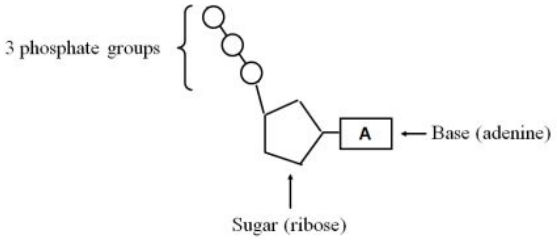
CAIE Biology A-level

Topic 12: Energy and respiration

Notes

ATP

Adenosine triphosphate is a nucleotide derivative and consists of **ribose, adenine and three phosphate groups**.



- **Energy is released when ATP is hydrolysed** to form **ADP and a phosphate molecule**. This process is catalysed by **ATP hydrolase**.

- The **inorganic phosphate can be used to phosphorylate other compounds**, as a result making them more reactive.

- **Condensation of ADP and inorganic phosphate catalysed by ATP synthase produces ATP** during photosynthesis and respiration.

ATP is synthesised by:

1. **Chemiosmosis**
    - The movement of **protons** across a membrane which synthesises ATP
    - Protons **diffuse down a concentration gradient** through a **partially permeable membrane**
    - As protons flow down energy is **released**
    - The energy is used in the attachment of ADP to an inorganic phosphate

2. **Substrate-level phosphorylation**
    - When 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 molecules).
    - This also happens in the **Krebs cycle**

Respiration

Respiration is the breakdown of a **respiratory substrate** such as glucose to **produce energy** in the form of ATP. There are two types of respiration:

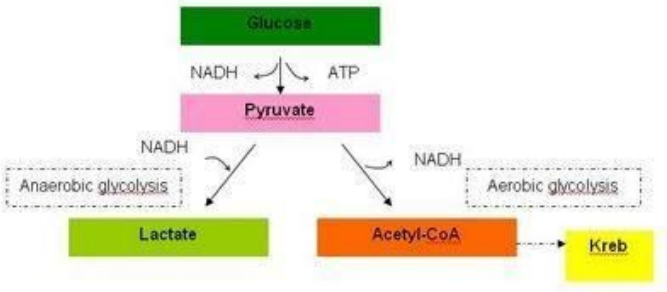
- **Aerobic**- occurs in the presence of oxygen. Produces large amounts of ATP.
- **Anaerobic**- occurs in the absence of oxygen. Produces less ATP and is less efficient.

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 causes 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. In aerobic respiration which occurs in cytoplasm of cells.



In this process glucose is **phosphorylated** to produce **1,6 bisphosphate (6C)**. This then breaks into 2 triose phosphate (3C) molecules. Each triose phosphate is then further oxidised into pyruvate producing 2 ATP molecules and 1 reduced NAD per triose phosphate molecule.

Overall 1 glucose molecule produces; two pyruvate molecules, 2 ATP and 2 NADH through glycolysis.

If there is **sufficient oxygen** then pyruvate will enter the mitochondrial matrix for the **link reaction.**

In **anaerobic respiration** the pyruvate is further converted into lactate with the help of NADH. **Lactate** is then converted back to pyruvate in the liver.

The link reaction

The next step of aerobic reaction is **the link reaction**.

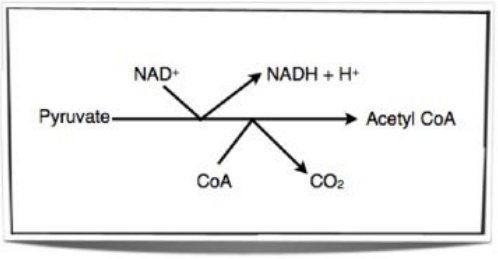


Figure: IB guides

- Pyruvate enters the **mitochondrial matrix** via **active transport**
- 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

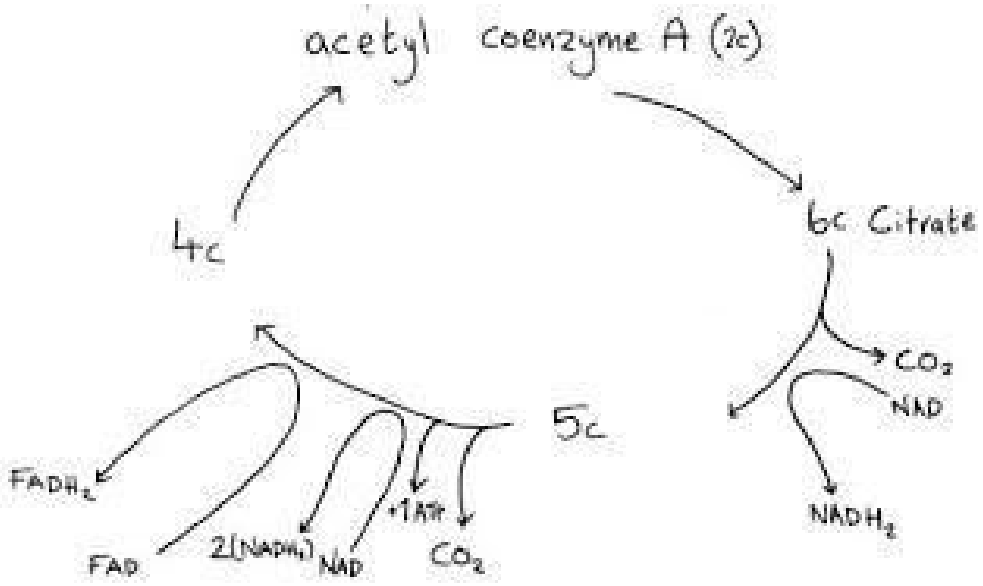
Each glucose molecule produces 2 pyruvates hence the link reaction produces a total of 2 carbon dioxide, 2 NADH and 2 acetyl coenzyme A's.

