# 14. RESPIRATION IN PLANTS

- **Respiration** is the oxidation of nutrients in the cells to release energy and the trapping of this energy for ATP synthesis which is used in biological work.
- The compounds that are oxidized called **respiratory substrates.**
  E.g. Carbohydrates (most common), proteins, fats and organic acids

## BREATHING IN PLANTS

- For respiration, plants get $O_2$ and give out $CO_2$
- In plants, gaseous exchange occurs through **stomata** and **lenticels.**
- Plants need no specialized respiratory organs because-
  - **(i)** **Each plant part takes care of its own gas – exchange needs.** During photosynthesis, $O_2$ is released within the cell.
  - **(ii)** **Plants have only low demand for gas exchange.** They respire at rates much lower than animals do.
  - **(iii)** **Loose packing of parenchyma** cells in leaves, stems and roots provide an interconnected network of airspace.
  - **(iv)** **Almost all living cells in a plant have their surfaces exposed to air.**
    The interior cells are dead (only for mechanical support).

## RESPIRATION IN PLANTS

- The complete combustion of glucose yields energy most of which is given out as heat.

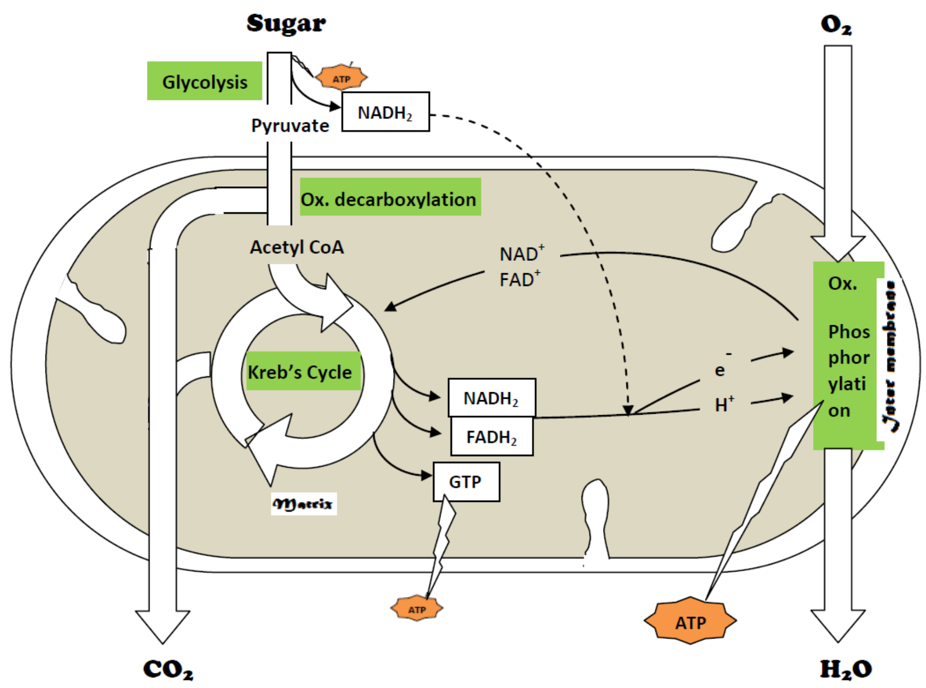
$$\mathbf{C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy}\ (2870\ \text{kJ})$$

Eukaryotic (plant) cell oxidises glucose in several small steps. It enables some steps to couple released energy to ATP synthesis.

The first cells on earth lived in atmosphere had no $O_2$. Those and certain present-day living organisms are adapted to anaerobic conditions. Some of them are **facultative** anaerobes. Others are **obligate.**

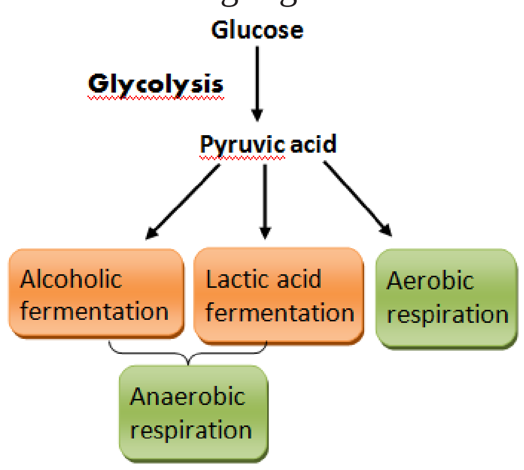
In eukaryotic cells, aerobic (using $O_2$) respiration is completed in 4 stages-

