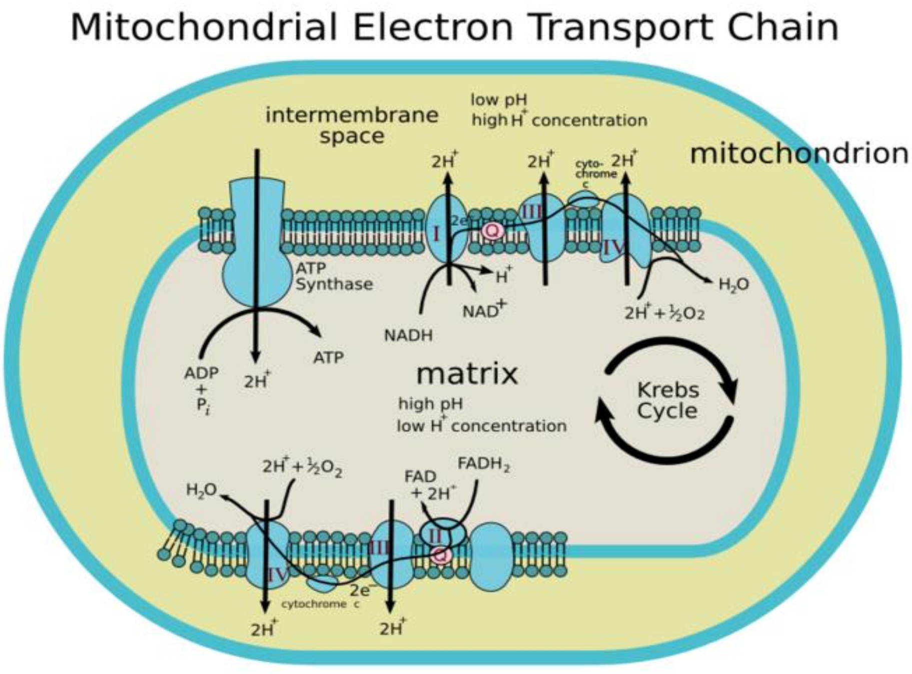
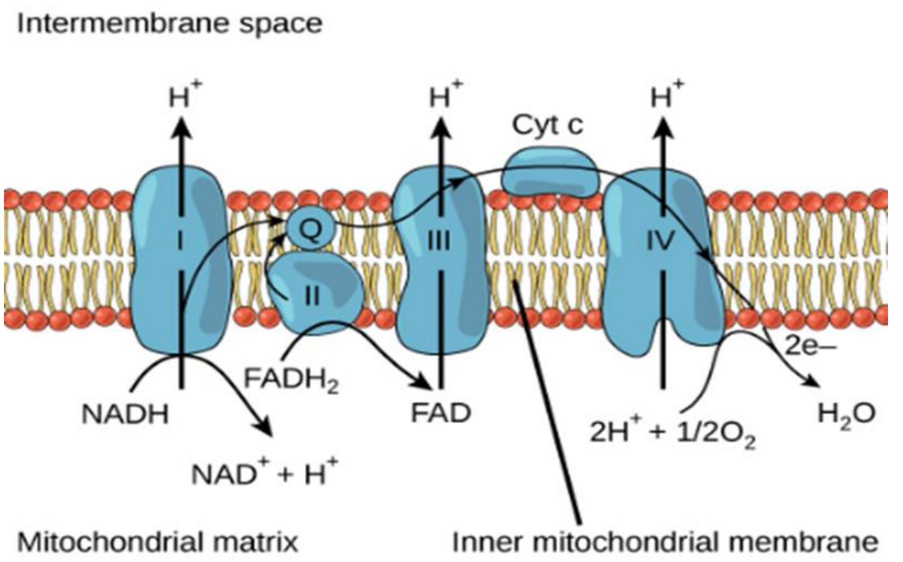
Electron Transport Chain
ETC



ETC !!!

Most of the ATP generated during the aerobic catabolism of glucose is not generated directly from Glycolysis and TCA pathways. Rather, it is **derived from a process that moves electrons through a series of electron transporters** that undergo redox reactions: **the electron transport chain.** This causes *hydrogen ions* to accumulate…



ELECTRON TRANSPORT CHAIN

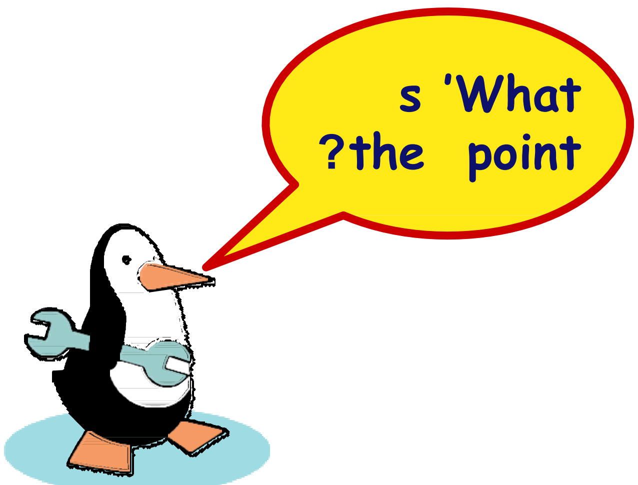
ETC is a transfer of electrons from electron donors (NADH, FADH2) to electron acceptors (O2) via ***redox*** reactions and through multiple carriers. The electron transfer is coupled with the transfer of protons (H^+ ions) across a m.membrane. This creates a proton gradient that drives the synthesis of adenosine triphosphate (ATP).

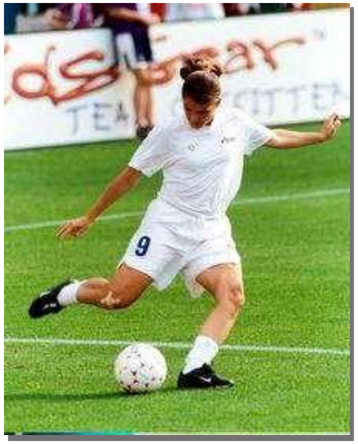
The final acceptor of electrons in the ETC during aerobic respiration is molecular oxygen

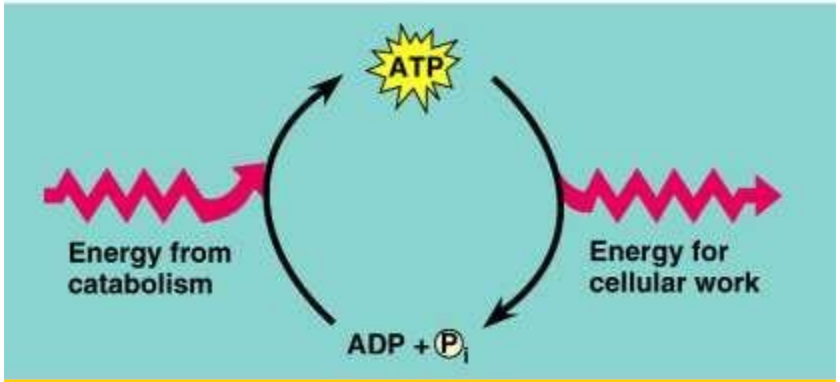
ATP accounting so far…

- Glycolysis 2 →ATP
- Kreb's cycle 2 →ATP
- Life takes a lot of energy to run, need to extract more energy than 4 ATP!

