CELLULAR RESPIRATION

- **Dutrochet** introduced the term **respiration** and studied it in plants.
- The breaking of the C-C bonds of complex compounds through oxidation within the cells, leading to release of considerable amount of energy is called respiration.
- "Cellular respiration is an enzyme controlled process of biological oxidation of food material in living cell, using molecular O_2 producing CO_2 and H_2O and releasing energy which store as ATP." ATP is also called energy currency.
- Respiration is **Amphibolic, oxidative and exergonic process**. It is also called **cellular respiration.**

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{enzyme}} 6CO_2 + 6H_2O + 686 \text{ Kcals/2870kJ.}$$

(Glucose)

- In **prokaryotes**, Respiration takes place in **cytoplasm** while in **eukaryotes**, it takes place in **cytoplasm** and **mitochondria.**
- The carbon skeleton produced during respiration is used as precursors for biosynthesis of other molecules in the cell. That's why we call it an amphibolic pathway as respiratory substrate is breaking down (Catabolism) and the intermediates of the catabolic pathway are used for the synthesis (Anabolism) of other biomolecule.
- **Respiratory substrate:** Organic compoundcs catabolised in the living cells to release energy are called respiratory substrates **e.g. Carbohydrate, fats, proteins, organic acid.**
- Respiration which uses carbohydrates or fats is termed as **floating respiration** whereas which uses proteins is called **protoplasmic respiration**

Differences between Respiration and combustion		
S.No.	**Respiration**	**Combustion**
1	It is a biochemical process	It is a physiochemical process
2	It occurs under biological control	It is not under biological control
3	55% of the energy is lost as heat	Almost entire energy is released as heat
4	Temperature remains low	Temperature rises considerably
5	45% of the energy is entrapped in the phosphate bonds of ATP	No ATP is formed
6	Each step of respiration is catalyzed by an enzyme	No enzyme is involved.

DO PLANTS BREATHE?

Plants have systems (in place) that ensure the availability of O_2. Plants, unlike animals, have no specialised organs for gaseous exchange (Breathing) but they have stomata and lenticels for this purpose. **There are several reasons why plants can get along without respiratory organs.**

(i) Each plant part takes care of its own gas-exchange needs. There is very little transport of gases from one plant part to another.

(ii) Plants do not present great demands for gas exchange. Roots, stems and leaves respire at rates far lower than animals do. Only during photosynthesis are large volumes of gases exchanged and, each leaf is well adapted to take care of its own needs during these periods. When cells photosynthesise, availability of O_2 is not a problem in these cells since O_2 is released within the cell.

(iii) The distance that gases must diffuse even in large, bulky plants is not great. Each living cell in a plant is located quite close to the surface of the plant. This is true for leaves but in stems, the 'living' cells are organised in thin layers inside and beneath the bark. They also have openings called lenticels.

(iv) The cells in the interior are dead and provide only mechanical support. Thus, most cells of a plant have at least a part of their surface in contact with air. This is also facilitated by the loose packing of parenchyma cells in leaves, stems and roots, which provide an interconnected network of air spaces.

A. Types of Respiration:

It is of two main types

(1) Aerobic

(2) Anaerobic

(1) Aerobic respiration:

- It uses oxygen and completely oxidizes the organic food to carbon dioxide and water and, therefore, it releases the entire energy available in glucose.
- It occurs in most plants and animals.

(2) Anaerobic respiration:

- This accounts only for partial breakdown of glucose to either lactic acid or ethanol and carbon dioxide.
- Less than 7% of the energy in glucose is released by anaerobic respiration.
- It occurs in the absence of oxygen in muscles, bacteria and yeast.

Mechanism of aerobic Respiration:

(1) Glycolysis:

- It is a partial oxidative process in which Hexose sugar (Glucose or fructose) splits to form two molecules of pyruvic acid.
- It is also called **EMP pathway** because it was discovered by three German scientists **Embden, Meyerhof and Parnas.**

Analysis of Glycolysis of One Molecule of Glucose (6C):

Requirement of ATP = 2

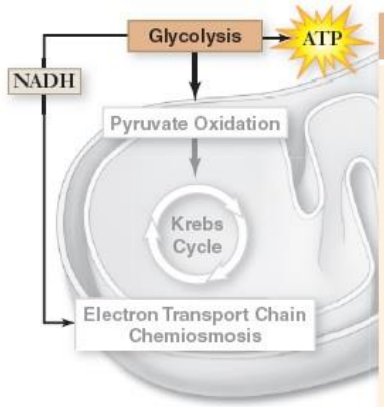
Production of ATP = 4

Net gain of ATP = 2

Production of NADH + H^+ = 2

Carbon skeleton / end product of glycolysis = 2 molecules of pyruvate (3C)

2 molecules of NADH+H^+ enter into mitochondria and are oxidized through ETS to form 6 ATP. So glycolysis in aerobic condition can cause net gain of 2 + 6 = 8 ATP.



1. Phosphorylation of glucose by ATP.

2–3. Rearrangement, followed by a second ATP phosphorylation.

4–5. The 6-carbon molecule is split into two 3-carbon molecules—one G3P, another that is converted into G3P in another reaction.

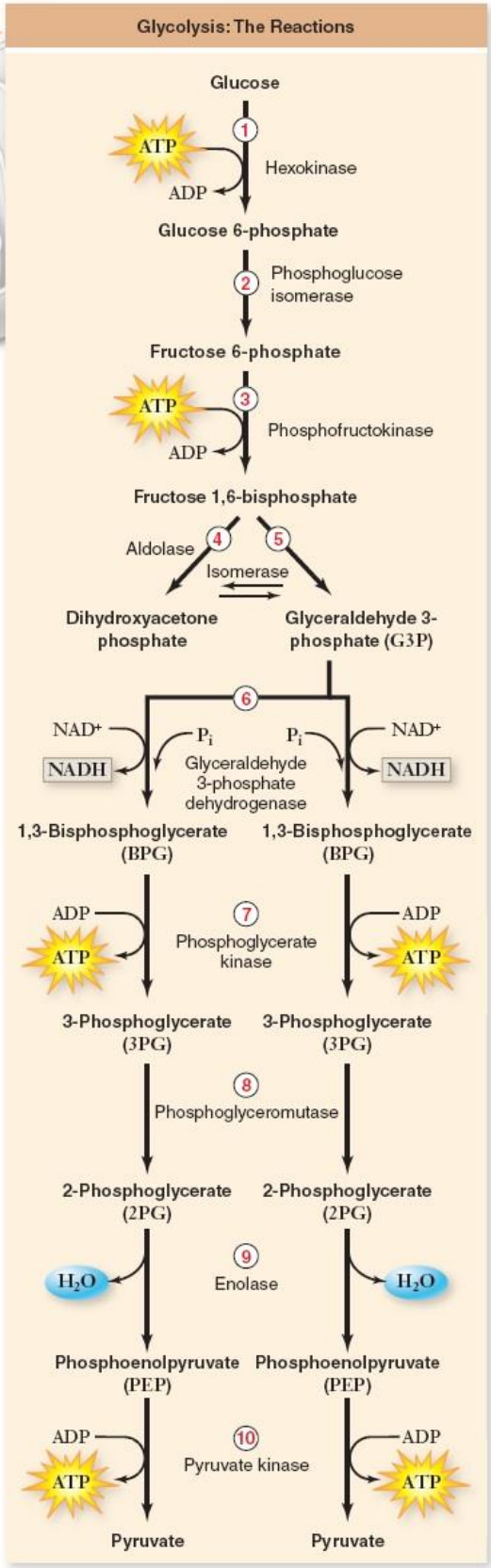
6. Oxidation followed by phosphorylation produces two NADH molecules and two molecules of BPG, each with one high-energy phosphate bond.