***1st Stage*** Glycolysis
***2nd Stage*** Oxidative decarboxylation
***3rd Stage*** Krebs' cycle
***4th Stage*** Oxidative phosphorylation




## *(1st-Stage)* GLYCOLYSIS (*Glycos*[G]= sugar, *lysis*[G]= splitting)

- It is the **partial oxidation** (breakdown) of **glucose** into 2 molecule of **pyruvic acid** in the absence of $O_2$.
- It **occurs in cytoplasm** of all living organisms. In anaerobes, it is the only process in respiration.




- Scheme was given by Gustav Embden, Otto Meyerhof, and J. Parnas (also known as ***EMP pathway***).
- In plants, glucose is derived from **sucrose** (end product of photosynthesis) or from **storage carbohydrate.**
  Sucrose is converted into glucose & fructose by the enzyme, ***invertase.*** These 2 monosaccharides enter the glycolytic pathway.

## Mechanism of glycolysis:-

- It includes 10 steps under the control of different enzymes.

***(Step-1)*** **Glucose** & **fructose** are phosphorylated to form **glucose-6-phosphate** by the enzyme ***hexokinase*.** An ATP supplies the phosphate.

***(Step-2)*** Glucose-6-phosphate is isomerised into **fructose-6-phosphate**.

***(Step-3)*** Fructose 6-phosphate is phosphorylated to **fructose 1,6-bisphosphate**. An ATP supplies the phosphate.

***(Step-4)*** Fructose 1, 6-bisphosphate is split into 3- carbon **dihydroxyacetone phosphate** and **3-phosphoglyceraldehyde** (PGAL).

***(Step-5)*** Dihydroxyacetone phosphate is then isomerised to **PGAL** itself. Thus 2 PGAL is formed from a single Fructose 1, 6-bisphosphate.

