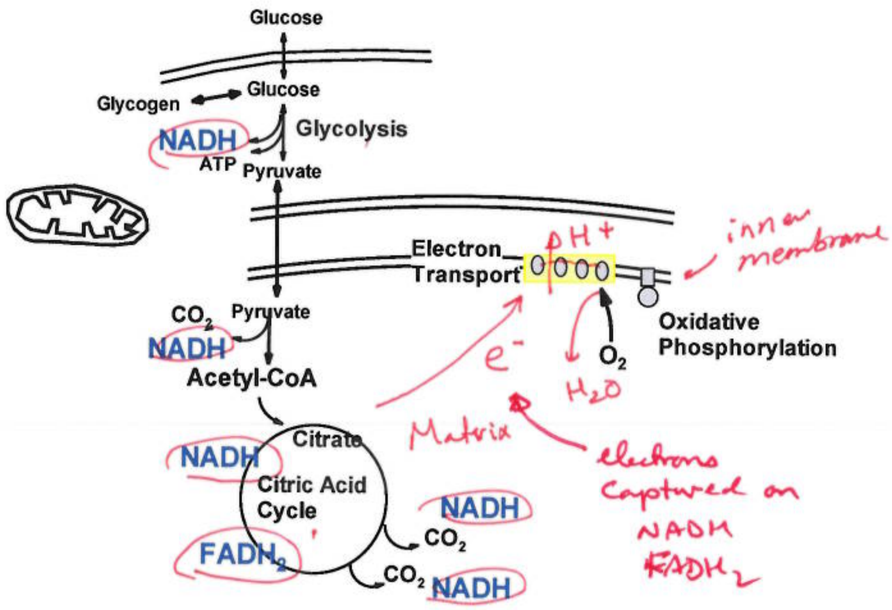
Lecture 30: Electron Transport & ATP Synthesis

Electron transport

Location: Inner mitochondrial membrane

Input: NADH, $FADH_2$

Output: Proton gradient across inner membrane, higher proton concentration between the two membranes.

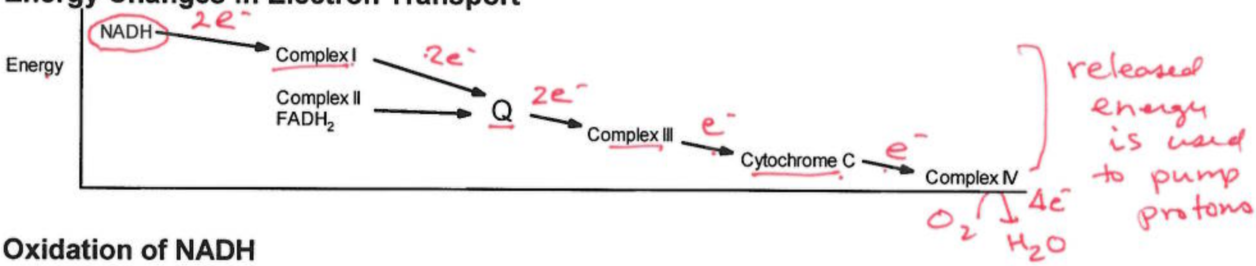


Overview:

- The energy captured by oxidation steps in glycolysis and the TCA cycle are stored on NADH and $FADH_2$.
- These compounds are oxidized in the electron transport chain, releasing additional energy as electrons are removed from them.
- This energy is stored in a **proton gradient** across the inner mitochondrial membrane.
- *The energy stored in this gradient is used to produce ATP.*
- Final electron acceptor is oxygen.

Addition of electrons to oxygen releases energy: $O_2 + 4\ H^+ + 4\ e^- = O_2 + 2\ H_2 \rightarrow 2\ H_2O$ + lots of energy

Energy Changes in Electron Transport

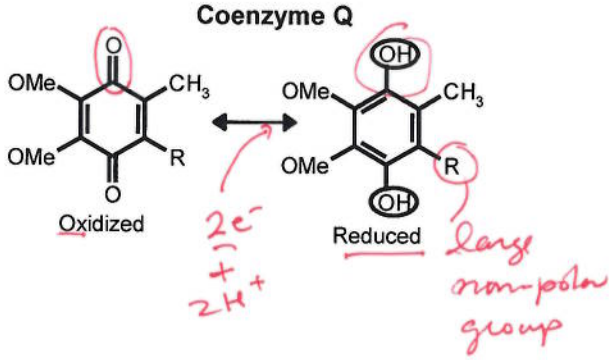


Oxidation of NADH

***Complex I*: NADH →NAD⁺**

- **NADH is oxidized back to NAD⁺.**
- **The electrons from NADH are transferred coenzyme Q, a non-polar electron carrier.** The membrane must be fluid for it to diffuse from one complex to the next.
- **Four protons** are pumped from the inside (matrix) to the intermembrane space for each pair of electrons processed.

