Cellular Respiration

“Making energy in cells”

\[ \text{Glucose (C}_6\text{H}_{12}\text{O}_6) + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{ATP} \]
Where do organisms get energy?

- **Autotrophs** (photosynthesis)
- **Heterotrophs** (consume food)
- **Decomposers** (detritus-decomposition)
What is Cellular Respiration?

- **Cellular** or **Aerobic** (in air) Respiration is a series of chemical reactions in the **mitochondrion** where molecules of **glucose** are broken down to make **CO₂**, **water**, and **ATP**.

\[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 38 \text{ ATP} \]
What's the point?

The point is to make ATP!
Where does cellular respiration occur?

- **Eukaryotes** - in the mitochondria
- **Prokaryotes** - in the cytoplasm
What are the parts of the mitochondrion?

Mitochondria (plural)

- Inner membrane
- Outer membrane
- Inner membrane space
- Matrix (innermost space)
- Cristae (folds)
What are the steps of cellular respiration?

1) Glycolysis
2) Krebs Cycle
3) Electron Transport
Glycolysis = “breaking glucose”

- In the **cytoplasm** of cell
- **Glucose** is broken down into **2 pyruvic acids**
- **2 net ATP** are produced
- **e- carrier:** 2 **NADH** produced

http://instruct1.cit.cornell.edu/courses/biomi290/ASM/glycolysis.dcr
Citric Acid Cycle (Kreb’s Cycle)

- Occurs in matrix
- **Pyruvic Acid** (3C) is broken down and CO$_2$ is released
- **Acetyl-Coenzyme A** (2C) combines with a (4C) to make **citric acid** (6C) in a cycle of steps
- More CO$_2$ released
- ATP & NADH & FADH$_2$ produced
- CoA reused each cycle
A Little Krebs Cycle History

- Discovered by Hans Krebs in 1937
- He received the Nobel Prize in physiology or medicine in 1953 for his discovery
- Forced to leave Germany prior to WWII because he was Jewish
Electron Transport Chain

- Occurs in **inner membrane**
- **Electrons** from NADH and FADH$_2$ are moved across the ETC
- e-, H+ and O$_2$ combine to make H$_2$O
- ATP synthase pumps H+ across membrane to make ATP
# Cellular Respiration Summary Chart

<table>
<thead>
<tr>
<th>Step</th>
<th>Input</th>
<th>Output</th>
<th>ATP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycolysis</td>
<td>Glucose</td>
<td>2 pyruvic acids</td>
<td>2 ATP</td>
</tr>
<tr>
<td>Pyruvic acid</td>
<td>2 Pyruvic acids</td>
<td>2 CO₂</td>
<td>0 ATP</td>
</tr>
<tr>
<td>conversion</td>
<td></td>
<td>2 Acetyl CoA</td>
<td></td>
</tr>
<tr>
<td>Kreb Cycle</td>
<td>2 Acetyl CoA (1 per</td>
<td>4 CO₂</td>
<td>2 ATP</td>
</tr>
<tr>
<td></td>
<td>cycle)</td>
<td></td>
<td>(1 made per cycle)</td>
</tr>
<tr>
<td>ETC</td>
<td>6O₂</td>
<td>6H₂O</td>
<td>34 ATP</td>
</tr>
<tr>
<td></td>
<td>FADH₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NADH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

= 38 ATP!
Maximum ATP Yield for Cellular Respiration

Glucose → Glycolysis

2 ATP, 4 ATP, 6 ATP → 2 NADH, 2 NADH

2 Pyruvate → 2 Acetyl CoA

2 Acetyl CoA → 6 NADH, 2 FADH₂

Cytoplasm → Mitochondria

6 NADH, 2 FADH₂ → Electron Transport Chain

Electron Transport Chain → 18 ATP

38 ATP (maximum per glucose)
What if there is no oxygen?

- **Anaerobic (without air) Respiration** or Fermentation occurs when oxygen is **NOT** present.
- Makes **only 2 ATP** from Glycolysis 😞
- Occurs in anaerobic bacteria, muscle cells and yeast.
Fermentation (anaerobic)

- Bacteria, yeast
  \[ \text{pyruvate} \rightarrow \text{ethanol} + \text{CO}_2 \]  
  \[ \begin{array}{c} 3C \\ \text{NADH} \end{array} \quad \begin{array}{c} 2C \\ \text{NAD}^+ \end{array} \quad \begin{array}{c} 1C \\ \text{to glycolysis} \end{array} \]
  - beer, wine, bread

- Animals, some fungi
  \[ \text{pyruvate} \rightarrow \text{lactic acid} \]  
  \[ \begin{array}{c} 3C \\ \text{NADH} \end{array} \quad \begin{array}{c} 3C \\ \text{NAD}^+ \end{array} \quad \begin{array}{c} \text{to glycolysis} \end{array} \]
  - cheese, anaerobic exercise (no O\textsubscript{2})
What is fermentation?

- Skips Citric Acid cycle & ETC (NO oxygen)
- In muscle cells this is **Lactic Acid fermentation** (when muscles get tired, not enough oxygen)
- In yeast this is called **Alcoholic fermentation** (makes ethanol)
  - Used in bread, wine and beer making
What's the point?
The point is to make **ATP**!
Food for Thought

• In what ways are plants and animals dependent on each other?
• How is breathing (ventilation) related to cellular respiration?
  • Hint: Think about both the reactants and the products of cellular respiration.
What’s the relationship here?