There's got to be a better way!



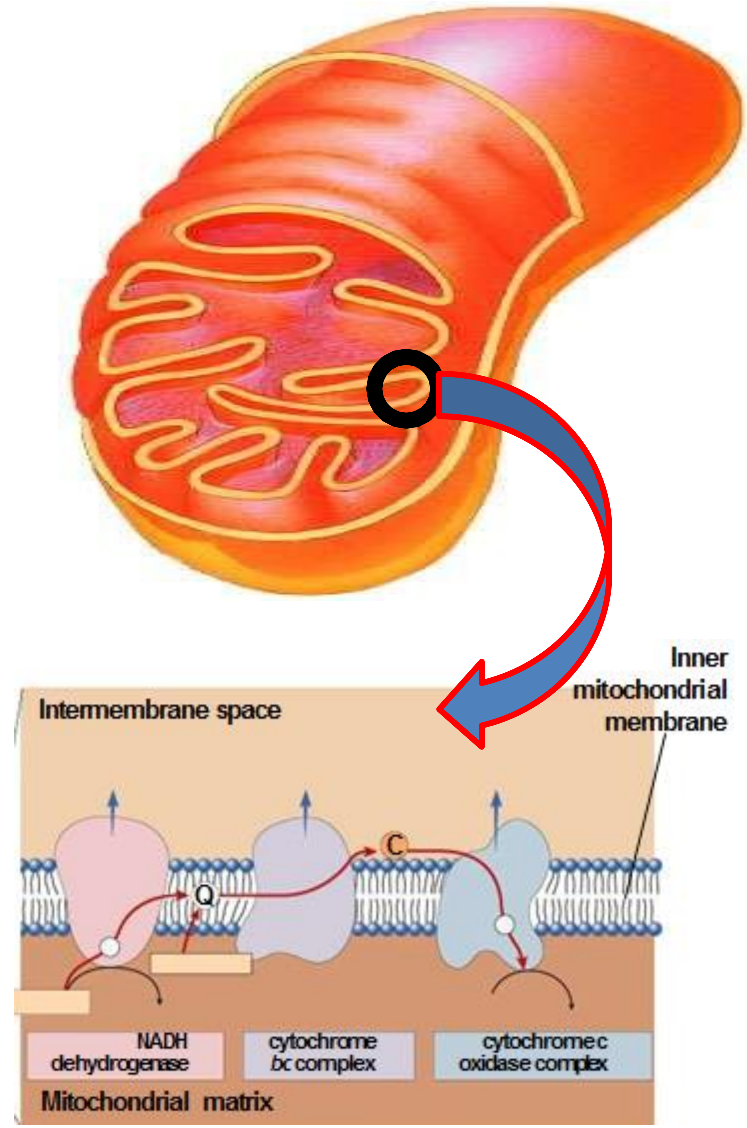


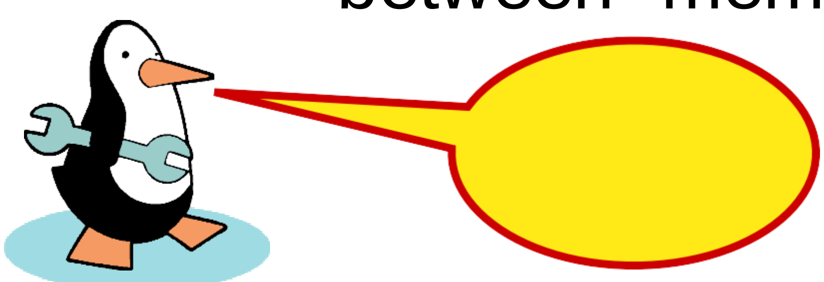


A working muscle recycles over 10 million ATPs per second

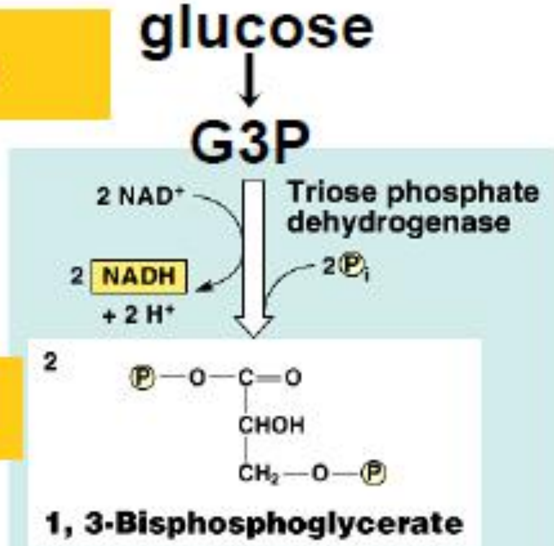
Mitochondria

- Double membrane
  - outer membrane
  - <u>inner membrane</u>
    - highly folded <u>cristae</u>
    - enzymes & transport proteins
  - <u>intermembrane space</u>
    - fluid-filled space between membranes