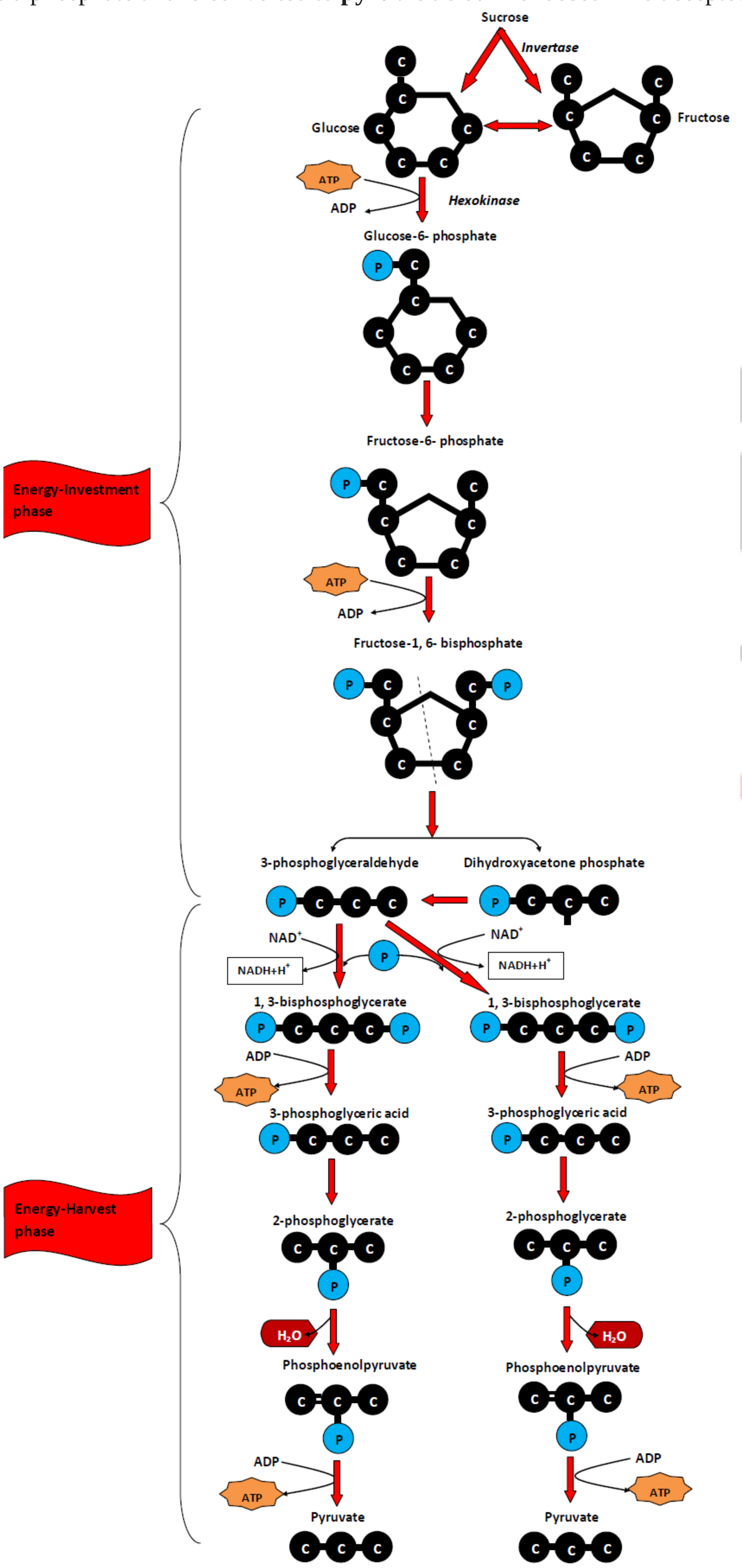
***(Step-6)*** Each of 2 PGAL is oxidised and with inorganic phosphate get converted to **1, 3-bisphosphoglycerate (DPGA).** During this, 2 H-atoms are removed from each PGAL and transferred to $NAD^+$ forming NADH $+H^+$.

***(Step-7)*** DPGA losses a phosphate in 1$^{st}$ carbon and is converted to **3-phosphoglyceric acid** (PGA). The loosed Pi is accepted by an ADP to form an ATP.

***(Step-8)*** 3-PGA's phosphate transferred from 3$^{rd}$ C to 2$^{nd}$ C forming **2-PGA**.

***(Step-9)*** 2-PGA losses a **water** molecule to form **Phosphoenol pyruvate** (PEP).

***(Step-10)*** PEP losses a phosphate and is converted to **pyruvic acid**. The loosed Pi is accepted by an ADP to form an ATP.




- ❖ In glycolysis **2 ATP** is utilised while **4 ATP** & **2 NADH $+H^+$** are synthesised from 1glucose molecule.
- ▪ In eukaryotic cell, **pyruvic acid (pyruvate)** is the utilised for aerobic respiration.

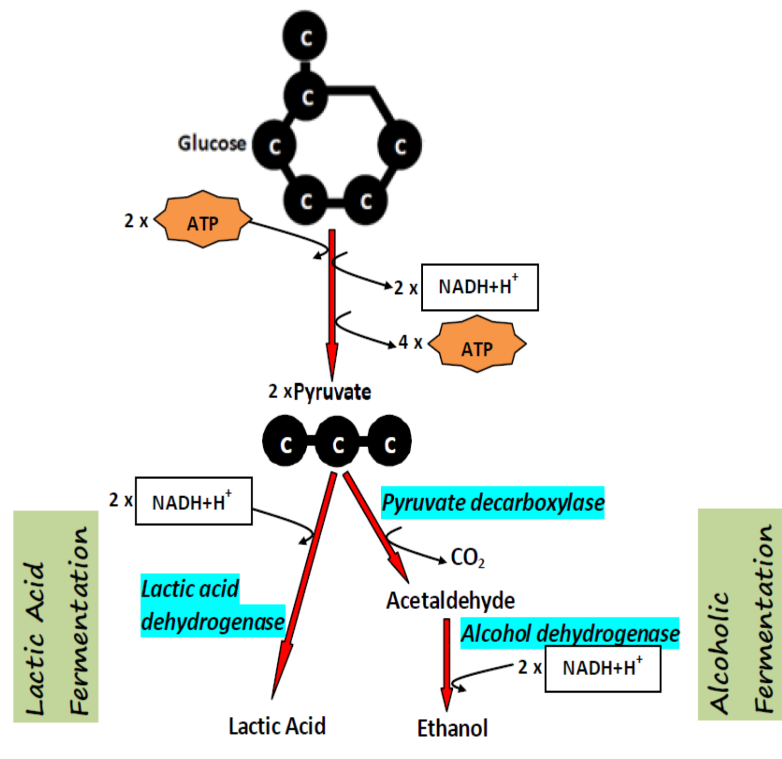
There is 2 other fate for pyruvic acid under anaerobic condition-

