

# RESPIRATION AND ENERGY TRANSFER

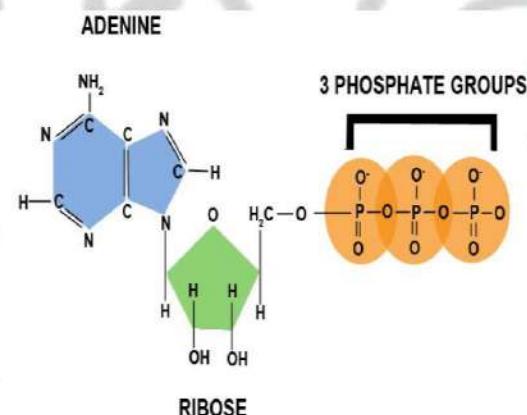
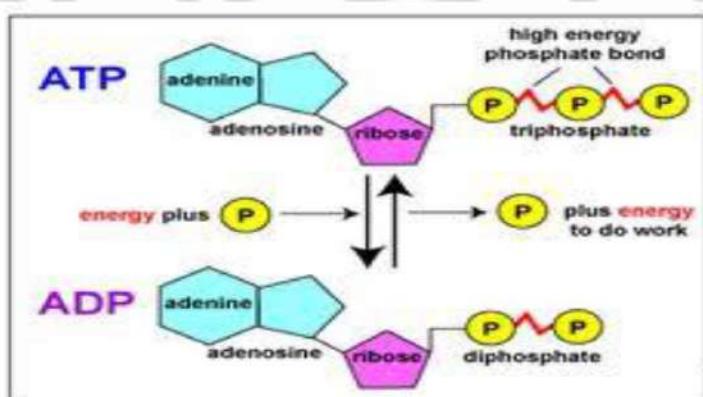
## ❖ Respiration:

- The oxidation of organic compounds in living cells to release energy to synthesize ATP molecules called as respiration.
- Catabolism [breakdown] or oxidation of food material into simpler substance to liberate energy is called as respiration.
- The process which involves oxidation of organic food material to release energy in the form of ATP.
- The biological oxidation of organic substances include stepwise breakdown of organic substances to release energy to synthesize ATP Molecules.
- Intracellular process of oxidation in which complex organic substances are broken down in stepwise manner to release energy in the form of ATP
- **Respiratory substrate:** CHO(glucose),proteins, fats and organic acid – forms of potential energy. Glucose is most preferred substrate due to availability and acceptance by all kinds of organisms.
- **Byproduct:**  $\text{CO}_2$  and  $\text{H}_2\text{O}$

## ❖ ATP: Currency of energy

- **Definition:** ATP is a triphosphate ester of adenosine ribonucleoside which is an energy rich chemical compound.
- **Chemical composition:**
  1. Adenine - nitrogen purine base
  2. Ribose( $\text{C}_5\text{H}_{10}\text{O}_5$ ) - Pentose sugar
  3. Phosphate groups (3)

Adenosine ribonucleoside = Adenine + Ribose
- **Formation of ATP:**



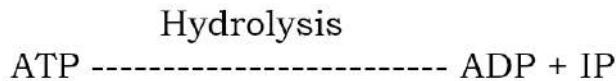
1. Adenosine ribonucleoside = Adenine + Ribose
2. Adenosine + 1 phosphate = Adenosine monophosphate(AMP)
3. AMP + 2<sup>nd</sup> phosphate = Adenosine diphosphate (ADP)
4. ADP + 3<sup>rd</sup> phosphate = Adenosine triphosphate (ATP)

## ○ Energy conversion:

**1. During release of energy:** ADP & IP converted into ATP.



**2. During requirement of energy:** ATP hydrolyzed into ADP & IP. During hydrolysis, high energy phosphate bond broken and energy released in the form of ADP and IP



3. Most of energy conversion in the cell is at ADP & ATP level.
4. ATP stores energy released during respiration in its high energy chemical bonds. The energy used for various cellular activities (Division, growth, movement, reproduction and biosynthesis).
5. On hydrolysis of an ATP molecule, 7.3 kcal energy is released.

## ❖ Mitochondria:

- **Definition:** The filamentous or rod shaped structure which is self-regulating, self-duplicating, semi autonomous living cell organelle. Mitochondria is a site for respiration i.e. ATP synthesis

- **Location:** Cytoplasm of eukaryotic cell.

- **Length :**  $1\text{-}4 \mu$  **Width :**  $0.5\text{-}10\mu$

- **Ultra structure:**

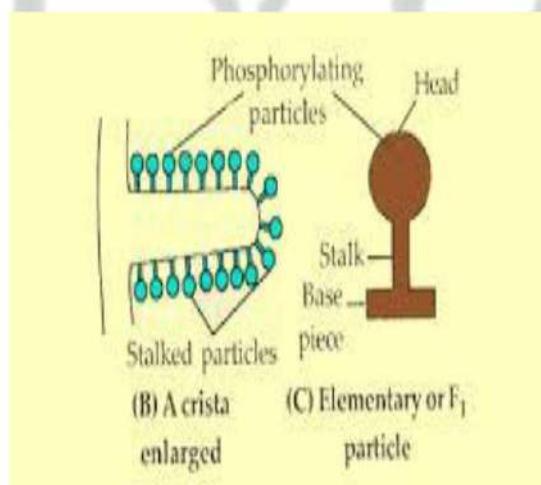
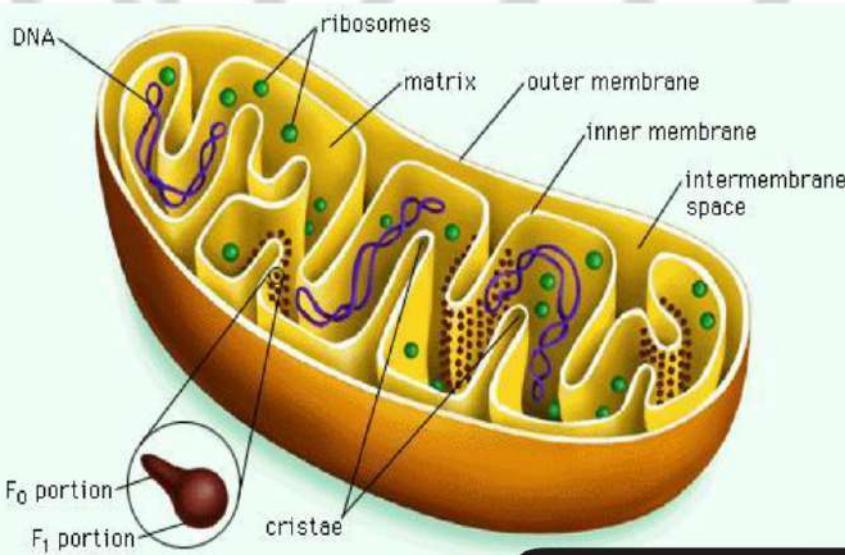
**1. Membranes:** Double membrane bound cell organelles.

- a. **Outer membrane:** It is smooth thin, tightly stretched, without folding and freely permeable. It is not associated with ATP synthesis

- b. **Inner membrane:** It is rough, thick, with folding and differentially permeable membrane. it is associated with ATP synthesis.

- **Crista:** Each fold of inner membrane forms finger like projections is called as crista. Cristae bears number of stalked particles called as  $F_1$  particles.

- **$F_1$  particles/Oxysome:** Tennis racket shaped particles present on 'm' face (facing matrix) of criste called as oxysomes/  $F_1$  particles/elementary particles. The electron carriers of ETS and enzymes required for ATP synthesis located on the body of oxysomes .Oxysomes helps in oxidative phosphorylation /ATP synthesis.



## **2. Chambers:**

- a. **Outer chamber:** It is present between outer and inner membrane.
- b. **Inner chamber:** It is surrounded by inner membrane and contains matrix.

**3. Matrix:** The liquid present in inner chamber is called as matrix .Matrix contains - a) DNA(single circular b) RNA c) Ribosomes(70's type) d)Respiratory pigments e) Respiratory enzymes and co enzymes.

## **o Functions:**

1. **Release of energy:** Mitochondria release energy in the form of ATP so called as power houses of cells.
2. **Storage of energy:** The energy in the form of ATP is stored and used for various cellular activities.
3. **Helps in aerobic respiration:** Mitochondria helps in aerobic respiration and releases energy.
4. **Helps in Kreb's cycle:** Respiratory enzymes required for Krebs's cycle
5. **Helps in oxidative Phosphorylation:** Mitochondria helps in oxidative phosphorylation
6. **Protein synthesis:** Mitochondria also help in protein synthesis because they contain DNA, RNA and ribosome.
7. **Helps in terminal oxidation and electron transport:** oxysomes /F<sub>1</sub> particles of criste helps in terminal oxidation.

