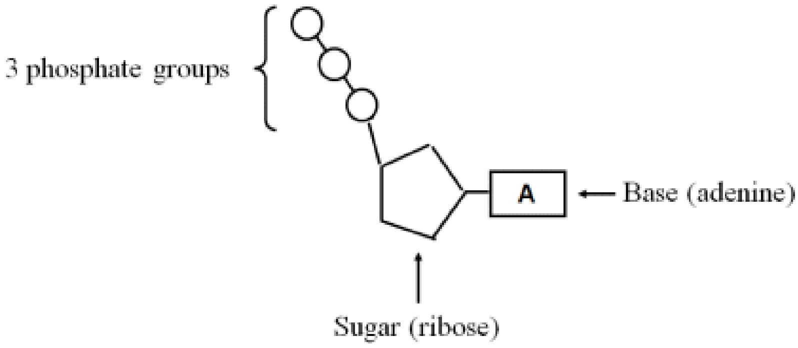
CAIE Biology A-level

Topic 12: Energy and respiration

Notes

ATP

Adenosine triphosphate is a nucleotide derivative and consists of ribose, adenine and three phosphate groups. It is a small, soluble molecule that provides a short-term energy store.



- Energy is released when ATP is hydrolysed to form ADP and an inorganic phosphate. This process is catalysed by ATP hydrolase.
- The inorganic phosphate can be used to phosphorylate other compounds, making them more reactive.
- During photosynthesis and respiration, condensation of ADP and inorganic phosphate is catalysed by ATP synthase to produce ATP.

ATP as a universal energy currency: ATP is used in all living organisms for different purposes. ATP hydrolysis can be carried out quickly wherever energy is needed within a cell, as it releases a useful amount of energy that is manageable. ATP is also relatively stable at normal cell pH levels. Living organisms need energy, specifically for active transport, movement, and anabolic reactions (e.g., DNA replication and protein synthesis).

ATP is synthesised by:

1. Chemiosmosis
    - The movement of protons down an electrochemical gradient across a membrane through ATP synthase, driving the synthesis of ATP.
    - Protons move down an electrochemical gradient through ATP synthase in the inner mitochondrial membrane.
    - The energy released as protons pass through ATP synthase is used to phosphorylate ADP to ATP.

2. Substrate-level phosphorylation
    - ATP is made from ADP and a phosphate group which is transferred from a highly reactive intermediate.
    - An example would be during glycolysis - ADP joins with the inorganic phosphates transferred from triose bisphosphate molecules forming 4 ATP per glucose molecule (net gain of 2 ATP).
    - This also happens in the Krebs cycle.

Respiration

Respiration is the breakdown of a **respiratory substrate** such as glucose to **release energy** that is used to **synthesise ATP via enzyme-controlled reactions**. There are two types of respiration:

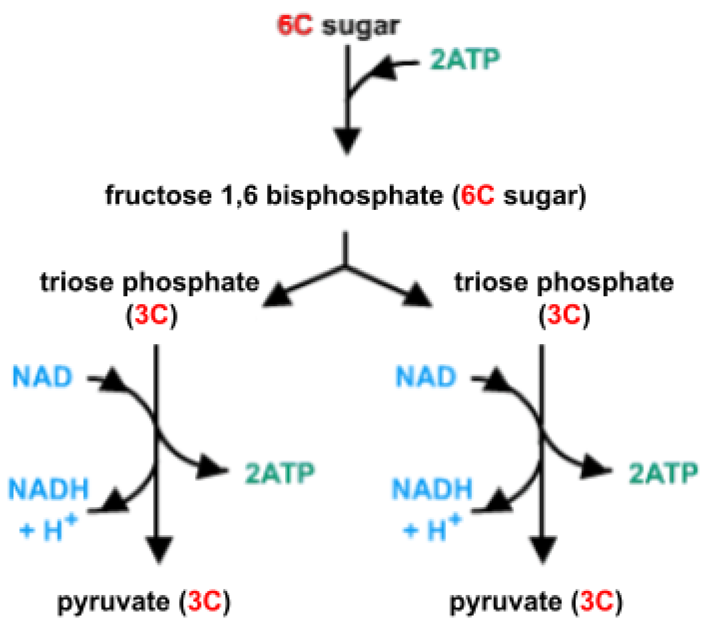
- **Aerobic** - occurs in the presence of oxygen. Produces large amounts of ATP.
- **Anaerobic** - occurs in the absence of oxygen. Produces less ATP and is less efficient.

