Respiration in Plants 14

* "It 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." The latter is also called energy currency.

  Respiration is **catabolic, oxidative and exergonic process**. It is also called **cellular respiration.**

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{enzyme}} 6CO_2 + 6H_2O + 686\ \text{K.cals}/2867\text{kJ}$$

(Glucose)

* In **prokaryotes**, Respiration takes place in **cytoplasm** while in **eukaryotes**, it takes place in **cytoplasm** and **mitochondria**

* **Dutrochet** introduced the term **respiration** and studied it in plants.

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.

Respiratory substrate : Organic compounds catabolised in the living cells to release energy are called respiratory substrates. **Ex: Carbohydrate, fats, proteins, organic acid.**

Differences between Respiration and combustion

S.No.	Respiration	Combustion
1	It is a biochemical process	It is a physicochemical process
2	It occurs under biological control	It does not occurs under biological control
3	Only a part of energy is lost as heat	Almost entire energy is released as heat
4	Temperature remains low	Temperature rises considerably
5	Most 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.

Blackman gave it various names on the basis of substrate. Respiration which uses carbohydrates or fats is termed **floating respiration** whereas which uses proteins is called **protoplasmic respiration**

Mechanism of aerobic Respiration :

It involves two types–**common pathway and pentose phosphate pathway**

(I) Common pathway of aerobic Respiration :

Glycolysis is common in aerobic respiration & anaerobic respiration hence it is called common pathway. The process of common pathway of aerobic respiration is completed in following steps.

(1) Glycolysis :

It is a partial oxidative process in which Hexose (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.**

