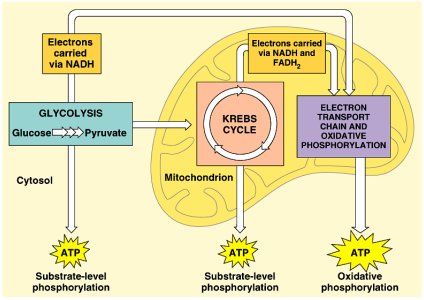
Cellular Respiration
Stage 4:
Electron Transport Chain

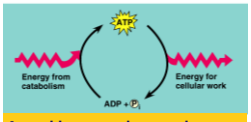
Cellular respiration



ATP accounting so far…

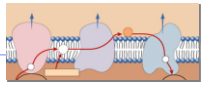
- Glycolysis → 2 ATP
- Kreb's cycle → 2 ATP
- Life takes a lot of energy to run, need to extract more energy than 4 ATP!

There's got to be a better way!



A working muscle recycles over 10 million ATPs per second

There *is* a better way!

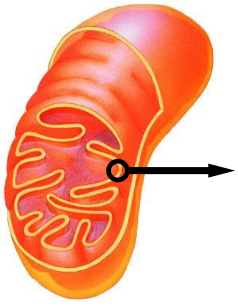


- Electron Transport Chain
  - series of proteins built into inner mitochondrial membrane
    - along cristae
    - transport proteins & enzymes
  - transport of electrons down ETC linked to pumping of H^+ to create H^+ gradient
  - yields ~36 ATP from 1 glucose*!*
  - only in presence of O_2 (aerobic respiration)

O_2

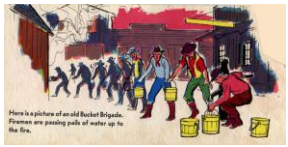
Mitochondria

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



Electron Transport Chain

- The electron transport chain occurs in electron carriers found in the inner mitochondrial membrane.
- Electrons pass down electron transport chain in a series of redox reactions
- Ex. Old time bucket brigade.



Electron Trasport

- The electrons entering the chain are high energy
- Complex I accepts NADH
- Complex II Accepts $FADH_2$
- Complex I and II produce Ubiquinone (substrate of complex III)
- Complex III accepts electrons from reduced ubiquinone and passes it to Cychrome C.

Electron Transport Chain

- Complex IV accepts electrons from Cytochrome C and uses it to make water in the process (reduces molecular oxygen)
- O_2 is final electron acceptor.

End of chain electrons are passed on to oxygen to form water

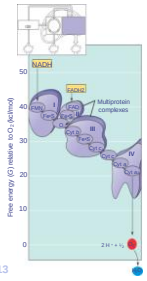
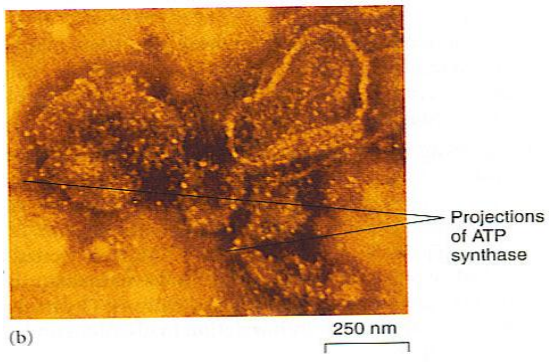
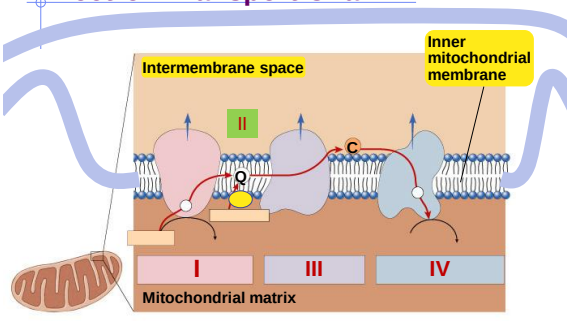


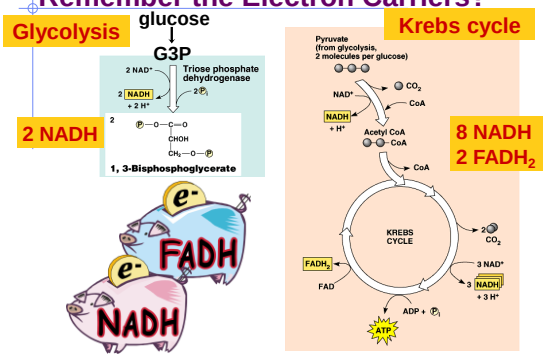
Figure 9.13



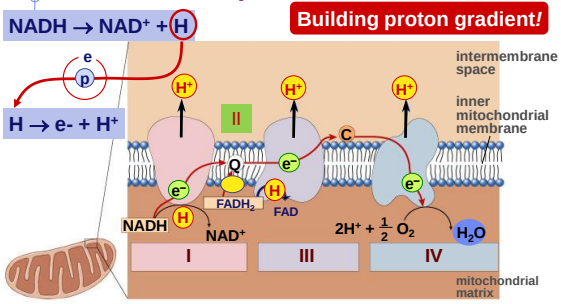
Electron Transport Chain



Remember the Electron Carriers?



