ELECTRONTRANSPORT CHAIN

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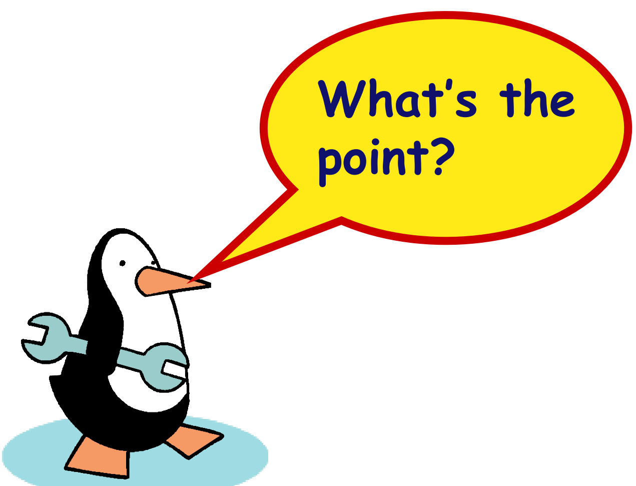
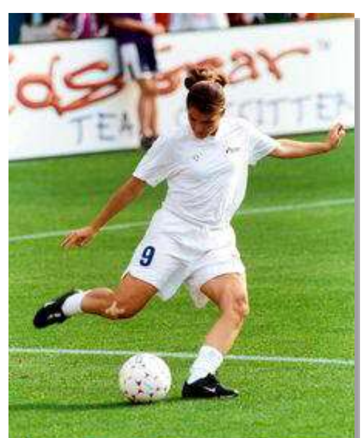
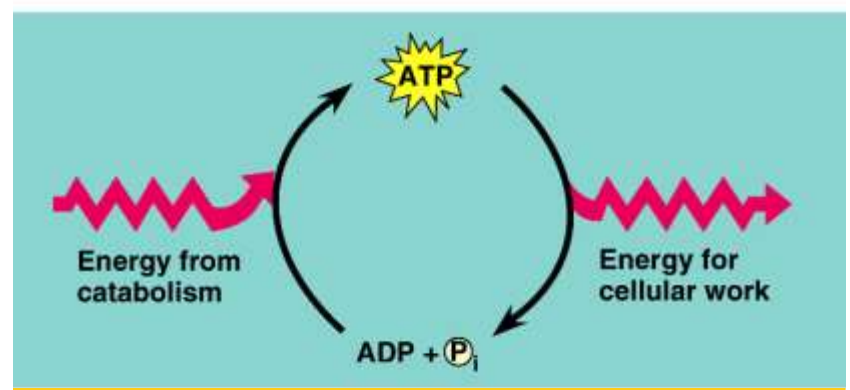
ATP accounting so far…

- 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!







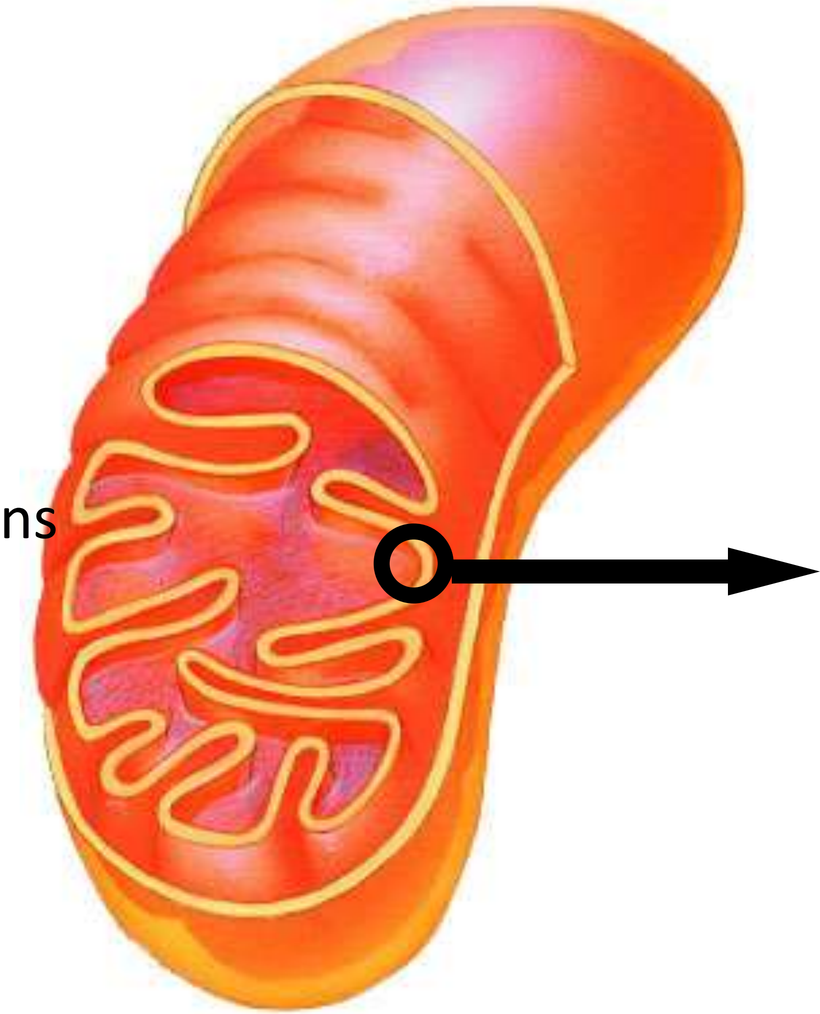
A working muscle recycles over 10 million ATPs per second

There is a better way!