Coenzyme Q



***Complex III*:**

- Electrons from $CoQH_2$ passed to cytochrome c.
- **Four protons** are pumped for each pair of electrons processed.

Cytochrome C: A small iron containing protein that shuttles electrons, one at time, from III to IV.

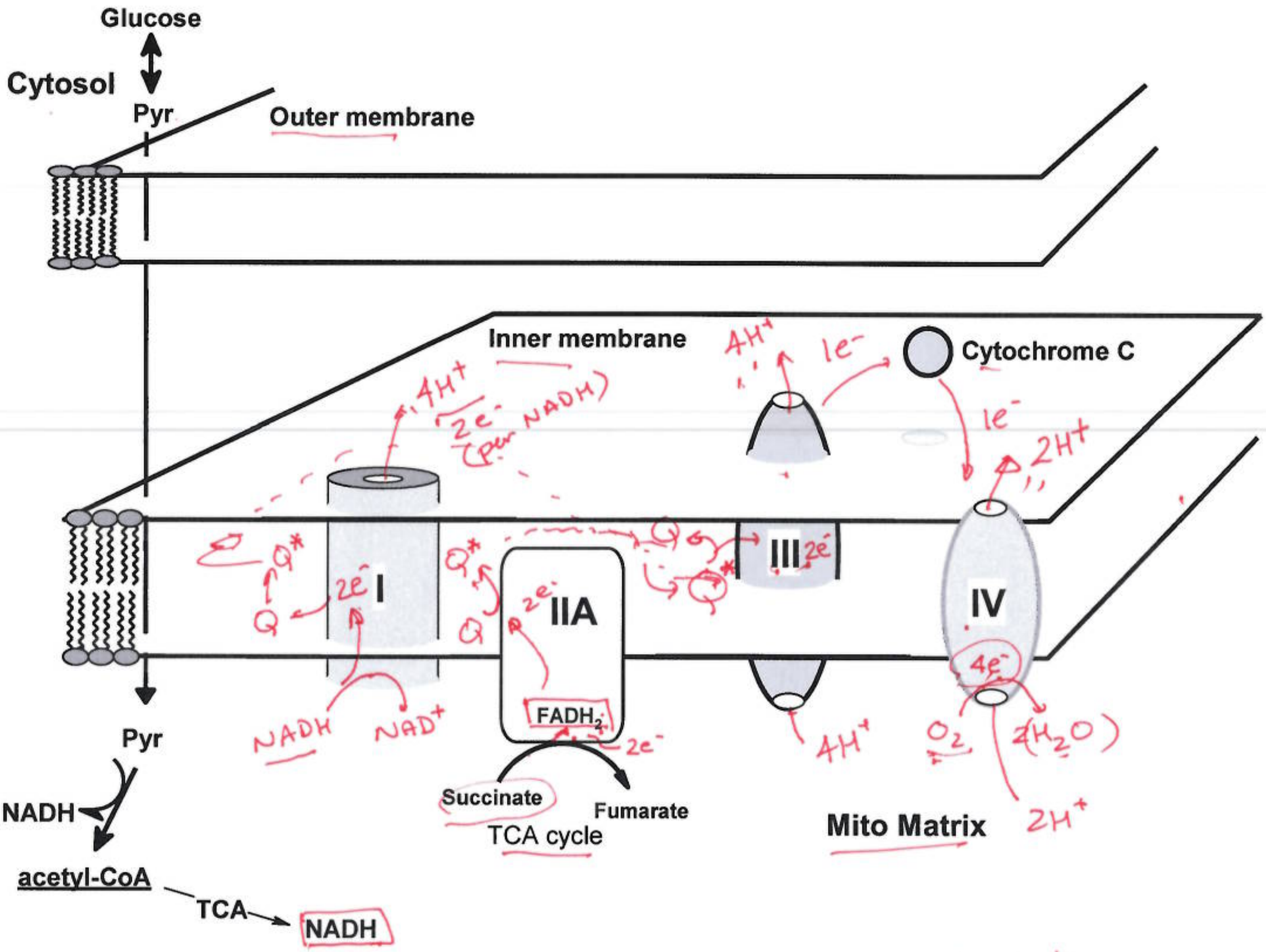
***Complex IV*: Cytochrome c oxidase**

- Donates a total of *four* electrons to O_2.
- Pumps an additional **two protons** for each pair of electrons that are processed.

