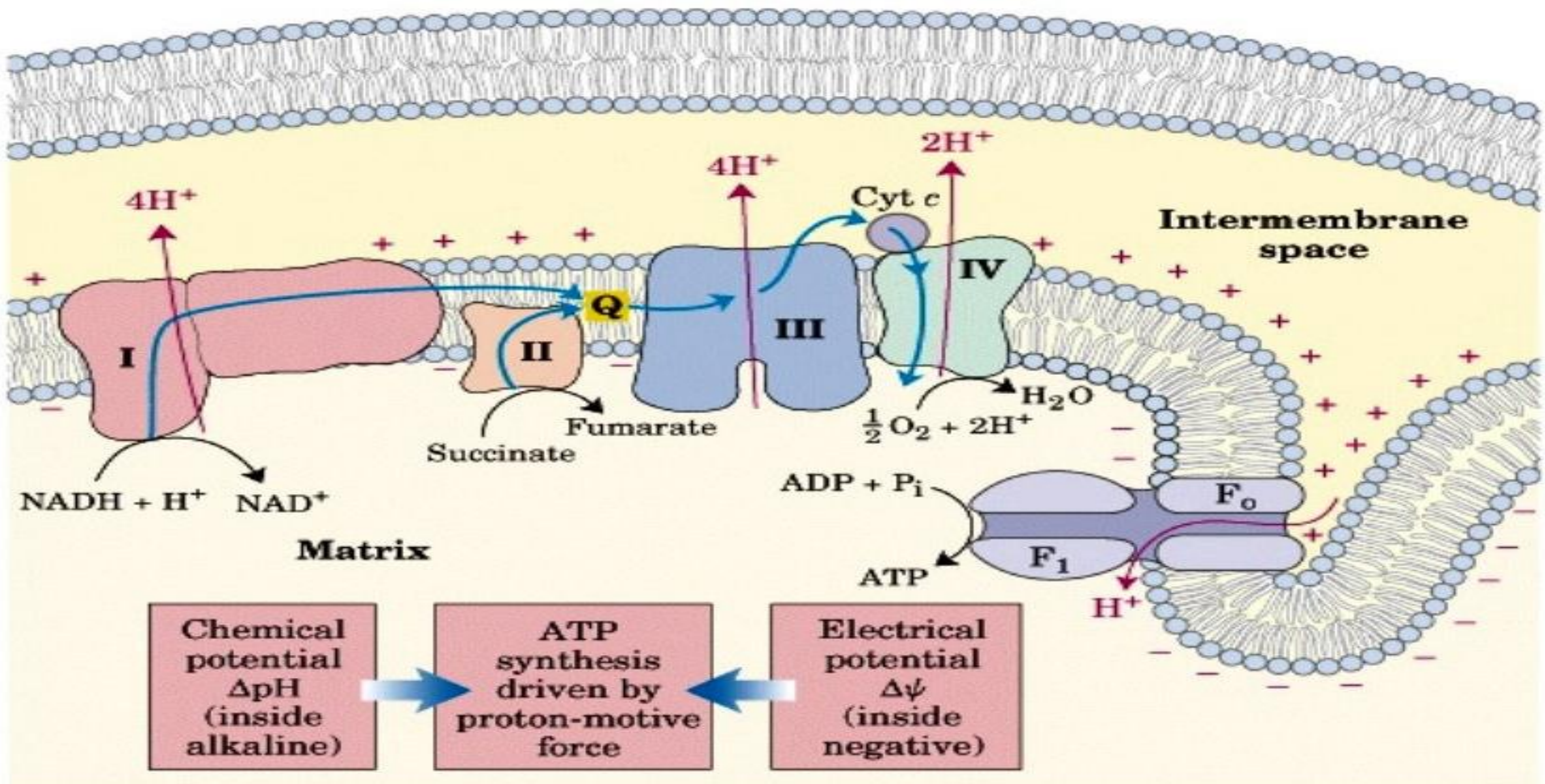
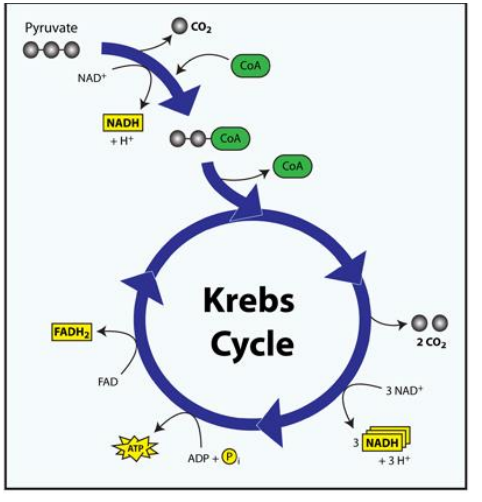
Electron Transport Chain & Oxidative Phosphorylation



