Cellular Respiration

1) Glycolysis

> $C_6H_{12}O_6 + 2ADP + 2NAD \rightarrow 2C_3H_4O_3 + 4ATP + 2ADP + 2NADH$
> Glucose + 2 ATP + 4 ADP + 2 NAD+ → 2 Pyruvic Acid + 4 ATP + 2 ADP + 2 NADH
>
> **Simplified:**
>
> > $C_6H_{12}O_6 \rightarrow 2C_3H_4O_3$
> > Glucose → 2 Pyruvic Acid + energy

- Happens **outside the Mitochondria** in the cytoplasm
- Phosphorelates **2 ADP** to **2 ATP**
- Reduces **2 NAD**
- The process requires two ATP to begin
- All cellular respiration, **both aerobic and anaerobic,** goes through glycolysis

Aerobic respiration

> $C_6H_{12}O_6 + 6O_2 + 36ADP \rightarrow 6CO_2 + 6H_2O + 36ATP$
> Glucose + Oxygen + ADP → Carbon Dioxide + Water + ATP

- Cellular respiration is different from breathing
- Cellular respiration is a chemical reaction to break down glucose to release energy
- it is aerobic because of the **presence of oxygen**
- Each glucose produces **38 ATP**, it is very efficient

Overview of processes after Glycolysis

> $C_3H_4O_3 + 1ADP + 4NAD + 1FAD \rightarrow 3CO_2 + 1ATP + 4NADH + 1FADH$
> Pyruvic Acid + 1 ADP + 4 NAD + 1 FAD → 3 Carbon Dioxide + 1 ATP + 4 NADH + 1 FADH2
>
> **Simplified:**
>
> > $C_3H_4O_3 \rightarrow 3CO_2$
> > Pyruvic Acid → 3 Carbon Dioxide + Energy

Steps in Aerobic respiration

1) Glycolysis

2) Formation of Acetyl CoA (optional learning)

> $C_3H_4O_3 + C_{21}H_{36}N_7O_{16}P_3S + NAD \rightarrow CO_2 + C_{23}H_{38}N_7O_{17}P_3S + NADH$
> Pyruvic Acid + CoA + NAD+ → Carbon Dioxide + Acetyl CoA + NADH
>
> **Simplified:**
>
> > $C_3H_4O_3 + CoA \rightarrow CO_2 + ACoA$
> > Pyruvic Acid + CoA → Carbon Dioxide + Acetyl CoA + Energy

- **Not** part of the Krebs cycle, it happens before
- Gets the Pyruvic acid ready to be used in the krebs cycle
- Performed by the Pyruvate dehydrogenase

3) Krebs Cycle (Citric Acid cycle or TCA)

Overview of the Kerbs Cycle

> $C_{23}H_{38}N_7O_{17}P_3S + 4NAD + 1FAD \rightarrow C_{21}H_{36}N_7O_{16}P_3S + 2CO_2 + 4NADH + 1FADH$
> Acetyl CoA + 4 NAD + 1 FAD → CoA + 2 Carbon Dioxide + 4 NADH + 1 FADH
>
> **Simplified:**
>
> > $CoA–C_2H_2O \rightarrow CoA + 2CO_2 + 4NADH + 1FADH$
> > Acetyl CoA → CoA + 2 Carbon Dioxide + 4 NADH + 1 FADH

- Happens inside the **Mitochondria**
  - In the mitochondrial **Matrix**
- Reduces **4 NAD and 1 FAD** to **4 NADH and 1 FADH**

Steps in the Kerbs Cycle (optional learning)

1) Formation of Citrate

1. Formation of the Citryl CoA

> $C_{23}H_{38}N_7O_{17}P_3S + C_4H_2O_5 \rightarrow C_{27}H_{42}N_7O_{22}P_3S$
> Acetyl CoA + Oxaloacetate (4C) → Citryl CoA
>
> **Simplified:**
>
> > $CoA–C_2H_2O + C_4H_2O_5 \rightarrow CoA–C_6H_6O_6$
> > Acetyl CoA + Oxaloacetate (4C) → Citryl CoA