Oxidation of $FADH_2$

***Complex II*: $FADH_2 \rightarrow FAD$**

- Two electrons from $FADH_2$ are transferred to CoQ.
- Does not pump any protons.
- CoQ goes to complex III
- Remaining path is the same as NADH oxidation:
  Complex III – 4 protons pumped/pair of electrons.
  Complex IV - 2 protons pumped/pair of electrons.



Let's count how many protons are pumped by the oxidation of one NADH: 10 H^+

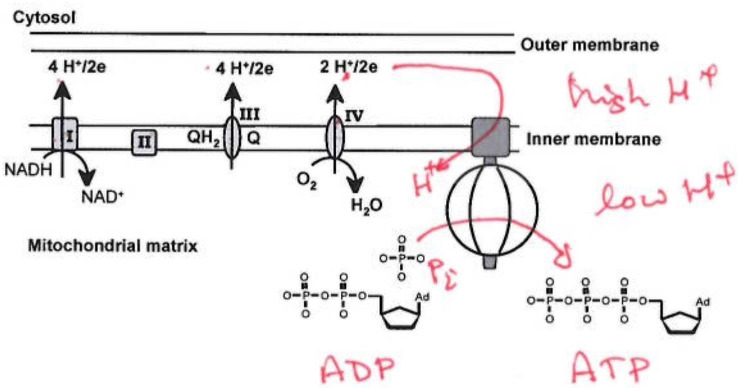
Let's count how many protons are pumped by the oxidation of one $FADH_2$: 6 H^+

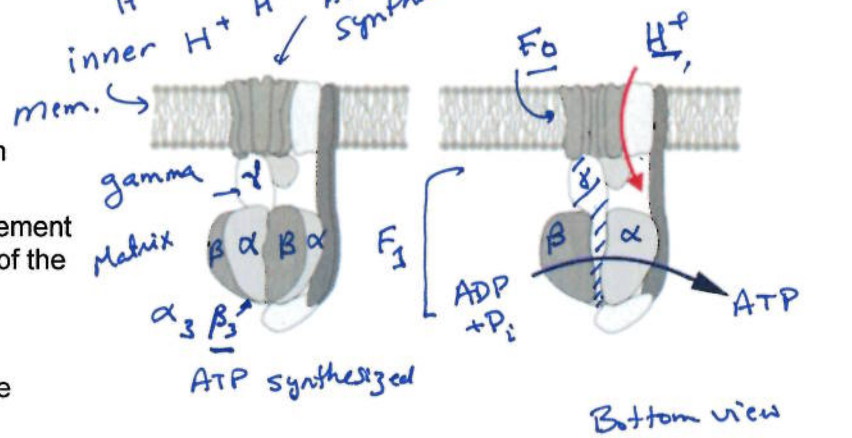
ATP Synthesis (Oxidative phosphorylation):

***ATP synthesis** is attained by coupling the energy stored in the proton gradient to the chemical synthesis of ATP.*

*The enzyme that accomplishes this coupling is called **ATP-synthase**. This is called **oxidative phosphorylation** since the generation of ATP is coupled to oxidation.*