Electron Transport Chain & Oxidative Phosphorylation

- The third stage of cellular respiration.
- NADH resulting from TCA cycle activity can be used:

1. For reductive biosynthesis.
2. To supply the energy for ATP synthesis via oxidative phosphorylation.



Redox reactions

Coupled Redox Reaction

involve the transfer of electrons from one chemical species to another.

e.g.

Oxidation of NADH by the electron transport chain:

NADH oxidation has the potential for driving the synthesis of a number of ATPs.

$NADH + ½ O_2 + H^+ \rightarrow NAD^+ + H_2O$

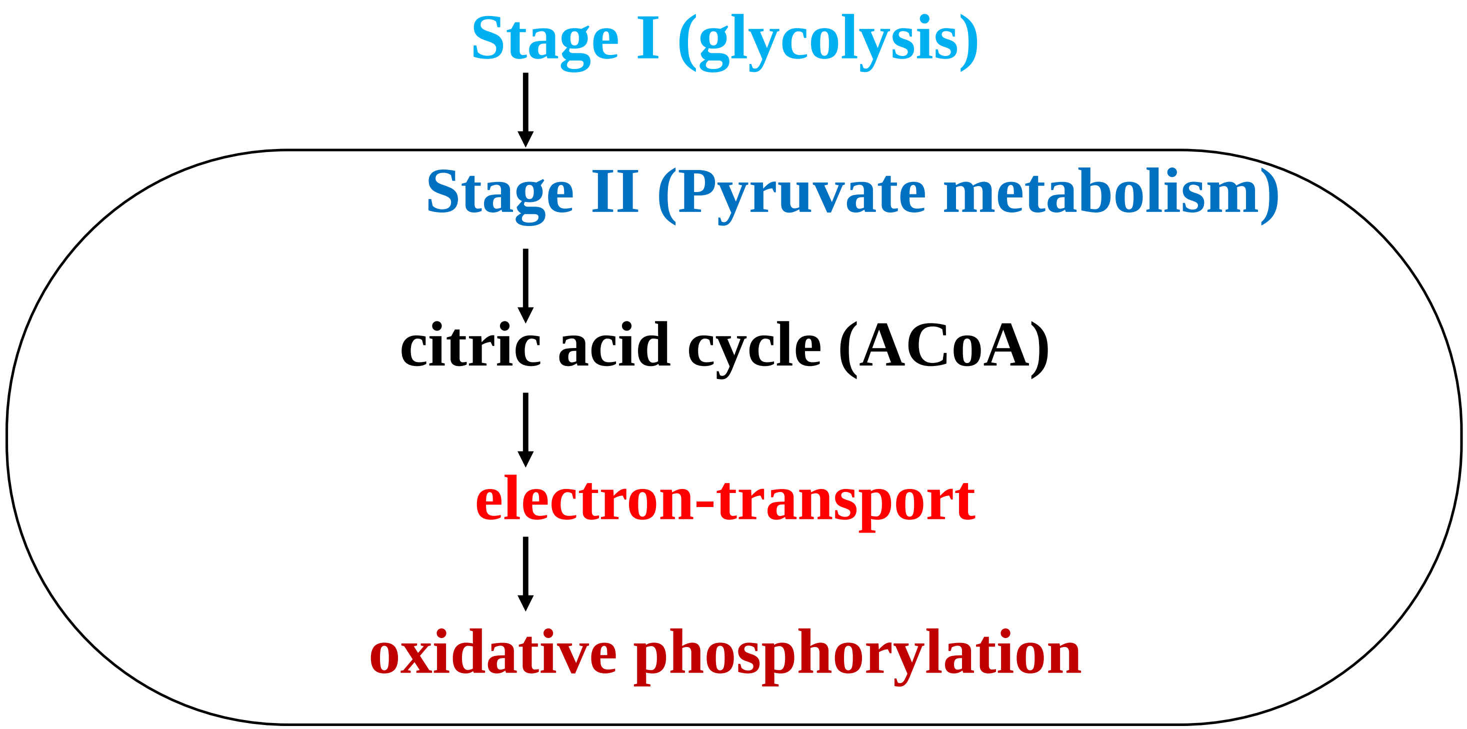
$\rightarrow \rightarrow$ synthesis of ATPs.

