Electron Transport System
or
Respiratory chain
or
oxidative phosphorylation

The most common type of oxidation found in respiration is by the removal of a pair of hydrogen from the oxidising substrate. At various stages in the glycolysis and Kreb's cycle, hydrogen atoms are released. The reduced co-enzymes ~~are~~ of the above respiratory processes are oxidised by molecular oxygen by way of a system of enzymes and co-enzymes called respiratory chain or electron transport system present in the inner mitochondrial membrane. The energy released from these oxidations is utilised in the synthesis of ATP. For aerobic organisms it is essential that the enzymes and reduction products of the Kreb's cycle be associated with this electron transport system. So, the synthesis of ATP is a electron flow through the ETS, with oxygen as the terminal electron acceptor, is known as oxidative phosphorylation which takes place in mitochondria.

The pair of hydrogen released from respiration ultimately gets dissociated into two protons and two electrons.

$$2H = 2H^{+} + 2e$$

The two protons released in the medium as hydrogen ions (H^{+}) are available for combination with O_2 to form water. But the pairs of hydrogen ($2H^{+} + 2e$) removed in various oxidation steps do not directly combine with oxygen. These are transported to oxygen molecule through a chain of enzymes known as respiratory chain. Enzymes catalysing the actual removal of hydrogen from the substrate are associated with inner mitochondrial membrane.

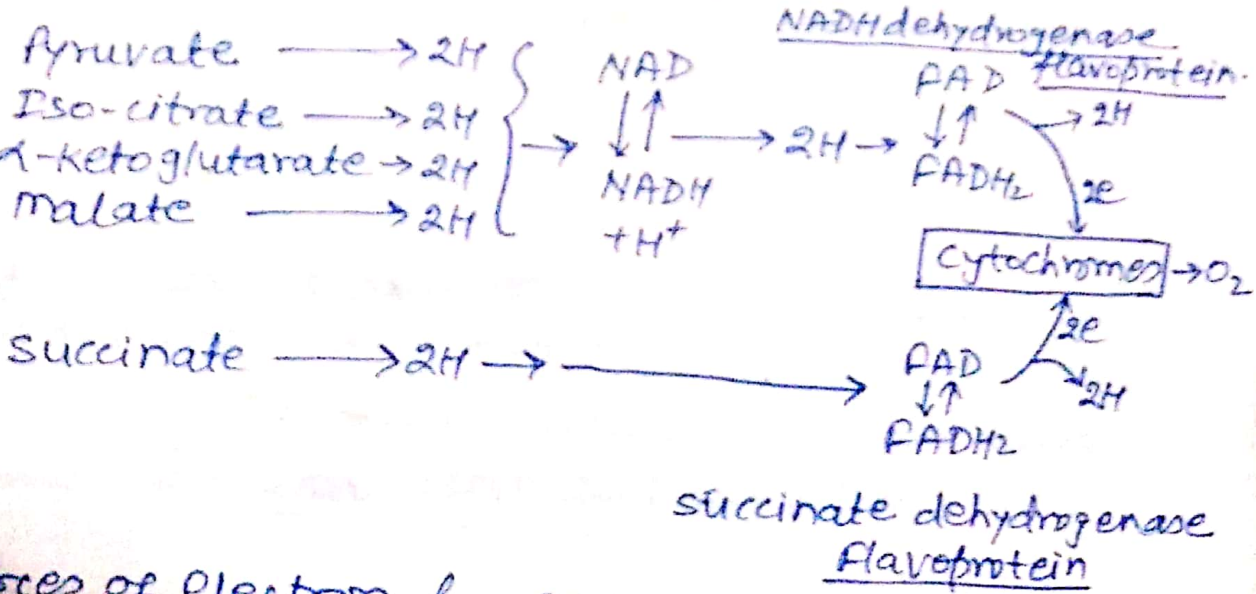
The electrons from the respiratory substrate to molecular oxygen are transfered step-wise. This stepwise transfer depends on the orderly and linear arrangement of different electron carriers (enzymes) of the respiratory chain. In this sequence each carrier enzyme is capable of accepting electrons from the preceeding carrier and to pass them on the next carrier. So, the ETS is a chain of carriers consisting of Nicotinamide adenine dinucleotide (NAD), Flavin nucleotide (FAD), Coenzyme Q and cytochromes (cyt b, c, a, a_3)

The hydrogen pairs released from respiration ultimately combines with the prosthetic (carrier) group NAD^+. For reduction of NAD^+, two electrons and one proton are transferred to this prosthetic group, the extra proton being released in the medium as H^+ ion

