Energy Transformation: Cellular Respiration

Outline

1. From chemical energy of covalent bonds to ATP
2. Electrons and H atoms in oxidation-reduction reactions in biological systems
3. The four major central metabolic pathways
   - Glycolysis-
   - Fermentation
   - Transition step
   - Krebs Cycle
   - Electron Transport chain & oxidative phosphorylation
5. Use of biomolecules other than glucose as carbon skeletons & energy sources
Heterotrophs

• Consumers and decomposers of the ecosystem

• Do not produce their own food (organic matter) and sustain themselves by eating other organisms
During cellular respiration the potential energy in the chemical bonds holding C atoms in organic molecules is turned into ATP.

In presence of oxygen
complete breakdown

\[
\text{C-C-C-C-C-C-C + O}_2 \rightarrow \text{CO}_2 + \text{ATP} \quad \text{large amount}
\]

In absence of oxygen
incomplete breakdown

\[
\text{C-C-C-C-C-C-C} \rightarrow 2 \text{C-C-C} + \text{ATP} \quad \text{small amount}
\]
Glycogen-lactic acid system

Swimmer
1.3–1.6 minutes (400 m)

Aerobic respiration

Marathon runner
Unlimited time (15 Km)
The different types of activities require different subset of muscle fibers that function either aerobically, with oxygen, or anaerobically, without oxygen

**Cellular respiration** is the process by which cells produce energy aerobically, in the presence of oxygen
Chemical bonds of organic molecules

- Chemical bonds involve electrons of atoms

- Electrons have energy

- Chemical bonds are forms of potential energy

- If a molecule loses an electron does it lose energy?

- When breaking chemical bond sometimes electrons released
Oxidation-Reduction

- **Oxidation** is the removal of electrons.
- **Reduction** is the gain of electrons.
- **Redox** reaction is an oxidation reaction paired with a reduction reaction.
In biological systems, the electrons are often associated with hydrogen atoms.

- Important soluble electron carriers (vitamins)
  - NAD⁺ (Niacin), and FAD (Vit B2) (ATP generation)
  - NADP⁺ (biosynthetic reactions)
In Metabolic pathways

<table>
<thead>
<tr>
<th>Oxidation</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>energy (loss)</td>
<td>energy (gain)</td>
</tr>
<tr>
<td>exergonic</td>
<td>endergonic</td>
</tr>
</tbody>
</table>

Reduced molecules have a higher energy level than their oxidized counterparts.
Metabolic Pathways

Linear Metabolic Pathways

Starting compound $\rightarrow$ Intermediate$_a$ $\rightarrow$ Intermediate$_b$ $\rightarrow$ End product

Branched Metabolic Pathways

Starting compound $\rightarrow$ Intermediate$_a$ $\rightarrow$ Intermediate$_{b1}$ $\rightarrow$ End product$_1$

Intermediate$_a$ $\rightarrow$ Intermediate$_{b2}$ $\rightarrow$ End product$_2$

Cyclic Metabolic Pathways

Starting compound $\rightarrow$ Intermediate$_a$ $\rightarrow$ Intermediate$_b$ $\rightarrow$ Intermediate$_c$ $\rightarrow$ Intermediate$_d$ $\rightarrow$ End product
An overview of the central metabolic pathways

- Glycolysis
- Transition step
- Tricarboxylic acid cycle, citric acid cycle (TCA or Krebs cycle)
- The Electron Transport Chain and oxidative phosphorylation
The diagram illustrates the processes of glycolysis, the Krebs cycle, and electron transport chain, showing the flow of electrons and the production of ATP. Glycolysis occurs in the cytosol and results in 2 ATP per glucose. The Krebs cycle, located in the mitochondrion, produces 2 ATP per turn of the cycle, with the electron transport chain producing 34 ATP through oxidative phosphorylation. The total maximum ATP produced per glucose is approximately 38 ATP.
Glycolysis