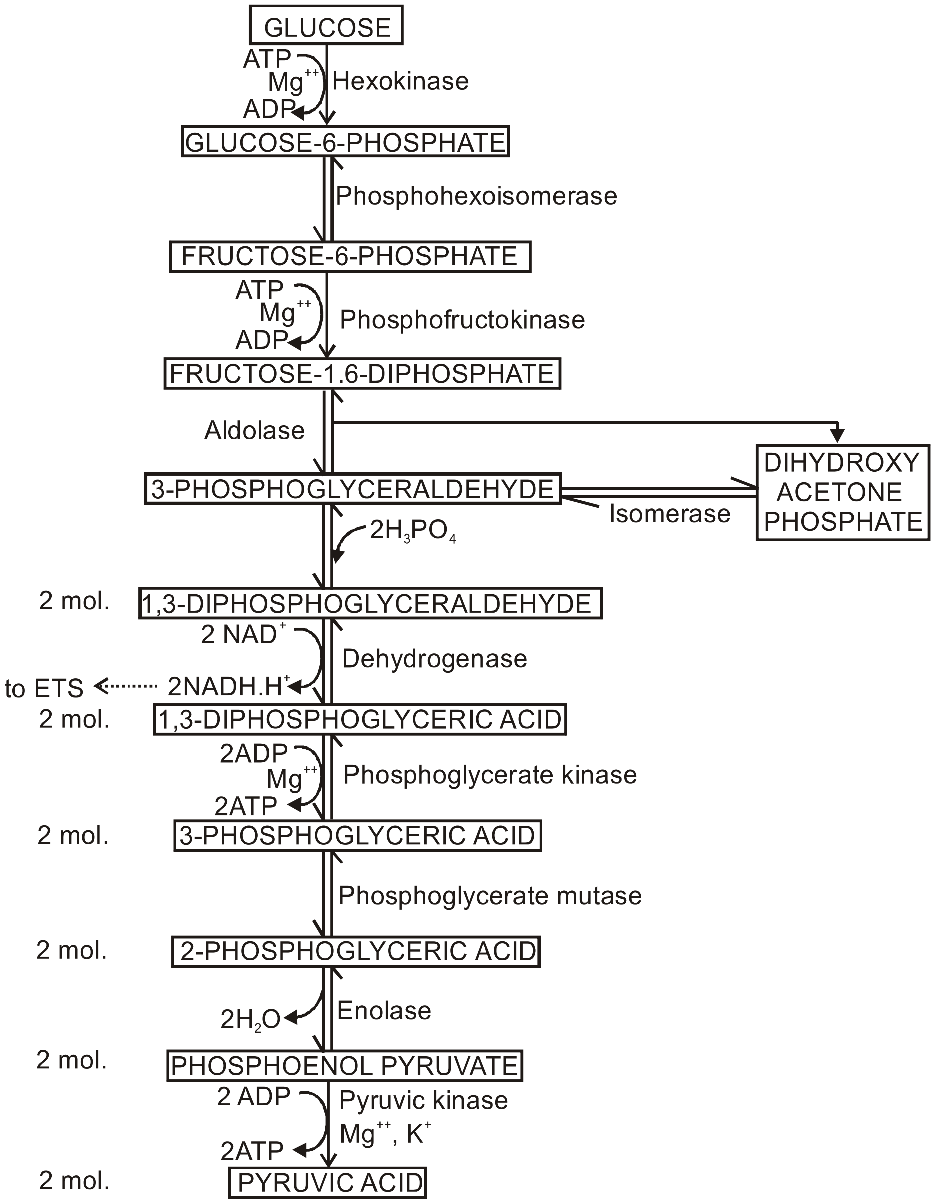

Fig : Different steps of Glycolysis

Energy production in glycolysis :

* In glycolysis one molecule of hexose sugar is splitted to form two molecules of 3-C compound pyruvic acid. 4 molecules of ATP are produced and 2 molecules of ATP are consumed so net gain is 2 ATP.
* 2 molecules of $NADH.H^+$ are also produced which enter into mitochondria and are oxidized through ETS to form 6 ATP. So glycolysis in aerobic condition can produce 2 + 6 = 8 ATP.

(2) Oxidative decarboxylation of pyruvic acid :

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

$$\text{Pyruvic acid} + \text{Co - A} + NAD^+ \xrightarrow[\text{Mg}^{++}\text{, TPP, Lipoic acid}]{\text{Pyruvate dehydrogenase}} \text{Acetyl Co - A} + CO_2 + NADH{+}H^+$$

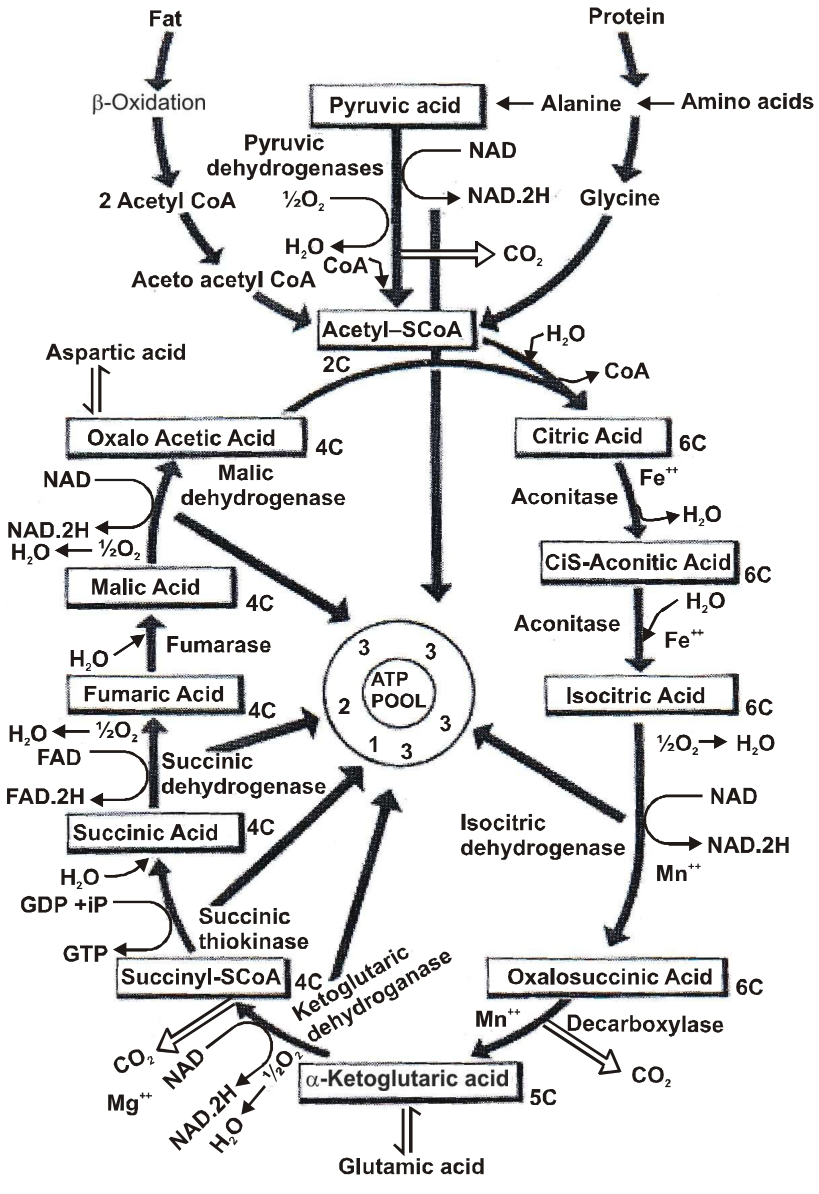

Fig:- Diagramatic representation of oxidative decarboxylation of pyruvic acid and of different chemical reactions in krebs Cycle

