**How Cells Harvest Energy: Cellular Respiration**

Chapter 7

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**Energy Flow**

Photosynthesis uses solar energy to produce glucose and O$_2$ from CO$_2$ and H$_2$O

Cellular respiration extracts energy from glucose by oxidation (using O$_2$) to make ATP and produces CO$_2$ and H$_2$O

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**Redox Reactions (oxidation and reduction simultaneously occur in a chemical reaction)**

**Reactants**
- Methane (H$_3$C·H)
- Oxygen (O$_2$)

**Products**
- Carbon dioxide (CO$_2$)
- Water (H$_2$O)

\[
\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + \text{Energy} + 2 \text{H}_2\text{O}
\]

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**The human body uses energy from ATP for all its activities**

**Table 6.4 Energy Consumed by Various Activities (in kcal)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Kcal Consumed per Hour by a 67.5-kg (150-lb) Person*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycling (racing)</td>
<td>514</td>
</tr>
<tr>
<td>Bicycling (slow)</td>
<td>170</td>
</tr>
<tr>
<td>Dancing (slow)</td>
<td>202</td>
</tr>
<tr>
<td>Dancing (fast)</td>
<td>599</td>
</tr>
<tr>
<td>Eating</td>
<td>28</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>186</td>
</tr>
<tr>
<td>Laboratory work</td>
<td>73</td>
</tr>
<tr>
<td>Running (7 min/mi)</td>
<td>865</td>
</tr>
<tr>
<td>Sitting (writing)</td>
<td>28</td>
</tr>
<tr>
<td>Sleeping or lying still</td>
<td>0</td>
</tr>
<tr>
<td>Standing (relaxed)</td>
<td>32</td>
</tr>
<tr>
<td>Swimming (2 mph)</td>
<td>535</td>
</tr>
<tr>
<td>Walking (3 mph)</td>
<td>138</td>
</tr>
<tr>
<td>Walking (4 mph)</td>
<td>231</td>
</tr>
</tbody>
</table>

* Not including kcal needed for body maintenance.
Cells need ATP

- ATP powers
  - Active transport
  - Mechanical work (movement)
  - Anabolic (endergonic) reactions

In glycolysis, glucose is oxidized to pyruvate.

The electrons from that reaction reduce NAD\(^+\) to NADH.

NADH carries the electrons to be used in the oxidative phosphorylation.
Substrate Level Phosphorylation

Electron Carrier NAD⁺

Glycolysis

Summary Glycolysis

- Converts 1 glucose (6 carbons) to 2 pyruvate (3 carbons)
- 10-step biochemical pathway
- Occurs in the cytoplasm
- Net production of 2 ATP molecules by substrate-level phosphorylation
- 2 NADH produced by the reduction of NAD⁺
NADH must be recycled

- For glycolysis to continue, NADH must be recycled to NAD⁺ by either:
  1. Aerobic respiration
     - Oxygen is available as the final electron acceptor
     - Produces significant amount of ATP
  2. Fermentation
     - Occurs when oxygen is not available
     - Organic molecule is the final electron acceptor

The Fate of Pyruvate is Dependent on Oxygen Availability

Fermentation occurs when oxygen is not available

Fermentation
**Products of pyruvate oxidation**

- For each 3 carbon pyruvate molecule:
  - 1 CO₂
  - Decarboxylation by pyruvate dehydrogenase
  - 1 NADH
  - 1 acetyl-CoA which consists of 2 carbons from pyruvate attached to coenzyme A
  - Acetyl-CoA proceeds to the Krebs cycle
Krebs Cycle (Citric Acid Cycle)

- For each Acetyl-CoA entering:
  - Release 2 molecules of CO₂
  - Reduce 3 NAD⁺ to 3 NADH
  - Reduce 1 FAD (electron carrier) to FADH₂
  - Produce 1 ATP
  - Regenerate oxaloacetate

At this point

- Glucose has been oxidized to:
  - 6 CO₂
  - 4 ATP
  - 10 NADH
  - 2 FADH₂

These electron carriers proceed to the electron transport chain
**Electron Transport Chain**

- ETC is a series of membrane-bound electron carriers
- Embedded in the inner mitochondrial membrane
- Electrons from NADH and FADH$_2$ are transferred to complexes of the ETC
- Each complex
  - A proton pump creating proton gradient
  - Transfers electrons to next carrier

**Why Electron Transport?**

Electrons from food

Energy released for ATP synthesis

High energy

Low energy

**Oxidative Phosphorylation:**

Electron Transport Chain & Chemiosmosis
**Chemiosmosis**

- Accumulation of protons in the intermembrane space drives protons into the matrix via diffusion
- Membrane relatively impermeable to ions
- Most protons can only reenter matrix through ATP synthase
  - Uses energy of gradient to make ATP from ADP + P$_i$

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**Certain poisons interrupt critical events in cellular respiration**
- Various poisons
  - Block the movement of electrons
  - Block the flow of H$^+$ through ATP synthase
  - Allow H$^+$ to leak through the membrane
ATP Yield

Example of feedback inhibition
2 key control points
1. In glycolysis
   - Phosphofructokinase is allosterically inhibited by ATP and/or citrate
2. In pyruvate oxidation
   - Pyruvate dehydrogenase inhibited by high levels of NADH
   - Citrate synthetase inhibited by high levels of ATP

Cells use many kinds of organic molecules as fuel for cellular respiration (catabolic processes)