7. Removal of high-energy phosphate by two ADP molecules produces two ATP molecules and leaves two 3PG molecules.

8–9. Removal of water yields two PEP molecules, each with a high-energy phosphate bond.

10. Removal of high-energy phosphate by two ADP molecules produces two ATP molecules and two pyruvate molecules.

The glycolytic pathway.
The first five reactions convert a molecule of glucose into two molecules of G3P. The second five reactions convert G3P into pyruvate.



Note: Except reaction 1st, 3rd and 10th all other reactions are reversible. Thus steps - 1st, 3rd and 10th are regulatory steps of glycolysis as they are irreversible.

(2) Oxidative decarboxylation of pyruvic acid:

- The pyruvic acid (3C) undergoes oxidative decarboxylation and forms acetyl Co-A (2C). It take place in mitochondria.
- This reaction is catalysed by enzyme pyruvate dehydrogenase and co-factors such as TPP, Co-A, Lipoic acid, NAD^+ and Mg^{++} ions.

$$\text{Pyruvic acid} + \text{CoA} + \text{NAD}^+ \xrightarrow[\text{Pyruvate dehydrogenase}]{\text{Mg}^{2+}} \text{Acetyl CoA} + \text{CO}_2 + \text{NADH} + \text{H}^+$$

(3) Krebs cycle:

- It was discovered by **Hans Krebs in muscles of pigeon.**
- It is also called **Tricarboxylic acid cycle (TCA cycle) or citric acid cycle (CA cycle)** because its **first stable product citric acid** contains three carboxylic groups (–COOH).
- It occurs in **matrix of mitochondria**.
- **Acetyl Co- A** (2C) is **connecting link** between **glycolysis** and **Krebs cycle**.

Analysis of Kreb cycle:

- The breakdown of one acetyl Co-A (2C) produces = 3 NADH + H^+ , 1 GTP, 1 $FADH_2$, 2 CO_2.
- $FADH_2$ and NADH + H^+ go to mitochondrial matrix to undergo oxidation

$$\text{Pyruvic acid} + 4\text{NAD}^+ + \text{FAD}^+ + 2\text{H}_2\text{O} + \text{ADP} + \text{Pi} \xrightarrow{\text{Mitochondrial Matrix}} 3\text{CO}_2 + 4\text{NADH} + 4\text{H}^+ + \text{FADH}_2 + \text{ATP}$$

