
* The amount of energy released in anaerobic respiration is much less than aerobic respiration.
* Fermentation is performed by some fungi & some bacteria (only by microbes) and is an extracellular process. No ATP is produced.

Both anaerobic respiration and fermentation are incomplete oxidations.

THE FOUR STAGES OF AEROBIC RESPIRATION

(i) **Glycolysis :** A 6-carbon glucose molecule is converted to two 3-carbon molecules of pyruvate and ATP and NADH are formed.

(ii) **Formation of acetyl coenzyme A :** Each pyruvate enters a mitochondrion and is oxidized to a 2-carbon group (acetate) that combines with coenzyme A, forming acetyl coenzyme A. NADH is produced, and carbon dioxide is released as a waste product.

(iii) **The citric acid cycle :** The acetate group of acetyl coenzyme A combines with a four-carbon molecule (oxaloacetate) to form a 6-carbon molecule (citrate). In the course of the cycle, citrate is recycled to oxaloacetate, and carbon dioxide is released as a waste product. Energy is captured as ATP and the reduced, high-energy compounds NADH and $FADH_2$.

(iv) **The electron transport chain and chemiosmosis :**
The electrons removed from glucose during the preceding stages are transferred from NADH and $FADH_2$ to a chain of electron acceptor compounds. As the electrons are passed from one electron acceptor to another, some of their energy is used to transport hydrogen ions (protons) across the inner mitochondrial membrane, forming a proton gradient. In a process known as chemiosmosis, the energy of this proton gradient is used to produce ATP.

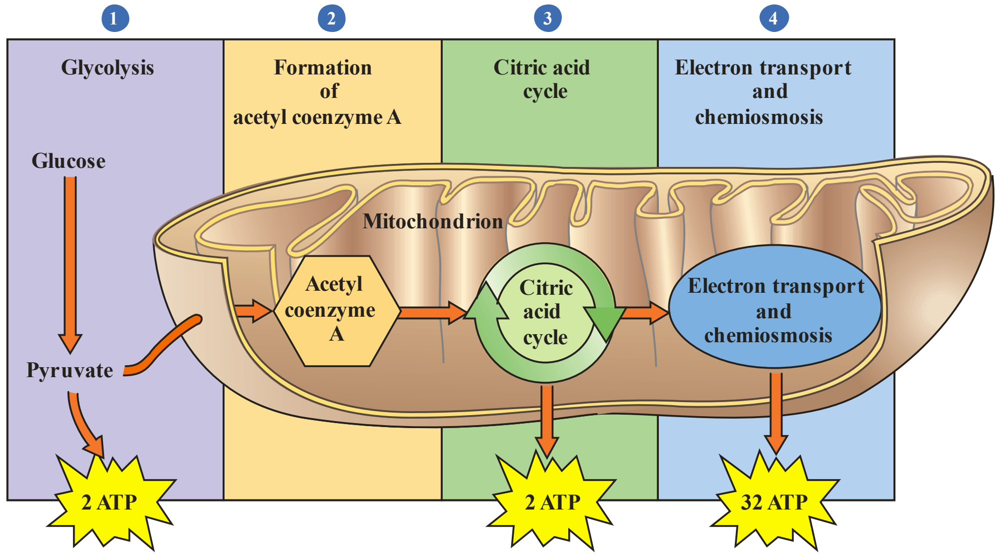


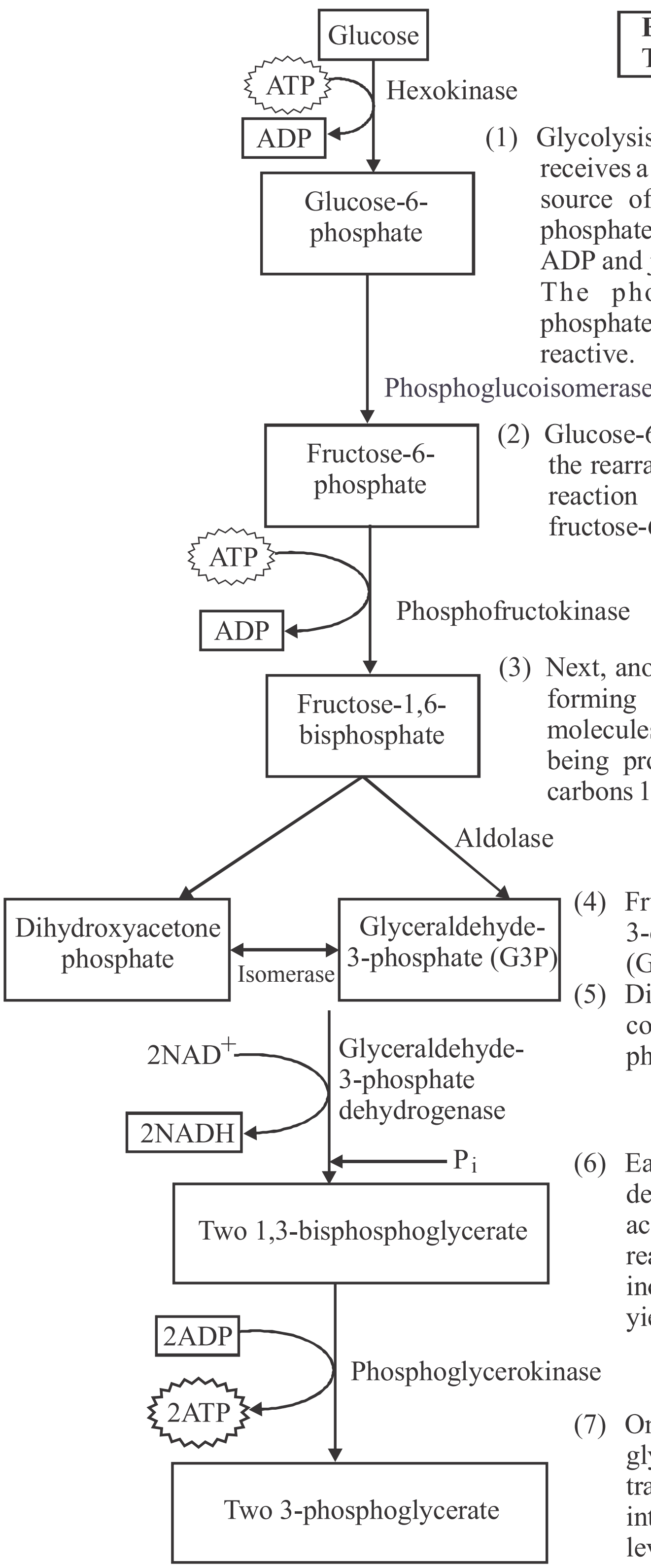
Figure : The four stages of aerobic respiration

Figure : The four stages of aerobic respiration.
(1) Glycolysis, the first stage of aerobic respiration, occurs in the cytosol. (2) Pyruvate, the product of glycolysis, enters a mitochondrion, where cellular respiration continues with the formation of acetyl CoA, (3) the citric acid cycle, and (4) electron transport/chemiosmosis. Most ATP is synthesized by chemiosmosis.

GLYCOLYSIS (EMP - (Embden, Meyerhof, Parnas) pathway)

Glyco: glucose ; Lysis: to split ; Glycolysis: "to split glucose"

A DETAILED LOOK AT GLYCOLYSIS



Energy investment phase and splitting of glucose
Two ATPs invested per glucose

(1) Glycolysis begins with a preparation reaction in which glucose receives a phosphate group from an ATP molecule. The ATP serves as a source of both phosphate and the energy needed to attach the phosphate to the glucose molecule. (Once the ATP is spent, it becomes ADP and joins the ADP pool of the cell until turned into ATP again.) The phosphorylated glucose is known as glucose-6-phosphate.Phosphorylation of the glucose makes it more chemically reactive.

(2) Glucose-6-phosphate undergoes another preparation reaction, the rearrangement of its hydrogen and oxygen atoms. In this reaction glucose-6-phosphate is converted to its isomer, fructose-6-phosphate.

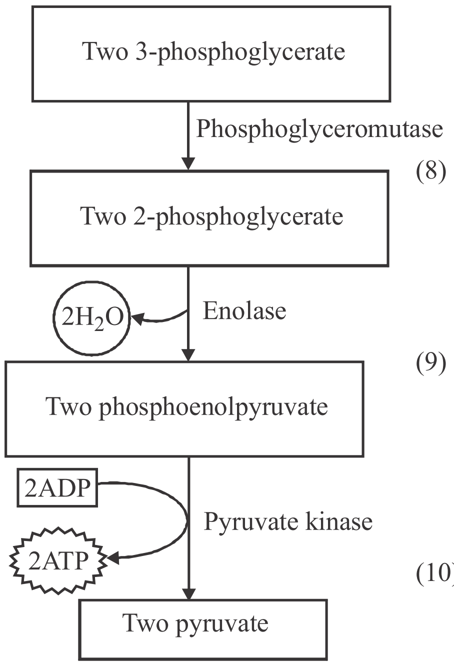
(3) Next, another ATP donates a phosphate to the molecule, forming fructose-1,6-bisphosphate. So far, two ATP molecules have been invested in the process without any being produced. Phosphate groups are now bound at carbons 1 and 6, and the molecule is ready to be split.

(4) Fructose-1,6-bisphosphate is then split into two 3-carbon sugars, glyceraldehyde-3-phosphate (G3P) and dihydroxyacetone phosphate.

(5) Dihydroxyacetone phosphate is enzymatically converted to its isomer, glyceraldehyde-3-phosphate, for further metabolism in glycolysis.

(6) Each glyceraldehyde-3-phosphate undergoes dehydrogenation with NAD^+ as the hydrogen acceptor. The product of this very exergonic reaction is phosphoglycerate, which reacts with inorganic phosphate present in the cytosol to yield 1,3-bisphosphoglycerate. (DGPA)

(7) One of the phosphates of 1,3-bisphosphoglycerate reacts with ADP to form ATP. This transfer of a phosphate from a phosphorylated intermediate to ATP is referred to as substrate-level phosphorylation.



(8) The 3-phosphoglycerate is rearranged to 2-phosphoglycerate by the enzymatic shift of the position of the phosphate group. This is a preparation reaction.

(9) Next, a molecule of water is removed, which results in the formation of a double bond. The product, phosphoenolpyruvate (PEP), has a phosphate group attached by an unstable bond.

(10) Each of the two PEP molecules transfers its phosphate group to ADP to yield ATP and pyruvate. This is a substrate level phosphorylation reaction.

Figure : A detailed look at glycolysis. A specific enzyme catalyzes each of the reactions in glycolysis. Note the net yield of two ATP molecules and two NADH molecules.

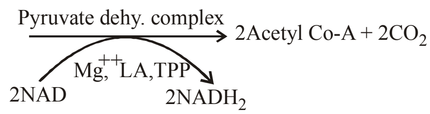
* The glycolysis is common phase for aerobic & anaerobic respirations both.
* In glycolysis, neither consumption of oxygen nor liberation of CO_2 take place.
* In glycolysis, 1 glucose, produces 2 mol. of pyruvic acids (3C)
* $2NADH_2$ & 2ATP are generated in glycolysis, which are equal to 8 ATP.
* Glycolysis is also known as oxidative anabolism or catabolic resynthesis, because it links with anabolism of fats and amino acids. An intermediate PGAL (3-phosphoglyceraldehyde) is used for the synthesis of glycerol later forms fats or lipid. PGA is used for synthesis of Serine, Glycine, Cystine. Alanine forms from pyruvate.

FORMATION OF ACETYL-Co-A (LINK REACTION)

* Glycolysis does not yield much ATP. So what is a cell to do?
  It must take the "energy rich" molecule, pyruvate, and extract the energy from it.
  This is done by shuttling the pyruvate into a special organelle ("little organ") in the cell called the mitochondrion.
  A special group of enzymes is located in the mitochondria that can do the job.
* The metabolic pathway is called the Krebs cycle, after the person who discovered it: Sir Hans Krebs.
* "The Bridge" : In order to move the pyruvate into mitochondria a complicated reaction occurs. It is technically not part of glycolysis, nor part of the Krebs cycle. We consider it "the bridge," since it bridges the two metabolic pathways. It occurs in mitochondria.
  Beginning molecule: pyruvate (3 carbons)
  Ending molecule: acetyl coenzyme A (2 carbons)
  Molecule lost: CO_2
  Molecule gained: coenzyme A. Energy gained: 1 NADH
* Acetyl coenzyme A (2-carbon), produced in the bridge, is fed into the Krebs cycle by reacting with oxaloacetate (4 carbon), producing citrate (6 carbon).
* Each time a carbon is removed from one of the molecules in the cycle, a carbon dioxide is produced.

* Acetyl Co-A is formed in perimitochondrial space by enzyme pyruvate dehydrogenase complex. (Mg^{++}, LA (Lipoic Acid), TPP (Thiamine pyrophosphate). NAD, CoA)

2-PA (Pyruvic acid) + 2Co-A



KREB CYCLE / TCA CYCLE / CITRIC ACID CYCLE

* This cycle was discovered by H.A. Kreb. (Nobel prize).
* TCA cycle occurs in mitochondrial matrix.
* Kreb cycle begins by formation of citric acid [TCA (Tri carboxylic acid)) & (Oxaloacetic acid) OAA is the acceptor molecule of Acetyl CoA in Kreb's cycle.
* A number of Krebs cycle intermediates are used in synthetic (anabolic) pathways, thus TCA cycle is also called amphibolic pathway or anaplerotic pathway.
* Begin with step (1), acetyl coenzyme A attaches to oxaloacetate. During the citric acid cycle, the entry of a two-carbon acetyl group is balanced by the release of two molecules of CO_2, Electrons are transferred to NAD^+ or FAD, yielding NADH and $FADH_2$, respectively, and ATP is formed by substrate-level phosphorylation.

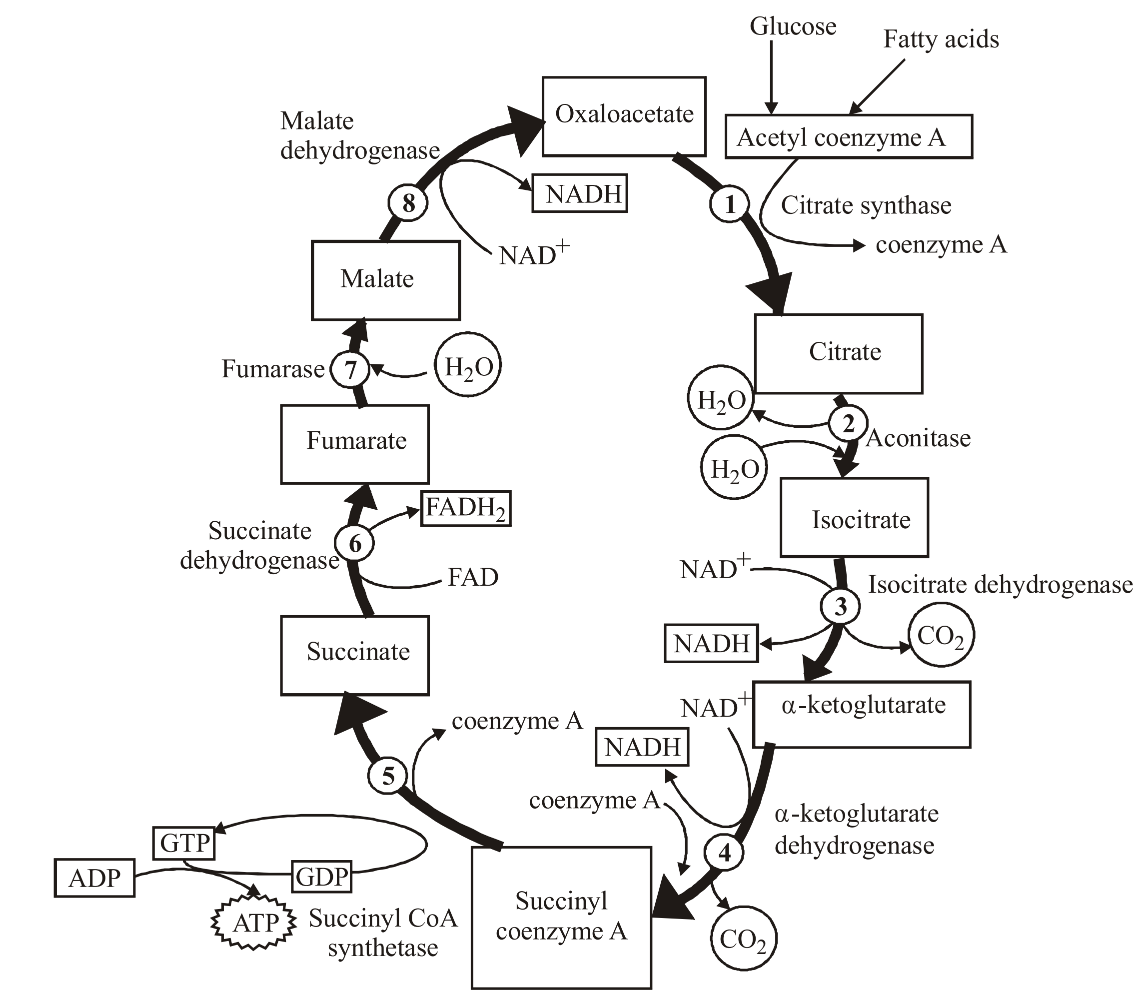


Figure : A detailed look at the citric acid cycle.