**B. Types:** A) Aerobic respiration

B) Anaerobic respiration

<b>Points</b>	<b>Aerobic respiration</b>	<b>Anaerobic respiration</b>
<b>1. Definition</b>	Respiration in the presence of free molecular O <sub>2</sub>	Respiration in the absence of free molecular O <sub>2</sub>
<b>2. Place of occurrence</b>	Cytoplasm and mitochondria	Cytoplasm
<b>3. 4.End product</b>	CO <sub>2</sub> and H <sub>2</sub> O	Ethyl alcohol and lactic acid
<b>4. .Nature of end product</b>	Non -Toxic	Less toxic
<b>5. Amount of energy released</b>	Large quantity (686Kcal/Glucose mol.)	Small quantity (50.4Kcal/Glucose mol.)
<b>6. Nature of oxidation</b>	Complete oxidation	Incomplete oxidation
<b>7. No. of ATP mol. released/glucose mol.</b>	38 ATP	2ATP
<b>8. No. of CO<sub>2</sub> mol. given out</b>	6	2
<b>9. Nature of cells</b>	All eukaryotic cells	Most of prokaryotic cells
<b>10. Phases</b>	1.Glycolysis 2.Krebs's cycle 3.ETS	1.Glycolysis 2.Fermentation
<b>11. Equation</b>	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> +6O <sub>2</sub> ----- 6CO <sub>2</sub> +6H <sub>2</sub> O +38ATP	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> -----2C <sub>2</sub> H <sub>5</sub> OH+2CO <sub>2</sub> +2ATP
<b>12. Examples</b>	Higher plants and animals	Most of prokaryotic cells, some bacterial cells and animal muscles

S N	Points	Chloroplast	Mitochondria
1	<b>Place of occurrence</b>	In all green plants	In all living organism except prokaryotic cells
2	<b>Color</b>	Green	colorless
3	<b>Identification mark</b>	Photosynthetic apparatus	Power house of cells
4	<b>Carrying out</b>	Photosynthesis	Kreb's cycle and ATP
5	<b>Effect of glucose</b>	Synthesis of glucose	Breakdown of glucose
6	<b>Membranes</b>	Smooth outer and inner membrane	Smooth outer and folded inner membrane
7	<b>Synthesis of ATP</b>	By photophosphorylation	By oxidative phosphorylation
8	<b>Nature</b>	Anabolic process	Catabolic process

Points	Photosynthesis	Respiration
<b>1. Definition</b>	The process in which green plants synthesized their own food by using simple inorganic material( $\text{CO}_2$ & $\text{H}_2\text{O}$ ) with the help of light	The process which involves oxidation of organic food material to release energy in the form of ATP
<b>2. Nature of process</b>	Anabolic(Building up)	Catabolic(Breaking down)
<b>3. Role of oxygen</b>	Given out	Taken out
<b>4. Role of <math>\text{CO}_2</math></b>	Taken in	Given out
<b>5. Time limit</b>	Day time	Day and night time
<b>6. Raw material required</b>	$\text{CO}_2$ & $\text{H}_2\text{O}$	Glucose & $\text{O}_2$
<b>7. End products</b>	Glucose & $\text{O}_2$	$\text{CO}_2$ & $\text{H}_2\text{O}$
<b>8. Place of occurrence</b>	Only in green cells with chloroplast	Green as well as non-green cells
<b>9. Chlorophyll</b>	Necessary	Not necessary
<b>10. Effect on energy</b>	Energy is absorbed	Energy is released
<b>11. Dependence of light</b>	Present	Absent
<b>12. Synthesis of ATP</b>	By photophosphorylation	By oxidative Phosphorylation
<b>13. Dry weight of plants</b>	Increased	Decreased

## ❖ Anaerobic respiration is less efficient than aerobic respiration

- Release of energy (Kcal):** In aerobic respiration, 686 Kcal energy released and in anaerobic respiration only 50.4 Kcal energy released from each molecule of glucose.
- No. of  $\text{CO}_2$  molecules released:** In aerobic respiration 6 molecules of  $\text{CO}_2$  are released and in anaerobic respiration only 2 molecules of  $\text{CO}_2$  are released.

**3. No. of ATP molecules formed:** In aerobic respiration, 38 molecules of ATP formed from 1 molecule of glucose and in anaerobic respiration only 2 molecules of ATP formed.

**4. Oxidation of glucose:** In aerobic respiration, complete oxidation of glucose and in anaerobic, there is incomplete oxidation of glucose.

From above the information, it is clear that anaerobic respiration is less efficient than aerobic respiration

❖ **Types:** A. Aerobic respiration    B. Anaerobic respiration

### A) Aerobic respiration :

❖ **Definition:** Respiration in the presence of free molecular O<sub>2</sub> is called as aerobic respiration

❖ **Stages/Phases:** 1. Glycolysis 2. Krebs's cycle 3. Electron transfer

### 1) Glycolysis/EMP pathway:

❖ **Definition:** Stepwise enzymatic breakdown of glucose molecules into two molecules of pyruvic acid is called as glycolysis.

❖ **EMP pathway:** Glycolysis discovered by 3 German scientists i.e  
1. Embeden    2. Meyer Hof    3. Parnas

❖ **Common Pathway:** EMP pathway is common for aerobic and anaerobic respiration. There is common breakdown of glucose.

❖ **Place of occurrence:** only in cytoplasm of cell [ cytoplasmic respiration ]

❖ **Role of Oxygen:** EMP pathway takes place in absence of molecular O<sub>2</sub>

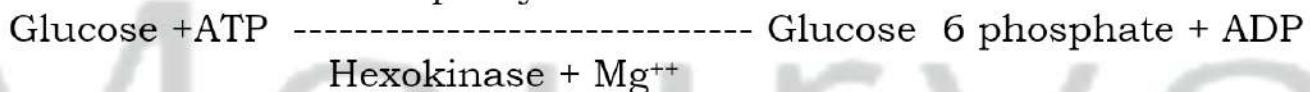
❖ **Mechanism:**

**A) Preparatory phase & Cleavage:** Initial phase of glycolysis includes phosphorylation and cleavage and results into formation of 2 PGAL mol.

#### 1. Phosphorylation(Phosphorylation of glucose to glucose 6 phosphate)

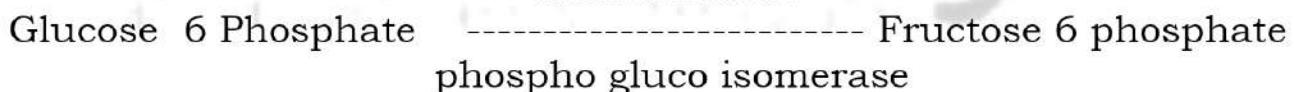
: The glucose undergoes Phosphorylation by using ATP molecules under the influence of enzyme hexokinase and there is formation of glucose 6 phosphate and ADP.(The phosphate from ATP attached to carbon no.6 of glucose and glucose 6 phosphate formed)

Phosphorylation



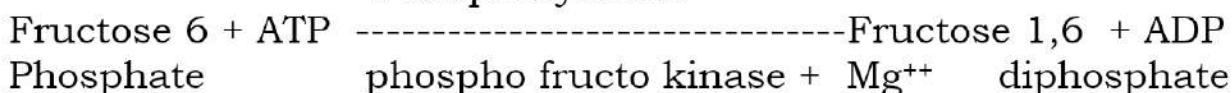
**2. Isomerization (Glucose 6 phosphate to fructose 6 phosphate):** Glucose 6 phosphate undergoes isomerization in the presence of enzyme phospho gluco kinase and there is formation of fructose 6 phosphate

Isomerization



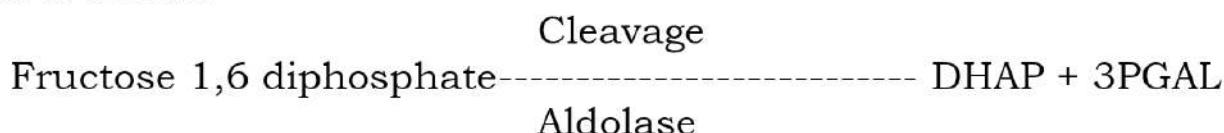
**3. Phosphorylation II(Phosphorylation of fructose 6 phosphate to fructose 1,6 diphosphate):** Fructose 6 phosphate undergoes phosphorylation in the presence of enzyme phospho fructo kinase and there is formation of fructose 1,6 diphosphate. In this process ATP is used and converted into ADP.

Phosphorylation

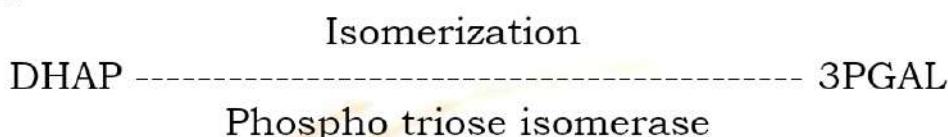


#### **4. Cleavage of fructose 1,6 diphosphate to 3 phosphoglyceraldehydes(3PGAL) and dihydroxyacetone phosphate(DHAP):**

Fructose 1,6 diphosphate undergoes cleavage in the presence of aldolase and there is formation of 1 molecule of PGAL and 1 mol. of DHAP.



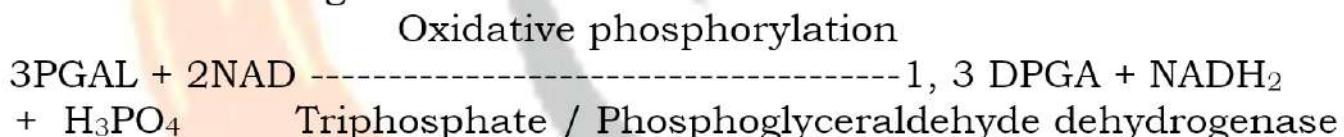
#### **5. Isomerization of DHAP to 3PGAL:** DHAP undergoes isomerization in the presence of enzyme phospho triose isomerase and there is formation of 3PGAL.



