CELL RESPIRATION

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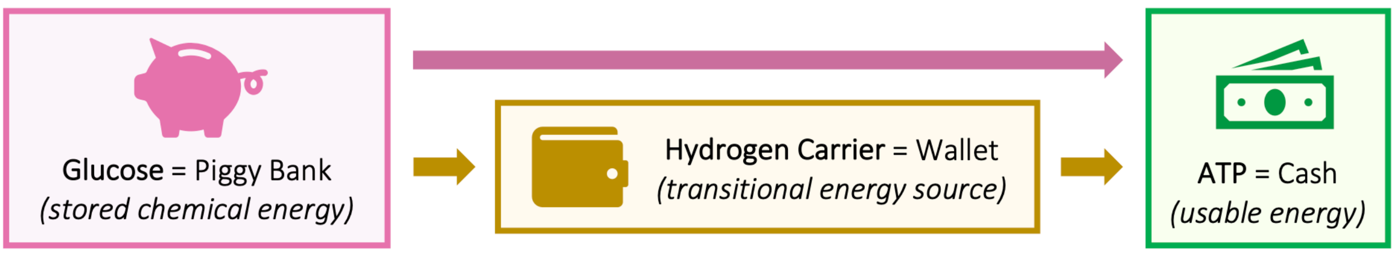
ENERGY CONVERSIONS

Organic molecules store energy in their chemical bonds – but this energy is not easily accessible for use by the cell. Cell respiration transfers this stored energy into **coenzymes**. Two types of coenzymes are used:

- **ATP:** Immediately available energy source (energy is released for use when ATP is hydrolysed to ADP)
- **Hydrogen carriers:** Transitional energy source (carries high energy electrons and protons for transfer)

ATP can be produced directly from organic molecules via substrate level phosphorylation (**pink arrow**) or it can be indirectly synthesised by hydrogen carriers (needs O_2) via oxidative phosphorylation (**yellow arrow**).



TYPES OF CELL RESPIRATION

Cell respiration involves one of two reaction pathways – either anaerobic respiration or aerobic respiration.

ANAEROBIC RESPIRATION	AEROBIC RESPIRATION
Partial digestion of glucose (to pyruvate)	**Complete** breakdown of glucose (to CO_2 and H_2O)
Oxygen **not** required for a **small** ATP yield	Oxygen **is** required for a **large** yield of ATP
Occurs entirely in the **cytosol**	Requires the **mitochondria**

ANAEROBIC RESPIRATION

Anaerobic respiration involves the partial breakdown of carbohydrates (glucose) in the absence of oxygen. It occurs in the **cytosol** and results in a low yield of ATP (net production = 2 ATP). This ATP is produced via substrate level phosphorylation. The process of anaerobic respiration involves glycolysis and fermentation.

GLYCOLYSIS

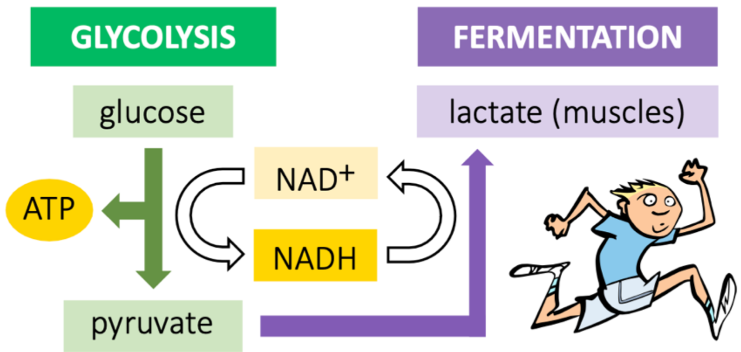
Both anaerobic and aerobic respiration begins with the breakdown of glucose in the cytosol via glycolysis. Glycolysis splits glucose into two molecules of **pyruvate** in a process that consumes two molecules of ATP. However, four molecules of ATP are produced via substrate level phosphorylation, resulting in a **net gain** of **two ATP** molecules. Additionally, the coenzyme NAD is loaded with hydrogen to form molecules of **NADH**.