STEPS

(1) The unstable bond attaching the acetyl group to coenzyme A breaks. The 2-carbon acetyl group becomes attached to a 4-carbon oxaloacetate molecule, forming citrate, a 6-carbon molecule with three carboxyl groups. Coenzyme A is free to combine with another 2-carbon group and repeat the process.

(2) The atoms of citrate are rearranged by two preparation reactions in which first, a molecule of water is removed, and then a molecule of water is added. Through these reactions citrate is converted to its isomer, isocitrate.

(3) Isocitrate undergoes dehydro-genation and decarboxylation to yield the 5-carbon compound α-ketoglutarate.

(4) Next α-ketoglutarate undergoes decarboxylation and dehydrogenation to form the 4-carbon compound succinyl coenzyme A. This reaction is catalyzed by a multienzyme complex similar to the complex that catalyzes the conversion of pyruvate to acetyl coenzyme A.

(5) In this step succinyl coenzyme A is converted to succinate, and substrate-level phosphorylation takes place. The bond attaching coenzyme A to succinate (-S) is unstable. The break down of succinyl coenzyme A is coupled to the phosphorylation of GDP to form GTP (a compound similar to ATP). GTP transfers its phosphate to ADP, yielding ATP.

(6) Succinate is oxidized when two of its hydrogens are transferred to FAD, forming $FADH_2$.The resulting compound is fumarate.

(7) With the addition of water, fumarate is converted to malate.

(8) Malate is dehydrogenated, forming oxaloacetate. The two hydrogens removed are transferred to NAD^+. Oxaloacetate can now combine with another molecule of acetyl coenzyme A, beginning a new cycle.

ELECTRON TRANSPORT SYSTEM (ETS)& OXIDATIVE PHOSPHORYLATION

(TERMINAL OXIDATION OF NADH + H^+ & $FADH_2$)

* Energy at the End of the Krebs Cycle : One molecule of glucose is converted into the following by the end of the Krebs cycle:

	From glycolysis	From the bridge	From the Krebs cycle	Total
ATP	2	0	2	4
NADH	2	2	6	10
$FADH_2$	0	0	2	2

There Still is a Problem…

Most of the energy from the original glucose has not been converted into ATP.

It is in a form of energy the cell can't easily use—NADH and $FADH_2$. One more process is required…

* The electron transport chain and oxidative phosphorylation

This process will convert all the NADH and $FADH_2$ into ATP.

* We have seen how one molecule of glucose has been catabolized into the following molecules:

Glycolysis has generated: 2 ATP, 2 NADH

The bridge has generated: 2 NADH

The Krebs cycle has generated: 2 ATP, 6 NADH, 2 $FADH_2$

The problem:

One glucose has only produced 4 ATPs.

We need more ATPs: a lot more, if we want to keep “staying alive.” Where the Action Is Occuring

* The Krebs cycle occurs inside the matrices of mitochondria.

Therefore, the matrices of mitochondria are full of the energy-rich molecules NADH and $FADH_2$.

The solution to our ATP needs: Electron Transport and Oxidative Phosphorylation

Converts the energy from NADH and $FADH_2$ into ATP. How?

By using the energy from NADH and $FADH_2$ to pump hydrogen ions (H^+) from the mitochondrial matrix into the intermembrane space.

Then, by allowing the hydrogen ions (H^+) to flow back into the matrix in a controlled way, ATP is synthesized.

The Two-Step Process :

(i) Electron Transport : A group of molecules, called the electron transport chain, moves electrons from one to another.

* The members of the chain are collected into complexes.
* The electrons come from NADH and FADH2.
* The final electron acceptor is oxygen.
* As the electrons are transferred along the chain, energy is transferred as well : this movement of electrons is an exergonic process.
* This exergonic process allows work to be done.
* The work done is moving hydrogen ions (H^+) out of the mitochondrial matrix and into the intermembrane space.
* The energy is now stored as potential energy-like water behind a dam.
* Key idea: the transfer of electrons is an exergonic process that provides the energy to pump the hydrogen ions out of the matrix

(ii) ATP Synthesis : The enzyme ATP synthase, embedded in the inner mitochondrial membrane, allows the hydrogen ions (H^+) to flow back into the matrix through a hole in its center.

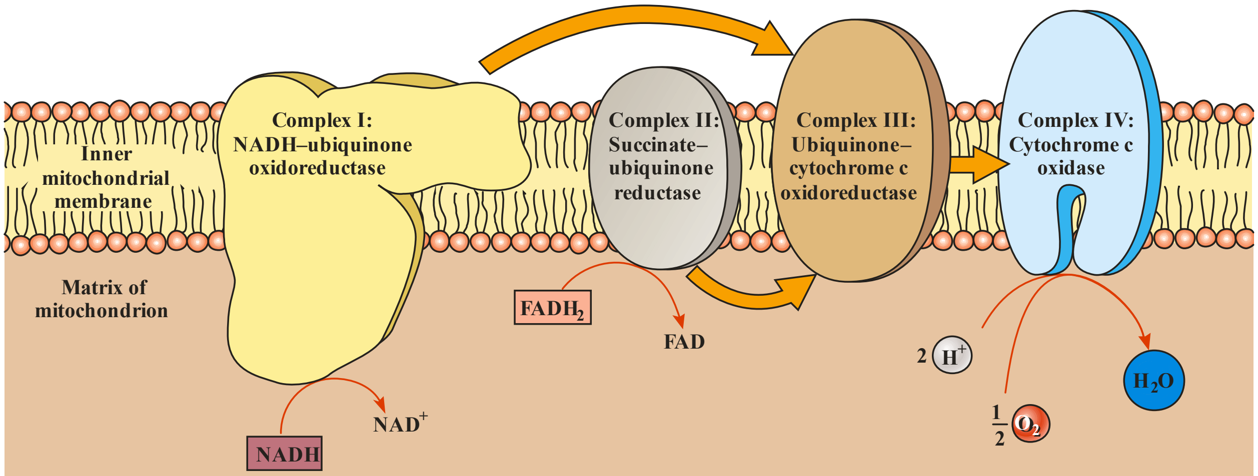


Figure : An overview of the electron transport chain

* It uses the ions' motion to convert ADP to ATP.
* This process is called oxidative phosphorylation because the ADP is phosphorylized, and via oxidation several oxygen derivatives can be formed.

The Electron Carriers

* **I** (NADH-ubiquinone oxidioreductase): An integral protein that receives electrons in the form of hydride ions from NADH and passes them on to ubiquinone
* **II** (Succinate-ubiquinone oxidioreductase *aka succinate dehydrogenase* from the TCA cycle): A peripheral protein that receives electrons from succinate (an intermediate metabolite of the TCA $_2$]. From succinate the electrons are received by [FAD] (a prosthetic group of the protein) which then become [$FADH_2$]. The electrons are then passed off to ubiquinone.
* **Q** (Ubiquinone/ ubiquinol): Ubiquinone (the oxidized form of the molecule) receives electrons from several different carriers; from I, II, Glycerol-3-phosphate dehydrogenase, and ETF. It is now the reduced form (ubiquinol) which passes its electron off to III.
* **III** (Ubiquinol-cytochrome c oxidioreductase): An integral protein that receives electrons from ubiquinol which are then passed on to Cytochrome c
* **IV** (Cytochrome c oxidase):An integral protein that receives electrons from Cytochrome c and transfers them to oxygen to produce water within the mitochondria matrix.
* **ATP Synthase:** An integral protein consisting of several different subunits. This protein is directly responsible for the production of ATP via chemiosmotic phosphorolation.

It uses the proton gradient created by several of the other carriers in the ETC to drive a mechanical rotor. The energy from that rotor is then used to phosphorolate ADT to ATP.

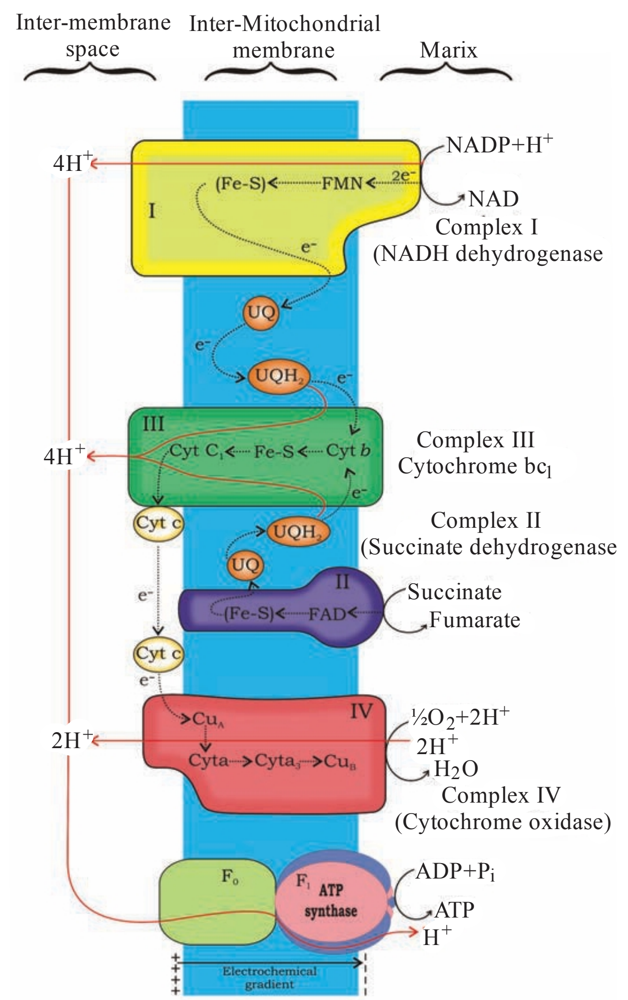


Figure : Electron Transport System (ETS)

* Complex I accepts electrons from NADH and serves as the link between glycolysis, the citric acid cycle,fatty acid oxidation and the electron transport chain.
* Electrons from NADH produced in the mitochondrial matrix during citric acid cycle are oxidised by an NADH dehydrogenase (complex I), and electrons are then transferred to ubiquinone located within the inner membrane.
* Complex II includes succinate dehydrogenase and serves as a direct link between the citric acid cycle and the electron transport chain.
* Ubiquinone also receives reducing equivalents via $FADH_2$ (complex II) that is generated during oxidation of succinate in the citric acid cycle.
* The reduced ubiquinone (ubiquinol) is then oxidised with the transfer of electrons to cytochrome c via cytochrome bc_1 complex (complex III).
* Cytochrome c is a small protein attached to the outer surface of the inner membrane and acts as a mobile carrier for transfer of electrons between complex III and IV.
* Complex IV refers to cytochrome c oxidase complex containing cytochromes a and a_3, and two copper centres.
* When the electrons pass from one carrier to another via complex I to IV in the electron transport chain, they are coupled to ATP synthase (complex V) for the production of ATP from ADP and inorganic phosphate.
* Oxidation of one molecule of NADH gives rise to 3 molecules of ATP, while that of one molecule of $FADH_2$ produces 2 molecules of ATP.

ATP Synthesis (Complex V)

* ATP synthesis occurs in the mitochondrial matrix.
* The endergonic formation of ATP from ADP + P_i is driven by two factors related to the electron transport

(i) **The proton gradient :** The transport of electrons caused protons to be pumped out of the matrix space. The resulting difference in pH can be coupled to ATP synthesis.

(ii) **The membrane potential :** The transport of H^+ out leaves the matrix at a negative electrical potential relative to the cytosol. The resulting difference in membrane potential can be coupled to ATP synthesis.

The "ATP synthase motor" (FoF_1 ATPase) converts the free energy of the proton gradient to chemical energy in the form of ATP.

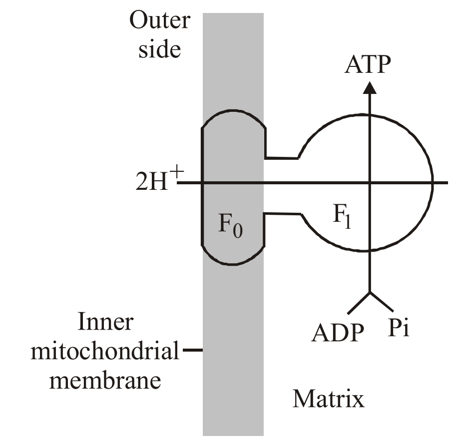


Figure : ATP synthesis in mitochondria

The F_0 Complex :

* Membrane-spanning, multiprotein complex (13 subunits: a, b_2, and c_{10})
* The antibiotic, oligomycin B, binds to Fo and prevents H^+ transport. Hence the name, Fo

The F_1 Complex

* Attached to Fo, it protrudes into the mitochondrial matrix.

AMPHIBOLIC PATHWAY

* Glucose is the favoured substrate for respiration. All carbohydrates are usually first converted into glucose before they are used for respiration.
* Fats would need to be broken down into glycerol and fatty acids first. If fatty acids were to be respired they would first be degraded to acetyl CoA and enter the pathway. Glycerol would enter the pathway after being converted to PGAL.
* The proteins would be degraded by proteases and the individual amino acids (after deamination) depending on their structure would enter the pathway at some stage within the Krebs' cycle or even as pyruvate or acetyl CoA.
* The respiratory pathway comes into the picture both during breakdown and synthesis of fatty acids. Similarly, during breakdown and synthesis of protein.
* The respiratory pathway is involved in both anabolism and catabolism, it would hence be better to consider the respiratory pathway as an amphibolic pathway rather than as a catabolic one.