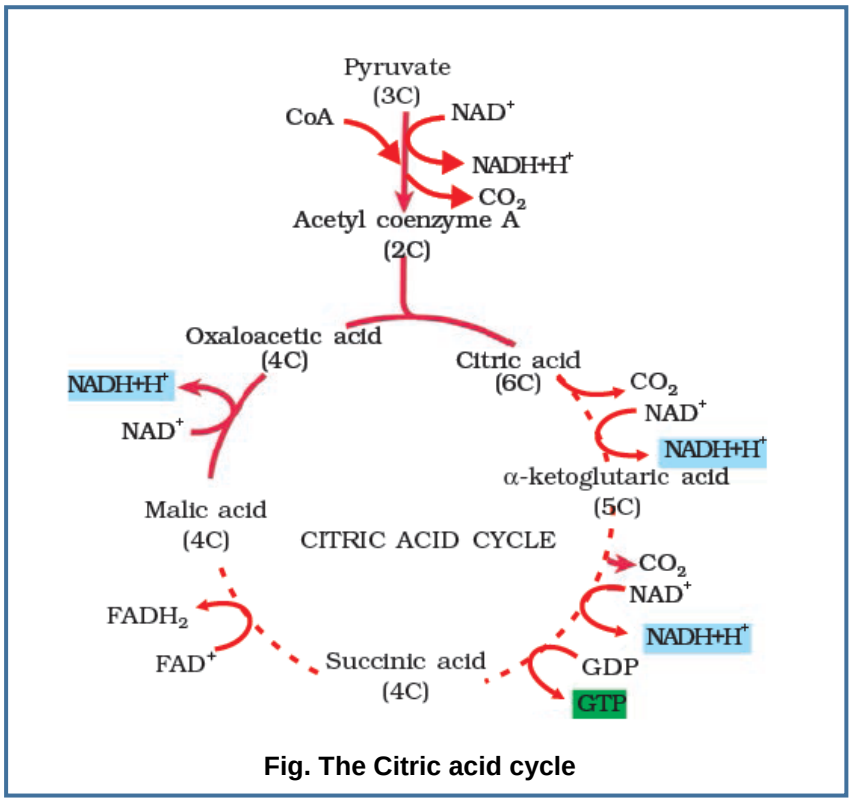


Fig. The Citric acid cycle

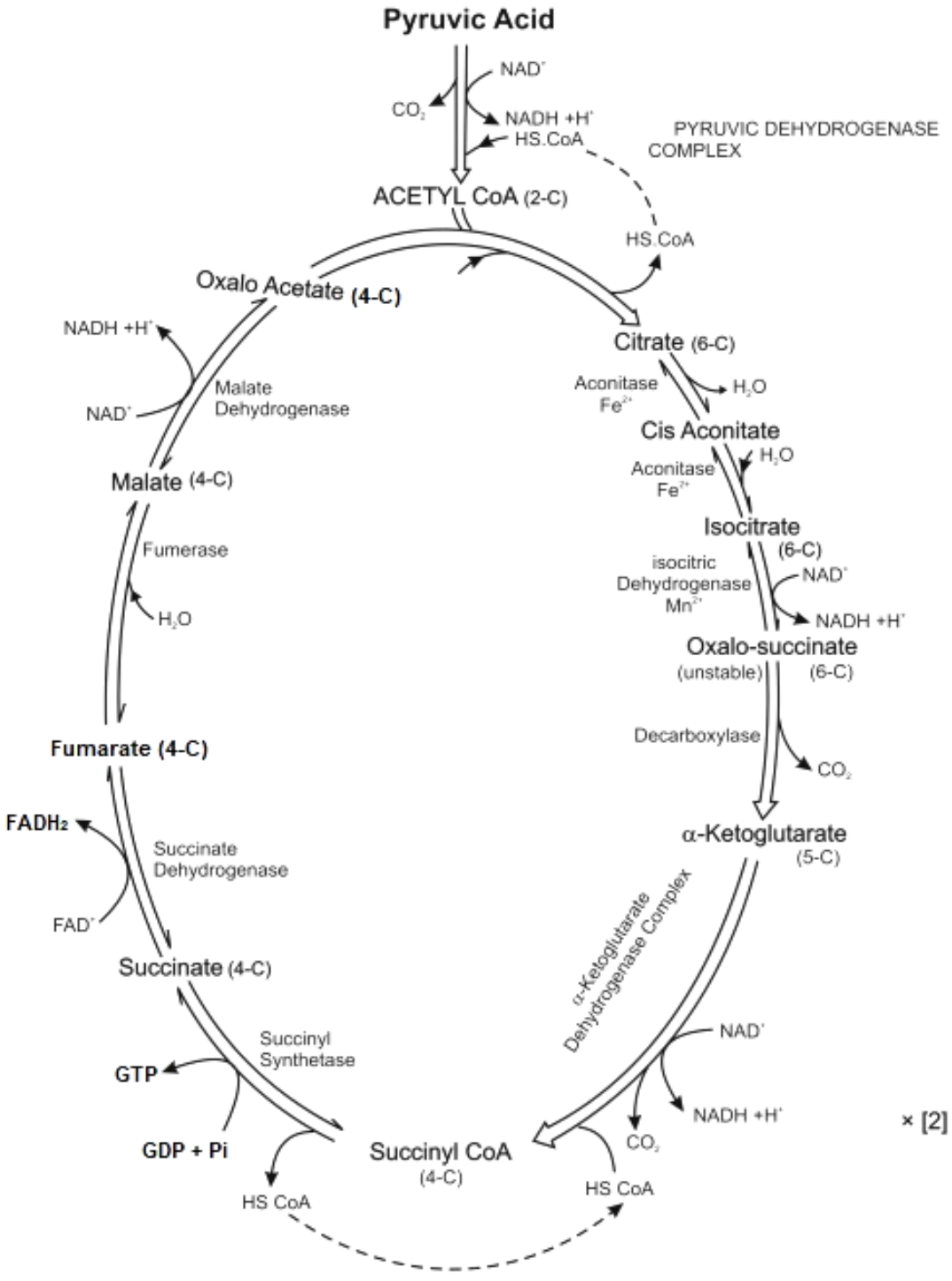


Fig. Schematic representation of Krebs cycle or TCA cycle

(4) Terminal oxidation:

- Atmospheric O_2 is directly involved in the end of catabolic process. It includes two steps.

(A) Electron transport system or ETS **(B) Oxidative Phosphorylation**

(A) Electron transport system or ETS:

- The metabolic pathway through which the electron passes from one carrier to another, is called the electron transport system (ETS)
- It is used for the energy stored in NADH $+H^+$ & $FADH_2$ here the NADH + H+ & $FADH_2$.
- These reducing equivalents are oxidised through e- transport system (ETS) & electrons are passed to oxygen resulting into formation of H_2O.
- In each group the enzymes are arranged in a specific series called electron transport chain (ETC) or mitochondrial respiratory chain or electron transport system (ETS).

Location: Inner mitochondrial membrane.

Process: Inner mitochondrial membrane possesses five complexes.

S.No.	Name of Complexes	Parts of Complex
1	Complex - I	NADH + H^+ Dehydrogenase complex (FMN & FeS)
2	Complex - II	Succinate Q-reductase complex (FAD & FeS)
3	Complex - III	Cyt. b-c_1 complex or cyt. c reductase complex (Cyt b, FeS & Cyt c_1)
4	Complex - IV	Cyt. c oxidase complex (Cu A , Cyt a, Cyt a_3 & Cu B)
5	Complex - V	ATP synthase/F_0-F_1 Complex F_0 – Integral membrane protein, acts as a channel protein. F_1 – headpiece, peripheral membrane protein has catalytic domain of ATP synthase.

- Two mobile carries are also there -

(a) Coenzyme quinone - It has two forms; the oxidised form is called quinone while the reduce form is called Quinol.

It is located within inner mitochondrial membrane and acts as a carrier of electrons **from complex-I and complex-II to complex-III.**

(b) Cytochrome C - It is small protein containing one heme group and is located to the **outer surface of inner membrane of mitochondria.**

It acts as a mobile carrier of electrons from complex-III to complex-IV.

- Mobile carriers are not a part of any of the complexes. The complex-I, III and IV serve dual purpose i.e. transfer electrons in ETS and pump protons from matrix to inter-membrane space of mitochondria.
- Complex-II acts only as an electron-carrier.
- Complex-V has F_0 particle which acts as a channel for protons from inter-membrane space to matrix.
- Complex-V has F_1 particle which has catalytic domain for ATP synthesis.
- It means **complexes-I to-IV are involved in electron transport whereas Complex V (F_0–F_1 particle) is connected with ATP synthesis.**
- **Oxidation of NADH + H^+ involves complex – I, III, IV & V**
- **Oxidation of $FADH_2$ involves complex – II, III, IV & V**

It includes following steps

(i) NADH is oxidised by an NADH dehydrogenase (complex I), and electrons are then transferred to ubiquinone.

(ii) Ubiquinone also receives electrons via (complex II) by the oxidation of $FADH_2$.

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

(iv) Cytochrome *c* acts as a mobile carrier for transfer of electrons between complex III and IV. In cytochrome, iron functions as activator. It accepts ($Fe^{+++} + e^- \rightarrow Fe^{++}$) and donates ($Fe^{++} - e^- \rightarrow Fe^{+++}$) electrons.

Complex IV refers to cytochrome *c* oxidase complex containing cytochromes *a* and a_3, and two copper centres.

(v) From complex-IV finally the electrons are accepted by the terminal electron acceptor i.e. oxygen.

As oxygen has the highest reduction potential in ETC.

(vi) Oxygen drives the whole process by removing hydrogen from the system. Oxygen also acts as the final hydrogen acceptor and leads to formation of water.

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

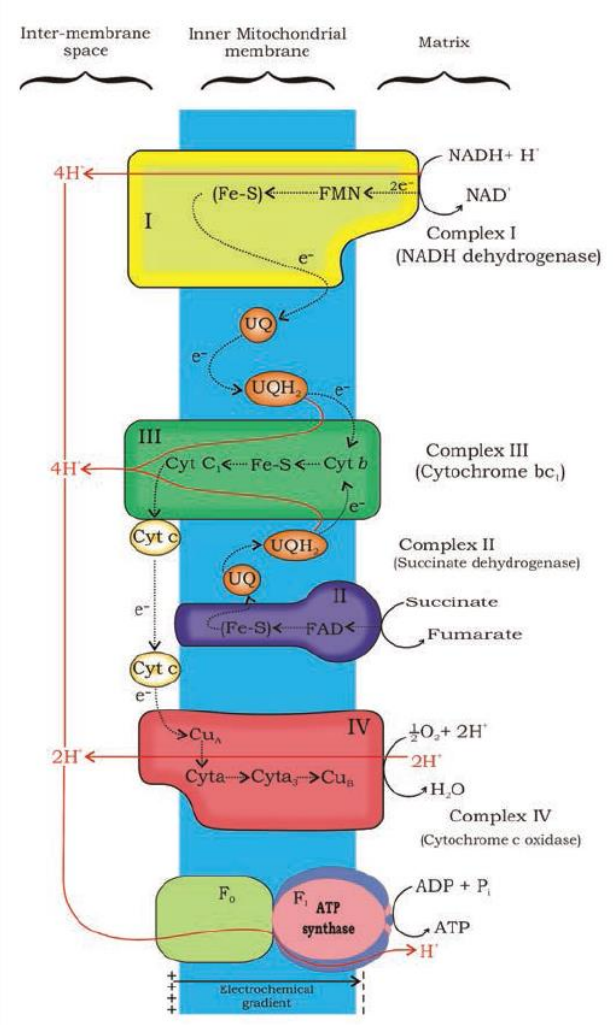


Figure: Electron Transport System (ETS)

(B) Oxidative Phosphorylation:

- The large amount of energy is released during the oxidation-reduction of NADH & $FADH_2$.