Some organisms and tissues are able to respire in both aerobic and anaerobic conditions. When yeast and plants respire under anaerobic conditions, they produce ethanol and carbon dioxide as end-products; mammalian muscle tissue produces lactate when oxygen is in low supply, which is associated with muscle fatigue.

Respiration is a **multi-step process** with each step catalysed by a **specific intracellular enzyme**.

Glycolysis

Glycolysis is the first process of both aerobic and anaerobic respiration. This process occurs in the cytoplasm of cells.



In this process, glucose is **phosphorylated** to produce **fructose 1,6 bisphosphate (6C)**. 2 ATP is used in this process. **Fructose 1,6 bisphosphate (6C)** then breaks into 2 triose phosphate (3C) molecules. Each triose phosphate molecule is then oxidised to pyruvate, producing ATP and NADH. Overall, the conversion of the two triose phosphate molecules to pyruvate produces 4 ATP and 2 NADH. However, since 2 ATP is used at the start of the process to phosphorylate the glucose, the **net product of glycolysis** would be **2 pyruvate molecules, 2 ATP and 2 NADH.**

If there is sufficient oxygen, then pyruvate will enter the mitochondrial matrix for the link reaction. In anaerobic respiration, pyruvate is converted into lactate using hydrogen from NADH. In the presence of oxygen, lactate is converted back to pyruvate in the liver.

Link Reaction

The next step of aerobic reaction is the link reaction, which takes place in the mitochondrial matrix.

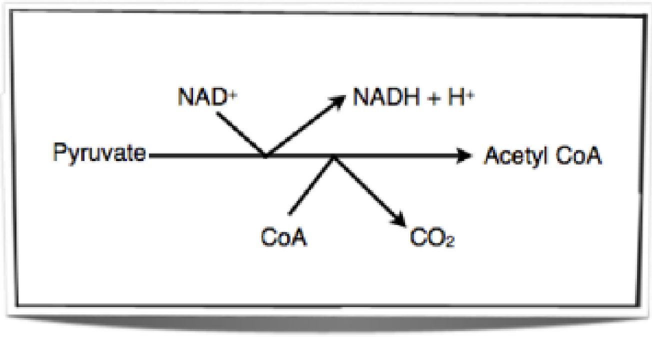


Figure: IB guides

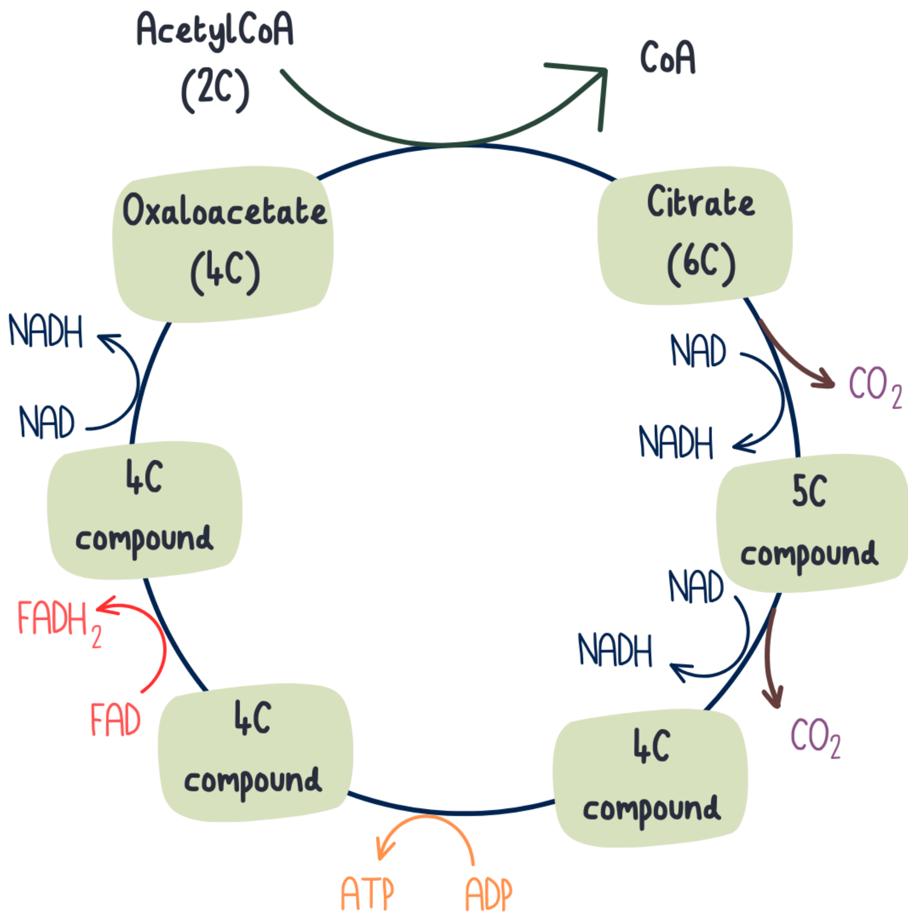
- Pyruvate enters the matrix of the mitochondria from the cytoplasm via carrier proteins.
- First, pyruvate undergoes oxidative decarboxylation which forms an acetyl group (2C) and NADH.
- Coenzyme A becomes bound to the acetyl group forming Acetyl coenzyme A (CoA)
- This helps deliver the acetyl group to the next stage of respiration.