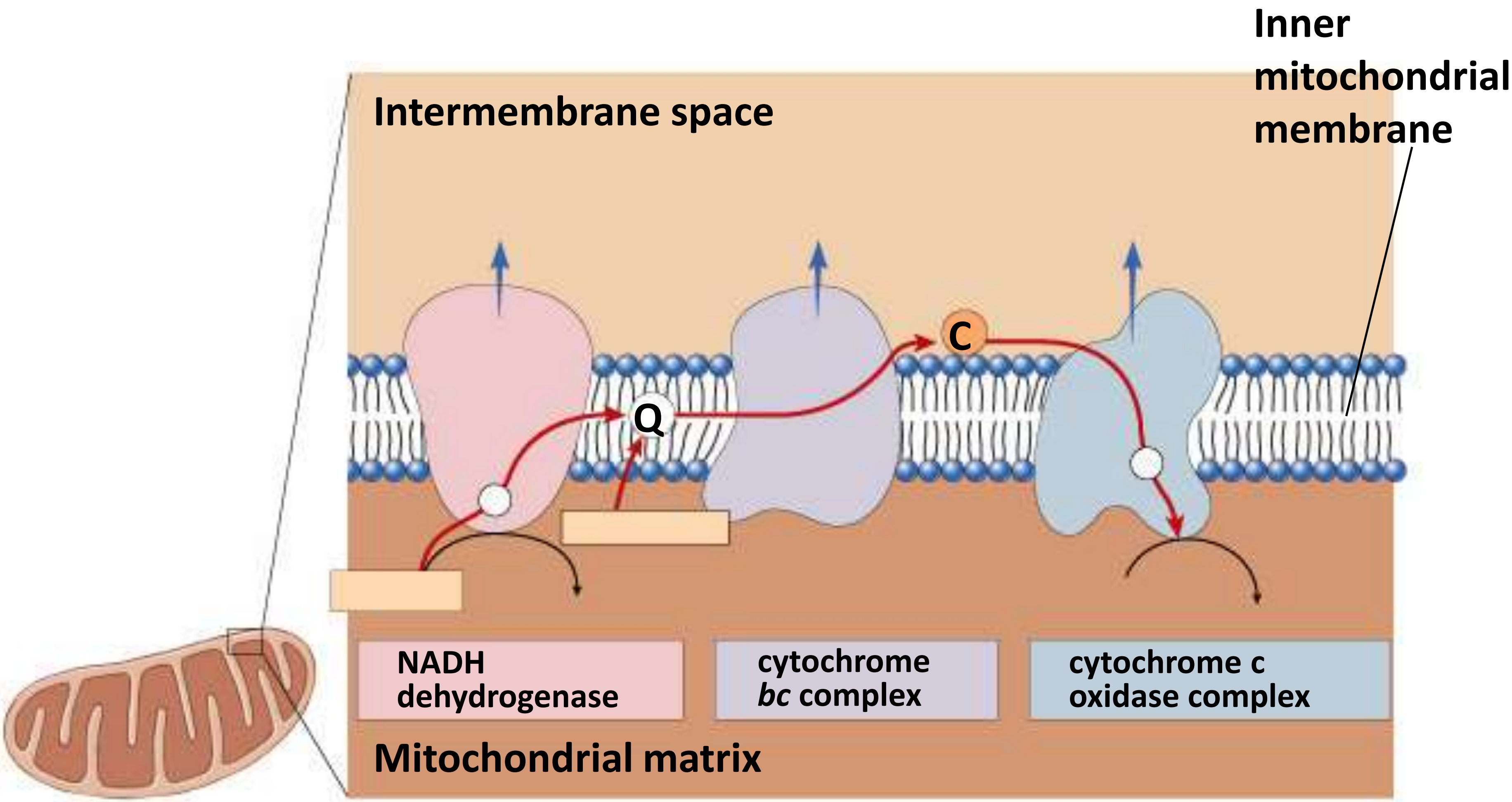
- Electron Transport Chain
  - series of molecules built into inner mitochondrial membrane
    - along cristae
    - transport proteins & enzymes
  - transport of electrons down ETC linked to pumping of H^+ to create H^+ gradient
  - yields ~34 ATP from 1 glucose*!*
  - only in presence of O_2 (aerobic respiration)

Mitochondria

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

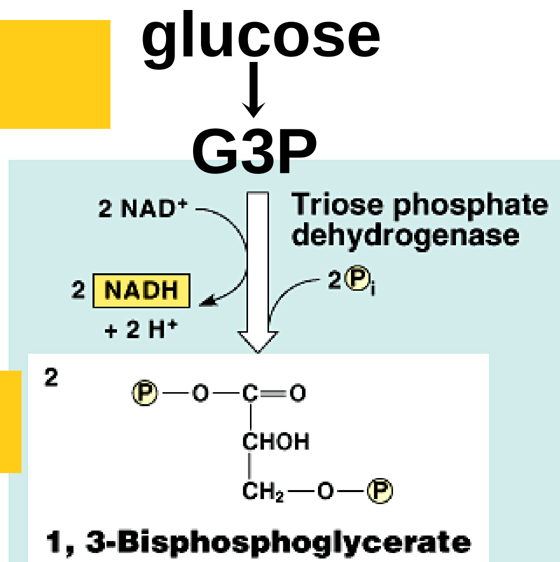


Electron Transport Chain



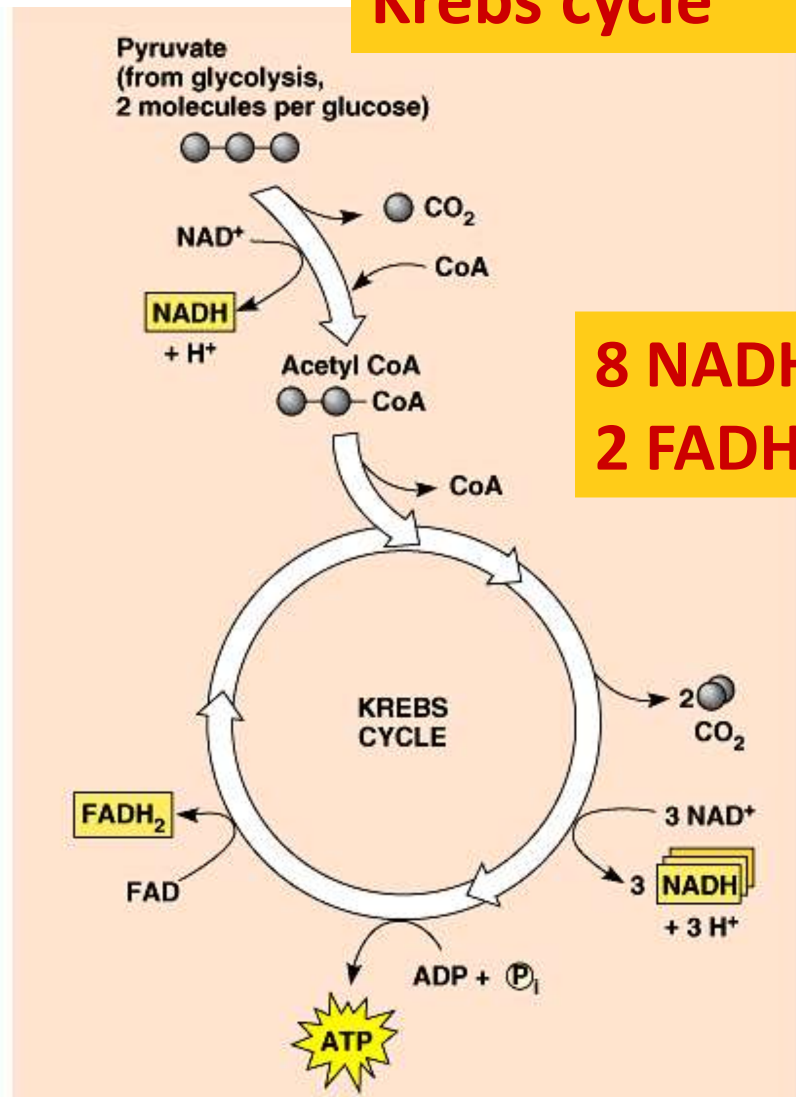
Remember the Electron Carriers?

