RESPIRATION IN PLANTS

AEROBIC RESPIRATION

OXIDATIVE DECARBOXYLATION OF PYRUVIC ACID:

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

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

Krebs cycle

1. Named after the scientist Hans Krebs who first elucidated it. It is also called TCA (tri carboxylic acid) cycle or CA (citric acid) cycle.
2. Krebs cycle occurs inside mitochondrial matrix of eukaryotic cells and cytoplasm of prokaryotic cells.
3. One turn of Krebs cycle involve four dehydrogenation , two decarboxylation and one substrate level phosphorylation.
4. OM is considered as the first member of the cycle.
5. All enzymes of Krebs cycle are located inside mitochondrial matrix except succinate dehydrogenase (Marker enzyme), which is located in inner membrane of mitochondria.

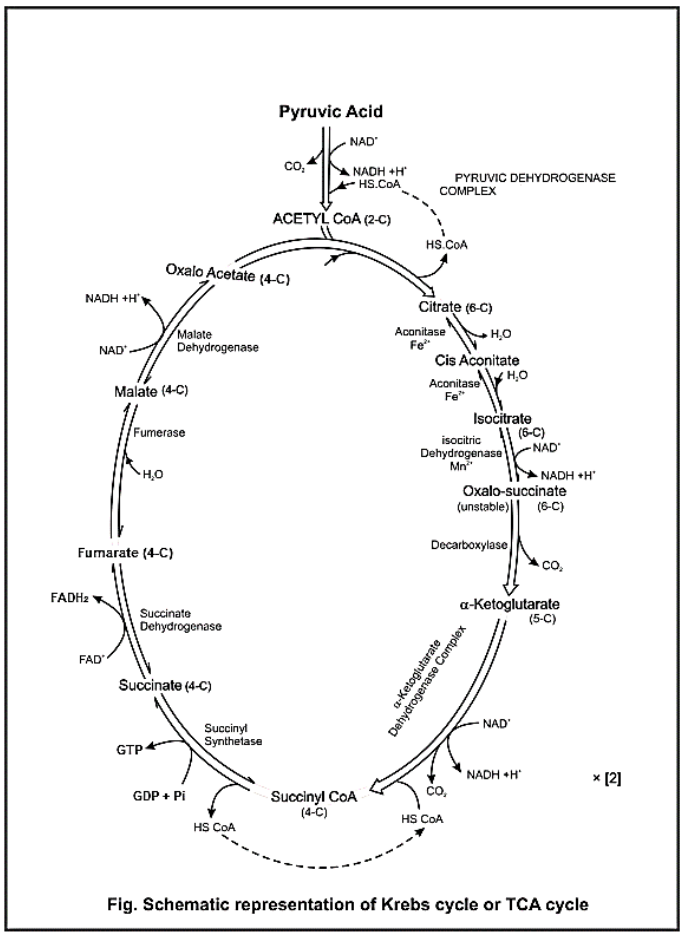


Fig. Schematic representation of Krebs cycle or TCA cycle

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 :

1. NADH is oxidised by an NADH dehydrogenase (complex I), and electrons are then transferred to ubiquinone.
2. Ubiquinone also receives electrons via (complex II) by the oxidation of $FADH_2$.
3. The reduced ubiquinone (ubiquinol) is then oxidised with the transfer of electrons to cytochrome c via cytochrome bc_1 complex (complex III).
4. 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.
5. Complex IV refers to cytochrome c oxidase complex containing cytochromes a and a_3, and two copper centres.
6. 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.
7. 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.

