From electrons to ATP

Oxidative phosphorylation takes place at the inner mitochondrial membrane. It couples oxidation of reduced coenzymes to ATP production through a proton gradient.

1. SUPPLY ELECTRONS

Reduced NAD and reduced FAD carry hydrogen from earlier stages of respiration. Hydrogen is separated into protons and electrons; electrons enter the electron transport chain. The coenzymes are reoxidised and can be used again.

2. TRANSFER ENERGY TO A GRADIENT

Electrons pass along a series of carriers in redox reactions, losing energy overall. Some of this energy drives proton pumping from the matrix into the intermembrane space, against the electrochemical gradient.

3. USE PROTON FLOW TO MAKE ATP

Protons return to the matrix down their electrochemical gradient through ATP synthase. This facilitated diffusion provides energy for ATP synthesis from ADP and inorganic phosphate. This coupling is chemiosmosis.

4. KEEP ELECTRONS MOVING

Oxygen is the final electron acceptor. It accepts electrons and combines with protons to form water. Removing electrons at the end allows continued electron flow and helps regenerate oxidised coenzymes.

Energy route: reduced coenzymes → electron transport → proton gradient → ATP.

Electron transfer and chemiosmosis: OpenStax, Biology 2e 7.4.
Energy coupling and carrier recycling: Cooper, The Cell, Metabolic Energy.

Scope: Cambridge Biology 9700, section 12.2, outcomes 1, 7-9, p. 33.

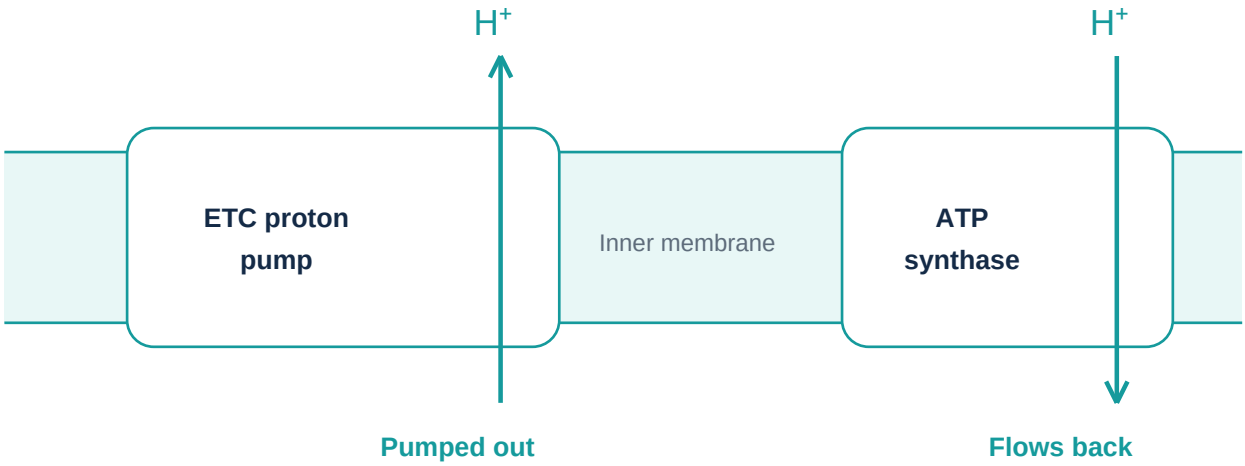
Follow protons across the membrane

The inner membrane separates two compartments. Pumping and return flow go in opposite directions; neither should be confused with the path of electrons.

1. A SIMPLIFIED MEMBRANE MODEL

INTERMEMBRANE SPACE

Higher proton concentration



MATRIX

$ADP + P_i \rightarrow ATP$

Arrows show proton movement, not electrons. ETC = electron transport chain. Protein shapes and spacing are schematic.

2. WHY THE MEMBRANE MATTERS

The inner membrane has low permeability to protons, so a gradient can be maintained. Cristae increase the surface area available for electron carriers and ATP synthase.

The gradient has a concentration component and an electrical component: the intermembrane side is relatively more positive. Proton return releases stored potential energy.

Membrane compartments and proton motive force: Alberts et al., The Mitochondrion.
Proton movement and ATP formation: OpenStax, Biology 2e 7.4.

Scope: Cambridge Biology 9700, section 12.2, outcomes 1, 7-9, p. 33.

Oxygen completes the pathway

Oxygen does not directly attach phosphate to ADP. Its role is at the end of electron transport; ATP synthase uses energy from proton movement.

1. OXYGEN IS REDUCED TO WATER

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

Electrons and matrix protons combine with oxygen to form water. This is the terminal reaction, not the equation for the whole of respiration.

2. IF OXYGEN IS ABSENT

Electron flow cannot be sustained without its final acceptor. Proton pumping stops and the gradient dissipates. ATP production by oxidative phosphorylation falls; glycolysis may continue if another pathway regenerates NAD.

3. DISTINGUISH THE TWO ATP-MAKING ROUTES

Substrate-linked phosphorylation transfers phosphate directly from an intermediate to ADP. Oxidative phosphorylation uses electron transport to build a gradient, then ATP synthase uses that gradient. Electrons do not flow through ATP synthase to make ATP.

4. CONNECT THIS TO THE WHOLE PATHWAY

Most ATP from aerobic glucose respiration is generated at this stage, not directly in the Krebs cycle. Reduced coenzymes transfer reducing power; they are not ATP. Exact ATP totals vary and are not required for this syllabus outcome.

Oxygen reduction and oxidative ATP production: Cooper, The Cell, Metabolic Energy.
Gradient-dependent ATP synthesis: Alberts et al., The Mitochondrion.

Scope: Cambridge Biology 9700, section 12.2, outcomes 1, 7-9, p. 33.