  This energy is used for pumping protons from matrix to inter-membrane space.

  It generates a proton motive force or gradient and when this gradient is broken (By complex-V/F_0) ATP is formed (By complex-V/F_1).
- In respiration it is the energy of oxidation-reduction utilised for formation of ATP. It is for this reason that the process is called oxidative phosphorylation.

Chemiosmotic Hypothesis:

- It was proposed by **Peter Mitchell** (1961).
- The process of creating an electrochemical gradient by transfer of protons across inner mitochondrial membrane during oxidation of NADH + H^+ & $FADH_2$ is called chemiosmosis.
- Here the gradient has two components – electric (difference of charges across the membrane) and chemical (difference of ions across the membrane)
- This electrochemical gradient is called proton motive force.
- Proton motive force causes the flow of protons from inter-membrane space across the inner mitochondrial membrane into matrix.
- Protons pass through the **F_0 particle** to matrix of mitochondria where ATP synthase catalyses the synthesis of ATP from ADP + Pi.
- **According to NCERT, $2H^+$** comes from inter membrane space to matrix of mitochondria via F_0 Channel and causes formation of 1 ATP.
- The figure of electron transport system given in NCERT shows accumulation of total $10H^+$ in inter membrane space during oxidation of one molecule of NADH + H^+ and one molecule of $FADH_2$.
- Now $2H^+$ from inter membrane space to matrix will cause formation of 1 ATP and $10H^+$ will cause formation of 5 ATP.
- **Oxidation of NADH + H^+ in ETS - 3ATPs are synthesized by the complete oxidation of 1 molecule of NADH + H^+.**
- **Oxidation of $FADH_2$ in ETS - Only 2 ATPs are synthesized by complete oxidation of one molecule of $FADH_2$**

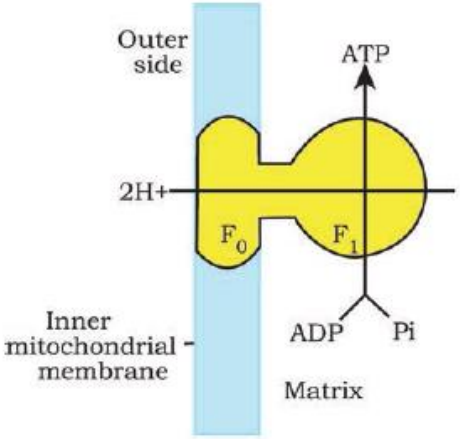


Fig. Diagrammatic presentation of ATP synthesis in mitochondria

ETS poison:

(i) Rotenone : It checks flow of electrons from Fes to CoQ.

(ii) Antimycin A : It prevents electron transport between cyt b and cyt c_1

(iii) Cyanide : It inhibits transfer of electrons from cyt a_3 to oxygen

In Mitochondria of some plants, Alternative oxidase is found & ETS continuously proceeds even in the presence of cyanide. It is called **cyanide Resistant Respiration (CRR) or Alternate electron pathway e.g. Spinach.**

(iv) Oligomycin: It inhibits complex-V by blocking proton channel (F_0 subunit)

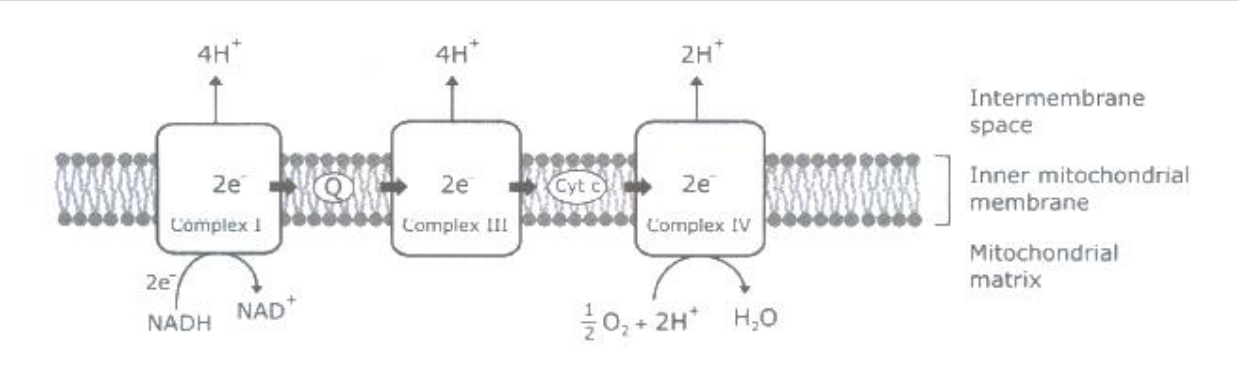
(v) 2, 4-dinitrophenol : It allows electron transport but inhibits ATP formation from ADP

Real Concept of ETS and Oxidative Phosphorylation

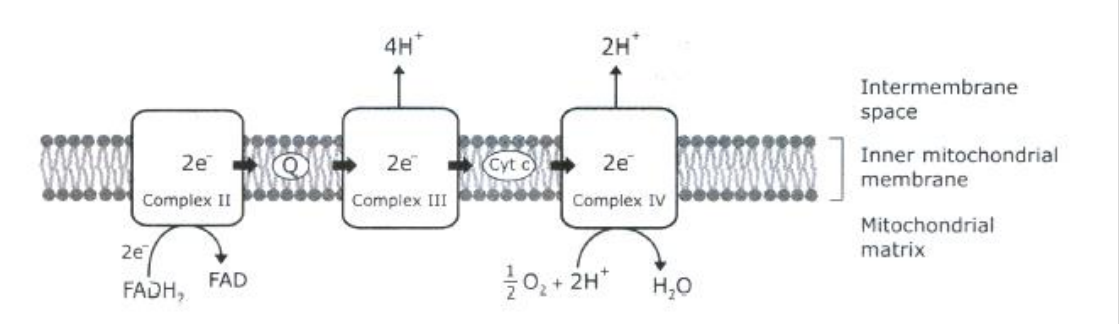
- The four complexes of ETS are arranged in increasing order of their reduction potential. So, when NADH + H^+ or $FADH_2$ are oxidised; they will transfer their electrons to complex I and complex II respectively.
- Now these electrons move to complex III → complex IV → O_2 which causes release of energy.
- This energy is utilized to pump protons from matrix to inter membrane space.
- It creates a proton motive force or proton gradient across the inner membrane of mitochondria.
- When these protons come back to matrix via F_0 particle; it causes phosphorylation i.e. formation of ATP by F_1 particle.

Let's see how?

1. NADH + H^+ (Coming from Glycolysis and Krebs cycle) is oxidised.
Total 10 H^+ are pumped in inter membrane space.



2. $FADH_2$ (Coming from Krebs cycle) is oxidised
Total 6H^+ are pumped in inter membrane space.



3. Working of ATP Synthase (F_0 - F_1) Particle.

(i) F_0 part is an integral membrane protein which acts as a channel for protons accumulated in inter membrane space.

(ii) When H^+ comes through F_0 particle, it interacts with negatively charged amino acid aspartate of F_0 particle (channel protein) and causes rotation of F_0 due to conformational changes in it.