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

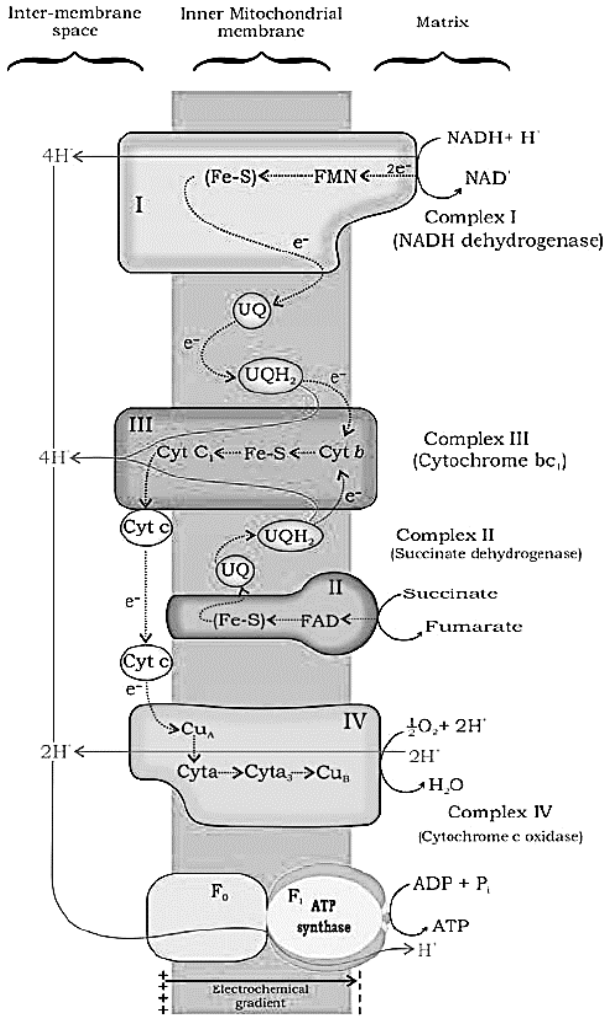


Figure: Electron Transport System (ETS)

(B) OXIDATIVE PHOSPHORYLATION:

- The large amount of energy is released during the oxidation-reduction of NADH + H^+ & FADH + H^+. 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.

OXIDATIVE PHOSPHORYLATION (CHEMIOSMOTIC THEORY/COUPLING THEORY)

1. During ETS of respiration CoQ (UQ) & FMN can releases H+ ions in perimitochondrial space and leads to differenctial H^+ ion concetration across inner mitochondrial membrane. This differential H^+ ion concentration across inner mitochondrial membrane leads to creation of proton gradiant (pH gradient) and Electrical potential (diffrence of charge). Both are collectively known as Proton motive force (PMF).
2. PMF do not allow stay of H^+ ions in Perirnitochondrial space (PMS) so they return towards the matrix through F_0 part of ATPase selectively. Passage of $2H^+$ ions through F_0 part or proton channel leads to synthesis of 1 ATP.

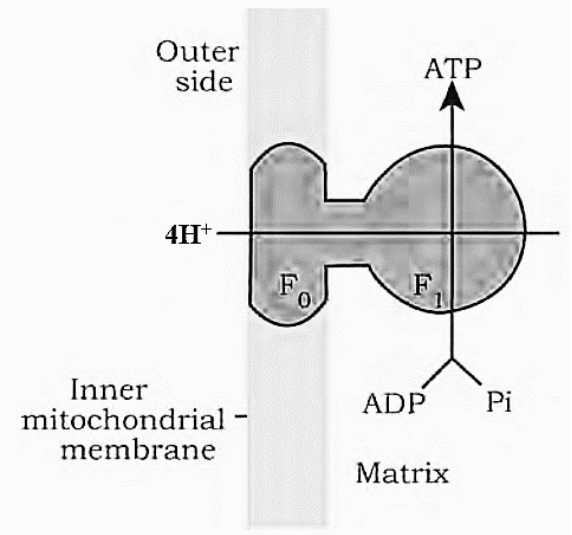


Fig. Diagrammatic presentation of ATP synthesis in mitochondria

3. Cytosolic or extra mitochondrial or glycolytic NADH transported to ETS by two type of shuttles (Only in eukaryotes) :

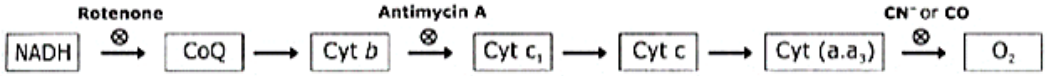
(a) Glycerol phosphate shuttle - Common shuttle system eg.- all plants, nerves and muscles.