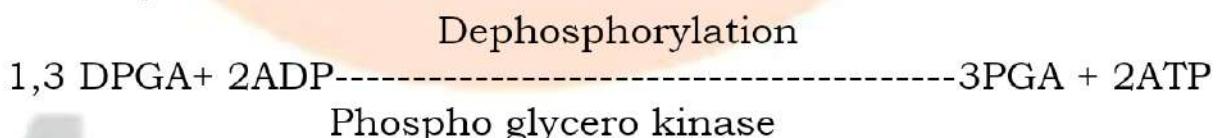
**B) Oxidative & pay off phase:** Oxidation by removal of hydrogen ions and ATP generation takes place(Harvest of energy)

#### **6. Oxidative phosphorylation of 3PGAL to 1,3DPGA :** 3PGAL undergoes oxidative phosphorylation in the presence of enzyme triphosphate dehydrogenase and there is formation of 1, 3, DPGA.

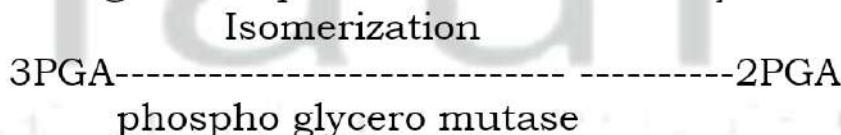
During oxidation (removal of hydrogen) , NAD is converted into NADH<sub>2</sub>.As there are 2 molecules of PGAL ,2 molecules of NADH<sub>2</sub> used. From Each NADH<sub>2</sub>, 3 ATP molecules are generated i.e. total 6 ATP molecules generated.



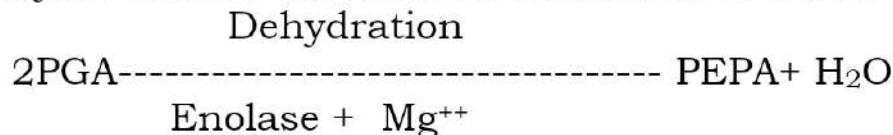
#### **7. ATP gererationI (Dephosphorylation of 1,3PGAL to 3PGA) :** 1, 3 DPGA undergoes dephosphorylation the presence of enzyme kinase and there is formation of 3PGA. In this dephosphorylation 2 ADP molecules used and converted into 2 ATP molecules.



#### **8. Isomerization of 3PGA to 2PGA:** 3PGA undergoes isomerization in the presence of enzyme phospho glycero mutase and there is formation of 2PGA.[Shifting of Phosphorous from 3C to 2C]

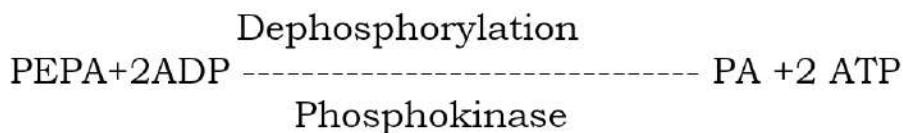


#### **9. Dehydration of 2PGA to PEPA:** 2PGA undergoes dehydration in the presence of enzyme enolase and there is formation of PEPA.

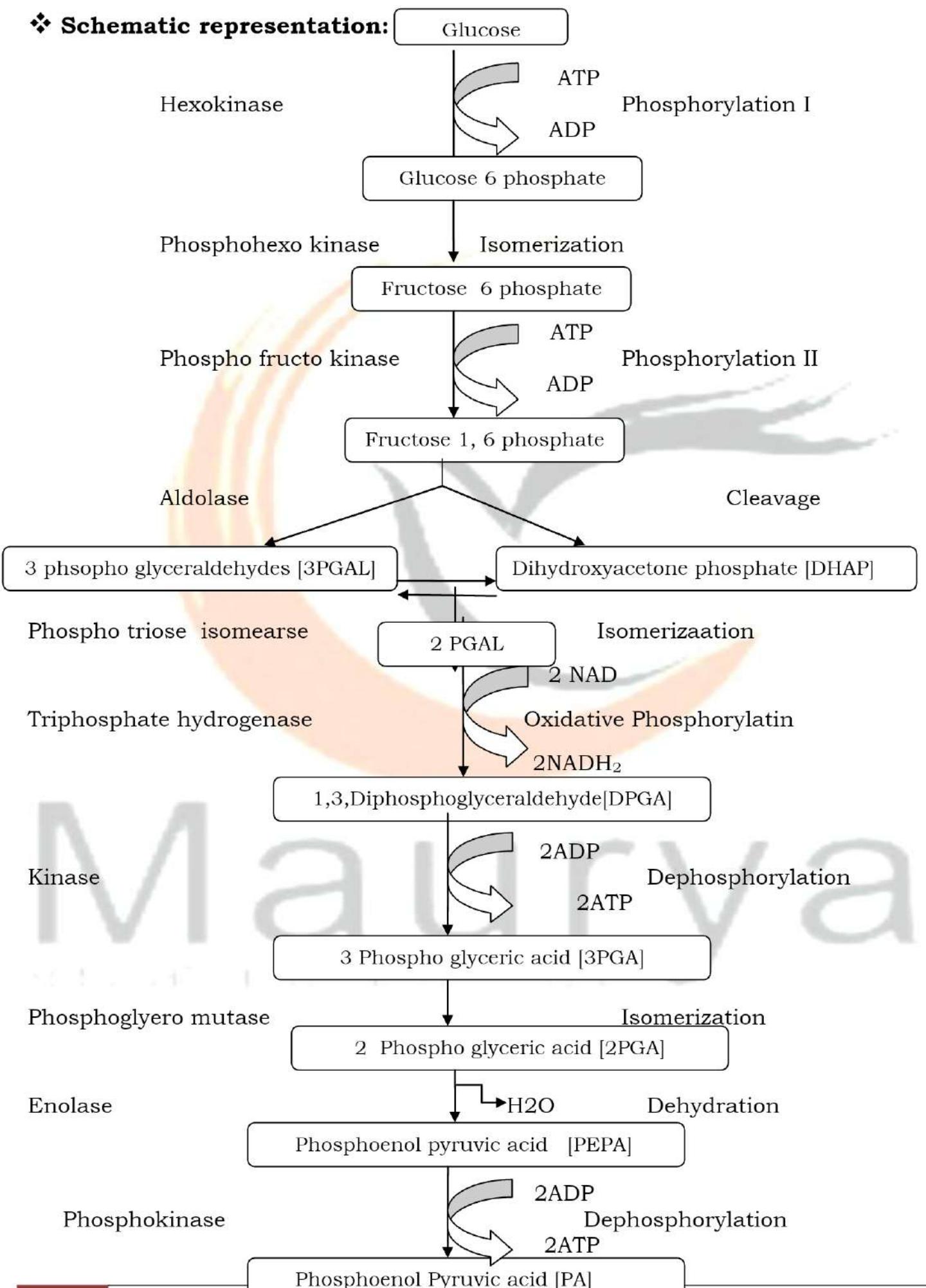


#### **10. ATP generation II /Dephosphorylation of PEPA to PA:** PEPA undergoes dephosphorylation in the presence of enzyme pyruvate Phosphokinase and there is formation of pyruvic acid.

For this, 2 ADP molecules are used and converted into 2 ATP mol.



❖ Schematic representation:



❖ **Number of Pyruvic acid molecules:** At the end of glycolysis from 1 glucose molecules, 2 pyruvic acid molecules formed because after cleavage of fructose 1,6 diphosphate ,there is formation of DHAP And 3PGAL.DHAP also undergoes isomerization and there is also formation of 3PGAL.From this two reactions 2 molecules of 3PGAL formed and from each 2PGAL ,there is formation of 2 PGA molecules. From 2 PGA molecules 2 molecules of PA formed at the end of Glycolysis.

❖ **Total no of ATP molecules formed in glycolysis:**

1. Total 4 ATP molecules are formed in glycolysis.
  - a) Dephosphorylation I(Step 7) = 2 ATP
  - b) Dephosphorylation II(Step 10) = 2 ATP
2. 2 ATP molecules are utilized in reaction 1and 3 (phosphorylation)
3. So, finally 2 ATP molecules are formed.
4. Therefore in actual process of glycolysis, breakdown of glucose forms 2 ATP molecules.

❖ **NADH<sub>2</sub> generation:** Oxidative phosphorylation[Step 6] = 2 NADH<sub>2</sub>

❖ **Net gain of ATP molecules In glycolysis:**

1. 2 ATP in actual process of glycolysis when there is breakdown of glucose to PA.
2. 6 ATP by ETS in glycolysis .NAD molecules used in oxidative phosphorylation and converted into NADH<sub>2</sub> .The NADH<sub>2</sub> forms 3 ATP molecules. In this,2 NADH<sub>2</sub> molecules present so 6 ATP molecules generation. So in this way, net gain of ATP in glycolysis is 8 ATP.

