Chapter 5: Microbial Metabolism

1. Enzymes

2. ATP Production

3. Autotrophic Processes
1. Enzymes
Biochemical Reactions

All living cells depend on biochemical reactions to maintain homeostasis.

All of the biochemical reactions in an organism are collectively referred to as metabolism, which is of 2 basic types:

**catabolic:** reactions that “break down” molecules
  - generally energy *releasing* or exergonic

**anabolic:** reactions that build new molecules
  - generally energy *requiring* or endergonic

**exergonic reactions provide energy for endergonic ones!**
All organisms, prokaryotic or eukaryotic, need to build the molecules they need, and find the energy to do so!
Metabolic Pathways

Most biochemical reactions are part of a series of reactions referred to as a **metabolic pathway**:

- it usu. takes multiple reactions to make “end-product”
- pathways can be **catabolic** or **anabolic**
- each reaction is catalyzed by its own enzyme
Enzyme Basics

Almost all biochemical reactions are catalyzed by a specific enzyme:

• proteins that accelerate the rate of a reaction without being changed themselves

  • lower the activation energy ($E_a$)

• the need for enzymes provides a way to control or regulate biochemical reactions

  • reactions won’t occur unless the enzyme that catalyzes the reaction is present & active
Enzymes lower the Activation Energy

**reactions won’t occur unless the \( E_a \) requirement is met**
Enzymes physically bind Substrates
Control of Enzyme Activity

Biochemical reactions can be controlled by changes in enzyme activity, which can be influenced in several ways:

1) Changes in the amount of enzyme or substrate
   - more enzyme &/or more substrate = more product!

2) Changes in temperature, pH or [salt]
   - can effect enzyme structure, hence its activity

3) Availability of any necessary cofactors
   - some enzymes don’t work w/o a non-protein cofactor

4) Effect of inhibitors
   - molecules that bind to enzymes & reduce their activity
Factors affecting Enzyme Activity

**Temperature**
- reactions occur more rapidly as temperature rises
  - **as long as enzyme is active (heat can denature enzymes)**

**pH**
- enzyme structure depends on pH
  - **pH affects charge of “R groups”, protein structure**

**[Substrate]**
- reactions occur more rapidly as [substrate] rises
  - **saturation occurs when [substrate] is high enough**
Enzyme Denaturation

- Enzymes are polypeptides that retain their ability to function only when folded properly.
- Changes in temperature, pH or [salt] can disrupt amino acid “R group” interactions causing the protein to unfold, i.e. become denatured.

**Mutations can also lead to misfolded, non-functional enzymes**
Some Enzymes Require Cofactors

• can be a metal ion, vitamin, or other “non-protein”
  • if the cofactor is organic, it is called a coenzyme

• enzyme is inactive w/o cofactor
Enzyme Inhibition

- inhibitors bind enzymes in 1 of 2 ways:
  - competitive inhibition (binding to active site)
  - allosteric inhibition (binding elsewhere, changing shape)

- inhibitors can bind **reversibly** (can “come off”) or **irreversibly** (don’t come off, e.g. “poisons”)
Feedback Inhibition

The end-products of metabolic pathways are important **reversible** enzyme inhibitors

- inhibit 1\textsuperscript{st} enzyme in pathway, turning the pathway “off”
  
  low [inhibitor] = pathway ON
  high [inhibitor] = pathway OFF

- can be competitive or allosteric inhibition

- provide an important way of regulating end-product levels
2. ATP Production
Adenosine Triphosphate (ATP)

Preferred source of useable energy for ALL cells:

- breaking bond of 3rd phosphate releases ideal amt of energy
- bond is easily broken (low $E_a$)

**This is why organisms convert “food” energy to “ATP” energy**
How is ATP produced?

In most organisms, energy from a “food source” is converted to energy in ATP by glycolysis followed by 1 of 2 processes:

FERMENTATION (low ATP yield)

or

RESPIRATION (high ATP yield)
Glycolysis

Glycolysis is a catabolic pathway by which sugars such as glucose (& several other “food” sources) are broken down to two 3-Carbon molecules of pyruvic acid (or pyruvate):

- releases energy to yield 2 ATP per glucose
- also transfers high energy electrons (+ H) to NAD⁺ to yield 2 NADH

Don’t memorize this!!
Oxidation/Reduction

Much of the energy in “food” molecules such as glucose is captured as high energy electrons (e⁻) by electron carriers such as NADH & FADH₂

- when a molecule receives or gains electrons it is said to be **reduced**
  
  **e⁻ are typically transferred as part of a Hydrogen atom**

- a molecule that gives up electrons (i.e., loses H) is said to be **oxidized**
Fermentation

ATP production begins & ends with glycolysis in organisms that ferment.