(b) Malate aspartate shuttle - Heart, liver and kidney etc.

4. In prokaryotes, shuttle mechanism is absent. They always get 38 ATP from aerobic respiration of 1 glucose.
5. Oxidation of one molecule of NADH gives rise to 3 molecules of ATP, while that of one molecule of $FADH_2$ produces 2 molecules of ATP.

ETS POISON:

1. **Rotenone :** It checks flow of electrons from Fes to CoQ.
2. **Antimycin A :** It prevents electron transport between cyt b and cyt c_1
3. **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.**
4. **Oligomycin:** It inhibits complex-V by blocking proton channel (F_0 subunit)
5. **2, 4-dinitrophenol :** It allows electron transport but inhibits ATP formation from ADP



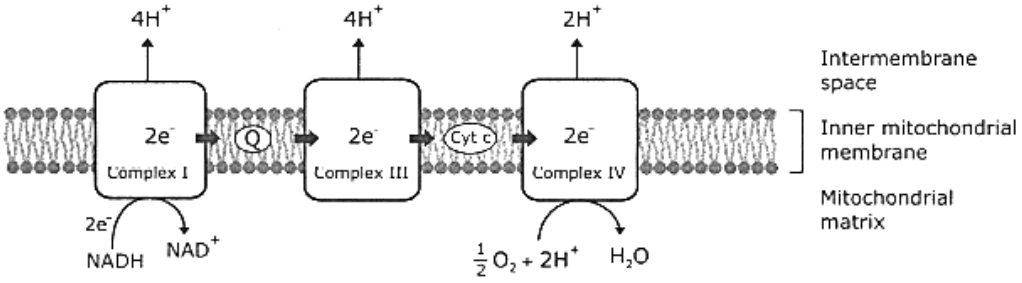
REAL CONCEPT OF ETS AND OXIDATIVE PHOSPHORYLATION

- 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?

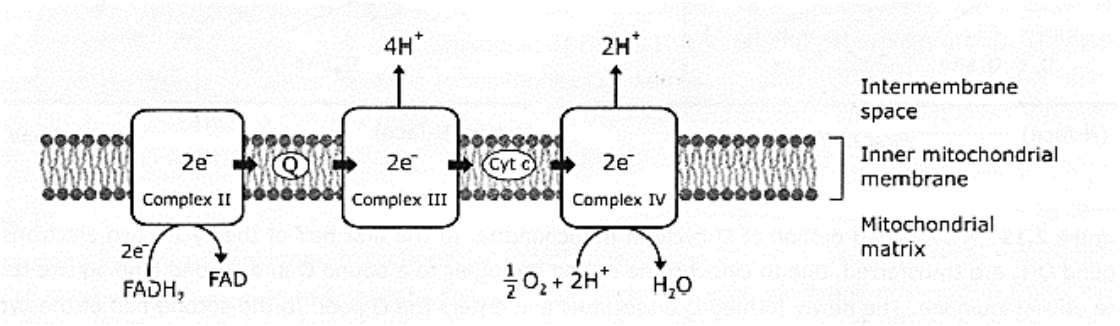
1. NADH + H^+ (Coming from Glycolysis and Krebs cycle) is oxidised.

   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.

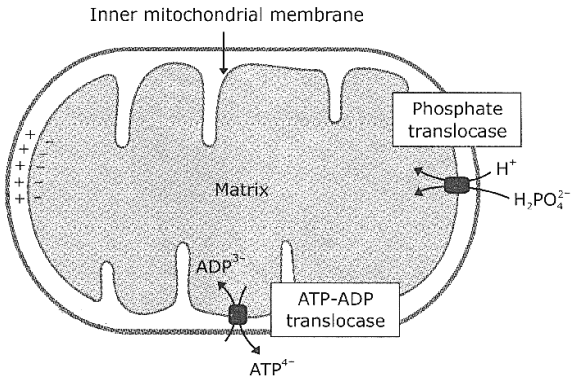


Fig. The phosphate and ATP / ADP translocase system in the inner mitochondrial membrane.

4. ATP - ADP exchange 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.