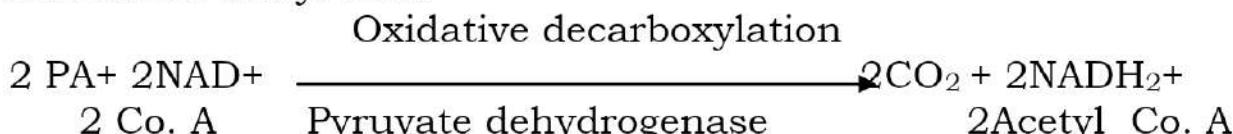
❖ **Reaction of glycolysis :**



❖ **Significance:**

1. **Formation of 2 molecules of PA:** In glycolysis, there is ----
2. **Formation of 2 molecules of NADH<sub>2</sub>**
3. **Formation of 2 molecules of ATP:**
4. **Net gain of ATP:** In glycolysis there is net gain of 8 ATP molecules i.e. 2 ATP from breakdown of glucose and 6 ATP from 2 molecules of NADH<sub>2</sub>.
5. **Incomplete oxidation of glucose:** In glycolysis, there is incomplete oxidation of glucose without use of atmospheric oxygen.
6. **Formation of intermediate compound:** Glycolysis helps in fat and protein metabolism.

❖ **Phase II/Link reaction/Oxidative decarboxylation /Acetelation of pyruvate :** PA undergoes oxidative decarboxylation in the presence of enzyme pyruvate dehydrogenase and there is formation of acetyl Co.A  
OR Removal of CO<sub>2</sub> along with oxidation by removal of hydrogen in the presence of enzyme pyruvate dehydrogenase (oxidase) and there is formation of acetyl Co.A



In this step 2 reactions work simultaneously i.e. oxidation and decarboxylation

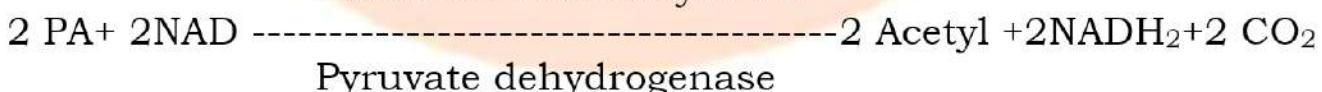
- a) **Oxidation:** Removal of H<sub>2</sub> from PA with the help of NAD and NAD converted into NADH<sub>2</sub>
- b) **Decarboxylation:** CO<sub>2</sub> is removed from PA and there is Carboxylation of PA. After oxidative decarboxylation, PA is converted into Acetyl. Acetyl fraction combines with co enzyme A and there is formation of Acetyl co enzyme A in the mitochondrial matrix.

## 2)Kreb's cycle/TCA cycle/Citric acid cycle:

- **Definition:** The process which involves further breakdown of PA into CO<sub>2</sub> and H<sub>2</sub>O is called as kreb's cycle. Sir Hans Krebs discovered this cycle so called as Krebs's cycle.
- **Complete oxidation of Acetyl Co.** enzyme and release of CO<sub>2</sub> in stepwise manner .During reactions, Co enzymes NAD and FAD takes up H<sub>2</sub> or 2H<sup>+</sup> removed during oxidation and NADH<sub>2</sub> and FADH<sub>2</sub> formed.
- **TCA (Tricarboxylic acid cycle):**The many organic acids formed during this cycle and each contains 3 carboxyl groups(-COOH) so called as TCA cycle.
- **Citric acid cycle:** The first stable compound formed in Krebs's cycle is citric acid so also called as citric acid cycle.
- **Place of occurrence:** Matrix of mitochondria.
- **Mechanism:** 2 molecules of pyruvic acid/pyruvate formed at the end of glycolysis .Therefore Kreb's cycle repeated twice for oxidation of every glucose molecule. Due to 2 turns ,6 NADH<sub>2</sub>,6 FADH<sub>2</sub> ,2 ATP molecules and 3 molecules of H<sub>2</sub>O used up and 2 molecules of CO<sub>2</sub> released

- 1. Oxidative decarboxylation of PA:** PA undergoes oxidative decarboxylation in the presence of enzyme pyruvate dehydrogenase and there is formation of acetyl.

Oxidative decarboxylation



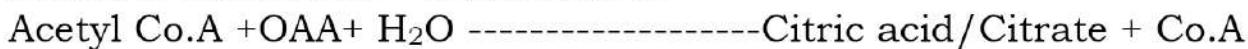
- 2. Formation of Acetyl Co.A:** Acetyl combines with co-enzyme A and there is formation of Acetyl Co.A.

Combination



### ❖ Reactions of Krebs cycle:

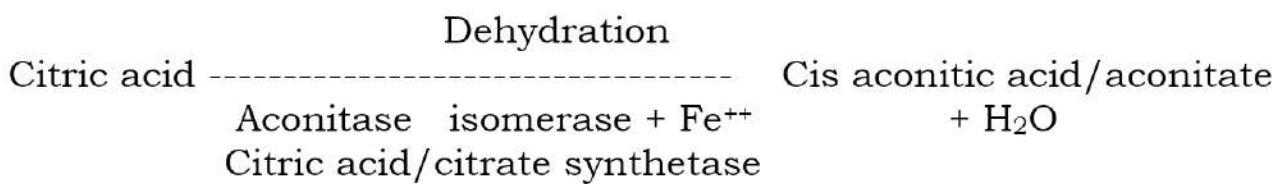
- 1. Condensation of Acetyl Co.A with OAA:** Acetyl Co.A combines with OAA in the presence of enzyme citric acid synthetase and there is formation of Citric acid Combination



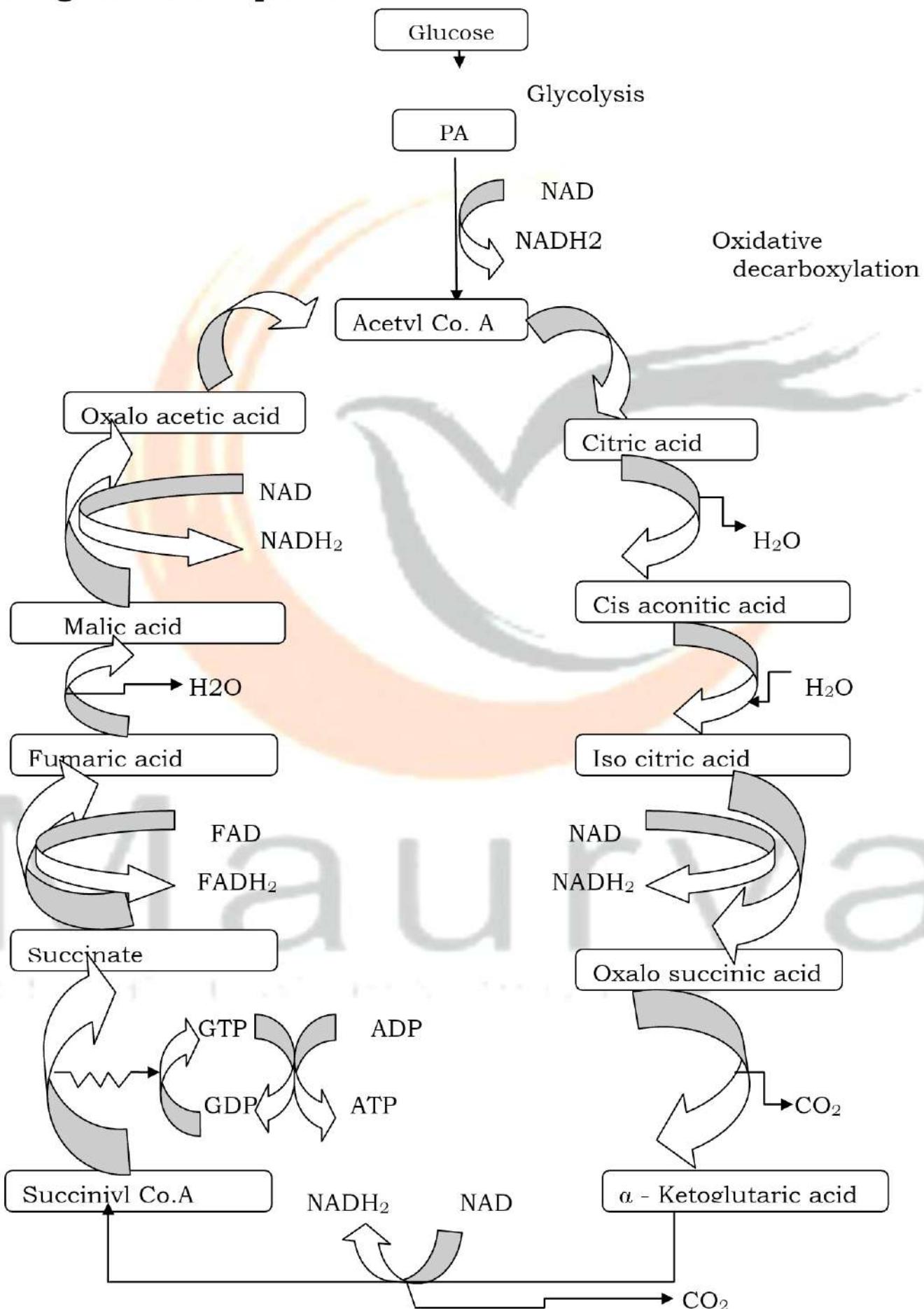
- 2. Isomerization of citric acid to isocitric acid:** Citric acid undergoes isomerization and there is formation of isocitric acid.

Isomerization involves two reactions i.e. dehydration and hydration.

