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2.7 Cellular Respiration

IB Biology - Revision Notes

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2.7.1 Cellular Respiration

Cellular Respiration Defined

- Cell respiration is the controlled release of energy from organic compounds to produce ATP
- Respiration is a **series of chemical reactions** that happens in **every cell**
- Its purpose is to **release energy** in usable forms from the chemical energy stored in food e.g. glucose
- Respiration is a **catabolic** process
- **Glucose** is the main respiratory fuel used in cells
  - **Lipids** and **proteins** can also be used

- **Organic** food substances contain **a lot of chemical energy**
- This **energy cannot be released in one, uncontrolled step** in cells, which would cause cell damage and tissue death
- Enzymes **control the release of energy** through a series of chemical reactions called a **pathway**
- This ends in the production of **ATP** (adenosine triphosphate)
  - To make ATP, a **phosphate group** is linked to adenosine diphosphate (**ADP**)
  - This process **requires energy** which comes from the breakdown of organic molecules

- The energy that is released is used for
  - Fuelling **anabolic** processes
  - Muscle contraction
  - Fuelling **active transport**
  - Moving molecules around the cell
  - **Generating heat** to maintain body temperature in warm-blooded animals

Exam Tip

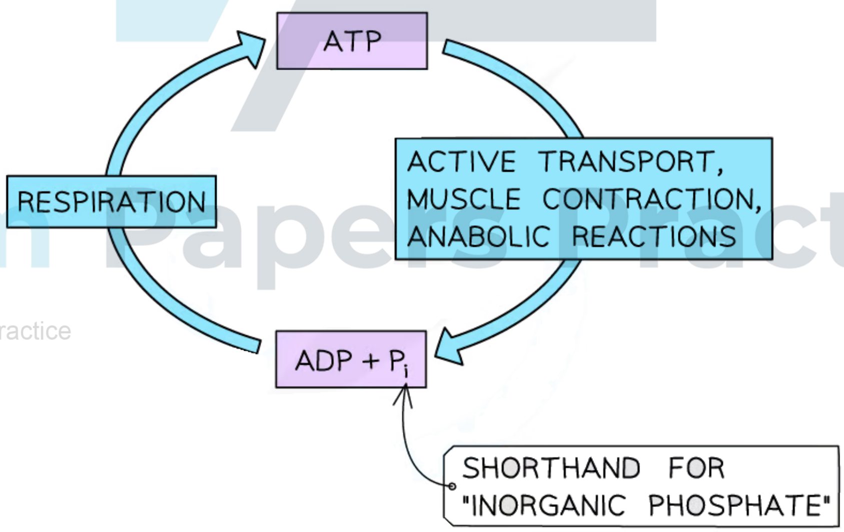
Respiration is **often confused with breathing,** but remember, respiration is a chemical process, breathing is a method of moving air in and out of the body

ATP

- ATP is a **source of energy** for cellular processes
- The energy can be released **immediately**, exactly when it is required
- All organisms require a **constant supply of energy** to maintain their cells and stay alive
- This energy is required:
  - In **anabolic** reactions – synthesizing larger molecules from smaller molecules
  - To **move molecules** across the cell membrane (active transport)
  - To move substances and organelles within the cell
  - In animals, energy is required:
    - For **muscle contraction** – to coordinate movement at the whole-organism level
    - In the **conduction of nerve impulses**, as well as many other cellular processes

- In all known forms of life, ATP from respiration is used to transfer energy in **all energy-requiring processes** in cells
- ATP is converted to **ADP** and **phosphate** when releasing its energy
  - ADP and phosphate can then be **re-converted to ATP** during respiration

- Organisms require a **constant supply of ATP** because much of the energy is dissipated (lost to the surroundings) as **heat**