(3) Krebs cycle :

* It was discovered by **Hans Krebs in muscles of pigeon.** He got Nobel prize in 1954.
* 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** is **connecting link** between **glycolysis** and **krebs cycle**.
* It includes both Anabolic and catabolic reactions. Thus it is a **Amphibolic pathway**. The acetyl Co-A (2c) reacts with oxaloacetic acid (4C) to form citric acid (6C) in kreb cycle.
* One molecule of Acetyl Co-A yields 3 $NADH.H^+$, 1 $FADH.H^+$ and 1 ATP (=12 ATP) through one kreb's cycle.
* Thus one molecule of pyruvic acid yields 4 $NADH.H^+$, 1 $FADH.H^+$, and one ATP molecule (= 15 ATP) so two molecules of pyruvic acid will produce 30 ATP. Similarly one molecule of pyruvic acid on oxidation through kreb's cycle yield 3 molecules of CO_2. Thus two molecules of pyruvic acid will produce 6 molecules of CO_2.

Bio Chemical reactions in Krebs Cycle ⇒

1. Acetyl Co–A + OAA $\xleftrightarrow[\text{Synthase}]{\text{Citrate}}$ Citric Acid + Co–A
(2C) (4C) (TCA)

2. Citric Acid $\xleftrightarrow[Fe^{++}]{\text{Aconitase}}$ Cis Aconitic Acid $\longrightarrow$ Isocitrate
(6C)

3. Isocitrate + **NAD^+** $\xleftrightarrow[\text{Dehydrogenase}]{\text{Isocitric}}$ Oxalosuccinic Acid + **$NADH_2$**
(6C)

4. Oxalosuccinic Acid $\xleftrightarrow[\text{Decarboxylase}]{Mn^{++}}$ α Ketoglutarate + **Co_2**
(6C) (5C)

5. α Ketoglutaric Acid $\xleftrightarrow{\text{Dehydrogenase comp.}}$ Succinyl Co A + Co_2
(5C) NAD → $NADH_2$ (TPP, LA, Mg^{++}, CoA) (4C)

(This reaction similar to link reaction)

6. Succinyl Co A $\xleftrightarrow{\text{Thiokinase}}$ Succinic Acid + Co A
(4C) GDP + ip → GTP (4C)

[Energy of thioester bond is released, which used in formation of GTP]

(GTP + ADP $\xrightarrow[\text{diphosphokinase}]{\text{Nucleoside}}$ GDP + ATP)

The GTP formed in reaction 6, reacts with ADP to form ATP and GDP, as GTP and ATP have approximatly same energy.

7. Succinic Acid $\xleftrightarrow{\text{Succinic dehydrogenase}}$ Fumaric Acid
(4C) FAD → $FADH_2$ (4C)

8. Fumaric Acid $\xleftrightarrow{\text{Fumarase}}$ Malic Acid
(4C) (4C)

9. Malate $\xleftrightarrow{\text{dehydrogenase}}$ OAA (Acceptor of Acetyl CoA)
(4C) NAD → $FADH_2$ (4C)

* α – Ketoglutaric acid + NH_4^+ + NAD (P)H

$$\xrightarrow[\text{dehydrogenase}]{\text{Glutamate}} \textbf{Glutamate} + H_2O + NADP^+$$

* This is known as **reductive amination** .
* The first formed amino acid (in plants) is **glutamic acid**, which forms other types of amino acids by the process of **transamination**.

  Ex. Glutamic acid

  + Pyruvic acid $\rightleftharpoons$ α–Ketoglutarate + alanine.

Point of remember :

Actually $NADH_2$ & $FADH_2$ form ATP through ETS.