NADH $\rightarrow$ 2.5 ATP

FADH2 $\rightarrow$ 1.5 ATP

Mitochondrial electron transport

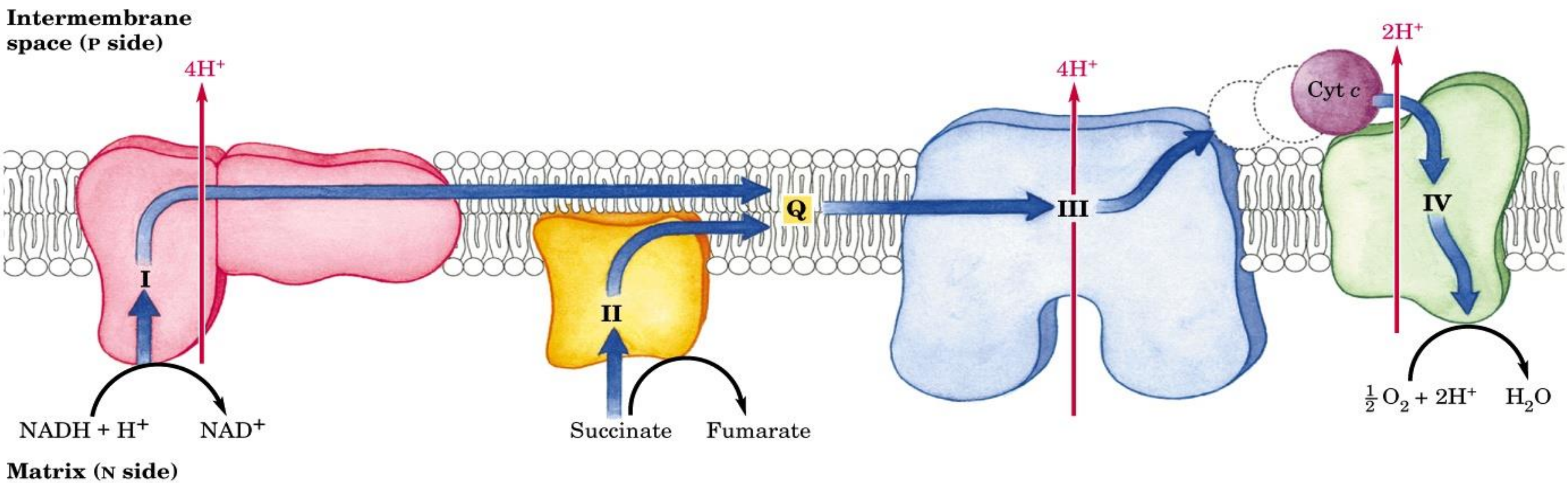
- **Stage I and II of carbohydrate catabolism converge at the mitochondria.**



Oxidative Phosphorylation

- ***The culmination of energy-yielding metabolism in aerobic organisms.***
- All oxidation steps in the **degradation** of carbohydrates, fats, & amino acids ***converge*** at this final stage of cellular respiration, in which the energy of oxidation drives the ***synthesis of ATP***.
- Occurs in mitochondria
- Involves the reduction of O_2 to H_2O with electrons donated by NADH & $FADH_2$.
- Consists of a series of sequentially acting electron carriers, most of which are integral proteins capable of accepting & donating either one or two electrons.

Respiratory Chain:
Summary of the flow of electrons & protons.