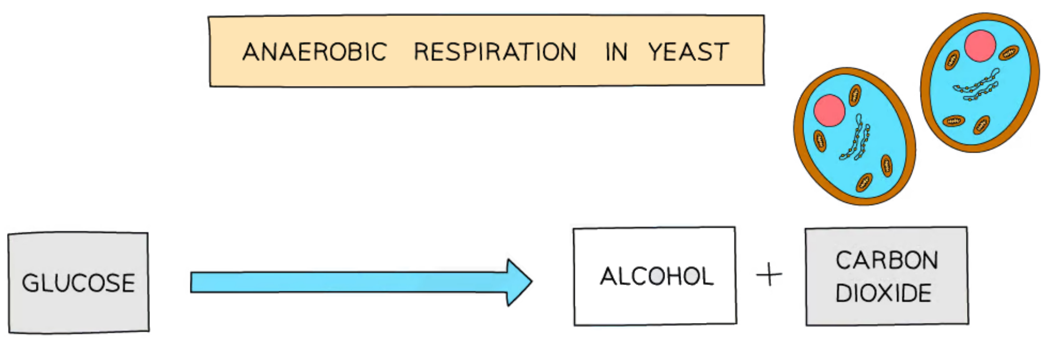


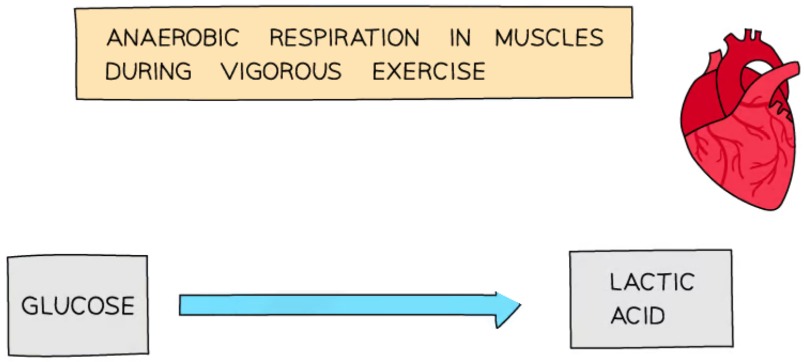
The constant cycling of ATP and ADP+Pi within a cell

2.7.2 Anaerobic Respiration

Anaerobic Respiration: ATP Yield

- In cells, there is a much **lower energy yield** from respiration in **anaerobic conditions** than in aerobic conditions
- There can be different ways in which oxygen becomes unavailable
  - When **oxygen supply can't keep up with demand** in heavily respiring cells
    - But a short supply of ATP is still required eg. **vigorous exercise** requiring a lot of muscle contraction
  - In conditions where oxygen **cannot reach the organisms** eg. in waterlogged soil
- In anaerobic respiration, **glucose is only partially oxidised** meaning only **a small part of its chemical energy is released** and transferred to ATP
  - The only ATP-producing reaction that continues is the first stage of respiration (around 2 ATP molecules per molecule of glucose)
- As there is no oxygen, **none of the remaining reactions** (of aerobic respiration) can take place
  - This means that around **36 ATP molecules are not produced anaerobically** that would otherwise have been produced in the presence of oxygen
  - 2 ATP molecules is better than zero ATP molecules, so anaerobic respiration can give **a short discharge of energy** when oxygen runs out
- Different types of organisms produce **different products** when respiring anaerobically
  - **Plants and yeasts** produce **ethanol** and **CO_2**
  - **Animals** produce **lactate**

