Microbiology
Microbial Metabolism I
Introduction to Metabolism

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Introduction

Why study microbiology?
To control and utilization of MICR❤❤RGANI$M$

 Physiology: The study of life processes in living cells
 Metabolism: The total of all chemical reactions in cells

Why microbial metabolism?

![Diagram showing the relationship between Physiology and Metabolism]

- **Physiology**:
  - Photosynthesis
  - Maintenance
  - Growth
  - Respiration
  - Reproduction
  - Fermentation

- **Metabolism**:
  - Catabolism
  - Anabolism
  - Chemical Work
  - Mechanical
  - Heat
  - Transport

Light Energy

BST
Overview of metabolism

Purpose: Trapping, generation and use of energy
Where: within cells (under controlled temperature and pH)
How: catalyzed by enzymes
Metabolism of microorganisms

- Interchangeable
- Macro- to micro-molecules or vice versa

**Catabolism**

- Polysaccharides
- Lipids
- Proteins
- Nucleic acids

**Anabolism**

- Monosaccharides
- Fatty acids, glycerol
- Amino acids
- Nucleotides

**Molecules**

- CO$_2$
- H$_2$O, O$_2$
- NH$_4^+$, NO$_3^-$
- PO$_4^{3-}$, SO$_4^{2-}$

**Polymers**

**Monomers**

- BST
Oxidation-Reduction Reaction
Electron Carriers
ATP (adenosine triphosphate)
## Oxidation-Reduction Reaction

### Table 8.1

<table>
<thead>
<tr>
<th>Redox Couple</th>
<th>$E'_0$ (Volts) $^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2H^+ + 2e^- \rightarrow H_2$</td>
<td>-0.42</td>
</tr>
<tr>
<td>Ferredoxin($Fe^{3+}$) + e$^-$ $\rightarrow$ ferredoxin ($Fe^{2+}$)</td>
<td>-0.42</td>
</tr>
<tr>
<td>NAD(P)$^+$ + H$^+$ + 2e$^-$ $\rightarrow$ NAD(P)H</td>
<td>-0.32</td>
</tr>
<tr>
<td>S + 2H$^+$ + 2e$^-$ $\rightarrow$ H$_2$S</td>
<td>-0.274</td>
</tr>
<tr>
<td>Acetaldehyde + 2H$^+$ + 2e$^-$ $\rightarrow$ ethanol</td>
<td>-0.197</td>
</tr>
<tr>
<td>Pyruvate$^-$ + 2H$^+$ + 2e$^-$ $\rightarrow$ lactate$^2-$</td>
<td>-0.185</td>
</tr>
<tr>
<td>FAD + 2H$^+$ + 2e$^-$ $\rightarrow$ FADH$_2$</td>
<td>-0.18$^b$</td>
</tr>
<tr>
<td>Oxaloacetate$^2-$ + 2H$^+$ + 2e$^-$ $\rightarrow$ malate$^2-$</td>
<td>-0.166</td>
</tr>
<tr>
<td>Fumarate$^2-$ + 2H$^+$ + 2e$^-$ $\rightarrow$ succinate$^2-$</td>
<td>0.031</td>
</tr>
<tr>
<td>Cytochrome $b$ ($Fe^{3+}$) + e$^-$ $\rightarrow$ cytochrome $b$ ($Fe^{2+}$)</td>
<td>0.075</td>
</tr>
<tr>
<td>Ubiquinone + 2H$^+$ + 2e$^-$ $\rightarrow$ ubiquinone H$_2$</td>
<td>0.10</td>
</tr>
<tr>
<td>Cytochrome $c$ ($Fe^{3+}$) + e$^-$ $\rightarrow$ cytochrome $c$ ($Fe^{2+}$)</td>
<td>0.254</td>
</tr>
<tr>
<td>Cytochrome $a$ ($Fe^{3+}$) + e$^-$ $\rightarrow$ cytochrome $a$ ($Fe^{2+}$)</td>
<td>0.29</td>
</tr>
<tr>
<td>Cytochrome $a_3$ ($Fe^{3+}$) + e$^-$ $\rightarrow$ cytochrome $a_3$ ($Fe^{2+}$)</td>
<td>0.35</td>
</tr>
<tr>
<td>NO$_3^-$ + 2H$^+$ + 2e$^-$ $\rightarrow$ NO$_2^-$ + H$_2$O</td>
<td>0.421</td>
</tr>
<tr>
<td>NO$_2^-$ + 8H$^+$ + 6e$^-$ $\rightarrow$ NH$_4^+$ + 2H$_2$O</td>
<td>0.44</td>
</tr>
<tr>
<td>Fe$^{3+}$ + e$^-$ $\rightarrow$ Fe$^{2+}$</td>
<td>0.771$^c$</td>
</tr>
<tr>
<td>O$_2$ + 4H$^+$ + 4e$^-$ $\rightarrow$ 2H$_2$O</td>
<td>0.815</td>
</tr>
</tbody>
</table>

$^a$ $E'_0$ is the standard reduction potential at pH 7.0.