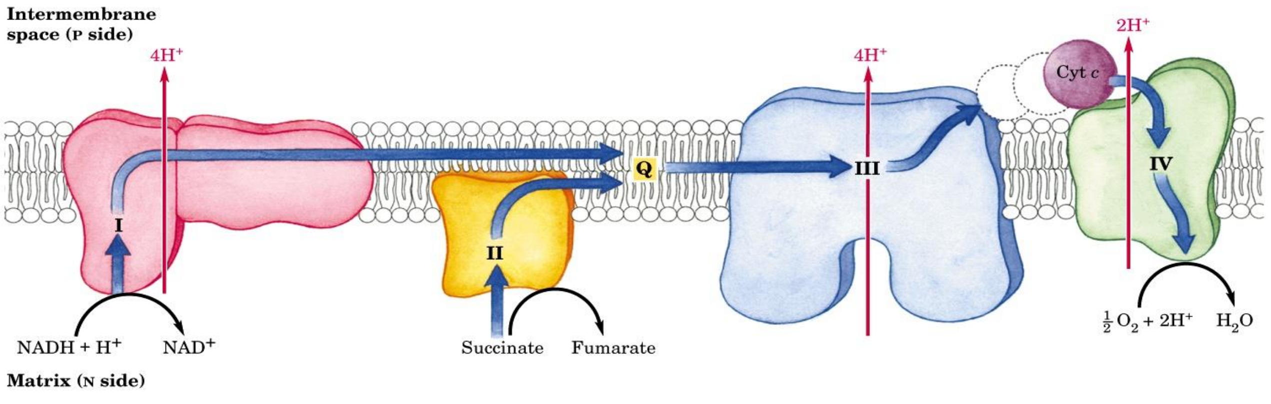
Respiratory Chain: summary of the flow of electrons & protons.

- Electrons reach Q through complexes I & II.
- QH_2 serves as a mobile carrier of electrons & protons, which passes electrons to complex III, which passes them to another mobile connecting link (cytochrome c).
- Finally, complex IV transfer electrons to O_2.