- Alcoholic fermentation
- Lactic acid fermentation

A) **Alcoholic fermentation:** Here, the pyruvic acid formed from glycolysis is converted to $CO_2$ and ethanol.
The enzymes, ***pyruvic acid decarboxylase*** and ***alcohol dehydrogenase*** catalyse these reactions.
E.g. Yeast. Yeasts poison themselves to death when the concentration of alcohol reaches about 13%.

B) **Lactic acid fermentation:** Here, pyruvic acid is converted to lactic acid by *lactate dehydrogenase*.
E.g. Some bacteria, In muscle cells (when $O_2$ is inadequate during exercise).

Net ATP production from fermentation of one glucose molecule = 2. (4 ATP from glycolysis – 2 ATP utilized).




**Drawbacks of fermentation**

***I.*** Energy production is limited. Less than 7% (56 KCal) of the energy in glucose is released and not all of it is trapped as high energy bonds of ATP.

***II.*** Hazardous products (acid or alcohol) are formed.

## (2nd-Stage) OXIDATIVE DECARBOXYLATION

- For this, the **pyruvate** (final product of glycolysis) is transported from the cytoplasm into the mitochondria matrix.
- Pyruvate undergoes **oxidative decarboxylation** to form **acetyl CoA** in presence of *pyruvic dehydrogenase*. It requires coenzymes **NAD$^+$** and **Coenzyme A.**
- ❖ During this process, 2 molecules of NADH+H$^+$ are produced from 2 molecules of pyruvic acid.
- The acetyl CoA then enters **tricarboxylic acid cycle**.

## (3rd-Stage) TRICARBOXYLIC ACID CYCLE (Krebs' cycle)

- TCA cycle was first elucidated by Hans Krebs. (Nobel prize in 1953)

**Mechanism of TCA cycle:-**

***(Step-1)*** **Acetyl CoA** (2C) condensate with **oxaloacetic acid (OAA-** 4C**)** and water to form **citric acid** (6C) in presence of the enzyme ***citrate synthase***. During this, a molecule of **CoA** is released.