(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 :

* It occurs in F_1 particles or Farnandez Moran subunits or oxysomes which are located on the inner membrane of mitochondria.
* In each group the enzymes are arranged in a specific series called electron transport chain (ETC) or mitochontrial respiratory chain or electron transport system (ETS).

  Process : Inner mitochondrial membrane possesses five complexes.

S.No.	Name of Complexes	Parts of ETS
1.	Complex-I	FMN-$NADH_2$ Dehydrogenase
2.	Complex-II	CoQ/UQ-$FADH_2$Dehydrogenase /Succinate dehydrogenase
3.	Complex-III	Cyt. b-Cyt c_1
4.	Complex-IV	Cyt. a & Cyt.a_3 (Cu Present)
5.	Complex-V	ATP synthase/ATPase

* **Complexes-I to-IV are involved in electron transport whereas Complex V (F_0–F_1 particle) is connected with ATP synthesis.**

It includes following steps

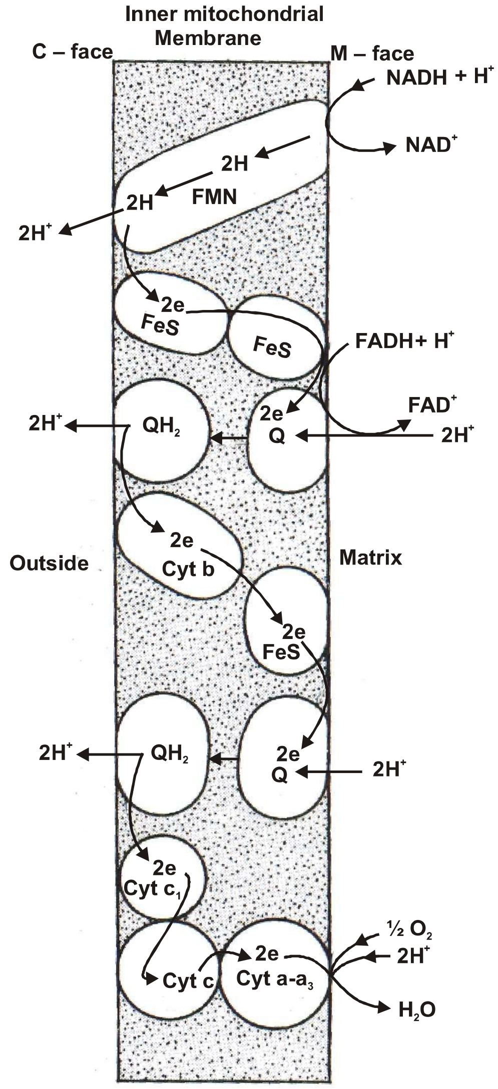

Fig : Electron Transport system (ETS)

(i) **ETS** consists of Flavins, FeS complexes, Quinone and cytochromes. Quinone is ubiquinone or CoQ. Electrons enter the mitochondrial electron transport chain at two routes-at FMN and at FAD. These routes join at conenzyme Q, where the electrons coming from the two routes collect.

(ii) NADH transfer its electron and H^+ ions to FMN, the first electron acceptor in route 1 of ETC. In this transfer NAD^+ is oxidised and FMN is reduced becoming $FMNH_2$. The electrons from succinate in krebs cycle are picked by FAD^+. The first electron carrier in the route 2 of ETC.

(iii) H-ions move to the outer chamber of mitochondria while electrons are accepted by cytochromes. The latter are **arranged in order of increasing their redox pentential**.

Cyt b $\rightarrow$ Cyt C_1 $\rightarrow$ Cyt C $\rightarrow$ Cyt a $\rightarrow$ Cyt a_3

Cytochrome a & a_3 are collectively called cytochrome oxidase. While **cytochrome a_3** is called **terminal oxidase**.

(iv) In cytochrome, iron functions as activator. It accept ($Fe^{+++} + e^- \ Fe^{++}$) and donate ($Fe^{++} - e^- \ Fe^{+++}$) electrons.