$C_6H_{12}O_6$ (*Glucose*) + 2 ATP → 2 × $C_3H_4O_3$ (*Pyruvate*) + **NADH** (*Hydrogen carrier*) + **4 ATP**

ENERGY INVESTMENT | **ENERGY PAYOFF (COENZYME LOADING)**

FERMENTATION

In the presence of oxygen, the hydrogen carriers produced by glycolysis may be used by the mitochondria to produce large amounts of ATP (via oxidative phosphorylation). However, in the absence of oxygen the hydrogen carriers must be unloaded to allow for glycolysis to continue (NADH must be unloaded to NAD). Fermentation involves the conversion of pyruvate via a reaction that unloads hydrogen carriers to restore stocks of NAD. In plants and yeasts, pyruvate is irreversibly converted into **ethanol** and **carbon dioxide**. In animals, pyruvate is converted into **lactic acid** (however, this reaction can be reversed if oxygen is present).



Fermentation Applications:

The products of fermentation may be used for variety of practical applications

Carbon dioxide causes bread to rise via leavening, while ethanol functions as an intoxicating agent in alcohol beverages

AEROBIC RESPIRATION

Aerobic respiration completes the breakdown of glucose begun by glycolysis. This process requires oxygen and occurs within the mitochondrion. The process of aerobic respiration involves three distinct reactions:

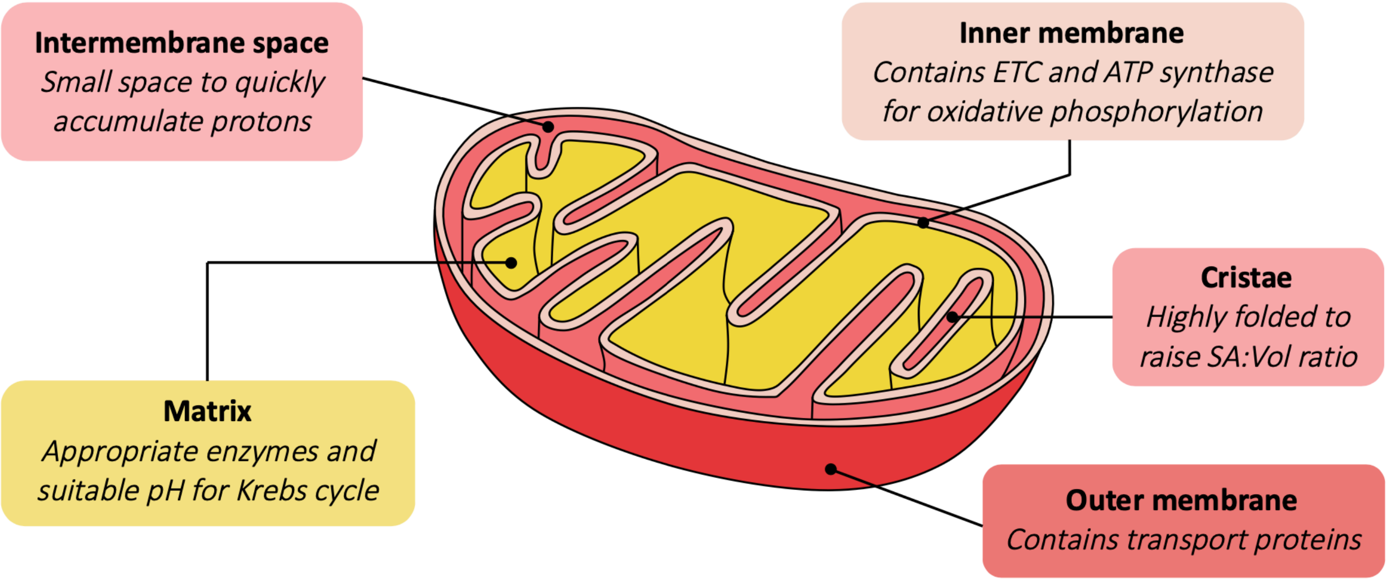
- **Link Reaction:** Pyruvate is shuttled into the mitochondria and converted into **acetyl CoA** (CO_2 released)
- **Krebs Cycle:** Pyruvate is broken down to make carbon dioxide and large amounts of hydrogen carriers
- **Electron Transport Chain:** Hydrogen carriers are unloaded to produce ATP (oxidative phosphorylation)