Each glucose molecule produces 2 pyruvates from glycolysis hence the link reaction produces a total of 2 carbon dioxide, 2 NADH and 2 acetyl coenzyme A molecules.

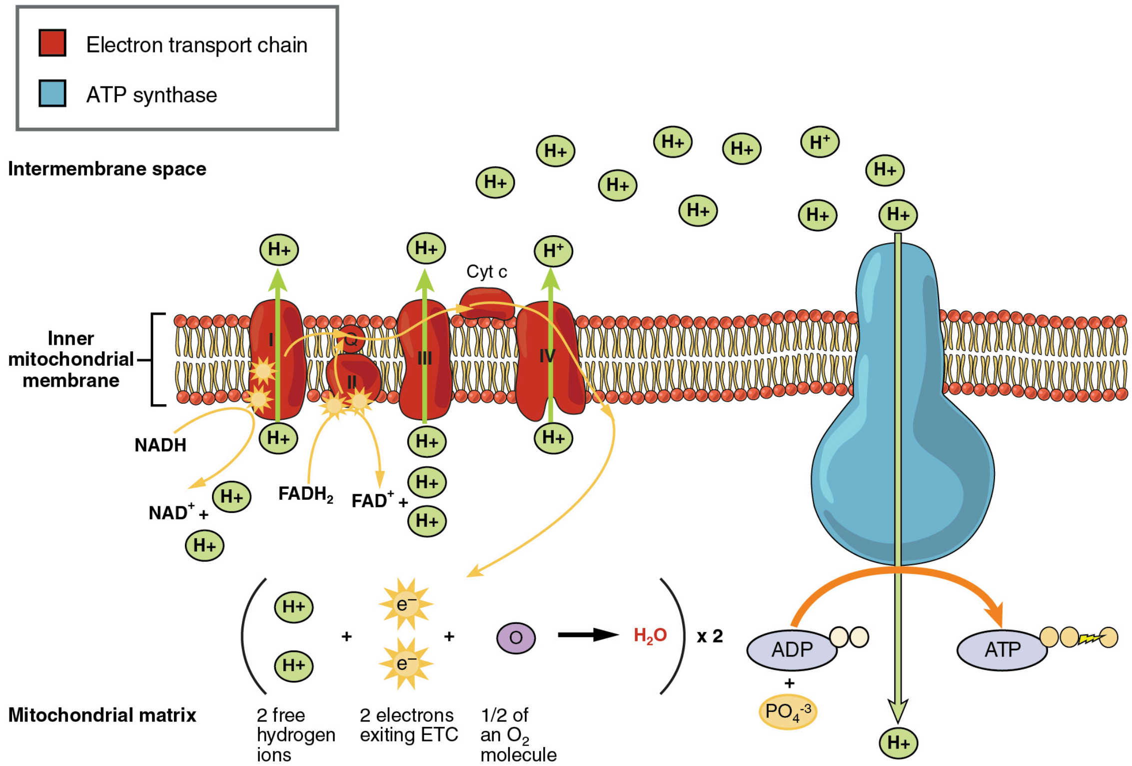
Krebs cycle

- Acetyl coenzyme A delivers the acetyl group to the Krebs cycle which also happens in the mitochondrial matrix.
- The 2C acetyl group is accepted by the 4C oxaloacetate forming 6C citrate.
- 6C citrate undergoes decarboxylation (removal of carbon dioxide) and dehydrogenation (removal of hydrogen) forming a 5C compound, carbon dioxide and NADH.
- The compound then undergoes further decarboxylation and dehydrogenation reactions until 4C oxaloacetate is reformed. Along this process, carbon dioxide, ATP, **NADH and $FADH_2$** are produced.

The Krebs Cycle must take 2 turns per glucose molecule.



Oxidative phosphorylation



Oxidative phosphorylation is the process in which ATP is synthesised in the **electron transport chain** in mitochondria. This takes place on the mitochondria's **inner membrane**.

This process generates the majority of ATP in aerobic respiration and it occurs as follows:

- Reduced coenzymes carry **hydrogen atoms** to the electron transport chain which occurs on the **inner mitochondrial membrane.**
- Hydrogen atoms dissociate into **protons (H+)** and **energetic electrons.**
- The electrons move through the **electron transport chain and** the proton gradient drives ATP synthesis through **chemiosmosis**.
- Electrons are carried from one electron carrier to another in a series of **redox reactions**: **the electron carrier** which passes the electron on is oxidised whereas the electron carrier which receives it is reduced.
- **Hydrogen ions (H+)** move across the membrane into the **intermembrane space**, causing a **higher** H+ concentration in the **intermembrane space** than the **matrix.**
- Hydrogen ions diffuse through **ATP synthase** by facilitated diffusion into the **mitochondrial matrix** down the **electrochemical gradient.**
