OCR (B) Biology A-level

4.1 Energy, Metabolism and Exercise

Notes

ATP

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

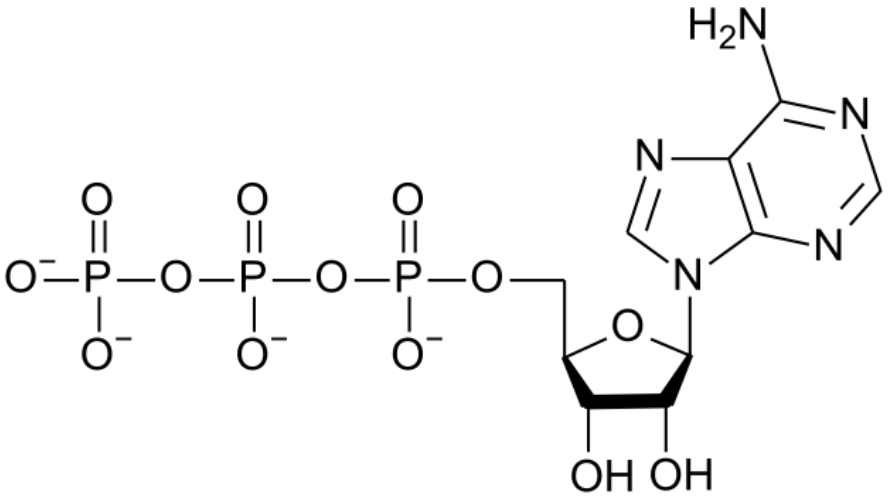


Image source: en.wikipedia.org

- **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.

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:

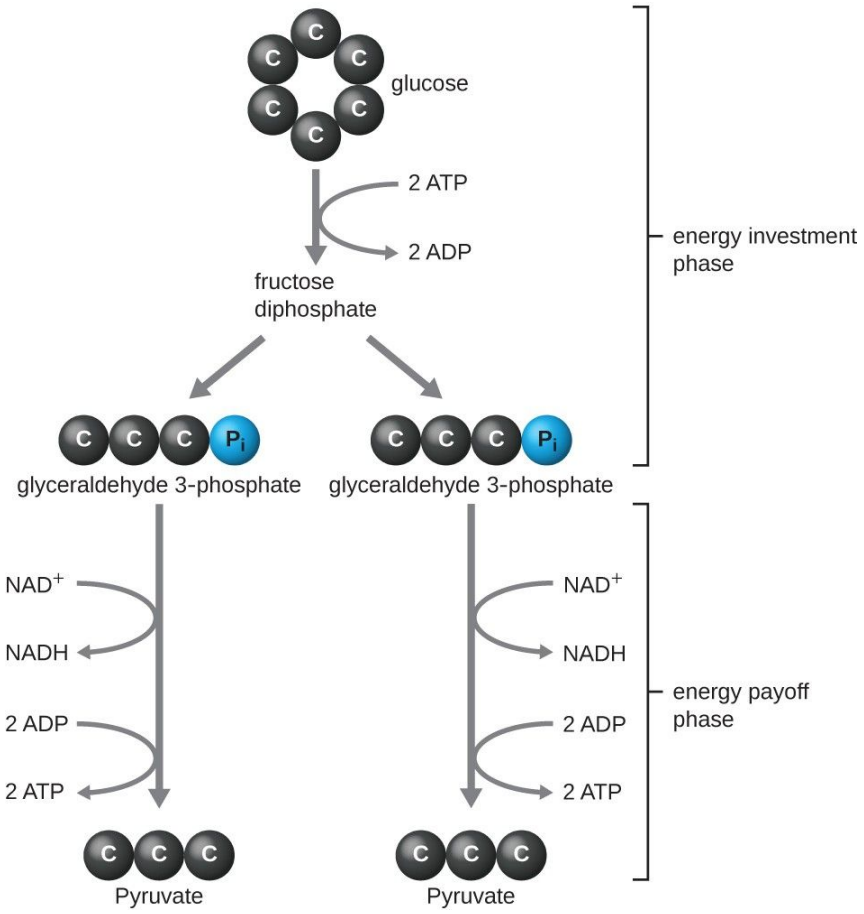
- **Aerobic**- occurs in the presence of oxygen. Produces large amounts of ATP.
- **Anaerobic**- occurs in the absence of oxygen. Produces less ATP and is less efficient.

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 produced 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 the cytoplasm of cells.
In this process glucose is **phosphorylated** to produce 2 molecules of **pyruvate**, 2 molecules of ATP and 2 molecules of **NADH**.