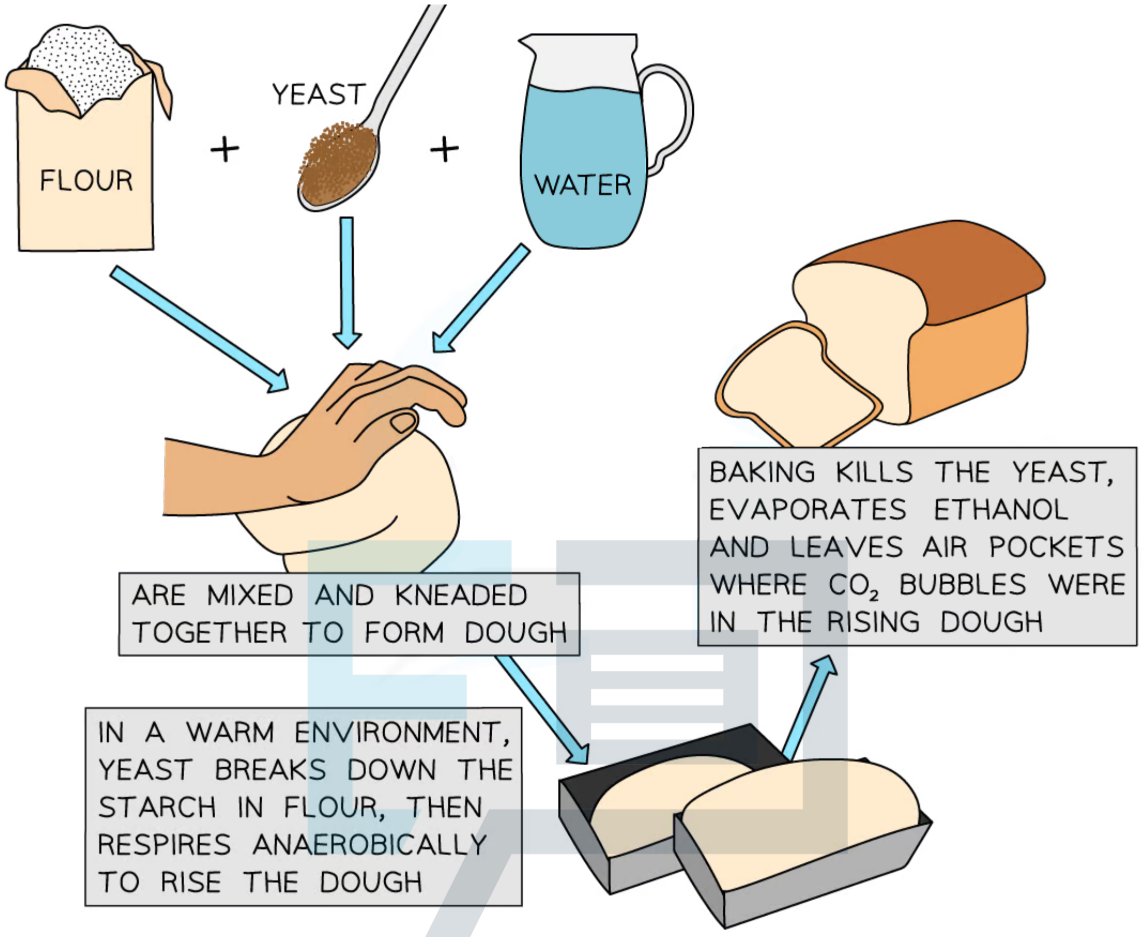




Anaerobic respiration in yeast produces different products to anaerobic respiration in animals

Anaerobic Respiration: Yeast

- Bakers can make use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking
- Yeasts are **single-celled fungi** that live in areas where sugars are present eg. on fruit or on leaves
- They can respire **aerobically** or **anaerobically**
- **Flour** contains starch, and when mixed with **water** and **yeast** can form a bread dough
- The dough is **kneaded** to mix everything together
- The dough is then **left in a warm place** to encourage the yeast to respire
- Yeast cells **grow rapidly in number** while oxygen is still present in the dough
  - The yeast **hydrolyses the starch** into maltose and glucose and respire the sugars, **aerobically at first**
- The dough soon **becomes anaerobic** (all the oxygen within it is used up aerobically by the yeast)
- **Anaerobic respiration takes over** and **CO_2 bubbles** begin to form in the dough
- These bubbles allow the dough to **rise** (swell up)
- Baking the dough **kills the yeast** and the bubbles form the fluffy texture of the finished bread
- **Ethanol**, the other product of anaerobic respiration of yeast, is produced but **evaporates** during the final baking stage