Glycolysis



4 NADH

Krebs cycle



8 NADH

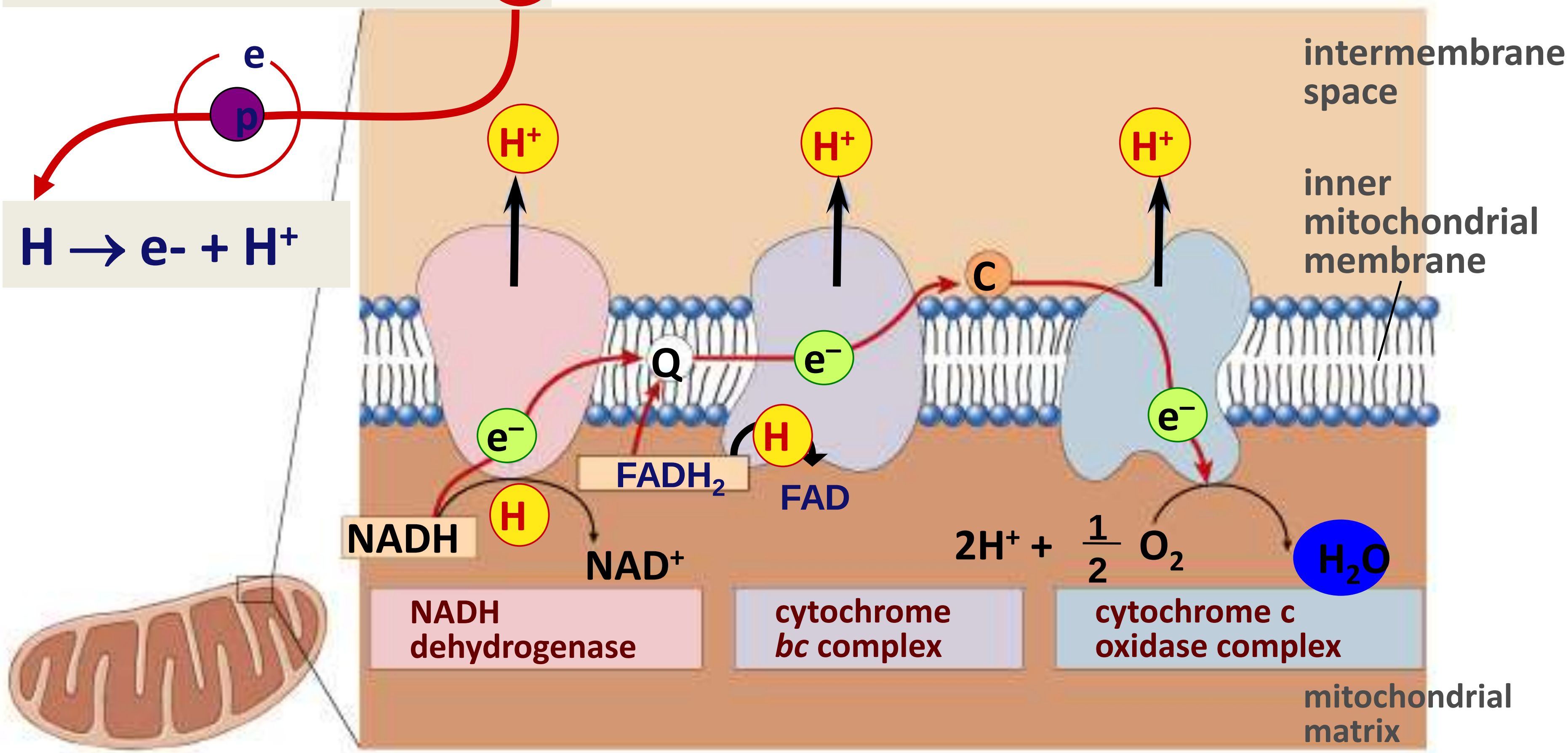
2 $FADH_2$

Electron Transport Chain

$NADH \rightarrow NAD^{+} + H$

Building proton gradient!