(iii) As F_0 and F_1 are associated with each other. The moment F_0 rotates, it facilitates F_1 to rotate.

(iv) F_1 is the catalytic part of ATP synthase. The rotation of F_1 exposes its catalytic site for ADP and P_i and causes formation of ATP.

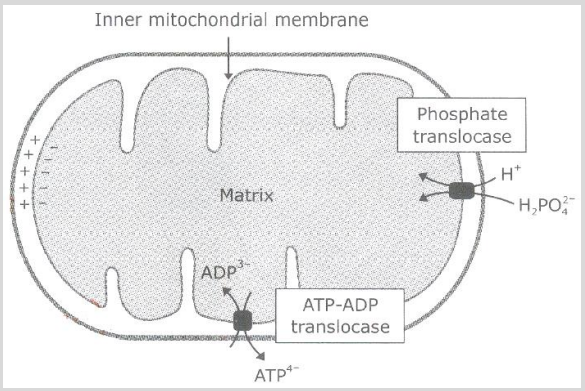


Fig. The phosphate and ATP / ADP translocase system in the inner mitochondrial membrane.

4. ATP - ADP exchnge across the inner mitochondrial membrane

(i) In order to synthesise ATP mitochondria need ADP and P_i. The ATP formed in mitochondrial matrix has to be pumped out of the matrix to the cytosol. For this, two translocase systems work as shown in the diagram.

(ii) ATP is pumped out of the mitochondria while ADP is pumped inside the mitochondria by the same transport channel (Antiport - ATP - ADP translocase).

(iii) To bring inorganic phosphate inside, 1 H^+ come alongwith it (Symport-Phosphate translocase)

Note: For the synthesis of 1 ATP; 1 H^+ comes from phosphate translocase and 3 H^+ comes from ATP synthase (F_0). In total 4H^+ enter from intermembrane space to matrix for the synthesis of 1 ATP.

Analysis of ETS and oxidative phosphorylation :

- During oxidation of NADH + H^+ , 10 protons are accumulated in inter membrane space. So 2.5 molecules of ATP will be produced.
- During oxidation of $FADH_2$, 6 proton are accumulated in intermembrane space so 1.5 molecules of ATP will be produced.
- By this way, the total amount of ATP formed from oxidation of one molecule of glucose is 32 / 30.

THE RESPIRATORY BALANCE SHEET

To calculate the net gain of ATP for every glucose molecule one need to follow certain assumptions.

i. 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.

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

iii. None of the intermediates in the pathway are utilised to synthesise any other compound.

iv. 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. All pathways work simultaneously and do not take place one after another. Substrates enter the pathways and are withdrawn from it as and when necessary, ATP is utilised as and when needed. Hence, there can be a net gain of 36 ATP molecules during aerobic respiration of one molecule of glucose.

- Production of ATP molecules in various processes are as follow -

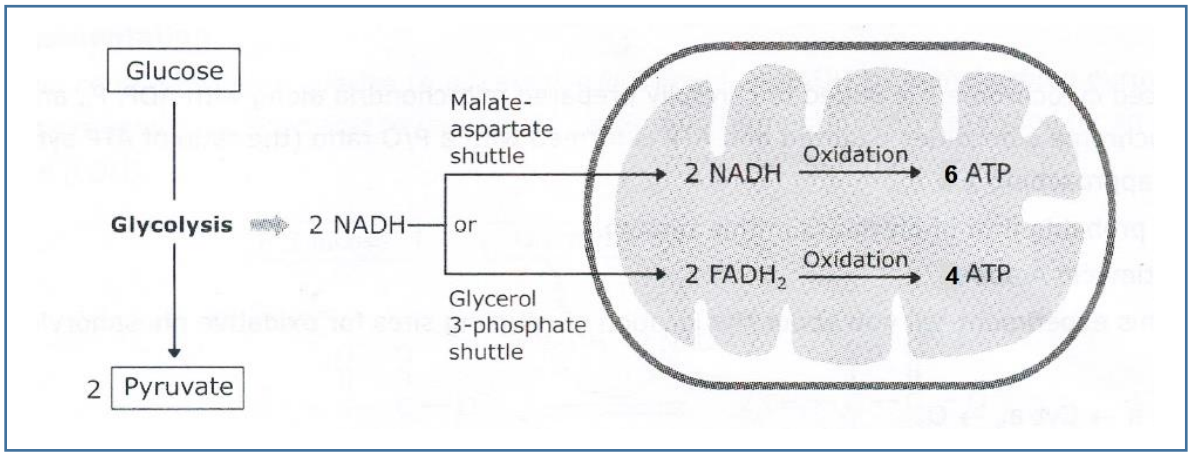
Table

Stage	**Production of ATP by substrate level phosphorylation**	**Formation of NADH $+H^+$ /$FADH_2$**	**Synthesis of ATP by ETS in Mitochondria (NCERT)**
Glycolysis	2	2 NADH + H^+	2 × 3 = 6
Oxidative decarboxylation of Pyruvic acid	—	2 NADH + H^+	2 × 3 = 6
Krebs Cycle	2	6 NADH + H^+ 2 $FADH_2$	6 × 3 = 18 2 × 2 = 4
	4		34
Total production of ATP by oxidation one molecule of glucose (NCERT) = 34 + 4 = 38 ATPs			

- The production of 38 ATP or 36 ATP in respiration depends upon types of shuttle system.
- The NADH of glycolysis is produced in cytoplasm which has to be carried inside the matrix of mitochondria to carry out ETS.
- This NADH is carried to cytoplasm by means of two shuttle systems -

  (a) Malate aspartate shuttle (Heart, Liver, Kidney etc.)

  (b) Glycerol 3- phosphate shuttle (Plants, Nerves, Muscles etc.)



If malate aspartate shuttle is active then the amount of ATP produced by oxidation of one molecule of glucose will be 38 and if glycerol 3-phosphate shuttle is active then amount of ATP would be 36.

Efficiency of Cellular respiration one molecule of glucose:

Hydrolysis of 1 ATP gives 8.1 Kcal energy under physiological condition.

During aerobic respiration if total net gain is 38 ATP molecules then total trapped energy is

38 × 8.1 = 307.8 Kcal.

The total energy content of 1 molecule of glucose is 686 Kcal.

$$\text{Efficiency} = \frac{307.8}{686} \times 100 = 44.86\%$$

Pasteur Effect

- Yeast consumes more glucose when growing anaerobically than aerobically. This effect is called Pasteur Effect.
- Louis Pasteur observed that when yeast is exposed to aerobic conditions (in the presence of oxygen), their glucose consumption and ethanol production drop. Whereas in the absence of oxygen glucose consumption increases several fold.
- Reason for the decrease in consumption of glucose is that fermentation results in the production of 2 ATPs per glucose wherase aerobic respiration yields 38 ATPs per glucose.
- Hence, for the generation of same amount of ATP to perform essential metabolic activities, more consumption of glucose is needed in anaerobic condition.