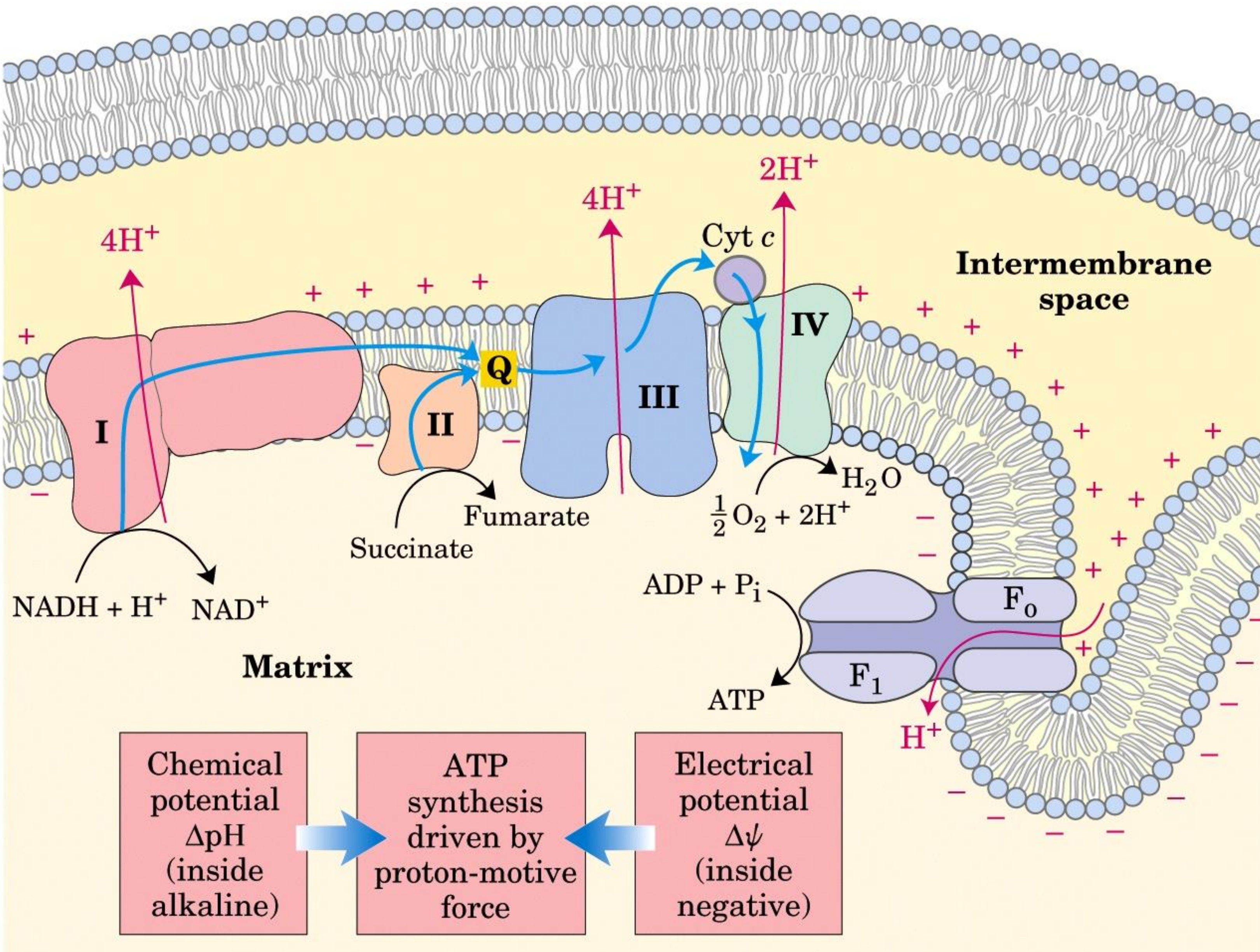
Electron-transport chain

- Composed of **four** large protein **complexes**.
- **Complex I** - NADH-Coenzyme Q oxidoreductase
- **Complex II** - Succinate-Coenzyme Q oxidoreductase
- **Complex III** - Coenzyme Q-Cytochrome c oxidoreductase
- **Complex IV** - Cytochrome c oxidase

- Many of the components are integral membrane proteins with groups to move electrons.



Oxidative Phosphorylation



Electron-transport and oxidative phosphorylation

- **Recycling is accomplished by stepwise oxidation and transfer of electrons to oxygen.**

$$\mathrm{NADH} + H^+ + \tfrac{1}{2}\,O_2 \xrightarrow{\mathrm{ADP} + P_i \;\to\; \mathrm{ATP}} \mathrm{NAD}^+ + H_2O$$

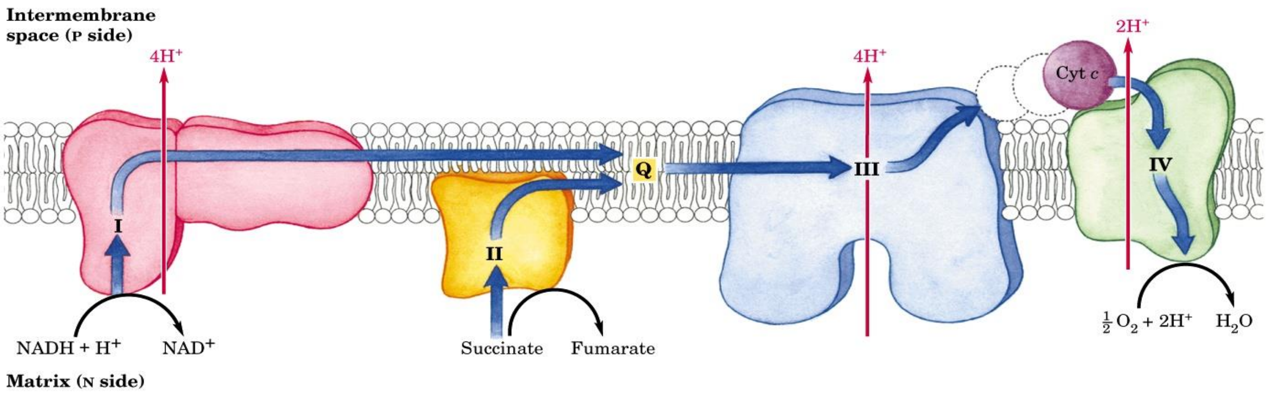
$$\mathrm{FADH}_2 + \tfrac{1}{2}\,O_2 \xrightarrow{\mathrm{ADP} + P_i \;\to\; \mathrm{ATP}} \mathrm{FAD} + H_2O$$

NAD^+ and FAD are then made available for additional oxidative metabolism.
The energy released during electron transport is coupled to ATP synthesis.