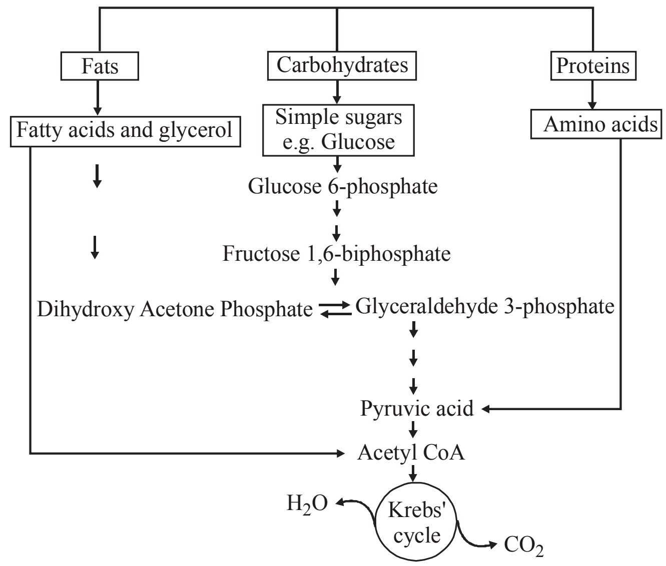


Figure : Interrelationship among metabolic pathways showing respiration mediated breakdown of different organic molecules to CO_2 and H_2O

THE RESPIRATORY BALANCE SHEET

* It is possible to make calculations of the net gain of ATP for every glucose molecule oxidised; but in reality this can remain only a theoretical exercise. These calculations can be made only on certain assumptions that:
* There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway following one after another.
* The NADH synthesised in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.
* None of the intermediates in the pathway are utilised to synthesise any other compound.
* Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.
* But this kind of assumptions are not really valid in a living system;

Bioenergetic of Respiration - (1 mol of glucose)

(1) EMP pathway :

(i) ATP forms at substrate level phosphorylation $\Rightarrow$ 4 ATP

(ii) ATP produces via ETS $2NADH_2 \Rightarrow$ 4 or 6 ATP

(iii) ATP consumed in glycolysis $\Rightarrow$ 2 ATP

8 or 10 ATP – 2 ATP = 6 or 8 ATP

(2) Link reaction or Gateway reaction :

$2NADH_2 = 6\ ATP$ (via ETS)

(3) Kreb cycle :

(i) ATP produced at substrate level phosphrylation $= 2\ GTP/2ATP$

(ii) ATP produced via ETS

$6\ NADH_2 \rightarrow 18\ ATP$

$2FADH_2 \rightarrow 4\ ATP$

24 ATP

Total $\rightarrow$ 36 or 38 ATP

* 1 Fructose 1,6-Biphosphate = 40 ATP
* 1 Pyruvic acid = 15 ATP
* 1 Acetyl co-A or 1 TCA cycle = 12 ATP

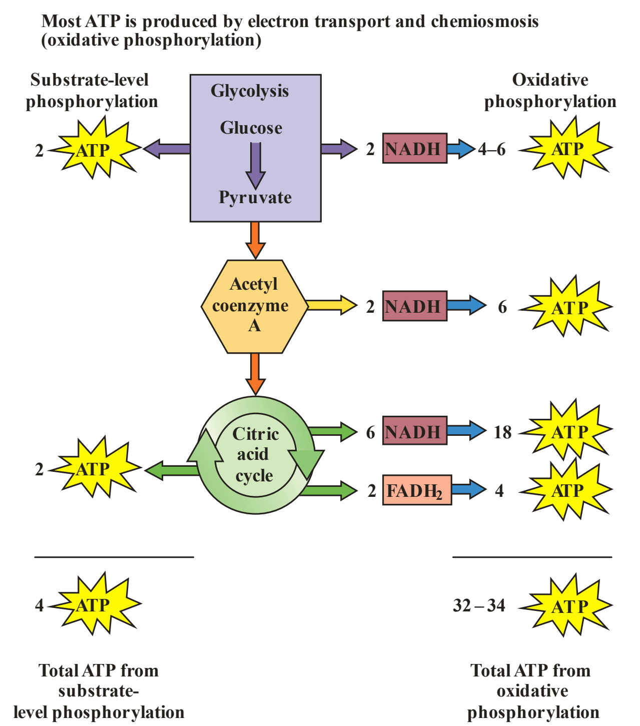


Figure : Energy yield from the complete oxidation of glucose by aerobic respiration

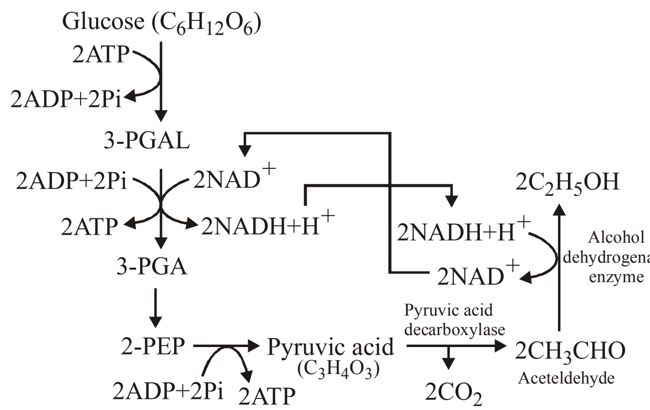
FERMENTATION

* Cruick Shank & Pasteur (1898).
* Fermentation is much similar to anaerobic respiration, but this is an extracellular process & substrate is present outside the cell. Energy released as heat, no ATP generated.

Types of Fermentation :

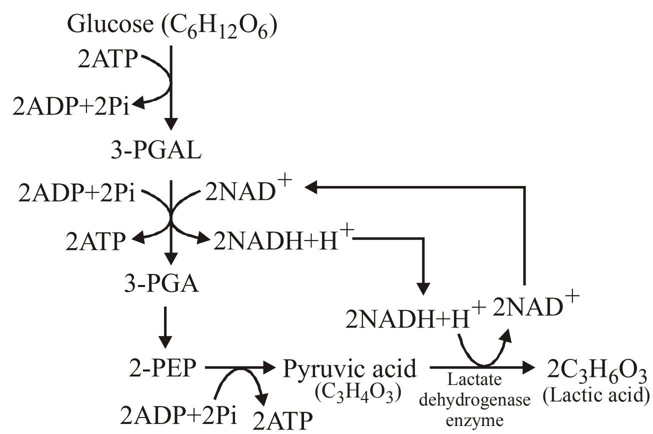
(i) Alcoholic fermentation :

This is the oldest & the best known type of fermentation performed by yeast & some bacteria.



(ii) Lactic acid fermentation :

It occurs during curd formation.



Comparison of fermentation and aerobic respiration:

* Fermentation accounts for only a partial breakdown of glucose whereas in aerobic respiration it is completely degraded to CO_2 & H_2O.
* In fermentation there is a net gain of only two molecules of ATP for each molecule of glucose degraded to pyruvic acid whereas many more molecules of ATP are generated under aerobic conditions.
* NADH is oxidised to NAD^+ rather slowly in fermentation, however the reaction is very vigorous in case of aerobic respiration.

RESPIRATORY QUOTIENT (R.Q.)

* The ratio of the volume of CO_2 released to the volume of O_2 taken in respiration is called R.Q.
* $$R.Q. = \frac{\text{Vol. of } CO_2 \text{ liberated}}{\text{Vol. of } CO_2 \text{ consumed}}$$

Value of R.Q. depends upon the type of respiratory substrate used & measured by Ganong's respirometer.

(i) **Carbohydrates :** R.Q. = 1

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

(ii) **Fat/Oil :** RQ = 0.70 or R.Q. < 1

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

Tripalmitin

* When proteins are respiratory substrates the ratio would be about 0.9.

(iii) **Anaerobic respiration :** RQ = ∞ ;

$$RQ = \frac{2CO_2}{0O_2} = \infty$$

CONCEPT REVIEW

* **Aerobic respiration** is a catabolic process in which a fuel molecule such as glucose is broken down to form carbon dioxide and water. It includes **redox reactions** that result in the transfer of electrons from glucose (which becomes oxidized) to oxygen (which becomes reduced).
* Energy released during aerobic respiration is used to produce up to 36 to 38 ATPs per molecule of glucose.
* The chemical reactions of aerobic respiration occur in four stages:glycolysis, formation of acetyl CoA, the citric acid cycle, and the electron transport chain/chemiosmosis.
* During **glycolysis**, a molecule of glucose is degraded to two molecules of **pyruvate**. Two ATP molecules (net) are produced by **substrate-level phosphorylation** during glycolysis. Four hydrogen atoms are removed and used to produce two NADH.
* During the formation of **acetyl CoA**, the two pyruvate molecules each lose a molecule of carbon dioxide, and the remaining acetyl groups each combine with **coenzyme A**, producing two molecules of acetyl CoA; one NADH is produced per pyruvate.
* Each acetyl CoA enters the **citric acid cycle** by combining with a four-carbon compound, **oxaloacetate**, to form **citrate**, a six carbon compound. Two acetyl CoA molecules enter the cycle for every glucose molecule. For every two carbons that enter the cycle as part of an acetyl CoA molecule, two leave as carbon dioxide. For every acetyl CoA, hydrogen atoms are transferred to three NAD^+ and one FAD; only one ATP is produced by substrate-level phosphorylation.
* Hydrogen atoms (or their electrons) removed from fuel molecules are transferred from one electron acceptor to another down an **electron transport chain** located in the mitochondrial inner membrane; ultimately these electrons reduce molecular oxygen, forming water. In **oxidative phosphorylation**, the redox reactions in the electron transport chain are coupled to synthesis of ATP through the mechanism of **chemiosmosis**.
* Glycolysis occurs in the cytosol, and the remaining stages of aerobic respiration take place in the mitochondrion.
* In glycolysis, each glucose molecule produces 2 NADH and 2 ATP (net). The conversion of 2 pyruvates to acetyl CoA results in the formation of 2 NADH. In the citric acid cycle, the 2 acetyl CoA molecules are metabolized to form 6 NADH, 2 $FADH_2$ and 2 ATP. Adding up, we have 4 ATP, 10 NADH, and 2 $FADH_2$.
* When the 10 NADH and 2 $FADH_2$ pass through the electron transport chain, 32 to 34 ATP are produced by chemiosmosis. Therefore, each glucose molecule produces a total of up to 36 to 38 ATP.
* In chemiosmosis, some of the energy of the electrons in the electron transport chain is used to pump protons across the inner mitochondrial membrane into the intermembrane space. This pumping establishes a proton gradient across the inner mitochondrial membrane. Protons accumulate within the intermembrane space, lowering the pH.

* In **anaerobic respiration**, electrons are transferred from fuel molecules to an electron transport chain; the final electron acceptor is an inorganic substance such as nitrate or sulfate, not molecular oxygen.

* **Fermentation** is an anaerobic process that does not use an electron transport chain. There is a net gain of only two ATPs per glucose; these are produced during glycolysis. To maintain the supply of NAD^+ essential for glycolysis, hydrogen atoms are transferred from NADH to an organic compound derived from the initial nutrient.

* Yeast cells carry out **alcohol fermentation**, in which ethyl alcohol and carbon dioxide are the final waste products. Certain fungi, prokaryotes, and animal cells carry out **lactate (lactic acid) fermentation**, in which hydrogen atoms are added to pyruvate to form lactate, a waste product.

* The major steps in aerobic respiration and the sites where they occur are listed in the given table.

Step	Site of occurrence
1. Glycolysis	1. Cytoplasm
2. Krebs cycle	2. Matrix of mitochondria
3. Electron transport system	3. Inner mitochondrial membrane
4. Oxidative phosphorylation	4. F_0-F_1 particles in the inner mitochondrial membrane

* **Summary Reactions for Aerobic Respiration**

The complete oxidation of glucose:

$$C_6H_{12}O_6 + 6O_2 + 6\,H_2O \rightarrow 6\,CO_2 + 12\,H_2O + E\ (36\text{-}38\ ATP)$$

Glycolysis:

$$C_6H_{12}O_6 + 2ATP + 2ADP + 2P_i + 2NAD^+ \rightarrow 2\ \text{Pyruvate} + 4\ ATP + 2\ NADH + H_2O$$

The conversion of pyruvate to acetyl CoA:

$$2\ \text{Pyruvate} + 2\ \text{Coenzyme A} + 2\ NAD^+ \rightarrow 2\ \text{Acetyl CoA} + 2\ CO_2 + 2\ NADH$$

The citric acid cycle:

$$2\ \text{Acetyl CoA} + 6\ NAD^+ + 2\ FAD + 2\ ADP + 2\ P_i + 2\ H_2O \rightarrow 4\ CO_2 + 6\ NADH + 2\ FADH_2 + 2\ ATP + 2\ CoA$$

The processing of the hydrogen atoms of NADH and $FADH_2$ in the electron transport chain:

$$NADH + 3\ ADP + 3\ P_i + \frac{1}{2}O_2 \rightarrow NAD^+ + 3\ ATP + H_2O$$

$$FADH_2 + 2\ ADP + 2\ P_i + \frac{1}{2}O_2 \rightarrow FAD + 2\ ATP + H_2O$$

* **Summary reactions for Fermentation**

Lactate fermentation:

$$C_6H_{12}O_6 \rightarrow 2\ \text{Lactate} + \text{Energy}\ (2\ ATP)$$

Alcohol fermentation:

$$C_6H_{12}O_6 \rightarrow 2\ CO_2 + 2\ \text{Ethyl alcohol} + \text{Energy}\ (2ATP)$$

* **Table : Summary of Aerobic Respiration**

S.N.	Stage	Summary	Some starting materials	Some end products
1.	Glycolysis (in cytosol)	Series of reactions in which glucose is degraded to pyruvate; net profit of 2 ATPs; hydrogen atoms are transferred to carriers; can proceed anaerobically.	Glucose, ATP, NAD^+, ADP, P_i	Pyruvate, ATP, NADH
2.	Formation of acetyl CoA (in mitochondria)	Pyruvate is degraded and combined with coenzyme A to form acetyl CoA; hydrogen atoms are transferred to carriers; CO_2 is released	Pyruvate, coenzyme A, NAD^+	Acetyl CoA, CO_2, NADH
3.	Citric acid cycle (in mitochondria)	Series of reactions in which the acetyl portion of acetyl CoA is degraded to CO_2; hydrogen atoms are transferred to carriers; ATP is synthesized	Acetyl CoA, H_2O, NAD^+, FAD, ADP, P_i	CO_2, NADH, $FADH_2$, ATP
4.	Electron transport & chemiosmosis (in mitochondria)	Chain of several electron transport molecules; electrons are passed along chain; released energy is used to form a proton gradient; ATP is synthesized as protons diffuse down the gradient; oxygen is final electron acceptor.	NADH, $FADH_2$, O_2, ADP, P_i	ATP, H_2O, NAD^+, FAD

* **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 is a linear pathway.	It is a cyclic pathway.
It oxidizes glucose partly, producing pyruvate.	It oxidises acetyl coenzyme A fully.
It consumes 2 ATP molecules.	It does not consume ATP
It generates 2 ATP molecules net from 1 glucose molecules	It generates 2 GTP/ATP molecules from 2 succinyl coenzyme A molecules.
It yields 2 NADH per glucose molecule.	It yields 6 NADH molecules and 2 $FADH_2$ molecules from 2 acetyl coenzyme A molecules.
It does not produce CO_2.	It produces CO_2.
All enzyme catalysing glycolytic reactions are dissolved in cytosol.	Two enzymes of Krebs cycle reactions are located in the inner mitochondrial membrane, all others are dissolved in matrix.

* **Table : A Comparison of Aerobic Respiration, Anaerobic Respiration, and Fermentation**

	Aerobic Respiration	Anaerobic Respiration	Fermentation
Immediate fate of electrons in NADH	Transferred to electron transport chain	Transferred to electron transport chain.	Transferred to organic molecule.
Terminal electron acceptor of electron transport chain	O_2	Inorganic substances such as NO_3^- or SO_4^{2-}	No electron transport chain.
Reduced product (s) formed.	Water	Relatively reduced inorganic substances	Relatively reduced organic compounds (commonly, alcohol or lactate)
Mechanism of ATP Synthesis	Oxidative phosphorylation/ chemiosmosis; also substrate level phosphor-rylation	Oxidative phosphory-lation/chemiosmosis; also substrate-level phosphorylation	Substrate-level phosphorylation only (during glycolysis)

IMPORTANT POINTS

* The reactions of Krebs cycle take place in matrix of mitochondria.
* The number of molecules of pyruvic acid formed from one molecule of glucose at the end of glycolysis is 2.
* RQ. is ratio of CO_2 produced to O_2 consumed.
* R.Q. for the fatty substance / fat is less than one.
* R.Q.for glucose / carbohydrate is 1.
* RQ of sprouting potato is 1.
* RQ. of protein rich pulse/ Pisum sativum is less than one.
* In mitochondria, ATP synthesis occurs at the cristae.
* Acetyl CoA is key intermediate compound linking glycolysis to Krebs cycle.
* Maximum amount of energy / ATP is liberated on oxidation of fats.
* End product of glycolysis is pyruvic acid.
* Sequence in Krebs cycle is Isocitric acid → oxalosuccinic acid → α-ketoglutaric acid.
* Out of 36 ATP molecules produced per glucose molecule during respiration. 2 are produced outside mitochondria and 34 inside mitochondria.