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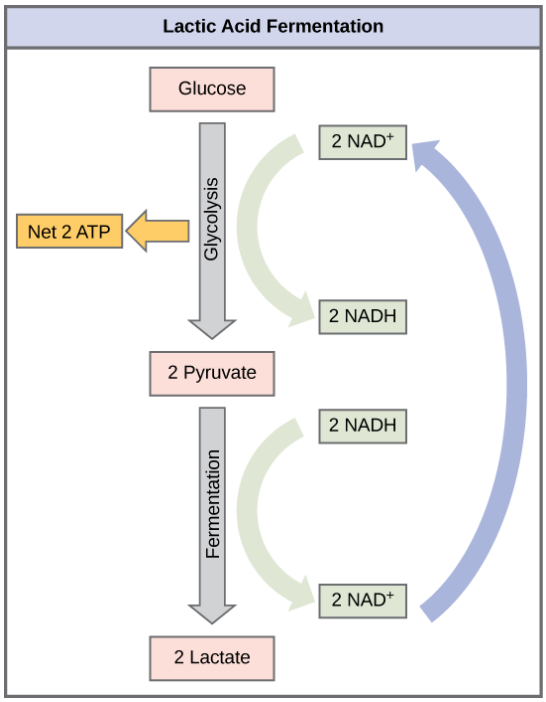
In **anaerobic respiration** the pyruvate is further converted into lactate with the help of NADH. **Lactate** is then converted back to pyruvate in the liver.

The link reaction:
The next step of aerobic reaction is **the link reaction** where pyruvate is converted to **acetyl coenzyme A** with the help of **NADH.**