The role of anaerobic respiration of yeast in breadmaking to cause bread dough to rise

Anaerobic Respiration: Lactate Production

- Animals have evolved a system to provide **a short burst of energy** in exceptional circumstances
  - Anaerobic respiration can help to **generate powerful muscle contractions** in the short term eg. to escape from a predator or to catch prey
- For humans, anaerobic respiration plays a role in **sport and exercise** more than in survival
- Glucose is metabolised to **lactate** when oxygen can't be supplied quickly enough to muscle cells
- Lactate **accumulates** in those cells and tissues
- Lactate is **toxic above a certain level** and can cause discomfort and even pain (**cramp**)
- This **limits how long an athlete can perform anaerobically for** eg. sprinters, who typically only race over 400 metres or less
- After lactate is produced it has to be **broken down aerobically**
- The breakdown of lactate needs extra oxygen
  - This extra oxygen is referred to as an **oxygen debt**
  - It explains why animals **breathe deeper and faster** for a period of time **after exercise**

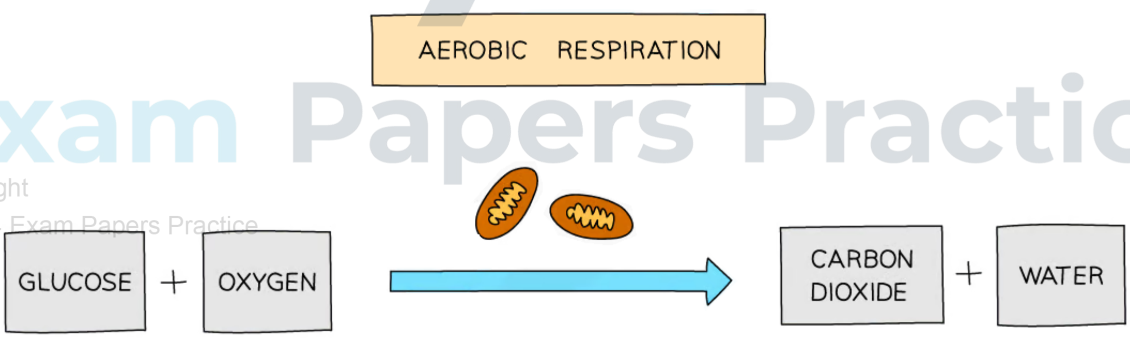
Exam Tip

You won't be expected to know the total yield of ATP from each type of respiration in detail but be prepared to explain why anaerobic respiration produces substantially less ATP than aerobic respiration.

2.7.3 Aerobic Respiration

Aerobic Respiration

- Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose
- The presence of oxygen allows glucose to be **broken down fully** into carbon dioxide and water
- This yields far more energy (approx. 36 ATP molecules) than anaerobic respiration (2 ATP molecules) per molecule of glucose
- CO_2 is a **waste product** and has to be excreted
  - Except in plants where it is used for photosynthesis
- Water is a **by-product** and contributes to the organism's water needs
  - Some animals that live in deserts **drink very little** but survive on this water
- Most of the reactions of aerobic respiration, in eukaryotes, take place in the **mitochondria**



Aerobic respiration releases energy during the reaction between glucose and oxygen

Comparing combustion and respiration

- There are **important similarities** between the **burning** (combustion) of fuels and the **two forms of respiration**
- Both **require oxygen** and produce CO_2 and **water**
- Both **release heat** from the breakdown of chemical bonds in the fuel

2.7.4 Skills: Respiration

Respirometer

Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer

- Respirometers are used to measure and investigate the **rate of oxygen consumption** during respiration in organisms
- The experiments usually **require live organisms** such as seeds or invertebrates
  - **Use of animals should be minimised** when seeds can provide excellent data

