Cellular Respiration

Big Picture

Cells require chemical energy to function. Energy cannot be recycled, so organisms require a constant input of energy, which is why humans need to eat. The process that requires oxygen and converts food into chemical energy (in the form of ATP) is cellular respiration. Cellular respiration can be summarized by:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + ATP$$

The general order of the processes is:

- Glycolysis
- Krebs Cycle
- Electron Transport Chain
- ATP Synthase

Realize that in general, the outputs of one process are the inputs of following processes. Knowing the inputs and outputs of each step is key to understanding cellular respiration!

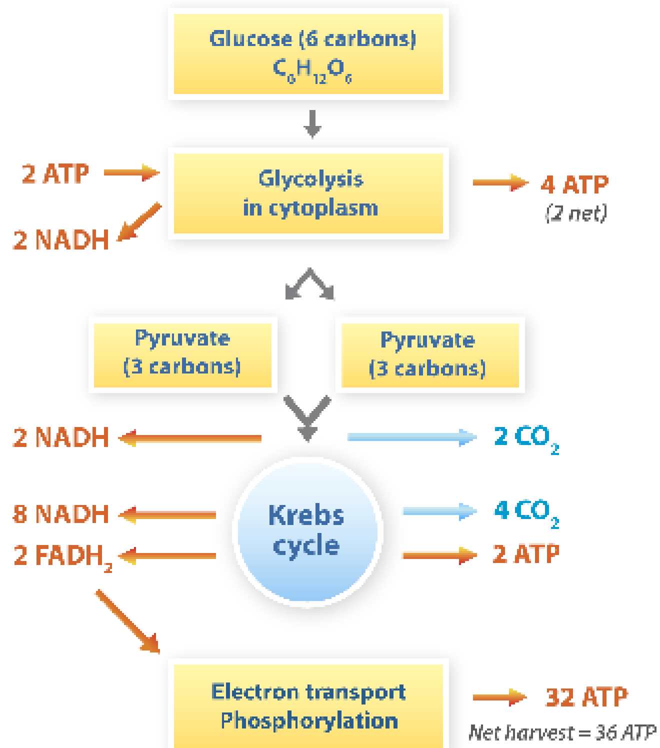

Image Credit: CK-12 Foundation, CC-BY-NC

Key Terms

Cellular Respiration: Process in which cells break down glucose and make ATP for energy.

Glycolysis: First stage of cellular respiration in which glucose is split, in the absence of oxygen, to form two molecules of pyruvate (pyruvic acid) and two (net) molecules of ATP.

Glucose: Simple carbohydrate with the chemical formula $C_6H_{12}O_6$ that is the nearly universal food for life.

Pyruvic Acid (aka **pyruvate**)**:** A 3-carbon molecule that results from the splitting of glucose.

ATP (adenine triphosphate): Energy-carrying molecule that cells use to power their metabolic processes.

ADP (adenine diphosphate): The molecule that results from dephosphorylation (a phosphate group is removed).

Krebs Cycle: Second stage of aerobic respiration in which two pyruvate (pyruvic acid) molecules from the first stage react to form ATP, NADH, and $FADH_2$.

NADH: Molecule that acts as an electron carrier in cellular respiration.

Electron Transport Chain (ETC): Series of electron-transport molecules that pass high-energy electrons from molecule to molecule and capture their energy.

Anaerobic Respiration: Type of cellular respiration that does not require oxygen.

Aerobic Respiration: Type of cellular respiration that requires oxygen.

Mitochondrion (plural, **mitochondria**)**:** Organelle in eukaryotic cells that makes energy available to the cell in the form of ATP molecules.

Fermentation: A type of anaerobic respiration that allows ATP to be made through glycolysis.

Notes

Cellular Respiration cont.

Stage I: Glycolysis

The first step in **cellular respiration** is **glycolysis**, an **anaerobic** process. Glycolysis occurs in several steps to split **glucose** and make **pyruvate**, **ATP**, and **NADH** in the cytosol of the cytoplasm. Pyruvate is used for the Krebs cycle while NADH is collected for the electron transport chain.

Stage II: Entering the Krebs Cycle

The next two stages of cellular respiration are **aerobic** processes that occur in the **mitochondria**.

Before the **Krebs cycle**, pyruvate is combined with an enzyme called CoA (Co-enzyme A) to form acetyl-CoA. Acetyl-CoA enters the Krebs cycle and combines with a four-carbon molecule to form citric acid.

A series of reactions releases energy from the carbon compounds, which is captured in molecules of $FADH_2$, NADH, and ATP.

Glycolysis producese two pyruvic acids, so it takes two turns through the Krebs cycle to completely breakdown the original glucose.

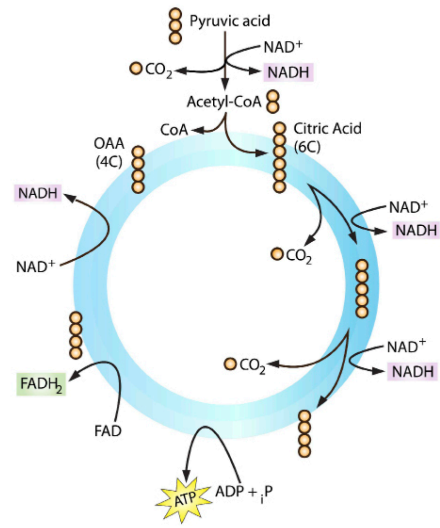

Figure: Krebs cycle

Image Credit: CK-12 Foundation, CC-BY-NC

Stage III: Electron Transport Chain and ATP Synthase

In the **electron transport chain (ETC)**, $FADH_2$ and NADH molecules from the Krebs cycle are oxidized. The oxidation of the electron carriers (NADH and $FADH_2$) produces H^+ ions and electrons.

