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Catabolism in Animals

Glycolysis

Citric Acid Cycle

Oxidative Phosphorylation (electron transport) (chemiosmosis)

Lactic Acid Fermentation

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Oxidative Phosphorylation:
Electron transport - Chemiosmosis - ATP synthesis

- Glycolysis and the citric acid cycle supply:
  - 10 NADH and 2 FADH
  - extracted from each glucose molecule burned

- These two electron carriers donate electrons to the electron transport chain (ETC)

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Fig. 9 - 5

(a) Uncontrolled reaction

H₂ + 1/2 O₂

Explosive release of heat and light energy

(b) Electron transport

Controlled release of energy for synthesis of ATP

2H⁺ + 2e⁻ → 1/2 O₂ (from food via NADH)
The electron transport chain (made mostly of multi-protein components) is in the cristae of the mitochondrion.
The carriers alternate reduced and oxidized states as they accept and donate electrons.
Electrons drop in free energy as they go down the chain and are finally passed to $O_2$ forming $H_2O$.
$H^+$ are released from carriers as they move into chain.

Electrons are passed through a number of proteins including cytochromes (each with an iron atom) to $O_2$.
The electron transport chain generates no ATP.
It simply uses the energy to push the freed hydrogen ions $H^+$ out of the mitochondrial matrix into the intermembrane space.

The energy stored in a $H^+$ gradient across a membrane couples the redox reactions of the electron transport chain to ATP synthesis.
The $H^+$ gradient is referred to as a proton motive force, emphasizing its capacity to do work.
Chemiosmosis - the use of E in a H⁺ gradient to drive cellular work

1. Electron transfer in the ETC causes proteins to pump H⁺ from the mitochondrial matrix to the intermembrane space
   - H⁺ then moves back across the membrane, passing through channels in ATP synthase
   - ATP synthase uses the exergonic flow of H⁺ to drive phosphorylation of ATP

Oxidative Phosphorylation:
Electron transport - Chemiosmosis - ATP synthesis

- Glycolysis and the citric acid cycle supply:
  - 10 NADH and 2 FADH₂
    - extracted from each glucose molecule burned
  - NADH carries enough energy to make 3 ATP
  - FADH₂ carries enough energy to make 2 ATP
- Enough for 34 ATP from each glucose

Flow of energy during cellular respiration:
glucose → NADH → electron transport chain → proton motive force → ATP
~ 40% of energy in glucose is transferred to ATP
Other Catabolic Pathways

- **Fermentation** is a partial degradation of sugars that occurs (with/without) O₂
  - Alcohol fermentation – *Saccharomyces cerevisiae*
  - Lactic acid fermentation – *Lactobacillus acidophilus*
  - Acetic acid fermentation – *Escherichia coli*
- **Anaerobic respiration** is similar to aerobic respiration but consumes compounds other than O₂
  - Sulfate-reducing bacteria and archaea

Fermentation

- Fermentation does not generate ATP directly
- Instead it makes glycolysis run as a cycle
  - Fermentation involves reactions that regenerate NAD⁺, which can be reused by glycolysis
  - Two common types are alcohol fermentation and lactic acid fermentation

![Diagram of glycolysis and fermentation]

**What is the FINAL electron acceptor?**

1. Glucose
2. ADP → ATP
3. NAD⁺ → NADH
4. Pyruvate
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\[
\begin{align*}
2 \text{ADP} + 2 \text{Pi} & \rightarrow 2 \text{ATP} \\
\text{Glucose} & \rightarrow \text{Glycolysis} \\
\text{2 NAD}^+ & \rightarrow 2 \text{NADH} + 2 \text{H}^+ \\
\text{2 Pyruvate} & \rightarrow \text{2 Acetaldehyde} \\
\end{align*}
\]

(a) Alcohol fermentation

Where does the CO\(_2\) go?

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Fermentation and Aerobic Respiration Compared

- Both processes use glycolysis to oxidize glucose and other organic fuels to pyruvate
- Final electron acceptors: an organic molecule (such as pyruvate or acetaldehyde) in fermentation and O\(_2\) in cellular respiration
- Cellular respiration produces ~38 ATP per glucose molecule
- Glycolysis/fermentation produces 2 ATP per glucose molecule

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CATABOLISM

GLYCOLYSIS

OXYDATIVE PHOSPHORYLATION (electron transport) (chemiosmosis)

FERMENTATION lactic acid ethanol

“Cellular Respiration” “Anaerobic Metabolism”
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![Diagram of metabolic pathways]

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Biosynthesis (Anabolic Pathways)

- The body uses small molecules to build other substances
- These small molecules may come directly from food, from glycolysis, or from the citric acid cycle

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Regulation of Cellular Respiration via Feedback Mechanisms

- Feedback inhibition is the most common mechanism for control
- If ATP concentration begins to drop, respiration speeds up; when there is plenty of ATP, respiration slows down
- Control of catabolism is based mainly on regulating the activity of enzymes at strategic points in the catabolic pathway
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**Practice Questions**

1. "Glucose + Fructose -------> Sucrose" is an example of which type of reaction?
   - a. catabolism
   - b. anabolism

2. Does the equation above generate or use energy?

3. What is the name of the high-energy, recyclable molecule in which energy is stored?

4. In glycolysis, glucose is broken down. Is glucose oxidized or reduced?

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**Practice Questions**

5. Are the following oxidized/reduced forms?
   - NAD+
   - NADPH
   - FAD

6. Are the above molecules:
   - inorganic cofactors?
   - organic coenzymes?

7. What is the primary function of the above molecules in cellular respiration?
Practice Questions

Name the stages of cellular respiration (A, B, C)
Name the organelle (D); Where does each stage occur?
How many ATP are generated at each stage?
What type of phosphorylation occurs at each stage to generate ATP?