Chapter 6:
CELLULAR RESPIRATION

1. Overview of Respiration
2. Glycolysis
3. The Citric Acid Cycle
4. Oxidative Phosphorylation
1. Overview of Respiration
What is Cellular Respiration?

It is the process by which organisms use energy from “food” (e.g., glucose, fatty acids) to fuel the endergonic synthesis of ATP.

- requires $(O_2)$, occurs in most organisms (plants, too!)
- provides a supply of usable energy for cells (ATP)
Cellular Respiration and the Human Body

- respiratory system acquires $O_2$, removes $CO_2$
- digestive system provides glucose and fats as a source of energy

**cellular respiration takes place in mitochondria**
Respiration occurs in 3 stages:

1) Glycolysis
   - initial break down of glucose

2) Citric Acid Cycle
   - completes the break down of glucose

3) Oxidative Phosphorylation
   - electron transport to generate H⁺ gradient
   - chemiosmosis to produce ATP!

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The Stages of Cellular Respiration

1. **GLYCOLYSIS**
   - **Glucose** → **Pyruvate**
   - **Cytoplasm**
   - ATP (2)
   - Substrate-level phosphorylation

2. **CITRIC ACID CYCLE**
   - **NADH**
   - **FADH₂**
   - **Mitochondrion**
   - ATP (2)
   - CO₂
   - Substrate-level phosphorylation

3. **OXIDATIVE PHOSPHORYLATION**
   - **NADH** and **FADH₂**
   - **Mitochondrion**
   - ATP (34!)
   - Oxidative phosphorylation

- High-energy electrons carried by NADH
- ATP
- CO₂
2. Glycolysis
What is Glycolysis?

A series of chemical reactions to break down glucose into two 3-carbon pyruvate molecules (1\textsuperscript{st} step in glucose metabolism)

- occurs in the cytoplasm, does \textbf{NOT} require O\textsubscript{2}
- energy in the form of e\textsuperscript{-} captured by the e\textsuperscript{-} carrier \textbf{NADH}
- also yields 2 ATP, thus the products of glycolysis are:

\[
\begin{align*}
2 \text{ ATP} & \quad 2 \text{ NADH} & \quad 2 \text{ pyruvate}
\end{align*}
\]
Instead of moving on to the Citric Acid Cycle, pyruvate will undergo fermentation when there’s not enough O₂:

- produces lactic acid (animals), ethanol (yeast), acetic acid, methane (other microbes) or other byproducts
- results in relatively low energy yield (2 ATP per glucose)
- important for “recycling” the electron carrier NAD⁺
3. The Citric Acid Cycle
The Citric Acid Cycle occurs in the “Matrix”

- yield from 2 pyruvate (i.e., 1 glucose):
  - 2 ATP
  - 8 NADH
  - 2 FADH$_2$
What is the Citric Acid Cycle?
• series of chemical reactions that finish the breakdown of glucose
  • 3-C pyruvate from glycolysis broken down to 3 CO₂

Where does it occur?
• in the mitochondrial matrix
  • pyruvate from cytoplasm gets transferred across inner mitochondrial membrane into the matrix

Where does the released energy end up?
• as high energy electrons (e⁻) in the electron carriers NADH & FADH₂ (plus heat)
  • e⁻ passed on to the “electron transport chain” (ETC)
The Citric Acid Cycle

pyruvate → Acetyl CoA + CO₂

CITRIC ACID CYCLE

2 CO₂

FADH₂ → FAD

3 NAD⁺ + 3 H⁺

ATP → ADP + P
4. Oxidative Phosphorylation
Overview of Oxidative Phosphorylation

“Oxidative Phosphorylation” refers to the addition of a 3rd phosphate to make ATP (“phosphorylation”) by a process that depends on oxidation-reduction reactions (“oxidative”), and occurs in 2 stages:

A) electron transport
   - e\(^{-}\) from NADH and FADH\(_{2}\) are passed along the electron transport chain (ETC) via oxidation-reduction reactions
   - convert energy from e\(^{-}\) into energy stored in H\(^{+}\) gradient

B) chemiosmosis
   - energy from H\(^{+}\) gradient used to make ATP
Oxidation & Reduction

OXIDATION – loss of e\(^-\) (usually with a hydrogen atom)

REDUCTION – gain of e\(^-\) (usually with a hydrogen atom)
e⁻ Transport generates H⁺ Gradient

- energy from e⁻ used to pump H⁺ ions (fr. lo→hi conc)
Electron Transport

High energy electrons (e\textsuperscript{-}) from NADH, FADH\textsubscript{2} transferred to e\textsuperscript{-} transport chain (ETC)

- ETC is a series of proteins in the inner mitochondrial membrane through which e\textsuperscript{-} are passed

Energy released through e\textsuperscript{-} transport used to create H\textsuperscript{+} gradient (necessary to make ATP)

- H\textsuperscript{+} pumped across inner mitochondrial membrane out of the matrix into the intermembrane space

Oxygen (O\textsubscript{2}) is essential for electron transport!

- O\textsubscript{2} is the final electron acceptor at the end of the ETC

**no O\textsubscript{2} = no e\textsuperscript{-} transfer = no ATP production = death!**
Chemiosmosis used to make ATP

- **ATP synthase** uses energy of H⁺ flow to make ATP
Chemiosmosis

“The flow of a substance (H⁺) from high to low concentration”

Energy derived from the flow of H⁺ is used to synthesize ATP (from ADP & Pᵢ)

- H⁺ flows “down” concentration gradient through ATP synthase in the inner mitochondrial membrane
- ATP synthase = enzyme complex that catalyzes:
  \[ \text{ADP} + \text{P}_i \xrightarrow{H^+ \text{ flow}} \text{ATP} \]

Yields up to 34 ATP per glucose molecule!

- in addition to 2 ATP in glycolysis, 2 ATP in Krebs cycle
Summary of Oxidative Phosphorylation
Respiration is simply a Series of Energy Conversions!

I. Energy stored in sugars and fats is converted to energy temporarily stored in electron carriers (NADH & FADH$_2$)
   - via Glycolysis & the Krebs Cycle

II. Energy stored in NADH & FADH$_2$ is converted to energy temporarily stored in an H$^+$ gradient
   - via electron transport

III. Energy stored in an H$^+$ gradient is converted to energy stored in molecules of ATP
   - via chemiosmosis (which fuels ATP synthesis)
Key Terms for Chapter 6

• glycolysis, fermentation
• Citric Acid Cycle
• electron carriers (NADH, FADH$_2$)
• oxidation vs reduction
• oxidative phosphorylation, chemiosmosis
• electron transport chain (ETC)
• ATP synthase

Relevant Review Questions:
1-4, 6, 9, 10, 14