

CELLULAR RESPIRATION



Glycolysis	2 ATP	
The Krebs Cycle	2 ATP	↖ ↗ 36 ATP for each glucose ↖ ↗
Oxidative Phosphorylation	32 ATP	

I. Glycolysis (in cytoplasm, no oxygen required)

1. 2 ATP are added.
2. 2 NADH are produced.
3. 4 ATP are produced.
4. 2 pyruvate (pyruvic acid) are formed.

II. The Krebs Cycle (in mitochondrial matrix)

1. **Pyruvate to acetyl CoA.** In a step leading up to the actual Krebs cycle, pyruvate combines with **Coenzyme A (CoA)** to produce **acetyl CoA**. In that reaction 1 NADH and 1 CO₂ are also produced.
2. **Krebs cycle: 3 NADH, 1 FADH₂, 1 ATP, CO₂**
The CO₂ produced by the Krebs cycle is the CO₂ animals exhale when they breathe.

III. Oxidative Phosphorylation (electron transport chain in the mitochondrial membrane)

The process of extracting ATP from NADH and FADH₂. Electrons from NADH and FADH₂ pass along an electron transport chain. These electrons pass from one carrier protein to another along the chain, losing energy at each step.

Cytochromes and various other modified proteins participate as carrier proteins in this chain. One of these cytochromes,

Cytochrome c, is often compared among species to assess genetic relatedness.

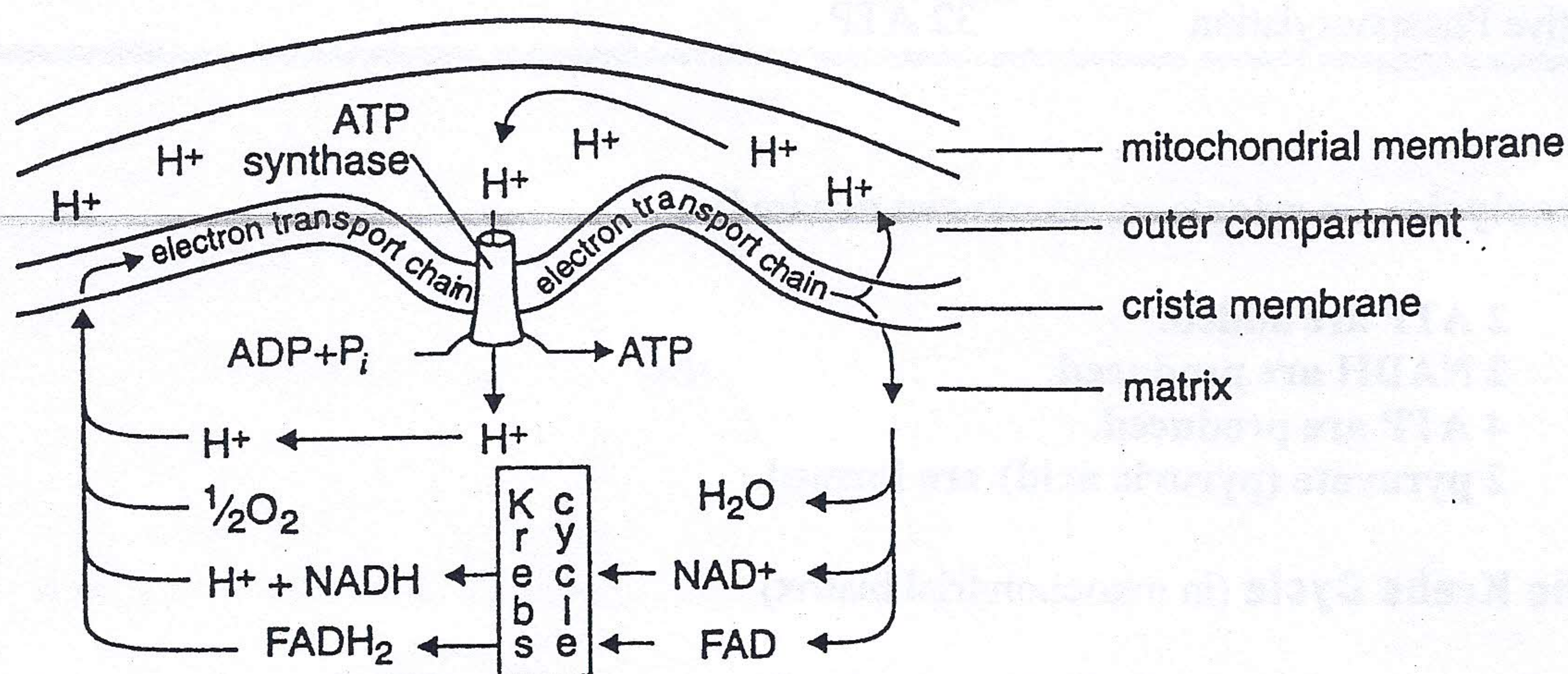
The last electron acceptor at the end of the chain is **oxygen**. The