Fermentation is all about recycling NAD$^+$ so that glycolysis can continue:

- NADH is oxidized to NAD$^+$ by reducing pyruvate to lactic acid for example
Different organisms recycle NAD\(^+\) in different ways, resulting in a variety of fermentation end-products.

<table>
<thead>
<tr>
<th>Fermentation End-Product(s)</th>
<th>Industrial or Commercial Use</th>
<th>Starting Material</th>
<th>Microorganism</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ethanol</strong></td>
<td>Beer</td>
<td>Malt extract</td>
<td><em>Saccharomyces cerevisiae</em> (yeast, a fungus)</td>
</tr>
<tr>
<td></td>
<td>Wine</td>
<td>Grape or other fruit juices</td>
<td><em>Saccharomyces cerevisiae var. ellipsoideus</em></td>
</tr>
<tr>
<td></td>
<td>Fuel</td>
<td>Agricultural wastes</td>
<td><em>Saccharomyces cerevisiae</em></td>
</tr>
<tr>
<td><strong>Acetic Acid</strong></td>
<td>Vinegar</td>
<td>Ethanol</td>
<td><em>Acetobacter</em> (bacterium)</td>
</tr>
<tr>
<td><strong>Lactic Acid</strong></td>
<td>Cheese, yogurt</td>
<td>Milk</td>
<td><em>Lactobacillus, Streptococcus</em> (bacteria)</td>
</tr>
<tr>
<td></td>
<td>Rye bread</td>
<td>Grain, sugar</td>
<td><em>Lactobacillus delbruckii</em> (bacterium)</td>
</tr>
<tr>
<td></td>
<td>Sauerkraut</td>
<td>Cabbage</td>
<td><em>Lactobacillus plantarum</em> (bacterium)</td>
</tr>
<tr>
<td></td>
<td>Summer sausage</td>
<td>Meat</td>
<td><em>Pediococcus</em> (bacterium)</td>
</tr>
<tr>
<td><strong>Propionic Acid and Carbon Dioxide</strong></td>
<td>Swiss cheese</td>
<td>Lactic acid</td>
<td><em>Propionibacterium freudenreichii</em> (bacterium)</td>
</tr>
<tr>
<td><strong>Acetone and Butanol</strong></td>
<td>Pharmaceutical, industrial uses</td>
<td>Molasses</td>
<td><em>Clostridium acetobutylicum</em> (bacterium)</td>
</tr>
<tr>
<td><strong>Glycerol</strong></td>
<td>Pharmaceutical, industrial uses</td>
<td>Molasses</td>
<td><em>Saccharomyces cerevisiae</em></td>
</tr>
<tr>
<td><strong>Citric Acid</strong></td>
<td>Flavoring</td>
<td>Molasses</td>
<td><em>Aspergillus</em> (fungus)</td>
</tr>
<tr>
<td><strong>Methane</strong></td>
<td>Fuel</td>
<td>Acetic acid</td>
<td><em>Methanosarcina</em> (bacterium)</td>
</tr>
<tr>
<td><strong>Sorbose</strong></td>
<td>Vitamin C (ascorbic acid)</td>
<td>Sorbitol</td>
<td><em>Gluconobacter</em></td>
</tr>
</tbody>
</table>
Respiration

After glycolysis, energy in pyruvate & NADH is used to produce much more ATP by respiration:

KREBS CYCLE
- breaks down pyruvate to 3 CO₂, energy captured as e⁻ by NADH & FADH₂

ELECTRON TRANSPORT
- e⁻ from NADH, FADH₂ used to produce H⁺ gradient

CHEMIOSMOSIS
- H⁺ gradient used to make ATP
The Krebs cycle

- a cyclical metabolic pathway catalyzed by enzymes in the matrix of mitochondria
- requires 2-C acetyl groups connected to coenzyme A (acetyl-CoA)

\[(3\text{-C}) \text{ pyruvate } + \text{ CoA} \rightarrow (2\text{-C}) \text{ acetyl-CoA } + \text{ CO}_2 \]

(Krebs cycle)
Electron Transport & Chemiosmosis

Occurs in the mitochondria of eukaryotes and at the plasma membrane of prokaryotes.

