NOTES: Chapter 9 (Part 2): Glycolysis & Krebs Cycle (9.2 & 9.3)
**CELLULAR RESPIRATION:**

reactions in living cells in which sugars are broken down and energy is released

\[
\text{Glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{ENERGY}
\]

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}
\]
● Food (glucose), like fuel, is “burned” by our cells for energy; however if it is burned all at once, too much energy is released.

● So, the reaction is broken down into many small steps controlled by **ENZYMES**
• the energy is transferred to the bonds of **ATP** which **stores and releases** the energy in **usable amounts** (packets) to be used by the cell
Recall: the ATP cycle

The ATP/ADP Cycle

energy input

ADP + Pi

energy output

ATP
- **Glucose** = “large denomination” ($100)

- **ATP** = “small change” ($1)

*For each molecule of glucose, the cell can make approximately 36-38 ATP.*
# Steps of Cellular Respiration:

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<td>NADH, FADH(_2), O(_2)</td>
<td>H(_2)O, ATP</td>
<td>32-34 (approx.)</td>
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2 Modes of ATP Synthesis

1) **oxidative phosphorylation**: mode of ATP synthesis powered by **redox reactions** which transfer electrons from **FOOD \(\rightarrow\) OXYGEN**

*(occurs at the electron transport chain, or e.t.c.)*
2) Substrate-level phosphorylation:

- involves the enzyme-catalyzed transfer of inorganic phosphate from a molecule to ADP to form ATP.
- mode of ATP synthesis occurring in:
  - glycolysis (2 ATP)
  - Krebs cycle (2 ATP)
GLYCOLYSIS:
= “splitting of sugar”

Summary of Glycolysis:
1 Glucose \rightarrow 2 pyruvate

2 ADP + 2 P_i \rightarrow 2 ATP
(via substrate-level phosphorylation!)

2 NAD^+ \rightarrow 2 NADH
Glycolysis occurs in 10 steps:

#1-5: energy-investment phase (2 ATP)

#6-10: energy-payoff phase (4 ATP)

NET GAIN OF 2 ATP!
Energy investment phase

Glucose

2 ADP + 2 P

2 ATP used

Energy payoff phase

4 ADP + 4 P

4 ATP formed

2 NAD$^+$ + 4 $e^-$ + 4 H$^+$

2 NADH + 2 H$^+$

2 Pyruvate + 2 H$_2$O

Net

Glucose $\rightarrow$ 2 Pyruvate + 2 H$_2$O

4 ATP formed − 2 ATP used $\rightarrow$ 2 ATP

2 NAD$^+$ + 4 $e^-$ + 4 H$^+$ $\rightarrow$ 2 NADH + 2 H$^+$
Glucose

\[ \text{Glucose} \xrightarrow{\text{Hexokinase}} \text{ADP} \]

\[ \text{ATP} \]

\[ \text{Glucose-6-phosphate} \]
2 NAD$^+$ + 2 H$^+$ + 2 NADH → Triose phosphate dehydrogenase

2 ADP + 2 ATP → Phosphoglycerokinase

2-Phosphoglycerate → 3-Phosphoglycerate → 1, 3-Bisphosphoglycerate
$\text{2 NAD}^+ + \text{2 NADH} + \text{2 H}^+ \rightarrow \text{2 ADP} + \text{2 ATP}$

1. **Triose phosphate dehydrogenase**

2. **1, 3-Bisphosphoglycerate**

3. **Phosphoglycerokinase**

4. **2 ADP**

5. **2 ATP**

6. **3-Phosphoglycerate**

7. **Phosphoglycerokinase**

8. **2 ATP**

9. **2 ADP**

10. **Pyruvate kinase**

11. **2 ATP**

12. **Pyruvate**

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KREBS CYCLE:

- glycolysis releases $<1/4$ of energy in glucose

- the majority remains in the 2 pyruvate

- IF molecular $O_2$ is present: pyruvate enters a mitochondrion, where enzymes of the KREBS CYCLE (a.k.a. the CITRIC ACID CYCLE) complete oxidation
**BUT FIRST....**

- Before the Krebs Cycle can begin, pyruvate must be converted to acetyl CoA, which links the cycle to glycolysis.
But FIRST:

2 Pyruvate $\rightarrow$ 2 acetyl CoA

This conversion occurs in 3 steps:

1) carboxyl group removed & given off as CO$_2$ 
   (2 CO$_2$ produced, 1 for each pyruvate)

2) each remaining 2-C fragment is oxidized forming acetate; the extracted electrons are transferred to NAD$^+$, forming NADH 
   (2 NADH produced, 1 for each fragment).
Final step of pyruvate $\rightarrow$ acetyl CoA step:

3) Coenzyme A (from vitamin B) is attached to acetate $\rightarrow$ acetyl CoA…

...on to the Krebs Cycle for further oxidation!
Pyruvate $\rightarrow$ Acetyl CoA

1. Pyruvate dehydrogenase
2. NAD$^+$ to NADH
3. Formation of CO$_2$ and Coenzyme A

Transport protein
Krebs Cycle (a.k.a. Citric Acid Cycle):
- 2 molecules of acetyl CoA enter the cycle (in the matrix of a mitochondrion) & each combine with a molecule of \textbf{OXALOACETATE}…
• For EACH molecule of acetyl CoA that enters:
  ➔ 2 molecules of CO₂ are given off
  ➔ 3 molecules of NADH are formed
  ➔ 1 molecule of FADH₂ is formed
  ➔ 1 molecule of ATP formed by substrate phosphorylation (direct transfer of $P_i$ to ADP from an intermediate substrate)
Pyruvate  
(from glycolysis,  
2 molecules per glucose)

\[ \text{NAD}^+ \xrightarrow{\text{pyruvate dehydrogenase}} \text{NADH} + H^+ \]

\[ \text{Acetyl CoA} \]

\[ \text{Citric acid cycle} \]

\[ 2 \text{CO}_2 \]

\[ 3 \text{NAD}^+ \]

\[ 3 \text{NADH} + 3 H^+ \]

\[ \text{FADH}_2 \]

\[ \text{FAD} \]

\[ \text{ADP} + P_i \xrightarrow{\text{ATP synthase}} \text{ATP} \]
- The Krebs Cycle has eight steps, each catalyzed by a specific enzyme;
- The acetyl group of acetyl CoA joins the cycle by combining with oxaloacetate, forming citrate;
- The next seven steps decompose the citrate back to oxaloacetate, making the process a cycle!
- The NADH and FADH\textsubscript{2} produced by the cycle relay electrons extracted from food to the electron transport chain.
Oxaloacetate makes this a CYCLE! (&, P.S., it is my #7 most favorite term in bio!) 😊
SO, since 2 molecules of acetyl CoA go through the cycle, the “totals” are:

- $4 \text{ CO}_2$
- $6 \text{ NADH}$
- $2 \text{ FADH}_2$
- $2 \text{ ATP formed}$
KREBS CYCLE ANIMATION!