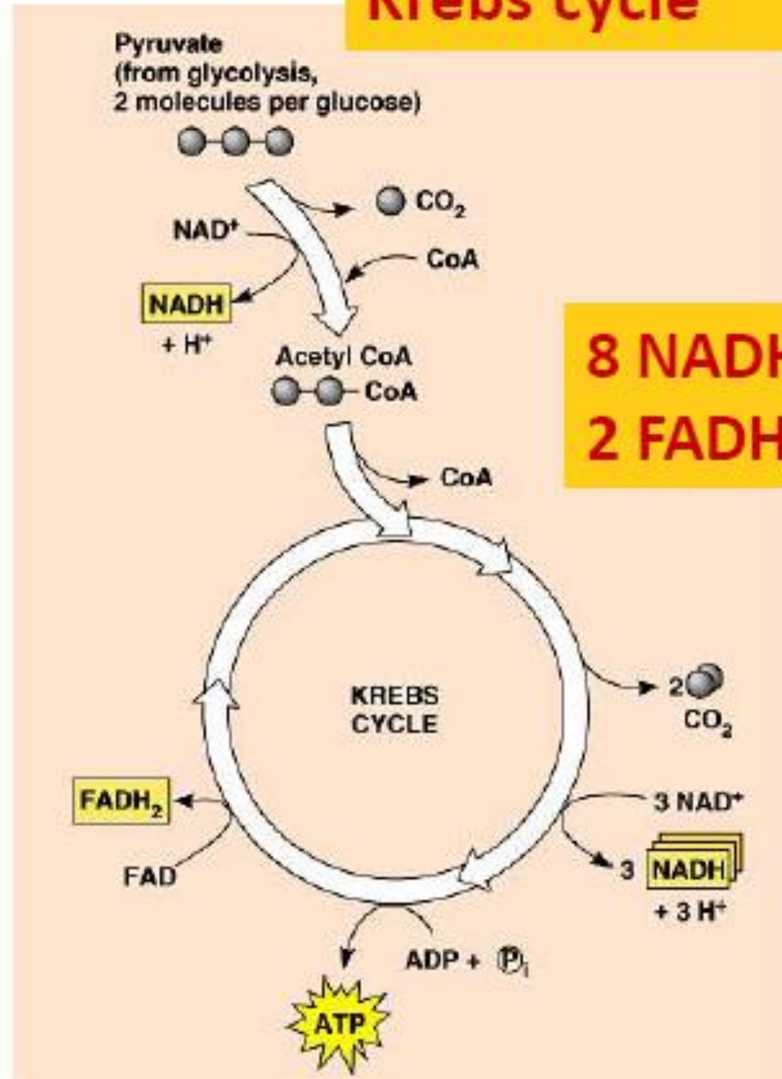


Glycolysis



2 NADH

Krebs cycle

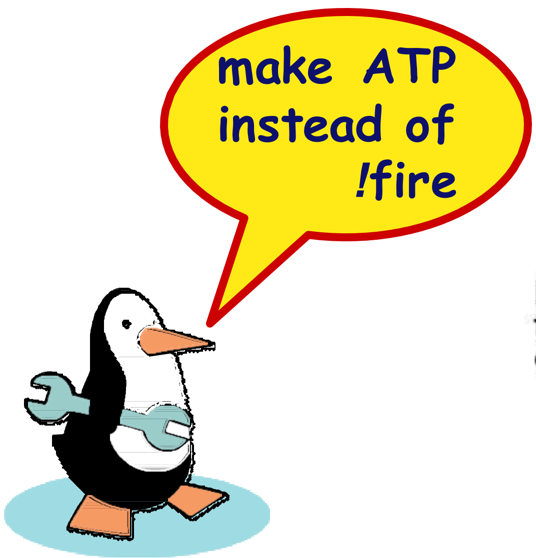


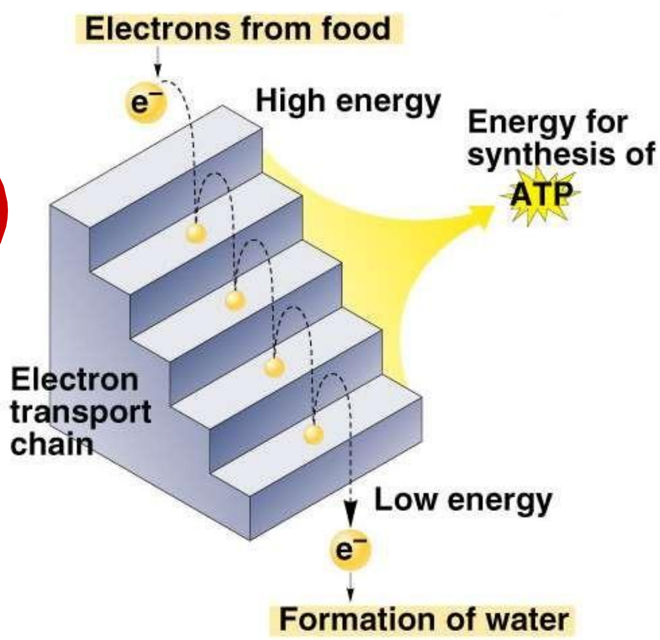
8 NADH

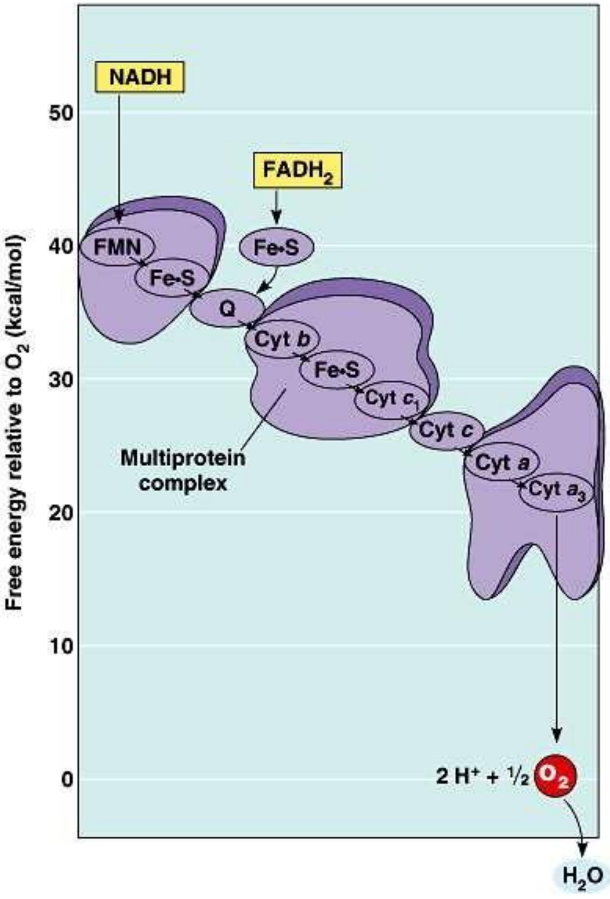
$2\ FADH_2$

Electrons flow downhill

- Electrons move in steps from carrier to carrier downhill to O_2

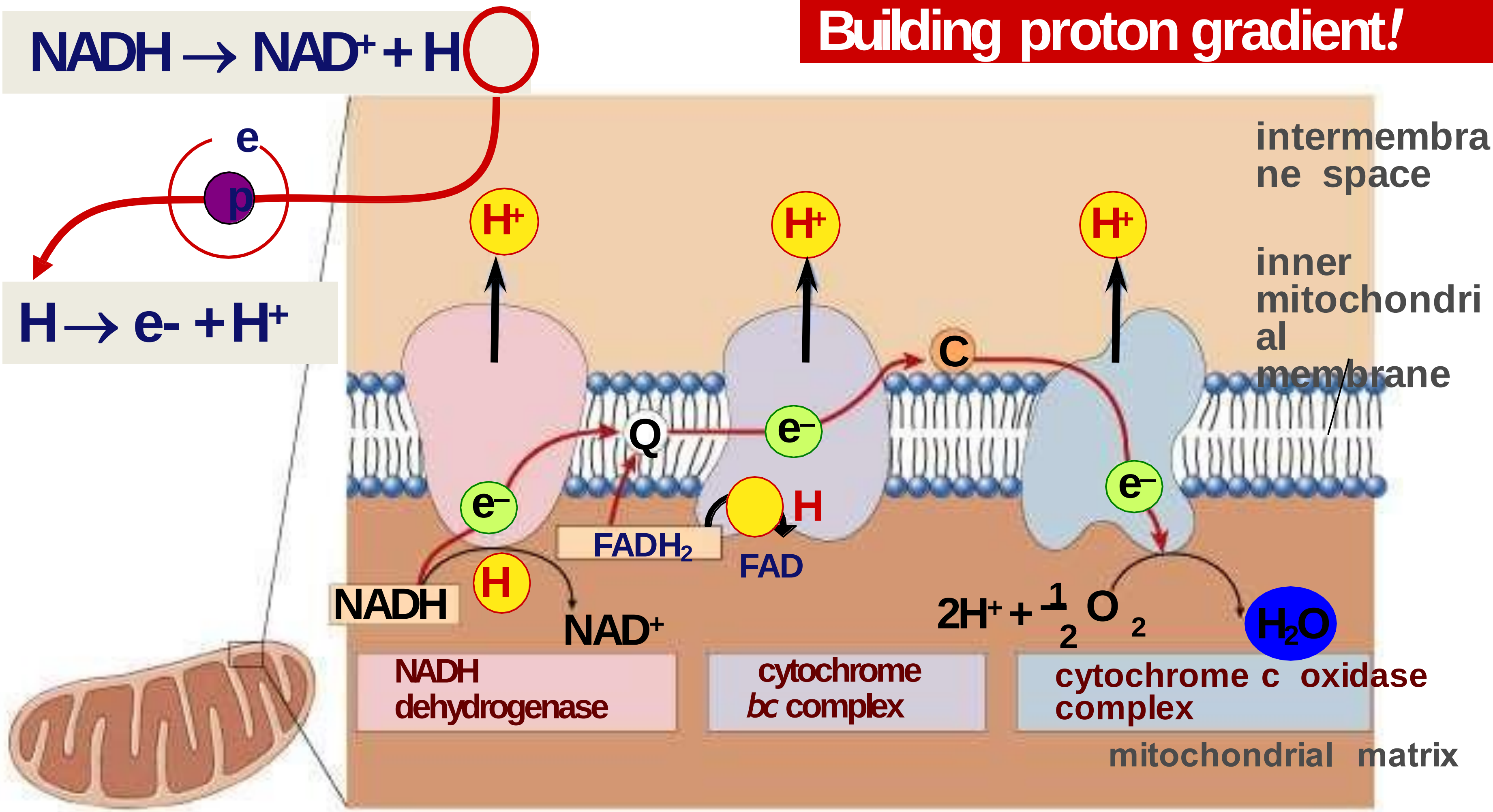






Electron Transport Chain

Building proton gradient!



What powers the proton (H^+) pumps?…

Components of ETC

Complex	Name	No. of Proteins	Prosthetic Groups
