Lecture 15 - Respiration

Respiration

It is an energy yielding process in which the energy substrate is oxidized using the exogenous or externally derived electron acceptor. Respiration may be aerobic or anaerobic. In aerobic respiration oxygen serve as final electron acceptor and in anaerobic respiration inorganic compounds can serve as final electron acceptors . During respiration energy (ATP)is produced via oxidative phosphorylation

Oxidative phosphorylation

If the organism is a respiratory type (that means complete oxidation of glucose), it needs four essential metabolic components for their respiration and oxidative phosphorylation.

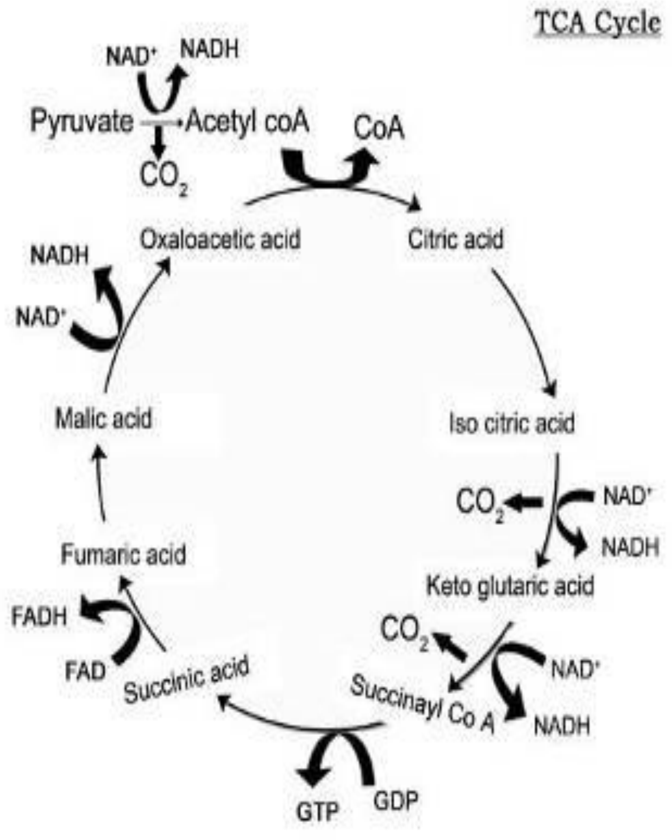
a. Tricarboxylic acid cycle (also known as citric acid cycle or Kreb's cycle) The pyruvate formed during glycolysis will be completely oxidized to 3 CO2 by the use of this cycle. During oxidation of one pyruvate through TCA cycle, 4 NADH2, 1 FADH2 and 1 GTP are produced along with 3 CO2.

b. A membrane and associated Electron Transport System (ETC) The electron transport chain is a sequenctial transfer of electrons through electron carriers to a terminal electron acceptor. During this flow of electron in the membrane, a proton motive force across the membrane leads to the formation ATP (is referred as electron transport phosphorylation).

c. An outside electron carrier: for aerobic respiration, O_2 is the terminal electron acceptor and reduced to H_2O. This is normal for higher organisms. But in anaerobic bacteria, the terminal electron acceptor may be of nitrite, nitrate, sulphate or carbon dioxide.

d. A membrane bound ATPase enzyme: The proton motive force developed during ETC leads to formation of ATP by enzyme ATPase present in the membrane.

a. Tricarboxylic acid cycle/ Kreb cycle/ Citric acid cycle



The tricarboxylic acid (TCA) cycle is a sequence of reactions that generates energy in the form of ATP and reduced coenzyme molecules ($NADH_2$ and $FADH_2$). It also performs other functions. Many intermediates in the cycle are precursors in the biosynthesis of amino acids, purines, pyrimidines, etc. For example, oxaloacetic acid and α – ketoglutaric acid are amino acid precursors.

Thus the TCA cycle is an **amphibolic cycle**, which means that it functions not only in catabolic (breakdown) but also in anabolic (synthesis) reactions.