- The released electrons travel along the protein complexes of the ETC, which pump the remaining H^+ ions into the intermembrane space.
- The H^+ ions are pumped across the inner membrane to create the gradient needed to power ATP synthase. The H^+ concentration gradient allows the H^+ ions to enter the matrix via ATP synthase, which creates ATP from ADP.

ETC is an aerobic process, as it requires oxygen molecules to attract and combine with the electrons at the end of the ETC to make water.

Cellular Respiration: Per Glucose

	Inputs	Outputs	Net Gain (per each process)
Glycolysis	1 Glucose 2 ATP	2 Pyruvates 4 ATP 2 NADH	2 Pyruvates 2 ATP 2 NADH
The Krebs Cycle	2 Acetyl-CoA	2 ATP 8 NADH 2 $FADH_2$	2 ATP 8 NADH 2 $FADH_2$
Electron Transport Chain	10 NADH 2 $FADH_2$	34 ATP	34 ATP
Total Molecules of ATP			38 ATP

Cellular respiration is very complex as it involves several reactions occurring. Because of its complexity, inefficiencies in some processes, such as the ETC and ATP synthase, often lead to less than 38 molecules of ATP produced by the end of cellular respiration (around 28 or 29 molecules).

Cellular Respiration cont.

Biology

Anaerobic Respiration

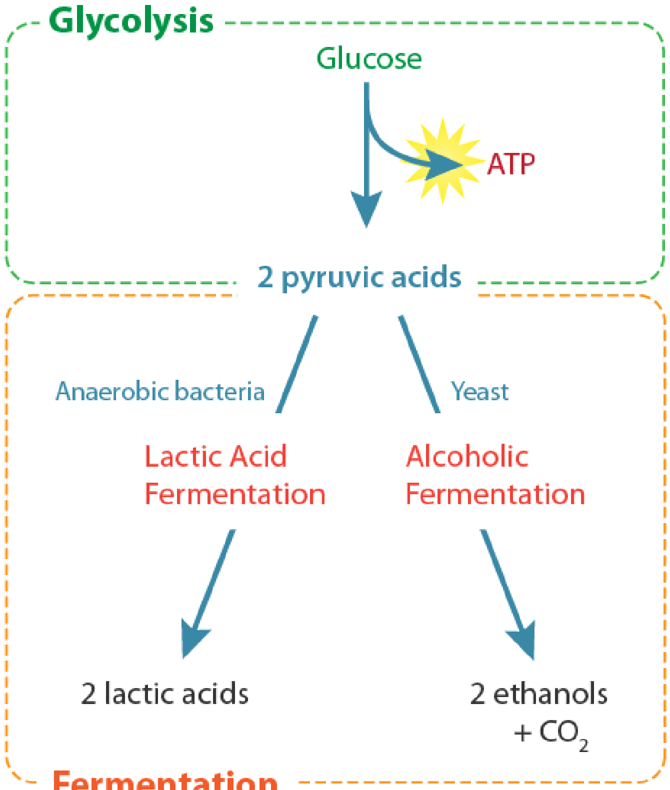

Image Credit: Jin Yu, CC-BY-NC-SA 3.0

While cellular respiration does require oxygen as a whole, glycolysis is an anaerobic process. Glycolysis is a part of both aerobic cellular respiration as well as anaerobic **fermentation**. The difference between the two processes is what happens to the pyruvate it makes afterwards!

Aerobic vs. Anaerobic Respiration

Aerobic respiration advantages:

- Produces a lot more ATP - aerobic respiration can produce 38 ATP, while anaerobic respiration can only produce 2 ATP

Anaerobic respiration advantages:

- Can produce energy when oxygen is not available
- Produces ATP very quickly

Fermentation

Fermentation does not produce ATP, but it re-generates NAD^+, which keeps the process of glycolysis moving. Glycolysis produces ATP, so fermentation allows for constant production of ATP. There are two types of fermentations:

Lactic acid fermentation:

- Pyruvic acid becomes lactic acid
- NADH becomes NAD^+, NAD^+ continues glycolysis
- Used by muscles when you work really hard
- The continuation of glycolysis allows the cell to make a total of 2 ATP molecules each time (compare to the 38 molecules of ATP produced in aerobic cellular respiration!)

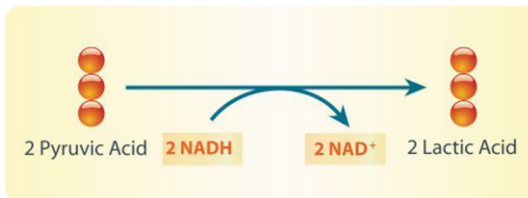

Image Credit: CK-12 Foundation, CC-BY-NC

Alcoholic fermentation:

- Pyruvic acid changes to ethanol and carbon dioxide
- NAD^+ is produced, which allows glycolysis to continue
- Used by yeast in bread (the carbon dioxide gas is what makes the small holes in bread)

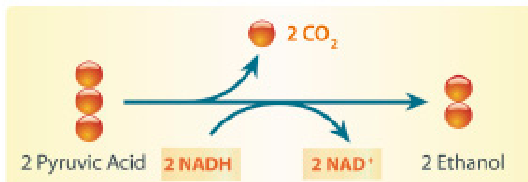

Image Credit: CK-12 Foundation, CC-BY-NC

Notes