Cell Respiration

Chapter 5

Cellular Respiration

• Release of energy in biomolecules (food) and use of that energy to generate ATP
  
  \[
  \text{ENERGY (food)} + \text{ADP} + \text{P}_1 \rightarrow \text{ATP}
  \]

• Two methods of breaking down food
  – Aerobic Respiration: oxygen utilizing
  – Anaerobic Respiration: no oxygen used

Aerobic Respiration

• Uses oxygen in breakdown of materials and release of energy
  
  \[
  \text{C}_6\text{H}_12\text{O}_6 \text{ (glucose)} + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy}
  \]

• Energy is released in small increments via long metabolic pathways
  – Allows cells to efficiently release and use energy contained in food molecules

Glycolysis

• Occurs in cytoplasm of the cell

• Breakdown of one glucose molecule into two pyruvate molecules

• Yields 2 ATP molecules (net) and 2 NADH molecules

Glycolysis: Overview

• Glycolysis
  – glucose \rightarrow pyruvate

• Krebs Cycle
  – formation of electron carriers and CO₂

• Oxidative Phosphorylation
  – electron carriers used to generate ATP

Glycolysis

\[
\begin{align*}
\text{Glucose (6C)} & \rightarrow 2\text{ATP} + 2\text{ADP} + 2\text{NADH} + 2\text{Pyruvate (3C)} \\
2\text{ATP} & + 2\text{ADP} + 2\text{NAD} & 2\text{ADP} + 2\text{ATP} + 2\text{NADH} & + 2\text{Pyruvate (3C)} \\
\text{NADH} & = \text{high-energy electron carrier}
\end{align*}
\]
**Glycolysis**

- Glucose $\rightarrow$ pyruvate
- $2 \text{NAD}^+ + 2\text{H}^+ + 4e^- \rightarrow 2 \text{NADH}$
- $2 \text{ADP} + 2 \text{P}_i \rightarrow 2 \text{ATP}$

**Kreb’s Cycle**

- Occurs in the mitochondrial matrix
- Cyclical series of reactions

**Krebs Cycle: Acetyl-CoA Formation**

- Pyruvate transported into mitochondrial matrix
- $\text{CO}_2$ cleaved off of pyruvate, forming acetate
- Acetate linked to Coenzyme A (CoA) to form acetyl-CoA
- One NADH formed for each pyruvate

**Krebs Cycle (The Cycle Itself)**

- Acetyl-CoA (2C) linked to oxaloacetic acid (4C), to form citric acid (6C)
- Citric acid ultimately converted into oxaloacetic acid + 2$\text{CO}_2$
- 1 GTP, 3 NADH and 1 FADH per each acetyl-CoA

**Krebs Cycle**

- 3 $\text{CO}_2$, 1 GTP, 4 NADH and 1 FADH$_2$
  produced for each pyruvate molecule.
- Total: 6$\text{CO}_2$, 2 GTP, 8 NADH, 2FADH$_2$
Oxidative Phosphorylation

- Occurs across the inner mitochondrial membrane
- Electrons from NADH and FADH$_2$ are transported along an electron transport chain
- Energy released used to produce ATP

Oxidative Phosphorylation

- H$^+$ pumped from inside the membrane to the outside
  - forms [H$^+$] gradient (more outside than inside)
- H$^+$ flows back in through ATP synthase
  - generates ATP
- Electrons and H$^+$ received by O$_2$
  - forms H$_2$O

Overall Reaction for Aerobic Respiration

\[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \]

How Much ATP is Produced Per Glucose Molecule?

<table>
<thead>
<tr>
<th>Process</th>
<th>ATP Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycolysis</td>
<td>2</td>
</tr>
<tr>
<td>Krebs Cycle</td>
<td>(2 GTP) 2 ATP</td>
</tr>
<tr>
<td>Oxidative Phosphorylation</td>
<td>26 ATP</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>30 ATP</strong></td>
</tr>
</tbody>
</table>

Triglyceride Catabolism

- Fatty acids are converted into acetyl-CoA
- Large amounts of ATP produced per fatty acid

Amino Acid Catabolism

Different amino acids can be converted into various Krebs Cycle intermediates
Anaerobic Respiration

- Produce ATP in the absence of O₂
- Used regularly by skeletal muscle fibers and RBCs
- Two steps:
  - Glycolysis - produce ATP
  - Lactate Formation – regenerate NAD⁺

Glycolysis in Anaerobiosis

- Glucose → Pyruvate
- Net 2 ATP produced
- NAD⁺ → NADH
- Need NAD⁺ to drive glycolysis!

Lactate Formation

- Pyruvate → Lactate
- NADH → NAD⁺
- Glycolysis can continue

How Much ATP is Produced Per Glucose Molecule?

<table>
<thead>
<tr>
<th>Glycolysis</th>
<th>2 ATP</th>
</tr>
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<tbody>
<tr>
<td>TOTAL</td>
<td>2 ATP</td>
</tr>
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</table>

- Most of the energy from glucose is still present in the lactate
- Lactate accumulation leads to ↓ pH