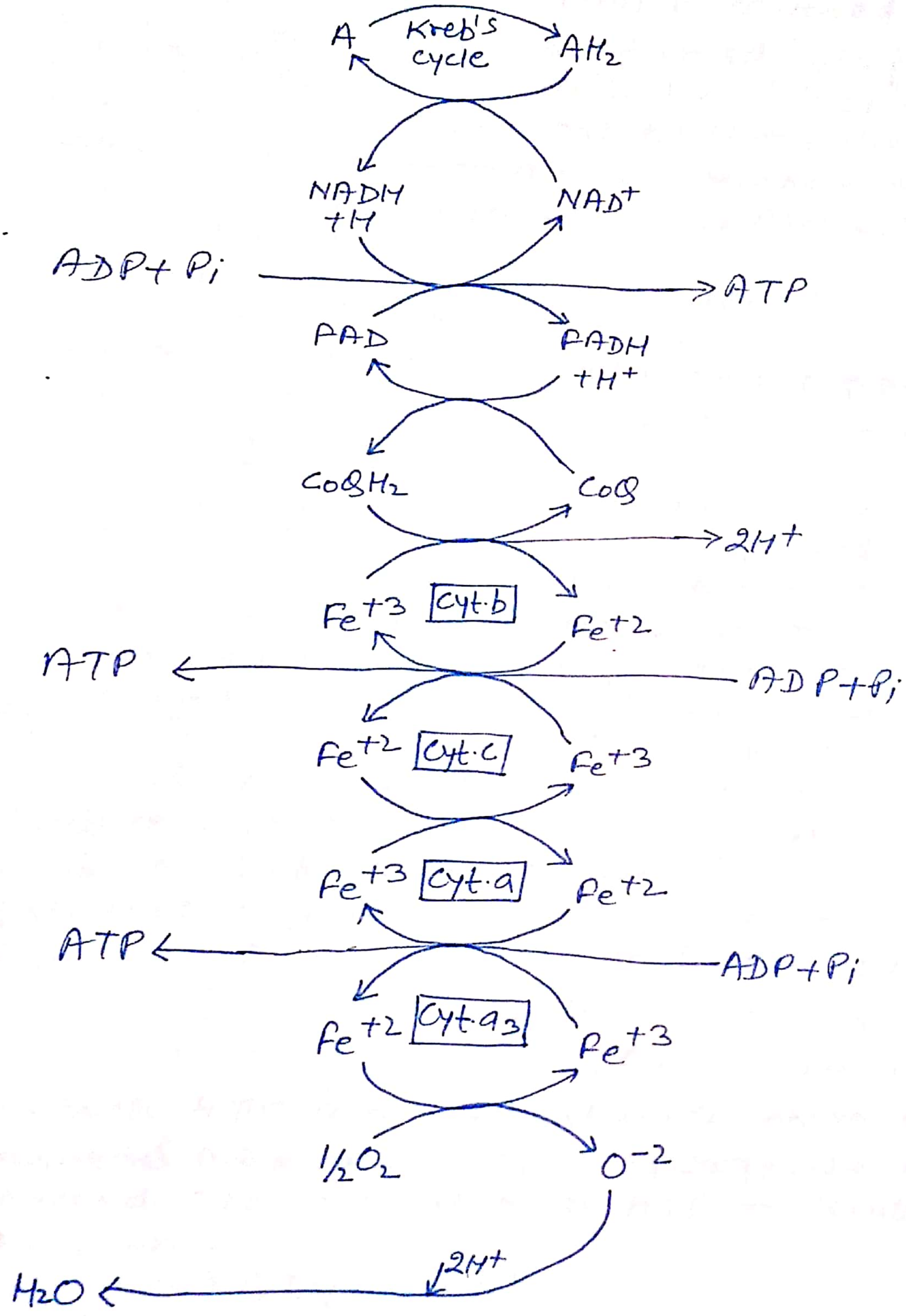
$$2H \longrightarrow 2H + 2e$$

$$NAD^+ + 2H + 2e \longrightarrow NADH + H^+$$

The reduced NAD molecules are reoxidised by the prosthetic group FAD. In this oxidation of $NADH_2$, two electrons and one proton are transferred from $NADH_2$ to FAD group. Then from FAD group electrons flow through the successive order of cytochromes. The different carriers are lined up one after the other in sequence of their relative oxidation-reduction potential. The hydrogen pair removed from succinate is transfered to FAD group of succinate dehydrogenase as second branch of respiratory chain.



Sources of electron for ETS



Electron Transport System

Thus with each step in the system, the energy level of the electron is lowered and the energy difference is transformed into phosphate bond energy by the conversion of ADP to ATP. For every pair of electrons passed along this system, three ATP are formed. The synthesis of ATP occurs in the oxidation of NADH, cytochrome b, c_2 and a. At the lowest energy level, the electrons are passed to oxygen from reduced cytochrome a_3, thereby activating the oxygen. In this stage, oxygen will accept free hydrogen ions to form water.

Energy release from ETS

During this oxidation process, enormous amount of energy is released in graded sequence. while the electron passes through the chain which consists of mainly the molecules of enzyme with iron as prosthetic group, some amount of energy is released at every step. At certain steps the energy released by the electron is not sufficient to bind inorganic phosphate (Pi) with ADP to produce ATP and is wasted as heat or light. But at some steps, energy released by electrons is sufficient to bind inorganic phosphate with ADP to form ATP. At these steps production of ATP occurs.

In fact, 0.28 volts of energy released at any step of electron transfer is sufficient to produce ATP from ADP and Pi. So, where the electron releases 0.28 volts or more energy, the ATP is formed. The formation of ATP molecules occurs between:—

NADH → FAD
Cyt b → Cyt c
Cyt a → Cyt a_3

Thus, the respiratory chain controls the gradual release of energy and functions as chemical machinery of mitochondria. This process of ATP synthesis during oxidation of co-enzymes is called oxidative phosphorylation.

Net amount of energy synthesised as ATP from a molecule of glucose :-

The kreb's cycle produces three molecules of NADH and one molecule of reduced flavoprotein (FAD) from one molecule of acetyl co-enzyme A.

Three molecules of NADH produces 3ATP each, totalling as 9 ATP. Two molecules from reduced flavoprotein. 12 molecules are produced from kreb's cycle by oxidation of one molecule of acetylco-enzyme A. ~~one molecule is produced by succinic co-enzyme.~~ Thus 24 molecules of ATP are produced by two molecules of acetylco-enzyme A. one molecule is produced by succinic co-enzyme.

Thus ~~3×3 = 9 + 12×2 = 9+24~~

$(3\times3)+(2\times12)+2+1 = 9+24+2+1 = 36$ ATP and 2 molecules of ATP arise from glycolysis totalling as 38 molecules. | ~~NET ATP~~