* Krebs cycle is complete oxidation of acetyl CoA without electron transport.
* Cytochromes are electron acceptors.
* Ubiquinone of ETC is not a protein.
* Fructose 1 : 6 biphosphate splits into two triose phosphates by enzyme aldolase.
* Lactic acid fermentation does not produce CO_2 and NADH.
* Iron-porphyrin protein complex occurs in cytochrome.
* Fructose 6-phosphate is changed to fructose 1,6-diphosphate by phosphofructokinase.
* Substrate phosphorylation occurs during α-ketoglutaric acid $\rightarrow$ Succinic acid.
* Krebs cycle is absent in erythrocytes.
* Cofactor required for formation of acetyl CoA is TPP, Lipoic acid, Mg^{2+}, CoA.
* Hexokinase enzymes is absent in mitochondria.
* Oxygen is reduced to water in electron transport.
* Acetyl CoA forms a 6-C compound after combines with oxaloacetic acid.
* 3-phosphoglyceraldehyde is oxidised in glycolysis to form 1, 3-biphosphoglycerate.
* In mitochondria, enzyme cytochrome oxidase is present in inner membrane.
* Decarboxylation occurs during Kreb cycle.
* Glycolysis reduces 2 molecules of NAD^+ per glucose.
* In ETC, first ATP is formed when hydrogen passes from NAD to FMN.
* Chemiosmotic theory of ATP synthesis in mitochondrion is based on H^+ gradient.
* In TCA cycle, during the conversion of succinyl Co-A to succinic acid a molecule of GTP is synthesised.

  This is a substrate level phosphorylation. In a coupled reaction, GTP is converted to GDP with the simultaneous synthesis of ATP from ADP.

QUESTION BANK

EXERCISE - 1 (LEVEL-1) [NCERT EXTRACT]

SECTION - 1 (VOCABULARY BUILDER)

Choose one correct response for each question.
For Q.1-Q.4
Match the column I with column II.

Q.1

Column I	Column II
a. Fats made of three fatty-acid chains attached to glycerol.	(i) Glycogen
b. Glycolysis metabolite made from glycerol	(ii) Glyceraldehyde
c. Storage form of glucose.	(iii) Triglycerides
d. Result of running reactions of glycolysis in reverse	(iv) Glucose

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

Q.2

Column-I	Column-II
a. TCA cycle	(i) Inner mitochondrial membrane
b. $F_0 - F_1$ particles	(ii) Hans Krebs
c. End product of glycolysis	(iii) Oxidative decarboxylation
d. Pyruvate dehydrogenase	(iv) Pyruvic acid

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

Q.3

Column-I	Column-II
a. R.Q.	(i) Chemiosmotic ATP synthesis.
b. Mitchel	(ii) Muscle fatigue.
c. Cytochromes	(iii) Inner mitochondrial membrane
d. Lactic acid	(iv) Alcoholic fermentation
e. Yeast	(v) Respirometer

Codes
(A) a-(v), b-(i), c-(iii), d-(ii), e-(iv)
(B) a-(v), b-(i), c-(iii), d-(iv), e-(ii)
(C) a-(i), b-(v), c-(ii), d-(iii), e-(iv)
(D) a-(v), b-(ii), c-(iv), d-(iii), e-(i)

Q.4

Column-I	Column-II
a. Glycolysis	(i) Inner mitochondrial membrane
b. TCA cycle	(ii) Mitochondrial matrix
c. ETS	(iii) Cytoplasm

Codes
(A) a-(iii), b-(i), c-(ii) (B) a-(iii), b-(ii), c-(i)
(C) a-(i), b-(ii), c-(iii) (D) a-(ii), b-(i), c-(iii)

SECTION - 2 (BASIC CONCEPTS BUILDER)

For Q.5 to Q.30 :
Choose one word for the given statement from the list.

Citrate synthase, Fermentation, Glycos, Catabolism, Lysis, 2, 3, Oxidized, Infinity, tricarboxylic acid cycle, Oxaloacetic acid (OAA), Lactic acid, Mitochondria, Electron transport system, Glucose, Chlorophyll-a, Glycolysis, Lactic acid and ethyl alcohol, Inner Mitochondrial membrane, Phosphorylation, EMP pathway, Partially, Inner mitochondrial membrane.

Q.5 The term glycolysis has originated from the Greek word ____ and ___.

Q.6 The metabolic pathway through which the electron passes from one carrier to another is called ____.

Q.7 Respiratory substrates are the organic substances which are __ during respiration to liberate energy.

Q.8 Break down process is also called ____.

Q.9 Anaerobic respiration is also called as ____.

Q.10 During the processof aerobic respiration, ___ gets oxidized and its electrons get transferred to the electron transport chain while in photosynthesis, _____ gets oxidized to transfer moleculesto the electron transport chain.

Q.11 In anaerobic respiration bacteria produce ____.

Q.12 The enzyme ____ is used to catalysed when condensation of acetyl group with oxaloacetic acid to yield citric acid.

Q.13 In aerobic respiration complete oxidation of pyruvate by the stepwise removal of all the hydrogen atom makes ____ molecule of CO_2.

Q.14 Kreb's cycle is completed with the formation of ____.

Q.15 Phase common in aerobic and anaerobic respiration is ____.

Q.16 Citric acid cycle is also known as ____.

Q.17 Number of NADH + H^+ molecule released in Kreb's cycle is ____.

Q.18 The NADH synthesised in ___ is transferred into the mitochondria and undergoes oxidative ____.

Q.19 Respiratory quotient in anaerobic respiration is ____.

Q.20 Glucose break down takes place ______ in fermentation.

Q.21 Electron Transport System (ETS) occurs in ____.

Q.22 Aerobic respiration takes place in ____.

Q.23 It is possible to make calculation of the net gain of ATP for every ____ molecule oxidised.

Q.24 Glycolysis is also known as ____.

Q.25 The product of aerobic glycolysis in skeletal muscle and anaerobic fermentation in yeast are respectively _____ and ______.

Q.26 In cellular respiration, all of the ATP is produced in the mitochondria. **[True / False]**

Q.27 All of the energy released by the breakdown of sugars is stored in ATP. **[True / False]**

Q.28 Carbohydrates are used by the cell to produce energy, while proteins and fats are used to store energy in the cell. **[True / False]**

Q.29 The electron transfer system and chemiosmosis produce the maximum number of ATP molecules. **[True / False]**

Q.30 Cellular respiration takes place only in eukaryotic cells. **[True / False]**

SECTION - 3 (ENHANCE PROBLEM SOLVING SKILLS)

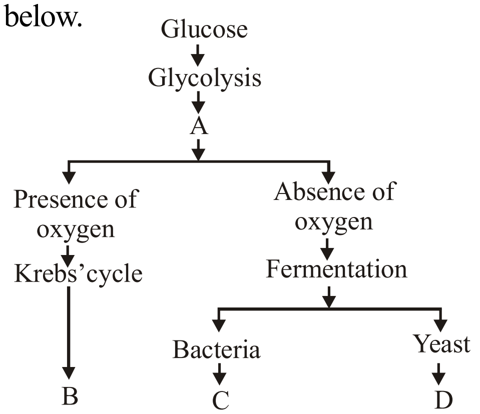
Choose one correct response for each question.

PART - 1 : GLYCOLYSIS

Q.31 Sucrose is converted into
(A) glucose and fructose
(B) triose phospate and pyruvic acid
(C) oxilic acid and citric acid
(D) citric acid and pyruvic acid

Q.32 In which of the following reactions of glycoysis, oxidation takes place?
(A) Glucose 6-PO_4 to fructose 6-PO_4.
(B) Glyceraldehyde 3-phosphate to 1, 3-diphosphoglycerate.
(C) 1, 3-diphosphoglycerate to 3-phosphoglycerate
(D) 2-phosphoglycerate to phosphoglycerate.

Q.33 The following is a simplified scheme showing the fate of glucose during aerobic and anaerobic respiration. Identify the end products that are formed at stages indicated as A, B, C and D. Identify the correct option from those given below.



(A) A-Carbon dioxide and water, B-Pyruvic acid, C-Ethyl alcohol and carbon dioxide, D-Lactic acid
(B) A-Pyruvic acid, B-Carbon dioxide and water, C-Lactic acid, D- Ethyl alcohol and carbon dioxide
(C) A-Pyruvic acid, B-Carbon dioxide and water, C-Ethyl alcohol and carbon dioxide, D- Lactic acid
(D) A-Pyruvic acid, B-Ethyl alcohol and carbon dioxide, C-Lactic acid, D-Carbon dioxide and water

Q.34 In plants, glucose is derived from which of the following?
(A) Protein (B) Fat
(C) Oxalic acid (D) Sucrose

Q.35 Which one is correct sequence in glycolysis?
(A) G-6- P $\rightarrow$ PEP $\rightarrow$ 3PGAL $\rightarrow$ 3PGA
(B) G-6-P $\rightarrow$ 3PGAL $\rightarrow$ 3PGA $\rightarrow$ PEP
(C) G- 6- P $\rightarrow$ PEP $\rightarrow$ 3PGA $\rightarrow$ 3PGAL
(D) G- 6- P $\rightarrow$ 3PGA $\rightarrow$ 3PGAL $\rightarrow$ PEP

Q.36 What is true about the end products of glycolysis?
(A) 2 pyruvic acid + 2 ATP + 2 $NADH_2$
(B) 2 pyruvic acid + 2 $NADH_2$
(C) 1 pyruvic acid + 2 ATP + 2 $NADH_2$
(D) 2 pyruvic acid + 1 ATP + 1 $NADH_2$

Q.37 Which of the following scientist has given the scheme of glycolysis?
(A) Gustav Embden et. al
(B) Kreb et. al
(C) Fritz Lipmann et. al
(D) None of these

Q.38 In glycolysis, from glucose to pyruvic acid involves more than seven reactions. Each individual reaction needs
(A) one molecule of ATP
(B) one molecule of ADP
(C) one molecule of NAD
(D) one molecule of specific enzyme

Q.39 What is the correct order of the stages of cellular respiration?
(A) Kreb's cycle – Electron transport chain – Glycolysis
(B) Electron transport chain – Kreb's cycle – Glycolysis
(C) Glycolysis – Kreb's cycle - Electron transport chain
(D) Glycolysis – Electron transport chain – Kreb's cycle

Q.40 Glycolysis takes place in
(A) all living cells
(B) eukaryotic cells only
(C) prokaryotic cells only
(D) None of these

Q.41 Where is ATP synthesised in glycolysis?
(A) When 1,3 di PGA is changed into 3PGA.
(B) When glucose is converted into glucose-6-phosphate.
(C) Both (A) and (B)
(D) When. 1,6 diphosphate is broken in triose phosphate.

PART - 2 : FERMENTATION

Q.42 During anaerobic respiration in yeast
(A) H_2O and CO_2 are end-products.
(B) CO_2, ethanol and energy are end-products.
(C) CO_2 and H_2O are end-products.
(D) CO_2, acetic acid and energy are end-products.

Q.43 Fermentation is represented by the equation
(A) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 686$ k cal
(B) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + 59$k cal
(C) $6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6O_2$
(D) $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Q.44 The oxidation of pyruvic acid to CO_2 and H_2O is called –
(A) fermentation
(B) citric acid cycle
(C) glycolysis
(D) oxidative phosphorylation

Q.45 During the exercise, pyruvic acid is reduced to
(A) lactic acid (B) fumaric acid
(C) glutamic acid (D) oxaloacetic acid

Q.46 Anaerobic respiration can occur in
(A) lower organism
(B) higher plants and animals
(C) Both (A) and (B)
(D) None of the above

Q.47 In anaerobic respiration in plants
(A) oxygen is absorbed.
(B) oxygen in released.
(C) carbon dioxide is released.
(D) carbon dioxide is absorbed.

Q.48 Pyruvate $\rightarrow C_2H_5OH + CO_2$
The above reaction needs two enzymes named as
(A) pyruvate decarboxylase and alcohol dehydrogenase.
(B) pyruvate decarboxylase and enolase.
(C) pyruvate decarboxylase and pyruvate kinase.
(D) pyruvate carboxylase and aldolase.

Q.49 Identify a, b and c in the given reaction of lactic acid fermentation and select the correct option.

$$\text{Pyruvic acid} + a \xrightleftharpoons[\text{FMN, } Zn^{2+}]{\text{Lactate dehydrogenase}} b + c.$$

(A) a = NADH, b = Lactic acid + CO_2, c = NAD^+
(B) a = NADH, b = Lactic acid, c = NAD^+
(C) a = NAD^+, b = Lactic acid, c = NADH
(D) a = NAD^+, b = Lactic acid + CO_2, c = NADH

Q.50 In respiration incomplete oxidation of glucose is done under
(A) aerobic respiration
(B) anaerobic respiration
(C) Both (A) and (B)
(D) None of these

Q.51 In alcoholic fermentation
(A) there is no electron donor.
(B) oxygen is the electron acceptor.
(C) triose phosphate is the electron donor, while acetaldehyde is the electron acceptor.
(D) triose phosphate is the electron donor, while pyruvic acid is the electron acceptor.

PART - 3 : AEROBIC RESPIRATION

Q.52 Citric acid cycle was discovered by
(A) Hans Krebs'; 1937
(B) Jon Mathai; 1937
(C) Parna; 1936
(D) Embeden; 1936

Q.53 Identify A and B in the given reaction.
Pyruvic acid +Co-A + NAD^+

$$\xrightarrow[\text{Pyruvate dehydrogenas}]{Mg^{2+}} A + B + NADH + H^+$$

(A) A-PEP; B-CO_2
(B) A-Acetyl Co-A; B-CO_2
(C) A-CO_2; B-H_2O
(D) A-Acetyl Co-A; B- H_2O

Q.54 Which of the following conversions involve ATP synthesis during glycolysis?
(A) Glucose $\rightarrow$ Glucose -6-phosphate
(B) Fructose-6-phosphate $\rightarrow$ Fructose-1, 6-biphosphate
(C) 1,3-bisphosphoglyceric acid (BPGA) $\rightarrow$ 3-phosphoglyceric acid (PGA)
(D) All of these

Q.55 Acetyl Co-A binds to oxaloacetic acid to form
(A) formaldehyde (B) citrate
(C) acetate (D) isocitrate

Q.56 Decarboxylation is involved in
(A) electron transport system
(B) glycolysis
(C) Krebs' cycle
(D) lactic acid fermentation

Q.57 In oxidative decarboxylation, enzyme used to
(A) pyruvate decarboxylase
(B) pyruvate dehydrogenase
(C) pyruvate hydrogeneticase
(D) pyruvate dehydrogeneticase

Q.58 Which of these steps in Krebs' cycle indicates substrate level phosphorylation?
(A) Conversion of succinyl acid to α-ketoglutaric acid.
(B) Conversion of succinic acid to malic acid.
(C) Conversion of succinyl Co-A to succinic acid.
(D) Conversion of malic acid to oxaloacetic acid.

Q.59 Fate of pyruvic acid during aerobic respiration is
(A) lactic acid fermentation
(B) alcoholic fermentation
(C) oxidative decarboxylation
(D) oxidative phosphorylation.

Q.60 Aerobic respiration is
(A) the process in which complete oxidation of organic substances in the absence of oxygen.
(B) the process in which complete oxidation of organic substances in the presence of oxygen.
(C) the process in which incomplete oxidation of organic substances in the absence of oxygen.
(D) the process in which incomplete oxidation of organic substances in the presence of oxygen.