2. Formation of the Citrate

> $C_{27}H_{42}N_7O_{22}P_3S + H_2O \rightarrow C_{21}H_{36}N_7O_{16}P_3S + C_6H_5O_7 + H$
> Citryl CoA + Water → CoA + Citrate + Hydrogen
>
> **Simplified:**
>
> > $AoC–C_6H_6O_6 + H_2O \rightarrow CoA + C_6H_5O_7$
> > Citryl CoA + Water → CoA + Citrate

Overview

> $C_{23}H_{38}N_7O_{17}P_3S + C_4H_2O_5 + H_2O \rightarrow C_{21}H_{36}N_7O_{16}P_3S + C_6H_5O_7 + H$
> Acetyl CoA + Oxaloacetate (4C) + Water → CoA + Citrate (6C) + Hydrogen
>
> **Simplified:**
>
> > $CoA–C_2H_2O + 4C \rightarrow CoA + 6C$
> > Acetyl CoA + Oxaloacetate (4C) → CoA + Citrate (6C)

2) Formation of Isocitrate

> $C_6H_5O_7 \rightarrow C_6H_5O_7$
> Citrate → Isocitrate

- The Chemical formula is the same, but the bonds are in different places
- This process consists of removing the water molecule and readding it in a different place

3) Formation of α-ketoglutarate and oxidation of Isocitrate

> $C_6H_5O_7 + NAD \rightarrow C_5H_4O_5 + CO_2 + NADH$
> Isocitrate (6C) + NAD → α-glutenate (5C) + Carbon Dioxide + NADH
>
> **Simplified:**
>
> > $6C \rightarrow 5C + CO_2$
> > Isocitrate (6C) → α-glutenate (5C) + Carbon Dioxide + NADH

- Produces **1 NADH**

4) Formation of Succinyl CoA and oxidation of the ketoglutarate

> $C_5H_4O_5 + NAD + C_{21}H_{36}N_7O_{16}P_3S \rightarrow C_{25}H_{40}N_7O_{19}P_3S + CO_2 + NADH$
> α-glutenate (5C) + NAD + CoA → Succinyl CoA + Carbon Dioxide + NADH
>
> **Simplified:**
>
> > $5C + CoA \rightarrow CoA–C_4H_4O_3 + CO_2$
> > α-glutenate (5C) + CoA → Succinyl CoA + Carbon Dioxide + NADH

- Produces **1 NADH**

5) Formation of Succinate

> $C_{25}H_{40}N_7O_{19}P_3S + ADP \rightarrow C_4H_4O_4 + CoA + ATP$
> Succinyl CoA + ADP → Succinate (4C) + CoA + ATP
>
> **Simplified:**
>
> > $CoA\text{–}C_4H_4O_3 \rightarrow 4C + CoA + ATP$
> > Succinyl CoA → Succinate (4C) + CoA + ATP

- ATP production is actually from GDP→GTP, which's phosphate group gets moved to an ADP, making it an ATP
- Produces **1 ATP**

6) Production of Fumarate and oxidation of Succinate

> $C_4H_4O_4 + FAD \rightarrow C_4H_2O_4 + FADH_2$
> Succinate (4C) + FAD → Fumarate (4C) + FADH2
>
> **Simplified:**
>
> > $4C + FAD \rightarrow 4C + FADH_2$
> > Succinate (4C) + FAD → Fumarate (4C) + FADH2

- Produces **1 FADH2**

7) Production of Malate

> $C_4H_2O_4 + H_2O \rightarrow C_4H_4O_5$
> Fumarate (4C) + Water → Malate (4C)
>
> **Simplified:**
>
> > $4C + H_2O \rightarrow 4C$
> > Fumarate (4C) + Water → Malate (4C)

8) Production of Oxaloacetate and oxydation of Malate

> $C_4H_4O_5 + NAD \rightarrow C_4H_2O_5 + NADH$
> Malate (4C) + NAD → Oxaloacetate (4C) + NADH
>
> **Simplified:**
>
> > $4C + NAD \rightarrow 4C + NADH$
> > Malate (4C) + NAD → Oxaloacetate (4C) + NADH

- Produces **1 NADH**

4) Electron Transport Chain

The Hydrogen and electrons from the Hydrogen carriers (NADH + FASH) are released, which creates a **positive concentration gradient**, which forces the **ATP Synthase** to produce ATP from ADP.