The overall reaction of the TCA cycle can be summarized as follows:

$$\textbf{Acetyl - CoA + 3 } H_2O \textbf{ + 3 } NAD^+ \textbf{ + FAD + ADP + } P_i \rightarrow 2CO_2 \textbf{ +CoA + 3}NADH_2 \textbf{ +}FADH_2 \textbf{ +ATP}$$

Since the breakdown of glucose by glycolysis yields two acetyl - CoA molecules which can enter this cycle, the overall equation for the cycle, per glucose molecule breakdown, is twice as above.

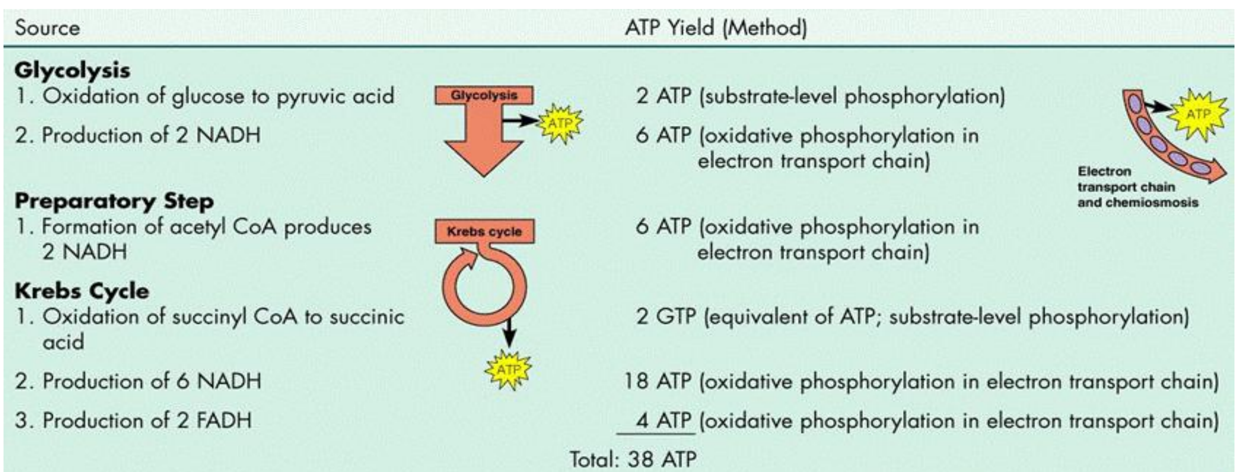
Energy yield in aerobic respiration

We may now look at the energy yield from the aerobic breakdown of some molecules of glucose when the electrons stored in the reduced coenzyme molecules are fed into the electron - transport chain. As shown previously, the electrons are transferred stepwise from the coenzyme carriers to molecular oxygen, and this transfer is coupled to the generation of ATP by oxidative phosphorylation

For each glucose molecule broken down, there are 12 reduced coenzymes to be oxidized: 2 $FADH_2$ (1 from each turn of the TCA cycle) and 10$NADH_2$ (2 from glycolysis; 2 from the gateway step between glycolysis and the TCA cycle, i.e., pyruvic acid to acetyl - CoA; and 6 from two turns of the TCA cycle). Since 3 ATP are produced from each $NADH_2$ and 2 ATP from each $FADH_2$, there are 34 ATP generated from the reduced coenzymes via oxidative phosphorylation through the respiratory chain. But the total yield of ATP from the aerobic respiration of 1 glucose molecule is 38: 34 from the oxidation of reduced coenzymes, 2 from glycolysis, and 2 from the side reaction of TCA cycle, that is, from 2 GTP.

The complete oxidation of glucose via glycolysis, the TCA cycle, and the respiratory chain is summarized in this overall reaction:

$$\mathbf{C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O}$$



Source	ATP Yield (Method)
Glycolysis	
1. Oxidation of glucose to pyruvic acid	2 ATP (substrate-level phosphorylation)
2. Production of 2 NADH	6 ATP (oxidative phosphorylation in electron transport chain)
Preparatory Step	
1. Formation of acetyl CoA produces 2 NADH	6 ATP (oxidative phosphorylation in electron transport chain)
Krebs Cycle	
1. Oxidation of succinyl CoA to succinic acid	2 GTP (equivalent of ATP; substrate-level phosphorylation)
2. Production of 6 NADH	18 ATP (oxidative phosphorylation in electron transport chain)
3. Production of 2 FADH	4 ATP (oxidative phosphorylation in electron transport chain)
	Total: 38 ATP