The Electron Transport Chain

- **A series of carrier molecules that are, in turn, oxidized and reduced as electrons are passed down the chain.**

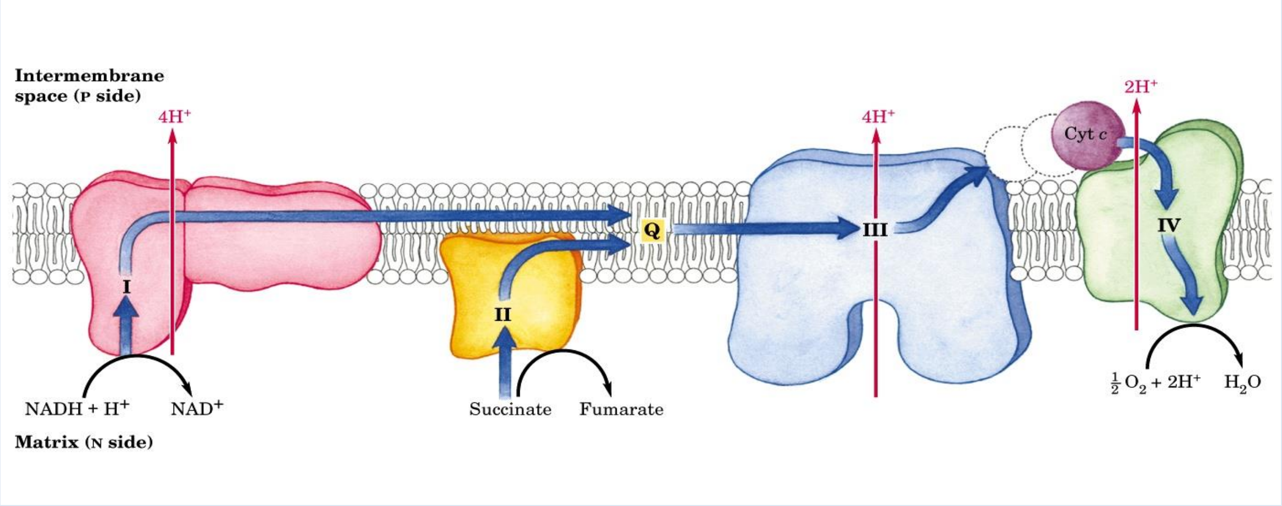
- **Aerobic respiration: The final electron acceptor in the electron transport chain is molecular oxygen (O_2).**