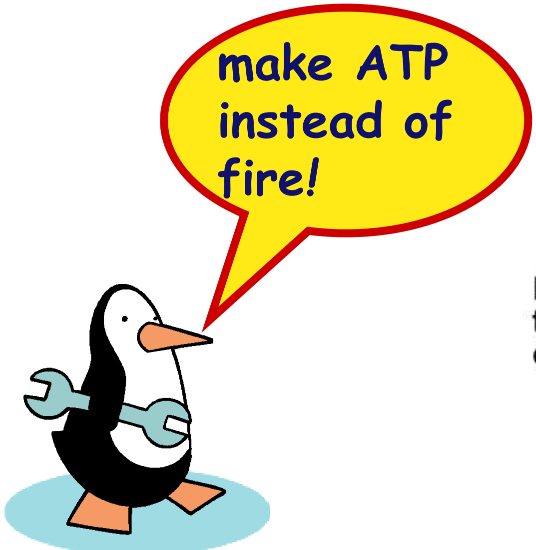
$H \rightarrow e- + H^{+}$

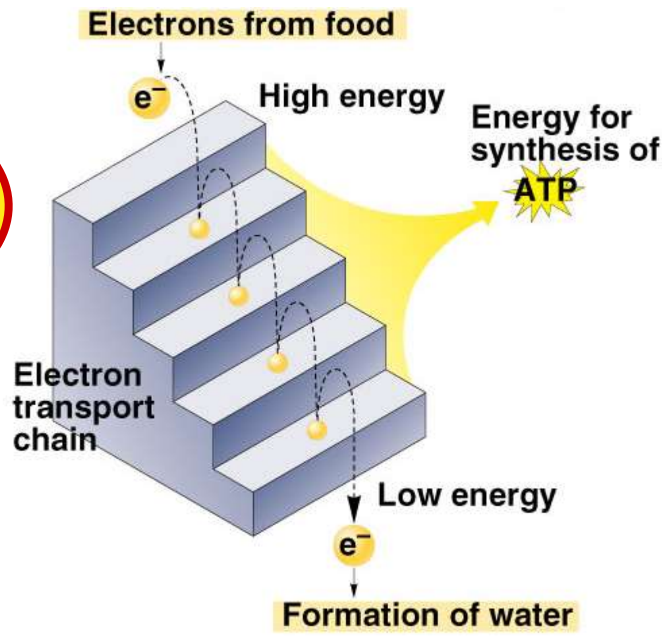


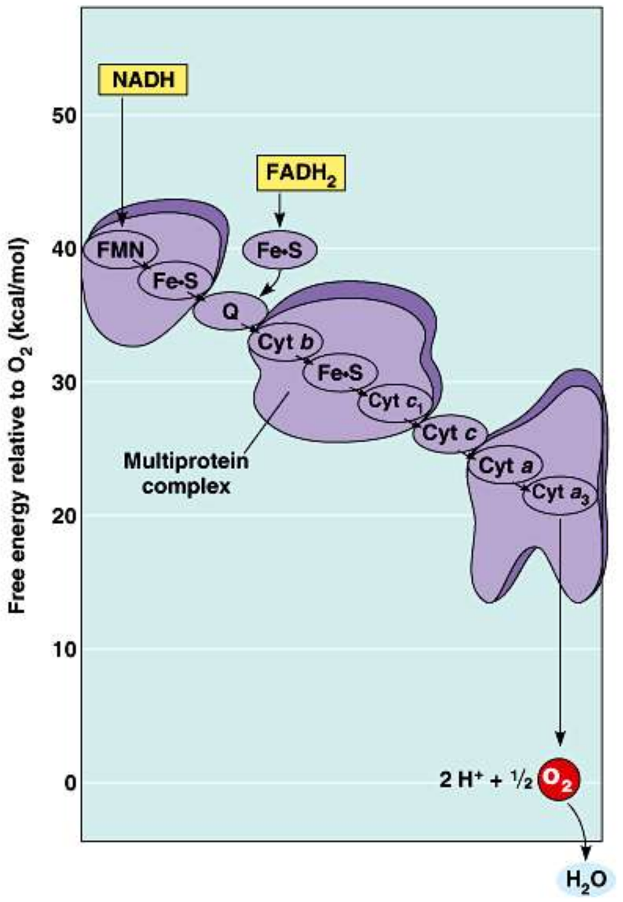
What powers the proton (H^{+}) pumps?...

Electrons flow downhill

- Electrons move in steps from carrier to carrier downhill to O_2
  - each carrier more electronegative
  - controlled oxidation
  - controlled release of energy





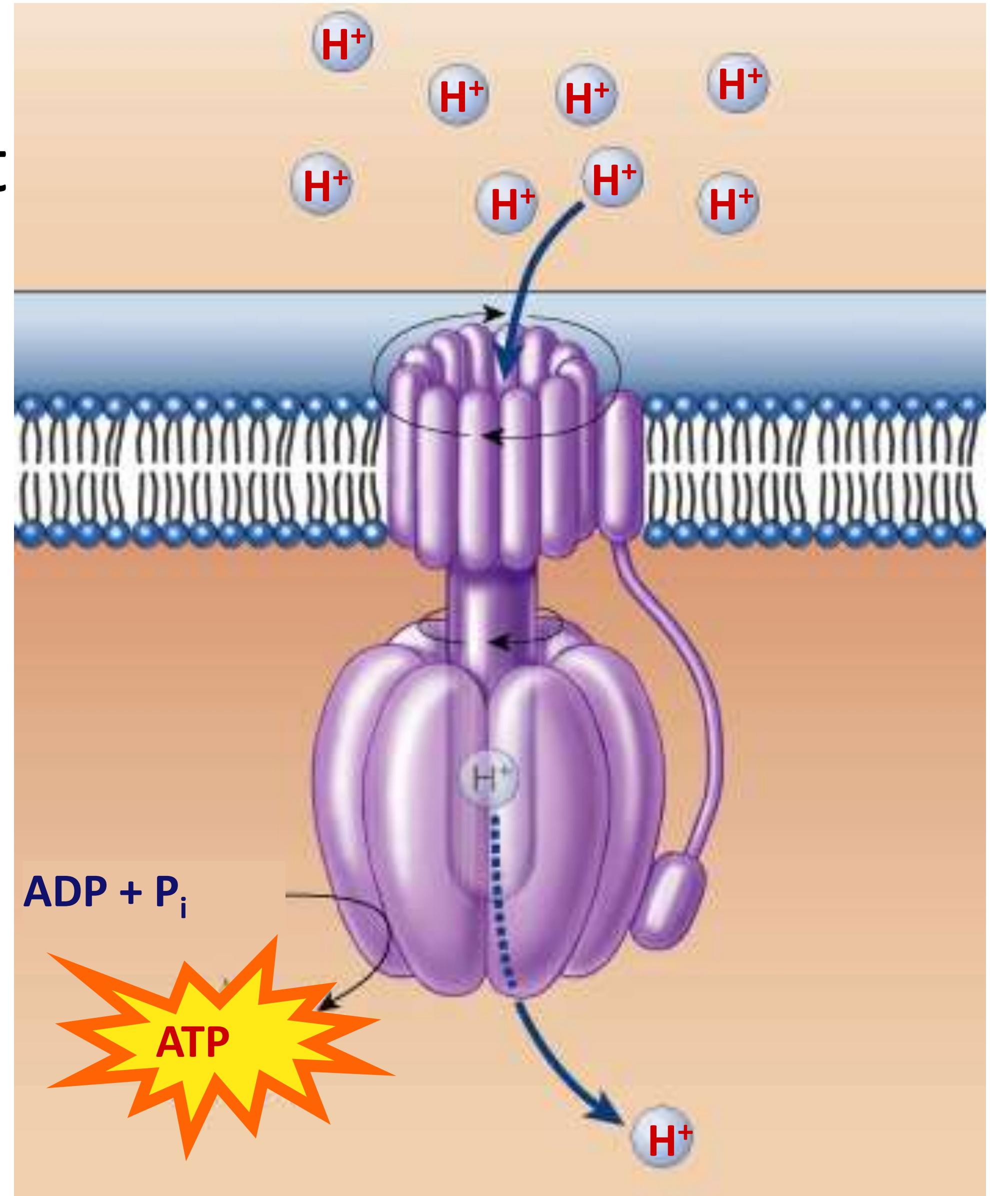


“proton-motive” force

We did it!