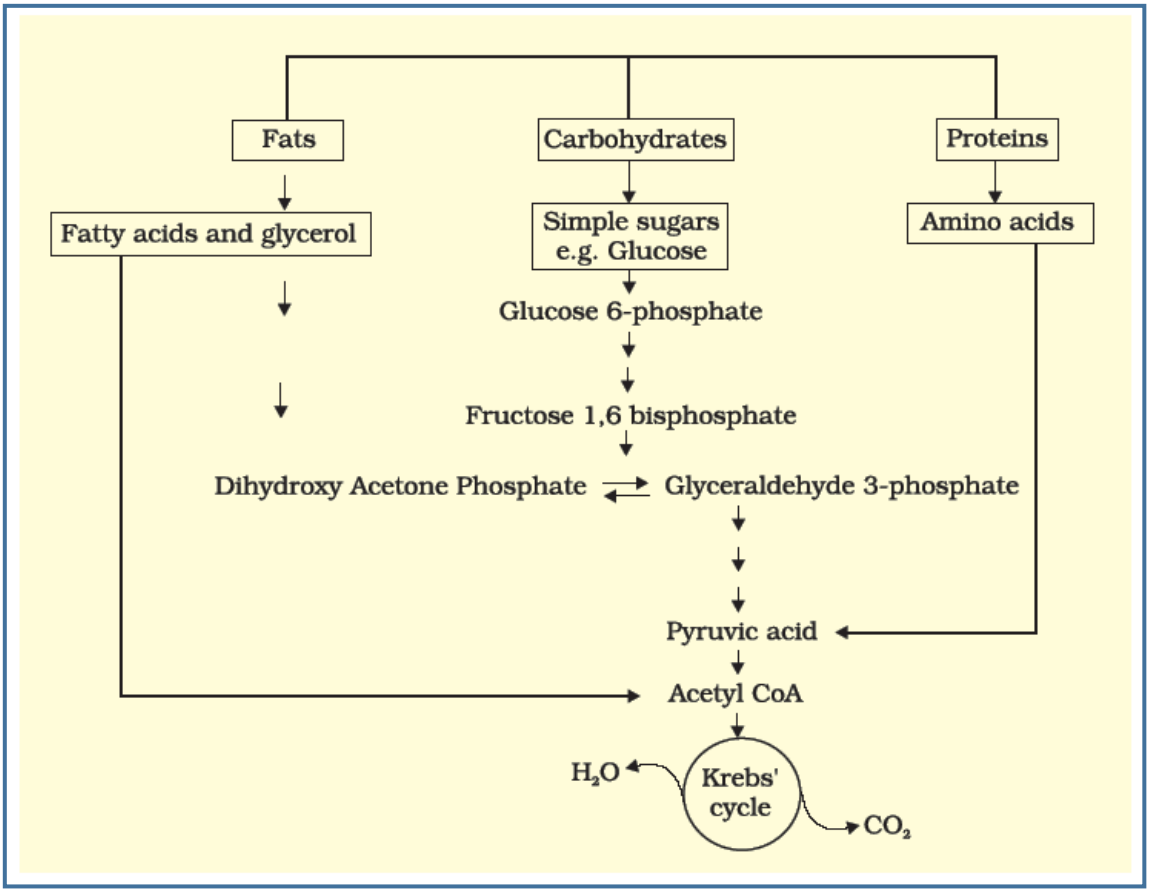
Warburg Effect

- Most cancer cells exhibit increased glycolysis and use this metabolic pathway for generation of ATP as a main source of their energy supply. This phenomenon is known as the Warburg effect.

AMPHIBOLIC PATHWAY

- Glucose is the favoured substrate for respiration. All carbohydrates are usually first converted into glucose before they are used for respiration.
- Other substrates can also be respired, as has been mentioned earlier, but then they do not enter the respiratory pathway at the first step.
- 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 Kreb's cycle or even as pyruvate or acetyl CoA.
- Since respiration involves breakdown of substrates, the respiratory process has traditionally been considered a catabolic process and the respiratory pathway as a catabolic pathway.
- But it is important to recognise is that it is these very compounds that would be withdrawn from the respiratory pathway for the synthesis of the said substrates.
- Hence, fatty acids would be broken down to acetyl CoA before entering the respiratory pathway when it is used as a substrate.
- But when the organism needs to synthesise fatty acids, acetyl CoA would be withdrawn from the respiratory pathway for it. Hence, the respiratory pathway comes into the picture both during breakdown and synthesis of fatty acids.
- Similarly, during breakdown and synthesis of protein too, respiratory intermediates form the link. Breaking down processes within the living organism is catabolism, and synthesis is anabolism.
- Because the respiratory pathway is involved in both anabolism and catabolism, (hence it would be better to consider the respiratory pathway as an amphibolic pathway rather than as a catabolic one) so called amphibolic pathway.



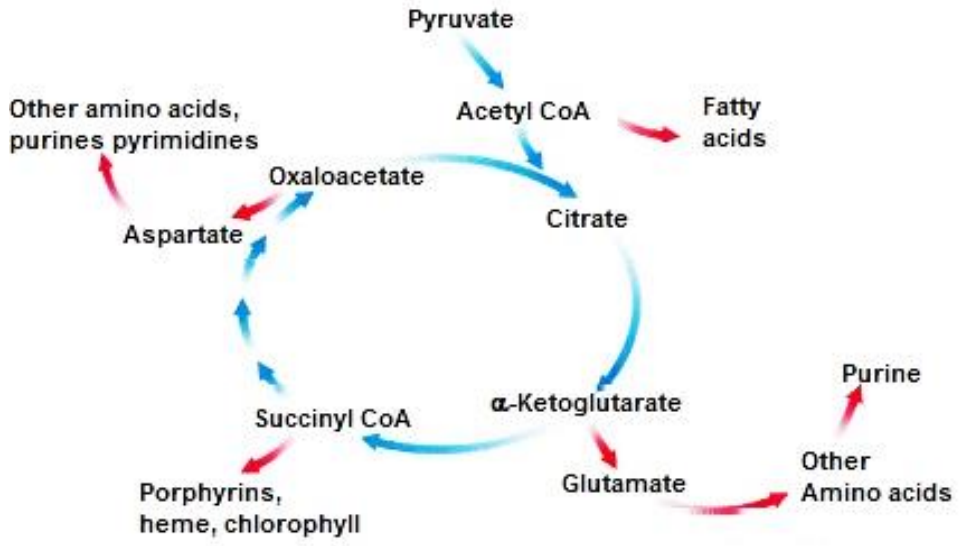


Fig. Interrelationship among metabolic pathways showing respiration mediated Breakdown of different organic molecules to CO_2 and H_2O

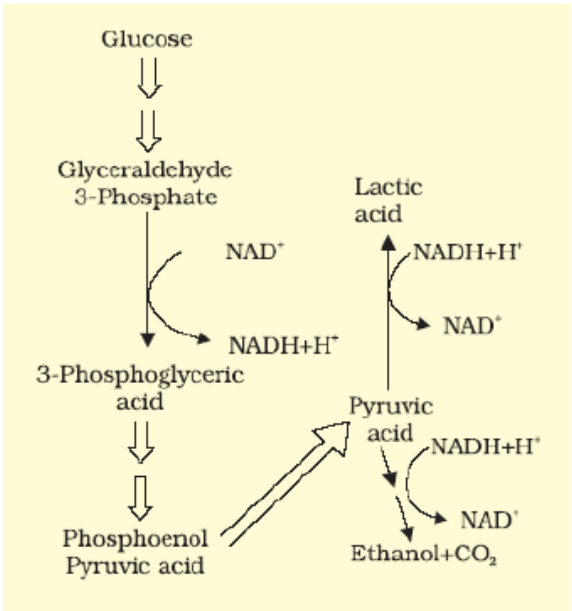
(2) Anaerobic respiration / Fermentation:

- It does not use molecular oxygen and incompletely oxidizes the organic food with or without production of CO_2.
- Therefore, it releases a small amount of energy.
- It is also called **intramolecular respiration.**

$C_6H_{12}O_6 \xrightarrow{\text{Enzyme}} 2C_2H_5OH + 2CO_2 + 50$ K.cal/210kJ

(Glucose) (Ethyl alcohol)

- The organisms which carry out anaerobic respiration are termed anaerobes.