- There are **many different designs of respirometers**, though they all have certain features in common
  - A **sealed container** containing **live organisms** and **air**
  - An alkaline solution (eg. potassium hydroxide) to absorb CO_2
  - A **capillary tube** connected to the container and set **against a graduated scale** (a **manometer**)

- The organisms **respire aerobically** and **absorb oxygen** from the air
- The CO_2 they release is **absorbed by the alkali**
- This **reduces the air pressure** inside the sealed chamber
- The manometer fluid (shown in red below) **moves towards the organisms** because of the pressure drop inside the chamber
- The respirometer must be kept in **very temperature-controlled conditions** because slight fluctuations in temperature can affect the air pressure
  - A **thermostatically controlled water bath** is the best way to maintain a constant temperature

- **Repeat readings** should be carried out for each set of experimental conditions, in order to **identify** and **eliminate anomalies**
  - **Repeat** readings give a **reliable** mean

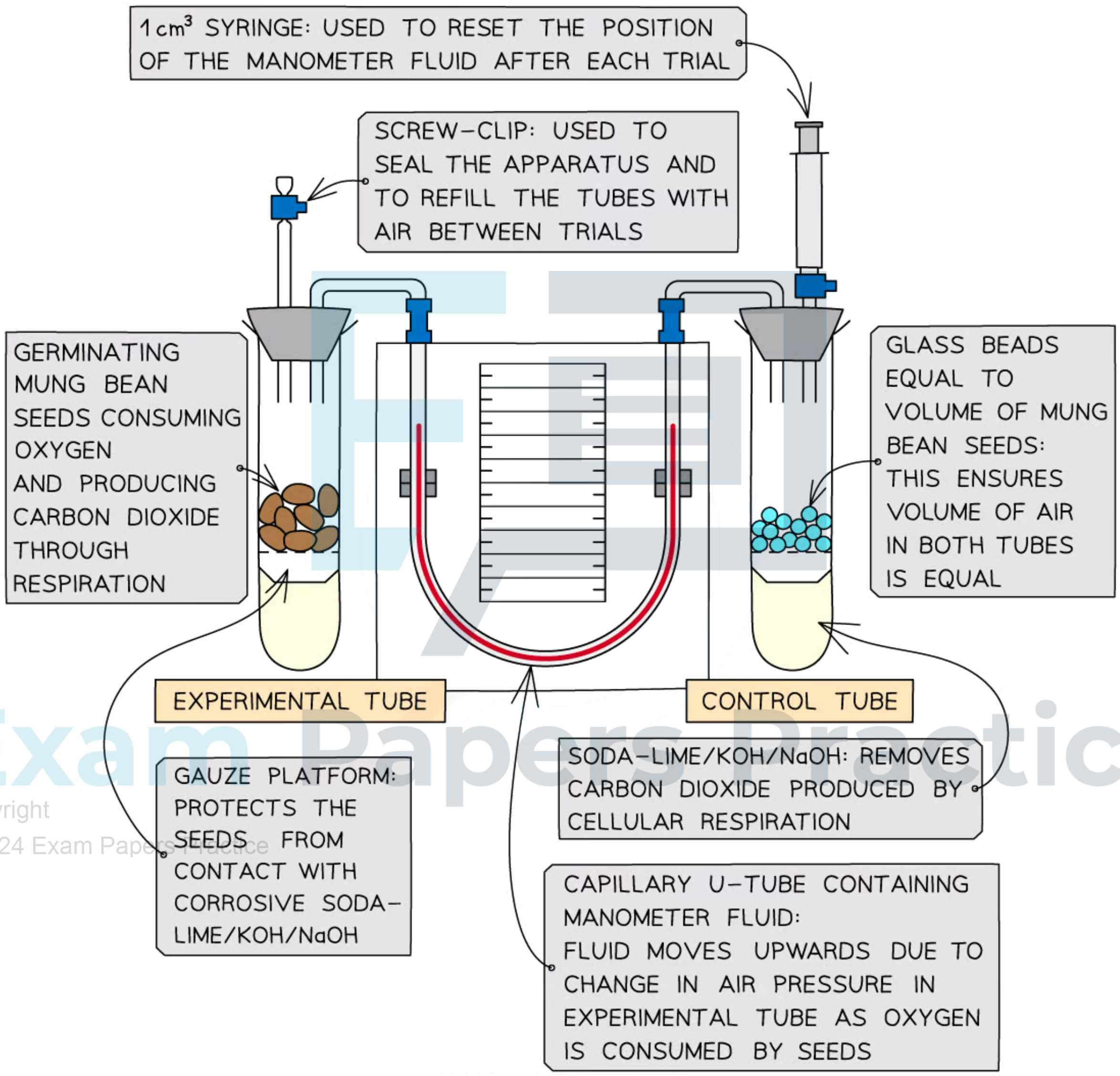
Analysis

- Respirometers can be used in experiments **to investigate how different factors affect the rate of respiration** of organisms over time
  - Eg. temperature – using a series of water baths

Use of technology to measure rate of respiration

- **Technological devices** can automate and make the measurement of respiration rate easier
  - Not to be confused with **breathing rate**

- **Oxygen sensors** and **CO_2 monitors** can measure oxygen and CO_2 concentration in real-time
  - Without the need to expose the subject to hazards such as strong alkalis
- **Dataloggers** can record data over a period of time for analysis later



The typical set-up of a respirometer

The equation for calculating a change in gas volume

- The volume of oxygen consumed ($mm^3 min^{-1}$) can be worked out using the radius of the lumen of the capillary tube *r* (mm) and the distance moved by the manometer fluid *h* (mm) in a minute using the formula:

$$\pi r^2 h$$

Worked example