ATP generation in aerobic respiration

Energy yield

ATP YIELD per molecule of glucose broken down in aerobic respiration

		18 ATP (6 $NADH_2$)	
• 6 ATP(2 $NADH_2$)		4 ATP (2 $FADH_2$)	
• 2 ATP	6 ATP(2 $NADH_2$)	2 ATP (2 GTP)	
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• **8 ATP**	**6 ATP**	**24 ATP**	**= 38 ATP**
• **Glycolysis**	**Gateway Step**	**TCA Cycle**	

Electron transport chain (ET)

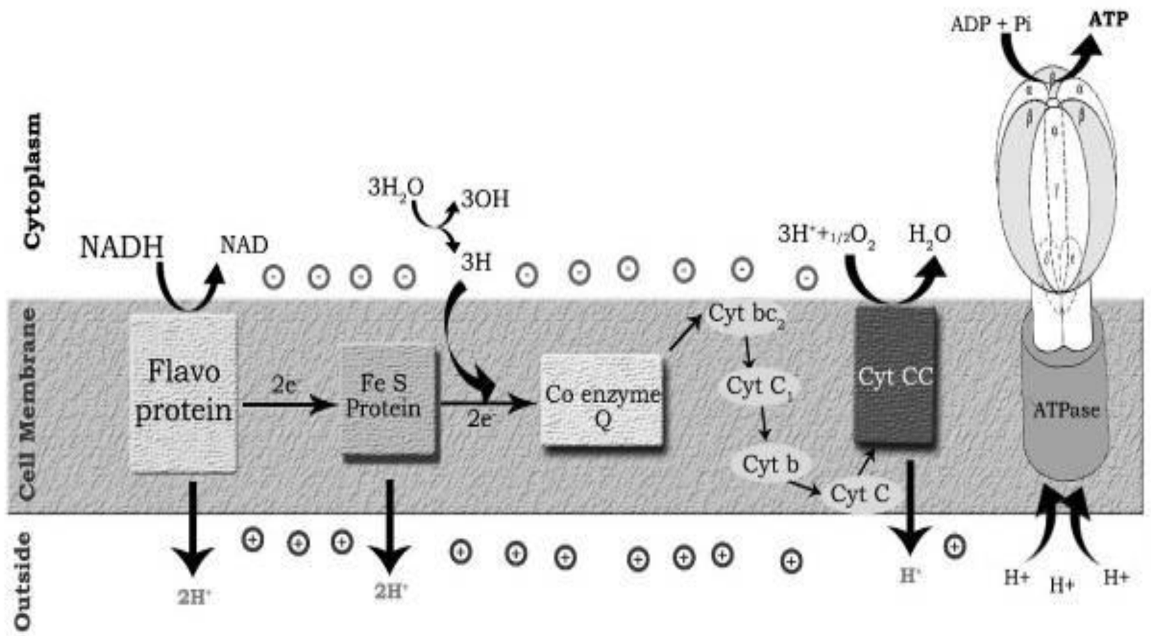
- ETC is the sequences of O/R reactions that occur in cells
- ET involves

  Initial e- donor, Terminal e- accepter and e- carriers

- ➢ In Eukaryotes, ETC are in mitochondria or chloroplast membrane
- ➢ In Prokaryotes, ETC in cytoplasmic membrane