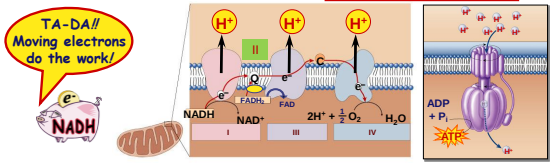
Electron Transport Chain



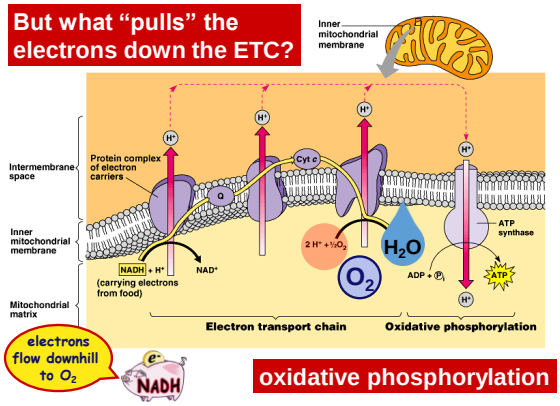
What powers the proton (H⁺) pumps?…

Stripping H from Electron Carriers

- Electron carriers pass electrons & H⁺ to ETC
  - H cleaved off NADH & $FADH_2$
  - electrons stripped from H atoms → H⁺ (protons)
    - electrons passed from one electron carrier to next in mitochondrial membrane (ETC)
    - flowing electrons = energy to do work
  - transport proteins in membrane pump H⁺ (protons) across inner membrane to intermembrane space



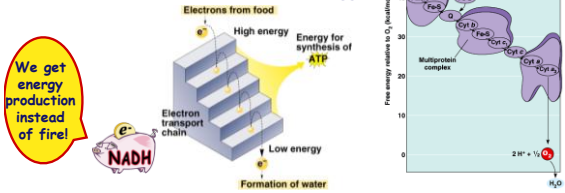
But what "pulls" the electrons down the ETC?



oxidative phosphorylation

Electrons flow downhill

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



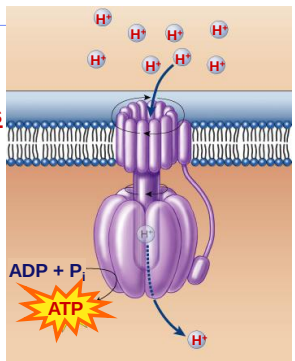
We did it!

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

$ADP + P_i \rightarrow ATP$

All of this depends on there being ADP and phosphate in the mitochondrial matrix!