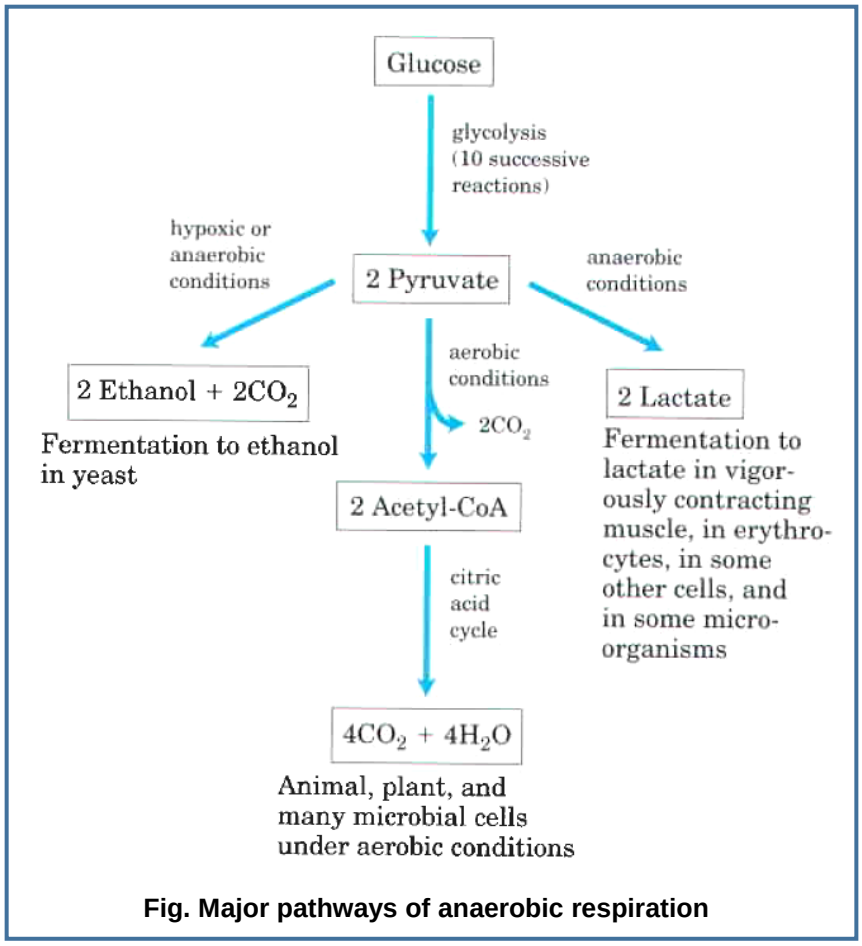


Fig. Major pathways of anaerobic respiration

Mechanism of Anaerobic Respiration: It includes two steps

(i) Glycolysis: It is similar to glycolysis of aerobic respiration except absence of 2NADH. H^+

(ii) Anaerobic breakdown of pyruvic acid: On the basis of organism, type of tissue and nature of end product, anaerobic respiration or fermentation involves following types.

1. Alcoholic fermentation: This process starts through the formation of pyruvic acid from glucose. Alcohol is formed by pyruvic acid in two steps.

(a) $2\ CH_3.\ CO.\ COOH \xrightarrow[TPP]{\text{decarboxylase}} 2\ CH_3\ CHO + 2CO_2$
(Pyruvic acid) (Acetaldehyde)

(b) $2\ CH_3\ CHO + 2\ NADH.H^+ \xrightarrow{\text{dehydrogenase}} 2C_2H_5OH + 2NAD^+$

This reaction takes place in bacteria, fungi and higher plants.

2. Lactic acid fermentation: Pyruvic acid is reduced into lactic acid through fermentation in some bacteria like **Lactobacillus lactis.**

$2\ CH_3\ CO.\ COOH + 2\ NADH.H^+ \xrightarrow[FMN,\ Zn^{++}]{\text{dehydrogenase}} 2\ CH_3\ CHOH\ COOH + 2\ NAD^+$
(Pyruvic acid) (Lactic acid)

Differences between Aerobic respiration & anaerobic respiration

S.No.	Aerobic respiration	Anaerobic respiration
1	It uses O_2	It does not use O_2
2	CO_2 and H_2O produce due to destruction of glucose	Glucose reduces into CO_2 and alcohol
3	It occurs in majority of organisms (animals & plants)	It occurs in few organisms (yeasts, some bacteria and parasitic forms)
4	It occurs in cytoplasm & mitochondria	It occurs in cytoplasm only
5	Its 50% chemical energy convert into kinetic energy	less than 10 % chemical energy of its, convert into kinetic energy
6	38 ATP produce	Only 2 ATP produce
7	It involves 5 steps-Glycolysis, pyruvate oxidation, TCA cycle, ETS and chemiosmotic ATP synthesis	It involves 2 steps - Glycolysis and incomplete breakdown of pyruvate
8	Its enzymes present in both cytoplasm and mitochondria	Its enzymes present only in cytoplasm.

Respiratory Quotient or R.Q.:

- R.Q. is the ratio of the volume of CO_2 released to volume of oxygen taken in respiration.

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

- RQ is determined by respirometer.
- Rate of respiration is measured by **Ganong's respirometer**.

1. R.Q. of carbohydrates:

When carbohydrates are the respiratory substrate than R.Q. is one

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 686 \text{ K. cals.}$$

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

2. R.Q. of Fats:

When fats are the respiratory substrate, the value of R.Q. become less than one because the fats are poorer in oxygen and they require more O_2 for their oxidation.

$$2C_{51}H_{98}O_6 + 145O_2 \longrightarrow 102CO_2 + 98H_2O + E$$

(Tripalmitin)

$$R.Q = \frac{102CO_2}{145O_2} = \frac{102}{145} = 0.70$$

3. R.Q. of Proteins:

When proteins are the respiratory substrate, the value of R.Q. become less than one **(usually 0.9)**.

4. R.Q. of organic acid:

When organic acid (in succulent plants in presence of light) are oxidized in respiration the R.Q. become more than one because organic acids are rich in oxygen and requires less oxygen for their oxidation.

$2(COOH)_2 + O_2 \longrightarrow 4CO_2 + 2H_2O + E$
(Oxalic acid)

$$R.Q = \frac{4CO_2}{O_2} = \frac{4}{1} = 4$$

$C_4H_6O_5 + 3O_2 \longrightarrow 4CO_2 + 3H_2O + E$
(Malic acid)

$$R.Q = \frac{4CO_2}{3O_2} = \frac{4}{3} = 1.33$$

5. R.Q. in succulent plants:

In some fleshy or succulent plants e.g. Opuntia, Bryophyllum, Carbohydrates are incompletely oxidized to organic acid in dark without the evolution of CO_2 thus the value of R.Q. remain 0.