Q.61 Sequence of events in Kreb's cycle is
(A) acetyl Co-A $\rightarrow$ Citrate $\rightarrow$ Pyruvate $\rightarrow$ Oxaloacetic acid $\leftarrow$ fumarate $\leftarrow$ Malate $\leftarrow$ Succinate α-ketoglutaralte
(B) Acetyl Co-A $\rightarrow$ Citric acid $\rightarrow$ α-ketoglutarate acid $\rightarrow$ Oxaloacetic acid $\leftarrow$ Malic acid $\leftarrow$ Fumaric acid $\leftarrow$ Succinic acid
(C) Acetyl Co-A $\rightarrow$ Citric acid $\rightarrow$ Malic acid Oxaloacetic $\leftarrow$ Oxaloacetic acid Succinic $\leftarrow$ α-ketoglutaric acid
(D) All are wrong

Q.62 In Krebs' cycle
(A) ATP is converted into ADP.
(B) pyruvic acid is converted into CO_2 & H_2O.
(C) glucose is converted into CO_2.
(D) pyruvic acid is converted into ATP.

Q.63 TCA cycle enzymes are present in
(A) cytoplasm.
(B) inter membrane space of mitochondria.
(C) mitochondrial matrix.
(D) inner membrane of mitochondria.

Q.64 Krebs' cycle is also called metabolic sink as it is a common pathway for –
(A) carbohydrates, fats and proteins (amino acids).
(B) carbohydrates and fats only.
(C) carbohydrates and organic acids only.
(D) proteins and fats only.

Q.65 Which of these are respiratory poisons or inhibitors of electron transport chain?
(A) Cyanides (B) Antimycin-A
(C) Carbon monoxide (D) All of these

Q.66 Which one of following is complex V of the ETS of inner mitochondrial membrane?
(A) NADH dehydrogenase
(B) Cytochrome oxidase
(C) Ubiquinone
(D) ATP synthase

Q.67 Connecting link between glycolysis and Kreb's cycle is
(A) Acetyl Co-A (B) pyruvic acid
(C) CO_2 (D) None of these

Q.68 FAD is electron acceptor during which of the following?
(A) α- ketoglutarate $\rightarrow$ Succinyl Co. A
(B) Succinic acid $\rightarrow$ Fumaric acid
(C) Succinyl Co-A $\rightarrow$ Succinic acid
(D) Fumaric acid $\rightarrow$ Malic acid

Q.69 In which part of mitochondria does ATP synthesis occur?
(A) F_1
(B) F_0
(C) Cristae
(D) Inner membrane of mitochondria

Q.70 In citric acid cycle first step is
(A) Acetyl Co-A combines with oxalo acetic acid.
(B) Acetyl Co-A combines with citric acid.
(C) citric acid combines with oxaloacetic acid
(D) citric acid combines with malic acid.

Q.71 In electron transport system, which of the following acts as a final hydrogen acceptor.
(A) Oxygen (B) Hydrogen
(C) Calcium (D) Ubiquinone

Q.72 In aerobic respiration removal 3 molecules of CO_2 occurs in –
(A) matrix of the mitochondria
(B) inner membrane of the mitochondria
(C) Both (A) and (B)
(D) Anywhere in the mitochondria

Q.73 Indentify enzyme A in the given reaction of Kreb's cycle. $OAA + Acetyl\ Co\text{-}A + H_2O \xrightarrow{A} Citric\ acid + Co\text{-}A$
(A) Oxaloacetate synthetase
(B) Citrate synthetase
(C) Aconitase
(D) Dehydrogenase

Q.74 In mitochondria, enzyme cytochrome oxidase is present in
(A) outer membrane (B) perimitochondrial
(C) inner membrane (D) matrix

Q.75 The main purpose of electron transport chain is to –
(A) cycle NADH + H^+ back to NAD^+
(B) use the intermediate from TCA cycle
(C) breakdown pyruvic acid
(D) All of the above

Q.76 Oxidative decarboxylation is
(A) pyruvic acid is oxidised to carbon dioxide
(B) pyruvic acid is subsidised to oxygen
(C) pyruvic acid is oxidised to oxygen
(D) pyruvic acid is subsidised to carbon dioxide

Q.77 Which one is product of aerobic respiration?
(A) CO_2 and H_2O (B) Ethyl alcohol
(C) Lactic acid (D) Pyruvic acid

Q.78 Which one is not correct about Kreb's cycle?
(A) It is also called citric acid cycle.
(B) The intermediate compound which links glycolysis with Kreb's cycle is malic acid.
(C) It occurs in mitochondria.
(D) It starts with six carbon compound.

PART - 4 : AMPHIBOLIC PATHWAY

Q.79 Which one of the following reaction is an example of oxidative decarboxylation?
(A) Conversion of succinate to fumarate.
(B) Conversion of fumarate to malate.
(C) Conversion of pyruvate to acetyl Co-A.
(D) Conversion of citrate to isocitrate.

Q.80 Aerobic respiratory pathway is appropriately termed as –
(A) catabolic (B) parabolic
(C) amphibolic (D) anabolic

Q.81 Synthesis process in organism is also called
(A) catabolism (B) anabolism
(C) Both (A) and (B) (D) None of these

PART - 5 : RESPIRATORY QUOTIENT

Q.82 The Respiratory Quotient (RQ) or respiratory ratio is

(A) $RQ = \frac{\text{Volume of } O_2 \text{ evolved}}{\text{Volume of } CO_2 \text{ consumed}}$

(B) $RQ = \frac{\text{Volume of } O_2 \text{ consumed}}{\text{Volume of } CO_2 \text{ evolved}}$

(C) $RQ = \frac{\text{Volume of } CO_2 \text{ consumed}}{\text{Volume of } O_2 \text{ evolved}}$

(D) $RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$

Q.83 Respiratory Quotient (RQ) is one in case of
(A) fatty acids (B) nucleic acids
(C) carbohydrate (D) organic acids

Q.84 The RQ value of oxalic acid is
(A) 1.0 (B) 0.7
(C) 4 (D) 1.5

Q.85 Respiratory quotient can vary due to
(A) temperature (B) respiratory substrate
(C) light and oxygen (D) respiratory product

Q.86 The respiratory quotient during cellular respiration would depend on the
(A) nature of enzymes involved
(B) nature of the substrate
(C) amount of carbon dioxide released
(D) amount of oxygen utilised

Q.87 The respiratory quotient (RQ) of some of the compounds are 4.1 & 0.7. These compounds an identified respectively as –
(A) malic acid, palmitic acid and tripalmitin
(B) oxalic acid, carbohydrate and tripalmitin
(C) tripalmitin, malic acid and carbohydrate
(D) palmitic acid, carbohydrate and oxalic acid

Q.88 If RQ is 0.6 in a respiratory metabolism, it would mean that –
(A) carbohydrates are used as respiratory substrate.
(B) organic acids are used as respiratory substrate.
(C) the oxidation of the respiratory substrate consumed more oxygen than the amount of CO_2 released.
(D) the oxidation of respiratory substrate consumed less oxygen than the amount of CO_2 released

PART - 6 : RESPIRATORY BALANCE SHEET

Q.89 Calculation of ATP gain for every glucose is made on certain assumptions.Choose the correct option in accordance with the statement given above.
(A) The pathway functioning is sequential and orderly.
(B) One substrate forms the reactant for the others.
(C) TCA cycle and ETS pathway follow one after another.
(D) All of the above

Q.90 NADH is oxidised to NAD^+ slowly during ____
(A) aerobic respiration (B) Krebs' cycle
(C) fermentation (D) glycolysis

Q.91 Choose the correct statement –
(A) Intermediates in the pathway are utilised to synthesise other compounds.
(B) No alternative substrates other than glucose is allowed to enter the pathway at intermediate stages.
(C) None of the substrate is respired in the pathway at intermediary stages.
(D) Pathway functioning is insequential.

EXERCISE - 2 (LEVEL-2)

Choose one correct response for each question.

Q.1 How many ATP molecules are invested in glycolysis?
(A) 2 (B) 4
(C) 32 (D) 38

Q.2 Which of the following is the end product of glycolysis?
(A) glucose (B) pyruvate
(C) citric acid (D) acetyl-CoA

Q.3 Where in the cell does glycolysis take place?
(A) cytoplasm
(B) mitochondrial matrix.
(C) intermembrane compartment.
(D) inner membrane of mitochondria.

Q.4 Before processing fat through cellular respiration, it must be broken down into ___.
(A) amino acids
(B) glycerol and fatty acids
(C) nucleotides
(D) monosaccharides

Q.5 All of the following steps of cellular respiration produce ATP except –
(A) the citric acid cycle
(B) pyruvate oxidation
(C) glycolysis
(D) the electron transfer system

Q.6 Which of the following steps of cellular respiration generates the maximum number of ATP molecules?
(A) citric acid cycle (B) pyruvate oxidation
(C) glycolysis (D) electron transfer system

Q.7 How many ATP molecules are produced by the citric acid cycle?
(A) 1 (B) 2
(C) 4 (D) 32

Q.8 Only about 30 percent of the energy from glucose is stored in ATP. What happens to the remaining energy?
(A) It is stored in NADH.
(B) It is released as heat.
(C) It is converted to fat.
(D) It is wasted as light energy.

Q.9 During exercising, when oxygen is limited, additional ATP molecules are produced in the muscles by –
(A) aerobic respiration
(B) anaerobic respiration
(C) the citric acid cycle
(D) the electron transfer system

Q.10 Where in the cell does the fermentation step take place?
(A) cytoplasm
(B) mitochondrial matrix
(C) intermembrane compartment
(D) inner membrane of mitochondria

Q.11 Yogurt is a bacterial culture. As this culture older, it becomes increasingly sour due to the accumulation of lactic acid. Which of the following steps in bacteria is responsible for producing this acid?
(A) glycolysis
(B) citric acid cycle
(C) electron transfer system
(D) fermentation

Q.12 While making the dough for bread, addition of yeast causes the dough to rise. Which of the following chemical(s) released by yeast makes this happen?
(A) lactic acid
(B) alcohol and carbon dioxide
(C) ATP and NADH
(D) pyruvate and acetyl-CoA.

Q.13 What is the net production of ATP molecules during anaerobic respiration of one glucose molecule?
(A) 2 (B) 4
(C) 32 (D) 38

Q.14 Per glucose molecule, which of the following organisms makes more ATP molecules?
(A) strict aerobes (B) strict anaerobes
(C) Both (A) and (B) (D) None of these

Q.15 The chemical whose presence or absence decides if pyruvates will go in the mitochondria for oxidation or remain in the cytoplasm for fermentation is –
(A) carbon dioxide (B) oxygen
(C) ATP (D) NADH

Q.16 The process of splitting larger molecules into smaller ones is an aspect of metabolism called –
(A) anabolism
(B) fermentation
(C) catabolism
(D) oxidative phosphorylation

Q.17 The synthetic aspect of metabolism is called –
(A) anabolism
(B) fermentation
(C) catabolism
(D) oxidative phosphorylation

Q.18 Production of acetyl CoA from pyruvate –
(A) is anabolic
(B) takes place in mitochondria
(C) takes place in cytoplasm
(D) takes place in endoplasmic reticulum

Q.19 The pathway through which glucose is degraded to pyruvate is called
(A) aerobic respiration
(B) the citric acid cycle
(C) the oxidation of pyruvate
(D) glycolysis

Q.20 The reactions of ___ take place within the cytosol of eukaryotic cells.
(A) glycolysis
(B) oxidation of pyruvate
(C) the citric acid cycle
(D) chemiosmosis

Q.21 ATP synthase –
(A) is a cytochrome
(B) converts ATP to ADP
(C) couples protons to electrons to form water
(D) resides in cristae of mitochondria

Q.22 Before pyruvate enters the citric acid cycle, it is decarboxylated, oxidized,and combined with coenzyme A, forming acetyl CoA, carbondioxide, and one molecule of
(A) NADH (B) $FADH_2$
(C) ATP (D) ADP

Q.23 Dehydrogenase enzymes remove hydrogen atoms from fuel molecules and transfer them to acceptors such as –
(A) O_2 and H_2O (B) ATPand FAD
(C) NAD^+ and FAD (D) CO_2 and H_2O

Q.24 Which of the following is a major source of electrons for the electron transport chain?
(A) H_2O (B) ATP
(C) NADH (D) ATP synthase

Q.25 In the process of ___, electron transport and ATP synthesis are coupled by a proton gradient across the inner mitochondrial membrane.
(A) chemiosmosis (B) deamination
(C) anaerobic respiration (D) glycolysis

Q.26 Which of the following is a common energy flow sequence in aerobic respiration, starting with the energy stored in glucose?
(A) glucose $\rightarrow$ NADH $\rightarrow$ pyruvate $\rightarrow$ ATP
(B) glucose $\rightarrow$ ATP $\rightarrow$ NADH $\rightarrow$ electron transport chain
(C) glucose $\rightarrow$ NADH $\rightarrow$ electron transport chain $\rightarrow$ ATP
(D) glucose $\rightarrow$ oxygen $\rightarrow$ NADH $\rightarrow$ water

Q.27 In the electron transport chain
(A) water is the final electron acceptor.
(B) cytochromes carry electrons.
(C) the final e^- acceptor has a negative redox potential
(D) glucose is a common carrier molecule

Q.28 During strenuous muscle activity, the pyruvate in muscle cells may accept hydrogen from NADH to become-
(A) acetyl CoA (B) ethyl alcohol
(C) lactate (D) pyruvate

Q.29 Pyruvate dehydrogenase complex is used in converting –
(A) Pyruvate to glucose
(B) Glucose to pyruvate
(C) Pyruvic acid to lactic acid
(D) Pyruvate to acetyl Co-A

Q.30 The first compound of TCA cycle is –
(A) Oxalo succinic acid (B) Oxalo acetic acid
(C) Citric acid (D) Cis aconitic acid

Q.31 Which of the following is coenzyme-II –
(A) NAD (B) NADP
(C) FAD (D) None of the above

Q.32 Where does the synthesis of enzyme occur in a cell –
(A) Inside the nucleus
(B) In lysosomes
(C) On the surface of ribosome
(D) Inside the vacuole

Q.33 Excess of ATP inhibits the enzyme -
(A) Phosphofructokinase
(B) Hexokinase
(C) Aldolase (Lyases)
(D) Pyruvate decarboxylase

Q.34 The process of oxidative phosphorylation takes place
(A) Mitochondria (B) Chloroplasts
(C) Ribosomes (D) Cytoplasm

Q.35 R.Q. of which diet is less than unit –
(A) Carbohydrate (B) Fats
(C) Organic acid (D) Sugar

Q.36 Pyruvic acid is the end product of which process?
(A) Kreb's cycle
(B) Calvin cycle
(C) Pentose phosphate pathway
(D) Glycolysis

Q.37 1 molecule glucose + 6 molecule of O_2 and 38 ADP combined to form 6 H_2O, 6 CO_2 and –
(A) 38 molecules of ATP (B) 28 ATP
(C) 38 ADP (D) 28 ADP

Q.38 Number of ATP obtained at the end of Kreb's cycle –
(A) 2 ATP (B) 4 ATP
(C) 36 ATP (D) 38 ATP

Q.39 R.Q. is represented by –
(A) O_2 / CO_2 (B) CO_2 / O_2
(C) $V_2 / V_2 – V_1$ (D) O_2 taken in

Q.40 Which is the site of Kreb's cycle –
(A) Chloroplast (B) Golgibody
(C) Mitochondria (D) Endoplasmic reticulum

Q.41 Conversion of pyruvic acid into ethyl alcohol is mediated –
(A) Phosphatase
(B) Dehydrogenase
(C) Decarboxylase & dehydrogenase
(D) Catalase

Q.42 The commonest living, which can respire in the absence of O_2 is –
(A) Fish (B) Yeast
(C) Potato (D) Chlorella

Q.43 The formation of Acetyl Co-A from pyruvic acid is the result of its –
(A) Reduction
(B) Dehydration
(C) Phosphorylation
(D) Oxidative decarboxylation