- oxygen (O$_2$) is usually the final electron acceptor, but other molecules can play this role in anaerobic respiration
Lipids and proteins can also be used as sources of energy to produce ATP

- different amino acids enter glycolysis or the Krebs cycle at various stages
- fatty acids are broken down to acetyl groups & fed into the Krebs cycle
## Summary of ATP Production

### TABLE 5.5: Aerobic Respiration, Anaerobic Respiration, and Fermentation Compared

<table>
<thead>
<tr>
<th>Energy-Producing Process</th>
<th>Growth Conditions</th>
<th>Final Hydrogen (Electron) Acceptor</th>
<th>Type of Phosphorylation Used to Generate ATP</th>
<th>ATP Molecules Produced per Glucose Molecule</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic Respiration</strong></td>
<td>Aerobic</td>
<td>Molecular oxygen ($O_2$)</td>
<td>Substrate-level and oxidative</td>
<td>36 (eukaryotes) 38 (prokaryotes)</td>
</tr>
<tr>
<td><strong>Anaerobic Respiration</strong></td>
<td>Anaerobic</td>
<td>Usually an inorganic substance (such as $NO_3^-$, $SO_4^{2-}$, or $CO_3^{2-}$ but not molecular oxygen ($O_2$))</td>
<td>Substrate-level and oxidative</td>
<td>Variable (fewer than 38 but more than 2)</td>
</tr>
<tr>
<td><strong>Fermentation</strong></td>
<td>Aerobic or anaerobic</td>
<td>An organic molecule</td>
<td>Substrate-level</td>
<td>2</td>
</tr>
</tbody>
</table>

**Obligate anaerobes:**
- fermentation or anaerobic respiration

**Obligate aerobes:**
- aerobic respiration (& brief periods of fermentation)

**Facultative anaerobes:**
- can survive via aerobic respiration OR fermentation
3. Autotrophic Processes
All organisms depend on Autotrophs

Autotrophs can produce organic molecules from CO$_2$, an inorganic carbon source.

• all heterotrophs require an organic source of carbon
• organic molecules, directly or indirectly, come from autotrophs

The source of energy for autotrophic processes can be:

LIGHT: photoautotrophs that carry out photosynthesis

CHEMICAL: chemoautotrophs that use various molecules as a source of high energy e$^-$. 
Light Reactions of Photosynthesis

Electrons (from H₂O) energized by sunlight:

• fuel the synthesis of ATP through electron transport & chemiosmosis (much like respiration)

• ultimately reduce NADP⁺ to NADPH

• ATP & NADPH provide energy to fuel production of sugars in the “dark” reactions
“Dark” Reactions

Involves an anabolic pathway known as the Calvin-Benson cycle:

- endergonic reactions of this pathway are fueled by ATP & NADPH from the “light” reactions

- resulting sugars can be used as a source of energy or to build other organic molecules

Don’t memorize this!!
Summary of Energy Metabolism

All organisms

Energy source

Chemical

Chemotrophs

Carbon source

Organic compounds

Chemoheterotrophs

Final electron acceptor

O₂

All animals, most fungi, protozoa, bacteria

Not O₂

Organic compound

Fermentative: *Streptococcus*, for example

Inorganic compound

Electron transport chain: *Clostridium*, for example

Light

Phototrophs

Carbon source

CO₂

Photoheterotrophs

Use H₂O to reduce CO₂?

Yes

Oxygenic photosynthesis (plants, algae, cyanobacteria)

No

Anoxyogenic photosynthetic bacteria (green and purple bacteria)

CO₂

Chemooautotrophs

Green nonsulfur bacteria, purple nonsulfur bacteria

Key Terms for Chapter 5

- catabolic, anabolic; exergonic, endergonic
- activation energy, substrate, active site
- cofactor vs coenzyme, denatured
- feedback inhibition: competitive vs allosteric
- glycolysis, fermentation, respiration
- Krebs cycle, electron transport, chemiosmosis
- oxidation vs reduction
- Calvin-Benson cycle

Relevant Chapter Questions
rvw: 1-7, 18, 20-22   MC: 1, 4-10