Krebs Cycle

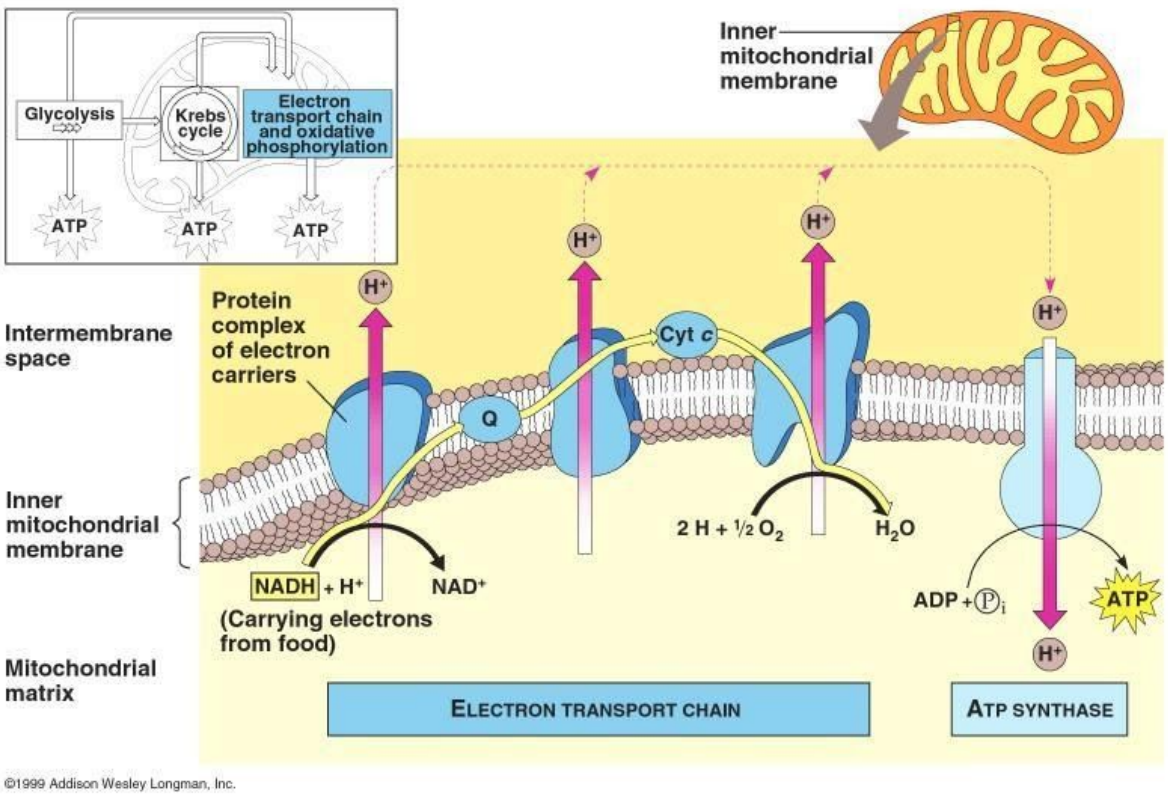
- Acetyl coenzyme A delivers the acetyl group to the Krebs cycle which also happens in the mitochondrial matrix

- 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 reduced NAD
- The compound then undergoes further decarboxylation and dehydrogenation (around 4 times) until eventually 4C oxaloacetate is reformed. During this carbon dioxide, ATP, **reduced NAD and reduced FAD** 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 following:

- Reduced coenzymes carry **hydrogen atoms** to the electron transport chain which occurs on the **inner mitochondrial membrane**
- Hydrogen atoms dissociate into **protons** and **energetic electrons**
- The electrons move through the **electron transport chain** and and protons synthesise ATP 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** move across the membrane into the **intermembrane space** – as a result of this, the concentration of the hydrogen ions in the **intermembrane space** is high
- Hydrogen ions go 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 atoms are produced from hydrogen ions and electrons. The **hydrogen atoms are then combined with oxygen to produce water**

- Approximately 4 hydrogen ions produce one ATP molecule.

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 to determine if the organism is undergoing anaerobic respiration.

RQ = carbon dioxide produced / oxygen consumed

Different respiratory substrates have different RQ values e.g. carbohydrates have a value of 1.0, lipids – 0.8 and proteins 0.9.

Rice adaptations:

- Rice grows with its roots **submerged in water**
- Large number of **aerenchyma** 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

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

Alcohol fermentation

- Happens in yeast
- **Irreversible**
- Pyruvate undergoes decarboxylation forming ethanal
- The ethanal then acts as a hydrogen acceptor from NADH
- Produces ethanol which is a 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.