Q.44 Which of the following is link between carbohydrate and fat metabolism –
(A) CO_2 (B) Acetyl Co-A
(C) Pyruvic acid (D) Citric acid

Q.45 End product of glycolysis is
(A) Citric acid
(B) Glyceraldehyde
(C) Phosphoglyceraldehyde
(D) Pyruvic acid

Q.46 First reaction in pentose phosphate pathway is –
(A) Oxidation of glucose-6-phosphate
(B) 6-Phosphogluconic acid
(C) Ribose-5-phosphate
(D) Fructose-5-phosphate

Q.47 Oxidation of one molecule of glucose in aerobic respiration results in the formation of –
(A) 36 ATP molecules (B) 38 ATP molecules
(C) 3 ATP molecules (D) 15 ATP molecules

Q.48 Enzyme cytochrome oxidase can be inhibited by
(A) Iodo acetate (B) Azides & Cyanides
(C) Oligonlycins (D) Dinitrophenol

Q.49 In the electron transport chain during terminal oxidation, the cytochrome, which donates electrons to O_2 is –
(A) Cytochrome-b (B) Cyto-C
(C) Cyto-a_3 (D) Cyto-f

Q.50 Number of oxygen atoms required for aerobic oxidation of one pyruvate –
(A) 5 (B) 8
(C) 10 (D) 12

Q.51 Alternate name of Krebs cycle is –
(A) Glyoxylate cycle (B) Glycolate cycle
(C) Citric acid cycle (D) EMP Pathway

Q.52 Respiration in plants
(A) Occurs only during day
(B) Results in the formation of vitamins
(C) Is characteristic of all living cells
(D) Often requires CO_2

Q.53 In plants energy is produced during the process of –
(A) Photosynthesis (B) Transpiration
(C) Respiration (D) Water absorption

Q.54 A very important feature of respiration is that –
(A) It liberates energy
(B) It provides O_2
(C) Utilize CO_2
(D) Synthesize complex compounds

Q.55 β-oxidation takes place in –
(A) Cell Membrane
(B) Mitochondrial Membrane
(C) Oxysomes Head
(D) Perimitochondrial space

Q.56 Which enzyme break downs the fructose-I, 6-Diphosphate–
(A) Hexokinase (B) Phosphatase
(C) Aldolase (D) None

Q.57 Link between glycolysis & TCA cycle is –
(A) Pyruvic acid (B) Acetyl Co-A
(C) Citric acid (D) None

Q.58 Acceptor of acetyl Co-A in Kreb's-cycle is
(A) Malic acid (B) Fumaric acid
(C) α-ketoglutaric acid (D) Oxalo acetic acid

Q.59 When 2-pyruvic acids forms two lactic acid by anaerobic respiration then –
(A) One ATP is lost (B) 3 ATP is lost
(C) 6 ATP is lost (D) None

Q.60 During oxidative phosphorylation following provides energy for the ATP formation
(A) Co-A
(B) NADPH
(C) Efflux of proton to PMS
(D) Pyruvic acid

Q.61 Anaerobic respiration takes place in –
(A) Ribosome (B) Nucleus
(C) Cytoplasm (D) Vacuole

Q.62 Among the following, identify the substrate required for the only oxidative reaction that occurs in the process of glycolysis.
(A) 3-phosphoglyceric acid
(B) Glyceraldehyde 3-phosphate
(C) Fructose-6-phosphate
(D) Glucose-6-phosphate

Q.63 RQ value of 4 may be expected for the complete oxidation of which one of the following?
(A) Glucose (B) Malic acid
(C) Oxalic acid (D) Tartaric acid

EXERCISE - 3 (LEVEL-3)

Choose one correct response for each question.

Q.1 Match each of the following terms with its correct definition.

(i)	Fermentation	a.	Organisms that must have oxygen to survive.
(ii)	Lactate fermentation	b.	Organisms that require an oxygen-free environment to survive.
(iii)	Alcohol fermentation	c.	Process that converts pyruvates into lactate or alcohol.
(iv)	Strict anaerobes	d.	Process that produces alcohol and carbon dioxide.
(v)	Facultative anaerobes	e.	Process that produces lactate in muscles.
(vi)	Strict aerobes	f.	Organisms that can do aerobic or anaerobic respiration.

(A) (i) - c; (ii) - e; (iii) - d; (iv) - b; (v) - f; (vi) - a
(B) (i) - c; (ii) - e; (iii) - b; (iv) - d; (v) - f; (vi) - a
(C) (i) - d; (ii) - e; (iii) - c; (iv) - b; (v) - f; (vi) - a
(D) (i) - c; (ii) - d; (iii) - e; (iv) - b; (v) - a; (vi) - f

Q.2 Arrange the following steps of cellular respiration in the correct sequence.
(a) Citric acid cycle
(b) Electron transfer system
(c) Glycolysis
(d) Pyruvate oxidation
Choose the correct option –
(A) c, d, a, b (B) d, a, b, c
(C) a, b, c, d (D) c, d, b, a

Q.3 Which multi protein complex in the electron transport chain is responsible for reducing molecular oxygen?
(A) complex I (NADH-ubiquinone oxido-reductase)
(B) complex II (succinate-ubiquinone-reductase)
(C) complex III (ubiquinone-cytochrome c oxidoreductase)
(D) complex IV (cytochrome c oxidase)

Q.4 A net profit of only 2 ATPs can be produced anaerobically from the __ of one molecule of glucose, compared with a maximum of 38 ATPs produced in __.
(A) fermentation; anaerobic respiration.
(B) aerobic respiration; fermentation.
(C) aerobic respiration; anaerobic respiration.
(D) fermentation; aerobic respiration.

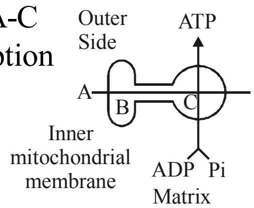
Q.5 Enzymes, vitamins and hormones can be classified into a single category of biological chemicals, because all of these–
(A) enhance oxidative metabolism.
(B) are conjugated proteins.
(C) are exclusively synthesized in the body of a living organism.
(D) help in regulating metabolism.

Q.6 During which stage in the complete oxidation of glucose are the greatest number of ATP molecules formed from ADP –
(A) Conversion of pyruric acid to acetyl CoA.
(B) Electron transport chain
(C) Glycolysis
(D) Krebs cycle

Q.7 The deficiencies of micronutrients, not only affects growth of plants, but also vital functions such as photosynthetic and mitochondrial electron flow. Among the list given below, which group of three elements shall affect most, both photosynthetic and mitochondrial electron transport
(A) Cu, Mn, Fe (B) Co, Ni, Mo
(C) Mn, Co, Ca {4) Ca, K, Na

Q.8 Chemiosmotic theory of ATP synthesis in the chloroplast and mitochondria is based on –
(A) Proton gradient.
(B) Accumulation of K ions.
(C) Accumulation of Na ions.
(D) Membrane potential.

Q.9 In the given diagram of ATP synthesis in mitochondria. Identify A-C and Choose the correct option accordingly.



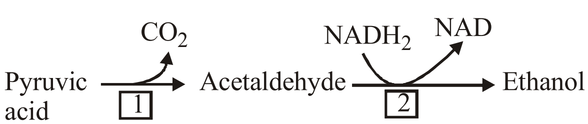
(A) A -H^+, B- F_1, C- F_0
(B) A- $3H^+$, B -F_0, C- F_1
(C) A-$2H^+$, B-F_0, C-F_1
(D) A-$5H^+$, B-F_1, C-F_0

Q.10 In which of the following, reduction of NAD does not occur?
(A) Isocitric acid $\rightarrow$ α-ketoglutaric acid
(B) Malic acid $\rightarrow$ Oxaloacetic acid
(C) Pyruvic acid $\rightarrow$ Acetyl coenzyme A
(D) Succinic acid $\rightarrow$ Fumaric acid

Q.11 If RQ is less than 1.0 in a respiratory metabolism, it would mean that –
(A) carbohydrates are used as respiratory substrate.
(B) organic acids are used as respiratory substrate.
(C) the oxidation of the respiratory substrate consumed more oxygen than the amount of CO_2 released.
(D) the oxidation of the respiratory substrate consumed less oxygen than the amount of CO_2 released.

Q.12 If O_2 is not present, yeast cells break down glucose to –
(A) $CO_2 + H_2O$ (B) CO_2 + Lactic acid
(C) $C_2H_5OH + H_2O$ (D) C_2H_5OH and CO_2

Q.13 Identify the enzymes 1 and 2 in the given reaction and select the correct option.



(A) 1 = Ethanol dehydrogenase, 2 = Pyruvate decarboxylase
(B) 1 = Ethanol decarboxylase, 2 = Pyruvate dehydrogenase
(C) 1 = Pyruvate decarboxylase, 2 = Ethanol dehydrogenase
(D) 1 = Pyruvate dehydrogenase, 2 = Ethanol dehydrogenase

Q.14 In the electron transport system present in the inner mitochondrial membrane, complex I and IV are respectively.
(A) NADH dehydrogenase and $FADH_2$.
(B) $NADH_2$ and NADH dehydrogenase.
(C) NADH dehydrogenase and cytochrome oxidase complex.
(D) NADH dehydrogenase & ATP synthetase.

Q.15 R.Q. of maturing fatty seeds will be
(A) 1 (B) More than one
(C) 0 (D) 0.7

Q.16 Anaerobic degradation of proteins by microbes is known –
(A) Putreification (B) Degradation
(C) Decomposition (D) None

Q.17 In which one of the following do the two names refer to one and the same thing :
(A) Kreb's cycle and Calvin cycle.
(B) Tricarboxylic acid cycle and citric acid cycle.
(C) Citric acid cycle and Calvin cycle.
(D) Tricarboxylic acid cycle and urea cycle.

Q.18 In alcohol fermentation –
(A) Triose phosphate is the electron donor, while acetaldehyde is the electron acceptor
(B) Triose phosphate is the electron donor, while pyruvic acid is the electron acceptor
(C) There is no electron donor.
(D) Oxygen is the electron acceptor.

Q.19 In glycolysis, during oxidation electrons are removed by–
(A) Molecular oxygen (B) ATP
(C) Glyceraldehyde (D) NAD^+

Q.20 Aerobic respiration is how many times useful than anaerobic respiration –
(A) 2 (B) 8
(C) 19 (D) 38

Note (Q.21-Q.27) :
(A) Statement- 1 is True, Statement-2 is True, Statement-2 is a correct explanation for Statement -1.

(B) Statement -1 is True, Statement -2 is True ; Statement-2 is NOT a correct explanation for Statement-1.
(C) Statement - 1 is True, Statement- 2 is False.
(D) Statement -1 is False, Statement -2 is False.

Q.21 **Statement 1 :** Glycolysis occurs in cytoplasm.
Statement 2 : Enzymes for glycolysis are found in cytoplasm. It is common in aerobic/anaerobic respiration.

Q.22 **Statement 1:** The inner membrane of mitochondria contains systems involving electron transport.
Statement 2 : The mitochondrial matrix contains enzymes of Kreb's cycle.

Q.23 **Statement 1 :** The product of the first reaction of the Kreb's cycle is citric acid, a six carbon compound.
Statement 2 : The first reaction of the Kreb's cycle is the condensation of acetyl CoA with oxaloacetate.

Q.24 **Statement 1 :** Substrate level phosphorylation is present in glycolysis.
Statement 2 : Substrate level phosphorylation causes synthesis of ATP.

Q.25 **Statement 1 :** One way of indicating the ATP yield from oxidative phosphorylation is the P/O ratio.
Statement 2 : The cell stores 40% of the chemical energy.

Q.26 **Statement 1 :** F_1 particles are present in the inner mitochondrial membrane.
Statement 2 : An electron gradient formed on the inner mitochondrial membrane, forms ATP.

Q.27 **Statement 1 :** During photophosphorylation (of photosynthesis), light energy is utilized for the production of proton gradient during ATP synthesis.
Statement 2: In respiration, energy of oxidation-reduction is utilized for the phosphorylation and thus the process is called oxidative phosphorylation.

Q.28 Glycolysis
I. causes partial oxidation of glucose (one molecule) to form 2-molecules of pyruvic acid and 2 ATP as net gain.
II. takes place in all living cells.
III. uses 2 ATP at two steps.
IV. scheme was given by Gustav Embden, Otto Mayerhof and J Parnas.
Choose the correct option containing appropriate statements from the above.
(A) I, II and III (B) I, II and IV
(C) I, II, III and IV (D) Only I

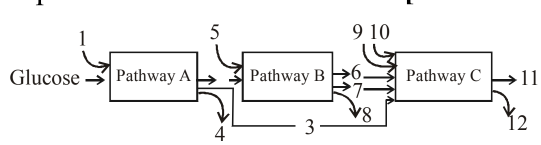
Q.29 In glycolysis, NADH + H^+ is formed from NAD, when
(A) 3-phosphoglyceraldehyde (PGAL) is converted to 1,3- bisphosphoglycerate (BPGA).
(B) triose phosphate is converted to 2-phosphoglycerate.
(C) 2-phosphoglycerate is converted to 2- phosphopyruvate.
(D) 2-phosphopyruvate is converted to 2-pyruvic acid.

EXERCISE - 4 (PREVIOUS YEARS AIPMT/NEET EXAM QUESTIONS)

Choose one correct response for each question.

Q.1 Which of the metabolites is common to respiration mediated breakdown of fats, carbohydrates and proteins – **[NEET 2013]**
(A) Acetyl CoA
(B) Glucose-6-phosphate
(C) Fructose 1, 6-bisphosphate
(D) Pyruvic acid

Q.2 The three boxes in this diagram represent the three major biosynthetic pathways in aerobic respiration. Arrows represent net reactants or products. **[AIPMT 2014]**



Arrow numberd 4, 8 and 12 can all be :
(A) FAD^+ or $FADH_2$ (B) NADH
(C) ATP (D) H_2O

Q.3 In which one of the following processes CO_2 is not released? **[AIPMT 2014]**
(A) Aerobic respiration in plants.
(B) Aerobic respiration in animals.
(C) Alcoholic fermentation.
(D) Lactate fermentation.

Q.4 Which of the following biomolecules is common to respiration-mediated breakdown of fats, carbohydrates and proteins? **[NEET 2016 PHASE 2]**
(A) Glucose-6-phosphate
(B) Fructose 1,6-bisphosphate
(C) Pyruvic acid
(D) Acetyl CoA

Q.5 Oxidative phosphorylation is – **[NEET 2016 PHASE 2]**
(A) Formation of ATP by transfer of phosphate group from a substrate to ADP.
(B) Oxidation of phosphate group in ATP.
(C) Addition of phosphate group to ATP.
(D) Formation of ATP by energy released from electrons removed during substrate oxidation.

Q.6 Which statement is wrong for Krebs' cycle? **[NEET 2017]**
(A) There are three points in the cycle where NAD^+ is reduced to $NADH + H^+$.
(B) There is one point in the cycle where FAD^+ is reduced to $FADH_2$.
(C) During conversion of succinyl CoA to succinic acid, a molecule of GTP is synthesised.
(D) The cycle starts with condensation of acetyl group (acetyl CoA) with pyruvic acid to yield citric acid.

Q.7 What is the role of NAD^+ in cellular respiration?
(A) It is a nucleotide source for ATP synthesis.
(B) It functions as an electron carrier.
(C) It functions as an enzyme. **[NEET 2018]**
(D) It is the final electron acceptor for anaerobic respiration.

Q.8 Which of these statements is incorrect?
(A) Glycolysis operates as long as it is supplied with NAD that can pick up hydrogen atoms.
(B) Glycolysis occurs in cytosol.
(C) Enzymes of TCA cycle are present in mitochondrial matrix. **[NEET 2018]**
(D) Oxidative phosphorylation takes place in outer mitochondrial membrane.