Complex I	NADH Dehydrogenase NADH-Coenzyme Q Reductase	46	,FMN .Fe-S cntrs
Complex II	Succinate-CoQ Reductase	5	-eF ,$_{560}$FAD, cyt b .srtnc S
Complex III	Cyt c Reductase	11	cyt b_H, cyt b_L, $_{ekseiR}$S-eF ,$_1$cyt c
Complex IV	Cytochrome c Oxidase	13	,$_3$cyt a, cyt a $_B$uC ,$_A$uC

Composition of the Electron Transport Chain

Four large protein complexes.

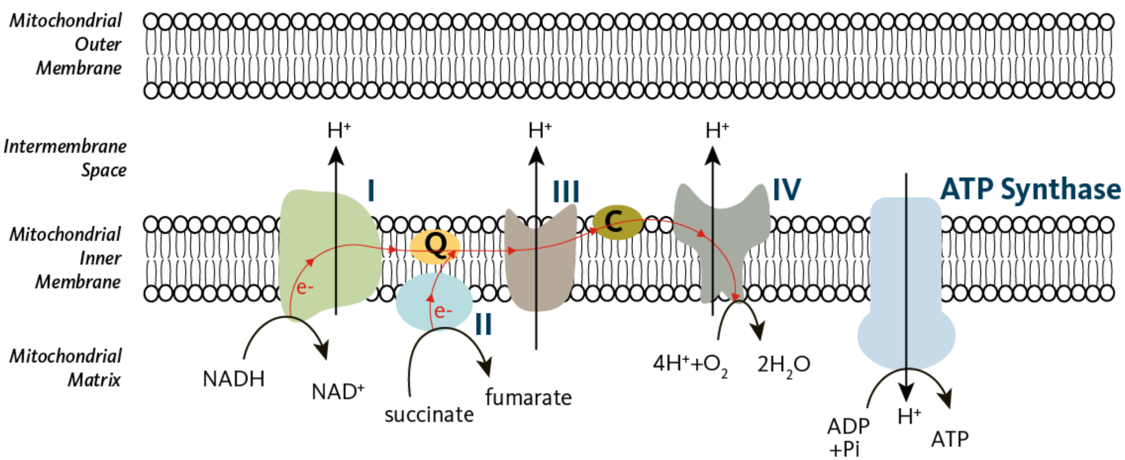
- Complex I - NADH-Coenzyme Q reductase
- Complex II - Succinate-Coenzyme Q reductase
- Complex III - Cytochrome c reductase
- Complex IV - Cytochrome c oxidase.