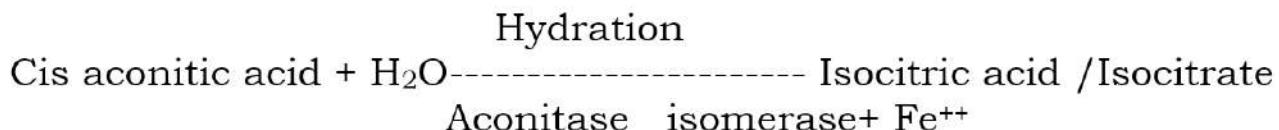
- a) **Dehydration of Citrate/Citric acid:** Citric acid undergoes dehydration in the presence of aconitase isomerase and there is formation of Cis aconitic acid and H<sub>2</sub>O



- **Diagrammatic representation:**

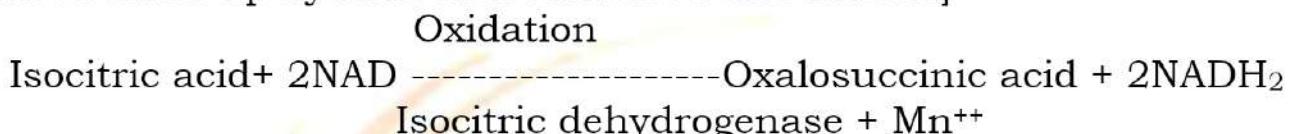


**b) Hydration of Cis aconitic acid/Cis aconitate:** Cis aconitic acid undergoes hydration in the presence of aconites isomerase and there is formation of isocitric acid



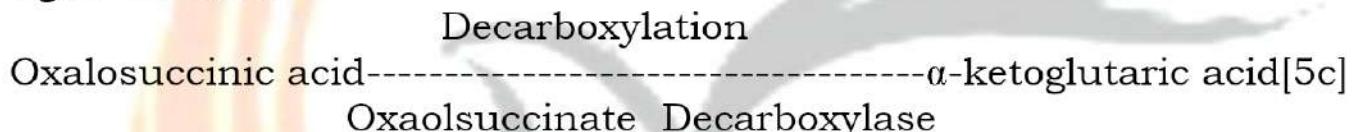
### 3. Dehydrogenation I (Oxidation of isocitric acid to oxalosuccinic acid):

Isocitric acid undergoes oxidation in the presence of enzyme isocitric dehydrogenase and there is formation of oxalosuccinic acid/Succinate .NAD is used during oxidation and converted into NADH<sub>2</sub> [ 2H<sup>+</sup> atoms released takes up by NAD and converted into NADH<sub>2</sub>]



### 4. Decarboxylation I (Decarboxylation of oxalosuccinic acid/Succinate to $\alpha$ -ketoglutaric acid):

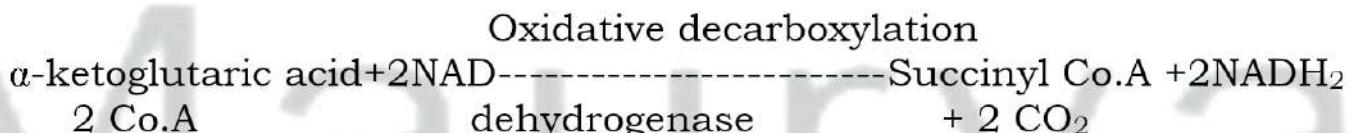
Oxalosuccinic acid undergoes decarboxylation in the presence of enzyme decarboxylase and there is formation of  $\alpha$ -ketoglutaric acid.



### 5. Dehydrogenation/Decarboxylation II (Oxidative decarboxylation of $\alpha$ -ketoglutaric acid to succinic acid/Succinate) :

$\alpha$ -ketoglutaric acid undergoes oxidative decarboxylation in the presence of enzyme  $\alpha$ -ketoglutaric acid dehydrogenase and there is formation of succinyl Co.A Or Removal of CO<sub>2</sub> along with oxidation by removal of hydrogen in the presence of enzyme  $\alpha$ -ketoglutaric acid dehydrogenase (oxidase) and there is formation of Succinyl Co.A.

$\alpha$ -ketoglutaric acid undergoes oxidative decarboxylation and there is formation of succinic acid .



In this step 2 reactions work simultaneously i.e. oxidation and decarboxylation

**a) Oxidation:** Removal of H<sub>2</sub> from  $\alpha$ -ketoglutarate with the help of NAD and NAD converted into NADH<sub>2</sub>

**b) Decarboxylation:** CO<sub>2</sub> is removed from  $\alpha$ -ketoglutarate and there is carboxylation of  $\alpha$ -ketoglutarate. After oxidative decarboxylation,  $\alpha$ -ketoglutarate is converted into Succinyl. .Succinyl fraction combines with co enzyme A and there is formation of succinyl co enzyme A in the mitochondrial matrix.

### 6. Hydration and phosphorylation :

**a) Dehydration:** Succinyl Co.A undergoes decarboxylation in the presence of enzyme succinyl kinase and there is formation of succinic acid





Succinyl thiokinase

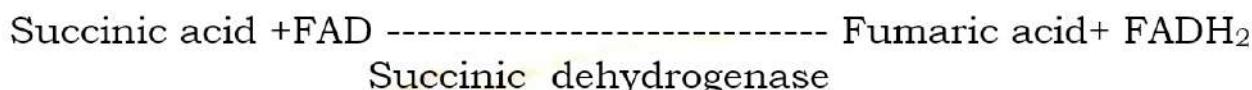
- b) Substrate level phosphorylation:** ATP synthesis takes place without entering in ETS . GTP is unstable compound transferred to ATP by using ADP.



### 7. Dehydrogenation III (Oxidation of succinic acid to fumaric acid):

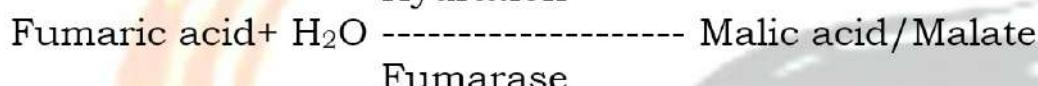
Succinic acid undergoes oxidation in the presence of enzyme succinic dehydrogenase and there is formation of fumaric acid. FAD (flavin adenine dinucleotide) used during oxidation converted into FADH<sub>2</sub>.

Oxidation



- 8. Hydration of fumaric acid to malic acid:** Fumaric acid undergoes hydration in the presence of enzyme fumarase and there is formation of Malic acid.

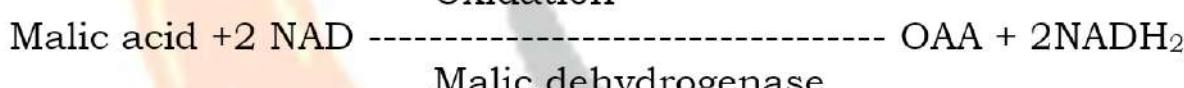
Hydration



### 9. Dehydrogenation IV (Oxidation of malic acid to oxaloacetic acid):

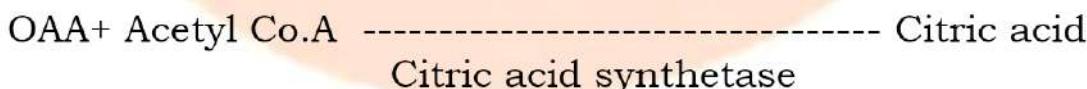
Malic acid undergoes oxidation in the presence of enzyme malic dehydrogenase and there is formation of oxaloacetic acid.

Oxidation



- 10. Recycling of OAA:** OAA reenter in TCA cycle and combines with acetyl Co.A in the presence of enzyme citric acid synthetase and there is formation of citric acid .In this way ,cycle is repeated again and again

Combination



- Total gain of ATP from 1 Glucose molecule during aerobic respiration:**

Sr.No.	Steps involved	Reduced coenzyme	ATP through ETS	Direct ATP formed	Total
1	Glycolysis	2 NADPH <sub>2</sub>	6 ATP	2ATP	8ATP
2	Acetylation	2 NADPH <sub>2</sub>	6 ATP	-	6ATP
3	Krebs's cycle	6 NADPH <sub>2</sub> 2 FADH <sub>2</sub>	18 ATP 4 ATP	2ATP	24ATP
<b>Total</b>		<b>10 NADPH<sub>2</sub></b> <b>2 FADH<sub>2</sub></b>	<b>30ATP</b> <b>4ATP</b>	<b>4ATP</b>	<b>38 ATP</b>

#### ❖ Significance:

- Generation of ATP:** In TCA cycle ,total 24 molecules of ATP formed i.e. from NADH<sub>2</sub>,18 ATP molecules ; from FADH<sub>2</sub> 4 ATP molecules formed.

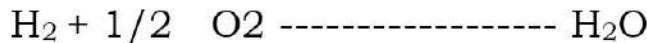
- Formation of 6 NADPH<sub>2</sub>:**

### **3. Formation of 2FADH<sub>2</sub>:**

### **4. Formation of intermediate compound:** Intermediate compounds

acts as starting material for synthesis of many other organic compounds.

### **5. Complete oxidation of PA:** In oxidation, H<sub>2</sub> is removed and removed H<sub>2</sub> joins to O<sub>2</sub> and there is formation of H<sub>2</sub>O and this is called terminal oxidation.