(v) These electron from cytochrome oxidase react with atom of oxygen making it active. This activated oxygen react with 2 Hydrogen ions forming molecule of water.

$$O + 2e^- \rightarrow ½\ O^{-2} \xrightarrow{2H^+} H_2O$$

(B) Oxidative Phosphorylation :

* Synthesis of ATP in the presence of oxygen in mitochondria is called **Oxidative Phosphorylation**. The latter can be explained by **Chemiosmotic theory.**

CHEMIOSMOTIC THEORY :

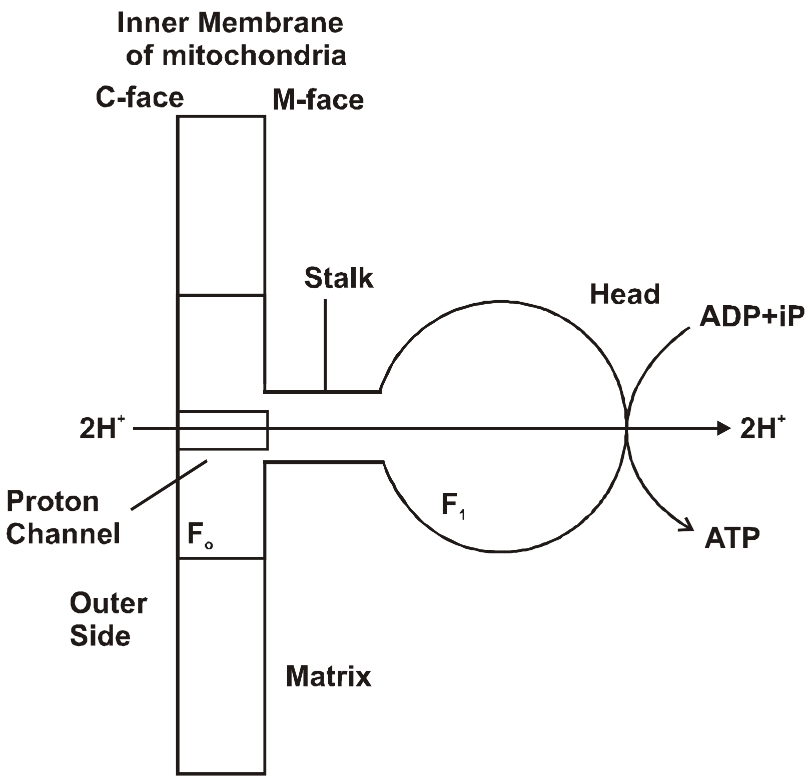

Fig:- Synthesis of ATP by ATPase complex

* It was proposed by **Peter Mitchell** (1961). He got nobel prize in 1978. During oxidation of NADH the H^+ ions move in outer chamber of mitochondria that causes different pH across the membrane which creates an electric potential across the inner mitochondrial membrane that produces **proton gradient or proton motive force.**

* Proton motive force causes the flow of protons from the outer chamber across the inner mitochondrial membrane in to matrix. Protons pass through the **F_o - F_1 ATPase particle** where ATPase catalyses the synthesis of ATP from ADP + Pi.

Route 1 of ETS-3ATP are synthesized by the complete oxidation of 1 molecule

of NADH.H^+.

Route 2 of ETS- Only 2 ATP are synthesized by complete oxidation of one mole of FADH.H^+.

BALANCE SHEET OF ATP IN RESPIRATION :

* In respiration, complete oxidation of one molecule of glucose forms 38 ATP (or 36 ATP) along with CO_2 and H_2O. Production of ATP molecules in various processes are as follow -

Table

Stage	Production of ATP by substrate level phosphorylation	Formation of NADH/FADH	Synthesis of ATP by ETS in Mitochondria
Glycolysis	2	2 NADH	$2 \times 3 = 6$
Oxidative decarboxylation of Pyruvic acid	—	2 NADH	$2 \times 3 = 6$
Krebs Cycle	2	6 NADH 2 FADH	$6 \times 3 = 18$ $2 \times 2 = 4$
	4		34 (or 32)

* Thus complete oxidation of **one molecule** of **glucose** produces **38 ATP (or 36 ATP)**. The production of 38 ATP or 36 ATP in respiration depends upon types of shuttle system.

(II) Pentose phosphate pathway of respiration :

* This cycle was firstly studied by **Warburg (1935), Dicken (1938)** in Animal tissues. It occurs in Adipose tissue in Liver, mammary glands of animals. It takes place in **cytoplasm**.

(2) Anaerobic respiration :

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

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} \xrightarrow{\text{Enzyme}} \underset{\text{(Ethyl alcohol)}}{2C_2H_5OH} + 2CO_2 + 50 \text{ K.cal/210kJ}$$

* The organisms which carry on anaerobic respiration are termed anaerobes.

Fermentation :

* **Fermentation** was first reproted by **Louis pasteur** and remarked that fermentation occurs only when living yeast cells are present. He used the term **zymosis**.