Cytochromes : Electron-transfer proteins that contain a heme prosthetic group

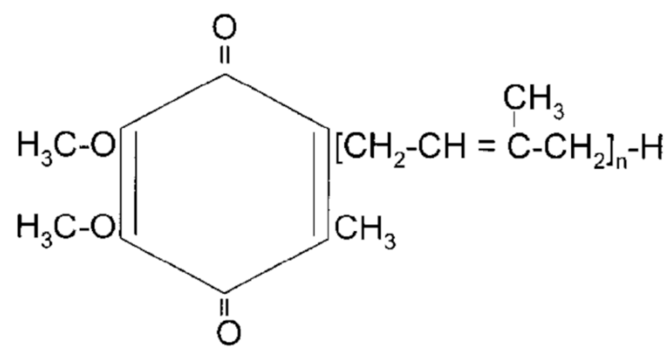
Co enzyme Q (ubiquinone)

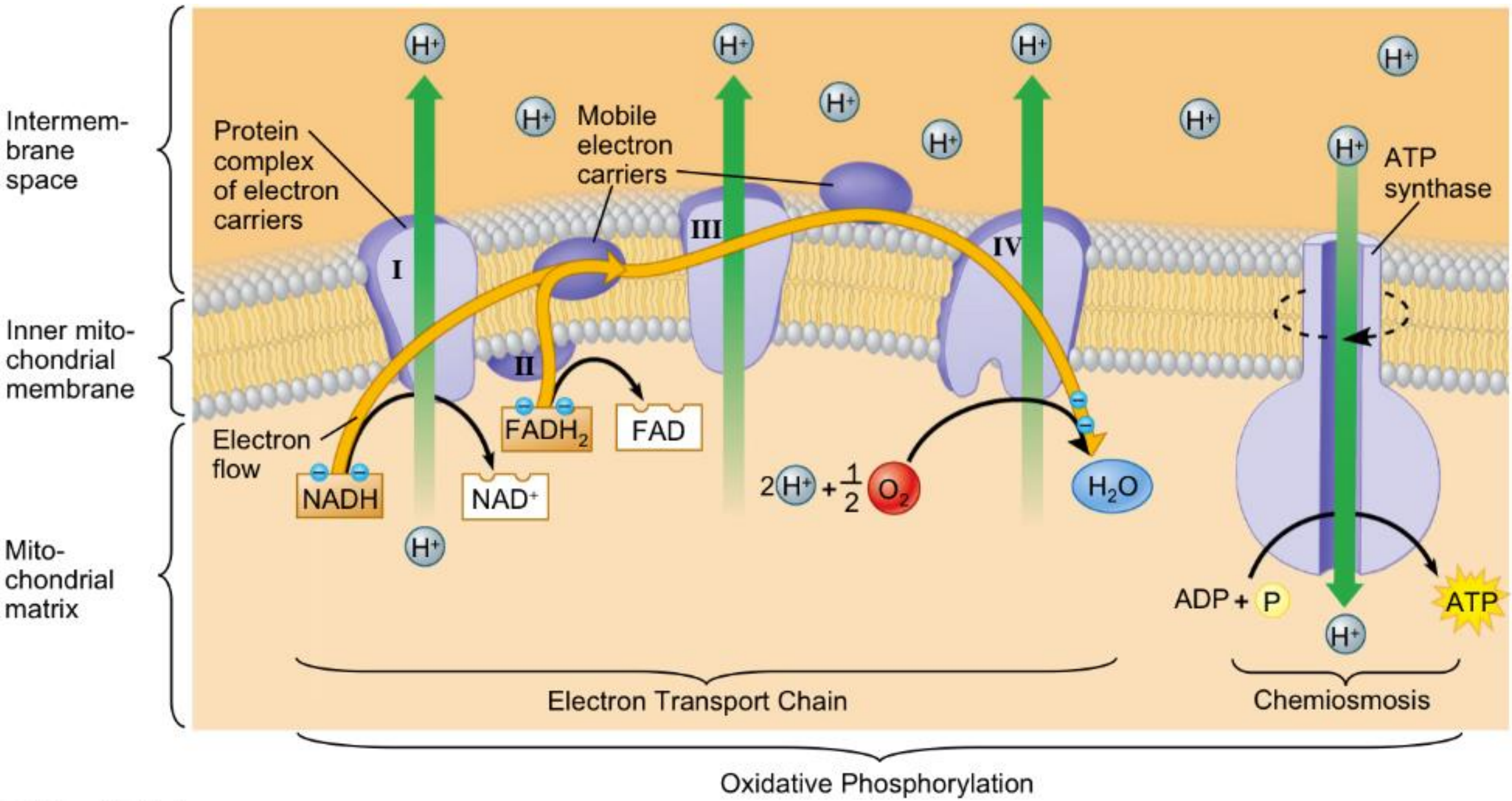
- It is a benzoquinone linked to a number of isoprene units.
- **Coenzyme Q** (CoQ, Q, Ubiquione) is very **hydrophobic**. It dissolves in the hydrocarbon core of a membrane.

Figure 2. Mitochondrial Electron Transport Chain



Coenzyme Q_{10} is a lipid-soluble component of the mitochondrial inner membrane that is critical to electron transport (in red) in the mitochondrial respiratory chain. Coenzyme Q_{10} carries electrons from complexes I and II to complex III, thus participating in ATP production. *C, cytochrome C; e-, electron; H^+, proton; Q, coenzyme Q_{10}.*





Intermem-
brane
space
Inner mito-
chondrial
membrane
Mito-
chondrial
matrix
Protein
complex
of electron
carriers
Mobile
electron
carriers
I
II
III
IV
H+
Electron
flow
NADH
NAD+
FADH2
FAD
2 H+ + 1/2 O2
H2O
ATP
synthase
ADP + P
ATP
Electron Transport Chain
Chemiosmosis
Oxidative Phosphorylation

- Complex I(NADH Dehydrogenase)

Complex I: catalyzes oxidation of NADH, with reduction of coenzyme Q.

NADH + H+ + Q → NAD+ + QH2

Coenzyme Q accepts 2 e- and picks up 2 H+ to yield the fully reduced **QH2**

Complex I includes at least **46 proteins…**

Pumps 4 protons across the mitochondrial membrane

Electrons pass from

- NADH → FMN → Fe-S cluster → ubiquinone
  (flavin mononucleotide) (Coenzyme Q)

Complex II(succinate dehydrogenase)

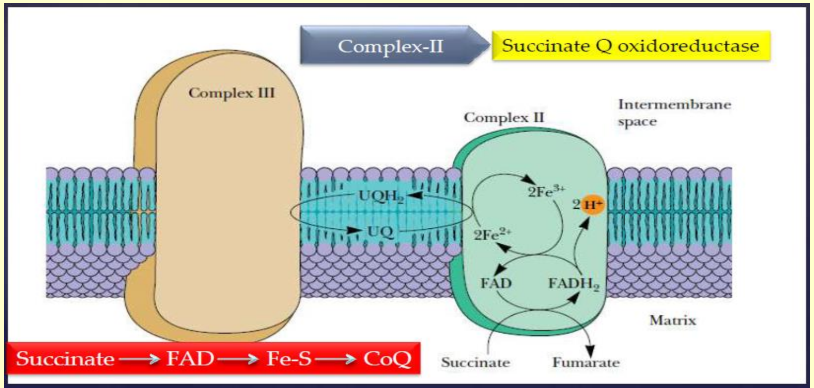
Succinate Dehydrogenase of the Krebs Cycle is also called **complex II** or Succinate-CoQ Reductase

FAD is the initial e⁻ acceptor

• FAD is reduced to **$FADH_2$** during oxidation of succinate to fumarate.