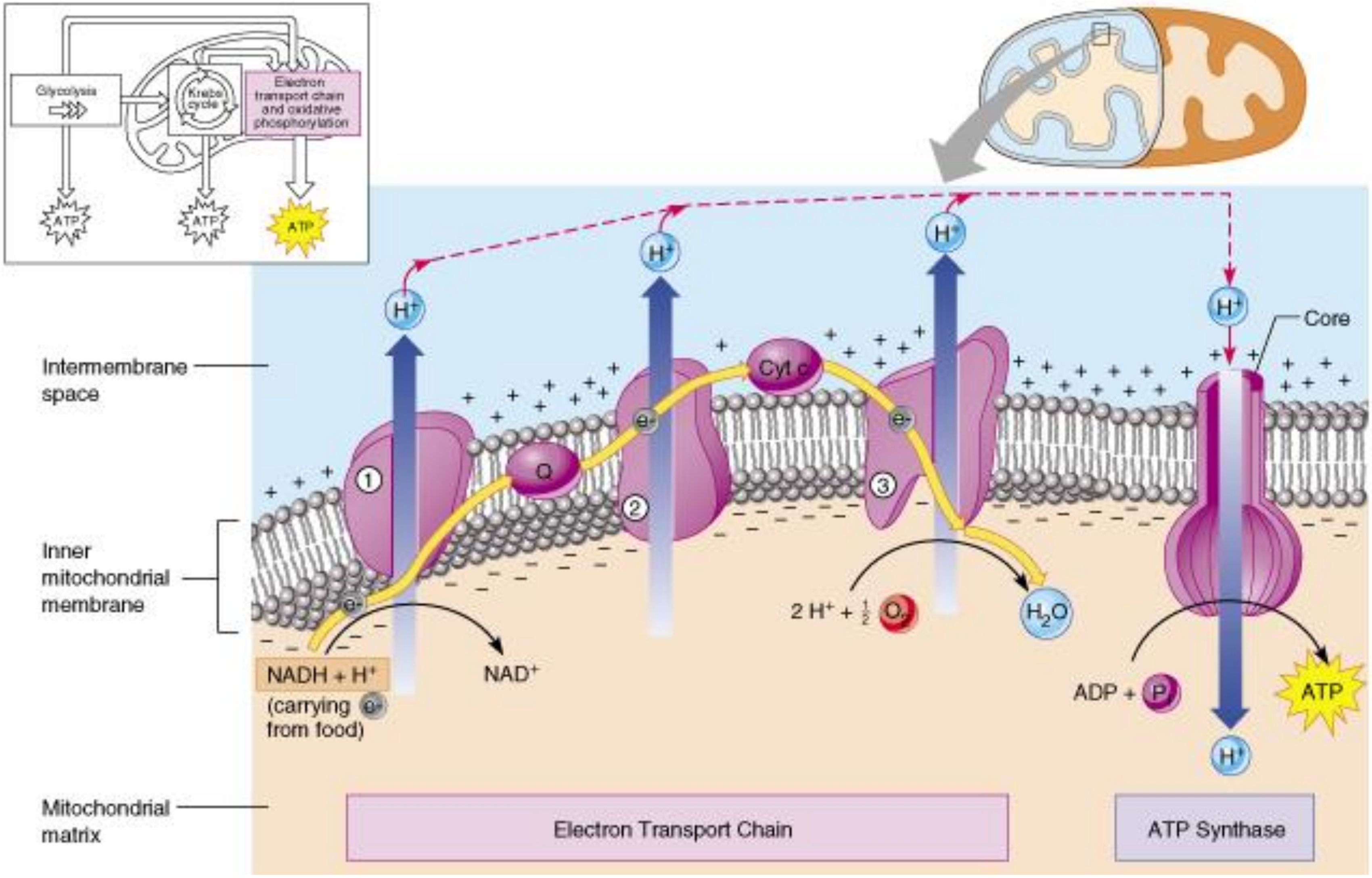
The Electron Transport Chain

- Energy released can be used to produce ATP by chemiosmosis ??
- The chemiosmotic process whereby the movement of substances (e-) across a membrane is coupled to chemical reactions
  - Coupling oxidation to phosphorylation
  - Electron transfer is used to pump hydrogen ions into the intermembrane space (3 pumps)
  - A steep diffusion gradient across the membrane results
  - When hydrogen ions flow back across the membrane through ATP synthase, energy is captured and attaches phosphate groups to ADP to make ATP.

(Flow of H^+ down gradient powers ATP formation)



Coupling of electron-transport with ATP synthesis



ATP

- https://www.youtube.com/watch?v=39HTpUG1MwQ

- https://www.youtube.com/watch?v=LQmTKxI4Wn4

For oxidative phosphorylation to proceed

1. High concentration of protons must be developed on the outside of the inner membrane ---→ creates proton gradient.

2. The inner mitochondrial membrane must be physically intact ---→

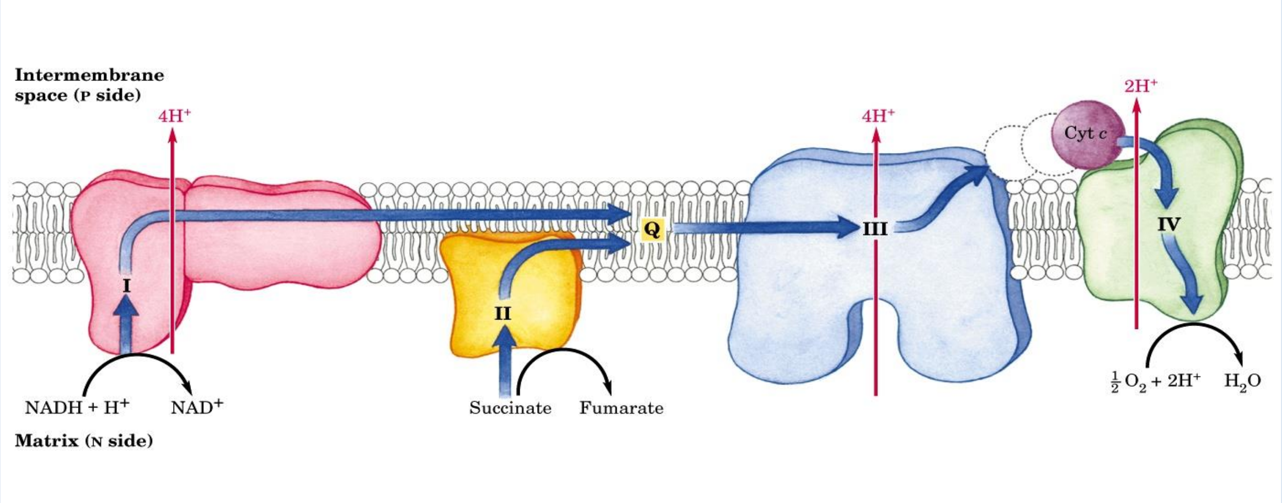
protons enter matrix only through ATP synthase.