### **6. Regeneration of OAA:**

### **7. Release of 6 CO<sub>2</sub> and 6 H<sub>2</sub>O molecules:** (Reaction no 7 and 8)

## **3) Electron transport system/E.T.S./ Terminal oxidation:**

❖ **Definition:** The oxidative process in which hydrogen is removed progressively from respiratory substrate (glucose) is called as electron transport system **Or** Oxidation of reduced co enzymes into their oxidized forms called ETS.

❖ **Role Of H<sub>2</sub> removed:** The hydrogen removed from respiratory substrate does not combine with O<sub>2</sub> directly but it is transported through ETS/ETC or respiratory chain.

The hydrogen ion ionizes into photons and electrons. The photons released in mitochondrial matrix but electrons channeled through ETS

❖ **Place of occurrence:** Inner membrane of mitochondria (on cristae)

### **Elements of ETS**

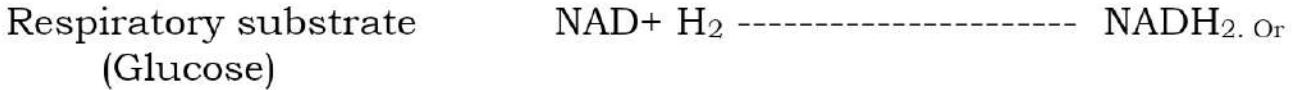
1. NAD: Nicotinamide adenine dinucleotide
2. FAD: Flavin adenine dinucleotide
3. Cytochromes(Electron Carriers) :Cyt.b , Cyt.c<sub>1</sub> , Cyt.c Cyt.a , Cyt.a<sub>3</sub>
4. Co.enzymes: FMN, Red Co.Q. [Ubiquinone]

❖ **Mechanism:** In glycolysis and Kreb's cycle , oxidation/dehydrogenation takes place and NAD and FAD reduced into NADH<sub>2</sub> and FADH<sub>2</sub> .These reduced co enzymes are converted back into their oxidized form.

Synthesis of ATP takes place with the help of energy released during electron transfer. Free molecular O<sub>2</sub> is final acceptor of electrons.

Oxysomes plays important role in ETS. Electron carrier arranged on the body of oxysomes in order to their decreasing energy level.

**1. Role of NAD/FAD :** During process of respiration, 2 H<sub>2</sub> atoms are removed from respiratory substrate glucose and accepted by NAD or FAD .NAD is reduced to NADH<sub>2</sub> or FAD reduced to FADH<sub>2</sub>.



**2. Role of NADH<sub>2</sub> /FADH<sub>2</sub> :** NADH<sub>2</sub> enters in ETS. NADH<sub>2</sub> is oxidized to NAD with removal of H<sub>2</sub>.



FADH<sub>2</sub> enters in ETS. FADH<sub>2</sub> is oxidized to FAD with removal of H<sub>2</sub>.

**3. Role of FMN:** Two H<sub>2</sub> atoms releases from NADH<sub>2</sub> is accepted by FMN and FMN reduced to FMNH<sub>2</sub>.



**4. Role of FMNH<sub>2</sub>:** FMNH<sub>2</sub> is oxidized and there is formation of FMN and 2 H<sub>2</sub>

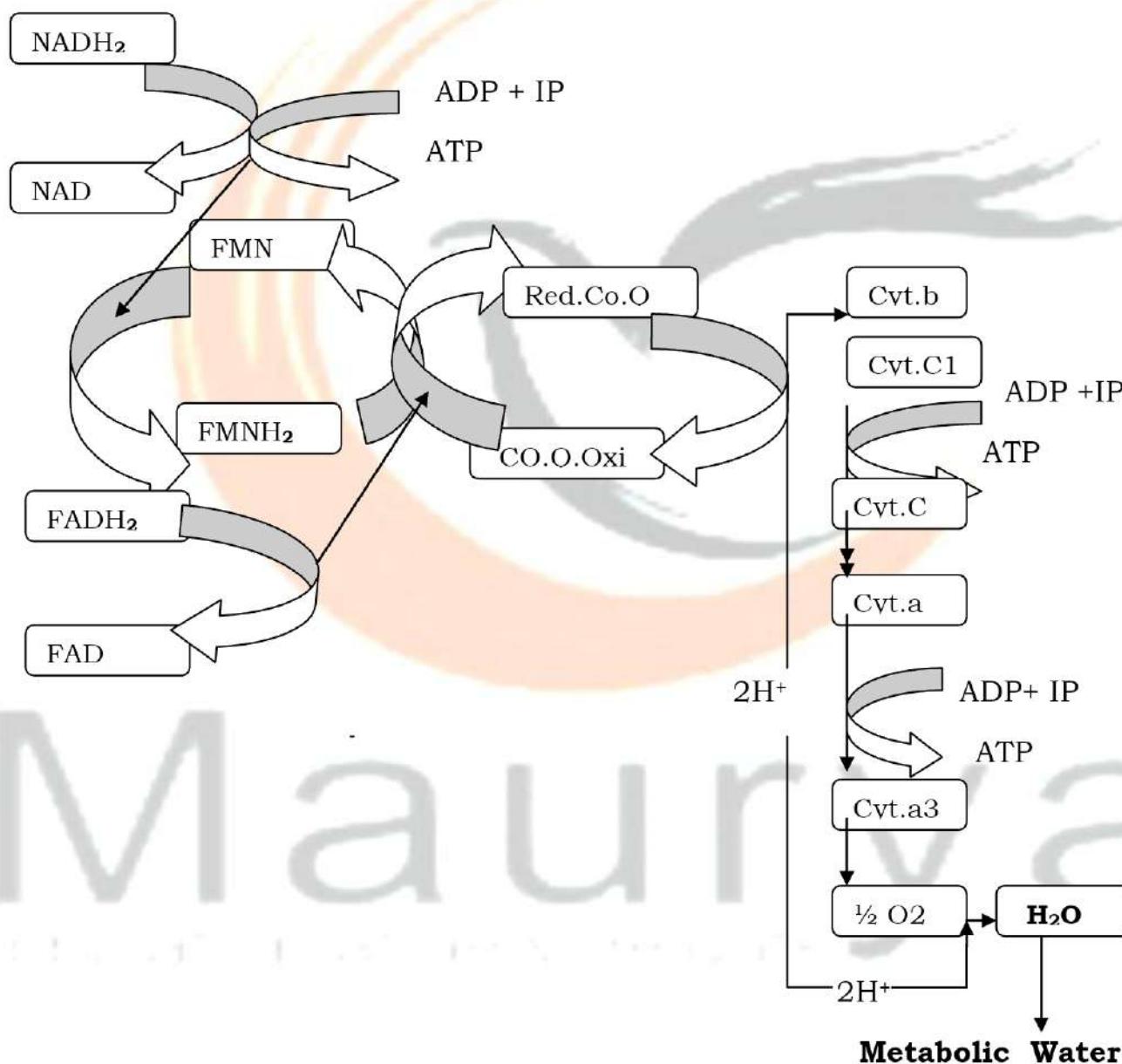


**5. Role of Red CO.Q [ubiquinone] :** Two H<sub>2</sub> atoms releases from FMNH<sub>2</sub> or FADH<sub>2</sub>. is accepted by Red Co.Q. and Red Co.Q. reduced to Red Co.Q.oxi.

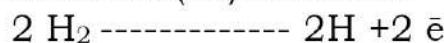
**6. Role of Red Co.Q.oxi :** Red Co.Q.oxi is oxidized and there is formation of Red Co.Q.[ubiquinone]



#### ❖ Diagrammatic representation:



**7. Role H<sub>2</sub> of atoms :** 2 H<sub>2</sub> atoms splits into 2 photons(2H) which are +ve charged ions and 2 electrons(2e)which are -ve charged ions.



**8. Role of cytochrome:** The cytochrome helps in passing of electrons along ETS. The electrons are passed from cyt.b to cyt.c then cyt.c to cyt.a and cyt.a to cyt a3

**9. Path of electron:** NAD ----- FAD ----- cvt.b ----- cvt.c ----- cvt.a ----- cvt.a3

**10. ATP generation steps :** Biosynthesis of ATP molecules using energy released during oxidation of respiratory substrate called as oxidative phosphorylation.

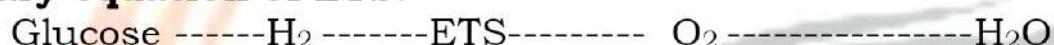
- a. **Step1:** When there is transfer of H<sub>2</sub> with  $\bar{e}$  from NADH<sub>2</sub> to FAD, there is generation of ATP
- b. **Step2:** When there is transfer of H<sub>2</sub> with  $\bar{e}$  from cyt.b to cyt.c.
- c. **Step 3:** When there is transfer of H<sub>2</sub> with  $\bar{e}$  from cyt.a to cyt.a3.

**11. Terminal oxidation:** The process in which H<sub>2</sub> from cyt.a3 is passed to molecular O<sub>2</sub> and there is formation of H<sub>2</sub>O is called as terminal oxidation. Or two electrons react with atmospheric O<sub>2</sub> to produce O— which joint with 2H<sup>+</sup> molecules to produce water.

Oxygen is last electron acceptor in ETS. At the end of ETS ,H<sub>2</sub> react with atmospheric O<sub>2</sub> to form water molecule called as metabolic water.