$2C_6H_{12}O_6 + 3O_2 \longrightarrow 3C_4H_6O_5 + 3H_2O + E$
(Glucose) (Malic acid)

$$R.Q = \frac{0CO_2}{3O_2} = \frac{0}{3} = 0$$

6. R.Q. of fatty seeds:

It is less than one (<1)

7. R.Q. during anaerobic respiration:

Due to absence of O_2 the value of R.Q. is infinite because CO_2 is evolved without the intake of oxygen.

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + E$
(Glucose)

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

Factors affecting respiration:

1. Temperature	**2. Light**
3. CO_2	**4. O_2**
5. Water	**6. Mineral salt**
7. Respiratory substrate	**8. Pollutants**
9. Age	**10. Protoplasmic factor**

1. **Temperature:** Optimum temperature = 30° C, Q_{10} value = 2–2.5 or 3. Below 0°C the rate of respiration is greatly reduced. Although in some plants respiration takes place even at –20° . Dormant seeds kept at –50° C survive.
2. **Light:** Light affects the rate of respiration indirectly. Increase in light → increase in rate of photosynthesis → increase in concentration of respiratory substrate → increase in the rate of reaction.
3. **CO_2:** If the amount of CO_2 in the air is more than the usual, rate of respiration is decreased, germination of seed is reduced and rate of growth falls down.

4. **O_2 :** On slight increasing or decreasing the amount of oxygen in the environment, rate of respiration is not affected. On decreasing the amount of oxygen 1.9% in the atmosphere aerobic respiration become negligible, this is called extinction point of aerobic respiration. But anaerobic respiration takes place.
5. **Water:** Rate of respiration $\propto$ amount of water. Dry seeds show very low rate of respiration but as they imbibe water, rate of respiration is increased.
6. **Mineral salts:** Chlorides of alkali cations as well as divalent cations of alkali increase (Li, Ca, Mg) the rate of respiration.
7. **Respiratory substrate:** Increase in respiratory substrate leads to increase in rate of respiration, but it shows saturation.
8. **Pollutants:** High concentration of gaseous air pollutants like SO_2, NO_x and O_3 inhibit respiration by damaging cell membrane. These gaseous pollutant cause increase in pH which in turn affect ETS.
9. **Age:** Rate of respiration decreases with maturity and increasing age.
10. **Protoplasmic factor:** More protoplasm $\rightarrow$ High rate of respiration. Meristematic cells have higher rate of respiration than mature cells.

Read and digest:

1. Exchange of respiratory gases (O_2 and CO_2) between an organism and its environment is called **external respiration.**
2. Exchange of respiratory gases between tissue cells and extracellular environment is called **internal respiration.**
3. 1 molecule of glucose yields 56 Kcal or 2 ATP in anaerobic respiration and 686000 calories (686k cal) or total of 38 ATP in aerobic respiration. But net gain of ATP in eukaryotes is 38 or 36 depending upon type of shuttle system. Thus, ratio of ATP in aerobic and anaerobic respiration is 36: 2 i.e, 18 : 1 or 38 : 2 i e., 19 : 1.
4. One molecule of **sucrose** produces **76 ATP**.
5. **Extinction point:** It is the minimum concentration of oxygen below which aerobic respiration is stopped.
6. Photosyntesis is 10 times faster than respiration.
7. PGAL is connecting link between respiration and photosynthesis.
8. **RBC and muscles** obtain **energy** by **glycolysis or anerobic respiration**.
9. **Metabolism of one molecule of palmitic acid yields 129 ATP.**
10. **RQ of Mixed diet is < 1 (0.7).**
11. **1 molecule of Fructose 1, 6–bisphosphate** yields **40 ATP** during respiration.
12. **Krebs cycle** is **amphibolic cycle**. It undergoes **2 decarboxylations** and **4 oxidations** to form CO_2 & H_2O.

Resonate the Concept

1. **Acetic acid fermentation: Acetobacter aceti bacteria forms acetic acid from alcohol.**

   (a) $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

   (b) $C_2H_5OH + O_2 \xrightarrow{A.aceti} CH_3COOH + H_2O$

2. **Butyric acid fermentation - In the presence of hydrogen acceptor & decarboxylase enzyme Anaerobic bacteria Bacillus butyricus and Clostridium butyricum form butyric acid from glucose or lactic acid**

   (a) $\underset{\text{(Lactic acid)}}{C_6H_{12}O_6} + 2NAD^+ \xrightarrow{\text{decarboxylase}} \underset{\text{(Butyric acid)}}{C_4H_8O_2} + 2CO_2\, 2NADH.H^+$

   (b) $\underset{\text{(Glucose)}}{C_6H_{12}O_6} + 2NAD^+ \xrightarrow{\text{decarboxylase}} \underset{\text{(Butyric acid)}}{C_4H_8O_2} + 2CO_2\, 2NADH.H^+$

3. **Pentose Phosphate Pathway:**

   The alternative pathway of glycolysis to produce the sugars that make up nucleotides is called pentose phosphate pathway.

   It is also called the phosphogluconate pathway or the hexose monophosphate shunt

   It is special because no energy is formed in the form of ATP.

   It generates NADPH and 5-C sugars as well as ribose 5-phosphate (used for synthesis of nucleotides)

   It has two phases - oxidative phase leads to formation of 2NADPH while non-oxidative phase leads to synthesis of 5-C sugars.

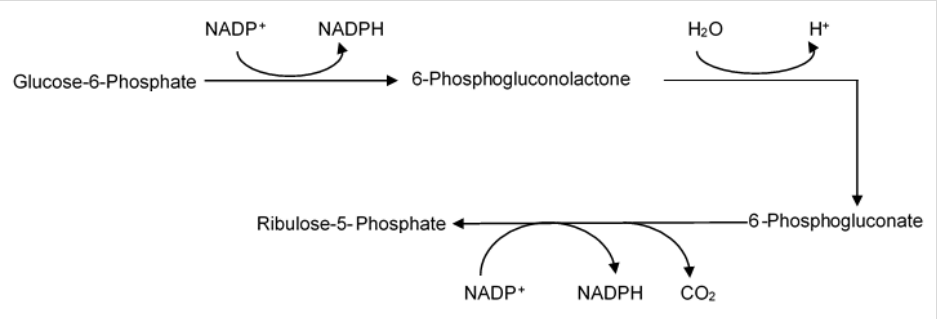
   Location: Mostly cytosol but in plants most steps take place in mitochondria.

   Outcome: **NADPH** (for fatty acids synthesis, for prevention of oxidative stress)

   Ribose-5-phosphate (for synthesis of nucleotides)

   Erythrose-4-phosphate (for synthesis of aromatic amino acids and vitamin B_6)

   Reactions of Oxidative phase (Irreversible):



   Note: In **oxidative phase,** 3 molecules of glucose-6-phosphate give rise to 3 molecules of CO_2 and 3 molecules of 5-C sugars and 6 molecules of NADPH

   Reaction of non-oxidative phase (Reversible):

   3×Ribulose 5-phosphate ⟶ 2×Glucose-6-phosphate + Glyceraldehyde 3-phosphate

Note: The 3 molecules of 5-C sugars are rearranged to regenerate 2 molecules glucose-6-phosphate and 1 molecule of glyceraldehyde 3-phosphate in **non-oxidative phase.**