$^b$ The value for FAD/FADH$_2$ applies to the free cofactor because it can vary considerably when bound to an apoenzyme.

$^c$ The value for free Fe, not Fe complexed with proteins (e.g., cytochromes).
Electron Transport Systems

NADH
Electron Carriers

Transfer electrons between different locations

Energy flow in metabolism

NAD\(^+\)  nicotinamide adenine dinucleotide

NADP\(^+\)  nicotinamide adenine dinucleotide phosphate
ATP: Adenosine TriPhosphate

A high-energy molecule

\[ \text{ATP} + \text{H}_2\text{O} \quad \overset{\text{H}^+}{\underset{\text{H}^-}{\rightleftharpoons}} \quad \text{ADP} + \text{P}_i \quad \Delta G^\circ = -7.3 \text{ kcal/mol} \]
Enzyme Structure

**Apoenzyme**

- protein component of an enzyme

**Cofactor**

- nonprotein component of an enzyme
  - prosthetic group – firmly attached
  - coenzyme – loosely attached

**Holoenzyme** = apoenzyme + cofactor

**Coenzyme**

- often act as carriers, transporting substances around the cell
# Enzymes: Classification

<table>
<thead>
<tr>
<th>Type of Enzyme</th>
<th>Reaction Catalyzed by Enzyme</th>
<th>Example of Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidoreductase</td>
<td>Oxidation-reduction reactions</td>
<td>Lactate dehydrogenase: Pyruvate + NADH + H⁺ ⇌ lactate + NAD⁺</td>
</tr>
<tr>
<td>Transferase</td>
<td>Reactions involving the transfer of groups between molecules</td>
<td>Aspartate carbamoyltransferase: Aspartate + carbamoylphosphate ⇌ carbamoylaspartate + phosphate</td>
</tr>
<tr>
<td>Hydrolase</td>
<td>Hydrolysis of molecules</td>
<td>Glucose-6-phosphatase: Glucose 6-phosphate + H₂O → glucose + Pᵢ</td>
</tr>
<tr>
<td>Lyase</td>
<td>Removal of groups to form double bonds or addition of groups to double bonds</td>
<td>Fumarate hydratase: l-malate ⇌ fumarate + H₂O</td>
</tr>
<tr>
<td>Isomerase</td>
<td>Reactions involving isomerizations</td>
<td>Alanine racemase: l-alanine ⇌ d-alanine</td>
</tr>
<tr>
<td>Ligase</td>
<td>Joining of two molecules using ATP energy (or that of other nucleoside triphosphates)</td>
<td>Glutamine synthetase: Glutamate + NH₃ + ATP → glutamine + ADP + Pᵢ</td>
</tr>
</tbody>
</table>
Enzymes

Characteristics
- Lower activation energy
- Key-Lock relation: active or catalytic site
- Catalyze reactions by concentrating substrate and binding correctly

Environmental Effects
- pH
- Temperature
- Denature
Metabolic Regulation

Nature
- Exceptionally complex and difficult
- Able to respond to environmental changes

Significance
- Essential for the cell to conserve energy and material
- Essential for the cell to maintain metabolic balance

How
- Amount of metabolites and enzymes
- Activity of enzymes
- Feedback inhibition
Compartmentation
the differential distribution of enzymes and cofactors among separate cell structures

Enzyme activity
is coordinated through regulation of the transport of metabolites and coenzymes between cell compartments
Regulation Mechanisms

Central Dogma

Regulate enzyme activity

At translation

At transcription

No product

No enzyme

No mRNA
Allosteric Regulation
Example E. coli ACTase

Diagram of enzyme kinetics with substrate concentration vs. velocity, showing Michaelis-Menten equation parameters $K_m$, $V_{max}$, and $V_{max}/2$.

Chemical reactions:
1. L-Glutamine + HCO$_3^-$ + 2ATP $\rightarrow$ Carbamoyl phosphate + ATP
2. Carbamoyl phosphate $\rightarrow$ Aspartate + ATP
3. Aspartate + CTP $\rightarrow$ Carbamoylaspartate + P$_i$
4. Carbamoylaspartate $\rightarrow$ Uridine monophosphate (UMP) + CTP

Structural diagrams showing the approximate location of the catalytic site and regulatory sites.
Covalent Modification

Reversible addition or removal of a chemical group alters enzyme activity
Feedback (End Product) Inhibition

Maintain appropriate concentration for each metabolite
Pacemaker enzyme or rate-determining reaction