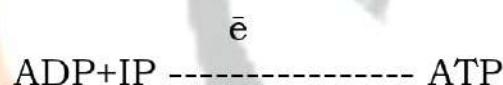


❖ **Summary equation of ETS:**



❖ **Significance:**

**1. Synthesis of ATP:** In ETS, some energy from  $\bar{e}$  is used for formation of ATP by using ADP & IP [34 ATP molecules produced through ETS out of 38 ATP]



**2. Formation of metabolic H<sub>2</sub>O:** In terminal oxidation, H<sub>2</sub> combines with O<sub>2</sub> and there is formation of H<sub>2</sub>O. The water formed is called as metabolic water. In this way O<sub>2</sub> is last electron acceptor in ETS.

**3. Complete oxidation of substrate:** ETS helps in complete oxidation of substrate because O<sub>2</sub> is available to accept H<sub>2</sub> and there is formation of H<sub>2</sub>O

**4. Prevention of damage cells:** Energy is released step by step so prevents cell damage.

**5. Energy from ETS:** energy from ETS is used by various cells for cellular activities.

**6. No. of ATP molecules released by H<sub>2</sub> or electron pair in ETS:** 3 ATP molecules are released in ETS.

**7. Provides H<sub>2</sub>O necessary for Kreb's Cycle.**

**8. Regenerates oxidized co enzymes(NAD & FAD)\**

## B) Anaerobic respiration:

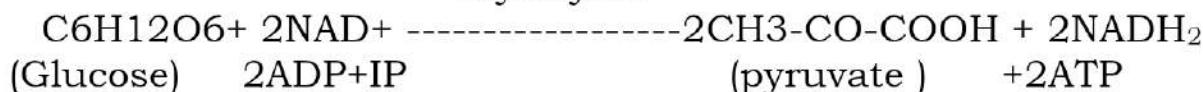
**1. Definition:** The process of respiration takes place in the absence of free molecular oxygen is called as anaerobic respiration. Or Incomplete oxidation of the respiratory substrate in the absence of oxygen to yield CO<sub>2</sub> & ethyl alcohol.

**2. Place of Occurrence:** No. of Bacteria , Yeast and many other organisms without mitochondria in cytoplasm.

**3. Mechanism :**

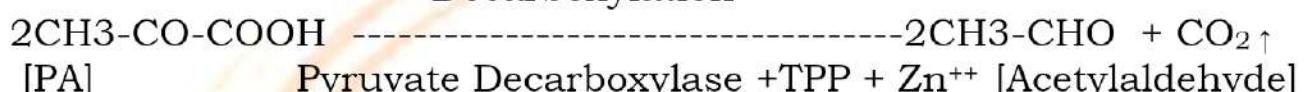
**1. Glycolysis (Degradation of glucose):** Glycolysis is common for aerobic and anaerobic respiration. In glycolysis, there is breakdown of glucose and 2 molecules of PA, 2 molecules of ATP and 2 molecules of NADH<sub>2</sub> are formed.

### Glycolysis



**2. Decarboxylation of PA to acetaldehyde:** PA does not enter in Krebs cycle because of absence of free molecular O<sub>2</sub>. The PA undergoes decarboxylation in the presence of enzyme pyruvate decarboxylase and there is formation of acetylaldehyde. Co enzyme thiamine pyrophosphate (TPP) and co factor Zn<sup>++</sup> necessary for this reaction.

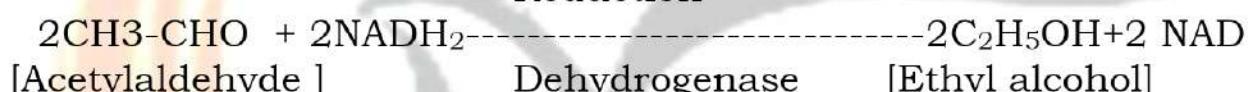
### Decarboxylation



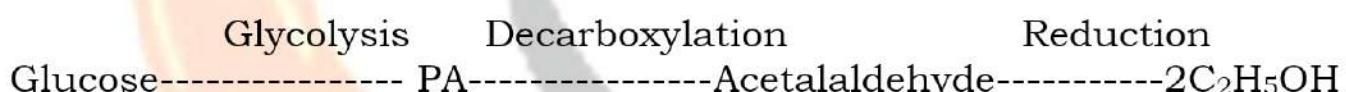
**3. Reduction of Acetaldehyde to ethyl alcohol (2H<sub>5</sub>OH):**

Acetylaldehyde undergoes reduction with the help of NADH<sub>2</sub> and there is formation of ethyl alcohol.

### Reduction



### ❖ Summary:



**❖ Fermentation:** Anaerobic oxidation reduction process in which organic compounds/respiratory substrate like glucose are broken down into simple compounds with activity of micro-organisms.

Fermentation is similar to anaerobic respiration but it is extra or intra cellular.

### 4. Types:

1. Alcoholic fermentation:
2. Lactic acid fermentation:

### 1. Alcoholic fermentation:

**❖ Definition:** The fermentation in which sucrose (molasses) converted into glucose and glucose is converted into alcohol by the activities of microbes (Yeast) is called as alcoholic fermentation.

**❖ Substrate:** Glucose

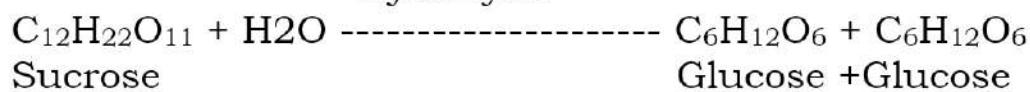
In many cases molasses used as substrate for alcoholic fermentation.

**❖ Micro-organisms:** Saccharomyces cerviae

### ❖ Mechanism:

1. **Hydrolysis (Conversion of sucrose into glucose) :** Sucrose undergoes hydrolysis and converted into glucose.

### Hydrolysis

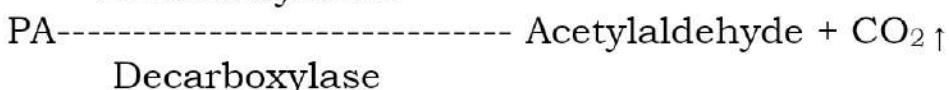


**2. Glycolysis (Conversion of glucose to PA) :** Glucose undergoes glycolysis and two molecules of PA formed. Sucrose Glucose +Glucose Glycolysis



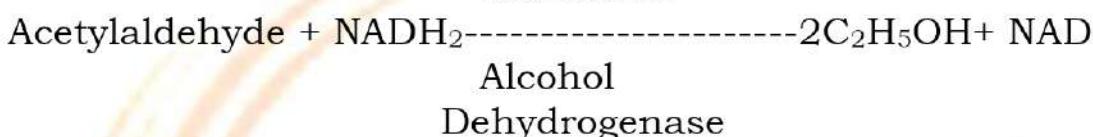
**3. Decarboxylation(Conversion of PA to acetaldehyde) :** The PA undergoes decarboxylation the presence of enzyme decarboxylase and there is formation of acetylaldehyde.

Decarboxylation

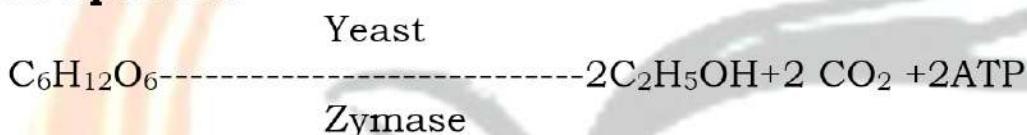


**4. Reduction of acetaldehyde to ethyl alcohol:** Acetylaldehyde undergoes reduction with the help of  $\text{NADH}_2$  in the presence of enzyme alcohol dehydrogenase and there is formation of ethyl alcohol.

Reduction



### 5. Overall equation:



### 6. Summary:



- from above equation it is clear that, in alcoholic fermentation, glucose undergoes fermentation with the help of yeast and in the presence of zymase enzyme to form 2 molecules of  $\text{C}_2\text{H}_5\text{OH}$ ,2 molecules  $\text{CO}_2$  and 2 molecules of ATP

## 2. Lactic acid fermentation:

**1. Definition:** The process of fermentation in which lactose is converted into lactic acid by the action of enzymes produced by lactic acid fermenting bacteria.

**2. Micro-organisms/Lactic acid bacteria:** The bacteria which convert lactose into lactic acid and causes souring of milk is called as lactic acid bacteria.

**Examples:** 1. *Lactobacillus bulgaricus*      2. *Streptococcus lactis*  
              3. *Bacillus subtilis*                  4. *Acromobacteror lacticum*

## 3. Mechanism:

**1. Hydrolysis (Convesrion of lactose to glucose and Galactose) :**

lactose undergoes hydrolysis and converted into glucose and galactose.

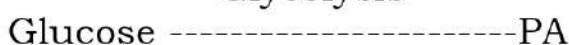
Hydrolysis



**2. Glycolysis/Degradation (Conversion of glucose to Pyruvate) :**

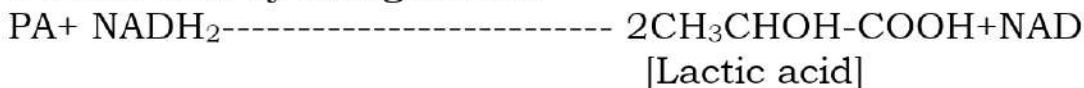
Glucose undergoes glycolysis and 2 molecules of PA are formed.