- This provides energy for the **phosphorylation** of ADP to produce ATP. This requires the presence of oxygen (oxidative phosphorylation).
- Hydrogen ions and electrons combine with **oxygen** to form **water**.

Respiratory substrates

Respiratory substrates include **carbohydrates, lipids and proteins** which release varying amounts of energy, depending on the number of hydrogens in the structure which are oxidised to water. For instance, the number of hydrogens is greater in fatty acids than carbohydrates.

The **respiratory quotient (RQ)** can be measured to determine which respiratory substrate is being used and whether anaerobic respiration is occurring.

RQ = carbon dioxide produced / oxygen consumed

Different respiratory substrates have different RQ values:

Respiratory substrates	RQ values
Carbohydrates	≈ 1.0
Lipids	≈ 0.7
Proteins	≈ 0.9

Rice adaptations:

- Rice grows with its roots **submerged in water.**
- Rice is adapted to grow in water via **ethanol fermentation** in roots (in addition to aerenchyma) to survive anaerobic conditions.
- A large amount of **aerenchyma** is present in the **stem** and the **roots** which facilitates **gaseous exchange**. This allows oxygen to enter the roots for aerobic respiration.
- When the plant is submerged under too much water, the plant stem will undergo fast growth to help keep the top of the plant above water.

Anaerobic respiration

Lactate fermentation

- Occurs in mammals.
- **Pyruvate** acts as a hydrogen acceptor from the NADH.
- This is catalysed by **lactate dehydrogenase.**
- Forms lactate and regenerates NAD.
- In the presence of oxygen, the **lactate can be converted back into pyruvate** in the liver.

Alcohol fermentation

- Occurs in yeast.
- This process is **irreversible in anaerobic conditions.**
- Pyruvate undergoes decarboxylation forming ethanal.
- The ethanal then acts as a hydrogen acceptor from NADH.
- Produces ethanol which is toxic to yeast cells and NAD is regenerated.

Aerobic respiration has a **much higher yield of ATP** than anaerobic respiration because it completely breaks down glucose.