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

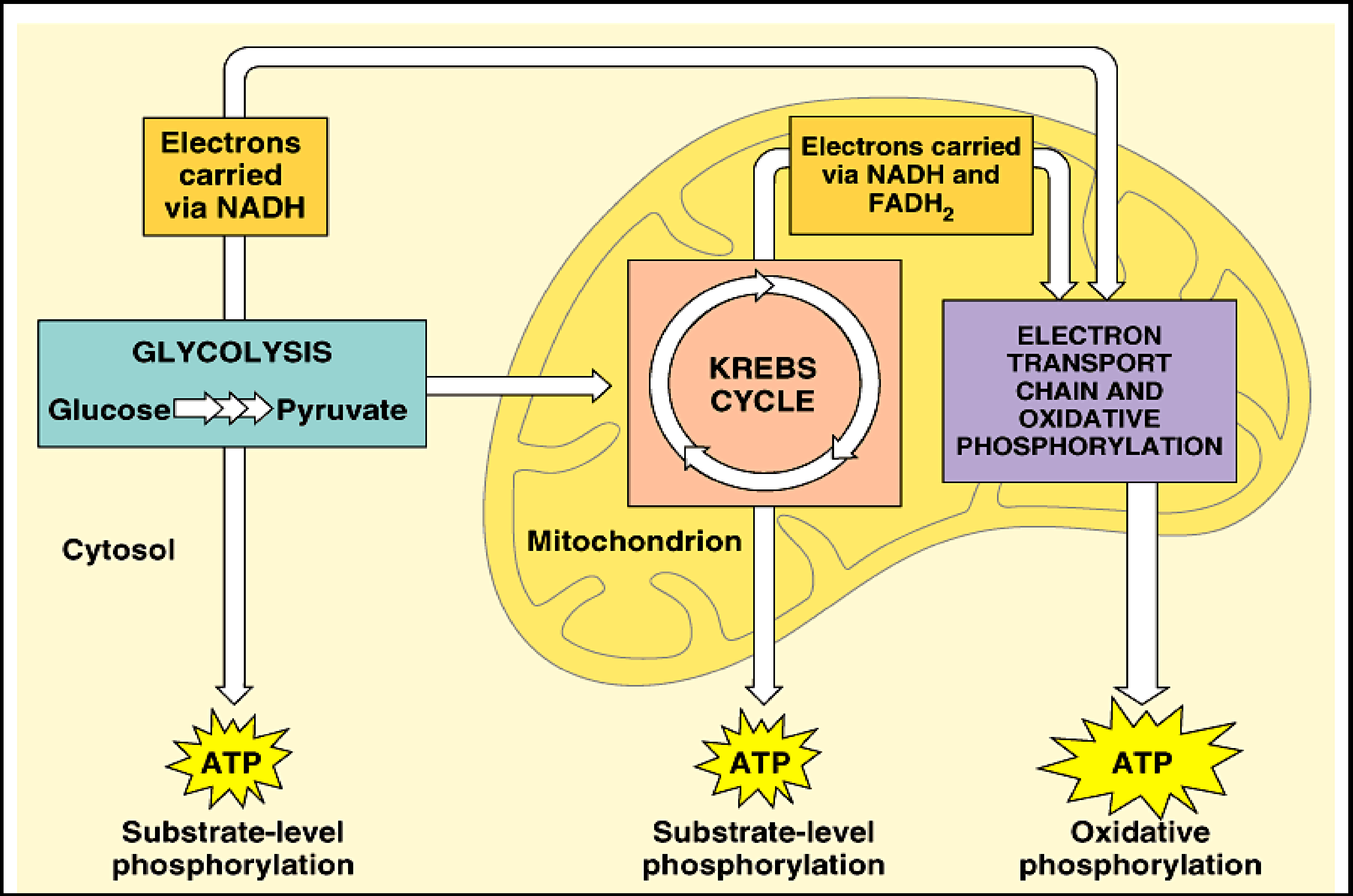
$ADP + P_i \rightarrow ATP$



ELECTRON TRANSPORT CHAIN(ETC)

- ETC couple a chemical reaction b/w an electron donor and electron acceptor to the transfer of H+ ions across a membrane, through a set of mediating biochemical reactions
- These H+ ions are used to produce ATP
- ETC used for extracting energy from sunlight(photosynthesis) and from redox reactions such as the oxidation of sugar (respiration)

CELLULAR RESPIRATION



COMPONENTS OF ETC

- **NAD & Flavoprotein** :H-carriers in celluiar respiration
- **Non heme metalloprotein (Fe-S- Protein):**iron cycles between 3+ and 2+ states.
- **Ubiquinone or CoQ:** region serves as an anchor to inner mitochondrial membrane.
- **Cytochromes** : Electron-transfer proteins that contain a heme prosthetic group

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

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

• Complex I(NADH Dehydrogenase)

- Electrons pass from
- NADH → FMN → Fe-S cluster → ubiquinone
  (flavin mononucleotide) (coenzyme Q)

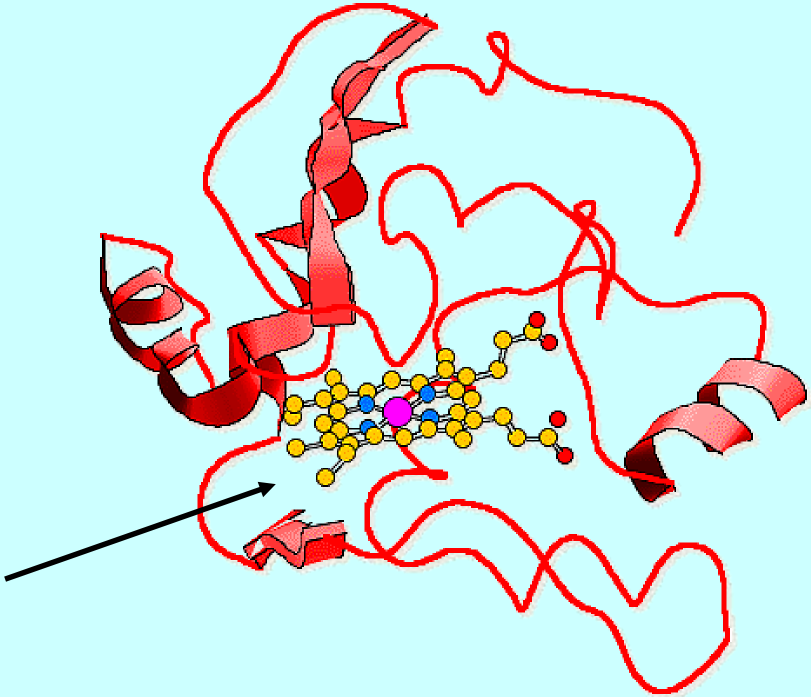
Complex II(succinate dehydrogenase)

- Entry point for $FADH_2$.
- Succinate dehydrogenase (from the citric acid cycle) directs transfer of electrons from succinate to CoQ via $FADH_2$.
- Acyl-CoA dehydrogenase (from β-oxidation of fatty acids) also transfers electrons to CoQ via $FADH_2$.