• Multi – step breakdown of glucose into intermediates
• Turns one glucose (6-carbon) into two pyruvate (3-carbon) molecules
• Generates a small amount of ATP (substrate-level phosphorylation)
• Generates reducing power - NADH + H⁺
Pyruvate as a key juncture in catabolism
Fermentation

- An extension of glycolysis
- Takes place in the absence of oxygen (anaerobic)
- Regenerates NAD\(^+\) from NADH + H\(^+\)
- ATP generated by substrate-level phosphorylation during glycolysis
- A diversity of end products produced (i.e. lactic acid, alcohols, etc.)
(a) Alcohol fermentation
(b) Lactic acid fermentation
Pyruvate (from glycolysis, 2 molecules per glucose)

NAD^+ + H^+ → NADH

CoA

Acetyl CoA

CO₂

KREBS CYCLE

FADH₂

FAD

3 NAD⁺

3 NADH + 3 H⁺

2 CO₂

ADP + P_i → ATP

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Transition step

• Between glycolysis and Krebs Cycle, in the mitochondrion
• Uses **coenzyme A** (Vit B derivative)
• Turns pyruvate (3-carbon) into Acetyl-CoA (2-carbon) and releases one CO₂ molecule
• Generates reducing power NADH + H⁺
Conversion of pyruvate to acetyl CoA, the junction between glycolysis and the Krebs cycle.
Krebs or TCA Cycle

- A cyclical pathway
- Accepts – acetyl – CoA
- Generates 2 – CO\textsubscript{2} molecules (for every acetyl-CoA)
- Generates reducing power NADH + H\textsuperscript{+} and FADH\textsubscript{2}
- Generates a small amount of ATP (substrate-level phosphorylation)
Electron Transport Chain and ATP generation

**Electron transport chain:**
- Membrane-bound electron carriers
- Mostly proteins with non-protein groups.
- NADH vs. FADH$_2$
- No direct formation of ATP
- Pumps H$^+$ into the inter-membrane space forming a gradient
Oxidative Phosphorylation and ATP generation

ATP Generation:

1. ATP synthase: Protein complex
2. Driven by proton (H⁺) gradient
3. Direct forms ATP by combining transport of H⁺ across membrane, by facilitated diffusion, with the chemical reaction producing ATP
Electron Transport chains and oxidative phosphorylation

http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter9/animations.html#

ATP Synthase Gradient: The Movie

http://vcell.ndsu.edu/animations/atpgradient/movie.htm
Chemiosmosis couples the electron transport chain to ATP synthesis

intermembrane space

inner mitochondrial membrane

mitochondrial matrix

Electron transport chain

Oxidative phosphorylation

NADH + H+ → NAD+
(carrying electrons from food)

Cyt c

2 H+ + ½O2 → H2O

ADP + Pi → ATP

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Certain poisons interrupt critical events in cellular respiration

- Block the movement of electrons
- Block the flow of $H^+$ through ATP synthase
- Allow $H^+$ to leak through the membrane
Energy yield: How many ATP molecules are generated during cellular respiration of a single glucose molecule?

Maximum per glucose: About 38 ATP
Sources of cellular glucose

- Glucose from food in the intestine, which gets to working muscle through the bloodstream
- Glycogen storage supplies in the muscles
- Breakdown of the liver's glycogen into glucose, gets to working muscle through the bloodstream
Food, such as peanuts

Carbohydrates: Sugars → Glucose, G3P, Pyruvate → GLYCOLYSIS

Fats: Glycerol, Fatty acids → Acetyl CoA → CITRIC ACID CYCLE

Proteins: Amino acids → Amino groups

OXIDATIVE PHOSPHORYLATION (Electron Transport and Chemiosmosis)

ATP production
Food molecules provide raw materials for biosynthesis consuming ATP.

ATP needed to drive biosynthesis:

- **CITRIC ACID CYCLE**
- **Acetyl CoA**
- **GLUCOSE SYNTHESIS**
  - Pyruvate → G3P → Glucose

- **Amino groups** → **Amino acids** → **Proteins**
- **Fatty acids** → **Fats**
- **Glycerol** → **Carbohydrates**
- **Sugars**

Cells, tissues, organisms