"proton-motive" force

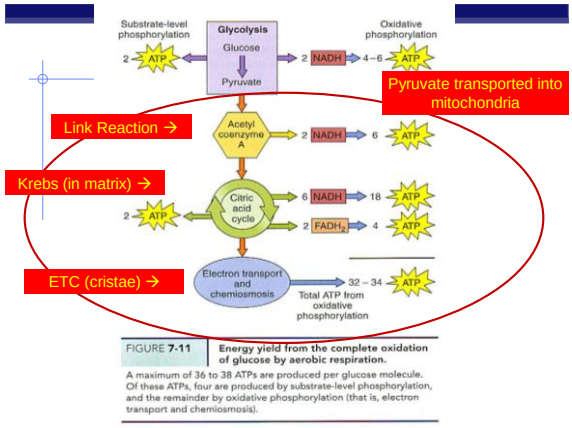


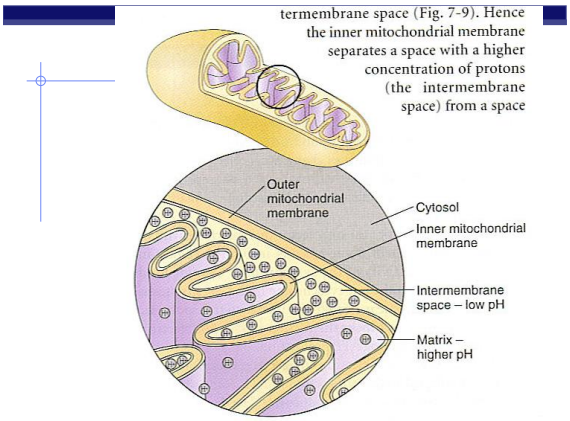
Chemiosmosis

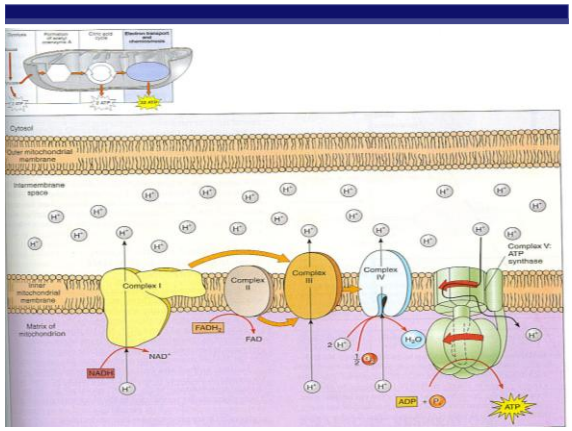
- Electron chain stablishes a proton gradient
- Some energy is used to move protons (H⁺) across a membrane.
- Protons move across inner mitochondrial membrane into intermembrane space.
- Inner mitochondrial separates high proton concentration with low proton concentration.

Chemiosmosis

- Complexes I, III, and IV move H across the membrane.
- Diffusion of Protons from high {H} area to low {H} area is limited by ATP synthase (complex V)
- H provides energy for the formation of ADP + P_i to produce ATP.
  - ADP and Pi are pumped back into the matrix!







- Chemiosmosis and the electron transport chain

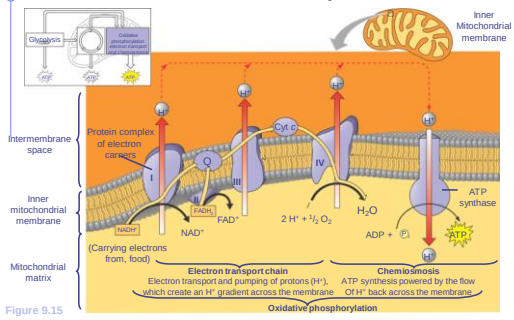


Figure 9.15

There are three main processes in this metabolic enterprise

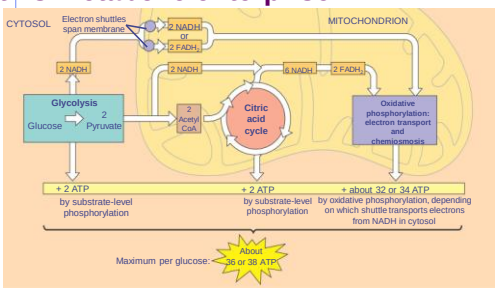
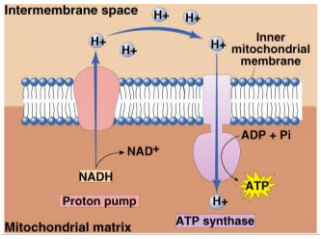


Figure 9.16

Chemiosmosis

- **The diffusion of ions across a membrane**
  - build up of proton gradient just so H+ could flow through ATP synthase enzyme to build ATP

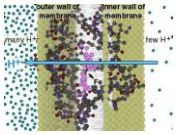
Chemiosmosis links the Electron Transport Chain to ATP synthesis



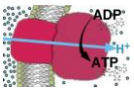
1961 | 1978

Peter Mitchell

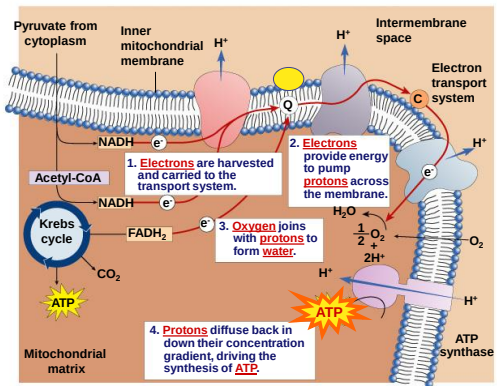
- **Proposed chemiosmotic hypothesis**
  - revolutionary idea at the time



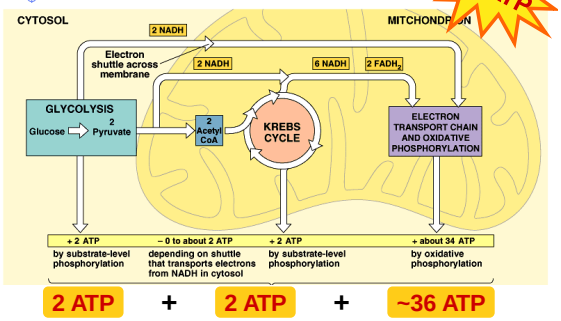
proton motive force



1920-1992



Cellular respiration



2 ATP + 2 ATP + ~36 ATP

Summary of cellular respiration: On your own paper—by end of class

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \sim 40\ ATP$

- Where did the glucose come from?
- Where did the O_2 come from?
- Where did the CO_2 come from?
- Where did the CO_2 go?
- Where did the H_2O come from?
- Where did the ATP come from?
- What else is produced that is not listed in this equation?
- Why do we breathe?