$\frac{1}{2}$ O₂ accepts two electrons and, together with 2 H⁺, forms water.

Chemiosmotic theory describes how phosphorylation occurs.

CHEMIOSMOTIC THEORY

Electrons from NADH and FADH₂ lose energy as they pass along the electron transport chain in oxidative phosphorylation. That energy is used to phosphorylate ADP to ATP.



Chemiosmosis in Mitochondria

1. **H⁺ accumulate in the outer compartment.** The Krebs cycle produces NADH and FADH₂ in the matrix. As these two molecules move through the electron transport chain, H⁺ (which is only a proton) are pumped from the matrix across the cristae and into the outer compartment (between the cristae and the mitochondrial outer membrane).
2. **A pH and electrical gradient across the crista membrane is created.** The accumulation of H⁺ in the outer compartment creates a proton gradient (equivalent to a pH gradient) and an electrical charge (or voltage) gradient. These gradients are potential energy reserves in the same manner as water behind a dam is stored energy.
3. **ATP synthases generate ATP.** Channel proteins (ATP synthases) in the cristae allow the protons in the outer compartment to flow back into the matrix. The protons moving through the channel generate the energy for these channel proteins to produce ATP. It is similar to how the turbines in a dam generate electricity when water flows through them.

ANAEROBIC RESPIRATION (occurs in the cytoplasm alongside glycolysis)

If oxygen is not present, there is no electron acceptor to accept the electrons at the end of the electron transport chain. If this occurs, then NADH accumulates. Once all the NAD^+ has been converted to NADH, the Krebs cycle and glycolysis both stop (Both need NAD^+ to accept electrons). Once this happens, no new ATP is produced and the cell soon dies.

2 processes replenish NAD^+ so that glycolysis can proceed once again:

1. Alcoholic Fermentation
2. Lactate Fermentation

Alcoholic Fermentation

Occurs in plants, fungi (such as yeasts), and bacteria.

- 1) **Pyruvate to acetaldehyde.** For each pyruvate, 1 CO_2 and 1 acetaldehyde are produced. The CO_2 formed is the source of carbonation in fermented drinks such as beer and champagne.
- 2) **Acetaldehyde to ethanol.** The important part of this step is that the energy in NADH is used to drive this reaction, releasing NAD^+ . For each acetaldehyde, 1 ethanol is made and 1 NAD^+ is produced. The ethanol (ethyl alcohol) produced here is the source of alcohol in beer and wine.

Lactate Fermentation

There is only one step in lactate fermentation. A pyruvate is converted to lactate (or lactic acid) and in the process, NADH gives up electrons to form NAD^+ . As in alcohol fermentation, the NAD^+ can now be used in glycolysis. When O_2 again becomes available, lactate can be broken down and its store of energy can be retrieved. Because O_2 is required to do this, lactate fermentation creates what is often called an oxygen debt.