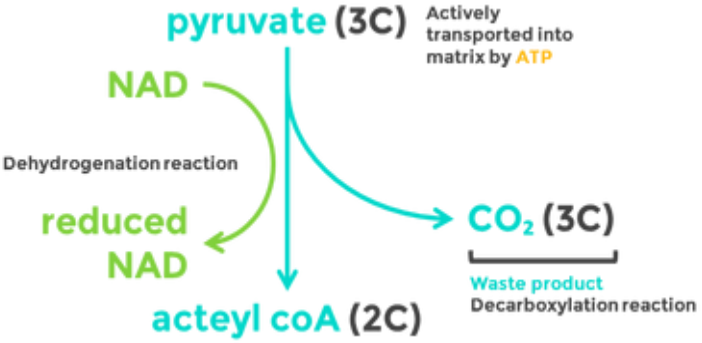


Image source: bio.libretexts.org

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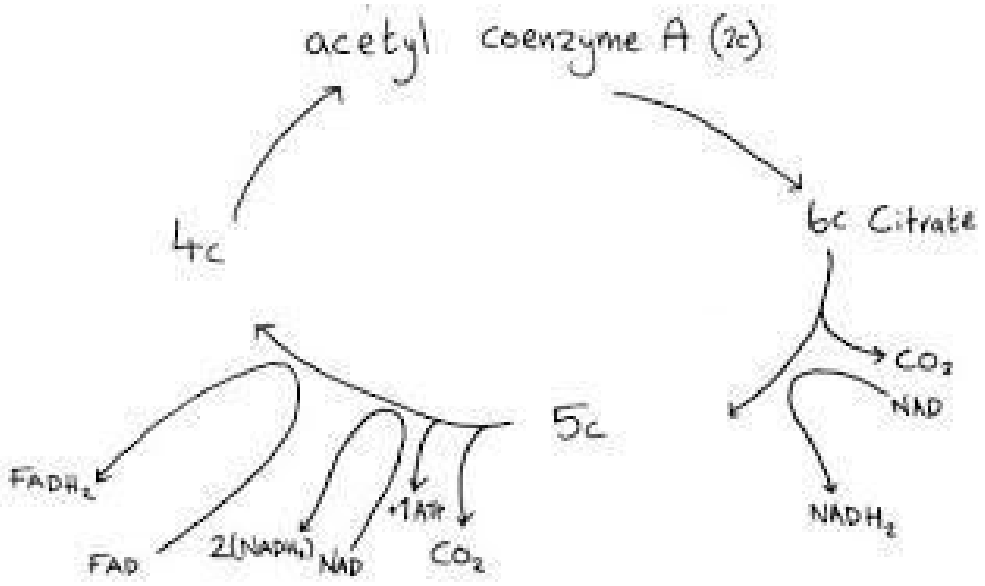
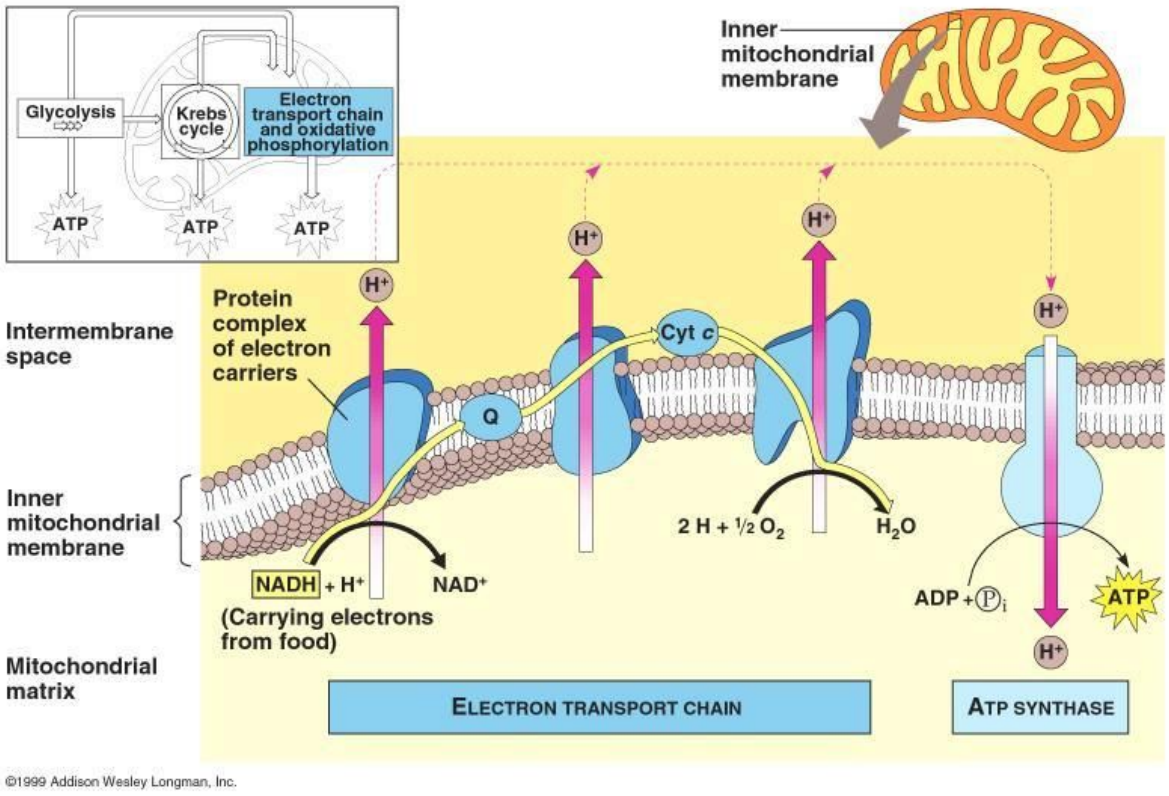
Krebs Cycle

Acetyl-CoA then enters the **Krebs cycle** where glucose is oxidised and carbon dioxide, ATP, **reduced NAD and reduced FAD** are produced. The Krebs cycle also includes **decarboxylation** (removal of carbon dioxide) and **dehydrogenation** (removal of hydrogen) to convert 6-carbon citrate to 4-carbon oxaloacetate.



Oxidative phosphorylation



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Oxidative phosphorylation is the process in which ATP is synthesised in the **electron transport chain** in mitochondria. This process generates the majority of ATP in aerobic respiration and it occurs as following:

- Reduced coenzymes carry **hydrogen ions** and electrons to the electron transport chain which occurs on the **inner mitochondrial membrane**
- 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 diffuse through ATP synthase into the **mitochondrial matrix** down the **electrochemical gradient**
- ATP is produced using ATP synthase, a **stalked granule**. Approximately 4 hydrogen ions produce one ATP molecule.
- Hydrogen atoms are produced from hydrogen ions and electrons. The **hydrogen atoms are then combined with oxygen to produce water**

Respiratory substrates include **carbohydrates, lipids and proteins** which release varying amounts of energy, depending on the number of hydrogens in the structure that 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