- Complex III (cytochromes b, c1 and c)

- Electron transfer from ubiquinol to cytochrome c.

cytochrome c



heme prosthetic group

• Complex IV

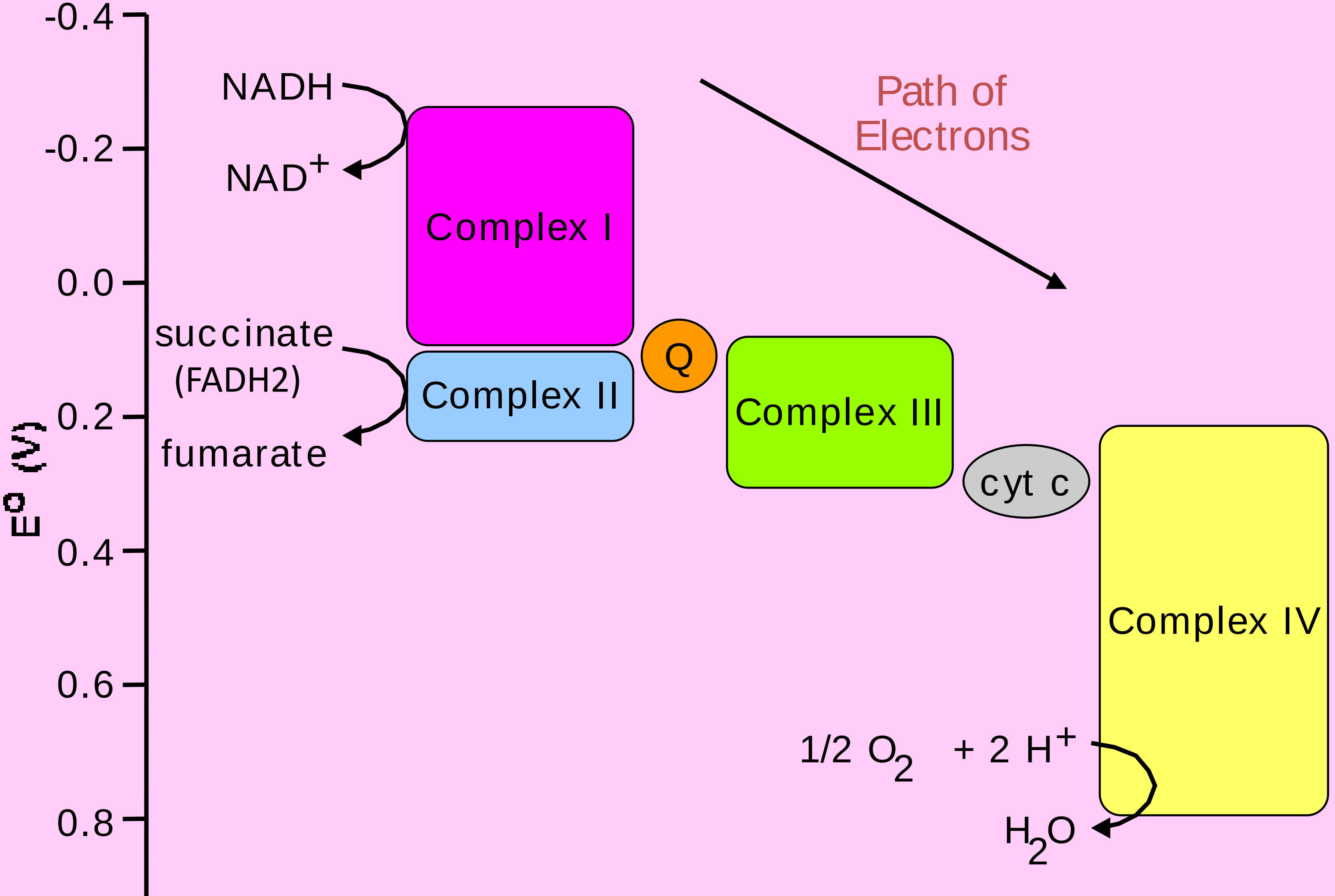
- Combination of cytochromes a and a_3, 10 protein subunits, 2 types of prosthetic groups: 2 heme and 2 Cu.

- Electrons are delivered from cytochromes a and a3 to O2.

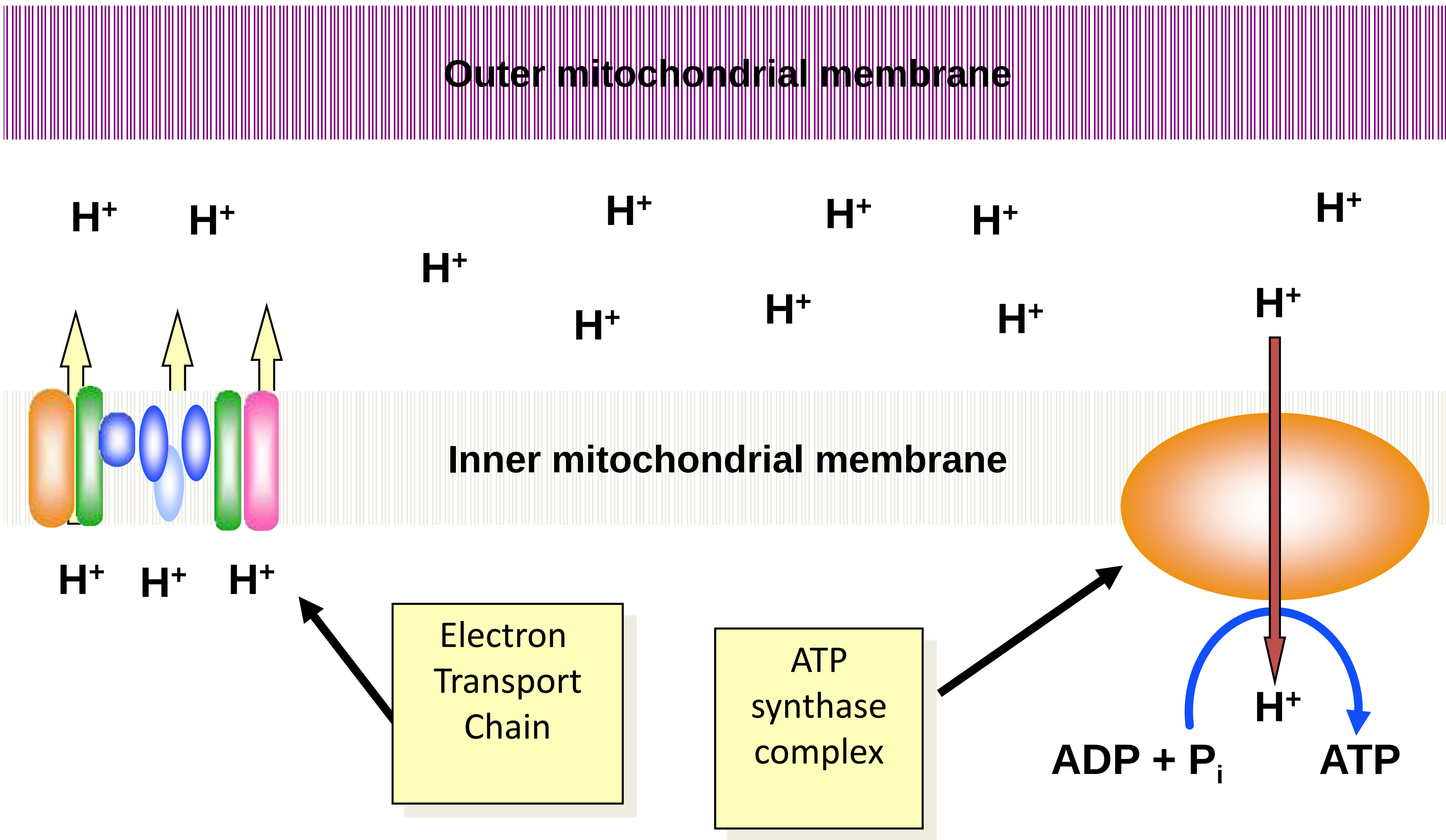
- Several chemicals can inhibit the pathway at different locations.