***(Step-2)*** **Citrate** is isomerised to **isocitrate.**

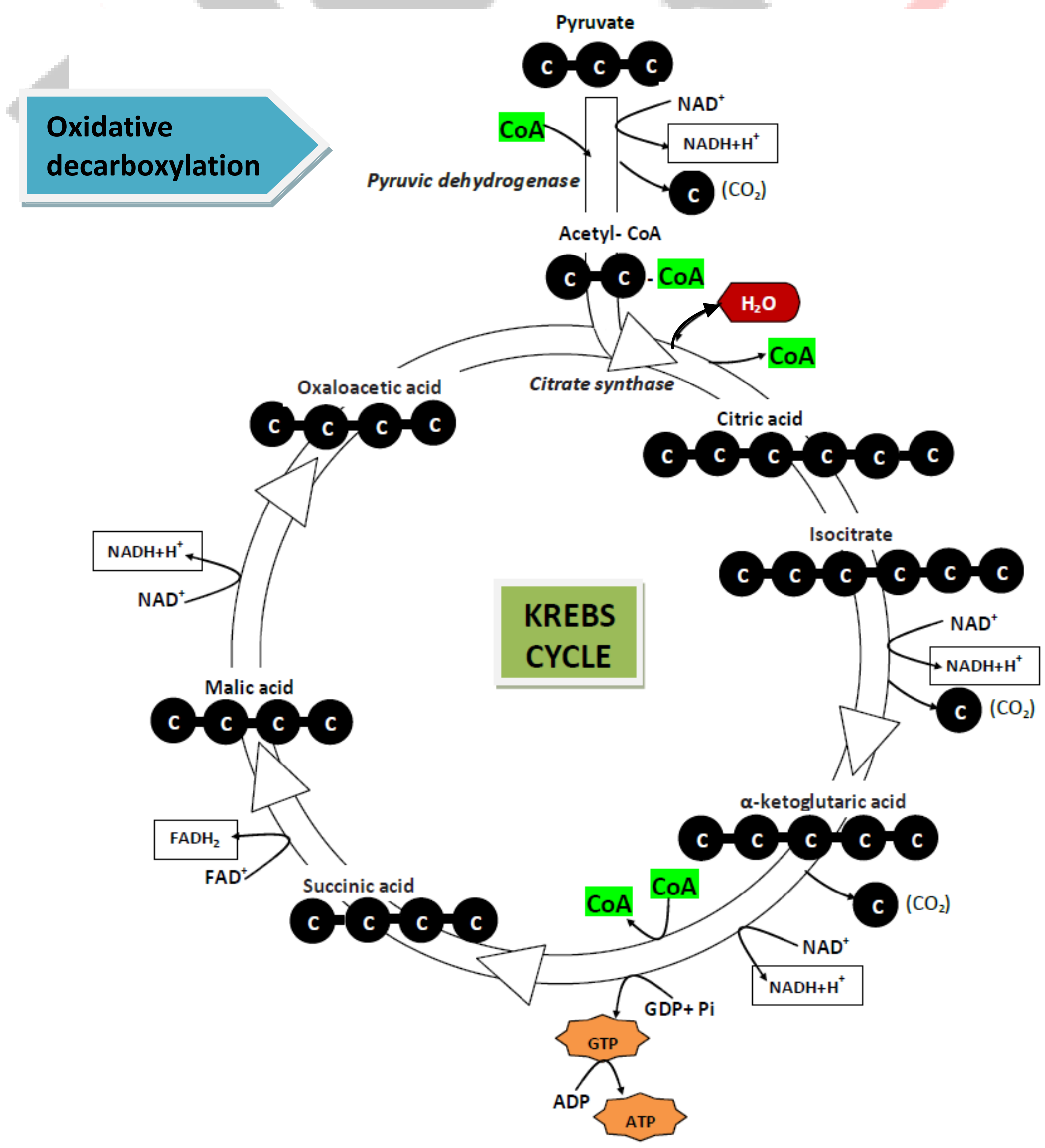
***(Step-3)*** Isocitrate is decarboxylated to form α–**ketoglutaric acid** (5C). This step reduces NAD$^+$ to NADH+ H$^+$.

***(Step-4)*** α–ketoglutaric acid is decarboxylated to form **succinyl-CoA** (4C). This step also reduce NAD$^+$ to NADH+ H$^+$

***(Step-5)*** Succinyl-CoA is converted to **succinic acid**. This step leads to a substrate level phosphorylation of GDP to form GTP. This reaction is simultaneously coupled with the synthesis of ATP from ADP.