Q.9 Respiratory Quotient (RQ) value of tripalmitin is
(A) 0.9 (B) 0.7 **[NEET 2019]**
(C) 0.07 (D) 0.09

Q.10 Which of the following statements regarding mitochondria is incorrect? **[NEET 2019]**
(A) Outer membrane is permeable to monomers of carbohydrates, fats and proteins.
(B) Enzymes of electron transport are embedded in outer membrane.
(C) Inner membrane is convoluted with infoldings.
(D) Mitochondrial matrix contains single circular DNA molecule and ribosomes.

Q.11 Conversion of glucose to glucose-6-phosphate, the first irreversible reaction of glycolysis, is catalyzed by **[NEET 2019]**
(A) Aldolase (B) Hexokinase
(C) Enolase (D) Phosphofructokinase

Q.12 The number of substrate level phosphorylations in one turn of citric acid cycle is : **[NEET 2020]**
(A) Three (B) Zero
(C) One (D) Two

ANSWER KEY

EXERCISE-1 (SECTION-1&2)

(1) (B) **(2)** (A) **(3)** (A)
(4) **(B).** **(5)** Glycos, lysis
(6) Electron transport system. **(7)** Oxidized
(8) Catabolism **(9)** Fermentation
(10) Glucose, Chlorophyll-a **(11)** Lactic acid
(12) Citrate synthase **(13)** 3
(14) Oxaloacetic acid (OAA) **(15)** Glycolysis
(16) Tricarboxylic acid cycle **(17)** 3
(18) Glycolysis; Phosphorylation **(19)** Infinity
(20) Partially
(21) Inner mitochondrial membrane
(22) Mitochondria **(23)** Glucose
(24) EMP pathway
(25) Lactic acid and ethyl alcohol.
(26) False **(27)** False **(28)** False
(29) True **(30)** False

EXERCISE - 1 [SECTION-3]

Q	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
A	A	B	B	D	B	A	A	D	C	A	A	B	B	B	A	C	C	A	B	B	D	A	B	C	B
Q	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
A	C	B	C	C	B	B	B	C	A	D	D	A	B	A	A	A	A	B	C	A	A	A	B	C	C
Q	81	82	83	84	85	86	87	88	89	90	91														
A	B	D	C	C	B	B	B	C	D	C	A														

EXERCISE - 2

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

EXERCISE - 3

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	A	A	D	D	D	B	A	A	C	D	C	D	C	C	B	A	B	A	D	C	A	B	A	B	B
Q	26	27	28	29																					
A	C	B	C	A																					

EXERCISE - 4

Q	1	2	3	4	5	6	7	8	9	10	11	12
A	A	C	D	D	D	D	B	D	B	B	B	C

SOLUTIONS

EXERCISE-1

(1) (B) **(2)** (A) **(3)** (A)

(4) **(B).** Common pathway of aerobic respiration consists of three steps-
(I) Glycolysis (II) TCA/Krebs cycle and (III) ETS
It occurs in both prokaryotes and in eukaryotes.
(I) Glycolysis site :
In prokaryotes $\rightarrow$ Cytosol
In eukaryotes $\rightarrow$ Cytosol
(II) TCA / Krebs cycle site
In prokaryotes $\rightarrow$ Cytosol
In eukaryotes $\rightarrow$ Mitochondria
(III) ETS (Terminal oxidation)
In prokaryotes $\rightarrow$ Plasma membrane
In eukaryotes $\rightarrow$ Inner mitochondrial membrane

(5) **Glycos, lysis.** The term 'glycolysis' has originated from the greek words, glycos for sugar and lysis for splitting.

(6) Electron transport system.

(7) **Oxidized.** Respiration is an oxidative process in which respiratory substrates are oxidized to liberate energy inside the living cells.The common respiratory substrates are carbohydrates, proteins, fats and organic acids.The most common respiratory substrate is glucose.

(8) Catabolism

(9) **Fermentation.** Anaerobic respiration in microorganisms is called fermentation. It takes place in absence of oxygen and produced lactic acid, ethyl alcohol, etc. from glucose. It is useful in manufacture of wine, beer and bread.

(10) **Glucose, Chlorophyll-a.** The oxidative breakdown of respiratory substrates with the help of atmospheric O_2 is known as aerobic respiration. It involves complete breakdown of substrates into CO_2 and water, releasing energy. For example the simple chemical equation for aerobic breakdown of glucose is

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6CO_2 + 6\,H_2O + 2870\text{ kJ}/686\text{ K Cal}$$

While during photosynthesis chlorophyll a gets oxidized to transfer molecules to the electron transport chain.

(11) **Lactic acid.** In anaerobic respiration, bacteria produce lactic acid from pyruvic acid.

(12) **Citrate synthase.** TCA cycle starts with the condensation of acetyl group with Oxalo Acetic Acid (OAA) and water to yield citric acid. The reaction is catalysed by the enzyme citrate synthase.

(13) **3.** The aerobic respiration takes place within the mitochondria, the final product of glycolysis pyruvate is transported from the cytoplasm into the mitochondria.
The major events in aerobic respiration are :
The complete oxidation of pyruvate by the stepwise removal of all the hydrogen atoms, leaving 3 molecules of CO_2.
The passing on of the electrons removed as part of the hydrogen atoms to molecular O_2 with simultaneously synthesis of ATP.

(14) Oxaloacetic acid (OAA)

(15) **Glycolysis.** Glycolysis is an essential and first path of respiration. It is common in both aerobic and anaerobic respiration and occurs in the cytosol of all living cells of prokaryotes as well as eukaryotes.Cytosol is cytoplasm cell organelle.

(16) Tricarboxylic acid cycle

(17) **3.** One molecule of pyuvic acid is converted in acetyl Co-A for 3 molecule of $NADH + H^+$.

(18) Glycolysis; Phosphorylation

(19) **Infinity.** In anaerobic respiration CO_2 is evolved but oxygen is not used. Therefore in such case respiratory quotient will be infinite. e.g.,

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2 + \text{Energy}$$

Where, respiratory quotient

$$= \frac{\text{Evolved } CO_2}{\text{Consumed } O_2} = \frac{2CO_2}{0\,O_2} = \infty \text{ (Infinity)}$$

(20) **Partially.** Fermentation accounts for only a partial breakdown of glucose whereas in aerobic respiration it is completely degraded to CO_2 and H_2O.

(21) **Inner mitochondrial membrane.** Electron transport system occurs in inner mitochondrial membrane. Electron from NADH produced in the mitochondrial matrix during citric acid cycle are oxidised by an NADH dehydrogenase (complex) and electrons are then transferred to ubiquinone located within the inner membrane.

(22) **Mitochondria.** Aerobic respiration takes place within mitochondria, the final product of glycolysis, pyruvate is transported from the cytoplasm into the mitochondria.

(23) Glucose

(24) **EMP pathway.** Glycolysis which is also called EMP pathway is the common pathway to both anaerobic and aerobic metabolism.

(25) Lactic acid and ethyl alcohol.

(26) **False.** Glycolysis takes place in the cytoplasm, and it produces a total of four ATP molecules.

(27) **False.** Part of the energy is stored in ATP, and the remaining energy is released as heat.

(28) **False.** Fats and proteins can also be broken down to produce energy;

(29) **True.** This step generates as many as 32 molecules of ATP per glucose molecule;

(30) **False.** Cellular respiration takes place in prokaryotes and eukaryotes.

(31) **(A).** Sucrose is converted into glucose and fructose by the enzyme invertase and these two monosaccharide readily enter the glycolytic pathway

(32) **(B).** In glycolytic pathway, 3PGAL is converted into 1, 3-diphosphoglyceric acid by an oxidation and phosphorylation reaction, which occur in presence of H_3PO_4 and coenzyme NAD.

(33) **(B).** Glycolysis which is also called EMP pathway is the common pathway to both anaerobic and aerobic metabolism. Pyruvic acid is formed during glycolysis enter into mitochondria if O_2 is available and converted into CO_2 and water while in absence of O_2 bacteria form lactic acid and yeast form ethylalcohol acid and CO_2.

(34) **(D).** In plants, glucose is derived from sucrose which is the end product of photosynthesis or form storage carbohyate.

(35) **(B).** The correct sequence in glycolysis is

Glucose-6-Phosphate $\rightarrow$ 3 Phosphoglyceraldehyde $\rightarrow$ 3-Phosphoglyceric acid $\rightarrow$ Phosphoenol pvruvete $\rightarrow$ Pyruvic acid

(36) **(A).** In glycolysis two molecules of ATP are consumed during two phosphorylation reactions to form fructose 1, 6-biphosphate. In return four molecules of ATP are produced by substrate level phosphorylation (conversion of 1, 3-biphosphoglycerate to 3-phosphoglycerate and phosphoenol pyruvate to pyruvate). Two molecules of $NADH_2$ are formed at the time of oxidation of glyceraldehyde 3-phosphate to 1, 3-biphosphoglycerate.

The net reaction of glycolysis is as follows:

$$\text{Glucose} + 2\,NAD^+ + 2ADP + 2H_3PO_4 \rightarrow 2\text{ Pyruvate} + 2NADH + 2H^+ + 2ATP$$

Each NADH is equivalent to 3 ATP, so the net gain in glycolysis is 8 ATP.

(37) **(A).** The scheme of glycolysis was given by Gustav Embden, Otto Mayerhof and J Parnas. It is the only process in respiration for anaerobic organism. It is ofter referred as the EMP pathway.

(38) **(D).** Glycolysis involves ten step for each step, specific enzyme needs to go next step.

(39) **(C).** In a cellular respiration, energy stored in a glucose molecule which enters into cytoplasm is called glycolysis then enters into Kreb's cycle which is also called Tricarboxylic Acid Cycle (TCA cycle) and finally in electron transport chain or system. Therefore the correct sequence is Glycolysls-Kreb's cycle-Electron transport chain.

(40) **(A).** Glycolysis is a series of reactions that takes place in the cytoplasm of all prokaryotes and eukaryotes. The role of glycolysis is to produce energy (both directly and by supplying substrate for the citric acid cycle and oxidative phosphorylation) and to produce intermediates for biosynthetic pathway.

(41) **(A).** There is two step in glycolysis where ATP is formed or synthesised by ADP.

(i) When 1, 3, bisphosphoglyceric acid is changed into 3-phosphoglyceric acid.

(ii) When phosphoenolpyruvate (PEPA) is changed into pyruvic acid.

(42) **(B).** When oxygen is not available, yeast or some other microbes respire anaerobically. In case of anaerobic respiration, the value of respiratory quotient is not utilised.

e.g., $C_6H_{12}O_6$ (Glucose) $\xrightarrow{\text{zymase}}$ $3\ C_2H_5OH + 2CO_2$ + Energy
Ethyl alcohol

(43) (B)

(44) **(B).** Pyruvate is broken down to CO_2 and H_2O in citric acid or tricarboxylic acid cycle (TCA).

(45) **(A).** Like the bacterial respiration, in animal cells during the exercise when oxygen is inadequate for cellular respiration pyruvic acid is reduced to lactic acid by lactate dehydrogenase. The reducing agent is $NADH + H^+$ which is reoxidised to NAD^+ in both the process.

(46) **(C).** Generally lower organism, e.g., bacteria and fungi performs anaerobic respiration but also occur in higher organism.

(47) **(C).** Carbon dioxide is released by anaerobic respiration in plants.

(48) **(A).** During fermentation, the pyruvic acid releases one molecule of CO_2 to produce acetaldehyde. The acetaldehyde, then reoxidises NADH and is itself reduced to ethanol. These reactions are catalysed by the enzyme, pyruvic acid decarboxylase and alcohol dehydrogenase.

(49) (B)

(50) **(B).** In fermentation, incomplete oxidation of glucose is achieved under anaerobic condition by sets of reactions where pyruvic acid is converted to CO_2 ethanol and sometimes lactic acid.

(51) **(D).** In alcoholic fermentation, NADH (formed during conversion of triose-3-phosphate to 3-phosphoglycerate) is oxidised to NAD^+. Electrons are accepted by acetaldehyde formed by decarboxylation of pyruvate.

(52) **(A).** Citric acid cycle was discovered by British Chemist Hans Krebs in 1937. It is also known as Kreb's cycle and tricarboxylic acid cycle (TAC).

(53) **(B).** Pyruvic acid is 3C-compound. One of the three carbon atoms of pyruvic acid is oxidised to carbon dioxide in a reaction called oxidative decarboxylation. Pyruvate is first decarboxylated and then oxidised by the enzyme pyruvate dehydrogenase. The combination of the remaining 2-carbon acetate unit is readily accepted by a sulphur containing compound, coenzyme A (Co-A) to form acetyl Co-A.

(54) **(C).** In the energy conserving phase of glycolysis, the conversion of BPGA to PGA is catalyzed by phosphoglycerate kinase. The phosphate on carbon I is transferred to a molecule of ADP, yielding ATP and 3-phosphoglycerate. This type of ATP synthesis, traditionally referred to as substrate-level phosphorylation, involves the direct transfer of a phosphate group from a substrate molecule to ADP, to form ATP.

1, 3 bisphosphoglycerate + ADP

$$\xrightleftharpoons[\text{Mg}^{2+}]{\text{Phosphoglycerate kinase}} \text{3-phosphoglycerate} + \text{ATP}$$

(55) **(B).** In Krebs' cycle, acetyl Co-A add its two carbon fragment to oxaloacetate, a four carbon compound. The unstable bond of acetyl Co-A is broken as oxaloacetate displaces the Coenzyme and attaches to the acetyl group. The product is the 6 C-citrate.

(56) **(C).** Decarboxylation occurs in Kreb's cycle.

(57) **(B).** Pyruvate which is formed by the glycolytic catabolism of carbohydrate undergoes oxidative decarboxylation by a complex set of reactions catalysed by pyruvate dehydrogenase.

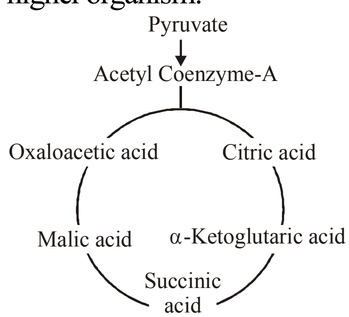
(58) **(C).** During the conversion of succinyl Co-A to succinic acid a molecule of GTP is synthesised. This is a substrate level phosphorylation. In a coupled reaction, GTP is converted to GDP with the simultaneaus synthesis of ATP from ADP.

(59) **(C).** During aerobic respiration, pyruvic acid which is formed during glycolysis enters mitochondrial matrix. It undergoes oxidative decarboxylation to produce CO_2 and NADH. The product combines with sulphur containing co-enzyme A to form acetyl CoA. This reaction is catalyzed by an enzyme complex pyruvate dehydrogenase. This step is called link reaction or gateway step as it links glycolysis with Krebs' cycle.

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

(60) (B). Aerobic respiration occurs in the presence of oxygen that leads to a complete oxidation of organic substances and releases CO_2, water and a large amount of energy. This type of respiration is most common in higher organism.

(61) (B).



(62) (B). In Krebs' cycle pyruvic acid is converted into CO_2 and water.

(63) (C). In eukaryotes, all the reactions of tricarboxylic acid (TCA) cycle or Krebs' cycle take place in the matrix of mitochondria because all enzymes of this cycle are found in the matrix of mitochondria except succinic dehydrogenase, which is located in the inner membrane of mitochondria. In prokaryotes, Krebs' cycle occurs in cytoplasm.

(64) (A). Krebs' cycle also know as TCA cycle or citric acid cycle, is a common pathway of oxidative breakdown of carbohydrates, fatty acids and amino acids. Amino acids enter the Krebs' cycle directly as glutamate (for α-ketoglutarate) and asparate (for oxaloacetate) after their deamination. Fats produce fatty acids and glycerol. Glycerol is phosphorylated and oxidized to form glyceraldehyde 3-phosphate. Fatty acids undergo oxidation to produce acetyl CoA. Acetyl CoA enters Krebs' cycle.

(65) (D). Cyanides, antimycin A, carbon monoxide inhibits the process of electron transport chain.