- Cyanide and CO can block e transport between a/a3 and O2.

Flow of electrons



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


Outer mitochondrial membrane
H+
H+
H+
H+
H+
H+
H+
H+
H+
H+
H+
Inner mitochondrial membrane
H+
H+
H+
Electron Transport Chain
ATP synthase complex
H+
ADP + Pi
ATP

FUNCTIONING OF ETC

- In ETC , the constituent molecule are arranged in the order of

➔increasing redox potential

➔Decreasing e- pressure

➔Diminishing free energy level

- so along the chain there would be a step by step flow of e- from most –ve initial donor to most +ve terminal acceptor(O_2)
- e- entering to ETC are energy rich
- As the flow down , they loss free energy
- Much of this energy get conserved in ATP

- ➔in ETC enzyme bound H is used as the fuel for energy generation
- ➔available from the dehydrogenation reactions of substrate oxidation
- ➔from H-donating substrates ,H-atoms are collected by dehydrogenase , and supplied to ETC , through NAD &FAD
- ➔They are serve as the acceptor , carrier & donor of H.
- ➔The H atoms soon donate their e- to ETC
- ➔These H+ ions soon escape to the aquas medium

- ➔NAD linked dehydrogenase remove 2 H-atoms from the substrate
- ➔1-transferred to NAD as hydride ion

  1-appers in the medium as H+
- ➔reduced substrate + NAD + ⇄ oxidized substrate + NADH+H
- ➔FAD-linked dehydrogenase remove 2 H atoms from the substrate
- ➔in most case ,both of them will be accepted by FAD ,yielding FADH2
- ➔reduced substrate + FAD ⇄ oxidized subsrtate+FADH2

➔from the co-enzyme channel , electrons are funneled to molecular oxygen though chain of e-carrier

➔they include flavoproteins , Fe-S,UQ, Co Q & cytochromes

➔in respiratory chain e- are transferred in 3 ways

1.As e- s , 2.as H-atoms,3. as hydride ions which bears two electrons

➔during the flow of e-,every members of ETC get Alternately reduced and oxidized in cyclic manner

➔in this process ,iron atoms oscillates between Fe^{2+} & Fe^{3+} states

- ➔at the initial end , this redox reaction chain is linked to dehydrogenation reaction , and at its terminal end to molecular oxygen
- ➔at the same time , some of its intermediate reactions are coupled with phosphorylation of ADP
- ➔dehydrogenation reactions maintain a steady flow of H & Phosphorylation reaction ensure a constant synthesis of ATP
- ➔ The coupling of redox reactions of the respiratory chain with the phosphorylation of ADP constitutes a reaction complex known as oxidative phosphorylation