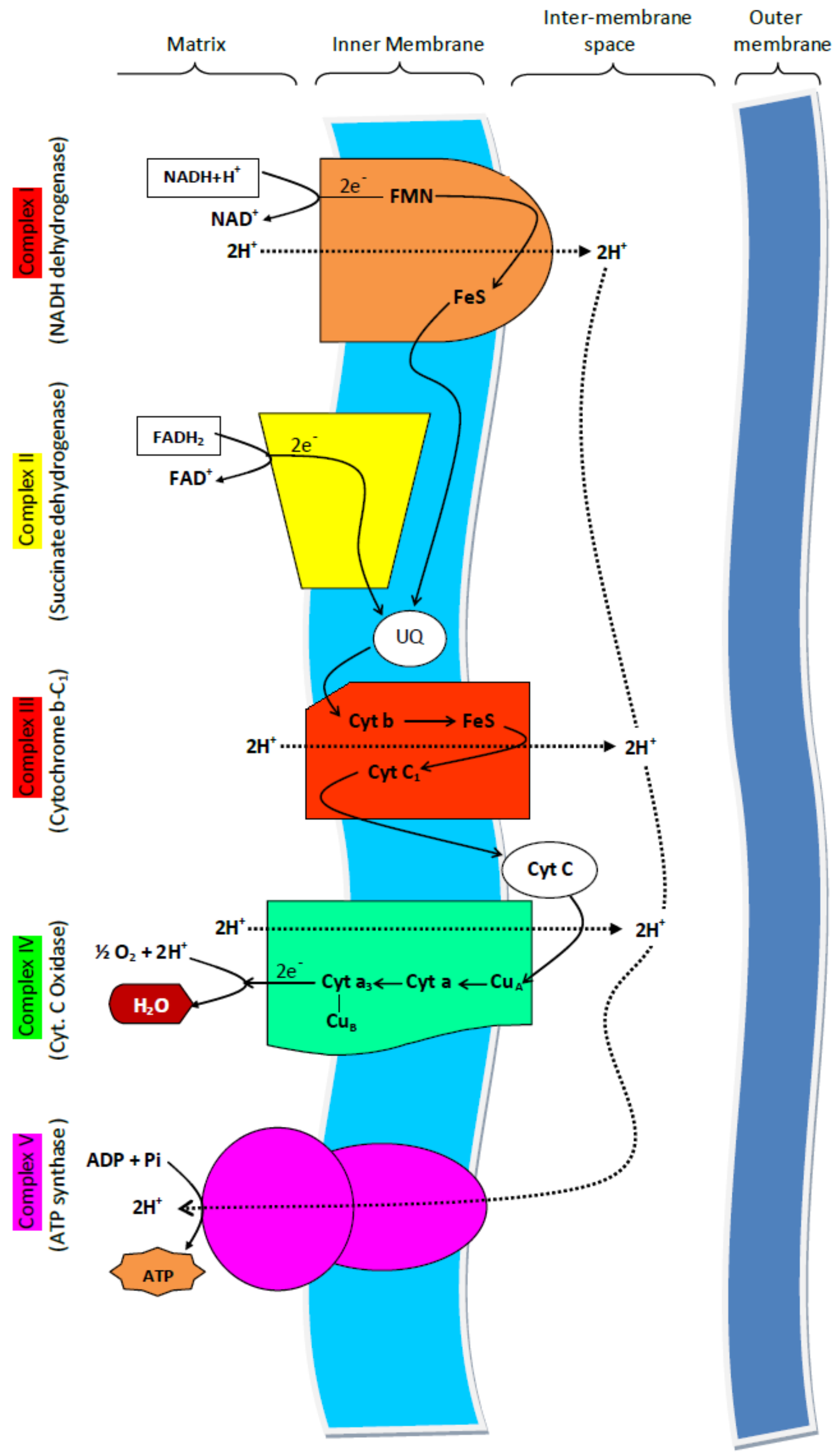
***(Step-6)*** Succinic acid convert to **malic acid** reduces FAD$^+$ to $FADH_2$.

***(Step-7)*** Malic acid oxidised to **OAA** and the cycle continues. This step also reduce NAD$^+$ to NADH+ H$^+$



## (4th-Stage) OXIDATIVE PHOSPHORYLATION

- This stage is to release and utilize the energy stored in $NADH+H^+$ and $FADH_2$ (formed during Glycolysis & Krebs' cycle) in synthesising ATP. **Electron Transport System (ETS)** facilitate this event.
- **ETS** is the metabolic pathway present in the **inner mitochondrial membrane** through which $e^-$ passes from one carrier to another.
  - When the $e^-$ (supplied by $NADH+H^+$ and $FADH_2$) passes from one carrier to another via complex I to IV, the **redox** reaction of carriers progressively extract the energy the $e^-$ possesses and used it to pump $H^+$ across the mitochondrial membrane. The $H^+$ gradient is used by ATP synthase **(complex V)** to produce ATP (phosphorylation). So this process is called **oxidative phosphorylation.**
  - The number of ATP molecules synthesised depends on the nature of the $e^-$ donor.
    - ♥ Oxidation of **1 NADH** molecule produces **3 ATP** molecules**.**
    - ♥ Oxidation of **1 $FADH_2$** molecule produces **2 ATP** molecules.