- Happens inside the Mitochondria
  - In the inner mitochondrial membrane (crystae)
- The 4 Complexes remove Hydrogen from the Hydrogen carriers
  - Complex 1 converts NADH to NAD+
  - Complex 2 converts FADH2 to FAD
  - Complex 3 uses additional energy from complex 1 and 3 to pump additional protons (hydrogen ions) to the Intermembrane Space
  - Complex 4 helps produce Water using Hydrogen and Oxygen
- The positive proton gradient of the Intermembrane Space pushes the ATP synthase to produce ATP from ADP
  - The process of making ATP takes the Hydrogen from the Intermembrance space back into the Matrix
- Additionally, Oxygen will bond with the uncharged Hydrogen to take away extra Hydrogen

Carrier	ATP produced
NADH	3 (or 2.5) ATP
FADH	2 (or 1.5) ATP

Aerobic Respiration Summary

-	Number of ATP produced	Number of NADH produced	Number of FADH produced
-	-	NADH	FADH
Glycolysis	2 ATP	2 NADH	0 FADH
Krebs Cycle	2 ATP	8 NADH	2 FADH
Electron Transport Chain	-	x3	x2
Total ATP produced	4ATP	30 ATP	4 ATP
Grand Total			38 ATP

Anaerobic respiration

Animal Cells (Lactic Acid Fermentation)

> $C_6H_{12}O_6 \rightarrow 2C_3H_6O_3 + 2ATP$
> Glucose → Lactic acid + Chemical Energy

- Very ineffecient, only produces **2 ATP**
- When you accumulate lactic acid, it is called oxygen debt, because you owe oxygen to your body (lactic acid)
- Lactic acid is **harmful** to your body
- Is only used in emergencies to quickly make energy
- This whole process is called **Fermentation**

NADH+ regeneration

> $C_3H_4O_3 + 2NADH \rightarrow C_3H_6O_3 + 2NAD$
> Pyruvic Acid + 2 NADH → Lactic Acid + 2NAD
>
> **Simplified:**
>
> > $C_3H_4O_3 \rightarrow C_3H_6O_3 + 2NAD$
> > Pyruvic Acid → Lactic Acid + 2 NAD

- Converts the Pyruvic Acid into Lactic Acid
- Recycles the NADH back to NAD+ so that it can be reused in Glycolysis

Anaerobic Respiration Summary

- Happens **outside the Mitochondria**
- Phosphrelates **2 ADP** to **2 ATP**
- The process requires two ATP to begin (Glycolysis)

-	Number of ATP produced	Number of H-carriers produced
-	-	NADH
Glycolysis	2 ATP	2 NADH
NAD+ regeneration	-2 NADH	
Grand Total	2 ATP	

Repaying the Oxygen Debt

> $C_3H_6O_3 + 3O_2 \rightarrow 3CO_2 + 3H_2O$
> Lactic acid + Oxygen → Carbon Dioxide + Water

- Break down lactic acid by adding oxygen
- Does not produce any energy at all

- Aerobic process
- Having Lactic Acid is called having an Oxygen debt

Yeast Cells (Alcoholic Fermentation)

> $C_6H_{12}O_6 \rightarrow 2C_2H_6O + 2CO_2 + 2ATP$
> Glucose → Ethanol + Carbon Dioxide + Chemical Energy

- Very ineffecient, only produces **2 ATP**
- Ethanol is toxic to yeast, and cannot be reversed
  - The Oxygen debt **cannot be reversed**
- Is only used in emergencies to quickly make energy
- Happens **outside the Mitochondria**
- The process requires two ATP to begin, and makes 4 ATP, making a net gain of 2 ATP

Steps of fermentation

1) Pyruvate Oxidation

> $C_3H_4O_3 \rightarrow C_2H_4O + CO_2$
> Pyruvic acid → Acetaldehyde + Carbon Dioxide

2) NAD+ Regeneration

> $C_2H_4O + 2NADH \rightarrow C_2H_6O + 2NAD$
> Acetaldehyde + 2 NADH → Ethanol + 2NAD
>
> **Simplified:**
>
> > $C_2H_4O \rightarrow C_2H_6O + 2NAD$
> > Acetaldehyde → Ethanol + 2 NAD

Anaerobic Respiration Summary

-	Number of ATP produced	Number of H-carriers produced
-	-	NADH
Glycolysis	2 ATP	2 NADH
Further Fermentation		-2 NADH
Grand Total	2 ATP	