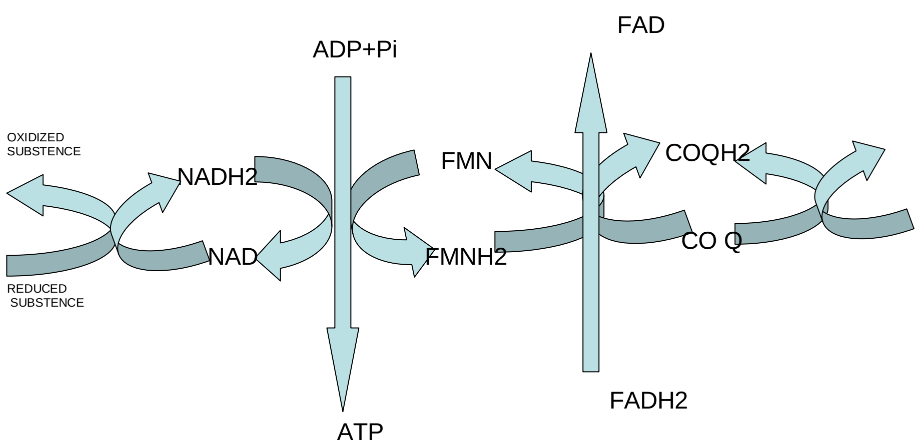
Components of Respiratory chain/ ETC

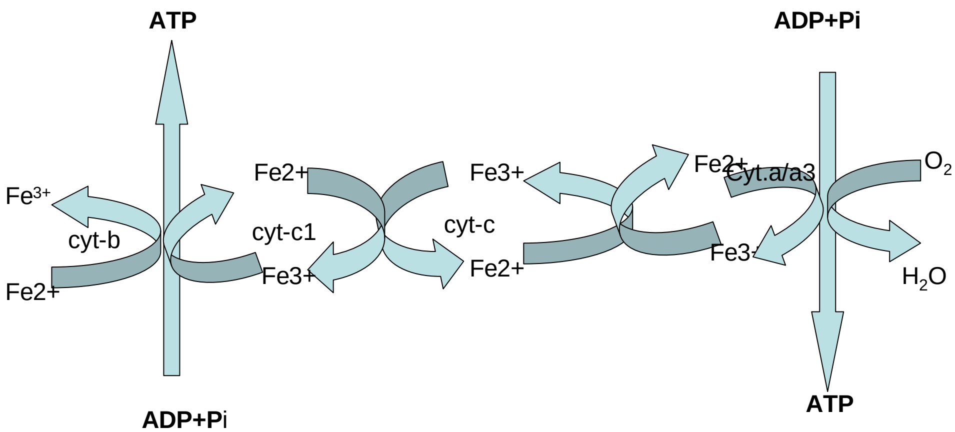
- It consists of enzymes or co enzymes
- NAD/NADP ……> NADH / NADPH
- FAD / FMN …….> FADH2 / FMNH2
- Coenzyme Q ---→ Ubiquinone
- Cytochromes --→ Cyt a,b,c



Electron Transport Chain - Proton motive force - ATP generation

Respiratory chain / ETC





CYt b-Fe $^{3+}$ + e- -------→ Cyt b-Fe $^{2+}$

Aerobic and anaerobic respirations

- The normal O_2 mediated respiration is referred as **aerobic respiration.** In aerobic organisms, the terminal electron acceptor will be of O_2.
- In some anaerobic organisms, after the electron transport chain, instead of O_2, some inorganic compounds like sulphate, nitrate or some organic compounds like fumarate act as terminal electron acceptor. Such type of respiration is referred as **anaerobic respiration**
- The process is named based on the compounds as **sulphur reduction**, **denitrification** and **methanogenesis**.

Anaerobic respiration

Some bacteria which utilizes reduced inorganic compounds as final electron acceptor as the substitute for oxygen is called anaerobic respiration.

The pathways for the dissimilation of the carbon and energy sources are identical with those in aerobic respiration, and electron transport occurs via a respiratory chain similar to that in aerobic cells. Oxygen is replaced as the terminal electron acceptor by nitrate. However, in some strict anaerobes, other compounds, such as carbon di oxide, or ions, such as sulphate ion, can be the terminal electron acceptors.

Aerobic and anaerobic respirations with specific examples

Terminal electron acceptor	**End product**	**Process name**	**Organism**
O_2	H_2O	Aerobic respiration	*Streptomyces*
NO_3	NO_2, N_2	Denitrification	*Pseudomonas denitrificans*
SO_4	S or H_2S	Sulphate reduction	*Desulfovibrio desulfuricans*
Fumarate	Succinate	Anaerobic respiration	*Escherichia*
CO_2	Methane (CH_4)	Methanogenesis	*Methanococcus*