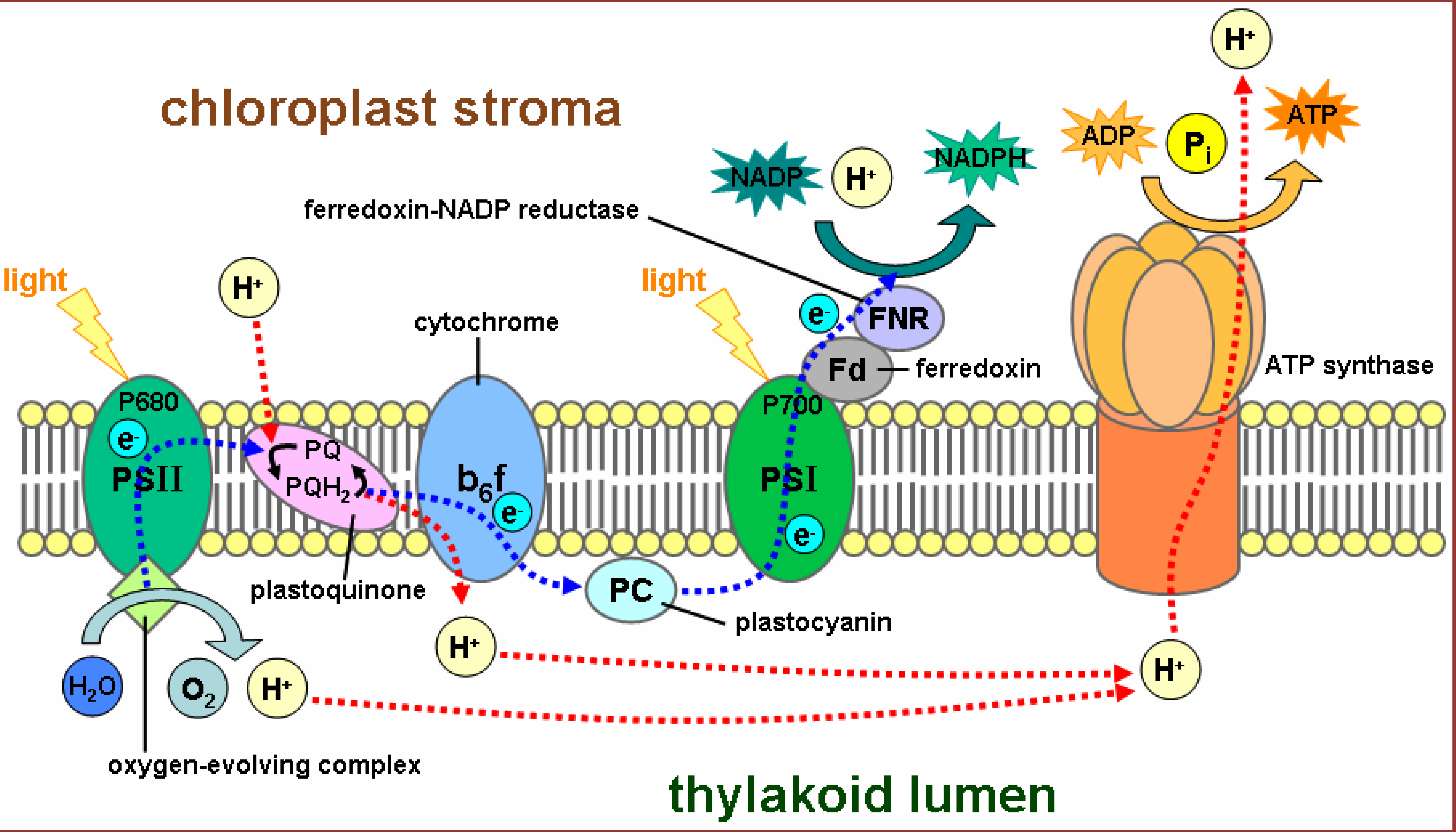
Oxidative phosphorylation

- The electron-transport chain moves electrons from NADH and $FADH_2$ to O_2.
- In the mean time, ADP is phosphorylated to ATP.

- The two processes are dependent on each other. ATP cannot be synthesized unless there is energy from electron transport ($\Delta G^{o\prime}$= +31 kj/mol). Electrons do not flow to O2, unless there is need for ATP.

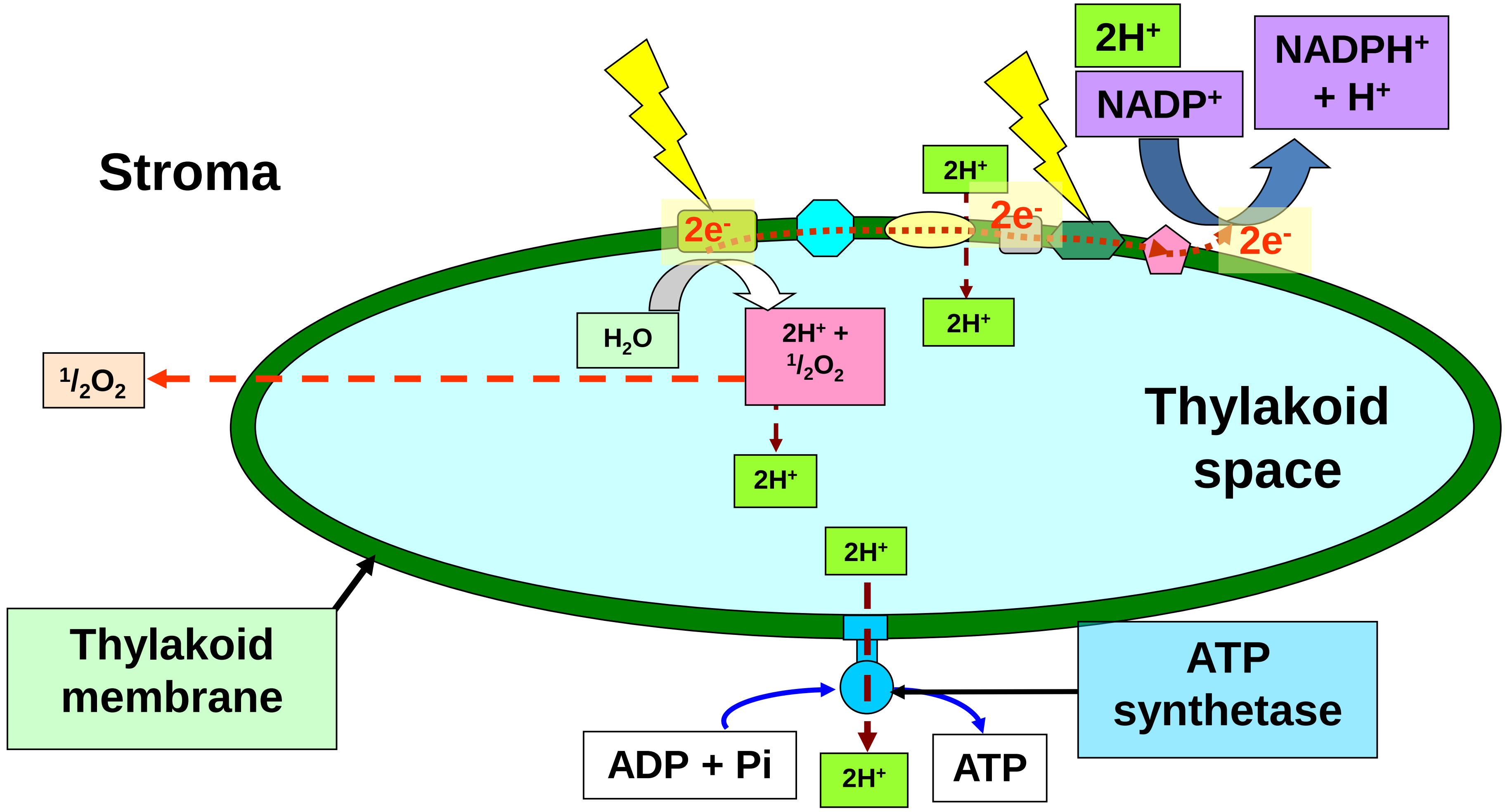
3 ATP are generated when two electrons are transported from NADH to O_2.

The oxidation of $FADH_2$ only produces 2 ATP.



chloroplast stroma
H+
NADP
H+
NADPH
ADP
Pi
ATP
ferredoxin-NADP reductase
light
H+
cytochrome
light
e-
FNR
Fd
ferredoxin
ATP synthase
P680
e-
PQ
PQH2
PSII
b6f
e-
P700
PSI
e-
plastoquinone
PC
plastocyanin
H+
H+
H2O
O2
H+
oxygen-evolving complex
thylakoid lumen

Photophosphorylation




Thank you ...