(66) (D). The complex V of ETS of mitochondrial membrane is ATP synthase, which has a head piece, stalk and a base piece. Out of these, the head piece is identified as the coupling factor 1 (F_1), stalk portion is necessary for binding F_1 to inner mitochondrial membrane and base piece is isolated as F_0 and present within the inner mitochondrial membrane.

(67) (A). With the 2-carbon acetate unit of pyruvic acid readily accepted by a sulphur containing compound coenzyme-A (Co-A) to form acetyl Co-A which is the connecting link between the glycolysis and Kreb's cycle.

(68) (B). In the krebs cycle, when succinic acid undergoes oxidation or dehydrogenation to form fumaric acid, two hydrogens are transferred to FAD. FAD is reduced to $FADH_2$ and enzyme involved in this step is succinic acid dehydrogenase.

(69) (A). During the oxidation process (occurs in inner mitochondrial membrane during electron transport system) enormous amount of free energy is released some of which is utiltsed by inner membrane sub units or F_1 particle containing three coupling factors and ATPase enzyme in the synthesis of ATP molecules.

(70) (A). In the first reaction of citric acid cycle one molecule of acetyl Co-A combines with 4-carbon Oxalo Acetic acid (OAA) to form 6 carbon citric acid and Co-A is released.

(71) (A). In electron transport system oxygen acts as the final hydrogen acceptor where it derives the whole proces by removing hydrogen from the system.

(72) (A). With the complete oxidation of pyruvate by the stepwise removal of all the hydrogen atoms form 3 molecules of CO_2, which occurs in matrix of the mitochondria.

(73) (B). The TCA cycle starts with the condensation of acetyl group with oxaloacetic acid (OAA) and water to yield citric acid. The reaction is catalysed by the enzyme citrate synthase and molecule of Co-A is released.

(74) (C). Cytochrome C-oxidase is present in inner mitochondrion membrane. It is IV complex of electron transport chain.

(75) (A). In electron transport chain respiratory process are to release and utilise the energy stored in $NADH + H^+$ and $FADH_2$. This is accomplished when they are oxidised through the electron transport system and the electron are passed on to O_2 resulting in the formation of H_2O.

(76) (A). One of the three carbon atoms of pyruvic acid which is the end product of glycolysis is oxidised to carbon dioxide in a reaction called oxidative decarboxylation. Pyruvate is first decarboxylated and oxidised by the enzyme pyruvate dehydrogenase.

(77) (A). CO_2 and H_2O is a product of aerobic respiration. Ethyl alcohol and lactic acid are formed as a result of anaerobic respiration (fermentation), while pyruvic acid is produced during both aerobic and anaerobic respiration.

(78) (B). Krebs cycle or citric acid cycle occurs in the matrix of mitochondria. It occurs in aerobic respiration. Acetyl Co-A is the connecting link between glycolysis and Kreb's cycle. Pyruvic acid is oxidised into acetyl Co-A (6C) which is the first or initiating organic acid of Krebs cycle.

(79) (C). The pyruvic acid formed during glycolysis enters to mitochondria where oxidative decarboxylation takes place and acetyl Co-A is formed. It occurs in presence of NAD^+, pyruvic acid dehydrogenase Complex and coenzyme A.

$$NAD^+ \rightarrow \text{Acetyl Co-A} + NADH + H^+ + CO_2$$

(80) (C). An amphibolic pathway is a biochemical pathway that serves both anabolic and catabolic processes. An important example of an amphibolic pathway is the Krebs' cycle, which involves both the catabolism of carbohydrates and fatty acid and the synthesis of anabolic precursors for amino acid synthesis, e.g., α-ketogluturate and oxaloacetate.

(81) (B). Synthesis process in organism is also called anabolism.

(82) (D). RQ is the ratio of volume of carbon dioxide evolved and volume of oxygen consumed.

(83) (C). RQ is one in case of carbohydrates, while for fatty acids is less than one and for organic acids RQ is more than one.

(84) (C). Respiratory Quotient (RQ) is the ratio of volume of CO_2 released to the volume of O_2 absorbed during respiration. In case of organic acids (e.g., Oxalic Acid), more CO_2 is released than the O_2 absorbed. Hence, RQ of organic acids is always more than one.

$$\underset{\text{Oxalic acid}}{2(COOH)_2} + O_2 \rightarrow 4CO_2 + H_2O + \text{Energy}$$

$$RQ = \frac{4CO_2}{1\,O_2} = 4$$

(85) (B). Respiratory quotient $= \dfrac{\text{Evolved } CO_2}{\text{Consumed } O_2}$

Hence, how much O_2 will consume. It all depends on substrate.

(86) (B). RQ is the ratio of the volume of carbon dioxide released to the volume of oxygen taken in respiration. It depends on the nature of the substrate, which is oxidised. For carbohydrates RQ is one, for fats and proteins less than one but more than one for organic acids etc.

(87) (B). Respiratory quotient is the ratio of carbon dioxide output to oxygen uses during respiration.

$$RQ = \frac{\text{Volume of } CO_2 \text{ formed}}{\text{Volume of } O_2 \text{ utilised}}$$

Substrate	RQ
Carbohydrate	1.00
Protein	0.80
Fat (tripalmitin)	0.70
Mixed diet	0.85
Organic acids (oxalid acid)	4.0-

(88) (C). RQ is the ratio of volume of carbon dioxide evolved and volume of oxygen consumed. If RQ is less than one it means the oxidation of the respiratory substrate consumed more

oxygen than the amount of carbon dioxide released.
Volume of carbon dioxide < Volume of oxygen

(89) **(D).** There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis TCA cycle and ETS pathway following one after another.

(90) **(C).** NADH is oxidised to NAD^+ rather slowly in fermentation, however, the reaction is vigorous in case of aerobic respiration.

(91) **(A).** Intermediate in the pathway are utilised to synthesise other compounds.

EXERCISE-2

(1) **(A).** During glycolysis, two ATP molecules are used to produce a total of four ATP molecules.

(2) **(B).** During glycolysis, one molecule of glucose is broken down to form two molecules of pyruvate.

(3) **(A).** Glycolysis takes place in the cytoplasm of the cell.

(4) **(B).** Fats are broken down to form glycerol and three fatty acids, which can then be further processed to produce energy.

(5) **(B).** The pyruvate oxidation step produces carbon dioxide and NADH, but not ATP.

(6) **(D).** The electron transfer system uses high energy electrons from NADH and $FADH_2$ to generate 32 ATP molecules.

(7) **(A).** As one molecule of acetyl-CoA enters the citric acid cycle, one molecule of ATP is produced.

(8) **(B).** When glucose is broken down, some of the energy is released as heat.

(9) **(B).** During exercise, most ATP are produced by aerobic respiration, but additional ATP are produced by anaerobic respiration.

(10) **(A).** The entire process of anaerobic respiration, glycolysis and fermentation, takes place in the cytoplasm.

(11) **(D).** Bacteria involved in making of yogurt break down glucose by anaerobic respiration to produce lactic acid and ATP.

(12) **(B).** Yeast breaks down glucose by anaerobic respiration to produce alcohol, carbon dioxide, and ATP.

(13) **(A).** During anaerobic respiration, from each molecule of glucose, a total of four and a net of two ATP molecules are produced.

(14) **(A).** From each molecule of glucose, 36-38 ATP molecules are produced during aerobic respiration, whereas 2-4 ATP molecules are produced by anaerobic respiration.

(15) **(B).** The presence or absence of oxygen determines aerobic or anaerobic breakdown of glucose.

(16)	(C)	**(17)**	(A)	**(18)**	(B)	**(19)**	(D)
(20)	(A)	**(21)**	(D)	**(22)**	(A)	**(23)**	(C)
(24)	(C)	**(25)**	(A)	**(26)**	(C)	**(27)**	(B)
(28)	(C)	**(29)**	(D)				

(30) **(C).** The whole purpose of a "turn" of the citric acid cycle is to produce two carbon dioxide molecules. This general oxidation reaction is accompanied by the loss of hydrogen and electrons at four specific places. These oxidations are connected to the electron transport chain where many ATP are produced.

(31) (B) **(32)** (C)

(33) **(A).** Phosphofructokinase (PFK) catalyzes the ATP-dependent phosphorylation to convert fructose-6-phosphate into fructose 1,6-bisphosphate and ADP, it is one of the key regulatory and rate limiting steps of glycolysis. PFK is able to regulate glycolysis through allosteric inhibition, and in this way, the cell can increase or decrease the rate of glycolysis in response to the cell's energy requirements.

(34) **(A).** Oxidative phosphorylation is a mechanism for ATP synthesis in both plant and animal cells. It involves the chemiosmotic coupling of electron transport and ATP synthesis. Oxidative phosphorylation occurs in the mitochondria.

(35) (B)

(36) **(D).** Glycolysis involves the breaking down of a sugar (generally glucose, although fructose and other sugars may be used) into more manageable compounds in order to produce energy. The net end products of glycolysis are two Pyruvate, two NADH, and two ATP.

(37) (A)

(38) **(D).** The theoretical maximum yield of ATP through oxidation of one molecule of glucose in glycolysis, citric acid cycle, and oxidative phosphorylation is 38 (assuming 3 molar equivalents of ATP per equivalent NADH and 2 ATP per FADH2).

(39) (B) **(40)** (C) **(41)** (C) **(42)** (B)
(43) (D) **(44)** (B) **(45)** (D) **(46)** (A)
(47) (B) **(48)** (B) **(49)** (C) **(50)** (A)
(51) (C) **(52)** (C) **(53)** (C) **(54)** (A)
(55) (D) **(56)** (C) **(57)** (C) **(58)** (D)
(59) (C) **(60)** (C) **(61)** (C)

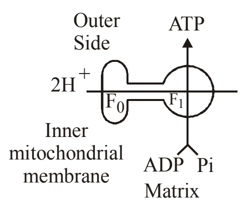
(62) **(B).** Glyceraldehyde-3-phosphate is required for the oxidative reaction during glycolysis.

(63) **(C).** The RQ value of 4 may be expected from complete oxidation of oxalic acid.

EXERCISE-3

(1) (A) **(2)** (A) **(3)** (D) **(4)** (D)
(5) (D) **(6)** (B) **(7)** (A) **(8)** (A)

(9) **(C).**

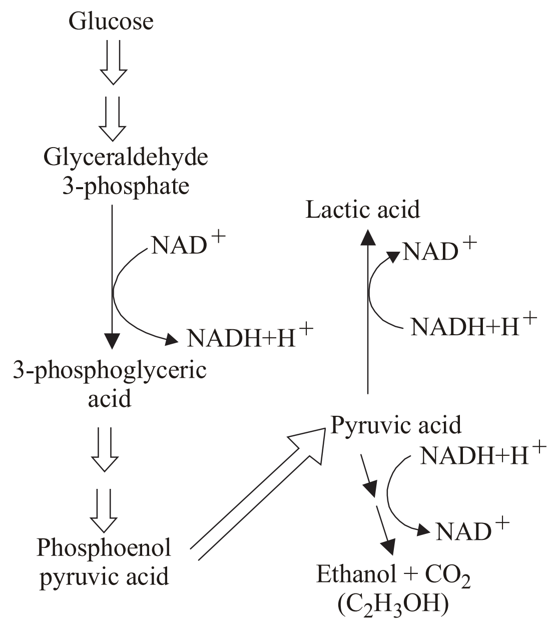


(10) **(D).** During the step of Krebs' cycle, where succinic acid undergoes oxidation or dehydrogenation to form fumaric acid, FAD is reduced to $FADH_2$ and enzyme involved in this step is succinic acid dehydrogenase.

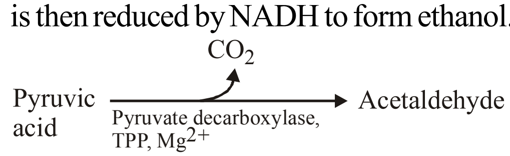
(11) **(C).** RQ is less then 1.0 in respiratory metabolism means that respiratory substrate consume more oxygen than the amount of CO_2 released.

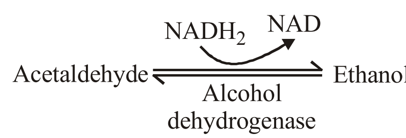
Substrate	RQ
Carbohydrate	One
Fats and proteins	Less than one
Orgganic acid	More than one
Succulents	Zero

(12) **(D).**



(13) **(C).** Given reaction represents alcoholic fermentation. In alcoholic fermentation, pyruvate is converted into ethanol in a two step pathway. Ethyl alcohol fermentation is quite common in fungi (e.g., *Rhizopus*, yeast) and bacteria. In yeast, pyruvate is decarboxylated to form acetaldehyde which is then reduced by NADH to form ethanol.





(14) **(C).** Electrons from NADH produced in the mitochondrial matrix during citric acid cycle are oxidised by an NADH dehydrogenase (complex I) and complex IV refers to cytochrome-c oxidase complex containing cytochromes a and a_3 and two copper centres.

(15) (B) **(16)** (A) **(17)** (B)
(18) (A) **(19)** (D) **(20)** (C)

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

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

(23) **(A).** The first reaction of the Krebs cycle is the condensation of acetyl CoA (2C compound) with oxaloacetate (2C compound). Citric acid, a 6 carbon-compound is the first product of Krebs cycle.

(24) **(B).** One of the two phosphates of diphosphoglycerate is linked by high energy bond. It can synthesize ATP and form 3-phosphoglycerate. The enzyme is phosphoglycerate kinase. The direct synthesis of ATP from metabolites is called substrate level phosphorylation.
During formation of phosphoenol pyruvate the phosphate radical pick up energy. It helps in the production of ATP by substrate level phosphorylation.

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

(26) **(C).** ATP synthetase is located in F_1, or head piece of F_0- F_1 or elementary particles. The particles are present in the inner mitochondrial membrane. ATP synthetase becomes active in ATP formation where there is a proton gradien having higher concentration of H^+ or protons on the F_0 side as compared to F_1 side.

(27) **(B).** Photophosphorylation occurs in the grana and requires the direct sunlight energy to make energy-carrier molecules that are used in the dark reaction. The light energy is trapped by chlorophyll to make ATP and NADPH. Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH, $FADH_2$) produced in respiration.

(28) (C)

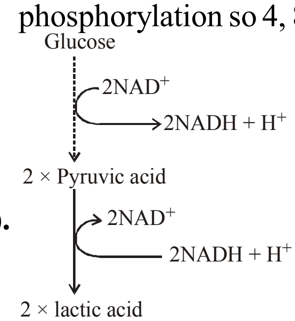
(29) **(A).** There is one step in glycolysis where $NAOH + H^+$ is formed from NAD^+ when 3-phosphoglyceraldehyde (PGAL) is converted to 1,3-bisphosphoglycerate (BPGA).

EXERCISE-4

(1) **(A).** Acetyl CoA is common to respiration mediated breakdown of fats, carbohydrates and proteins.

(2) **(C).** In a given diagram of aerobic respiration-pathway A is glycolysis, pathway B is Krebs cycle and pathway C is oxidative phosphorylation so 4, 8 & 12 are ATP.

(3) **(D).**



(4) **(D).** Acetyl CoA is common to fat, carbohydrate and protein catabolism.

(5) **(D).** Oxidative phosphorylation uses energy of oxidation reduction of substrate to generate ATP.

(6) **(D).** Kreb cycle starts with condensation of acetyl CoA (2C) with oxaloacetic acid (4C) to form citric acid (6C).

(7) **(B).** In cellular respiration, NAD^+ act as an electron carrier.

(8) **(D).** Oxidative phosphorylation takes place in inner mitochondrial membrane.

(9) **(B).** Respiratory Quotient (RQ)

$$= \frac{\text{Amount of } CO_2 \text{ released}}{\text{Amount of } O_2 \text{ consumed}}$$

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

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

(10) **(B).** In mitochondria, enzymes for electron transport are present in the inner membrane.

(11) **(B).** Hexokinase catalyse the conversion of Glucose to Glucose-6 phosphate. It is the first step of activation phase of glycolysis.

(12) **(C).**