$C_6H_{12}O_6$ (*Glucose*) + 6 O_2 (*Oxygen*) → 6 CO_2 (*Carbon dioxide*) + 6 H_2O (*Water*) + **30 ATP**

MITOCHONDRIA

The mitochondrion is an organelle in eukaryotic cells that is responsible for aerobic respiration. It is believed to have evolved via endosymbiosis, when an aerobic bacterium was engulfed by another prokaryotic cell. Evidence for this endosymbiotic origin includes the fact that the mitochondrion possesses circular DNA, 70S ribosomes has a double membrane. In terms of structure, the central region is called the **matrix** and is the location of the Krebs cycle. Mitochondria contain an inner membrane that is highly folded into **cristae**. The cristae are the site of the electron transport chain. By folding the inner membrane, the SA:Vol ratio is increased, which optimises electron transport.

Mitochondrion

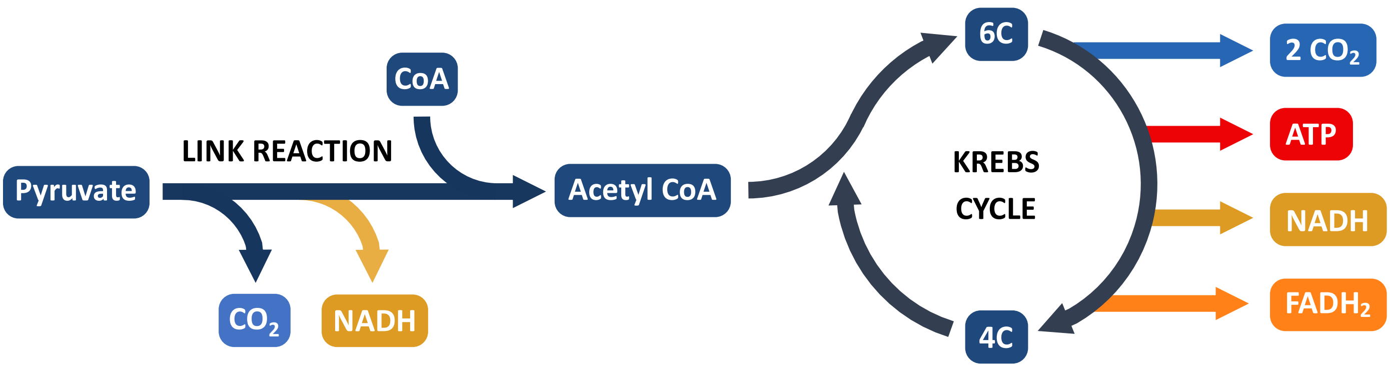


LINK REACTION

The link reaction connects the products of glycolysis with the aerobic processes in mitochondria. Pyruvate is transported from the cytosol into the matrix by carrier proteins on the mitochondrial membrane. It then loses a carbon atom (to form carbon dioxide) and hydrogen atoms (NAD is reduced to NADH). The acetyl compound is then combined to coenzyme A to form a final compound of acetyl coenzyme A (**acetyl CoA**).