A respirometer was set up with germinating mung beans in the experimental tube. After a period of equilibration, the liquid in the capillary was measured to move by 2.3 cm in 25 minutes 30 seconds. The capillary tube had an internal diameter of 0.30 mm. Calculate the rate of respiration of the mung beans, measured as the rate oxygen uptake, in $mm^3\ hr^{-1}$ Use the value of pi (π) = 3.141 and state your final answer to 2 significant figures

Step 1: Calculate the cross-sectional area of the capillary tube

Diameter = 0.30mm, so radius = 0.30 ÷ 2 = 0.15 mm

Cross sectional area = $\pi r^2 = 3.141 \times 0.15^2 = 0.0707\ mm^2$

Step 2: Calculate the volume of oxygen that had been taken up

The liquid moved 2.3 cm, which is 23mm

Volume of liquid moved in 25 minutes 30 seconds =

$\pi r^2 h$, where h = 23 mm
= $0.0707 \times 23 = 1.625\ mm^3$

Step 3: Calculate the rate of oxygen consumption per hour

25 minutes 30 seconds = 25.5 minutes

Rate per hour = $1.625 \times (60 \div 25.5)$
$3.824\ mm^3\ hr^{-1}$

To 2 sf = **$3.8\ mm^3\ hr^{-1}$**

NOS: Assessing the ethics of scientific research: the use of invertebrates in respirometer experiments has ethical implications

- The use of live animals in experiments has raised **ethical concerns**
- Should we be removing animals from their natural habitat?
  - Does **human learning** outweigh the suffering that may be caused?
- Will the animals suffer or feel **pain**?
  - How can **exposure to hazards be minimised** for the animals eg. avoiding contact with the alkali
  - Animals must be **returned** to their natural habitat **directly after** the readings have been taken
  - Can an **alternative method** that uses other non-animal species be found that still provides learning eg. the use of **germinating seeds**?
  - There must be **no laboratory work** that **causes pain or suffering** to animals or humans

Exam Tip

There are several ways you can manage variables and increase the reliability of results in respirometer experiments:

- Use a controlled water bath to keep the **temperature** constant
- Have a control tube with an equal volume of inert material to the volume of the organisms to compensate for changes in atmospheric **pressure**
- Repeat the experiment multiple times for reliability and calculate a **mean**