Inhibitors of Oxidative Phosphorylataion (Uncouplers)

1. Inhibitors of electron transport at specific sites in the electron transport assembly,

- **antimycin A** is a specific inhibitor of **cytochrome b**.

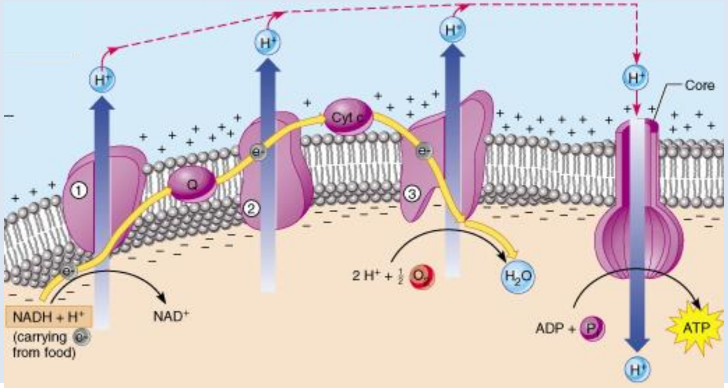
in the presence of antimycin A →
cytochrome b can be reduced but not oxidized



Inhibitors of Oxidative Phosphorylataion (Uncouplers)

2. stimulate electron transport by discharging the proton gradient (Uncouplers).

- Oxidation occurs but no phosphorylation
  - Electrons are transfered to oxygen and water is produced but there is no ATP produced
- pH gradients are disrupted across the membrane
  - Dinitrophenolate anion (dinitrophenol, DNP). react with protons in the intermediate space thus reducing the proton concentration
  - Antibiotics as gramicidin A and valinomycin are ionophores creating a channel through which ions as H+, Na+ & K+ pass through the membrane. Oxidation and electron transfer occurs without phosphorylation



Uncoupling of electron-transport and oxidative phosphorylation

- **In some special cases, the coupling of the two processes can be disrupted.**
- **Large amounts of O_2 are consumed but no ATP is produced.**
- **Used by newborn animals and hibernating mammals.**
- **Occurs in 'brown fat'- dark color due to high levels of mitochondria which contain thermogenin (uncoupling protein).**

Thermogenin allows the release of energy as heat instead of ATP.

table 19–4

Some Agents That Interfere with Oxidative Phosphorylation or Photophosphorylation

Type of interference	Compound*	Target/mode of action
Inhibition of electron transfer	Cyanide Carbon monoxide	Inhibit cytochrome oxidase
	Antimycin A	Blocks electron transfer from cytochrome *b* to cytochrome c_1
	Myxothiazol Rotenone Amytal Piericidin A	Prevent electron transfer from Fe-S center to ubiquinone
	DCMU	Competes with Q_B for binding site in PSII
Inhibition of ATP synthase	Aurovertin	Inhibits F_1
	Oligomycin Venturicidin	Inhibit F_o and CF_o
	DCCD	Blocks proton flow through F_o and CF_o
Uncoupling of phosphorylation from electron transfer	FCCP DNP	Hydrophobic proton carriers
	Valinomycin	K^+ ionophore
	Thermogenin	Forms proton-conducting pores in inner membrane of brown fat mitochondria
Inhibition of ATP-ADP exchange	Atractyloside	Inhibits adenine nucleotide translocase

*DCMU is 3-(3,4-dichlorophenyl)-1,1-dimethylurea; DCCD, dicyclohexylcarbodiimide; FCCP, cyanide-*p*-trifluoromethoxyphenylhydrazone; DNP, 2,4-dinitrophenol.