* It is anaerobic break down of carbohydrates and other organic compounds into alcohol, organic acid and CO_2 with the help of microorganisms. It can occurs in absense of oxygen.

Mechanism of Anaerobic Respiration :

It includes two steps

(i) Glycolysis : It is similar as 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 repiration 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) $$\underset{\text{(Pyruvic acid)}}{2CH_3.CO.COOH} \xrightarrow[\text{TPP}]{\text{decarboxylase}} \underset{\text{(Acetaldehyde)}}{2CH_3CHO} + 2CO_2$$

(b) $$2CH_3CHO + 2NADH.H^+ \xrightarrow{\text{dehydrogenase}} 2C_2H_5OH + 2NAD^+$$

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.**

$$\underset{\text{(Pyruvic acid)}}{2CH_3.CO.COOH} + 2NADH.H^+ \xrightarrow[\text{FMN, }Zn^{++}]{\text{dehydrogenase}} \underset{\text{(Lactic Acid)}}{2CH_3CHOH} + 2NAD^+$$

Similarities in fermentation and anaerobic respiration :

(i) Substrate is similar in both processes (Hexose sugars).

(ii) Intermediate compounds (Pyruvic acid and acete aldehyde)are similar.

(iii) Zymase enzyme participate in Alcoholic fermentation. Phosphate is essential in both processes

(iv) CO_2 release in both process. (Alcoholic, acetic acid & butyric acid fermentation).

Difference between Fermentation & Anaerobic respiration

S.No.	Fermentation	Anaerobic respiration
1	It takes place in micro organism, fungi (yeast)	It takes place in higher plants
2	It is extracellular process	It is intracellular process
3	ATP do not Produce	ATP produce
4	Zymase obtains from cell of yeast, micro organisms	Zymase enzyme is found in cell

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 organism (yeasts, some bacteria and parasitic form)
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 chemosmotic 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

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

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

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.

$$\underset{\text{(Tripalmatin)}}{2C_{51}H_{98}O_6} + 145O_2 \longrightarrow 102CO_2 + 98H_2O + E$$

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

$$\underset{\text{(Triolin)}}{C_{57}H_{104}O_6} + 80O_2 \longrightarrow 57CO_2 + 52H_2O + E$$

$$R.Q = \frac{57CO_2}{80O_2} = \frac{57}{80} = 0.71$$

3. R.Q. of Proteins :

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

FACTORS EFFECTING CELL RESPIRATION:-

(1) Temperature :-

* Optimum temp. for respiration is between 20-35°C. Maximum temp. is around 45°C.
* At low temp respiration is low due to inactivation of enzymes (Freeze preserve the food) while at very high temp. decrease, as enzyme denatured. Q_{10} = 2 to 3 for respiration.
* Production of potato crop is high on the hill areas due to low temp. throughout year.

  CPRI (Central potato Research Institute is situated at Kufri-Shimla (H.P.)

(2) Oxygen :-

* The inhibition of anaerobic respiration by O_2 concentration is called as **Pasteur's effect**.
* The minimum amount of oxygen, at which aerobic respiration takes place & anaerobic respiration become extinct is called as **extinction point**.
* Oxygen conc^n at which both aerobic & anaerobic respiration take place simultaneously is called as **transition point**.

(3) CO_2 :-

* If CO_2 concentration increases, then rate of respiration decreases in plants, (because stomata get closed).

(4) Salts :-

If a plant is transferrered from water to salt solution, it's respiration increases, this is known as **salt respiration.** Because absorption of ions requires metabolic energy.

(5) Hormones :-

* IAA, GA & cytokinin increase the respiration rate.
* The rapid increase in rate of respiration during ripening of fruits and senescence of leaves and plant organs is called as **"Climacteric respiration"**. This rate is decrease after sometime.

  It is due to production of **ethylene** hormone.

(6) Light :-

Rate of respiration increases with increase in light intensity.

Light controls the stomatal opening & influence on temp. and also produce respiratory substrates.

(7) Injury, disease & wounds :-

The respiration increases due to injury wounding & infection.

(8) Inhibitors :

CN, azides, DNP (Dinitrophenol), CO, rotenone, antimycin, amytal. etc inhibit the respiration.

(9) Age :

Rate of respiration is more in young cells. Rate of respiration at meristem apex is high.

(10) Water : Seeds are slow respiring part of plants, because dry seeds are deficient of H_2O.