Aerobic Cellular Respiration

• Products of Glycolysis

2 NADH + H^+
2 ATP — NET total
Substrate Level Phosphorylation
2 Pyruvate

• Products: Entering Mitochondria

1. Pyruvate: Translocation

* Transition Reactions:
   a. Loses CO_2
   b. Reduces NAD^+ into NADH + H^+
   c. Combines with Coenzyme A
   * Forming Acetyl CoA
   (2 carbon Molecule)

  ** NON-REVERSIBLE reaction **
2. NADH + H+: From Glycolysis
   a. Oxidized at mitochondrial membrane:
      * Electrons passed through mitochondrial membrane by:
        ~ REDOX reactions and shuttles

   - 2H + e– bound to malate
   - 2H + e– released from malate

* Electrons “caught” on mitochondrial coenzymes
  ~ Accepted by: FADH$_2$ or NADH+H+
1. Krebs Cycle (Citric Acid or TCA)

- **Function:** Cyclical set of mitochondrial reactions yielding reduced coenzymes

- **Products:** per Acetyl CoA – "per one turn"
  - A. 1 ATP : Substrate level Phosphorylation
  - B. 2 CO₂
  - C. 3 NADH + H⁺ & 1 FADH₂

- **Significance:** Energy re–diversion:
  - REDOX Reactions
  - Produce: "Reduced Coenzymes":
    - ~ 3 NADH + H⁺ & 1 FADH₂
Per Acetyl CoA:
One Turn:
1 ATP
2 CO₂
3 NADH+H⁺
1 FADH₂

Per Glucose:
Two Turns:
2 ATP
4 CO₂
6 NADH+H⁺
2 FADH₂

Total ATP produced per glucose:
Glycolysis & Krebs = 4 ATP

Overall Cellular Respiration:
Total cellular ATP = 30 - 32
Q: Where are the other 26–28 ATPs?
Q: Where is the energy needed to power the endergonic ATP production if ALL of the bonds in glucose are “broken”?
A: Reduced molecules NADH+ H⁺ & FADH₂
   ✯ Each coenzyme carries 2 e⁻s

Note: Total Mitochondrial ATP – 36 – 38 ATP
   6 ATP difference
Electron Transport / Oxidative Phosphorylation:

- REDOX reactions: *Transport Electrons*
  - "Oxidative" Oxidation of FADH₂ & NADH+H⁺
  - "Phosphorylation": Phosphorylate ADP + P into ATP

![Diagram of electron transport and oxidative phosphorylation](image-url)
**Location:** Inner Mitochondrial Membrane

- Contents: Series of Oxidizing/Reducing Agents
  - **Electron Transport Chain** (ETC)

1. **REDOX:** Oxidize NADH and FADH₂
   - **Transport**: Electrons to adjacent carrier

2. **Proton Pump:** Hydrogens
   - REDOX reactions “power” hydrogen pumps
   - Electrons produce proton pump: conformational shape change
First Pump: 4 Hydrogens
Second Pump: 4 Hydrogens
Third Pump: 2 Hydrogens

Function: Active transport of $H^+$ from Matrix into Inner Mitochondrial Space

Creating a $H^+$ CONCENTRATION Gradient

Disposal of electrons:
Reduce Oxygen into WATER

Oxygen Oxidizes last electron carrier:
* Last electron movement:
  * Oxygen pulls electron off ETC
  * Oxygen combines with electrons and $H^+$

$$2H^+ + 2e^- + \frac{1}{2}O_2 \rightarrow H_2O$$

Final Electron Acceptor: OXYGEN

* Highest electronegativity
4. Produce ATP

- Potential energy of concentration gradient used to "Power" ATP synthesis

Respiratory Assembly: Complex

- 2 part protein complex
  a. H⁺ Channel: Facilitated Diffusion
  b. ATP Synthase: Enzyme
**Function: ADP Phosphorylation**

- H⁺ flows down its concentration gradient
- H⁺ association causes conformational changes in protein structure
- Causing spinning of the protein rotor and activation of the catalytic sites for ATP production
Gradient lost = ATP produced

- 3 hydrogens = 1 ATP made in mitochondria
- 1 hydrogen = energy used to move ATP to cytosol
- 3 hydrogens = ATP theoretical yield
- 4 hydrogens = ATP actual yield (cytosolic)

NADH = 4 H⁺ + 4H⁺ + 2 H⁺ = 10 H⁺

\[ 10 \text{ H⁺} / 4 \text{ H⁺ per ATP} = 2.5 \text{ ATP} \]

FADH₂ = 4H⁺ + 2 H⁺ = 6 H⁺

\[ 6 \text{ H⁺} / 4 \text{ H⁺ per ATP} = 1.5 \text{ ATP} \]

First Pump: 4 Hydrogens
Second Pump: 4 Hydrogens
Third Pump: 2 Hydrogens

Theoretical Mitochondrial yield
NADH = 3 ATP
FADH = 2 ATP

ATP Check Sheet: ACTUAL YIELD

2 ATP Substrate level
2 ATP Substrate level
26 or 28 ATP Oxidative phosphorylation

= 30 or 32 ATP per glucose
1. Glycolysis:
   - 2 ATP
   - 2 NADH (Usually goes into mitochondria and FADH\(_2\)) \(\times\) 2.5 ATP = 5 ATP

2. Transition rxns
   - 2 NADH \(\times\) 2.5 ATP = 5 ATP
   - 2 NADH, 1.5 ATP = 3 ATP
   - 6 NADH \(\times\) 2.5 ATP = 15 ATP
   \[= 32 \text{ ATP} \text{ (passing to NADH)}\]

3. Krebs
   - 2 ATP
   - 2 FADH\(_2\), 1.5 ATP = 3 ATP
   - 6 NADH \(\times\) 2.5 ATP = 15 ATP
   \[= 30 \text{ ATP} \text{ (passing to FADH\(_2\))}\]

Table 5.2 | ATP Yield per Glucose in Aerobic Respiration

<table>
<thead>
<tr>
<th>Phases of Respiration</th>
<th>ATP Made Directly</th>
<th>Reduced Coenzymes</th>
<th>ATP Made by Oxidative Phosphorylation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycolysis</td>
<td>2 ATP per pair</td>
<td>2 NADH (but usually goes into mitochondria as 2 FADH(_2))</td>
<td>5 ATP (\times) 1.5 ATP = 7.5 ATP</td>
</tr>
<tr>
<td>Pyruvate to acetyl CoA</td>
<td>None</td>
<td>1 NADH + 2 NAD(^+) = 2 NADH</td>
<td>3 ATP (\times) 2 = 6 ATP</td>
</tr>
<tr>
<td>Krebs cycle</td>
<td>1 ATP + 2 NAD(^+) = 2 ATP</td>
<td>1 NADH + 2 NAD(^+) = 2 NADH</td>
<td>5 ATP (\times) 2 = 10 ATP</td>
</tr>
<tr>
<td>Total ATP</td>
<td>4 ATP</td>
<td></td>
<td>32 ATP or 34 ATP</td>
</tr>
</tbody>
</table>