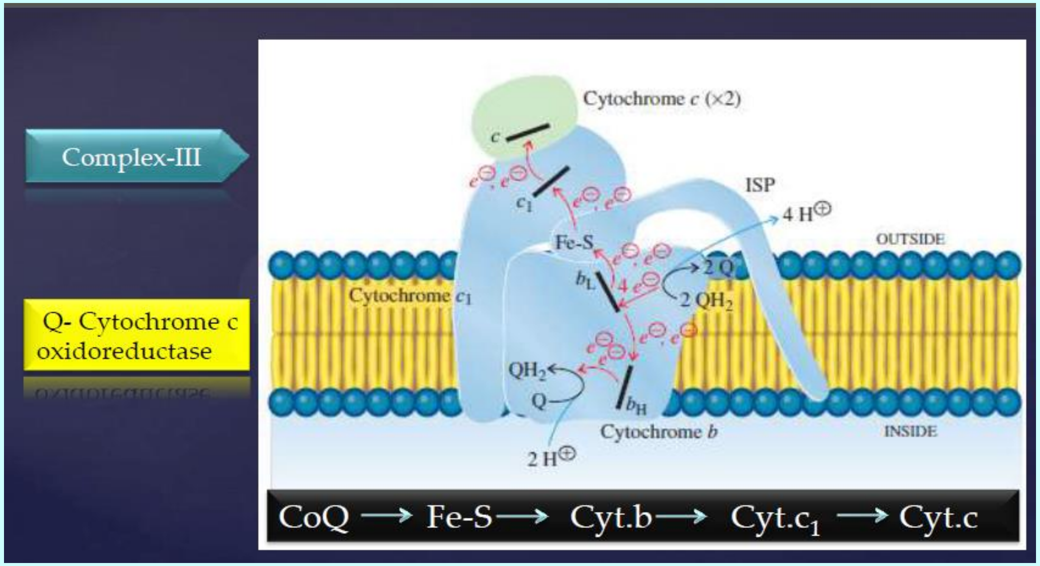
• $FADH_2$ is then reoxidized by transfer of electrons through a series of 3 iron- sulfur centers to CoQ, yielding **QH_2**.

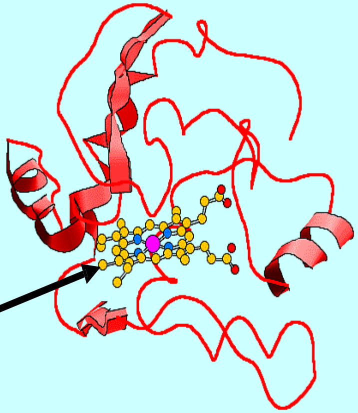
It does not pump any proton during transport of electron across the inner mitochondrial membrane



- Complex III cytochromes b, c 1 and c) **Cytochrome c reductase**

Electron transfer from ubiquinol to cytochrome c.