**Mechanism of Oxidative phosphorylation:-**

***(Step-1)*** $e^-$ from $NADH+H^+$ are oxidised by an **NADH dehydrogenase (complex I**-which contain FMN-Flavin Mono Nucleotide, a protein and is associated with Iron-sulphur protein **).** $e^-$ are then transferred to **ubiquinone** (UQ) located within the inner membrane.

***(Step-2)*** Ubiquinone also receives $e^-$ from **$FADH_2$** via **complex II.**

***(Step-3)*** The **reduced ubiquinone (ubiquinol)** is then oxidised with the transfer of $e^-$ to **cytochrome *bc*$_1$** in **complex III** and then to **cytochrome c.**
Cytochrome c is a small protein attached to the outer surface of the inner membrane. It acts as a mobile carrier for transfer of $e^-$ between complex III and IV.

***(Step-4)*** **Cytochrome *c* oxidase (Complex IV** –complex containing **cytochromes *a* & *a*$_3$,** and 2 Cu centres) pass $e^-$ on to $O_2$, which is reduced to $H_2O$ by the addition of $H^+$. This is called **terminal oxidation.**

***(Step-5)*** The passage of $H^+$ from inter membrane space to matrix through the **ATP synthase** is coupled for ATP production.
For each ATP produced, $2H^+$ passes through **ATP synthase** from the inter-membrane space to the matrix down the electrochemical proton gradient.

- **ATP synthase** complex consists of 2 major components, $F_1$ and $F_0$.
  - ✓ **$F_0$** is an integral membrane protein complex that forms the channel through which $H^+$ cross the inner membrane.
  - ✓ **$F_1$ headpiece** is a **peripheral membrane protein complex.** It contains the site for ATP synthesis from ADP & inorganic phosphate.

## THE RESPIRATORY BALANCE SHEET

- It is the calculations of the net gain of ATP for every glucose molecule oxidised.
- The net gain of ATP from each glucose molecule can be calculated based on the following assumptions:
  - All steps in Glycolysis, TCA cycle and ETS pathway occur in a sequential and orderly manner
  - The NADH synthesised in glycolysis is transferred into mitochondria and undergoes oxidative phosphorylation.
  - None of the intermediates in the pathway are utilised to synthesise any other compound.
  - Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.
- Such assumptions are not valid because,
  - 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 utilized as and when needed.
  - Enzymatic rates are controlled by multiple means.

Such calculations are useful to appreciate the efficiency of the living system in extraction and storing energy.

**Net gain of ATP molecules from 1 glucose molecule**

| | | |
|---|---|---|
| Glycolysis: | 2 ATP directly | = 2 ATP + |
| | 2 molecules of NADH | = 6 ATP + |
| Oxidative decarboxylation: | 2 NADH | = 6 ATP + |
| TCA cycle: | 6 NADH | = 18 ATP+ |
| | 2 FADH | = 4 ATP + |
| | 2 GTP | = 2 ATP |
| | Total | = 38 ATP - |
| | Transp. of $NADH_2$ | = 2 ATP |
| | Net gain | =36 ATP |

2 ATP molecules are spent for transporting 2 NADH molecules formed during glycolysis to the mitochondria.

The complete oxidation of 1 molecule of glucose gives =2870 kJ energy
Total energy stored by 1 ATP = 34 kJ
Total energy stored by 38 ATP = 1292 kJ

Efficiency of aerobic respiration= $\frac{1292}{2870}$ x 100 = 45%

The rest of energy generated during aerobic respiration is lost in the form of heat.

