Cellular Respiration
Stage 4:
Electron Transport Chain

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!
- 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 O₂ (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
- 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 Transport

- The electrons entering the chain are high energy
- Complex I accepts NADH
- Complex II accepts FADH₂
- Complex I and II produce Ubiquinone (substrate of complex III)
- Complex III accepts electrons from reduced ubiquinone and passes it to Cyochrome C.

Electron Transport Chain

- Complex IV accepts electrons from Cytochrome C and uses it to make water in the process (reduces molecular oxygen)
- O₂ is final electron acceptor.

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

Electron Transport Chain

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Remember the Electron Carriers?

- Glycolysis: glucose → 2 NADH
- Krebs cycle: 8 NADH
- Electron Carriers: NADH, FADH₂, Fe•S, FMN, Cytochrome C, Cytochrome C₁, Cytochrome C₃, Cytochrome a, Cytochrome a₃

Figure 9.13
Electron Transport Chain

**Building proton gradient!**

- **NADH → NAD⁺ + H⁺**
- **H → e⁺ + H⁺**
- **Intermembrane space**
- **Mitochondrial matrix**
- **NAD⁺**
- **NADH**
- **FAD⁺**
- **FADH₂**
- **2H⁺ + 1/2 O₂ → H₂O**
- **H⁺**
- **e⁻**
- **NAD⁺**

**What powers the proton (H⁺) pumps?…**

**Stripping H from Electron Carriers**

- **Electron carriers pass electrons & H⁺ to ETC**
  - H cleaved off NADH & FADH₂
  - electrons stripped from H atoms → H⁺ (protons)
  - 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?**

- **Electrons flow downhill**
  - each carrier more electronegative
  - controlled oxidation
  - controlled release of energy

**We did it!**

- **“proton-motive” force**
  - Set up a H⁺ gradient
  - Allow the protons to flow through ATP synthase
  - Synthesizes ATP

**Chemiosmosis**

- **Electron chain establishes 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 + Pi to produce ATP.
  - ADP and Pi are pumped back into the matrix!

Pyruvate transported into mitochondria

Krebs (in matrix) →

ETC (cristae) →

There are three main processes in this metabolic enterprise:

- Glycolysis
- Oxidative phosphorylation: electron transport and chemiosmosis
- Electron transport chain

Figure 9.15

Chemiosmosis and the electron transport chain

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

**Peter Mitchell**

- Proposed chemiosmotic hypothesis
  - revolutionary idea at the time

**Cellular respiration**

1. Electrons are harvested and carried to the transport system.
2. Electrons provide energy to pump protons across the membrane.
3. Oxygen joins with protons to form water.
4. Protons diffuse back down their concentration gradient, driving the synthesis of ATP.

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

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \sim 40 \text{ ATP} \]

- Where did the glucose come from?
- Where did the O2 come from?
- Where did the CO2 come from?
- Where did the CO2 go?
- Where did the H2O come from?
- Where did the ATP come from?
- What else is produced that is not listed in this equation?
- Why do we breathe?