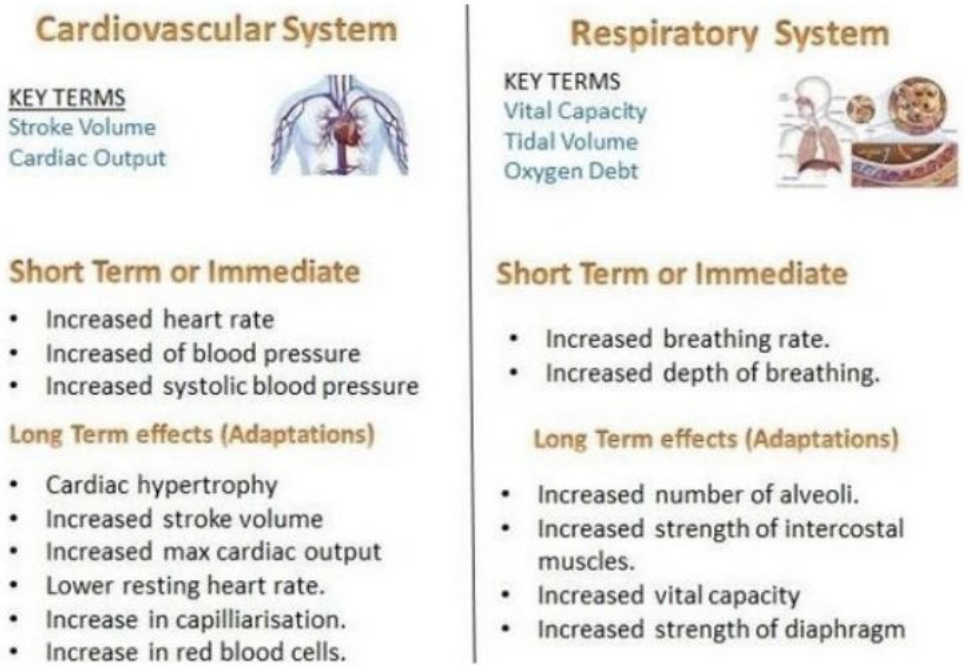
Different respiratory substrates have different RQ values e.g. carbohydrates have a value of 1.0, lipids – 0.8 and proteins 0.9.

4.1.2 Metabolism and exercise

Exercise

- Increased heart rate, cardiac output, respiratory rate and tidal volume
- The aim is to provide sufficient oxygen to the organs and working muscles
    - Dilatation of vessels to muscles
    - Constriction of vessels supplying the gut – supply the active body systems

- Other effects:



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Aerobic fitness:
Efficiency with which oxygen-dependent processes take place

Dependent on factors including:

Age
Gender
Participation in exercise
Training – frequency of exercise, intensity, time [how long exercise carried out], what kind of activity [FITT Formula] can be used to monitor outcome

- Measured by VO_2 max [maximum uptake of oxygen]
- **High aerobic fitness;** - lower resting heart rate, breathing rate and recovery time

- **Supplementation:**
    - Used by athletes to enhance performance in sports; encompasses many different forms. These are banned and illegal to use to prevent unfair advantage during sports
        - 'Blood doping' – use of hormones such as erythropoietin which increases red blood cell production in the body. This is banned to prevent unfair competition in sport.
        - Steroids: i.e. testosterone, oestrogen. May increase muscle bulk, however are associated with damaging side effects.

Carbohydrate loading is another technique which athletes use. Glycogen stores are built up by decreasing the amount of exercise and eating carbohydrate-rich foods.

Haemoglobin

Haemoglobin is a **water-soluble globular protein** which consists of **two beta polypeptide chains and a haem group**. It **carries oxygen** in the blood, as oxygen can bind to the haem (Fe^{2+}) group. Oxygen is then released when required. Each molecule can carry four oxygen molecules.

The **affinity of oxygen for haemoglobin** varies depending on the partial pressure of oxygen which is a measure of **oxygen concentration**. The greater the concentration of dissolved oxygen in cells the greater the partial pressure. Therefore, as **partial pressure** increases, the affinity of haemoglobin for oxygen increases, that is oxygen binds to haemoglobin more tightly. This occurs in the lungs in the process known as loading. **During respiration**, oxygen is used up therefore the partial pressure decreases - decreasing the affinity of oxygen for haemoglobin. As a result, oxygen is released in respiring tissues where it is needed. After the unloading process, the haemoglobin returns to the lungs where it binds to oxygen again.

Dissociation curves illustrate the change in haemoglobin saturation as partial pressure changes. The saturation of haemoglobin is affected by its affinity for oxygen, therefore in the case where partial pressure is high, haemoglobin has a high affinity for oxygen and is therefore highly saturated, and vice versa.

Saturation can also have an effect on affinity, as after binding to the first oxygen molecule, the affinity of haemoglobin for oxygen increases due to a change in shape, thus making it easier for the other oxygen molecules to bind.