## Comparison b/w anaerobic (fermentation) & aerobic respiration

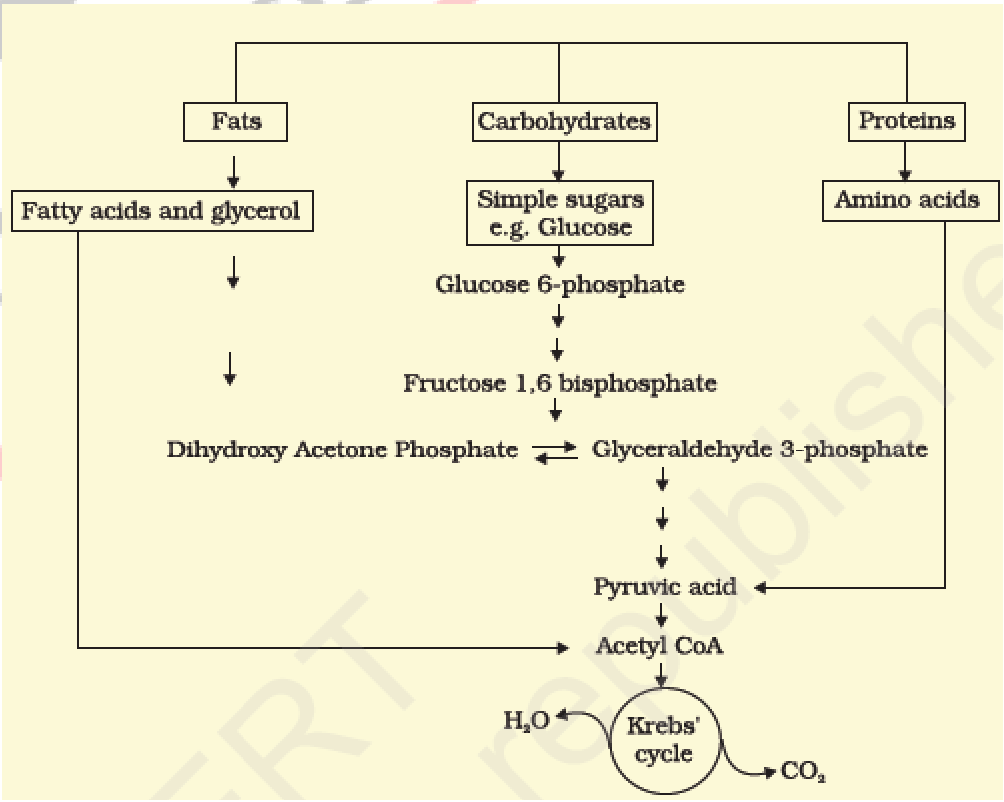
| Fermentation | Aerobic respiration |
|---|---|
| Occurs in the absence of $O_2$ | Occurs in the presence of $O_2$ |
| Partial breakdown of glucose to $CO_2$ and **ethyl alcohol** or **lactic acid**. | Complete breakdown of glucose to $CO_2$ and $H_2O$. |
| It occurs in the cytoplasm only | It occurs partly in the cytoplasm and the rest in mitochondria |
| Net gain of only 2 ATP molecules. | Net gain of 36 ATP molecules. |
| NADH is oxidised to $NAD^+$ rather slowly. | NADH is oxidised to $NAD^+$ very vigorously. |

## 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 are also respired-

(a) **Fats** breakdown into glycerol & fatty acid. Fatty acid is degraded to acetyl CoA and enters the pathway.
Glycerol is converted to PGAL and enters the pathway.

(b) **Proteins** are degraded by proteases into amino acids. Each amino acid (after deamination) enters the pathway as pyruvate.




- The respiratory pathway is an **amphibolic pathway** as it involves both anabolism (synthesis) and catabolism (break down).

## Respiratory quotient

- It is the ratio of the volume of $CO_2$ evolved to the volume of $O_2$ consumed in respiration.

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

- RQ depends upon the type of respiratory substrate.
  - **RQ for carbohydrates= 1**, because equal amounts of $CO_2$ and $O_2$ are evolved and consumed, respectively
  - **RQ for fats =< 1.**
  - **RQ for proteins = 0.9.**