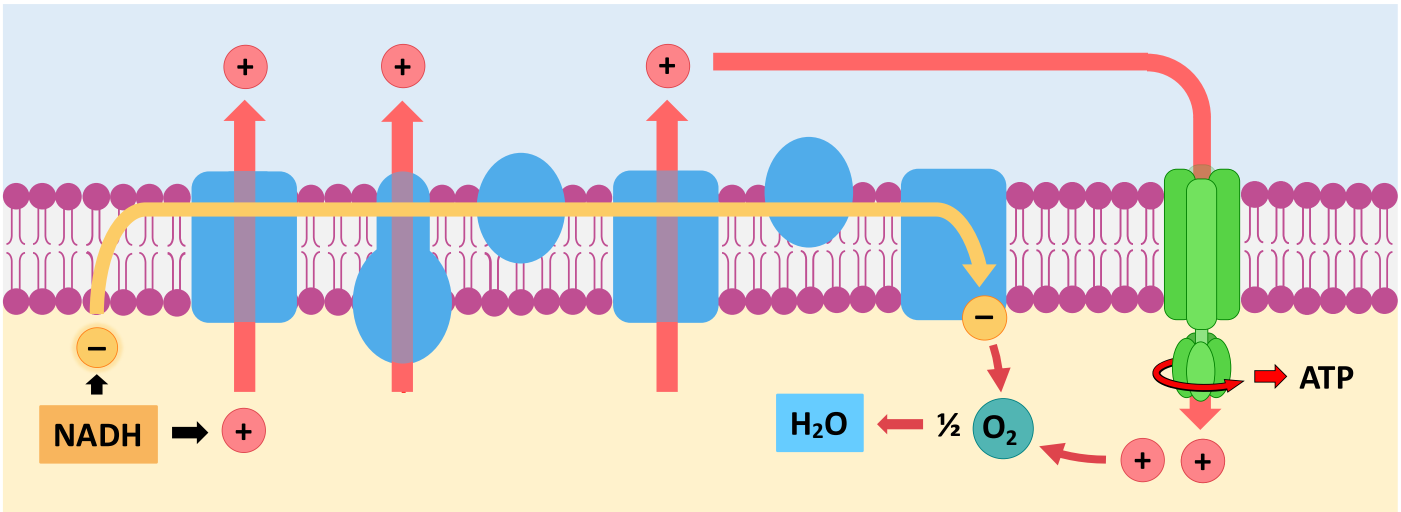
KREBS CYCLE

The acetyl CoA is combined with a 4C compound to make a 6C intermediate. This is then broken back down into the original 4C compound over a series of reactions collectively called the Krebs cycle (citric acid cycle). Each Krebs cycle produces carbon dioxide molecules, a small yield of ATP and a large quantity of hydrogen carriers (NADH and $FADH_2$). These hydrogen carriers will then be unloaded via the electron transport chain.



ELECTRON TRANSPORT CHAIN

Hydrogen carriers (NADH + $FADH_2$) are unloaded in the matrix to release protons and energised electrons. The electrons move across an electron transport chain on the inner membrane and become de-energised. The energy is used to pump protons into the intermembrane space, creating an electrochemical gradient. The protons diffuse back into the matrix via a transmembrane enzyme called **ATP synthase**, which uses the movement to catalyse ATP synthesis. The diffusion of protons down an electrochemical gradient is referred to as **chemiosmosis**. For the electron transport chain to continue to function, the de-energised electrons must be removed from the chain. **Oxygen** acts as the terminal electron acceptor, combining the electrons with protons in the matrix to form water. Because the synthesis of ATP involved the oxidation of hydrogen carriers, the ATP is produced via *oxidative* phosphorylation (as opposed to substrate level phosphorylation).



ENERGY SOURCES

Cell respiration involves the breakdown of organic compounds. Carbohydrates (glucose) are typically used as substrates for aerobic or anaerobic respiration because they are easy to digest and transport. Lipids are used as an alternative energy source, but can only be used aerobically – fatty acid chains are broken down into 2C compounds that form acetyl CoA (bypassing glycolysis). Lipids produce **more energy per gram** than carbohydrates as the carbon chains possess fewer oxygen but have more oxidizable hydrogen and carbon.