Glycolysis

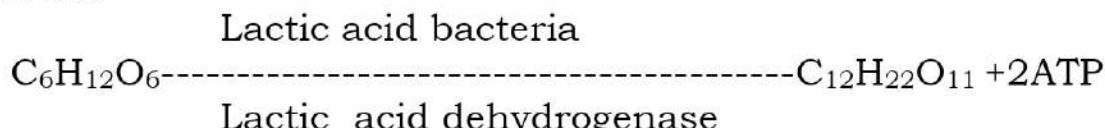


- Carboxylation process is absent.

**3. Reduction of PA to lactic acid:** PA acts as ultimate acceptor and it is reduced to lactic acid by using NADH<sub>2</sub>

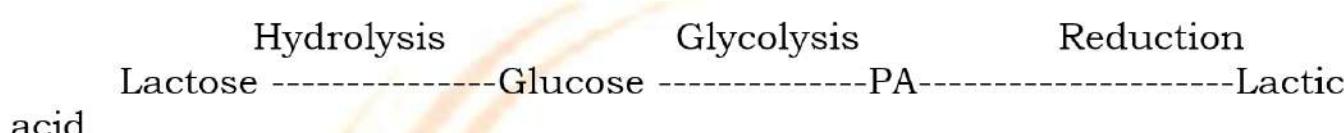


**4. Overall equation:**



- From above equation ,it is clear that after hydrolysis glucose undergoes glycolysis to form PA .The PA reduced to lactic acid with the help of lactic acid bacteria with the help of enzyme lactic acid dehydrogenase

**5. Summary:**



<b>Points</b>	<b>Alcoholic fermentation</b>	<b>Lactic acid fermentation</b>
<b>1. Substarate used</b>	Glucose	Lactose
<b>2. Micro-organisms</b>	Yeast	Lactic acid bacteria
<b>3. Enzymes used</b>	Zymase	Lactic acid dehydrogenase
<b>4. Release of CO<sub>2</sub></b>	Present	Absent
<b>5. Ultimate H<sub>2</sub> acceptor</b>	Acetylaldehyde	PA
<b>6. Overall reaction</b>	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> --- 2C <sub>2</sub> H <sub>5</sub> OH + 2 CO <sub>2</sub> + 2ATP	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> ----- 2CH <sub>3</sub> CHOH-COOH + 2ATP
<b>7. Summary reaction</b>	Glucose ---PA----- ----acetalaldehyde--- Ethyl alcohol	Lactose ----Glucose ----- PA-----Lactic acid
<b>8. Uses</b>	Commercial production of alcohol	Commercial production of fermented dairy products

❖ **Significance of Fermentation :**

**1. Manufacturing of alcohol:**

**2. Manufacturing of antibiotics:** Antibiotics are secondary metabolities.

Anaerobic fermentation

Specific microbes  $\longrightarrow$  Antibiotics  $\longrightarrow$  Released in fermentor

**3. Manufacturing of vitamins:**

Anaerobic/Aerobic fermentation

Specific  $\longrightarrow$  Vitamins  $\longrightarrow$  Autolysis  $\longrightarrow$  Released in  
Microbes intracellular process of microbes fermentor

4. Manufacturing of hormones, enzymes and glycerol.
5. Preparation of fermented dairy products:
6. Curing of tea and tobacco leaves
7. Curdling of milk and Ripening of cream.
8. Production of alcoholic beverages.
9. Tanning of leather

### ❖ Exchange of gases in plants :

- **Stomata and Lenticels:** Plants do not have specialized organs for respiration. Stomata and lenticels helps in gaseous exchange.
- **Root, stem and leaves :** respire at very low rates as compared to animals
- **Germinating seeds and floral buds:** respire at comparatively higher rates.
- Exchange of gases takes place during photosynthesis. Leaves are well adapted for exchange of gases.
- **Leaves:** In leaf, each living cell is located quite close to surface of plants and contains stomata.
- **Stem:** Living cells are beneath the bark and bark contains lenticels
- Loose packaging of Parenchymatous cells in stem and root provides interconnected network of air spaces which fascinated gaseous exchange.

### ❖ Respiratory Quotient/Ratio:

The ratio of volume of  $\text{CO}_2$  evolved to the volume of  $\text{O}_2$  consumed in respiration .RQ depends on respiratory substrate.

**1. CHO:** RQ of CHO is **1** (Complete oxidation)

$$\text{RQ} = \frac{6\text{CO}_2}{6\text{ O}_2} = 1$$

**2. Fat:** RQ is **0.7**

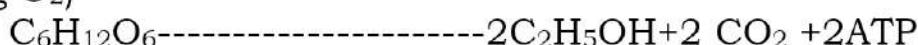


$$\text{RQ} = \frac{102\text{ CO}_2}{145\text{ O}_2} = 0.7$$

**3. Protein:** RQ is **0.9**

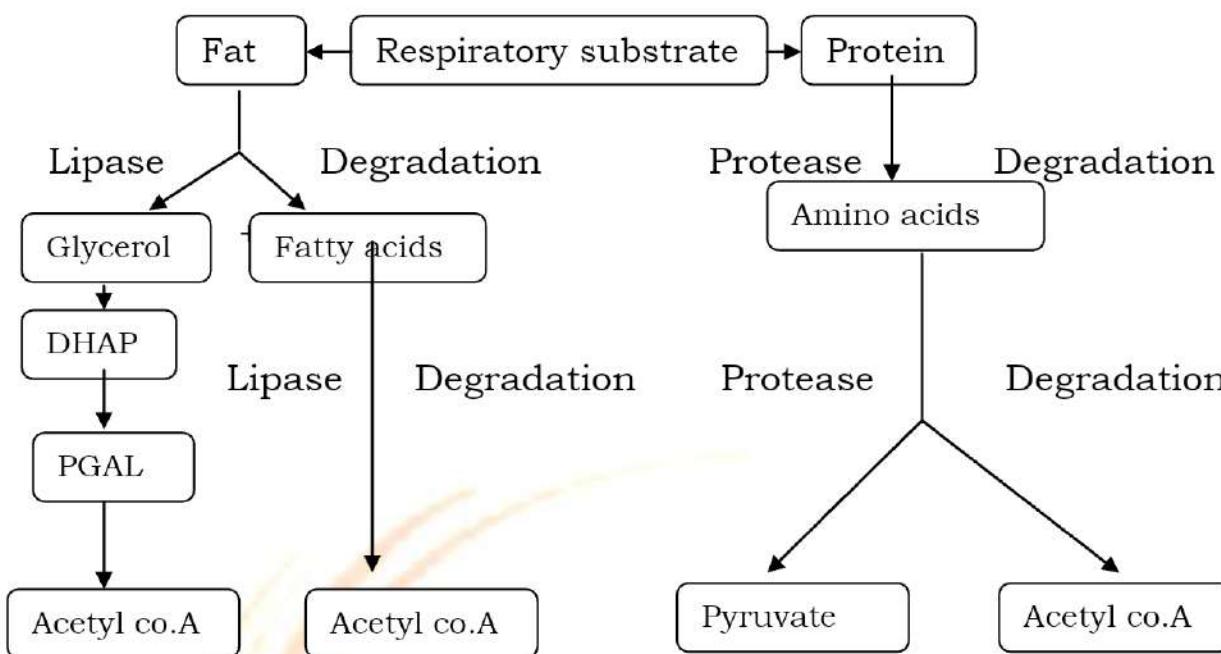
$$\text{RQ} = \frac{131\text{ CO}_2}{145\text{ O}_2} = 0.9$$

**4. Anaerobic Respiration:** RQ is **always affinity** (  $\text{CO}_2$  evolved without taking  $\text{O}_2$ )



$$\text{RQ} = \frac{2\text{CO}_2}{\text{Zero O}_2} = \text{Infinity}$$

## ❖ Respiration is Amphibolic pathway:



- Respiration is amphibolic pathway because during breakdown of substrates, respiratory intermediate forms which helps in synthesis as well as breakdown of proteins, fats, fatty acids and glycerol.
- Respiratory intermediates forms the links during synthesis or breakdown of Glycolysis and Kreb's cycle provides precursors for the many biosynthetic pathways.
- Respiratory intermediates [Carboxylic acids] produced during Kreb's cycles serves as precursors of many amino acids. Amino acids are building blocks for proteins.

## ❖ Significance of Respiration:

1. Release of energy: For biosynthesis of cellular material (CHO, Proteins, Lipids, Vitamins )
2. Synthesis of ATP and Providing carbon for photosynthesis:
3. Production of alcohol: In anaerobic respiration, alcohol is produced used in different medicines and product.
4. Preparation of organic acids: like lactic acid, acetic acid etc.
5. Providing starting material for synthesis of fats and proteins:
6. Heat generation and Conversion of Food energy into unstable form:
7. Maintaining O<sub>2</sub> and CO<sub>2</sub> balance.
8. Avoiding bursting of cells : In respiration energy is released step by step which avoids
9. Acts as source of energy for cell division, growth, repairs, replacement of worn out parts, movements and locomotion.
10. Intermediates of Kreb's cycle used as building blocks for synthesis of other complex compounds.
11. Fermentation used in dairies ,bakeries, distilleries, leather industries and paper industries
12. Commercial production of alcohol, organic acid, vitamins and antibiotics.
13. Energy of respiration converts insoluble substances into soluble substances