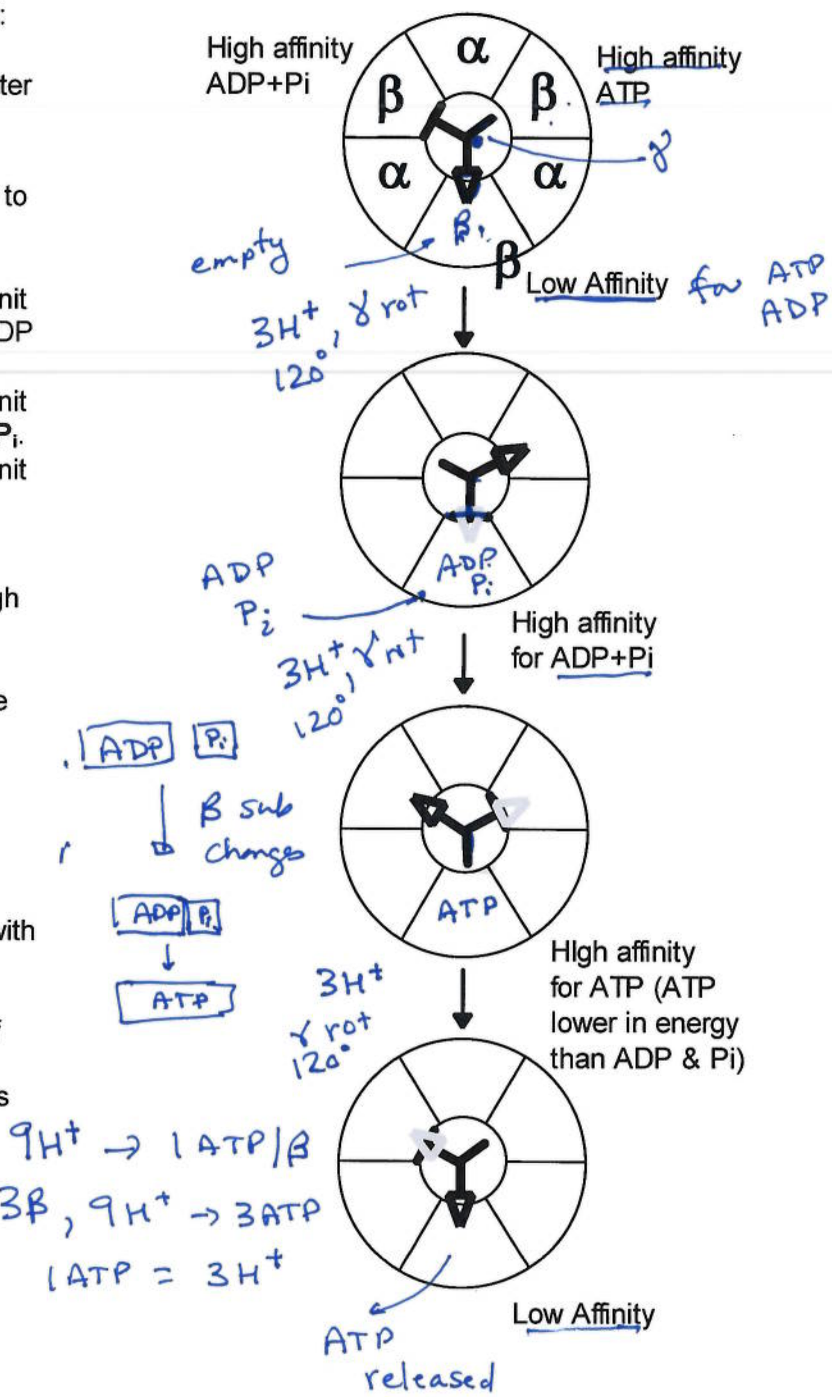
9 H^+ = 3 ATP synthesized





Structural Features:

1. The F_o Complex
   - Membrane-spanning, multi-protein complex.
   - Responsible for coupling the movement of three protons to 120° rotations of the **γ-subunit**.
2. The F_1 Complex
   - Attached to F_o, it protrudes into the mitochondrial matrix.
   - Composed of five different subunits: $\alpha_3\beta_3\gamma\delta\varepsilon$
   - The γ subunit is the shaft at the center of the $\alpha_3\beta_3$ disk. **γ rotates 120°/3 protons.**
   - The β subunits are asymmetric due to their interactions with the γ-subunit (allosteric effects).
     1. One conformation of the β subunit has very **low affinity** for both ADP and ATP.
     2. One conformation of the β subunit has **high affinity for ADP and P_i**.
     3. One conformation of the β subunit has **high affinity for ATP**.



How the motor works:

- Every time three proton move through the complex, the γ subunit rotates 120°.
- The rotation of γ subunit changes the conformation of the β-subunits such that the Gibbs energy of the bound ADP + P_i becomes higher than the energy of ATP, thus ATP forms spontaneously from the bound ADP and P_i.
- The newly-formed ATP is released with the transport of three additional protons.
- The actual synthesis, or formation of the bond between ADP and P_I, is catalyzed by conformational changes of the β-subunit that occur as a consequence of the rotation.
- Since all three β subunits are functioning at the same time, the transport of 9 protons in a complete cycle produces 3 ATP.

NADH	**~10 protons pumped**	**~ 3 ATP**
$FADH_2$	**~6 protons pumped**	**~2 ATP**