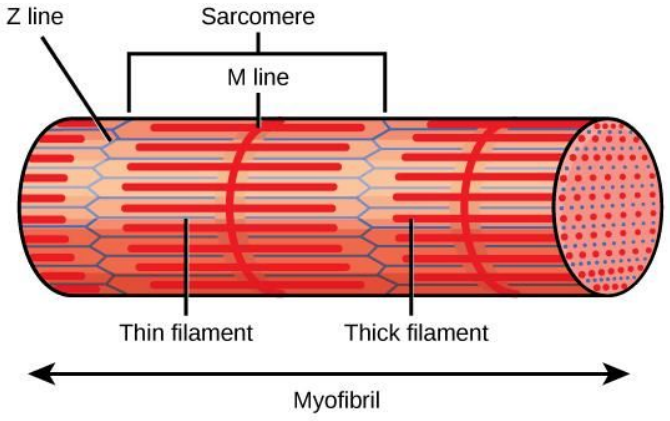
Fetal haemoglobin has a different affinity for oxygen compared to **adult haemoglobin**, as it needs to be better at absorbing oxygen because by the time oxygen reaches the placenta, the oxygen saturation of the blood has decreased. Therefore, fetal haemoglobin must have a **higher affinity for oxygen** in order for the foetus to survive at low partial pressure.

The affinity of haemoglobin for oxygen is also affected by the **partial pressure of carbon dioxide**. Carbon dioxide is released by **respiring cells,** which require oxygen for the process to occur. Therefore, in the presence of carbon dioxide, the affinity of haemoglobin for oxygen decreases, thus causing it to be released. This is known as the **Bohr effect.**

Muscles

- **Slow twitch fibres** are specialised for **slow contractions** and are adapted to **long periods of exercise,** such as marathon running and therefore **do not fatigue quickly. Fast twitch fibres** are adapted for **rapid release of energy** during intense exercise such as sprinting – **the contractions are intense and in short bursts.**

- Slow twitch fibres contain many **mitochondria** and a lot of **myoglobin** which results in slow twitch fibres being dark in colour. Fast twitch fibres have very few mitochondria and thus they are lighter in colour.
- Moreover, slow twitch fibres have low levels of **creatine phosphate** and **glycogen,** whereas fast twitch fibres have high levels of both creatine phosphate and glycogen.



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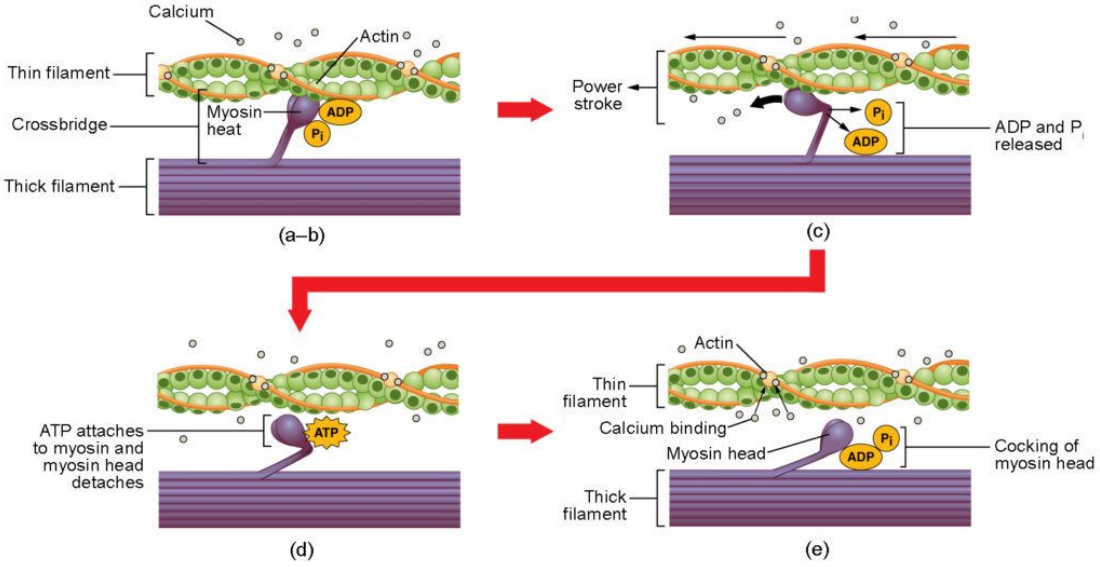
Muscle contraction occurs as the following [sliding filament theory]:



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