heme prosthetic group

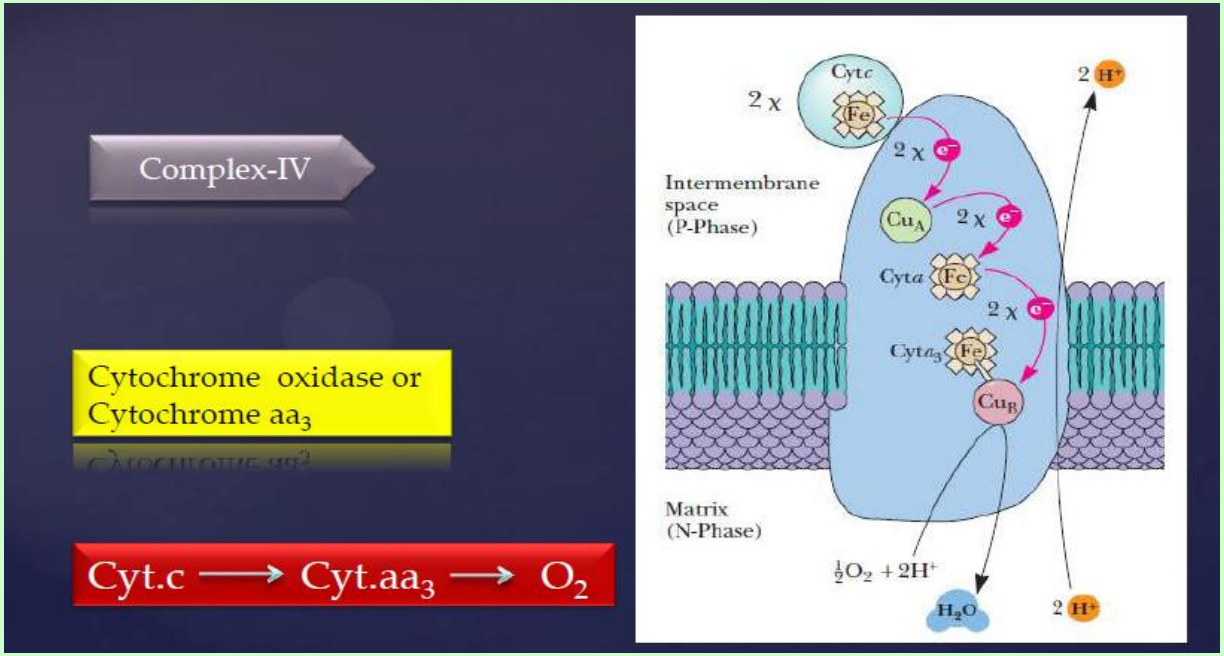
cytochrome c

• Complex IV

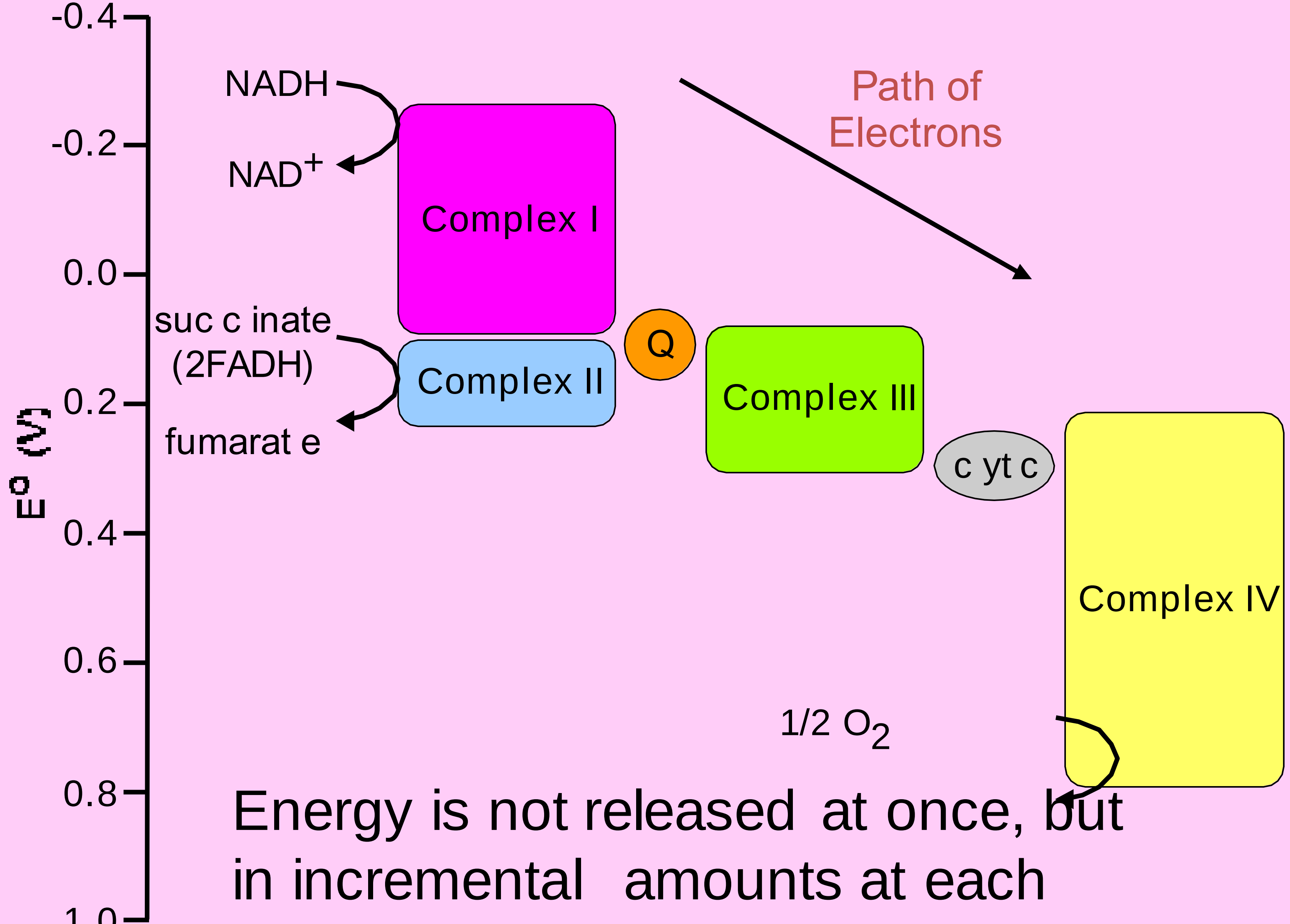
Cytochrome c oxidase

•Combination of cytochromes a and a10 ,3protein subunits. It catalyses the transfer of electrons from cyt c to molecular oxygen.

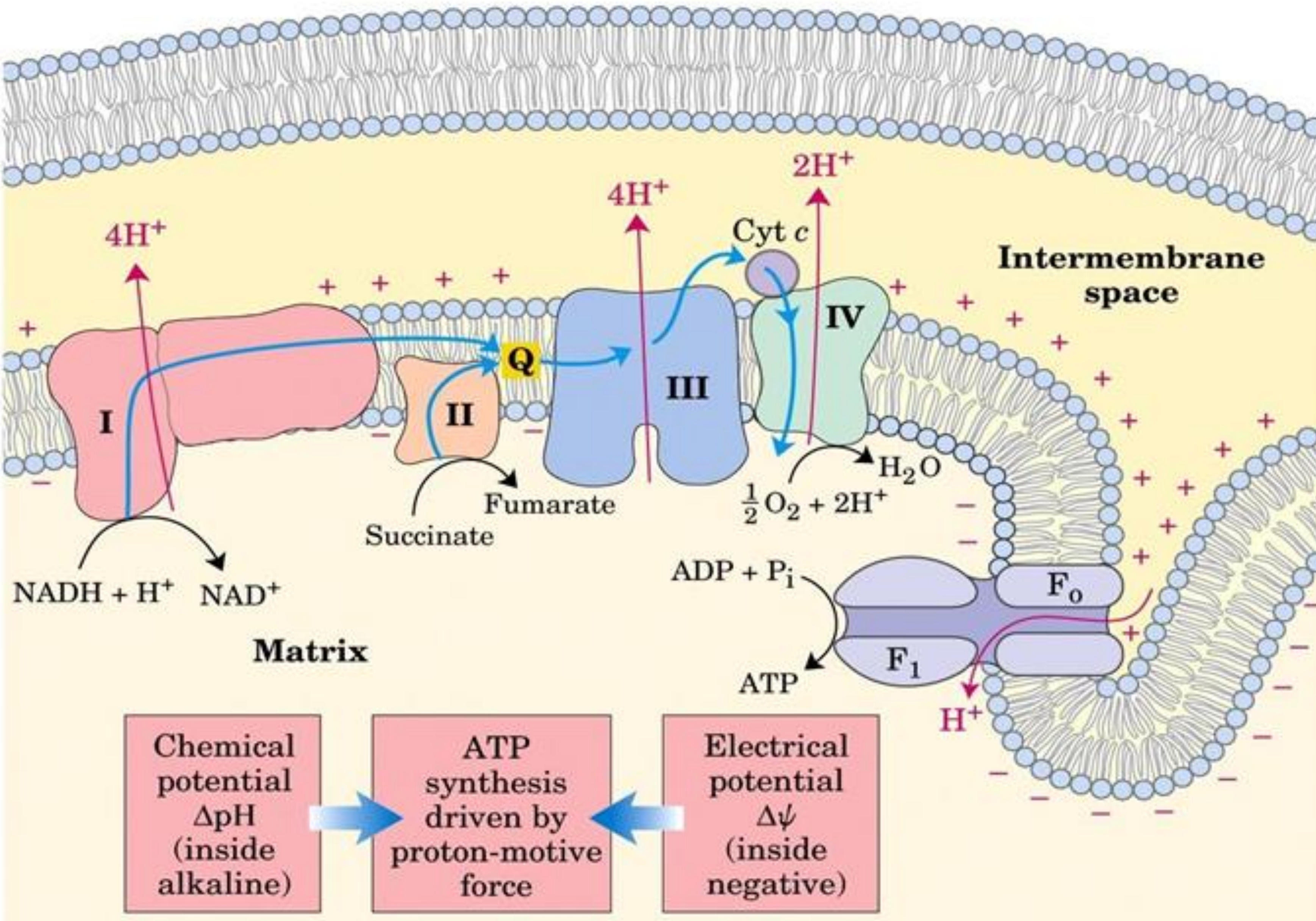
•Electrons are delivered from cytochromes a and a3 to O2 e- transfer: cyt c → Cu_A → cyt a → heme a_3/Cu_B →O2



Flow of electrons



Energy is not released at once, but in incremental amounts at each step.

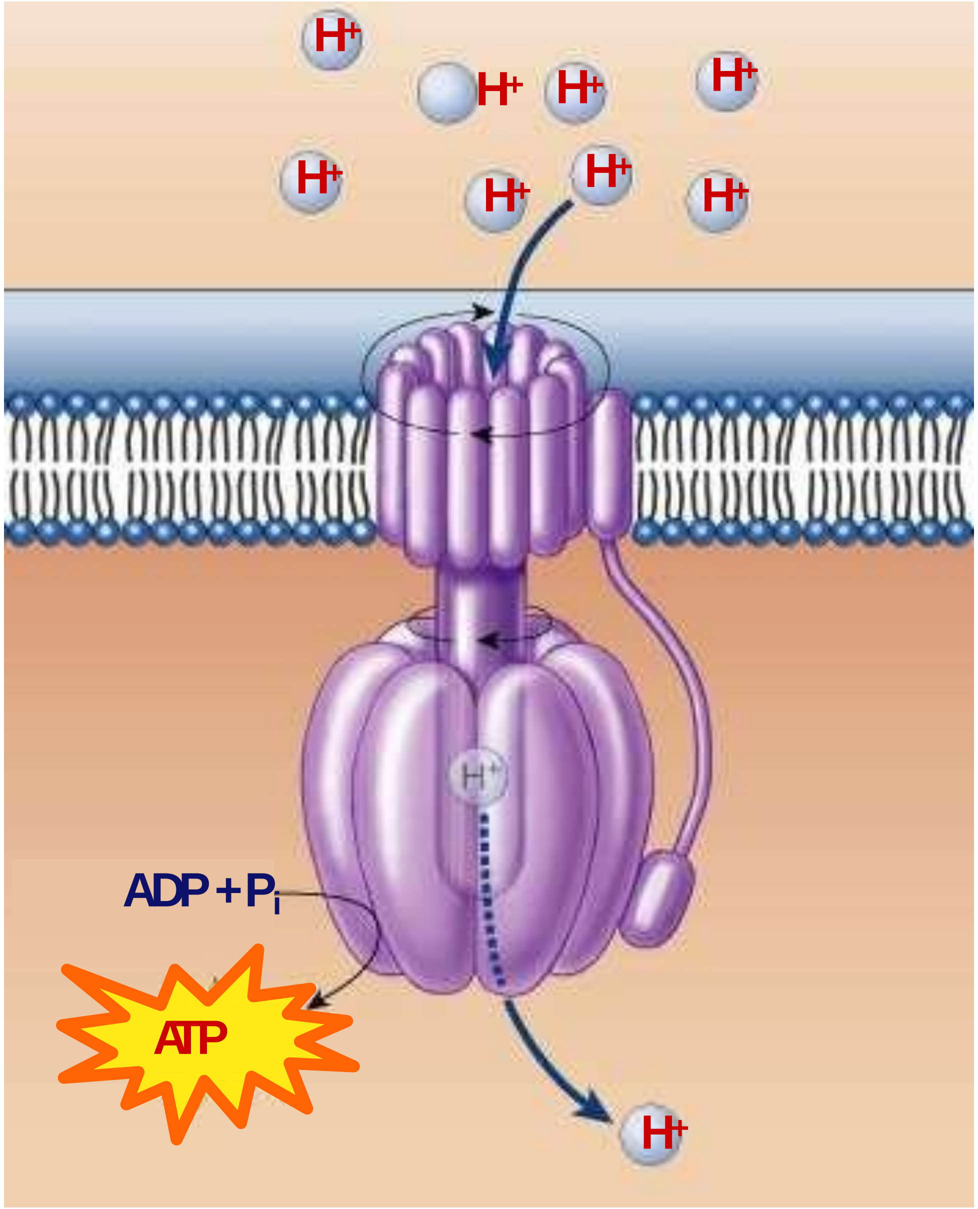


4H+
4H+
2H+
Cyt c
Intermembrane space
Q
I
II
III
IV
Succinate
Fumarate
1/2 O2 + 2H+
H2O
NADH + H+
NAD+
ADP + Pi
ATP
Fo
F1
H+
Matrix
Chemical potential ΔpH (inside alkaline)
ATP synthesis driven by proton-motive force
Electrical potential Δψ (inside negative)

“proton-motive” force

- Set up a H^+ gradient
- Allow the <u>protons</u> to flow through ATP synthase
- Synthesizes ATP

$ADP + P_i \rightarrow ATP$



Source	**Carbon Flow**	**Molecules of Reduced Coenzymes Produced**	**Net ATP Molecules Made by Substrate-Level Phosphorylation**	**Net ATP Molecules Made by Oxidative Phosphorylation**	**Theoretical Maximum Yield of ATP Molecules**
Glycolysis (EMP)	Glucose (6C) → 2 pyruvates (2C)	2 NADH	2 ATP	6 ATP from 2 NADH	8
Transition reaction	2 pyruvates (3C) → 2 acetyl (2C) + 2 CO_2	2 NADH		6 ATP from 2 NADH	6
Krebs cycle	2 acetyl (2C) → 4 CO_2	6 NADH 2 $FADH_2$	2 ATP	18 ATP from 6 NADH 4 ATP from 2 $FADH_2$	24
Total:	glucose (6C) → 6 CO_2	10 NADH 2 $FADH_2$	4 ATP	34 ATP	38 ATP